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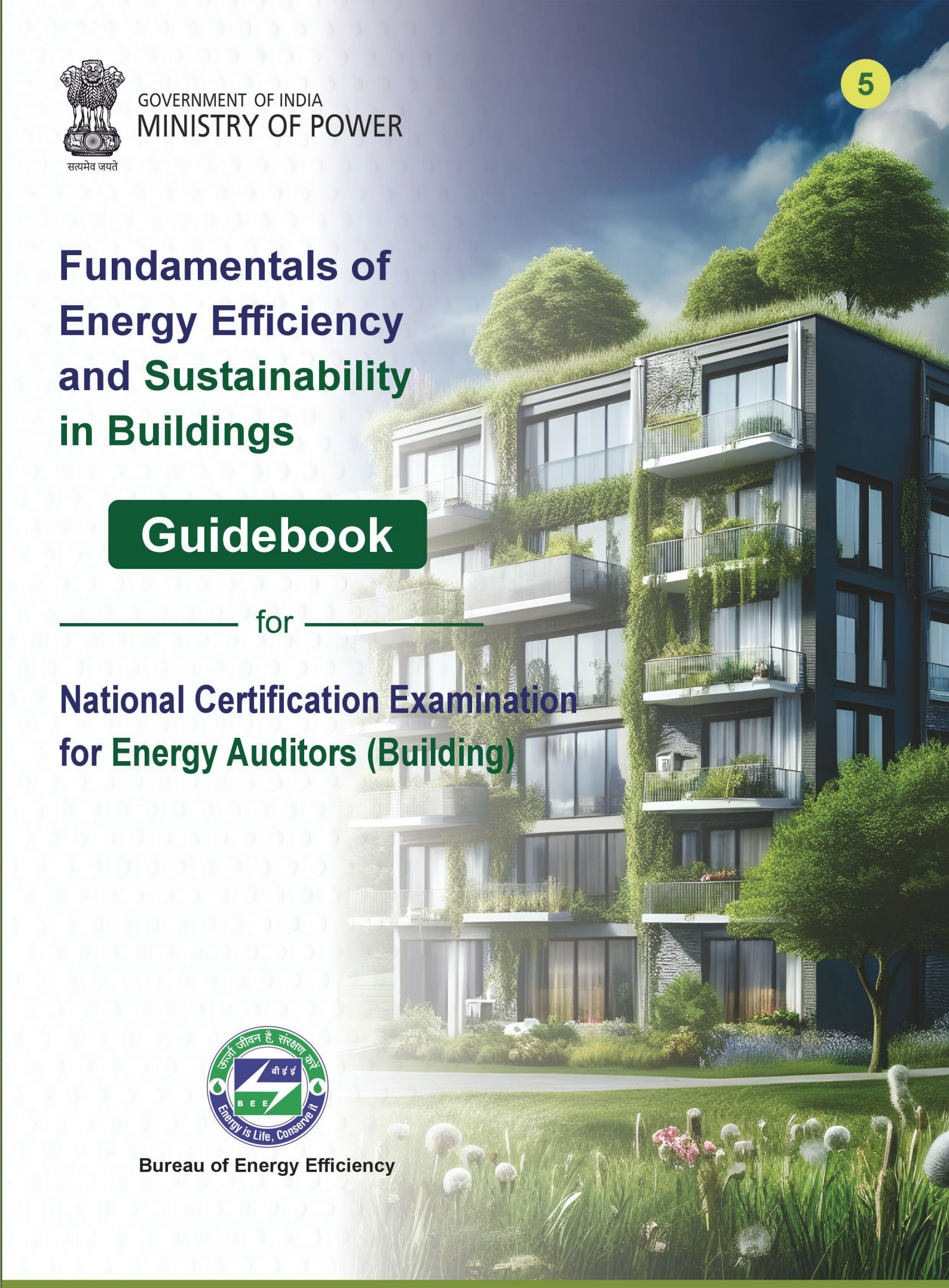
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Fundamentals of Energy Efficiency and Sustainability in Buildings

Guidebook

for

National Certification Examination for Energy Auditors (Building)



Bureau of Energy Efficiency

FIRST EDITION, 2026

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PREFACE

National Certification Examination for Energy Auditor (Building) aims to develop qualified professionals in the field of energy conservation in the building sector of India. At the initiative of Bureau of Energy Efficiency (BEE), for meeting the requirements of National Certification Examination for Energy Auditor (Building), The Energy and Resources Institute (TERI) has developed two guidebooks in respect of the following examinations.

Guidebook	Examination paper	Topic
Book 5	**Paper 5**	**Fundamentals of Energy Efficiency and Sustainability in Buildings**
Book 6	Paper 6	Code Compliance for Energy Efficiency and Sustainability in Buildings

These books comprehensively cover the fundamentals and compliance requirements of the Energy Conservation and Sustainable Building Code (ECSBC) and Eco Niwas Samhita (ENS) 2024. Candidates preparing for the National Certification Examination for Energy Auditor (Building) may use these resources alongside the ECSBC, ENS 2024 to develop a thorough understanding of code provisions, compliance methodologies for new buildings, and energy efficiency strategies for existing buildings.

Beyond their primary purpose, these books are also expected to serve as valuable reference material for practicing building professionals and officials of Urban Local Bodies (ULBs), supporting them in strengthening their knowledge and effectively applying code compliance approaches and energy efficiency practices in the building sector.

कृष्ण चन्द्र पाणिग्राही
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Director General

सत्यमेव जयते

Azadi Ka Amrit Mahotsav

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(Ministry of Power, Government of India)



JUNE 29, 2026

MESSAGE

The Guidebook for the National Certification Examination for Energy Auditor (Buildings) marks an important step in strengthening professional capacity for advancing sustainability and energy efficiency in India's building sector.

India's building stock is expanding rapidly, with total floor space projected to grow from estimated 20 billion m^2 in 2025 to roughly 34.3 billion m^2 by 2050. Residential buildings constitute the bulk of this stock, increasing from nearly 18.4 billion m^2 to about 30.2 billion m^2 over the same period, while commercial floor space is expected to rise from around 1.6 billion m^2 to approximately 4.1 billion m^2. This rapid anticipated growth in residential and commercial construction underscores the need for a qualified pool of professionals who can guide the transition towards sustained reductions in electricity demand, peak loads and building-related emissions.

Energy Conservation and Sustainable Building Code (ECSBC) and Eco Niwas Samhita (ENS) 2024 provide a unified framework for high-performance buildings, covering envelope efficiency, low-energy cooling, renewable integration and climate-sensitive design; with an expected 18% reduction in electricity consumption. By promoting efficient envelopes, better daylighting, appropriate glazing, and climate-responsive design, these codes help lower cooling loads and peak demand while improving thermal comfort for occupants. Together, ECSBC and ENS form a comprehensive framework that aligns building development with India's long-term pathway to net-zero emissions in the built environment.

This Guidebook has been developed as a key resource to support the implementation of ECSBC and ENS 2024. It provides a structured understanding of the principles, concepts, methodologies, and compliance approaches required for effective application of these codes on the ground. While intended as study material for candidates appearing in the National Certification Examination for Energy Auditor (Buildings), it also serves as a core technical reference for examination candidates and a practical handbook for architects, engineers and auditors. By helping create a pool of certified building energy auditors, this publication will contribute to transforming India's growing building stock into a driver of energy savings, emissions reductions, and improved environmental performance. I commend all the experts and institutions who have contributed to the preparation of this publication and wish all readers success in their professional endeavours.

(Krushna Chandra Panigrahy)

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ऊर्जा दक्षता ब्यूरो
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BUREAU OF ENERGY EFFICIENCY
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आज़ादी का अमृत महोत्सव



FOREWORD

The Bureau of Energy Efficiency (BEE), under the Ministry of Power, has been leading efforts to promote energy conservation and efficiency through policy initiatives, standards, capacity-building programs, and market transformation measures. Over time, its focus has expanded to encompass broader sustainability goals for the built environment. This evolution is reflected in the Energy Conservation and Sustainable Building Code (ECSBC) and ENS 2024, which integrate energy efficiency with broader sustainability considerations such as renewable energy integration, water conservation, waste management, indoor environmental quality, and climate-responsive building design.

Recognizing the growing importance of building energy performance and sustainability in India's energy-efficiency ecosystem, and the need for specialized professional expertise in this sector, the Bureau of Energy Efficiency has launched the National Certification Examination for Energy Auditors (Building). The certification will support the effective implementation of ECSBC, ENS, and other national initiatives aimed at advancing sustainable and resource-efficient buildings.

This Guidebook for the National Certification Examination for Energy Auditors (Building) has been developed as a comprehensive learning resource for aspiring professionals and a valuable reference for practitioners. The publication presents the fundamental principles and compliance approaches for the implementation of ECSBC and ENS.

As India advances towards a low-carbon, resource-efficient, and climate-resilient future, the role of certified building energy auditors will become increasingly important. I am confident that this guidebook will equip professionals with the knowledge and skills necessary to contribute meaningfully to the transformation of India's building sector and to the broader national mission of sustainable development.

I extend my sincere appreciation to the advisors, reviewers, and contributors for their invaluable contributions to this collaborative effort. I am confident that this publication will serve as a valuable resource in strengthening professional capacity and accelerating the adoption of sustainable and energy-efficient building practices across the country.

P. Samal.

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1. SUSTAINABLE SITE SELECTION AND PLANNING

Site selection and planning are critical stages in achieving the sustainability objectives of any building project. These processes must integrate a wide range of environmental considerations, especially in the context of accelerating urban growth and increasing ecological challenges. As cities expand, it becomes imperative to adopt sustainable site selection and planning parameters and establish rules, regulations and procedures that guide the protection, preservation, and enhancement of surrounding natural environments. Sustainable site planning section of the Energy Conservation and Sustainable Building Code (ECSBC) aims to incorporate the sustainability aspects of site selection and planning to the buildings falling under the purview of ECSBC.

1.1 Topsoil Preservation

Topsoil is the uppermost soil layer, typically extending 150–200 mm below ground level, and is rich in organic matter, nutrients, microorganisms, and plant roots. This biologically active zone supports vegetation growth, enhances water infiltration, and plays a vital role in maintaining on-site ecological balance.

Fertile soil is characterized by adequate physical structure, nutrient availability, and biological activity to sustain healthy plant growth. While fertility is concentrated in the topsoil, it declines significantly in deeper subsoil layers. Unlike excavated earth or construction fill, topsoil forms over long periods through natural processes and cannot be easily replaced once lost or degraded. Its preservation is therefore essential for sustaining long-term site productivity and ecological performance.



Figure 1 Stacking of topsoil on site in protected area

Topsoil contains the highest concentration of nutrients and biological activity required for vegetation. Construction activities frequently disturb or remove this layer, leading to ecological degradation and increased restoration costs. Accordingly, both ECSBC and ENS require responsible practices for topsoil preservation, storage, and reuse to prevent loss of site fertility during development.

Effective topsoil management includes careful stripping, stockpiling, stabilization, and reuse, along with measures to prevent erosion and sedimentation. Such practices help retain soil fertility, support ecological resilience, reduce resource demand, and ensure successful post-construction landscaping.

Topsoil Collection, Storage, and Reuse

To prevent topsoil degradation and erosion, topsoil should be carefully collected, stored, and reused using the following strategies:

- **Top-stripping:** From areas likely to be disturbed by buildings, roads, pathways and other infrastructure development, topsoil should be stripped to a depth of approximately 150–200mm (6–8 inches).
- **Stockpiling:** Topsoil must be stored in designated areas at a maximum height of 40 cm to maintain aeration and prevent compaction. It should be kept separate from subsoils, debris, and stones larger than 50 mm. The stocked topsoil should be covered with mulch or planted with ground cover to preserve the soil's fertility.
- **Reuse:** Stored topsoil is to be reapplied during landscape development and plantation activities after construction.

In some cases, topsoil may be temporarily removed, replaced by free-draining gravel during construction and later restored once work is complete. This method reduces contamination and ensures long-term soil health.

Topsoil Testing and Improvement

Before preservation, topsoil should be tested to determine its fertility and suitability for landscaping. The parameters for topsoil fertility as per Indian Council of Agricultural Research (ICAR) shall be tested in a accredited lab of ICAR for following parameters:

Organic Carbon(%) testing shall be done as per Colorimetric Method (Datta et al.) the test results below 0.50 percent are considered Low ; 0.50 – 0.75 percent are considered as medium and > 0.75 percent are considered as High.

Available Nitrogen Alkaline $KMnO_4$ N (Kg / ha) testing shall be done using Kjeldahl apparatus, test results < 280 are considered as low; 281-560 are considered as Medium and > 560 are considered as High.

Available phosphorus Olsen's P (kg/ha) is tested using Olsen Method, test results < 10 are considered as low , 11-25 are considered as Medium and > 25 are considered as High.

Available Potassium Ammonium Acetate - K (kg/ha)n is tested using Ammonium acetate extraction method , test results <120 are considered as low, 121-280 are considered as medium and > 280 are considered as High.

If nutrient levels are inadequate, the soil must be improved while reapplication through measures such as:

- Adding compost, organic matter
- Adjusting pH levels

- Incorporating natural fertilizers to restore productive capacity

Improving top-soil quality ensures successful planting, reduces long-term maintenance, and supports ecological restoration.

Sedimentation and Erosion Control Measures

Sedimentation is a major source of water pollution during construction. To prevent this:

- Natural site features such as contours, catchment areas, and ridges should be retained.
- The building design should minimize alteration of natural landforms.
- A sedimentation control plan must be implemented, including a temporary sedimentation pond at the lowest site point.
- Once sediments settle, clarified water may be safely discharged to municipal stormwater drains, preventing clogging and system overload.

After construction, the topsoil stored must be properly reapplied and stabilized. If fertility is insufficient, nutrient enhancement should be undertaken before planting.

Sedimentation basin: A sedimentation basin is a large retention structure created at the lowest point of the site to collect and trap sediment-laden runoff generated during construction. Key functions include:



Figure 2 Planning and locating sedimentation tank on site

- Allowing sediments to settle before water is discharged
- Reducing peak runoff through a flow-detention facility
- Preventing clogged stormwater infrastructure

This measure ensures that downstream water bodies and municipal storm drains remain free of sediment pollution.



Figure 3 Sedimentation tank lining using brick

Sediment trap: A sediment trap consists of an excavated pond placed across low-lying areas. It temporarily holds runoff, permitting sediment to settle before release. Characteristics include:

- Suitable for drainage areas smaller than 10 acres
- Maintained until the site is permanently stabilized with vegetation or completed structures

These traps prevent soil loss and protect water quality during vulnerable construction stages.

Contour Trenching: Contour trenching involves constructing ridges and channels parallel to slope contours, particularly on slopes greater than 10%. This assists in:

- Reducing runoff velocity
- Increasing infiltration and overland flow distance
- Minimizing sediment transport
- Retaining soil moisture for contour trenching

This technique is notably beneficial for steep or erosion-prone terrain.

Mulching: Mulching is a temporary soil stabilization technique that involves applying organic or inorganic material to the soil surface. Materials include straw, bark chips, grass clippings, stones, or brick chips. Netting or anchoring must be used on steep slopes to prevent mulch displacement. Mulching is particularly recommended for:

- Steep slopes (>33%) prone to high erosion
- Areas where temporary seeding is not feasible due to climatic or seasonal constraints Mulching provides immediate surface protection and helps retain moisture while seeds and plants establish.



Figure 4 Mulching of stored topsoil

Geotextiles: Geotextiles are porous fabrics made from synthetic or natural fibres, used to stabilize soil, reduce erosion, and support vegetation growth. Applications include:

- Stabilizing channels, swales, and steep embankments
- Protecting newly planted slopes until seedlings are established
- Serving as filters beneath rubble in areas exposed to high stormwater flows

Geotextiles enhance soil stability and reduce erosion in locations where mechanical reinforcement is required.

Compliance (topsoil/ fertile soil)

- **ECSBC (mandatory requirement)**
  - Preserve and stabilize 150–200 mm of fertile topsoil during pre-construction. Maintain its fertility and reuse it as the finished grade for planting, vegetation, or landscape areas. If it cannot be used on-site, ensure it is properly reused elsewhere.
- **ECSBC (additional mandatory requirement for ECSBC plus and Super ECSBC)**
  - Provide a sedimentation basin and soil-erosion channels at the stormwater outlet during construction to prevent loss of topsoil.
- **ENS (mandatory requirement)**
  - Preserve, stabilize, and maintain the fertility of 150–200 mm (6–8 inches) of topsoil. Use the stored topsoil for planting areas within or outside the site. If not used on-site, ensure its proper reuse.

1.2 Tree Preservation and Compensatory Planting

Mature trees are fully established trees with well-developed canopies, stable trunk diameters (as per local norms), extensive root systems, and strong ecological linkages with surrounding soil and biodiversity. They are structurally stable and more resilient to environmental stress than young trees.

Due to their age and slow growth, mature trees provide critical ecological functions—such as microclimate regulation, carbon sequestration, stormwater absorption, soil stabilization, and habitat

support—that cannot be quickly replaced. Their removal results in long-term environmental loss, as these benefits take decades to recover.

Therefore, preserving mature trees in situ is essential for sustainable site development. ECSBC and ENS emphasize minimizing tree removal and allowing it only in unavoidable cases.

Pre-construction Planning

Planning for tree preservation begins at the earliest stages of site assessment. Vegetation clearing should be minimized and any removal must be thoroughly documented. A detailed pre-construction tree survey must identify all trees on-site, mapping their precise locations, documenting species, age, trunk diameter and health and highlighting any heritage or endangered species. This survey also classifies trees into those that will be preserved, transplanted, or removed. All existing vegetation must be accurately marked on the site plan as per National Building Code (NBC) Part 10: Landscaping. The landscape plan should subsequently distinguish retained trees, transplanted specimens, and those slated for removal to ensure clarity during execution.

Protection Measures During Construction

During construction, all retained trees must be rigorously protected. Root Protection Zones (RPZs)—typically extending 6–8 times the trunk diameter or up to the drip line—must be clearly demarcated and barricaded, with no excavation, trenching, soil compaction, material storage, or vehicle movement permitted within this area. Barricades should remain in place throughout construction.

Key protection measures include preventing root damage from construction activities; avoiding cutting, filling, or changes to ground levels within the root zone; and prohibiting the use of trees for support, nailing, or any physical alteration. Activities such as lighting fires or emitting heat and gases beneath the canopy are not allowed. Young saplings should be protected with appropriate tree guards, and routine maintenance must be carried out to ensure plant health. Preservation zones should be periodically inspected, with observations and corrective actions recorded.

Continuous monitoring is essential—soil moisture must be maintained, and contamination from debris, concrete slurry, or chemicals must be prevented. Where necessary, measures such as aeration tubes can support root health, and utilities should be routed around or bridged over root zones to avoid disturbance.

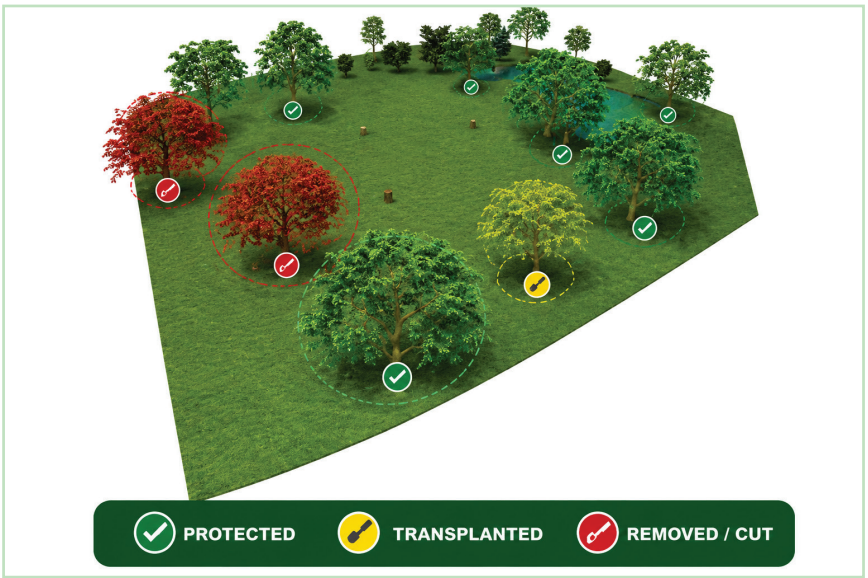


Figure 5 Identification of trees to be protected, transplanted, removed or cut (in red)

Transplantation and Compensatory Planting

Transplantation should only be considered when in-situ preservation is impossible and only for species capable of surviving the process. Transplantation must be carried out by certified arborists, with appropriate pre-conditioning (such as root pruning) and post-care (including irrigation and stabilization).

Where removal is unavoidable, compensatory planting using native species ensures ecological balance is restored over time and strengthens site resilience.

As per ECSBC and ENS, compensatory plantation should occur within the site in ratios of 1:3. The number of affected trees should include those that are felled or transplanted due to the construction work.

Tree preservation and compensatory planting together create a holistic framework for enhancing ecological integrity on development sites. While preservation maintains the strength of existing natural systems, compensatory planting provides continuity where disturbance is unavoidable. Through careful planning, strict protection protocols, scientific techniques, and thoughtful replanting strategies, ECSBC and ENS ensure that site development supports long-term environmental health, resilience, and landscape quality.



Figure 6 Protected trees with barricades

The detailed approach for topsoil preservation and compensatory plantation is provided in the National Building Code Part 10 Landscape Development, Signs and Outdoor Display Structures, Section 1 Landscape Planning, Design and Development.

Landscaping in Sustainable Site Planning

Landscaping is a fundamental component of sustainable site planning, shaping not only the aesthetic quality of a development but also its ecological performance, microclimate, water demand, and long-

term maintenance requirements. Thoughtfully designed landscapes help preserve local biodiversity, reduce heat island effects, promote groundwater recharge, and enhance the overall environmental resilience of the site. ENS emphasize the importance of using native and adaptive plant species, minimizing water demand, protecting natural landforms, and increasing vegetated area coverage to create landscapes that are both ecologically robust and resource efficient.

Sustainable Planting Strategies and Vegetation Planning

Sustainable landscaping focuses on selecting and arranging vegetation to support ecological functions while

minimizing resource use. Priority should be given to native and adaptive species, which are suited to local conditions, require less irrigation, and support biodiversity. As per ENS, at least 30% of the landscaped area must comprise native/adaptive species. Resource-intensive turf should be limited to functional areas.

Maintaining a high vegetated area ratio is equally important to ensure permeability and ecological activity. ENS prescribes minimum landscaped area requirements to prevent excessive surface hardening, improve microclimate, and enhance stormwater infiltration.

Landscape design should respect natural topography, working with existing slopes and drainage patterns to maintain ecological alignment. Meeting or exceeding ENS landscaping requirements strengthens site resilience and long-term sustainability.

Turf Management and Enhanced Ecological Landscaping

Turf management is critical in sustainable landscaping due to its high water and nutrient demands. Accordingly, turf should be limited to functional areas such as play or recreation zones, with ENS capping turf at a maximum of 30% of the total landscaped area. In non-essential areas, water-efficient alternatives—such as groundcovers, native grasses, wildflower meadows, and dry landscapes—should be used to reduce irrigation demand and maintenance needs.

Enhancing the proportion of vegetated areas through native species, layered planting (trees, shrubs, groundcovers), and biodiversity corridors improves ecological performance. These strategies mitigate heat island effects, enhance infiltration, strengthen habitat networks, and support overall site sustainability.

Water-Efficient Landscape Technologies

Modern landscape technologies play a key role in reducing water consumption and improving plant health. Drip irrigation systems deliver water directly to plant roots, minimizing evaporation losses and reducing unnecessary watering of non-vegetated areas. When integrated with soil moisture sensors,

irrigation becomes demand driven rather than schedule driven; ensuring water is supplied only when required. This combination significantly improves water efficiency and reduces operational costs.

Compliance (landscaping)

- **ENS (mandatory requirement)**
  - Minimize disturbance to natural site features. Except for low-lying areas, retain existing topography and gradients. Develop vegetated landscaping on at least 20% of the total landscaped area.
  - As per NBC, turf grass must not exceed 30% of the total landscaped area, in accordance with Clause 6.2.4.1.
  - To preserve biodiversity, minimum 30% of the landscaped area must use native or adaptive plant/ tree species, following Urban Greening Guidelines 2014, Section 8.
  - For plots > 5000 sq. m, comply with MoEFCC Notification (25 February 2022):
  - Plant and maintain 1 tree per 80 sq. m of land, ensuring minimum 10% tree cover. Existing trees may be counted.
  - As per Model Building Byelaws 2016, provide compensatory plantation for felled or transplanted trees in a 1:3 ratio within the same premises.

1.3 Selection of Site

Site selection is a fundamental aspect of sustainable development. As per ECSBC, projects must conform

to the applicable development/master plan, the Urban and Regional Development Plans Formulation and Implementation (URDPFI) Guidelines, and all statutory requirements to obtain development/building permits from the authority having jurisdiction. This includes compliance with relevant town planning, development, or municipal acts governing layout approval, building plans, water supply, sewage, drainage, electrification, and other infrastructure provisions. All necessary statutory clearances must be secured prior to approval.

The intent is to ensure that projects are planned in accordance with designated land use and regulatory frameworks, and that all statutory requirements are met before permits are granted.

1.4 Universal Accessibility and Design

Sustainable development extends beyond environmental performance to include social inclusion. A site that cannot be used safely and independently by people of diverse ages, abilities, and mobility needs does not meet holistic sustainability goals. Accordingly, ECSBC and ENS emphasize universal accessibility in open spaces, circulation, and external environments from the earliest stages of site planning.

While accessibility provisions often focus on indoor spaces, outdoor environments frequently remain inadequate. Barriers such as uneven surfaces, steep gradients, poor kerb design, inadequate lighting, narrow pathways, and lack of rest areas can restrict movement. Universal site design addresses these through barrier-free pathways, gentle slopes, tactile guidance, accessible parking, and clear wayfinding.

Key elements include properly graded, slip-resistant pathways, kerb ramps, designated drop-offs, adequate parking dimensions, and seating at intervals. Lighting, signage, and landscape features must also consider users with visual, auditory, or cognitive impairments.

Integrating these measures enhances safety, walkability, and user comfort, promotes inclusive access to open spaces, and reduces reliance on vehicles. Universal accessibility thus strengthens social inclusion, usability, and the long-term sustainability of the development.

Accessible Circulation, Pathways, and Level Management

Pathways and circulation

A universally accessible site begins with well-designed circulation routes. Pathways must be continuous, firm, stable and slip-resistant, with no abrupt changes in texture or alignment. Uneven surfaces interrupt movement and pose hazards for wheelchair users, people with visual impairments and individuals with reduced mobility. Slopes must be gentle with the National Building Code (NBC) recommending a maximum gradient of 1:12, with landings provided every 9 metres to allow rest and prevent fatigue. The minimum recommended width for ramps is 1.2 metres, ensuring comfortable movement for wheelchair users and caregivers walking alongside.

Tactile guidance elements further strengthen site accessibility. Tactile paving supports navigation for visually impaired users, particularly in open areas where directional cues may be limited. It assists with orientation and guides users to key facilities such as entrances, toilets, elevators, and public transport stops. Complementing tactile pathways with tactile maps at prominent entry points allows users to develop spatial awareness and understand site layout independently.

Level Changes and Access Points

Changes in level are common across large sites, but they must be addressed through inclusive design solutions. Drop curbs or kerb cuts should be aligned with pedestrian crossings, incorporate textured surfaces for visibility and traction and should not exceed a level difference of 15 mm. These modifications enable smooth transition for wheelchair users, parents with strollers, travelers with luggage and cyclists moving through the site.

Wherever stairs are provided, ramps must accompany them to ensure universal access to all major open spaces.

Inclusive Mobility Infrastructure: Parking and Public Transport Access

Accessible parking is a crucial yet often overlooked component of site-level accessibility. Such parking bays must be located closer to building entrances than standard parking spaces and directly connected to barrier-free walkways and ramps. Bays must be sized to allow wheelchair loading and unloading from

either side, ensuring unobstructed movement. As per ECSBC, one differently abled car park shall be provided for the first 100 parking spaces and one additional differently abled car park for every 250 parking spaces thereafter. The dimensions of the dedicated parking spaces will be as prescribed by NBC norms. These dedicated parking spaces need to be within 30 m of the main entrance of the building. Proper signage, surface markings, and adequate lighting must also be provided to ensure visibility and safety (as per NBC guidelines).

Compliance (universal accessibility)

- **ENS (mandatory requirement)**
  - Residential buildings must provide universal accessibility, including necessary features for children, elderly persons and persons with disabilities, as per Model Building Bylaws 2016 – Chapter 8.

Compliance (design for differently abled)

- **ECSBC (mandatory requirement)**
  - **Ramps:** Provide at least one accessible entrance with a ramp. Ramp design must follow NBC 2016, Part 3 – Annexure B-6.2.2 (Table 10), B-6.2.1(c) and B-6.2.4. Place a single row of tactile warning blocks at the start and end of each ramp as per NBC 2016, Part 3.
  - **Building main entrance gate:** The building's main entrance must be accessible to all users—persons with disabilities, elderly, and others with special needs—without requiring a separate entry. The accessible door must have a clear width ≥ 900 mm.
  - **Elevators:** In multi-storey buildings, provide at least one accessible elevator serving all usable levels, conforming to NBC 2016, Part 3 – Annexure B-6.4. The elevator door opening must be minimum 900 mm. Provide audio and Braille features for visually impaired users.
  - **Washroom:** Provide at least one accessible restroom in common areas or as required by local bylaws, located for easy access. Also provide one unisex wheelchair-accessible restroom meeting NBC 2016, Part 3 – Annexure B-9.2.2, with centrally placed water closet and washbasin. Provide additional accessible cubicles in male and female restrooms as per Annexure B-9.2.3. Flooring must be slip-resistant, anti-glare, and firm. Accessible toilet signage must comply with NBC 2016, Part 3 – Annexure B-9.18.

Compliance (dedicated parking for differently abled)

- **ECSBC (additional mandatory requirement for ECSBC Plus and Super ECSBC)**
  - Provide preferential parking for persons with disabilities as per NBC 2016, Part 3 – Annexure B-3.5:
    - 1 accessible parking space for the first 100 parking spaces
    - 1 additional accessible space for every 250 parking spaces thereafter
    - Parking must be located within 30 m of the main entrance
    - Install dedicated parking signages at a minimum height of 2.1 m
    - Paint the accessibility symbol on the floor as per NBC 2016, Part 3 – Annexure B-3.3

1.5 Mitigating Urban Heat Island

The urban heat island effect (UHIE) refers to the phenomenon in which urbanized areas experience higher

ambient temperatures than their surrounding rural or peri-urban regions. This temperature difference occurs due to the concentration of built surfaces, reduced vegetation, extensive impervious cover, and anthropogenic heat emissions associated with buildings, transport, and infrastructure. The UHIE manifests at multiple scales, ranging from city-wide temperature elevation to site-level or micro heat islands formed by unshaded roofs, paved surfaces, and dense building clusters.

The UHIE is primarily driven by the thermal properties of urban materials, surface albedo, solar exposure, and the suppression of natural cooling processes such as evapotranspiration. Once established, the UHIE alters local microclimates, increases cooling energy demand, stresses urban infrastructure, and adversely affects thermal comfort, public health, and environmental quality.

Urban Heat Island Effect and Its Causes

The UHIE is a well-documented phenomenon in which dense urban areas register significantly higher ambient temperatures-often 2–6°C above those of surrounding suburban or rural regions. This temperature difference is most pronounced during summer months and is especially noticeable at night, when urban surfaces continue releasing heat absorbed during the day. The UHIE arises primarily due to three thermal mechanisms: solar absorption, thermal mass, and albedo. Surfaces with low albedo absorb more heat; materials with high thermal mass store heat and release it slowly; and prolonged solar exposure worsens these effects. The UHIE can be further classified into roof heat islands (caused by dark roofs) and non-roof heat islands (caused by pavements, façades, roads, and open areas).

The primary contributors to UHIE are extensive hardscapes and thermally massive materials found in parking lots, roads, building envelopes, sidewalks, and paved areas. Urban geometry—narrow canyons, high-rise clusters, and reduced sky exposure—combined with the loss of vegetation, extensive impervious surfaces, and high levels of anthropogenic heat emissions (from transportation, industry; heating, ventilation, and air-conditioning or HVAC systems) collectively contribute towards UHIE. These surfaces and geometries absorb and retain heat, suppress natural cooling processes, and ultimately alter the local microclimate.

Micro-level heat islands are formed in smaller, site-specific contexts such as unshaded asphalt parking lots, dark rooftops, and large concrete surfaces. Although smaller in scale, these micro-heat islands cumulatively intensify overall UHIE across the city.

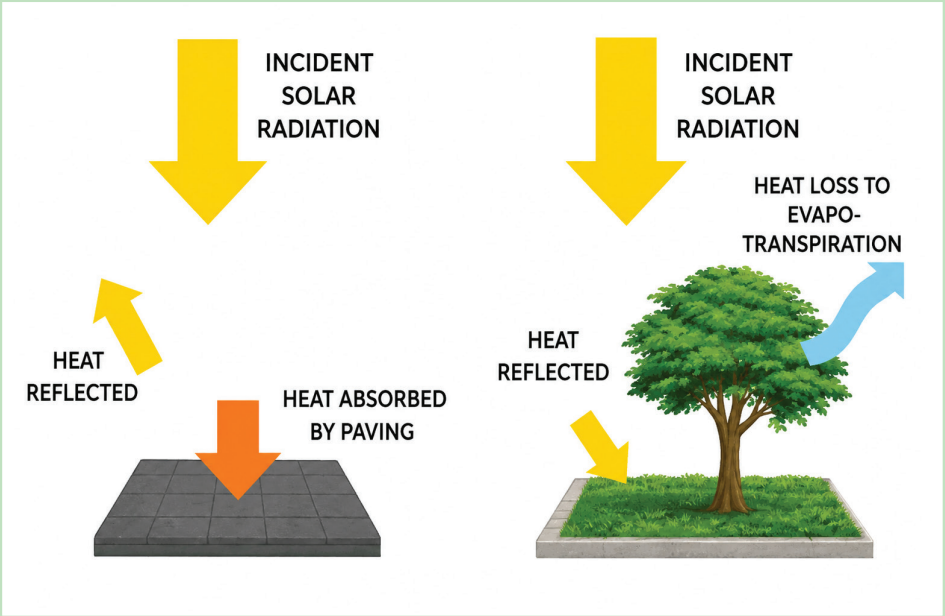


Figure 7 Graphical representation of UHIE

Site-level UHIE mitigation strategies

Given this widespread influence, mitigation strategies must occur at both city and site levels. While urban-scale interventions involve zoning reforms, city green spaces and mobility and road planning, the scope of this manual focuses on building-scale solutions that can effectively reduce UHIE contributions from individual sites. Key strategies include the following:

Cool/Light-Coloured Façades : Adopt high-reflectance finishes and low solar heat gain glazing with shading devices to limit heat absorption and reduce building cooling demand.

Green Roofs and Walls : Incorporate vegetated systems to provide insulation, promote evapotranspiration, reduce surface temperatures, and improve energy efficiency and air quality.

High-Albedo Walkways and Streets: Use light-coloured or reflective paving materials to lower surface temperatures, reduce heat accumulation, and improve outdoor thermal comfort.

Shaded Surfaces : Provide shading through trees, pergolas, or structures especially over walkways and parking to significantly reduce surface and ambient temperatures.

Optimized Paving Design : Plan efficient circulation with reduced road widths, shared access, and compact layouts to minimize paved area, lower embodied carbon, and maintain permeable, cooling surfaces.

Compliance (mitigating urban heat island)

- **ENS (mandatory requirement)**
  - Limit total paved area used for parking, roads, paths, etc. to ≤ 25% of the site area as per NBC.
  - Ensure > 50% of all paved surfaces use pervious paving, grass pavers, or open-grid systems.

Compliance (heat island reduction - roof areas)

- **ECSBC (mandatory requirement)**
  - For super ECSBC and ECSBC Plus buildings, reduce heat island effect by providing cool roofs or vegetated roofs on minimum 95% of net exposed roof area.

Compliance (heat Island reduction – non-roof areas)

- **ECSBC (mandatory requirement)**
  - Paved areas, including open parking and pathways, must not exceed 30% of the total site area (excluding building footprint), or comply with stricter local bylaws.
- ECSBC (additional mandatory requirement)
  - Provide structural shading over 100% of parking areas; shading materials must meet cool roof SRI ≥ 82.
  - Apply heat island reduction measures to 100% of paved areas, using any combination of:
    - Shade from existing or transplanted trees
    - Open-grid or grass pavers
    - Hardscape materials with SRI ≥ 29 and ≤ 64
  - Total paved areas (including uncovered parking and pathways) must remain ≤ 30% of the site area (excluding building footprint) or follow a stricter local byelaw.

1.6 Brownfield Remediation

Brownfield sites are previously developed or used lands that are underutilized, abandoned, or slated for redevelopment, where reuse is constrained by actual or suspected environmental contamination. This

contamination arising from past industrial, commercial, infrastructure, or waste-disposal activities—may affect soil, groundwater, or surface water quality.

They differ from greenfield sites (undeveloped land) and greyfield sites (underutilized but not contaminated). Due to potential contamination, brownfield redevelopment requires systematic site assessment, risk evaluation, and appropriate remediation to ensure environmental safety, regulatory compliance, and long-term viability.

Redeveloping brownfield sites is a key sustainable planning strategy, enabling reuse of urban land, reducing pressure on greenfield areas, and mitigating environmental and public health risks. Common contaminants include heavy metals, hydrocarbons, VOCs, industrial chemicals, solvents, pesticides, and leachates, which can degrade soil and water quality, release toxic vapours, and harm ecosystems and human health.

Assessment and Remediation Approach

A structured process begins with detailed site assessment, including soil and groundwater testing to identify contaminant types, concentrations, and distribution. This informs risk evaluation and selection of appropriate remediation strategies based on site conditions and regulatory requirements.

Common remediation methods include pump-and-treat systems for groundwater, bioreactors and land farming for biologically treating contaminated media, and in-situ techniques such as chemical oxidation or bioremediation to treat contaminants without excavation. Post-remediation, verification testing and regulatory approvals are required to confirm compliance and site safety.

Nature-Based Solutions

Sustainable approaches such as phytoremediation (using plants to absorb or stabilize contaminants) and bioaugmentation (using microorganisms to degrade pollutants) complement conventional methods. These techniques are cost-effective, minimally invasive, and support long-term ecological restoration while improving site quality.

Compliance (brownfield remediation)

- **ECSBC (mandatory requirement)**
  - Brownfield sites may be used only after proper remediation. Accepted techniques include, but are not limited to, pump and treat, bioreactors, land farming and in-situ remediation.
  - All remediation measures must comply with local building bylaws.
  - After remediation, the site must receive approval from the local statutory authority for its intended use.

1.7 Access to Amenities

A site that is well-connected to everyday services such as schools, shops, health care facilities, recreational areas, and public transport supports a more inclusive, efficient, and low-carbon lifestyle. ECSBC and ENS emphasize the importance of selecting sites and designing developments that minimize travel distances, reduce vehicular emissions, and enhance the daily convenience and well-being of users.

A well-planned site ensures that basic and community-oriented amenities are easily accessible by walking, cycling, or by using public transport. This not only reduces travel time and energy consumption but also promotes social interaction, encourages healthy choices, and improves the overall quality of life.

Influence of Amenities on Mobility and Environmental Impact

From a sustainability perspective, access to amenities directly influences transport-related emissions, which constitute a significant component of urban carbon footprints. When amenities are distant or poorly connected, users rely more heavily on private vehicles. This results in increased greenhouse gas (GHG) emissions, traffic

congestion, air pollution, and noise levels—conditions that undermine the environmental goals of sustainable development. In contrast, developments located near essential services help reduce reliance on cars, enabling people to choose walking, cycling, or mass transit for daily travel. This shift not only lowers emissions but also improves public health and enhances the economic vitality of neighborhoods.

A sustainable site should ideally be located within comfortable walking or cycling distance of key daily-use facilities, including grocery stores, medical clinics, parks and gardens, and community centers. Integrating these considerations into the early-planning phase leads to developments that are both environmentally responsible and socially inclusive.



Figure 8 Access to amenities in walking distance

Importance of Connectivity, Walkability, and Safe Access Routes

Access to amenities is also shaped by the quality of connections rather than mere proximity. Even when amenities are nearby, poorly designed pedestrian environments, unsafe road crossings, inadequate

lighting, or lack of barrier-free routes can discourage walking. Therefore, physical design strategies must complement locational benefits. Continuous and safe pedestrian pathways, shaded sidewalks, cycle tracks, universally accessible routes, and traffic-calming measures encourage people to choose non-motorized transport modes. A well-structured internal circulation network ensures that residents, workers, and visitors can reach amenities without encountering obstacles, discomfort, or safety concerns.

Beyond daily-use services, recreational and open-space amenities play a vital role in enhancing liveability. Proximity to public parks, lakes, neighbourhood greens, and civic spaces improves mental and physical well-being while providing opportunities for community interaction. Integrating green corridors and multi-use trails within and around the site allows people to reach such spaces safely and enjoyably. Sustainable site planning therefore recognizes amenities not only as functional destinations but also as contributors to holistic well-being.

Access to amenities is a multifaceted parameter that integrates environmental, social, and economic aspects of sustainability. By ensuring proximity to essential services, promoting safe and convenient access routes, and enabling reduced dependency on private vehicles, developments contribute to healthier lifestyles, lower emissions, and improved community cohesion. A sustainably planned site is not only energy efficient and environmentally responsible, but also deeply connected to the fabric of everyday life, enabling its users to thrive.

Compliance (access to amenities)

- **ECSBC (additional mandatory requirement)**
  - Provide access to at least four different amenities from the list of eligible amenities mentioned below in point 3, either within the building or within 800 m walking distance from the building entrance.
  - These amenities must be available once the building becomes operational.

Eligible amenities include ATM/Bank, health care clinic/hospital, grocery/supermarket, park/garden, pharmacy, restaurant/cafeteria, utility bill payment centre (electricity/water), post office/courier service. Note: Each type of amenity can be accounted only once.

1.8 Access to Public Transportation

Access to public transportation is a key determinant of site sustainability, influencing mobility patterns, energy use, and overall environmental impact. Well-connected sites reduce reliance on private vehicles, lower emissions, improve accessibility for diverse users, and support inclusive, resilient urban development. Accordingly, ECSBC emphasizes locating projects near reliable transit systems—such as buses, metro, and rail—to promote low-carbon mobility and reduce congestion.

Transportation is a major source of urban greenhouse gas emissions. Easy, safe, and frequent access to public transport encourages modal shift away from private vehicles, significantly reducing emissions

and improving air quality. However, accessibility depends not only on proximity but also on the quality of last-mile connectivity. Continuous, safe, universally accessible, and shaded pedestrian routes, along with safe crossings, are essential to ensure effective use of transit by all users.

At the planning stage, sites within approximately 800 m of transit nodes inherently support sustainable mobility. Developments should strengthen pedestrian and cycling linkages to existing systems and plan for future integration where transit is proposed.

Prioritizing public transport enhances environmental performance while improving social equity and economic viability by reducing travel costs, expanding access to opportunities, and increasing long-term site value. Complementary measures such as shuttle services, shared mobility hubs, and last-mile connectivity further improve accessibility, especially in large developments, while reducing internal vehicular movement and emissions.

Compliance (access to public transportation)

- **ECSBC (additional mandatory requirement): Ensure the project has convenient access to public transport through one of the following:**
  - Public transport (road, rail, or water) must be located within 800 m walking distance from the project exit gate, or
  - If no public transport is available within 800 m, provide a transport service connecting to the nearest public transport facility, serving at least 25% of building occupants.

1.9 In-situ Transit

In-situ transit refers to the internal mobility systems that enable safe, efficient, and low-carbon movement within a development site, governing everyday travel between buildings, amenities, parking areas, and access points. As campus-scale developments and large mixed-use sites grow in size, internal travel distances often exceed comfortable walking ranges, leading to increased reliance on motorized vehicles for short trips. Recognizing this challenge, ECSBC places explicit emphasis on bicycle-based internal mobility as a primary non-motorized, low-energy, and space-efficient mode, due to its ability to reduce internal vehicular movement, emissions and energy use while improving accessibility and user comfort. A well-planned in-situ transit framework therefore

prioritizes continuous bicycle networks, supported by safe pedestrian infrastructure and complementary clean internal transport systems, to strengthen environmental, social, and operational performance of the site.

Bicycle-centric Internal Mobility and Multimodal Integration

In line with ECSBC requirements, bicycle connectivity forms the backbone of sustainable in-situ transit planning, especially for large campuses. A continuous, safe, and legible bicycle lane network should connect all major buildings, functional zones, and shared amenities. Bicycle routes must be direct, shaded where possible, physically segregated from vehicular traffic and integrated with pedestrian networks to ensure safety and ease of use.

Adequate bicycle parking infrastructure is essential to support daily use. Parking should be provided near all primary building entrances, within short walking distances and sized appropriately to serve a meaningful proportion of occupants. Supporting amenities such as signage, lighting and way-finding further strengthen bicycle adoption and usability.

While cycling remains the priority, integration with walking routes, internal shuttle systems and external public transport nodes ensure seamless multimodal movement and convenient last-mile connectivity.

Supporting In-situ Transit Systems and Safe Street Design

For large or dispersed developments where distances exceed comfortable cycling or walking ranges, low-emission internal transport options such as electric shuttles, battery-operated vehicles or e-carts may be provided as supplementary systems. These should complement—not replace—bicycle and pedestrian networks.

Internal streets must be designed to prioritize non-motorized users. Traffic-calming measures, low- design speeds, raised pedestrians, bicycle crossings, and restricted through-movement enhance safety and encourage cycling. Landscaping elements such as shaded avenues and green corridors improve thermal comfort and make bicycle movement more attractive, while also supporting ecological functions.

Electric Vehicle Charging Infrastructure

Increased use of electric vehicles (EVs) here resulted in the need for providing adequate EV charging infra structure in the built environment. Standards for charging of electric vehicles presently restrict the charging arrangements to open area and upto first basement with provisions of necessary safety requirement considering availability of proper ventilation and means available for compartmentalized and water sprinkler fire barrier arrangement in basement. Suitable fire alarm/fire detection with gas monitoring system and fire ventilation system shall also be provided in basement.

Environmental, Social and Operational Benefits

A bicycle-oriented in-situ transit system delivers measurable environmental and social benefits. Reduced internal vehicle use lowers emissions, heat gain, and noise, while improved cycling and walkability enhance occupant health, safety, and satisfaction. Operationally, prioritizing bicycles reduces congestion, parking demand, and infrastructure costs, while creating a more efficient and resilient mobility network.

By placing bicycle mobility at the core of internal transit planning, supported by inclusive pedestrian infrastructure and clean internal transport systems, developments can align strongly with ECSBC requirements and advance broader sustainability objectives.

Compliance (in-situ transit)

- **ECSBC (additional mandatory requirement)**
  - For Super ECSBC buildings located within large campuses (total ground area > 1,00,000 m^2), the following shall be provided:

A **bicycle** lane network for internal movement, connecting all major buildings. Bicycle parking near every main building, located within 100 m of the entrance and sized to serve at least 10% of the total occupants.

Questions for Sustainable Site Selection and Planning

Section A: Objective Questions (MCQs) – 10 Nos

1. **As per ECSBC and ENS requirements, the depth of fertile topsoil that must be preserved during pre-construction is typically:**
   - A. 50–100 mm
   - B. 100–150 mm
   - C. 150–200 mm
   - D. 250–300 mm

2. **During topsoil preservation, the recommended maximum height for stockpiling stored topsoil is:**
   - A. 20 cm
   - B. 40 cm
   - C. 80 cm
   - D. 1 m

3. **Which of the following erosion control techniques is used on sloped sites by creating trenches along the natural slope lines to slow down water flow?**
   - A. Mulching
   - B. Sedimentation basin
   - C. Contour trenching
   - D. Geotextiles

4. **Under ECSBC and ENS guidelines, compensatory plantation for trees removed or transplanted should follow which ratio?**
   - A. 1:1
   - B. 1:2
   - C. 1:3
   - D. 1:3 or as per the local byelaws

5. **As per ENS landscaping requirements, the minimum percentage of landscaped area that must consist of native or adaptive plant species is:**
   - A. 10%
   - B. 20%
   - C. 30%
   - D. 50%

6. **For an ENS compliant building, turf grass area should not exceed what percentage of the total landscaped area for the incremental points?**
   - A. 20%
   - B. 30%
   - C. 40%
   - D. 50%

7. **ENS compliant building, requires that the total paved area used for parking, roads, and pathways should be limited to:**
   A. ≤ 15% of site area
   B. ≤ 20% of site area
   C. ≤ 25% of site area
   D. ≤ 40% of site area
8. **ECSBC recommends that public transportation facilities should ideally be located within what walking distance from the project exit gate?**
   A. 400 m
   B. 600 m
   C. 800 m
   D. 1 km
9. **For Super ECSBC buildings located within large campuses (>1,00,000 m^2), bicycle parking should be sized to serve at least what percentage of the total occupants?**
   A. 5%
   B. 10%
   C. 20%
   D. 30%
10. **As per ECSBC requirements for reducing Urban roof heat island effect in Super ECSBC and ECSBC Plus buildings, cool roofs or vegetated roofs must be provided on at least:**
   A. 50% of exposed roof area
   B. 75% of exposed roof area
   C. 90% of exposed roof area
   D. 95% of exposed roof area

Section B: Short Answer Questions – 5 Nos

1. Define topsoil and explain why preserving topsoil is important during construction activities.
2. What is meant by a Root Protection Zone (RPZ) and how does it help in preserving existing trees during construction?
3. List any four sustainable landscaping strategies recommended under ENS for improving ecological performance of sites.
4. Explain the Urban Heat Island Effect (UHIE) and identify two major factors contributing to it in urban areas.
5. What are brownfield sites, and why is environmental assessment and remediation required before redevelopment?

Section C: Long Answer Questions – 2 Nos

Q1. A commercial development project has the following site characteristics:

- Total site area = 10,000 m^2
- Building footprint = 4,000 m^2
- Paved surfaces (roads, parking, pathways) = 2,800 m^2

Assume the following requirements:

- ECSBC requirement: Paved areas must not exceed 30% of total site area excluding building footprint
- At least 50% of paved surfaces must use pervious paving or open-grid systems

Tasks

1. Calculate the maximum allowable paved area under ECSBC.
2. Check whether the project complies with ECSBC paving limits.
3. Calculate the minimum required pervious paving area.
4. Assess overall compliance with sustainable site planning requirements.

Q2. Describe the principles and implementation strategies of sustainable site selection and planning under ECSBC and ENS. Your answer should include discussion on:

- Topsoil preservation and erosion control measures
- Tree preservation and compensatory plantation
- Sustainable landscaping and vegetation planning
- Universal accessibility and barrier-free site design
- Urban Heat Island mitigation strategies
- Access to amenities and public transportation
- Brownfield site remediation

Explain how these measures collectively improve environmental performance, user comfort, and long-term sustainability of building developments.

Answer Key for MCQs

1. C
2. B
3. C
4. C
5. C
6. B
7. C
8. C
9. B
10. D

2. BUILDING PHYSICS

Building physics is a multidisciplinary field that applies principles of thermodynamics, climatology, and construction engineering to design buildings that are energy-efficient, climate-responsive, and comfortable for occupants.

A building is an enclosed system of components walls, roofs, floors, and windows that separates indoor and outdoor environments while providing shelter and functionality. In India, building design must respond to local climate and seasonal variations to achieve thermal comfort, effective daylighting, and energy efficiency.

High-performance buildings manage key factors such as heat flow, airflow, indoor air quality, moisture, solar gain, noise, fire safety, and structural loads, while ensuring durability and maintainability. Following the National Building Code (2016) and Energy Conservation and Sustainable Building Code (2024) , buildings can enhance sustainability by optimizing energy use, maximizing natural ventilation and daylight, and reducing dependence on mechanical systems.

This section provides:

- Heat transfer mechanisms: through concepts: conduction, convection, and radiation, and their role in influencing indoor thermal conditions and energy performance of buildings.
- Air properties and psychometrics: Provides essential insights into temperature, humidity, enthalpy, and dew points, with graphical tools like psychrometric charts, to design aid-passive design strategies and active cooling strategies.
- Climate: Presents India-specific climatic zones covering hot-dry, warm-humid, temperate, cold, composite, and their implications on building design, orientation, materials, and daylighting, in line with NBC, 2016 recommendations.
- Thermal comfort analysis: Introducing PMV, PPD indices, adaptive thermal comfort model, and Indian Model for Adaptive Comfort (IMAC) to quantify occupant comfort in both air-conditioned and naturally ventilated buildings, recognizing India's climatic diversity.

2.1 Heat Transfer

Heat transfer is a fundamental concept in thermodynamics that explains how thermal energy moves between bodies or systems because of temperature differences. It governs a wide range of natural and engineered processes, from changes in the physical state of materials to energy exchange in buildings, machines, and environmental systems. Understanding heat transfer requires a clear distinction between heat and temperature, as well as an appreciation of how energy is absorbed, stored, and released in different forms. These principles form the basis for analyzing thermal behaviour and are essential for studying sensible and latent heat, which describe how heat affects substances with or without a change in temperature.

Heat: Heat is a form of energy transfer between bodies or systems due to temperature difference. When two bodies at different temperatures are brought together, energy is transferred, the heat flows from the hotter body to the colder and may result in change of physical state/phase of the bodies or substance. A substance may absorb heat without an increase in temperature by changing from one physical state to another. For example, when heat is applied to an ice cube, it changes its state from solid to liquid, this is caused by the effect of heat. The SI Unit of Heat is Joule (J)

Temperature: Temperature plays a crucial role in thermodynamics, influencing various physical properties and processes. It determines the direction of heat transfer: heat flows spontaneously from a hotter object to a

cooler one until thermal equilibrium is reached. Understanding temperature is essential for analyzing and predicting the behaviour of systems in thermodynamic contexts.

Temperature is measured using various scales, including Celsius (°C), Kelvin (K), Fahrenheit (°F). The Kelvin scale is called absolute temperature, and the Kelvin is the SI unit for temperature.

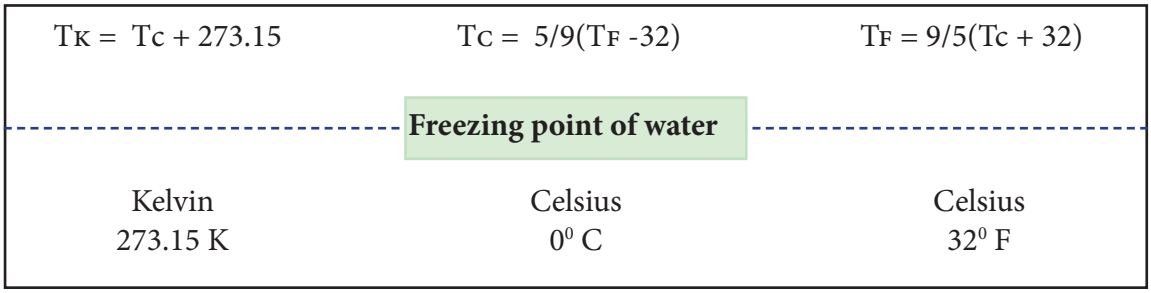


Figure 9 Various scales of temperature

Further, heat can be classified into two types: sensible and latent heat

Sensible Heat: Sensible heat is the amount of heat required to change the temperature of a substance without changing the state. When heat is applied to an object and it causes the temperature of the object to increase, it is known as sensible heat. Sensible heat can be added or removed from a substance without changing its phase without causing change in substance to melt, evaporate, or freeze.

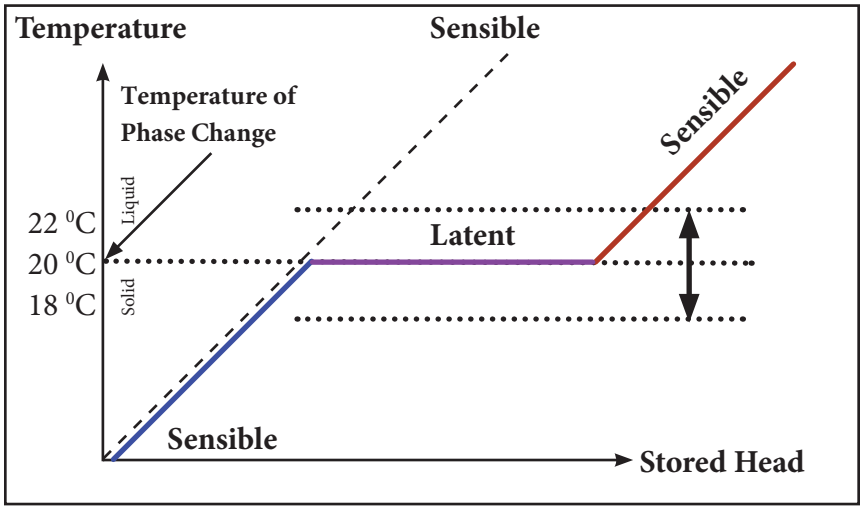


Figure 10 Sensible heat (merchantnavydecoded)

Latent Heat: Latent heat is the energy absorbed or released by a substance during a change in its physical state (phase) that occurs without changing its temperature. In latent heat, the energy is hidden within the substance's molecular structure during the phase transition. When the phase change happens, its internal energy changes even though its temperature remains constant.

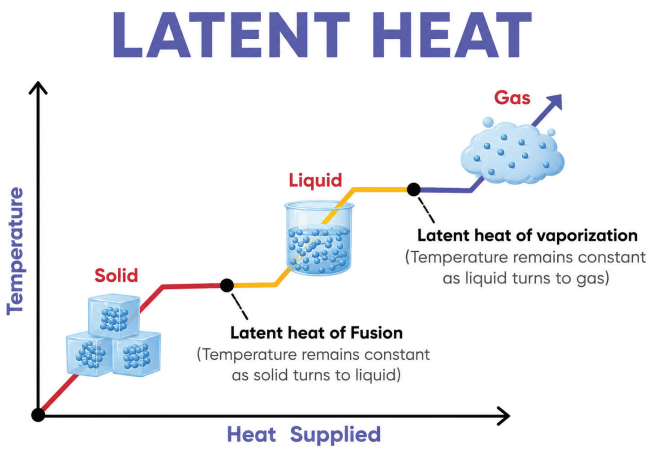


Figure 11 Latent heat (merchantnavydecoded)

Fundamentals of Heat Transfer: There are three modes of heat transfer mechanism, namely conduction, convection, and radiation. These three modes of heat transfer affects building heat gain/ loss which changes performance of the building.

Conduction: Conduction occurs when energy or heat is transferred by direct contact with objects and particles. It depends also on the property of the material known as conductivity (λ), measured as the heat flow density in a 1 m thick body.

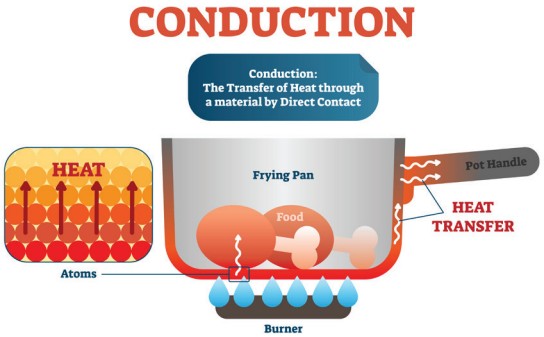


Figure 12 Illustrative example of Conduction

$$q=-k \times \Delta T$$

Where,

q = heat flux density

-k = material's conductivity

ΔT = temperature gradient

Convection: Convection occurs when energy is transferred by mass motion of molecules. This can occur through natural convection ie. due to density differences caused by temperature variations or forced convection ie, through external means such as fans or pumps that force the fluid to move. It is the transfer of heat from one point to another point within a fluid by mixing hot and cold portions of the fluid. Heat transfer by convection occurs because of the movement of fluid on a macroscopic scale in the form of circulating current. The circulating currents may be set up either by heat transfer process itself or some external agency. There are two types of convection, namely natural convection and forced convection.

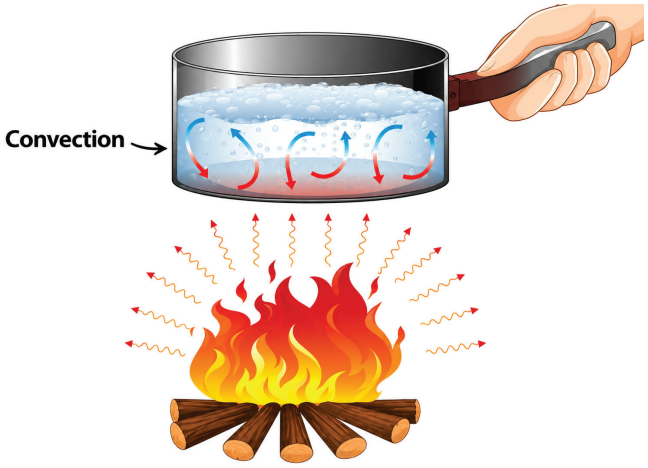


Figure 13 Illustrative example of convection

$$Qv = \mathbf{A} \times hc \times (\Delta t) \text{ or } Qv = \mathbf{A} \times hc \times (t2 - t1)$$

Where,

Qv = Heat flux

A= Surface area

hc = Convection coefficient

Radiation

Radiation is the movement of heat through space or vacuum without relying on conduction through the air or by the movement of air.

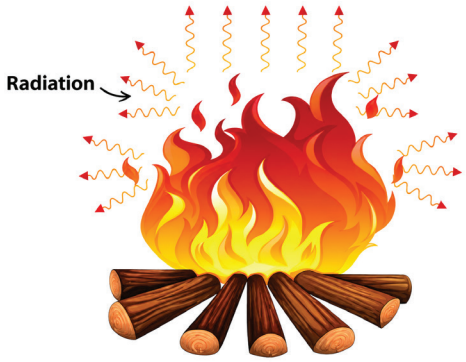


Figure 14 Illustrative example of radiation

$$Q_{net} = \varepsilon\sigma A (T_1^4 - T_2^4)$$

Where,

Q_{net} = Net heat transfer rate (in watts)

ε = Emissivity of the object (a value between 0 and 1)

σ (Stefan-Boltzmann constant) = 5.670374419...×10^{-8}W . m−2 . K^{-4}

A = Surface area of the object (in m^2)

ΔT^4 = Difference in absolute temperature (in Kelvin)

Heat Transfer in Buildings: Heat transfer in buildings occurs through conduction, convection, and radiation, affecting thermal, visual comfort, and energy efficiency. Through conduction heat travels through opaque building envelopes like walls, roofs, and floors. Through convection, heat is transferred by the movement of air currents caused by wind. Few of the examples are

a. air infiltration through gaps in the building envelope, or

b. through mechanical systems such as fans, ventilators, and air-conditioning systems,

c. through the circulation of hot water in heating systems.

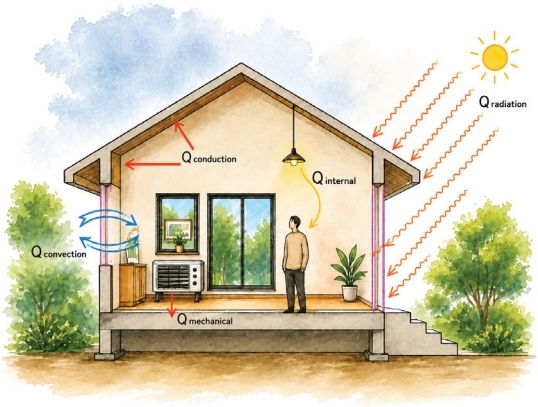


Figure 15 Heat transfer in buildings

The above image shows the Figure 15 Heat transfer in buildings, through Conduction refers to the transfer of heat through opaque construction such as walls and roofs. In the image, heat from the hot outdoor environment passes through the roof and wall assembly to the cooler indoor space. The rate of conductive heat transfer depends on the thermal conductivity and U-value of the building materials. Materials with lower U-values reduce conductive heat gain and improve energy efficiency.

$Qcon = UA(T_2 - T_1)$

Where,

U – U value of the opaque construction assembly

A – Area of the opaque construction assembly

$T_2 - T_1$ = Temperature difference of air temperature

Example: A building in Delhi with roof has the following properties

- U-value = 0.4 $W/m^2 \cdot K$
- Area = 100 m^2
- Outdoor temperature = 40°C
- Indoor temperature = 25°C

Determine the conduction through the roof

$\boldsymbol{Q} = 0.4 \times 100 \times (40 - 25)$; $\boldsymbol{Q} = 600\ \boldsymbol{W}$

Convection is the transfer of heat between a surface and moving air. The blue arrows near the opening represent air movement exchanging heat with the building surfaces. Convection occurs both outside the building due to wind and inside due to air circulation. Higher wind speeds and greater temperature differences increase convective heat transfer.

$QCon = h_c \times A \times (T_s - T_a)$

Where,

Q - Convective heat transfer

H_c - Convective heat transfer coefficient

A- Surface area

T_s - Surface temperature

T_a - Air temperature

Example: A building in Delhi with wall has the following properties

- Surface area = 20 m^2
- External surface temperature = 38°C
- Outdoor air temperature = 32°C
- External convective coefficient

Solution:

$\boldsymbol{Q = h \times A \times (T_s - T_a)}$

$\boldsymbol{Q} = 5 \times 20 \times (38 - 32)$

$\boldsymbol{Q} = 5 \times 20 \times 6$

$Q = 600\ \boldsymbol{W}$

Radiation represents heat transfer through electromagnetic waves, primarily from the sun. The solar rays striking the roof and walls indicate solar radiation absorbed by the building envelope. Solar radiation is often the largest contributor to heat gain in buildings, especially through glazing and exposed roofs. The amount of radiant heat entering the building depends on factors such as solar intensity, surface absorptivity, glazing properties, and shading devices.

Solar Radiation Heat Gain for opaque surfaces(Q) =$\alpha \times A \times I$

Where,

α - Surface absorptivity

A - Surface area

I - Incident solar radiation

Solar heat gain through glass (Qsolar) =SHGC×A×I

Where:

SHGC - Solar Heat Gain Coefficient

A - Glass area

I - Solar radiation intensity

Internal gains: Occupants, Internal lighting, equipment and other mechanical systems. Mechanical heat gain is represented by the air-conditioning unit. HVAC systems remove heat from the indoor environment but may also contribute to energy consumption and localized heat exchange. Overall, the image highlights the importance of designing high-performance building envelopes to control heat transfer, reduce cooling loads, and improve thermal comfort. Strategies such as insulation, low SHGC glazing, shading devices, cool roofs, and airtight construction are essential for achieving compliance with Energy Conservation and Sustainable Building Code and improving building energy performance.

Specific Heat Capacity: Specific heat capacity (c) of a material is a physical property, defined as the amount of heat energy required in per unit mass to produce a unit change in its temperatures. It is an intensive property and expressed in J/(kg·K).

Thermal Conductivity: It is the ability of a material to conduct the heat through its internal structure. It is the parameter in (W/m.K) that describes heat flux through a unit thickness of a material in a direction perpendicular to the isothermal planes, induced by a unit temperature difference. It does not change with the dimension or shape of the material but dependent on its temperature, density, and moisture content. Thermal conductivity is normally considered an intrinsic property of a homogenous material. When non-conductive modes of heat transfer occur within the specimen or the test specimen is non-homogeneous, the measured property of such materials is called apparent thermal conductivity. Materials with low apparent thermal conductivity are called insulation materials.

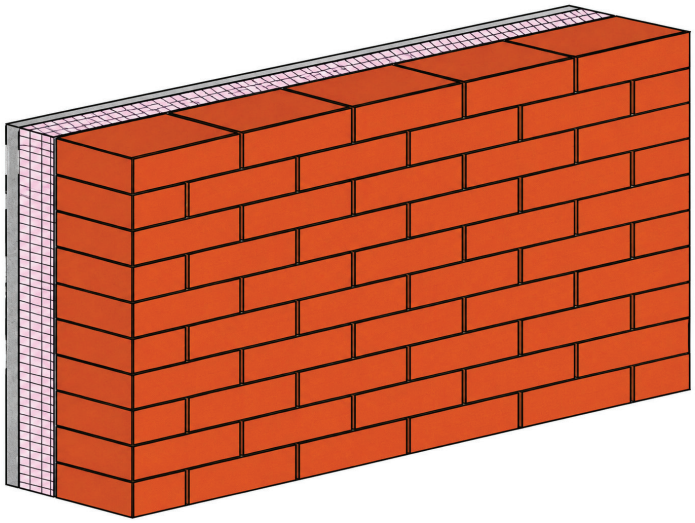


Figure 16 Assembly of a wall

Thermal Resistance: Thermal resistance is defined as the ratio of the temperature difference between the two faces of a material to the rate of heat flow per unit area. Conversely to thermal conductivity, thermal resistance (R) measures the opposition to the heat current in a material or system. It is measured in units of m^2·K/W. It

is essential to optimize the building insulation, evaluate the efficiency of electronic devices, and enhance the performance of heat sinks in various applications.

Thermal Transmittance: It is also known as U-value/factor. Thermal transmittance is the rate of heat flow per unit area per unit temperature difference and is calculated as the inverse of the total thermal resistance of all its components. A lower U-value indicates better insulation, meaning less heat is lost. The unit for thermal transmittance is watts per square metre Kelvin (W/m^2k). In building thermodynamics, it refers to how quickly heat passes through a material or assembly, such as a wall, window, or roof. For better insulation of the envelope, lower U-value material is desirable as it is more efficient at preventing heat from escaping in the winter and entering in the summer.

$$U = \frac{1}{R_T}$$

Where,

U = Thermal transmittance/ U- value of the material

R_t = Total thermal resistance of the material

R_1, R_2, R_3, R_n = Thermal resistance of the individual material layer of assembly

$$\mathbf{R_T = R_{si} + R_1 + R_2 + R_3 + R_n + R_{se}}$$

Table 1 Values of surface film resistance based on direction of heat flow

Direction	Direction of Heat Flow		
	Horizontal	Up	Down
R_{si}	0.13 m^2 K/W	0.10 m_2K/W	0.17 m^2 K/W
R_{se}	0.04 m^2 K/W	0.04 m^2 K/W	0.04 m^2 K/W

Thermal Emissivity: It is the ratio of radiant flux emitted by a surface to that emitted by a black surface at the same temperature. Emissivity refers to intrinsic properties of a material. Emissivity is defined only for a specimen of material that is thick enough to be completely opaque and has an optically smooth surface. Effective emittance refers to the properties of an object. It depends on surface layer thickness, oxidation, roughness, etc. It is a dimensionless number between 0 (for a perfect reflector) and 1 (for a perfect emitter).

ε = Emissive power of a body at temperature (T)/ Emissive power of a black body at same temperature (T)

$$\mathbf{q = \varepsilon \sigma A T^4}$$

Where,

q = Radiant heat flux (W/m^2)

ε = Emissivity of the object

σ = Stefan's constant (5.6703x10-8 W/m^2K4)

T = Absolute temperature (K)

A = Surface area of the material (m^2)

2.2 Air Properties

In the lower layers of the Earth's atmosphere, air behaves as a mixture of dry air and water vapour, where the amount of water vapour varies significantly with temperature and local climatic conditions. This water vapour content directly influences the thermodynamic behaviour of air and, consequently, affects thermal comfort, HVAC performance, energy use in buildings, and moisture-related risks. The following air properties are fundamental in the study of building physics and psychometrics, as they determine how air interacts with building materials, occupants, and mechanical systems. The important thermodynamic properties of air associated with the concentration of water vapour are as follows:

Dry Bulb Temperature : Dry bulb temperature (DBT) is the actual air temperature measured by a standard thermometer exposed to air but shielded from radiation and moisture. It represents the sensible heat content of air and is the most common temperature used in HVAC design. DBT does not account for moisture in the air. It is called 'dry bulb' because the thermometer's bulb remains dry during measurement. DBT is expressed in °C or °F and is plotted on the horizontal axis of the psychrometric chart.

Wet Bulb Temperature: Wet bulb temperature (WBT) is the lowest temperature air can reach by evaporative cooling. It is measured using a thermometer whose bulb is covered with a wet wick and exposed to airflow. When water evaporates from the wick, it cools the thermometer. WBT is always equal to or lower than DBT, the difference between DBT and WBT indicates the air's moisture content. Wet bulb temperature is a key for processes like evaporative cooling and determines the adiabatic saturation condition of air.

Relative Humidity: Relative humidity (RH) is the ratio of the actual amount of water vapour in the air to the maximum amount the air can hold at that temperature, expressed as a percentage. Higher RH means the air is more humid, reducing the effectiveness of evaporative cooling from the skin.

RH= ps/pv × 100%

Where,

Pv= Actual vapour pressure

Psat= Saturation vapour pressure at the same temperature

Specific Humidity / Humidity Ratio: Humidity ratio (HR) is the mass of water vapour present in 1 kg of dry air, expressed in grams/kg or kg/kg. This is a key measure in air-conditioning calculations because it quantifies water content, unlike RH, which is temperature dependent.

$$\omega = 0.622 \frac{p_v}{p_{atm} - p_v}$$

Where,

ω = specific humidity (mass of water vapor per unit mass of dry air)

P_v is partial pressure of water vapor.

P_{atm} is atmospheric pressure

Specific volume: Specific volume is the volume occupied by 1 kg of dry air plus its associated water vapour, expressed in m^3/kg. Specific volume increases when air is heated or when moisture is added, as warm and humid air is lighter.

It is the inverse of air density

$$v = \frac{1}{p}$$

Where,

v = Specific volume

p = air density

Enthalpy Enthalpy (h) represents the total heat content of air, including both sensible heat (from DBT) and latent heat (from water vapour). Enthalpy is essential for calculating cooling and heating loads.

$$h=1.006\ T + \omega\ (2501+1.86T$$

Where,

h = Enthalpy (kJ/kg)

T = Dry bulb temperature (°C)

ω = ω specific humidity (mass of water vapor per unit mass of dry air)

Dew Point Temperature: Dew point temperature (DPT) is the temperature at which air becomes fully saturated (RH = 100%), and water vapour begins to condense into liquid. It depends only on moisture content, not DBT. Higher dew point represents humid air. Conversely, lower dew point represents dry air. Dew point is important to predict condensation on surfaces and ensure thermal comfort in mechanical ventilation design.

Psychrometric chart:

A psychrometric chart is a graphical representation of the thermodynamic properties of moist air. It helps engineers, architects, and HVAC designers understand how temperature, humidity, and energy interact in buildings. This chart also helps evaluate whether passive measures like night flushing or radiative cooling could partially offset the heat and humidity, providing a visual and quantitative basis for designing effective comfort solutions.

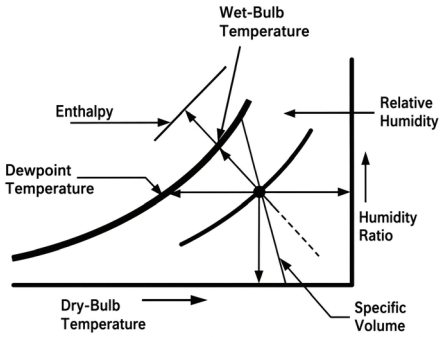


Figure 17 Structure of psychrometric chart

Example: Plot the outdoor air in Chennai at 35°C and 60% relative humidity.

The diagram plots below for the location of Chennai.

Dry bulb temperature = 35°C

Relative humidity = 60%

Enthalpy = 93 kJ/kg

Absolute Humidity = 22 g of water per kg of dry air

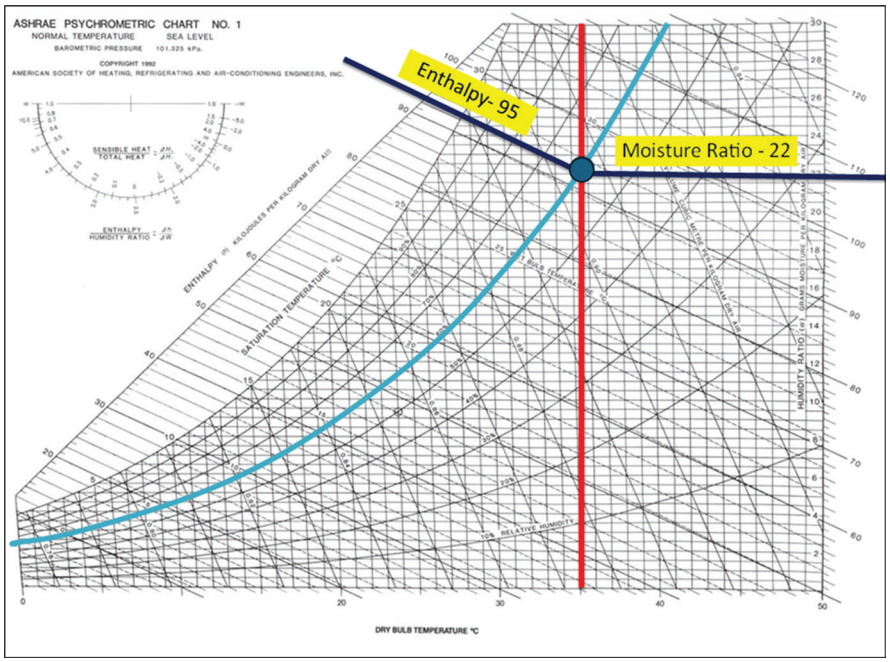


Figure 18 Psychometry chart

The above marked blue line represents the relative humidity and Red line represents the Dry bulb temperature, based on that the Enthalpy is 93 kJ/kg and Absolute Humidity = 22 g of water per kg of dry air.

2.3 Climate Fundamentals

Climate can be defined as the integration over time of the atmospheric condition's characteristic of a specific geographical location, distinguishing it from weather, which represents the momentary state of the atmosphere. On a global scale, climate is shaped by several key parameters that influence building design and environmental comfort. Location and sun path determine the solar exposure of a site, which varies with latitude and season.

For example, in the northern hemisphere, the sun is higher in the sky during summer months (May–July) and lower during winter, leading to longer summer days and shorter winter days. Understanding the sun path allows architects to design shading devices, such as overhangs, which block excessive solar heat in summer while permitting beneficial winter sunlight to enter, optimizing passive solar heating.

Global Climate Parameters

Location and sun path: Location defines the latitude, longitude, and time zone of a place, which directly influences how the sun moves across the sky throughout the year. The sun path is the apparent trajectory of the sun from sunrise to sunset. It determines:

- Solar altitude (height of the sun)
- Solar azimuth (horizontal angle)
- Day length
- Seasonal variations in heat and light
- Shadow patterns on building.

Understanding sun path helps optimize daylighting, solar heat gain, shading design, window orientation, and photovoltaic performance.

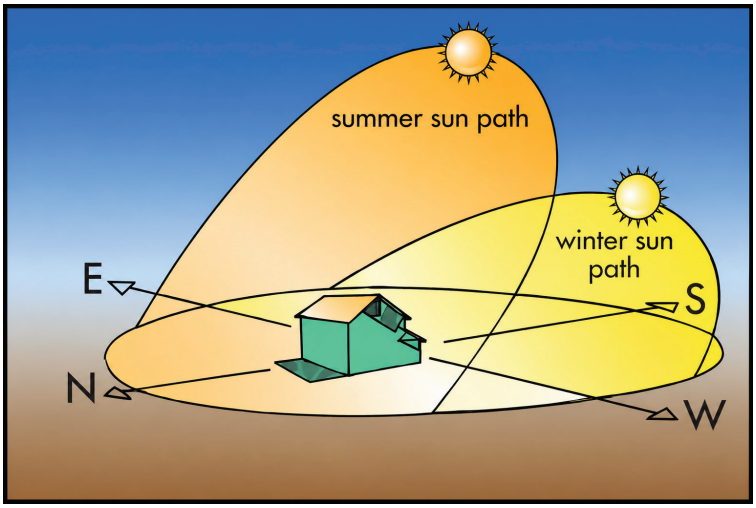


Figure 19 Sun path

In the Indian context, the sun path varies between summer and winter, influencing solar heat gain:

- **Summer:** The sun travels at a higher angle, primarily along the east–west axis. This allows effective shading of the south façade due to the high solar altitude, while the north façade receives relatively uniform, glare-free daylight.
- **Winter:** The sun moves at a lower angle across the southern sky (east to west). During this period, solar radiation penetrates deeper into south-facing façades, which can be beneficial for passive heating.

Impact of latitude on sun path

At lower latitude regions (generally below 15°N, such as Chennai and Thiruvananthapuram) experience a higher solar altitude throughout the year. During summer, the sun passes almost overhead, resulting in intense roof exposure and high solar heat gain. South façades are relatively easier to shade because of the steep solar angle, while east and west façades receive significant low-angle morning and evening solar radiation. These regions also receive higher annual solar exposure and require strong passive cooling strategies such as shading devices, cool roofs, and low SHGC glazing.

The below sun path diagrams for 12°N and 28°N indicate significant variation in the sun's proximity to the zenith with changing latitude. At 12°N, the sun reaches high solar altitude angles and passes close to the zenith during certain periods of the year, resulting in intense overhead solar exposure and shorter shadows.

At higher latitude regions (such as Delhi and Jaipur) experience comparatively lower solar altitude and greater seasonal variation in sun path. In winter, the sun angle becomes lower, allowing beneficial solar penetration into south-facing spaces for passive heating. During summer, although solar altitude increases, it is still lower compared to southern Indian cities. These regions often require a balance between summer shading and winter solar access.

In contrast, at 28°N, the sun remains lower in the sky and never reaches the zenith, leading to greater seasonal variation in solar altitude and longer shadow patterns. These variations influence the distribution of solar radiation on building surfaces and affect the thermal and daylight performance of buildings.

Although the sun path varies with latitude, azimuth, and seasonal changes, the east and west façades consistently receive the maximum solar radiation at lower angles throughout the year, making them critical surfaces for heat gain control.

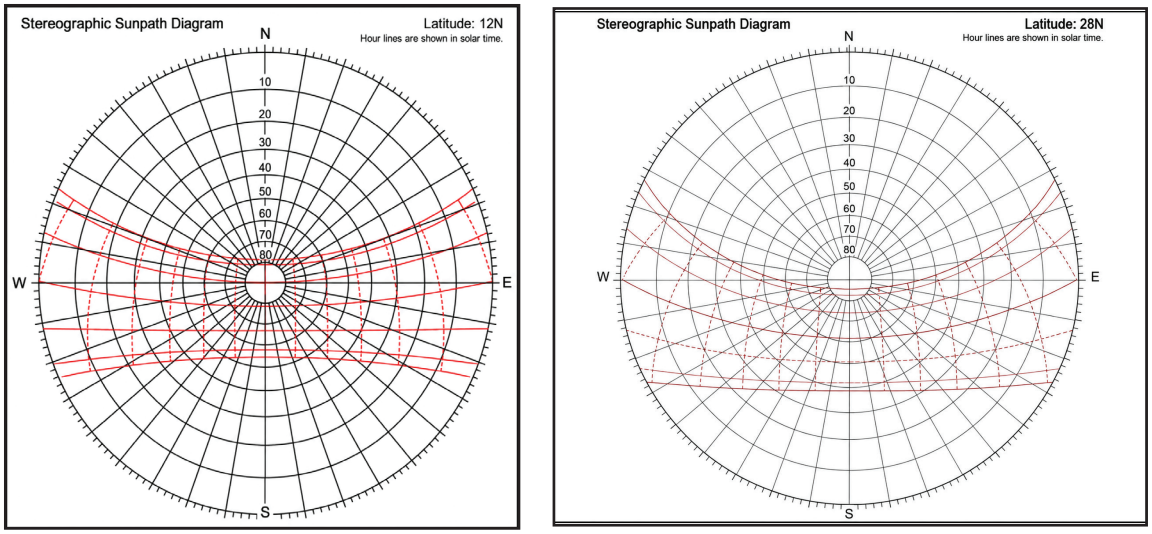


Figure 20 Sun path diagram for 12 degrees north and 28 degrees north (28N)

Solar radiation: It is the energy received from the sun, which varies with altitude and atmospheric conditions due to absorption, scattering, and reflection by gases, aerosols, clouds, and earth's surface. Solar radiation reaching the surface is categorized as direct, which travels straight from the sun and can cause local discomfort; diffuse, which is scattered and provides ambient light; and reflected, which depends on surface albedo. The understanding of solar radiation is important for understanding the concept of heat gain through building envelope.

It is the electromagnetic energy emitted by the sun, reaching the earth's surface in three components:

- Direct normal radiation (DNI) – Solar rays reaching the surface without scattering
- Diffuse horizontal radiation (DHI) – Scattered by atmospheric particles and clouds
- Global horizontal radiation (GHI) – Total solar energy on a horizontal surface

$$GHI = (DNI \times \cos(\theta z)) + DHI$$

Where,

θ_z is the solar zenith angle, representing the angle between the sun's rays and the vertical direction.

Example: For a location in India, calculate Global horizontal radiation (GHI), where Direct normal radiation (DNI) is 800 W/m² with 30° Solar zenith angle and Diffuse horizontal radiation (DHI) is 100 W/m²

Solution:

$$GHI = 800 \times \cos(30^{o}\text{^}) + 100$$
$$GHI = 800 \times 0.866 + 100$$
$$GHI = 692.8 + 100$$
$$GHI = 793\text{W/m^2}$$

Solar radiation depends on:

- Latitude and season
- Cloud cover

- Air pollution
- Atmospheric water vapor
- Surface tilt and orientation

Wind: Wind arises from differences in atmospheric pressure caused by uneven heating of land and water masses and the rotation of the earth. Winds redistribute heat and moisture, affect seasonal temperature and rainfall patterns, and are a major consideration in naturally ventilated buildings. (Ministry of Housing and Urban Affairs (MoHUA))

Example: The diagram below shows average monthly wind direction for time 9 AM to 6 PM and 6 PM to 9 AM (April to August)

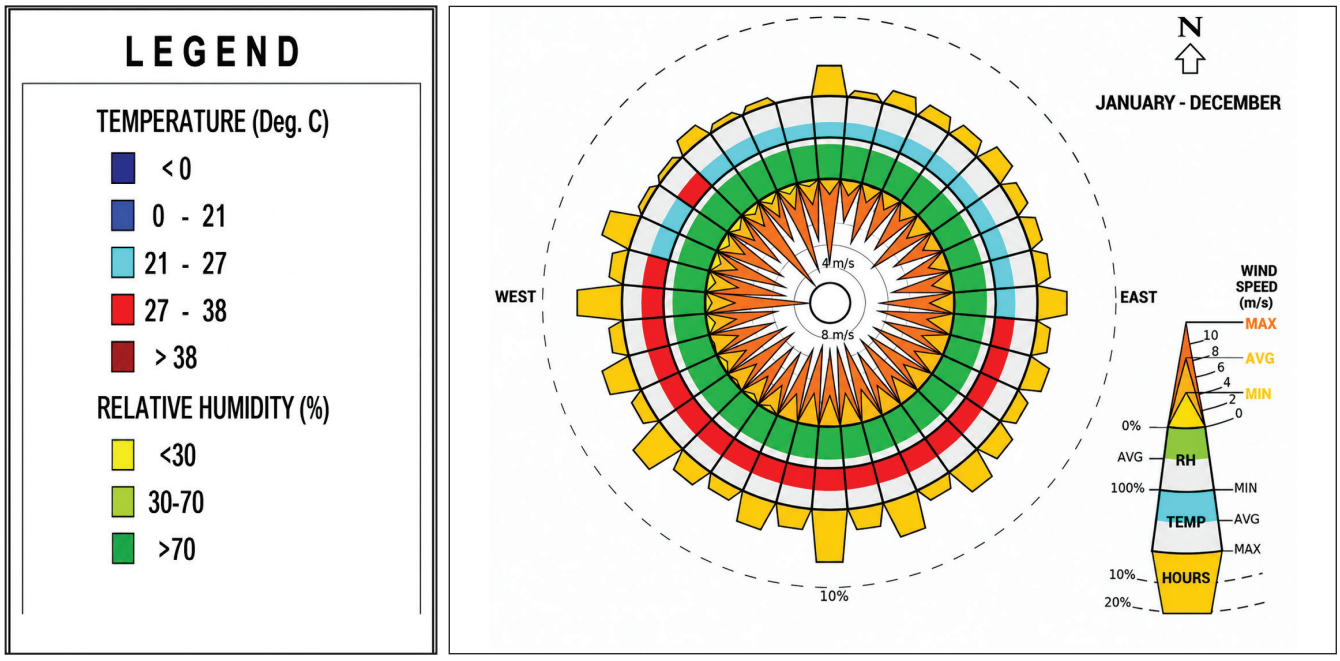


Figure 21 Windrose diagram, Chennai

A wind rose is a graphical representation that shows the frequency, direction, and speed of wind occurring at a specific location over a defined period of time. It is commonly used in climate analysis, urban planning, architecture, and building design to understand prevailing wind patterns and support climate-responsive decision-making. In a wind rose diagram, wind directions are arranged around a circular chart corresponding to the cardinal directions (north, south, east, west, etc.), while the length of each segment indicates how often the wind blows from that direction. Different colors or bands are often used to represent varying wind speed ranges.

For building and site planning, wind rose analysis helps in optimizing natural ventilation, improving thermal comfort, reducing cooling loads, controlling dust movement, and enhancing pedestrian comfort. It also supports the strategic placement of openings, landscaping, and wind barriers to improve overall environmental performance and energy efficiency of a development.

Sky condition: Presence or absence of clouds, influencing the intensity of solar radiation. Clear skies result in higher radiation and more solar gain, while overcast conditions reduce heat and light penetration. Precipitation encompasses all forms of water deposited from the atmosphere, including rain, snow, hail, dew, and frost, and plays a significant role in site planning, drainage design, and material selection. Collectively, these global

climate parameters provide the foundational information for designing buildings that respond effectively to local environmental conditions, enhance thermal comfort, and reduce energy demand.

Precipitation: It refers to all forms of water that fall from the atmosphere and are deposited on the earth's surface. This includes rain, snow, hail, dew, and frost. It represents the transfer of moisture from the atmosphere to the ground and is a key factor in determining local climate conditions, influencing water availability, landscape design, drainage systems, and building material durability. Precipitation patterns also affect thermal comfort and indoor humidity levels, making it an important consideration in sustainable building and environmental planning.

Climate: As per NBC, for the purpose of design of buildings, the country may be divided into the major climatic zones as given in the table below.

Table 2 Classification criteria for climate zone in india

Climate	Mean monthly maximum temperature (^{0}C)	Mean monthly relative humidity (%)
Hot-dry	Above 30	Below 55
Warm-humid	Above 30 Above 25	Above 55 Above 75
Temperate	25 - 30	Below 75
Cold	Below 25	All values
Composite	A climatic zone that does not have any season for more than six months may be called a composite zone.	

The climatic classification map of India is shown in below Figure.

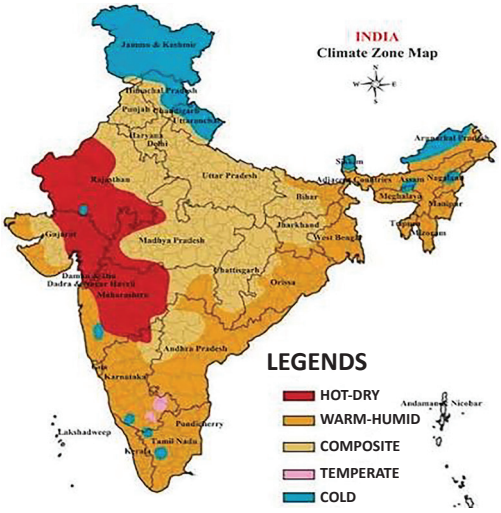


Figure 22 Classification of Indian climate

Hot and dry: This climate has high temperatures with low humidity and rainfall. This region has intense solar radiation and a generally clear sky. The winds are hot during the day and cool at night. The soil type is sandy ground with little vegetation. This region has low underground water tables and few sources of surface water. Annual precipitation is lesser than 500 mm. Sky conditions are cloudless with high solar radiation, causing glare. The outdoor design sky illuminance varies for different climatic regions of the country. The recommended design sky illuminance value is 10, 500 lux for hot-dry climate (NBC, 2016).

Composite: This climate has high temperatures in summer and cold in winter. It has low humidity in summer and high humidity in monsoons. This region has high direct solar radiation in all seasons except in monsoons season due to high diffused radiation. The winds are hot in summer, cold winds in winter, and strong winds in monsoons. The landscape is variable with seasonal vegetation The outdoor design sky illuminance varies for different climatic regions of the country. The recommended design sky illuminance values are 8000 lux for composite climate.

Warm and humid: This climate is moderately high during day and night. It has very high humidity and rainfall. This region has diffused solar radiation if cloud cover is high and intense if sky is clear. The winds are calm to very high winds from prevailing wind directions. The vegetation is abundant. The outdoor design sky illuminance varies for different climatic regions of the country. The recommended design sky illuminance values are 9000 lux for warm humid climate (NBC, 2016).

Temperate climate: This climate has moderate temperatures with moderate humidity and rainfall. It has same solar radiation throughout the year and sky is generally clear. The winds are high during summer depending on topography. The hilly or high plateau region is abundant with vegetation. The outdoor design sky illuminance varies for different climatic regions of the country. The recommended design of sky illuminance is 9000 lux for temperate climate.

Cold: This climate has moderate summer temperatures and is very low in winter with low humidity in cold/ sunny and high humidity in cold/cloudy. It has low precipitation in cold/ sunny and high in cold/cloudy. This region has high solar radiation in cold/sunny and low in cold/cloudy, cold winds in winter. The vegetation is very little in cold/sunny and abundant vegetation in cold/cloudy region. The outdoor design sky illuminance varies for different climatic regions of the country. The recommended design of sky illuminance values is 6800 lux for cold climate,

2.4 Occupant Comfort

Thermal balance and comfort

Thermal comfort is defined as that condition of mind which expresses satisfaction with the thermal environment (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2020). Thermal comfort is determined by six primary variables as mentioned in the diagram below.

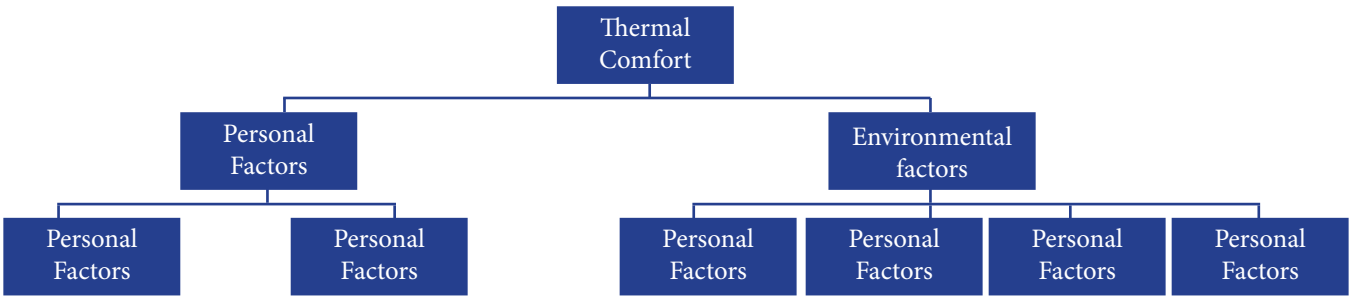


Figure 23 Factors affecting thermal comfort

2.5 Factors affecting thermal comfort

Clothing insulation: Clothing acts as an insulating layer between the human body and the surrounding environment, thereby reducing heat loss through convection, radiation, and evaporation. The clothing insulation is expressed in units of 'clo'. One clo corresponds to the insulation provided by a typical indoor business outfit

consisting of a suit, shirt, and undergarments. This unit reflects the total thermal resistance of the clothing ensemble, accounting for both the insulation of the fabric itself and the trapped air layers between the skin and the clothing. Higher clo values indicate greater insulation and a warmer sensation, while lower clo values correspond to lighter clothing and increased heat loss, affecting perceived comfort.

Metabolic rate: Metabolic rate is proportional to body weight and influenced by the factors: activity level, body surface area, age and sex, health, clothing, environmental conditions such as temperature, humidity, etc. The SI unit of metabolic rates is 'MET.' At higher metabolic rates, body generates more internal heat, increasing the body's need for cooling.

Relative Humidity (RH): Relative humidity above 65% limits the body's ability to cool itself through evaporation. When the surrounding air already contains a high amount of moisture, sweat on the skin cannot evaporate efficiently, and moisture released during breathing also evaporates more slowly. This reduces one of the body's key heat-dissipation mechanisms, causing people to feel hotter, sticky, and uncomfortable.

Conversely, when humidity drops below about 30%, the air becomes very dry and begins to draw moisture from the skin and mucous membranes. This can lead to dryness of the skin, irritation in the eyes, and drying of the throat and nasal passages, all of which contribute to discomfort and may make breathing feel harsher. Thus, maintaining moderate humidity levels is essential for effective heat regulation and overall thermal comfort.

Air temperature: Air temperature is a dominant factor in thermal comfort because it directly influences convective heat exchange between the human body and its surrounding environment. Convection occurs when air moves across the skin or clothing surface, carrying heat away if the air is cooler, or adding heat if the air is warmer.

When the air temperature is lower than the skin temperature (typically around 33–34°C), heat naturally flows from the body to the air. This continuous transfer helps the body maintain thermal balance and prevents overheating. The greater the temperature difference between the skin (or clothing surface) and the surrounding air, the more efficiently heat is dissipated.

On the other hand, if the air temperature approaches or exceeds skin temperature, the direction of heat flow reverses or stops, reducing the body's ability to cool itself. In such conditions, the body must rely more heavily on other cooling mechanisms, such as sweating and evaporative heat loss.

Therefore, even slight changes in air temperature significantly affect a person's thermal sensation—whether they feel cool, comfortable, or warm—because convective heat loss depends directly on this temperature gradient.

humidity, etc. The SI unit of metabolic rates is 'MET.' At higher metabolic rates, body generates more internal heat, increasing the body's need for cooling.

Mean Radiant Temperature: It is defined as the uniform temperature of an imaginary enclosure in which radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure, is used as a metric in thermal comfort assessment. It accounts for both long-wave and short-wave solar radiation and is a crucial factor in determining thermal comfort. The MRT is a key parameter for evaluating human energy balance and comfort in both indoor and outdoor settings. Unlike air temperature, the MRT reflects how surfaces like walls, windows, and ceilings affect an occupants' heat gain or loss. MRT can be calculated by various methods, among which measuring with globe thermometer is the most common, The black-globe thermometer consists of a black globe in the centre of which is placed a temperature sensor such as the bulb of a mercury thermometer, a thermocouple, or a resistance probe.

$$MRT = \sqrt[4]{Tg^4 + hcg/\varepsilon g\sigma\ (Tg - Ta)^4}$$

where

Ta = air temperature, in Kelvin;

Tg = black globe temperature, in Kelvin;

εg = emissivity of black globe;

σ = Stefane-Boltzmann constant; and

hcg = convective heat transfer coefficient of the black globe.

Air speed: Air movement contributes to the physiological cooling effect as it accelerates convection. The convective heat loss is relative to the body surface; it changes the skin and clothing surface heat transfer coefficient and increases evaporation from the skin. Even at constant air temperature, providing air movement can significantly improve thermal comfort, especially in warm humid climates.

Adjustment mechanism Human beings continuously adjust to their thermal environment through a combination of physiological, behavioral, and psychological mechanisms that help maintain comfort. Physiological adjustments include processes such as sweating, shivering, vasodilation, and vasoconstriction, which help regulate internal temperature by modifying heat gain or loss. Behavioral adjustments involve conscious actions—like changing clothing, altering posture, adjusting activity level, or modifying the immediate environment by opening windows, switching on fans, or seeking shade. Psychological mechanisms influence how individuals perceive the environment, shaped by factors such as past thermal experience, expectations, and cultural habits. Together, these mechanisms allow humans to adapt to varying conditions, especially in naturally ventilated environments where environmental variables fluctuate throughout the day. Further, the Thermal Comfort Evaluation parameters are explained in Chapter 11 Indoor Environment Quality.

2.6 Comfort Indices

Thermal comfort is often quantified using comfort indices, which mathematically express how different environmental and personal variables combine to create a sensation of comfort or discomfort. Among the commonly used indices are the predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) models, which relate physiological heat balance to occupants expected thermal sensation. These indices help in designing indoor environments that fall within acceptable comfort zones, representing ranges of temperature, humidity, air speed, and radiation where most occupants feel thermally neutral.

Predicted Mean Vote: Predicted mean vote (PMV) is essentially the mean vote of thermal sensation for a group of people exposed to the same environment. It assumes that not all individuals have the same perception of comfort, so the value represents the average. The goal of most HVAC systems is to maintain a PMV close to 0 (neutral), meaning that most people will feel comfortable (Quadco Engineering).

PMV considers all six variables to predict thermal sensation:

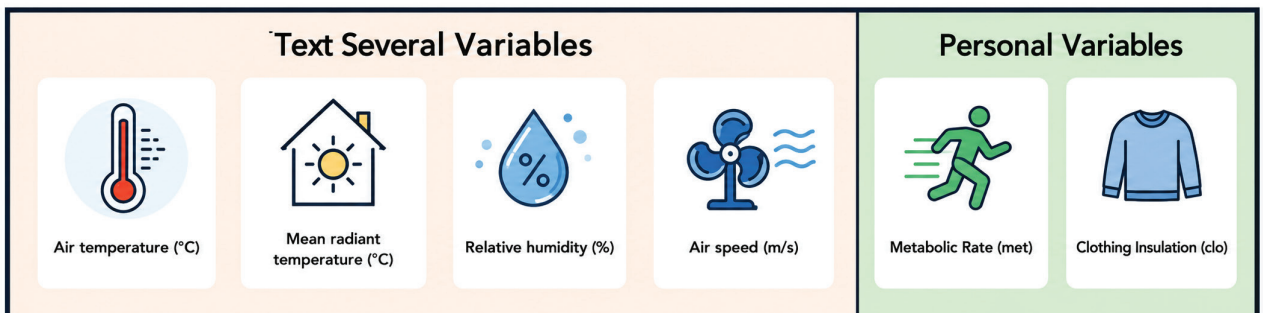


Figure 24 Variables to predict thermal sensation

In PMV, the thermal comfort index that predicts the average thermal sensation on a 7-point scale (from –3 cold to +3 Hot, where 0 is neutral). This index uses environmental and personal variables to estimate thermal comfort and sensation of occupants.

Table 3 Thermal indices PMV

-3	-2	-1	0	1	2	1
Cold	Cool	Slightly Cool	Neutral	Slightly warm	Warm	Hot

Predicted percentage dissatisfied: Predicted percentage dissatisfied (PPD) index predicts the percentage of people likely to feel thermally dissatisfied in a given indoor environment. Even at ideal thermal neutrality (PMV = 0), at least 5% of occupants feel uncomfortable, due to natural variations in human thermal sensitivity. This index has been formally integrated into ASHRAE Standard 55 (from 1981).

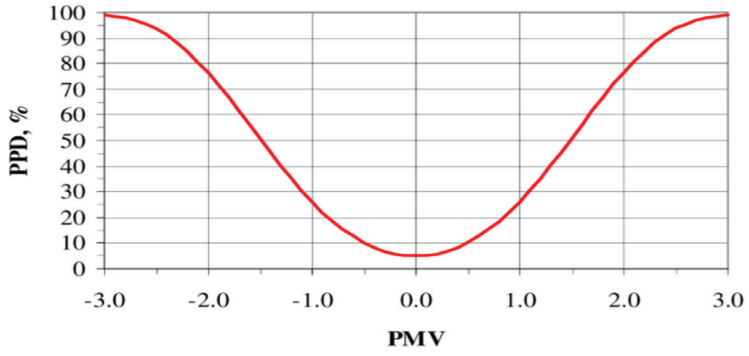


Figure 25 PPD as a function of predicted mean vote (PMV)

PPD is directly linked to PMV and reflects group-level satisfaction.

$$PMV = [0.303e^{-0.036M} + 0.028] \cdot L$$

Where,

- M = Metabolic rate (W/m^2)
- L = Thermal load on the body (difference between internal heat production and heat loss to environment)

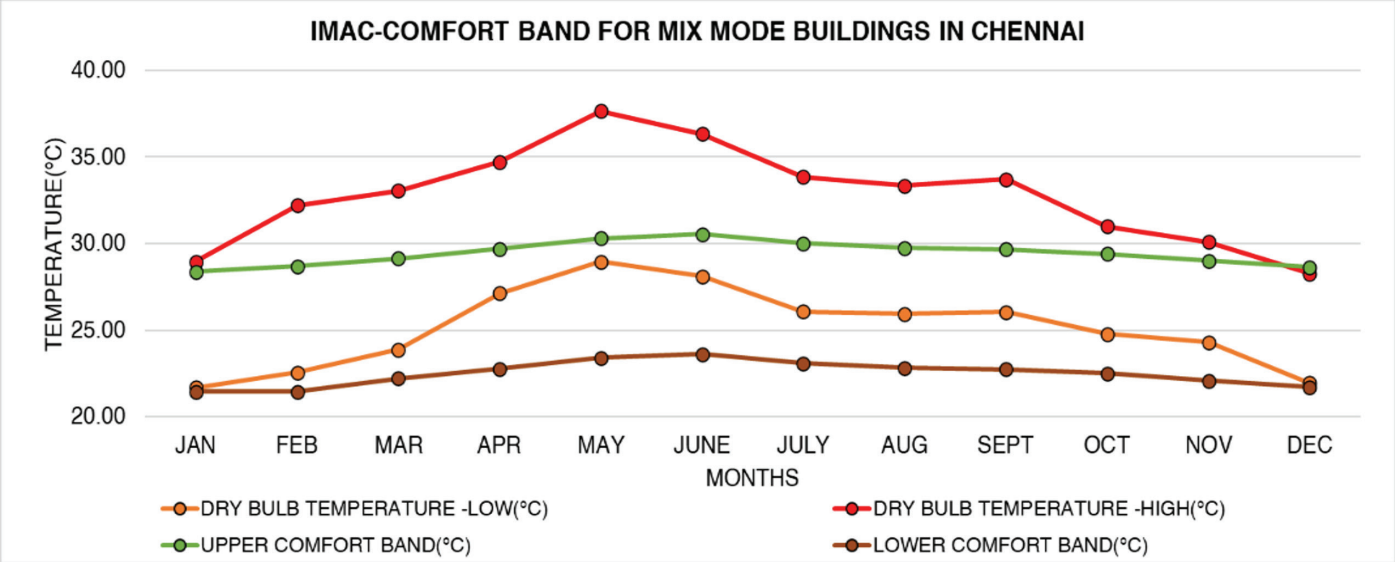
In the Indian context, the National Building Code (NBC) provides guidance on acceptable indoor environmental conditions for thermal comfort. The NBC specifies recommended values for air temperature, humidity, ventilation, and air speed, recognizing India's diverse climate zones. It acknowledges both air-conditioned and naturally ventilated buildings and encourages design strategies—like shading, insulation, thermal mass, and airflow management—to achieve comfort with minimal energy use. By using comfort indices and adhering to the NBC guidelines, designers can create indoor environments that support occupant well-being while promoting energy efficiency.

The Indian Model for Adaptive Comfort

The Indian Model for Adaptive Comfort (IMAC) is a climate-responsive comfort model developed specifically for India's varied climatic and cultural contexts. Unlike static models that assume fixed comfort temperatures, the IMAC recognizes that people in naturally ventilated buildings adapt their comfort expectations based on outdoor weather conditions. As the outdoor temperature increases, the temperature at which occupants feel comfortable also rises, reflecting long-term physiological, behavioral, and psychological adaptations.

The IMAC model proposes a series of adaptive comfort equations and comfort bands that are better aligned with Indian building patterns, occupancy behaviour, clothing levels, and lifestyle. This approach supports low-energy building design by allowing higher indoor temperatures in naturally ventilated spaces without compromising comfort.

Three models, natural ventilation, air-conditioned spaces, and mixed mode spaces are referred in (IMAC). Thermal comfort is further explained in 11 Indoor Environment Quality



Questions for Building Physics

Section A: Objective Questions (MCQs) – 10 Nos
1. In steady-state one-dimensional conduction, heat flux is directly proportional to: A. Specific heat B. Temperature gradient C. Density D. Humidity ratio
2. Thermal diffusivity of a material determines: A. Rate of heat storage B. Rate of heat conduction relative to storage capacity C. Solar reflectance D. Air leakage rate
3. Increasing air velocity improves thermal comfort primarily by: A. Reducing RH B. Increasing mean radiant temperature C. Increasing metabolic rate D. Increasing convective heat loss from skin
4. In hot-dry climates, high thermal mass is beneficial because it: A. Reduces ventilation B. Increases internal gains C. Creates thermal lag D. Increases solar absorption
5. Surface film resistance depends mainly on: A. Brick thickness B. Wind speed C. Glazing tint D. Roof slope
6. Relative humidity increases when: A. Temperature increases at constant moisture content B. Moisture content decreases C. Temperature decreases at D. Air pressure increases
7. Mean Radiant Temperature (MRT) mainly affects: A. Latent load B. Radiative heat exchange with occupants C. Infiltration D. SHGC D. SHGC

8. Time lag in building materials is primarily influenced by: A. Color of surface B. Thermal mass C. Visible Light Transmittance D. Air change rate
9. Increasing insulation thickness primarily reduces: A. SHGC B. VLT C. U-Value D. WWR
10. Thermal bridging most commonly occurs at: A. Window glass center B. Roof paint surface C. Slab-wall junctions D. Internal partitions

Section B: Short Answer Questions- 5 Nos
1. Explain the three modes of heat transfer with building-related examples. Calculate for the conduction
2. Define and differentiate between PMV model and Adaptive Comfort Model.
3. Explain the significance of a psychrometric chart and the key parameters represented on it.
4. In a commercial building, composite wall has the following layers with first layer being External plaster of 20 mm with thermal conductivity as 0.72 W/mK. Second layer Brick masonry of 230 mm with thermal conductivity as 0.81 W/mK, Third layer Internal plaster: 15 mm \ with thermal conductivity as 0.72 W/mK. Also the Indoor and outdoor air temperature are 24°C and 38°C respectively. Assume the internal and external Surface resistances as 0.12 m^2K/W and 0.06 m^2K/W respectively, calculate thermal transmittance.
5. Define time lag and decrement factor, Why are they important in passive cooling?
Section C: Long Answer Questions – 2 Nos
Q1. A commercial building envelope consists of a wall, roof, and glazing system exposed to outdoor conditions. Heat transfer occurs through conduction, convection, and solar radiation. The following data are given:

Wall	Roof	Glass
Wall area = 120 m^2	Roof area = 180 m^2	Glass area = 90 m^2
Wall U-value = 0.45 W/m^2K Indoor temperature = 25°C Outdoor temperature = 37°C Interior convective heat transfer coefficient = 8 W/m^2K Exterior convective heat transfer coefficient = 20 W/m^2K	Roof U-value = 0.35 W/m^2K Indoor air temperature = 25°C Outdoor air temperature = 37°C	Glass U-value = 2.8 W/m^2K Solar Heat Gain Coefficient (SHGC) = 0.32 Incident solar radiation = 650 W/m^2

a. Calculate the conductive heat transfer through the wall
b. Calculate the conductive heat transfer through the roof.
c. Determine the conductive heat transfer through the glazing.

Q2. Explain various Global Climate Parameters and its impact on building design in the Hot and dry climate.

Answer Key for MCQs

1. B 2. B 3. B 4. C 5. B	6. C 7. B 8. B 9. C 10. C

Answer Key for Short answer

4. R Total: 0.51 m^2K/W, U value: 1.95 W/m^2K

Answer Key for Long answer

1.

a. conductive heat transfer through the wall - 648 W

b. conductive heat transfer through the roof.- 756 W

c. conductive heat transfer through the glazing - 3024 W

3. BUILDING ENVELOPE

The building envelope is the set of structural elements—walls, roofs, floors, and openings—that separate indoor spaces from the external environment and act as a thermal barrier controlling heat transfer.In India's rapidly growing building sector, energy performance standards such as ECSBC (for commercial buildings) and ENS (for residential buildings), issued by the Ministry of Power, emphasize efficient envelope design to reduce energy use.

The envelope consists of:

- **Opaque elements:** roofs and external walls
- **Fenestration:** windows, doors, and skylights

Material selection is critical, as it affects heat gain/loss, energy consumption, durability, and environmental impact. Adopting energy-efficient materials and optimized glazing reduces operational energy demand and supports low-carbon, climate-responsive buildings.

3.1 Building Orientation and Form

Building orientation and form play a critical role in defining the long-term energy efficiency and sustainability of a building. With proper orientation and form considered at the design stage, several energy-saving strategies and conservation measures can be effectively integrated. This, in turn, significantly influences overall energy performance and reduces heat stress over the building's lifecycle. It also impacts embodied energy and establishes lower benchmarks for operational energy consumption.

Building Orientation

Building orientation refers to the positioning of a building with respect to seasonal variations in the sun's path and prevailing wind patterns. Understanding the sun's trajectory and its impact on building façades is essential for achieving optimal orientation.

An appropriately oriented building maximizes daylight availability while minimizing energy demand throughout its lifespan. Since orientation is a static design strategy, it provides long-term benefits without additional operational costs.

Design Considerations

The Figure 27 Initial design shows the initial design of the building. At the design stage, it is essential to align building orientation with local climatic conditions. The building should be oriented based on solar angles, solar heat gains and wind patterns.



Figure 27 Initial design



Figure 28 Longer axis along the east–west direction

- It is essential to orient the longer axis along the east–west direction to minimize heat gain on the building envelope.
- Reduce exposure of east and west façades, by reducing the surface area as they receive intense low-angle solar radiation as shown in the Figure 28.
- Maximize the use of the north façade through skylights, light shelves for consistent, diffused daylight.
- The south façade with appropriate thermal mass, shading devices to control seasonal solar gain as shown in the Figure 29.



Figure 29 South facade with thermal mass and shading devices

Building form and massing

Building form and mass is a fundamental aspect of the design process that determines the shape, size, and volume of a building. Building massing also plays a crucial role in shaping spatial design and helps optimize the use of natural resources such as sunlight and wind while minimizing energy loads.

Depending on project requirements, strategies such as courtyards, stepped forms, or compact layouts can be adopted during the early stages of design, enabling the integration of

- Passive cooling and heating
- Daylighting optimization
- Energy efficient building material selection

Design Considerations during Building Massing

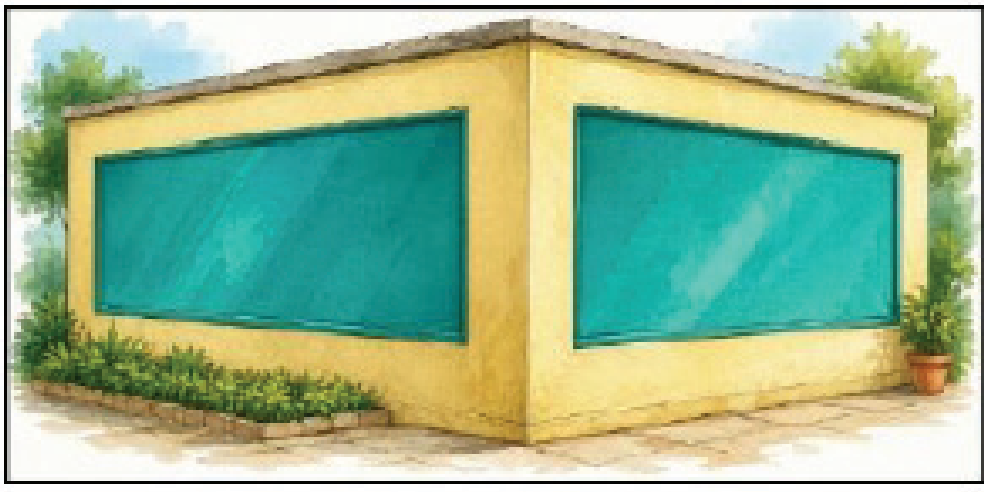


Figure 30 Initial design

Courtyard planning enhances ventilation and daylight, act as microclimate modifiers by promoting natural ventilation through stack and wind-driven effects. They also allow controlled daylight penetration into deeper building zones, reducing artificial lighting demand. Additionally, shaded courtyards can help in lowering ambient temperatures within the building.



Figure 31 Design with climate responsive courtyard

Compact building forms minimize the surface area exposed to external conditions, thereby reducing unwanted heat gain in summer and heat loss in winter. This improves thermal comfort and reduces dependence on mechanical systems. It is particularly effective in extreme climates where external exposure significantly impacts indoor comfort.



Figure 32 Longer axis along the east–west direction



Figure 33 Optimized shading devices and Longer axis along the east–west direction



Figure 34 Optimized shading devices and massing with design with climate responsive courtyard

3.2 Envelope Heat Transfer

Heat always flows from the warmer side of the building envelope to the colder side. Conduction, solar radiation, and infiltration are the major parameters of heat flowing through a building envelope. Radiation is heat flow over a distance from hot to cold, the way the sun's heat reaches earth. This causes occupants to use window shades to block excess radiation to maintain thermal and visual comfort.

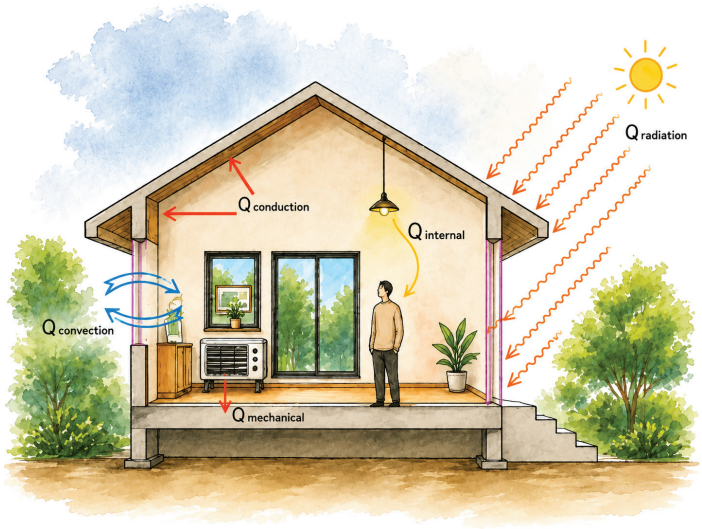


Figure 35 Heat transfer in buildings

This section aims to minimize heat transfer, enhance daylight utilization, and reduce energy demand for lighting and heating, ventilation, and air-conditioning (HVAC) systems. By improving envelope performance through insulation, efficient fenestration, and appropriate shading, buildings can achieve lower operational energy consumption and improved occupant comfort.

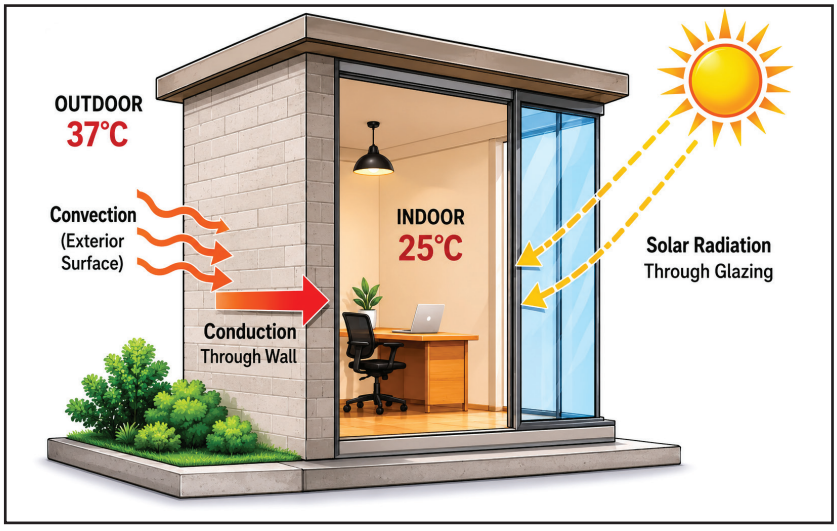


Figure 36 Convection, conduction and solar radiation through glazing in buildings

Thermal mass is the ability of a material to absorb, store and release heat. High thermal mass is beneficial when the diurnal variations of the place/location is higher. Generally, the materials with higher thermal mass indicate the longer the thermal lag. The heavyweight construction materials like concrete, brick and stone has higher thermal mass with longer thermal lag. The lightweight construction materials, like timber frames, and gypsums have low thermal mass. Thermal mass combined with other passive design principles can be significantly effective to improve the thermal comfort of the occupants.

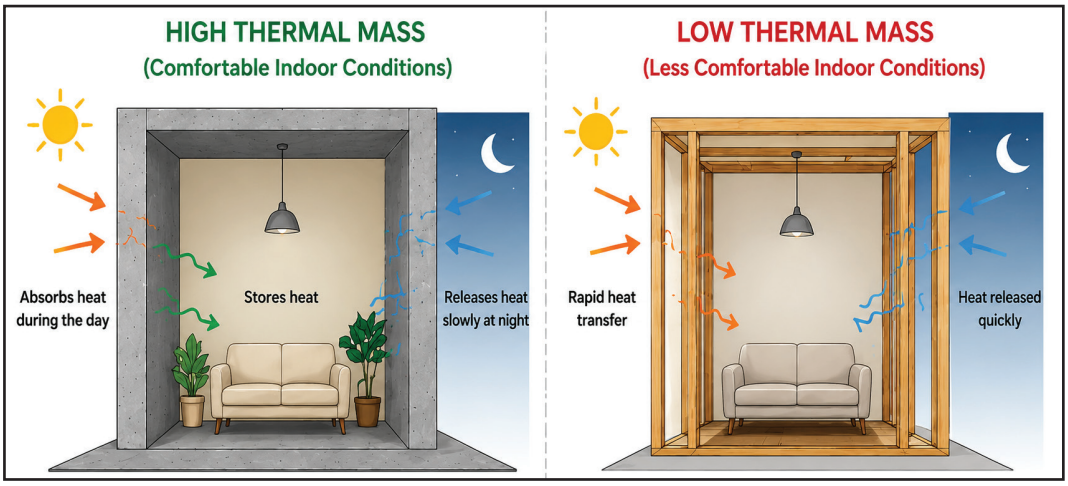


Figure 37 Effects of Thermal Mass based on the construction material

Thermal lag is the time difference between the occurrences of the maximum temperature at the outside and inside when subjected to periodic conditions of heat flow. It is expressed in hour (h).

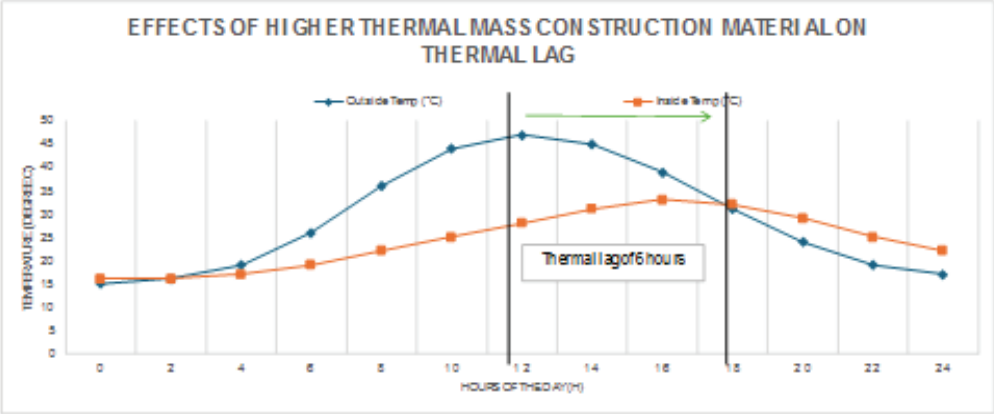


Figure 38 Effects of Higher Thermal Mass construction material on Thermal Lag

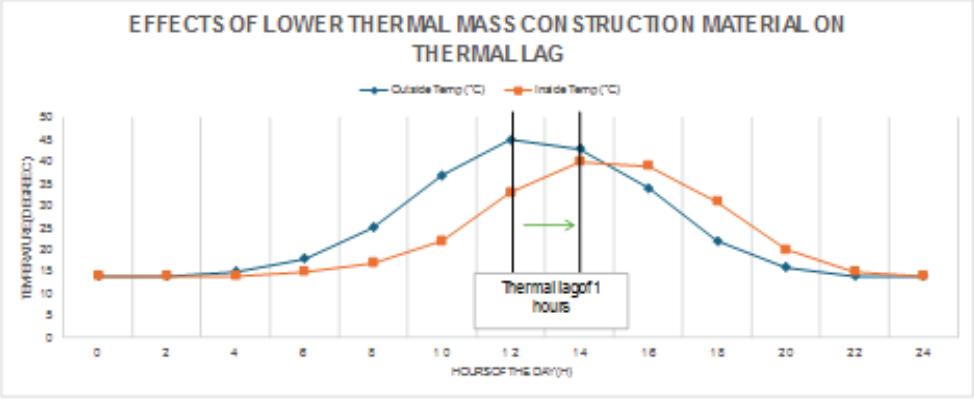


Figure 39 Effects of Lower Thermal Mass construction material on Thermal Lag

3.3 Opaque Construction in Building Envelope

Roof: The external roof assembly can be designed as a composite system of multiple functional layers, each contributing to structural stability, thermal resistance, weather protection, and durability. The thermal performance of the roof be evaluated by considering all constituent layers, with particular emphasis on the insulation layer, which plays a critical role in limiting heat transfer through the building envelope.

All roofs that are not covered by solar photovoltaics, or solar hot water, or any other renewable energy system, or utilities and services that render it unsuitable for the purpose, cool roofs or vegetated roofs may be considered. To qualify as a cool roof, the roofs with slopes less than 20° shall have an initial solar reflectance of no less than 0.70 and an initial emittance no less than 0.75.

Cool roof: Reflective paints or 'cool paints' can be used to reduce the amount of solar heat transmitted to the building. Upgrade roof and wall materials with high albedo materials to reduce heat gains. White or light-colored materials, green roof and 'cool paints' all can considerably reduce heat gains into the building and mitigate heat island effects. Application of High Solar Reflectance Index (SRI) paints on roof and walls to reduce the solar heat gains through roof.

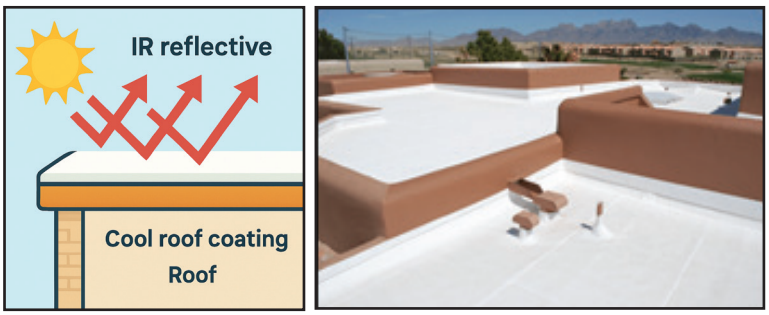


Figure 40 Cool roof

Vegetated roof: Roof with vegetation to reduce heat gains and improve the air quality of the space. This can considerably reduce heat gains into the building and mitigate heat island effects. This also acts as insulation and for a co-benefit of water collection. Cooling load on HVAC systems can be reduced by reflecting solar radiation.

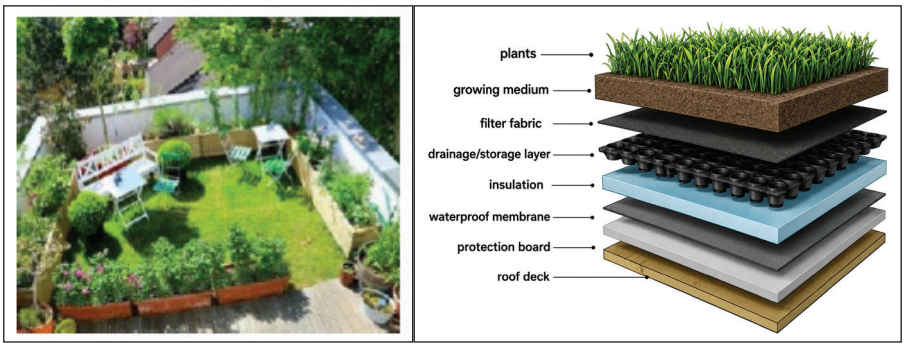


Figure 41 Vegetated roof

Opaque external wall: External walls constitute a major component of the building envelope and shall be designed to restrict heat transfer between the indoor and outdoor environments. The thermal performance of external walls shall be evaluated by considering compliance with ECSBC/ENS-prescribed thermal transmittance (U-value) limits.



Figure 42 Opaque external wall

3.4 Opaque Construction Thermophysical Properties

U-factor

It is also known as U-value/factor. Thermal transmittance is the rate of heat flow per unit area per unit temperature difference and is calculated as the inverse of the total thermal resistance of all its components. A lower U-value indicates better insulation, meaning less heat is lost. The unit for thermal transmittance is watts per square metre kelvin (W/m^2K). In building thermodynamics, it refers to how quickly heat passes through a material or assembly, such as a wall, window, or roof. For better insulation of the envelope, lower U-value material is desirable as it is more efficient at preventing heat from escaping in the winter and entering in the summer.

Mandatory Compliance (U-factor calculation), ECSBC 2024

For compliance with Mandatory Requirements of ECSBC 2024, U-factors shall be calculated for the opaque construction in accordance with ISO-6946. Or the testing shall be done in accordance with approved ISO Baseline for respective insulation type by an accredited independent laboratory and labelled or certified by the manufacturer.

For unrated products, use the default tables in Appendix A, of ECSBC 2024.

Mandatory Compliance (Thermal transmittance of the roof), ENS 2024

Thermal transmittance of the roof shall comply with the maximum Uroof value of 1.2 W/m2·K

Roof assembly U-factor – ECSBC prescriptive Compliance – ECSBC 2024

Table 4 Roof assembly U-factor (W/m²K) requirements for compliance

		Composite	Hot and dry	Warm and humid	Temperate	Cold
ECSBC	All building types except the following:	0.26	0.26	0.26	0.26	0.2
	Assembly, hospitality > 10,000 m2 AGA	0.2	0.2	0.2	0.2	0.2
ECSBC Plus	All building types	0.2	0.2	0.2	0.2	0.2
Super ECSBC building	All building types	0.18	0.18	0.18	0.18	0.18
Roof assembly U-factor – ECSBC prescriptive Compliance – ENS 2024						
Uroof (W/m2·K)		**Incremental Points**				
0.28 ≤ Uroof < 1.2		**Up to 4**				
Uroof < 0.28		**4**				

Table 5 Wall assembly U-factor (W/m²K) requirements for compliance

		Composite	Hot and dry	Warm and humid	Temperate	Cold
ECSBC	All building types except the following:	0.4	0.4	0.4	0.55	0.34
	No star hotel < 10,000	0.2	0.2	0.2	0.2	0.2
	Business < 10,000 m2 AGA	0.63	0.63	0.63	0.63	0.4
	School <10,000 m² AGA	0.85	0.85	0.85	1	0.4
ECSBC Plus	All building types except the following:	0.34	0.34	0.34	0.55	0.22
	No star hotel < 10,000 m² AGA	0.44	0.44	0.44	0.44	0.34
	Business < 10,000 m² AGA	0.44	0.44	0.44	0.55	0.34
	School <10,000 m² AGA	0.63	0.63	0.63	0.75	0.44
Super ECSBC	All building types,	0.22	0.22	0.22	0.22	0.22

Thermal transmittance of the building envelope (except the roof) for cold climate (Uenvelope, cold) ENS 2024

Uenvelope, cold (W/m2.K	Incremental Points
1.32 ≤ Uenvelope, cold < 1.8	Up to 6
0.36 ≤ Uenvelope, cold < 1.32	Up to 36
Uenvelope, cold < 0.36	36

Solar Reflectance

Solar reflectance is defined as the proportion of solar radiation that is reflected from the surface of non-transparent building envelopes after exposure, with the combined values of solar reflectance and solar absorptance equating to 1. It plays a crucial role in managing heat gain, preservation, and dissipation in building.

Compliance (Solar Reflectance)

For compliance with Mandatory Requirements of ECSBC 2024, solar reflectance for the external opaque roof construction material shall be determined in accordance with ASTM E903-96 by an accredited independent laboratory and labelled by the manufacturer.

Emittance

Emittance is defined as the ratio of the energy emitted by a surface per unit area to the energy emitted by a black surface at the same temperature, and can be specified in terms of spectral, directional, or total

values. It is often used to characterize the radiative properties of materials, with normal and hemispherical emittance being the most referenced forms.

Compliance (Emittance)

For compliance with Mandatory Requirements of ECSBC 2024, emittance for the external opaque roof construction shall be determined in accordance with ASTM E408- 71 (RA 2008) by an accredited independent laboratory, and labelled by the manufacturer.

Building Envelope Sealing

Building sealing is crucial for energy efficiency, structural integrity, occupant health, and durability by preventing air/water leaks, controlling temperature, blocking pollutants, and protecting materials from moisture/damage, ultimately saving costs, and enhancing comfort and building lifespan. It creates an airtight, watertight envelope, making buildings more sustainable and resilient against weather and noise.

3.5 Daylighting

Daylighting plays a crucial role in visual comfort because humans are naturally adapted to daylight conditions.

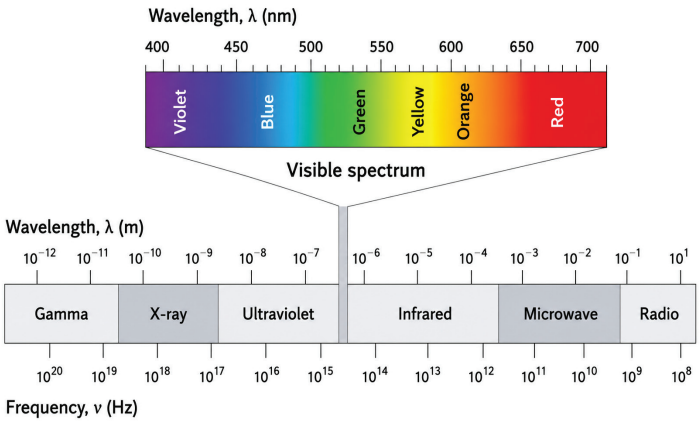


Figure 43 Visible spectrum of light

Good daylight penetration improves psychological well-being, reduces the need for artificial lighting, and enhances environmental perception. Metrics such as the daylight factor or useful daylight illuminance (UDI) quantify the availability of daylight in space. Also, access to a high-quality outdoor view significantly contributes to visual comfort, enhancing occupant productivity and overall satisfaction. Views dominated by natural elements, rather than built structures, are generally more beneficial for health and well-being.

Daylighting is dependent on several factors such as geographic location—Azimuth angle, altitude, latitude, cloud cover (overcast, clear, uniform), time of day, season, microclimate—ozone layer, atmospheric turbidity, air pollutants. Out of the total solar energy received on the surface of the earth, only 40% is visible radiation and the rest is ultraviolet (UV) and infrared (IR) wavelengths, not visible to the naked eyes.

The goals of a good daylighting design are to:

- Provide enough illuminance
- Minimize glare
- Provide overall visual comfort
- Result in improved aesthetics
- Enhance occupant comfort, productivity and health
- Reduce electric lighting energy usage

3.6 Fenestration

Energy-efficient glazing is glass that's designed to reduce the amount of heat that passes through it and can help save energy and reduce the carbon footprint. Energy–efficient glass provides an excellent alternative to control the heat gain in buildings and saves energy without compromising on the natural light coming inside the building or the brilliant aesthetics that add value to the façade. Ideal for solar and thermal insulating parameters, these glazing systems combine aesthetics with environmental sensibility. Performance parameters of glasses like visual light transmission (VLT), solar factor (SF), U-value, and internal reflection make buildings more efficient and ecologically viable.

Energy–efficient glazing, when used appropriately, can reduce the total energy consumption by anywhere between 8–10% of the total energy consumed and hence the accrued benefit of using these glazing keeps growing over the years (Kumar, Sachar, & Goenka, 2018). Furthermore, it is not just the recurring savings but also the reduction in the capex because of the lower energy loads required for conditioning the building. Typically, the heat gained/lost through glazing in a normal building in India particularly in a hot and dry climate between 20% and 30%. The incremental cost for the high-performance glazing can be recovered in a time span of 3-4 years.



Figure 44 Vertical fenestration

Glazing is classified based on the glass assembly, on appearance, coatings, tints, and through its thermal characteristics. Glazing, including the sash and frame together, is known as fenestration. The below figure shows the types of glazing based on the classifications.

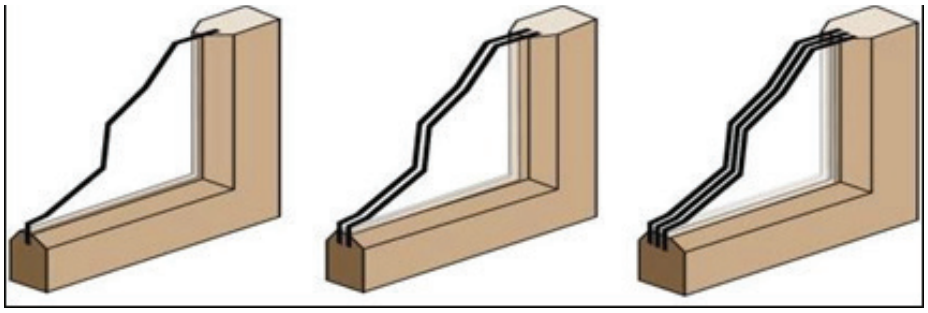


Figure 45 Types of glazing single, double, and triple glazing

Single glazing is a fenestration with one glazing enclosed with sash and frame. Double glazing has two layers of glass with an air gap or may be filled with inert gases. Triple glazing has three layers of glass with an air gap or may be filled with inert gases. The external layer of glazing may be Low E (emissivity)- coated glass. These layers affect the visual and thermal parameters of glazing. The glazing can be further classified based on its appearance, industrial modifications, and energy-efficient characteristics.

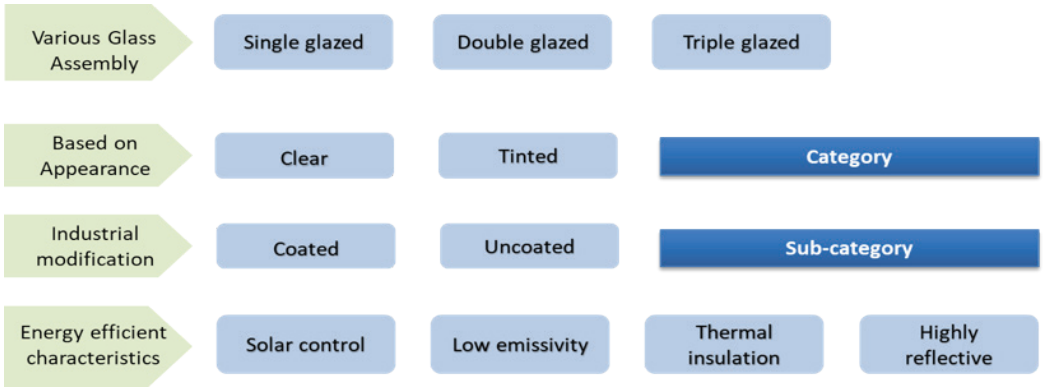


Figure 46 Classification of glazing

Fenestration as a whole can be classified as vertical fenestration that is a window and horizontal fenestration as skylight. The key metrics for identifying optimal area of window and skylights are through window–wall ratio (WWR) and skylight–roof ratio (SRR), respectively.

Window–Wall Ratio (WWR) is the ratio of the total area of windows (glazing) to the total gross wall area of a building, expressed as a percentage. Sloping glazing falls in the vertical category if it has a slope equal to or more than 60 degrees from the horizontal. If it slopes less than 60 degrees from the horizontal, the fenestration falls in the skylight category.)

Compliance (Window-Wall Ratio (WWR))

As per ECSBC 2024, for all climatic zones, vertical fenestration compliance maximum allowable WWR is 40% (applicable to buildings showing compliance using the standardized method, including building envelope trade-off method

WWR = (Total window area /Total gross wall area) x 100%

Skylight–roof ratio (SRR) is the ratio of the total skylight (top lighting) area to the total gross roof area, also a percentage.

SRR = (Total skylight area/Total gross roof area) x 100%

Compliance (Skylight–roof ratio (SRR)

In standardized method for compliance: maximum of 5% for ECSBC buildings, ECSBC Plus buildings, and Super ECSBC buildings.



Figure 47 Windows and skylight

Example: Calculation of WWR, SRR and WFR: Consider a building of 3 m (l) X 3 m (b) X 4 m (h) with an openable window of 2 m X 1.5 m of east wall and 0.15 m X 0.3 m of skylight on the roof.



Figure 48 Calculation of WWR and SRR

Solution:

Window area (m^2) = 2 m X 1.5 m = $3m^2$

North wall = 3 m x 4 m = 12 m^2

East wall = 3 m x 4 m = 12 m^2

West wall = 3 m x 4 m = 12 m^2

South wall = 3 m x 4 m = 12 m^2

Total wall area = North wall + East wall + West wall + South wall

= 12 m^2 + 12 m^2 +12 m^2 +12 m^2

=48 m^2

WWR = Total window area /Total gross wall area x 100%

= (3 m2/48 m2) X 100%

= 6.25%

Hence, the window is compliant with ECSBC.

Skylight area (m^2) = 0.15 m X 0.3 m = 0.45 m^2

Roof area = 3 m x3 m = 9 m^2

SRR = (Total Skylight area /Total gross roof area) x 100%

= (0.45/9) x 100%

= 5%

Hence the skylight is compliant with ECSBC.

Window-to-floor area ratio

Window-to-floor area ratio (WFR) determines the extent of fenestration relative to the usable floor area. While larger window areas enhance daylight and ventilation potential, excessive glazing can increase solar heat gain and thermal discomfort. The ENS mandates limits on WFR to achieve a balance between visual comfort, ventilation effectiveness, and thermal performance.

ENS (additional mandatory requirements)

- The building shall meet the minimum criteria for the openable WFR to ensure an adequate potential for natural ventilation as per Table 9 under provision number 5.2.1.1.1 of this code.

Example calculation:

Solution:

WFR = (Total window area /Total FLOOR area) x100

Window area (m2) = 2 m X 1.5 m = 3m^2

Considering 90% openable area for operable windows

Effective window openable area = 0.9m x^{3}m=2.7m^2

Total FLOOR area = 3 m X 3 m = 9m^2

=(2.7/9) x100

=30.0%

As per **Table 8: Minimum requirement of window-to-floor area ratio, WFRop, The window-to-floor area ratio, WFRop is compliant with ENS 2024.**

3.7 Fenestration Thermophysical Properties

Fenestration U-factor

The thermal transmittance or U-factor of fenestration is important to the energy efficiency of buildings. It represents the rate of heat flow through a unit area of fenestration when there is a one-degree temperature difference between the air on one side and the air on the other side. The U-factor includes consideration of the whole fenestration product (the combination of the glazing configuration and the window frame). Heat loss is

accounted for through the glass and edge of glass as well as the sash and frame elements. For skylights that sit on a curb, heat loss also includes the skylight curb. The heat loss is then normalized for the area of the rough frame opening provided for the fenestration.

Compliance (Fenestration U-Factor)

ECSBC 2024, the mandatory requirement compliance for fenestration U-value product shall be in accordance with ISO-15099.

Table 6 U-factor (W/m²K) exemption requirements for shaded building

Building type	Climate zone	Orientation	Maximum Effective SHGC	Mini mum VLT	PF
Unconditioned buildings or unconditioned spaces	All except cold	Non- north for all latitudes and north for latitude < 15°N	0.27	0.27	≥0.4
		North for latitude ≥ 15°N	0.27	0.27	≥0.0

Table 7 Skylight U-factor (W/m²K)

Climate	Maximum SHGC
All climatic zones	4.25 W/m2K

Solar Heat Gain Coefficient

The Solar Heat Gain Coefficient (SHGC) is the ratio of solar radiation that passes through fenestration to the amount of solar radiation that falls on the fenestration. Perfectly transmitting fenestration would have an SHGC of 1.0, but this is a physical impossibility since even the clearest glass absorbs or reflects some solar radiation. As with U-factor, the SHGC is also a whole product rating and accounts for the glazing material as well as the frame and sash. The SHGC is a property of the fenestration product and does not account for interior shading from Venetian blinds, vertical blinds, or draperies. As per ECSBC 2024, assembly U-factor shall be determined for the overall fenestration product (including the sash and frame).

Compliance (solar heat gain coefficient)

For ECSBC 2024, the mandatory compliance shall fenestration product in accordance with ISO-15099 or labelled or certified by the manufacturer except to ECSBC Building Envelope Section 5.2.1-(b)

Shading Coefficient

It is the measure of thermal performance of glazing. It is the ratio of solar heat gain through glazing due to solar radiation at normal incidence to that occurring through 3 mm thick clear, double-strength glass. Shading coefficient (SC), as used herein, does not include interior, exterior, or integral shading devices. Sometimes SC is also used in place of SHGC as the measurement for solar heat gain through fenestration products. The SC is the ratio of radiant heat gain through a given type of glass relative to a 3 mm thick clear glass which has SHGC value 0.87. Therefore, glass with SC value of 1 would have SHGC value equal to 0.87. (Energy Conservation and Sustainable Building Code, 2024)

$$1\ SC = 0.87\ SHGC$$

Equation 1 Conversion factor for SC and SHGC

Table 8 Vertical fenestration U-factor and SHGC requirements for compliance

Compliance levels	Requirements	Composite	Hot and dry	Warm and humid	Temperate	Cold
ECSBC	Maximum U-factor (W/m²K)	2.2	2.2	2.2	3	1.8
	Maximum SHGC on-north	0.25	0.25	0.25	0.25	0.62
	maximum SHGC north for latitude ≥ 15°N	0.5	0.5	0.5	0.5	0.62
	Maximum SHGC orth for latitude < 15°N	0.25	0.25	0.25	0.25	0.62
ECSBC Plus	Maximum U-factor (W/m²K)	1.8	1.8	1.8	2.2	1.8
	Maximum SHGC non-north	0.25	0.25	0.25	0.25	0.62
	maximum SHGC north for latitude ≥ 15°N	0.5	0.5	0.5	0.5	0.62
	Maximum SHGC north for latitude < 15°N	0.25	0.25	0.25	0.25	0.62
Super ECSBC	Maximum U-factor (W/m².K)	1.8	1.8	1.8	2.2	1.8
	Maximum SHGC non-north	0.2	0.2	0.2	0.2	0.62
	Maximum SHGC north for latitude ≥ 15°N	0.5	0.5	0.5	0.5	0.62
	Maximum SHGC north for latitude < 15°N	0.2	0.2	0.2	0.2	0.62

Table 9 Skylight SHGC requirements

Climate	Maximum SHGC
All climatic zones	0.35

Visible Light Transmittance

Visible light transmittance (VLT) is the ratio of light passing through the glazing to light passing through perfectly transmissive glazing. There is a strong relationship between the VLT and the SHGC. The lower the SHGC, generally the lower the VLT. Some glazing products, however, have a VLT higher than other products with the same SHGC. For instance, bronze, gray, and green tinted glass all have about the same SHGC for a given glass thickness, but green glass has a significantly higher visible transmittance. Likewise, some coatings applied to the surface of glazing reduce the SHGC more than they do the VLT. For good daylighting without excessive solar gain, look for a product whose VLT/SHGC ratio is higher.

Visual Light Transmittance – ECSBC 2024

Mandatory Compliance

VLT mandatory compliance under ECSBC 2024 shall be determined for the fenestration product in accordance with ISO 15099 by an accredited independent laboratory or labelled by the manufacturer.

Prescriptive Compliance (Visual Light Transmittance)

As per ECSBC 2024, for all climatic zones, vertical fenestration compliance, minimum allowable VLT is 0.27

Visual Light Transmittance – ENS 2024 As per Table 9: Minimum visible light transmittance (VLT) requirement	
Window-to-wall ratio (WWR)	Minimum VLT
0–0.30	0.27

0.31–0.40	0.2
0.41 –0.50	0.16
0.51 –0.60	0.13
0.61 –0.70	0.11

Air leakage

Air leakage in buildings refers to the uncontrolled flow of air through cracks, gaps, and openings in the building envelope, which can significantly affect energy efficiency, indoor comfort, and air quality. Air leakage occurs when outside air enters a building or conditioned indoor air escapes through gaps in the walls, floors, ceilings, windows, doors, and other building components. It is typically caused by imperfections in construction or deterioration of materials over time. Even small cracks can cumulatively result in significant air movement.

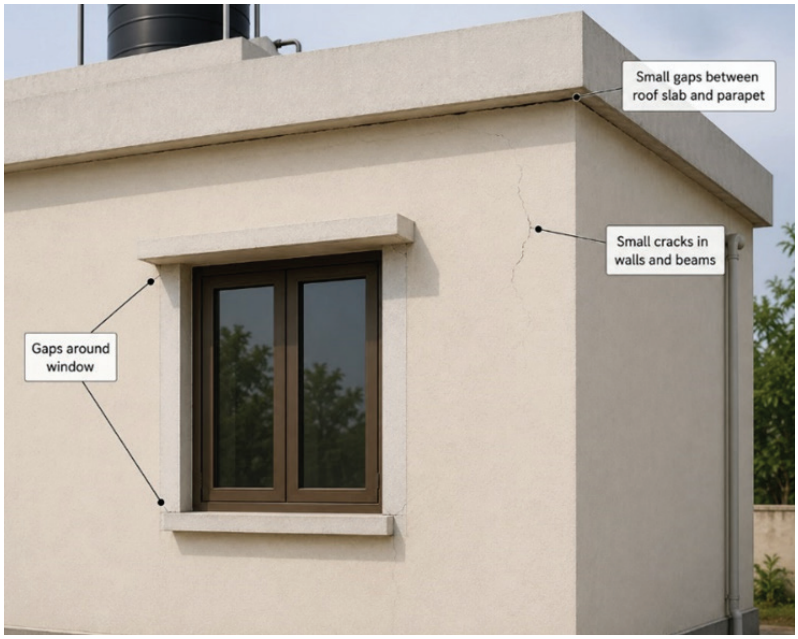


Figure 49 Air leakage in Buildings

3.8 Visual comfort

Visual comfort is the condition in which occupants feel satisfied and at ease due to the harmonious interaction between human vision, light, colour, and spatial environment. It is influenced not only by the quantity of light but also by its quality, distribution, and interaction with the human eye. Proper visual comfort enhances occupant well-being, productivity, and health, whereas inadequate or poorly designed lighting can cause eye strain, fatigue, headaches, and general discomfort. Factors such as poor brightness, high contrast differences, uneven luminance, or flickering lights can significantly degrade visual comfort.

Key factors determine optimal visual comfort in indoor environments

Luminance: Luminance (cd/m2) describes the brightness of a luminous surface which emits light through either auto luminance (as a light source), transmission, or reflection. Luminance is accordingly defined as the ratio of luminous intensity to the area on a plane at right angles to the direction of beam.

Illuminance: The amount of light falling on a surface or work plane is called illuminance. The illuminance can be measured by a lux meter, and it is the total luminous flux incident on a surface per unit area (lumen per

m^2). Illuminance must be appropriate for the task being performed; different activities require different levels of illumination to ensure that tasks can be carried out effectively.

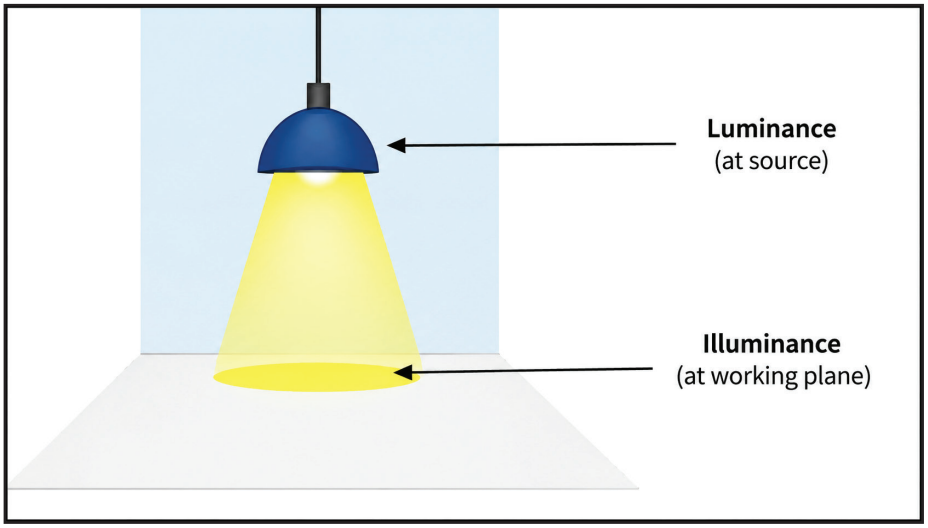


Figure 50 Explanation of luminance and illuminance

Brightness: Human beings judge brightness of an object relative to the brightness of the surroundings. It largely depends on the adaptation of the eye. Brightness is a perception of the observer. For example, car headlamps seem very bright at night but are just noticeable during the day. The brightness we perceive depends on the brightness of the headlamps relative to the overall lighting condition. The levels of brightness can result in useful contrast or discomfort glare as explained below.

Contrast: Contrast is the difference between the brightness of an object and that of its immediate background. Contrast can be extremely helpful in visual task performance. Objects with high contrast are easier to see than objects with low contrast. High contrast is the critical factor in visual appreciation of details such as outline, silhouette, and size, etc. which are the factors involved in tasks such as reading and writing.

Glare: Excessive contrast reduces the visibility resulting in glare. An extremely bright object against a dark background causes discomfort and can interfere with our visual perception. Direct glare is caused by a light source sufficiently bright to cause discomfort or loss in visibility.

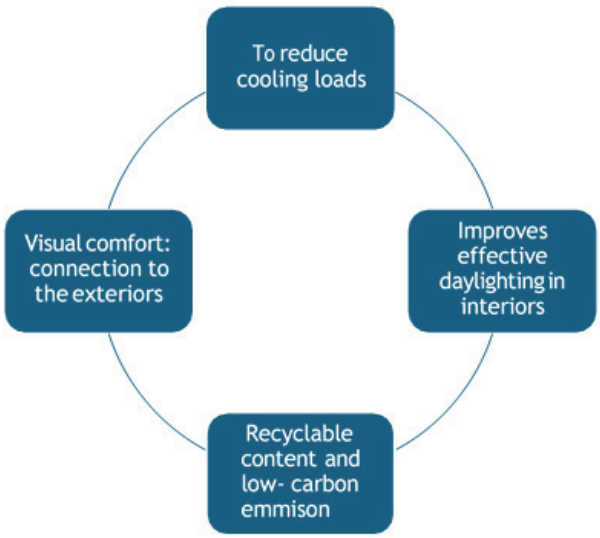


Figure 51 Benefits of energy-efficient fenestration

Usually, buildings having large, glazed areas tend to have the problem of glare inside the space due to direct sunlight coming inside. Further, light reflected off the glass façade can result in glare on neighbouring buildings and objects. Overall, glare is commonly associated with discomfort and hence undesirable. Glare can be controlled by using external shading devices on fenestrations and/or by using interior blinds.

3.9 Metrics of Evaluating Daylit Area

Daylight factor is a metric which captures the daylight conditions at a specific moment under defined conditions. This is dependent on location, specific time of day, and sky condition. Daylight factor (DF) is defined as the ratio of daylight illumination at a specific point (point in time) on a plane, due to both direct and indirect light from the sky to the illumination on a horizontal plane under an unobstructed hemisphere of the same sky. It is expressed as a percentage and is used to assess the amount of natural light in space, excluding direct sunlight (Daylight factor).

$$DF = \textit{Daylight internal (Ei) / Daylight external (Eo)} \times 100\%$$

Where,

Ei = Illuminance due to daylight at a point in the indoor working plane

Eo = Simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of an overcast sky.

Sample calculation of Daylight factor

Consider daylight external (Eo) at location of Delhi at 1:10 PM as 10500 lux and 3:10 PM – 9,700 lux with daylight internal (Ei) at 1:10 PM as 450 Lux and 3:20 PM as 150 lux, respectively.

Solution:

Daylight factor at 1:10 PM

DF = Daylight internal (Ei)/ daylight external (Eo) × 100%

= (450/10500) × 100%

= 4.29%

Daylight factor at 3:10 PM

DF = Daylight internal (Ei)/ Daylight external (Eo) × 100%

= (150/9700) × 100%

= 1.55%

spatial Daylight Autonomy (sDA) is a annual metrics assess how a space performs across all hours of an entire year, using climate data to account for varying weather and sun positions. this metric describing annual sufficiency of ambient daylight levels in interior environments. It is defined as the percentage of an analysis area (the area where calculations are performed typically across an entire space) that meets a minimum daylight illuminance level for a specified fraction of the operating hours per year.

sDA 300/50% is then reported as the percentage of analysis points across the analysis area that meets or exceeds this 300-lux value for at least 50% of the analysis period. The illuminance level and time fraction are included as subscripts, as in sDA3oo, 50%. The sDA value is expressed as a percentage of area (Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)).

Annual Sunlight Exposure (ASE) is a metric that describes the potential for visual discomfort in interior work environments. It is defined as the per cent of an analysis area that exceeds a specified direct sunlight

illuminance level more than a specified number of hours per year. (Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)).

Daylight compliance can be assessed by two types—manual and simulation.

Useful Daylight Illuminance (UDI) Useful daylight illuminance (UDI) considers the range between 100 lux and 2,000 lux on the work plane as 'useful daylight'. Above this threshold, daylight is not desired due to potential glare or overheating. Daylight levels below this range are considered inadequate for visual comfort or tasks. It is a common practice to assess illumination levels at the work plane level, since most of the activities are considered to take place at this height. There is limited research in support of considering 2,000 lux as an absolute upper threshold. However, UDI is widely used metric in the lighting industry and is considered more realistic in predicting daylight levels in space.

For ECSBC compliance with the UDI requirement shall be demonstrated through simulation using validated software.

- Buildings shall achieve illuminance levels between 100 lux and 2,000 lux over at least the minimum percentage of floor area prescribed in Table 5.1 of ECSBC 2024
- This performance shall be met for at least 90% of the potential daylit time during the defined analysis period.

Simulation Methodology

For compliance with ECSBC, Considerations for simulation of UDI shall be followed by the below-mentioned simulation requirements.

Analysis period and measurement height

- Illuminance measurements shall be taken at a work plane height of 0.8 m above the finished floor level.
- The analysis period shall cover a continuous minimum of 8 hours per day between 7:00 AM and 5:00 PM IST, resulting in a maximum of 2,920 annual hours, applicable to all building types except schools.
- For school buildings, the analysis period shall be a continuous minimum of 7 hours per day between 7:00 AM and 3:00 PM IST.

Spatial Resolution and Grid Requirements

The UDI shall be calculated using a point-by-point grid-based method. At least one calculation point per square metre of floor area shall be considered for all regularly occupied spaces.

Enclosed spaces: All spaces enclosed by permanent internal partitions, whether opaque, translucent, or transparent—with a height greater than or equal to 2.0 m from the finished floor level shall be included in the analysis.

Fenestration modelling: Fenestration elements shall be modelled using the actual visible light transmission (VLT) values as specified in the approved material specification sheets.

External obstructions: All natural or man-made daylight obstructions shall be modelled if the distance between the building façade and the obstruction is less than or equal to twice the height of the obstruction. Where surface reflectance values are unavailable, the below table shall be followed for obstructions.

Table 10 surface reflectance of obstructions

Surface reflectance of obstructions	Reflectance
Man-made vertical surfaces	30%
Natural obstructions	0%

Interior surface reflectance: Interior surface reflectance values shall be modelled based on actual material specifications. In the absence of such data, default reflectance values as provided in Table 5.2 of ECSBC 2024 shall be adopted.

Table 11 Surface reflectance values for unknown interior surfaces

Surface type	Reflectance
Wall or vertical internal surfaces	50%
Ceiling	70%
Floor	20%
Furniture (permanent)	50%

Manual Calculation - Methodology for Determining Daylight Extent Factors

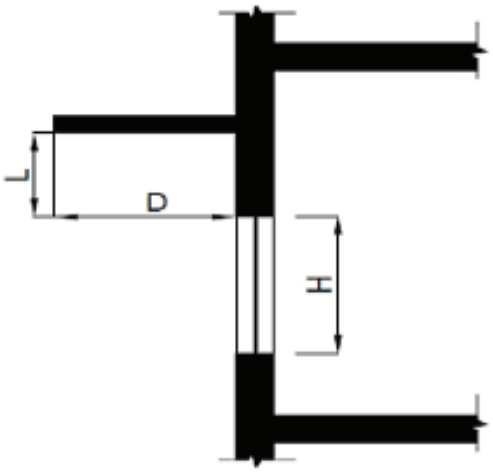
The alternative method of meeting the UDI requirement is through manual calculation of daylight extent factors (DEFs). Compliance shall be established by manually calculating the percentage of above-grade floor area that meets the UDI) requirement for at least 90% of the potential daylit time in a year, using the DEF specified in Table 5.4. of ECSBC 2024

Steps for manual calculations are given below:

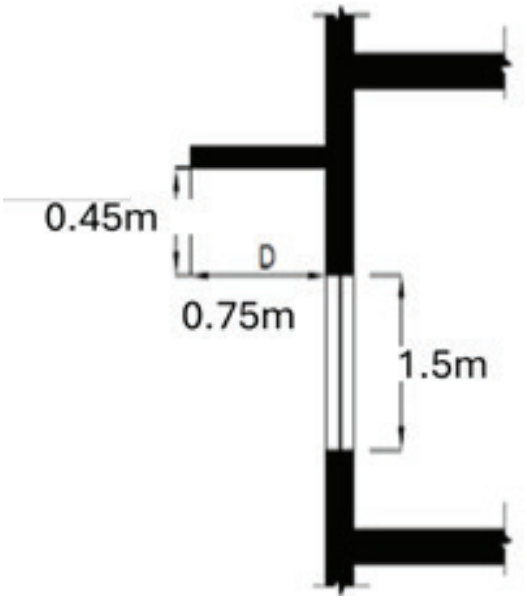
2. Determine the projection factor for every fenestration that has a shading device as per the following:

Projection factor, overhang: the ratio of the horizontal depth of the external shading projection to the sum of the height of the fenestration and the distance from the top of the fenestration to the bottom of the farthest point of the external shading projection, in consistent units

Projection factor , Overhang = D/(H+L)

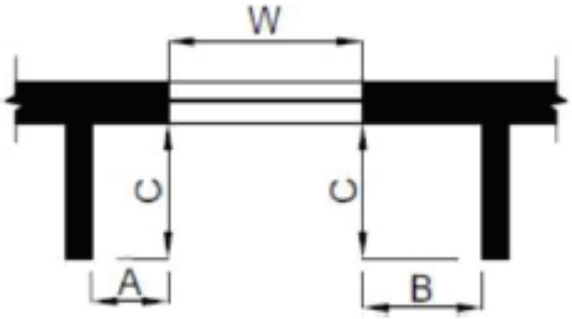


Example for

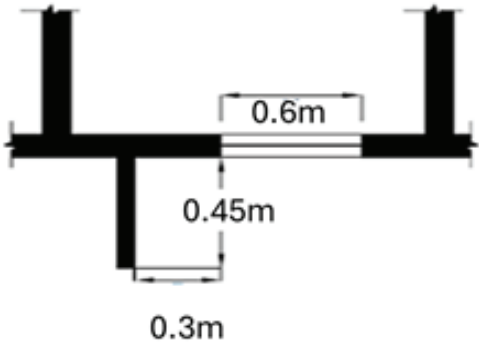


Projection factor for overhang = 0.75/(1.5+0.45)
=0.38

Projection factor, side fin: the ratio of the horizontal depth of the external shading projection to the distance from the window jamb to the farthest point of the external shading projection, in consistent units.



Projection factor Left Fin(PF left)= C/(A+W)
Projection factor Right Fin(PF right)= C/(B+W)
Projection Factor, overhang and side fin: average of ratio projection factor for overhang only and projection factor of side fin only



Projection factor for Left Fin = 0.45/(0.3+0.6)

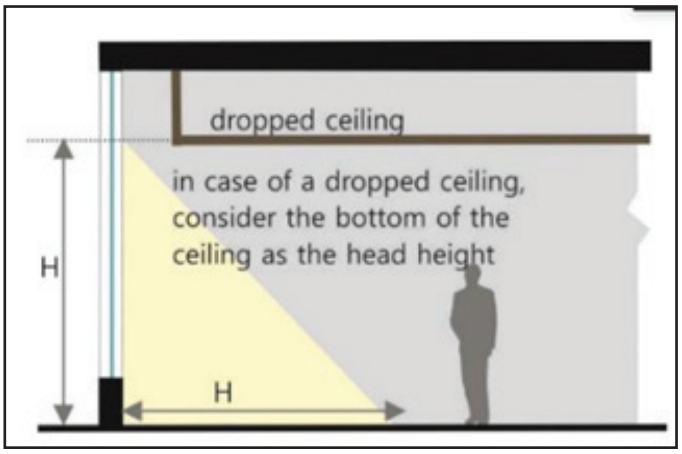
=0.45/(0.9)

=0.5

3. Determine the Daylight Extent Factor (DEF) from for each fenestration as per the orientation and corresponding VLT

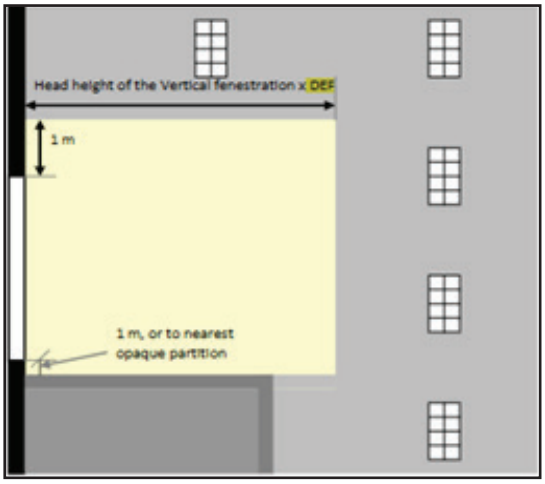
4. **A. Daylight extent perpendicular to fenestration:** In the direction perpendicular to the fenestration, the depth of the daylit area to be calculated as:

   - DEF multiplied by the head height of the fenestration, or the distance to an opaque internal partition is higher than the fenestration head height, whichever is less.
   - Formula to calculate Daylit area (distance perpendicular to fenestration) = DEF * H



b. **Daylight extent parallel to fenestration:** In the direction parallel to the fenestration, the width of the daylit area shall extend horizontally to:

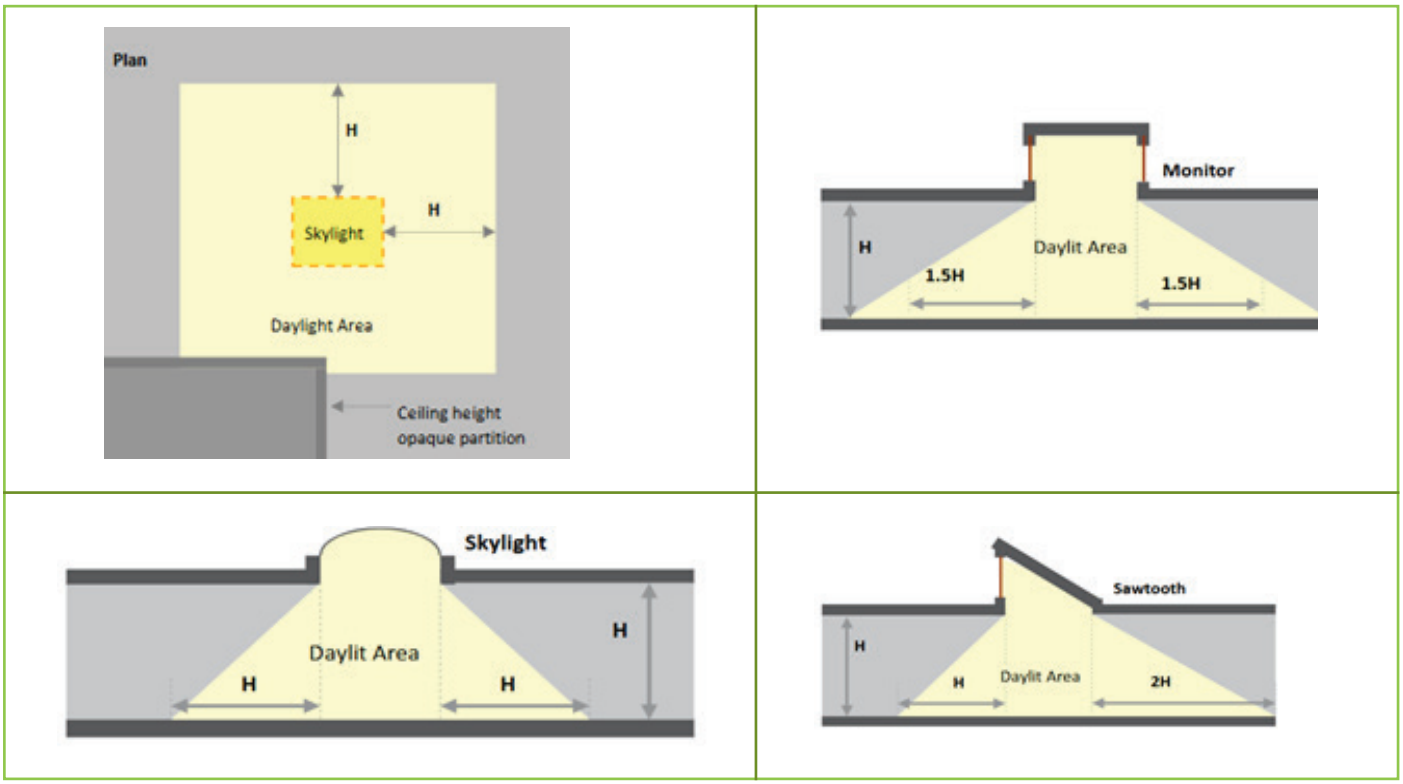
   - The fenestration width plus 1 m on each side, or
   - The distance to an opaque internal partition (with a minimum height of 2.0 m), or
   - One-half the distance to an adjacent fenestration, whichever is least.



c. **Daylight Extent for Skylights:** For skylights and roof apertures, the horizontal daylit extent in each direction to be calculated as the top aperture dimension plus.

   - H (floor-to-ceiling height) for skylight ; Daylit area for skylight = W+ (H*2)

- 1.5H for monitor skylights; Daylit area for monitor = W+ (1.5H*2
- Daylit area for sawtooth = H + W+ 2H
- The distance to the nearest opaque partition of at least 1.0 m height, or
- One-half the distance to an adjacent skylight or vertical glazing, whichever is least.



4. **Classification of Fenestration Orientation:** Glazed façades with non-cardinal orientations to be assigned to the nearest cardinal direction, provided the orientation lies within ±45 degrees of that cardinal direction, for the purpose of applying DEF values.

5. **Treatment of Overlapping Daylit Areas:** In cases where daylit areas overlap such as from fenestration on multiple orientations or between skylights, the overlapping area to be deducted from the total calculated daylit area to avoid double counting.

Calculation of manual compliance for Useful Daylight Illuminance (UDI)

An office building located in New Delhi, India is pursuing Daylight compliance. *Table 5.1 Daylight Requirement lists the minimum* daylight area requirements for compliance. The table specifies that for office buildings, minimum 40% of its floor area shall receive daylight in range of 100 – 2,000 lux for at least 90% of the year.

This typical floor has a rectangular layout (33 m x 38 m) of 1,254 m2. Visible light transmission (VLT) of glazing in all orientations is 0.39. Windows have light shelves and external shading devices with Projection Factor (PF) ≥ 0.4. Head height of fenestrations is 3.0 m.

For compliance at least 502 m2 (40% of 1,254 m2) of floor area shall fulfil the UDI requirements. Daylit area should be indicated in floor plans submitted to code enforcement authorities. Design guidelines on daylighting stated in NBC (Part 8: Building Services, Section 1: Lighting and Natural Ventilation, Subsection 4.2: Daylighting) should also be referred to achieve the ECBC, ECBC+, or Super ECBC requirement.

Compliance with T*able 5.1 Daylight Requirement* can be checked through two approaches.

(a) Analysis through software

If the whole building performance approach is used, compliance for daylighting requirements can be checked by analysing the façade and floor plate design in an analytical software as per *A8. BEE Approved Compliance Software.*

The image below, developed through an approved software, specifies the lux levels and time-period of a year during which lighting levels would be available. With this information, designers can check if the required minimum area as per *Table 5.1 Daylight Requirement.*

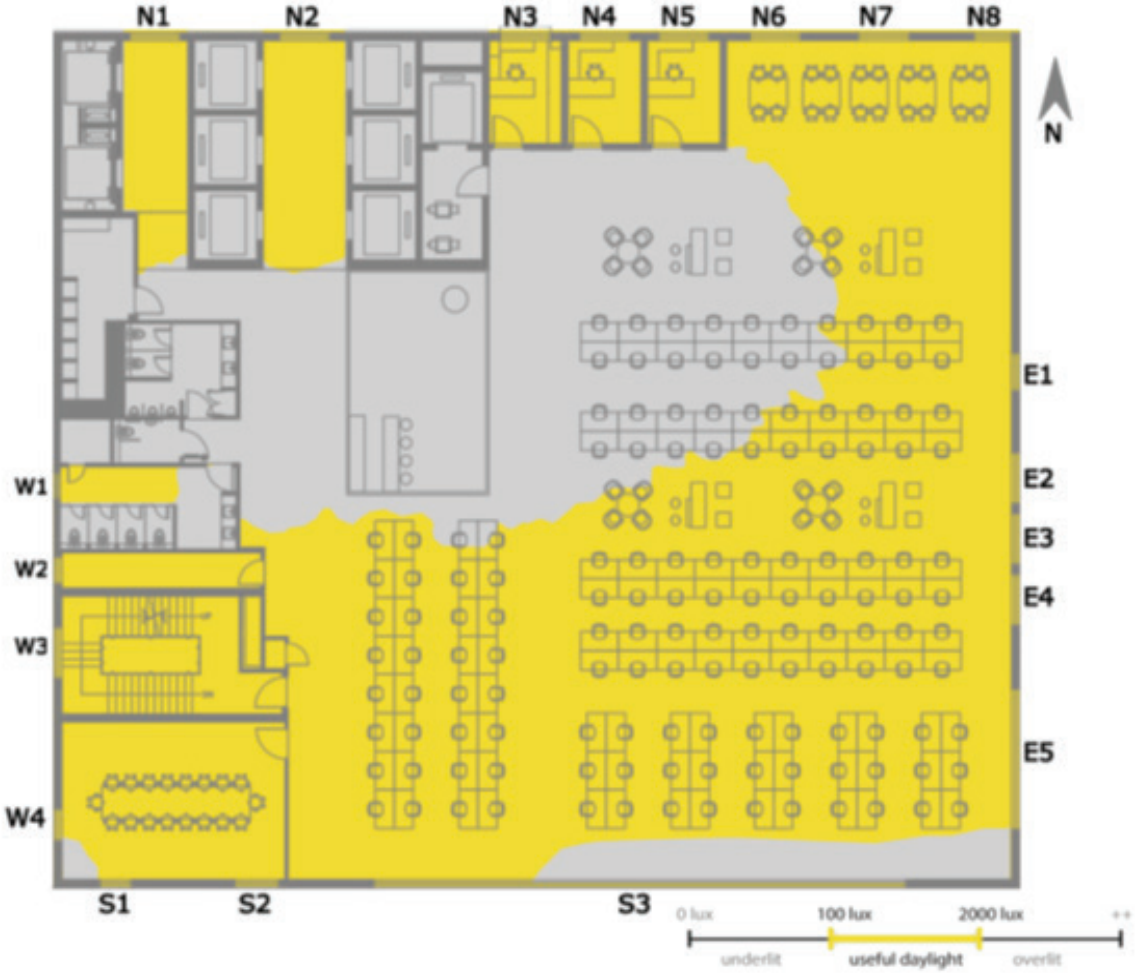


Figure 52 UDI Analysis with a Daylighting Analysis Software

(b) Manual calculation method

For projects adopting the prescriptive compliance approach, manual calculation method can be used for UDI compliance.

1. From Table 5.4. of ECSBC 2024 determine the daylight extent factor (DEF) for each orientation. For a building located in Delhi (latitude > 15 degrees), with glazing of VLT ≥ 0.39, shading PF ≥0.4 and light shelves in windows, DEFs for windows in North = 3.5, in South = 3.0, in East = 2.1, and in West = 1.8. Head height is 3.0 m.

2. For fenestration clear of any opaque obstructions calculate daylit floor area (AxB).

A: In the direction perpendicular to the fenestration, daylit area extends to head height of the fenestration multiplied by the daylight extent factor (DEF) or distance till an opaque partition higher than head height of the fenestration, whichever is less.

B: In the direction parallel to the fenestration daylit area extends a horizontal dimension equal to the width of the fenestration plus either one meter on each side of the aperture or the distance to an opaque partition, or one-half the distance to an adjacent fenestration, whichever is least.

3. For overlapping daylit areas such as corner windows. Subtract the overlapping daylit area from the sum of daylit area.

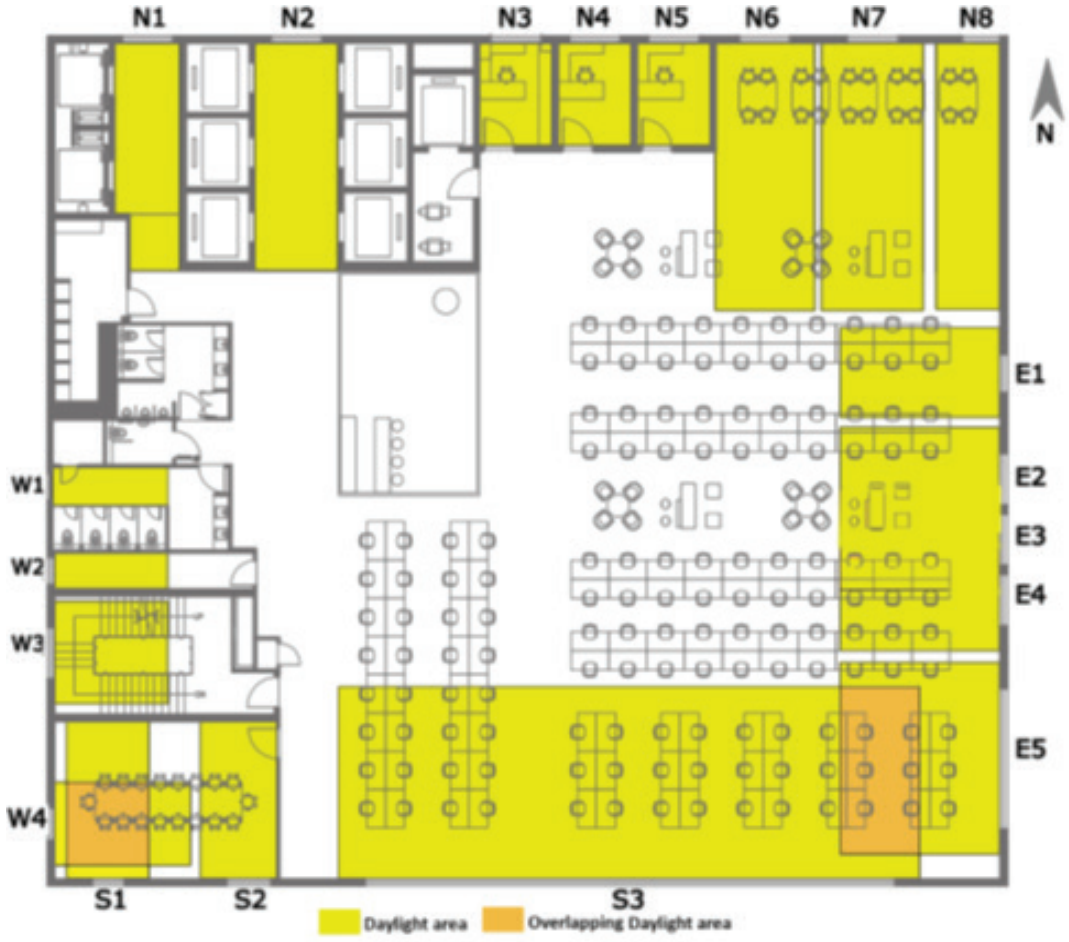


Figure 53 Daylit area through manual compliance

As per the calculations 616.5 m2 of floor area will meet the UDI requirements during 90% of the year.

This is 49.2 % of the total above grade floor area of 1,254 m2. Thus, the building floor will comply with UDI requirement.

Following Tables shows calculated Daylight Area Meeting UDI Requirement.

Manual calculation for Daylight Area Meeting UDI Requirement

Table 12 Orientation-NORTH

Orientation-NORTH, DEF-3.5, Fenestration Head Height H - 3m				
Window without opaque obstructions	Fenestration obstructions (m)	A= H x DEF (m)	B= L1+W+ L2 (m)	Area meeting the UDI requirements = AxB (m2)
N7	2	10.5	4	42
N6	2	10.5	4	42
N2	2	10.5	4	42

Window without opaque obstructions	Fenestration obstructions (m)	A= H x DEF (m)	B= L1+W+ L2 (m)	Area meeting the UDI requirements = AxB (m2)
N1	2	10.5	0.3+2+0.3=2.6	27.3
N3	2	4	0.4+2+0.4=2.8	11.2
N4	2	4	0.4+2+0.4=2.8	11.2
N5	2	4	0.4+2+0.4=2.8	11.2
N8	1	10.5	0+1.5+1.0=2.5	26.3
Daylit area meeting UDI requirement				213.2

Table 13 Orientation-South

Orientation-SOUTH, DEF-3, Fenestration Head Height H - 3m				
Window without opaque obstructions	**Fenestration obstructions (m)**	**A= H x DEF (m)**	**B= L1+W+ L2 (m)**	**Area meeting the UDI requirements = AxB (m2)**
S1	1.2	6.2	1.0+1.2+1.0=3.3	20.1
S2	1.7	6.2	1.0+1.7+0.3=3.0	18.6
S3	21	9	1.0+21.0+1.0=24	216
Daylit area meeting UDI requirement				254.7

Table 14 Orientation-East

Orientation-EAST, DEF-2.1, Fenestration Head Height H - 3m				
Window without opaque obstructions	**Fenestration obstructions (m)**	**A= H x DEF (m)**	**B= L1+W+ L2 (m)**	**Area meeting the UDI requirements = AxB (m2)**
E1	1.5	6.3	1.0+1.5+1.0=3.5	22.1
E5	5.5	6.3	1.0+5.5+1.0=7.5	47.3
Adjacent fenestration less than two meter apart	Fenestration Width W (m)	A= H x DEF (m))	B= L1+W+ L2 (m) L1, L2=one half of distance to adjacent fenestration	Area meeting the UDI requirements = AxB (m2)
E2	2	6.3	1.0+2.0+0.2=3.2	20.2
E3	2	6.3	0.2+2+0.2=2.4	15.1
E4	2	6.3	0.2+2+1=3.2	20.2
Daylit area meeting UDI requirement				124.9

Table 15 Orientation-West

Orientation-WEST, DEF-1.8, Fenestration Head Height H - 3m				
Window without opaque obstructions	**Fenestration obstructions (m)**	**A= H x DEF (m)**	**B= L1+W+ L2 (m)**	**Area meeting the UDI requirements = AxB (m2)**
W3	2	5.4	1.0+2.0+1.0=4.0	21.6
W4	1.4	5.4	1.0+1.2+1.0=3.2	17.3

Window without opaque obstructions	Fenestration obstructions (m)	A= H x DEF (m)	B= L1+W+ L2 (m)	Area meeting the UDI requirements = AxB (m2)
W1	1	5.4	0.3+1+0.3=1.6	8.6
W2	1	5.4	0.3+1+0.3=1.6	8.6
Daylit area meeting UDI requirement				56.1

Table 16 Overlapping area calculations

Overlapping area calculations			
Window with overlap areas	Width (m)	Depth (m)	Area (m2)
N4 and S1	3.3	3.3	10.9
S3 and E5	3.3	6.5	21.5
Overlapping daylight area (b)			32.4

Table 17 Total Daylit area

Total Daylit area	
ORIENTATION	Daylit area (m2)
NORTH	213.2
SOUTH	254.7
EAST	124.9
WEST	56.1
Total daylight area (a) 648.9	648.9
Total Overlapping daylit area (b) 32.4	32.4
Total daylit area meeting UDI requirement during 90% of the year (a-b)	616.5

3.10 Building Envelope Trade-off Method

Building Envelope Trade-off Method may be used in place of the prescriptive method. The building envelope complies with the code if the envelope performance factor (EPF) of the proposed building is less than the EPF of the baseline building, where the baseline building exactly complies with the standardized requirements of building envelope.

$$EPF_{Baseline} > EPF_{Proposed\ case}$$

Non-applicability for building envelope trade-off method

building envelope trade-off method shall not be used for buildings with WWR>40% (and/or) skylight with SRR > 5%.

The envelope performance factor shall be calculated using the below equations as per ECSBC requirement.

$$EPF_{Total} = EPF_{Roof} + EPF_{Wall} + EPF_{Fenest}$$

$$EPF_{Roof} = (\text{Croof} * \sum_{s=1}^{n} \text{Us As})$$

$$EPF_{Wall} = (\text{Cwall} \sum_{s=1}^{n} \text{Us As})$$

$$EPF_{Fenest} = C_{1\ fen,north} \sum_{w=1}^{n} \text{UwAw} + C_{2\ fen,north} \sum_{w=1}^{n} \left(\left(\frac{\text{SHGCw}}{\text{SEFw}}\right) * \text{Aw}\right) + C_{1\ fen,south} \sum_{w=1}^{n} \text{UwAw} + C_{2\ fen,south} \sum_{w=1}^{n} \left(\left(\frac{\text{SHGCw}}{\text{SEFw}}\right) * \text{Aw}\right) + C_{1\ fen,east} \sum_{w=1}^{n} \text{UwAw} + C_{2\ fen,east} \sum_{w=1}^{n} \left(\left(\frac{\text{SHGCw}}{\text{SEFw}}\right) * \text{Aw}\right) + C_{1fen,west} \sum_{w=1}^{n} \text{UwAw} + C_{2\ fen,west} \sum_{w=1}^{n} \left(\left(\frac{\text{SHGCw}}{\text{SEFw}}\right) * \text{Aw}\right)$$

Where,

EPF_{Roof} - Envelope performance factor for roofs. Other subscripts include walls and fenestration.

As, Aw - The area of a specific envelope component referenced by the subscript "s" or for windows the subscript "w".

SHGCw - The solar heat gain coefficient for windows (w).

SEFw A multiplier for the window SHGC that depends on the projection factor of an overhang or side fin.

Us The U-factor for the envelope component referenced by the subscript "s". CRoof - A coefficient for the "Roof" class of construction.

C_{wall} - A coefficient for the "Wall"

$c1_{Fenes}$ - A coefficient for the "Fenestration U-factor"

$c2_{Fenes}$ - A coefficient for the "Fenestration SHGC"

Values of "c" are taken from table 5.16 through table 5.20 of ECSBC for each class of construction.

Example: A 1,500 m2 single story daytime use office building in Delhi is trying to achieve ECSBC level compliance. Each side has a band of windows, without shading. The materials for the envelope have already been selected, prior to opting for ECSBC compliance. Their thermal properties are: roof assembly U-value= 0.4 W/m².K, external wall assembly U-value = .25 W/m².K, glazing SHGC = .25, VLT = 0.27, area weighted U-value for glazing = 1.8 W/m².K.

Dimensions of the building envelope are as follows:

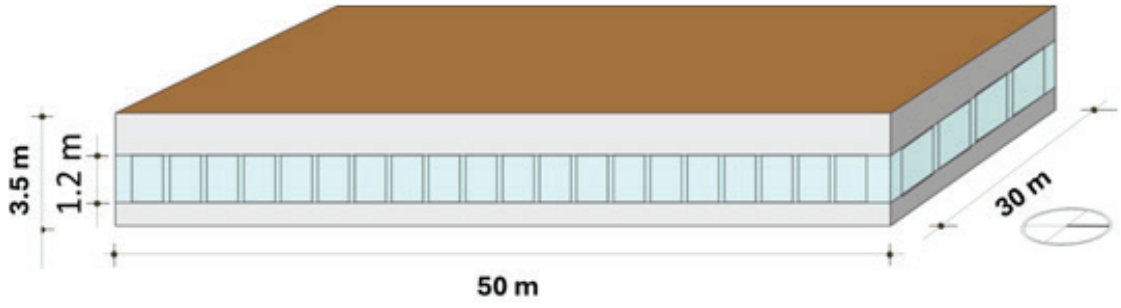


Figure 54 Dimensions of the building envelope

Determine the compliance of the building with respect to the requirements of ECSBC 2024.

Solution : According to 'ECSBC 2024 Appendix 2': Table A2.1 Climate Zone for Major Indian Cities, Delhi falls under the composite climate zone. To prove compliance through the prescriptive approach, U-factor, and SHGC must comply with requirements listed in Table 5.3 to 5.8 of ECSBC 2024, Table

5.9 TO 5.11 OF ECSBC 2024 and VLT and Window to Wall Ratio (WWR) with requirements in § 5.3.3 for a daytime use building in the composite climate zone. The table below lists thermal properties of the building envelope components and the corresponding prescriptive requirements for ECSBC complaint buildings.

a. Prescriptive Requirements and Proposed Thermal Properties as per ECSBC

Table 18 Prescriptive Requirements and Proposed Thermal Properties as per ECSBC

	Prescriptive / Base case U-factor (W/m2.K)			Proposed/Design Case U-factor (W/m2.K)			Area (m2)
Wall 1– North, South	0.4			0.25			69
Wall 2– East, West	0.4			0.25			115
Roof	0.33			0.4			1500
	Prescriptive/ Base Case			Proposed/Design Case			Area (m2)
	U-factor	SHGC	VLT	U-factor	SHGC	VLT	
Window –North	3	0.5	0.27	1.8	0.25	0.27	36
Window – South	3	0.27	0.27	1.8	0.25	0.27	36
Window –East	3	0.27	0.27	1.8	0.25	0.27	60
Window – West	3	0.27	0.27	1.8	0.25	0.27	60

Prescriptive method requires the WWR to be less than 40%.

Total Fenestration Area North, South = 2 x (30m x 1.2m) = 72 m2 Wall Area North, South = 2 ((30m x 3.5m)-(30m x 1.2m))= 138 m2 Total Fenestration Area East, West = 2 x (50m x 1.2m) = 120 m2

Total Wall Area East, West = 2 x (50m x 3.5m) - 2 x (50m x 1.2m) = 230 m2 Total Fenestration Area = 192 m2.

Total Wall Area = 560 m2 WWR= (192/560) *100

= 34%

Hence, the proposed building is compliant with the WWR requirements.

U-value of the roof of the proposed building, at 0.4 W/m².K does not fulfil prescriptive requirements.

Hence, this building will not be compliant if the prescriptive approach is followed. The compliance in prescriptive approach can also be demonstrated through building envelope trade-off.

B. Compliance through Building Envelope Trade-off method: Envelope performance factor (EPF) for the Standard Building and Proposed Building must be compared. As per the Building Envelope Trade-off method, the envelope performance factor (EPF) shall be calculated using the following equations:

$$EPF_{Total} = EPF_{Roof} + EPF_{Wall} + EPF_{Fenest}$$

Step 1: Calculation of EPF Proposed Building from actual envelope properties

EPF_{Roof} = (Croof * $\Sigma^{n}_{s=1}$ Us As)

= 27.3 x 0.40 x 1,500 = 16,380

EPF_{Wall} = (Cwall $\Sigma^{n}_{s=1}$ Us As)

= 43.9 x 0.25 x 368= 4038.8

$$EPF_{Fenest} = C_{1\ fen,north}\sum_{w=1}^{n} UwAw + C_{2\ fen,north}\sum_{w=1}^{n}\left(\left(\frac{SHGCw}{SEFw}\right) * Aw\right) + C_{1\ fen,south}\sum_{w=1}^{n} UwAw + C_{2\ fen,south}\sum_{w=1}^{n}\left(\left(\frac{SHGCw}{SEFw}\right) * Aw\right) + C_{1\ fen,east}\sum_{w=1}^{n} UwAw + C_{2\ fen,east}\sum_{w=1}^{n}\left(\left(\frac{SHGCw}{SEFw}\right) * Aw\right) + C_{1fen,west}\sum_{w=1}^{n} UwAw + C_{2\ fen,west}\sum_{w=1}^{n}\left(\left(\frac{SHGCw}{SEFw}\right) * Aw\right)$$

$EPF_{fen,north}$ = (23.7*1.8*36) +(238.2*(0.25/1)*36) =3679.56

$EPF_{fen,South}$ = (22.8*1.8*36) + (389.7*(0.25/1)*36) =4984.74

$EPF_{fen,East}$ = (21.6*1.8*60) + (347.4*(0.25/1)*60) =7543.8

$EPF_{fen,West}$ = (21.7*1.8*60) + (354.1*(0.25/1)*60) =7655.1

Therefore, $\mathbf{EPF}_{Fenest}$ = 23863.2

$EPF_{Proposed}$ = 16380 + 4038.8 +23863.2 =44282

Step 2: Calculating EPF Standard Building from prescriptive envelope requirements

The Baseline Building shall have the same building floor area, gross wall area and gross roof area as the Proposed Building. For mixed- use building the space distribution between different typologies shall be the same as the Proposed Design.

The U-factor of each envelope component shall be equal to the criteria from section 5.3 of ECSBC 2024 for each class of construction.

The SHGC of each window shall be equal to the criteria from section 5.4.3 of ECSBC 2024. Shading devices shall not be considered for calculating EPF for Baseline Building (i.e. SEF=1).

EPF_{Roof} = (Croof * $\sum^{n}_{s=1}$ Us As)

= 27.3 x 0.33 x 1,500 = 13,513.5

EPF_{Wall} = (Cwall $\sum^{n}_{s=1}$ Us As)

= 43.9 x 0.4 x 368= 6462.08

$$EPF_{Fenest} = C_{1\ fen,north}\sum_{w=1}^{n} UwAw + C_{2\ fen,north}\sum_{w=1}^{n}\left(\left(\frac{SHGCw}{SEFw}\right) * Aw\right) + C_{1\ fen,south}\sum_{w=1}^{n} UwAw + C_{2\ fen,south}\sum_{w=1}^{n}\left(\left(\frac{SHGCw}{SEFw}\right) * Aw\right) + C_{1\ fen,east}\sum_{w=1}^{n} UwAw + C_{2\ fen,east}\sum_{w=1}^{n}\left(\left(\frac{SHGCw}{SEFw}\right) * Aw\right) + C_{1fen,west}\sum_{w=1}^{n} UwAw + C_{2\ fen,west}\sum_{w=1}^{n}\left(\left(\frac{SHGCw}{SEFw}\right) * Aw\right)$$

EPF $f_{en,north}$= (23.7*3*36) +(238.2*(0.5/1)*36) =6847.2

$EPF_{fen,South}$ = (22.8*3*36) + (389.7*(0.27/1)*36) =6250.284

$EPF_{fen,East}$ = (21.6*3*60) + (347.4*(0.27/1)*60) =9515.88

$EPF_{fen,West}$ = (21.7*3*60) + (354.1*(0.27/1)*60) =9642.42

EPF_{Fenest} = 32255.78

$EPF_{Baseline}$ = **13,513.5 + 6462.08 +32,255.78**

$EPF_{Baseline}$ = 52231.364

Since $EPF_{Baseline} > EPF_{Proposed}$

therefore, the building is compliant with ECSBC building envelope requirements.

3.11 Passive strategies

Use shading devices (overhangs, louvers, fins): External shading devices block direct solar radiation before it enters the building, significantly reducing cooling loads. Their design should be orientation-specific to effectively respond to sun angles. Properly designed shading also helps in minimizing glare while maintaining daylight access.



Figure 55 Shading devices

Optimize window-to-wall ratio (WWR): Maintaining an optimal WWR ensures a balance between daylighting and thermal performance. Excessive glazing can lead to increased heat gain, especially on east and west façades. A well-designed WWR reduces cooling demand while still providing visual comfort and connection to the outdoors.

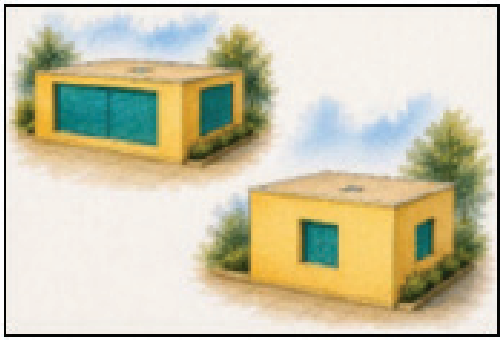


Figure 56 Optimize window-to-wall ratio (WWR)

Thermal mass and insulation: Materials with high thermal mass absorb and store heat during the day and release it gradually, stabilizing indoor temperatures. Insulation helps in reducing unwanted heat transfer through the building envelope. Together, they enhance energy efficiency by reducing peak cooling and heating loads.

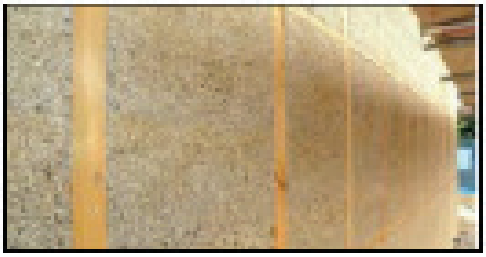


Figure 57 Hempcrete Insulation

Use reflective or high-albedo materials: High-albedo surfaces reflect a larger portion of solar radiation, reducing heat absorption by roofs and external walls. This helps in lowering surface temperatures and mitigating the urban heat island effect. Such materials contribute to improved indoor comfort and reduced cooling energy consumption.

Native Vegetation: Vegetation acts as a natural insulator and provides shading to building surfaces, reducing heat gain. Green roofs and walls also improve microclimate conditions through evapotranspiration. Additionally, plants and trees enhance biodiversity and contribute to overall environmental sustainability

3.12 Building Envelope Energy Efficiency Assessment for Existing Buildings

The building envelope forms the primary barrier between the conditioned indoor environment and external climatic conditions. Its performance directly influences cooling and heating loads, occupant comfort, daylight availability, and overall energy consumption. During an energy audit of an existing building, a systematic assessment of the building envelope helps identify opportunities to reduce unwanted heat gains and losses, improve thermal comfort, and lower energy costs.

A building energy auditor should begin by reviewing available architectural drawings, construction specifications, and previous energy audit reports to understand the envelope design and materials used. A detailed site inspection should then be conducted to verify actual construction conditions and identify any deterioration or modifications made after construction.

Wall Assessment

The auditor should identify wall construction materials (e.g., brick masonry, AAC blocks, concrete walls, insulated panels) and determine their thermal performance. Wall thickness, insulation presence, surface finish, and orientation should be documented. The wall thermal transmittance (U-value) should be calculated or estimated based on material properties and compared with applicable ECBC/ECSBC requirements. Dark-colored walls with high solar absorptance may contribute to increased heat gain and should be evaluated for reflective coatings or insulation retrofits.

Roof Assessment

Since the roof is often the largest source of solar heat gain in many climates, its construction and thermal characteristics should be carefully examined. The auditor should verify insulation type and thickness, roof finish, waterproofing condition, and the presence of cool roof treatments or green roofs. Roof U-values and Solar Reflectance Index (SRI) values should be assessed to determine compliance with energy efficiency standards and identify opportunities for reducing cooling loads.

Fenestration Evaluation

Windows and glazed openings significantly affect both daylight availability and solar heat gain. The auditor should document window dimensions, orientation, glazing type, frame material, and overall Window-to-Wall Ratio (WWR). Key performance parameters such as U-value, Solar Heat Gain Coefficient (SHGC), and Visible Light Transmittance (VLT) should be collected from manufacturer specifications or estimated through field assessment. The effectiveness of external shading devices, overhangs, fins, and louvers should also be evaluated.

Air Leakage and Infiltration

Uncontrolled air infiltration can substantially increase cooling and heating energy consumption. The auditor should inspect windows, doors, joints, and penetrations for gaps, damaged seals, or deteriorated weather stripping. Evidence of drafts or leakage should be documented. Where feasible, blower door testing or other air-tightness assessment methods may be used to quantify infiltration rates.

Daylighting Assessment

The auditor should evaluate the building's ability to utilize natural daylight while minimizing glare and excess solar heat gain. Window placement, orientation, glazing characteristics, shading devices, and daylight penetration should be assessed. Existing daylighting performance can be measured using a lux meter or evaluated against ECSBC daylight compliance criteria.

Moisture and Envelope Condition Assessment

The presence of moisture intrusion, condensation, dampness, mold growth, or deteriorated finishes can negatively affect both energy performance and occupant comfort. The auditor should inspect walls, roofs, windows, and sealant joints for signs of water penetration and envelope degradation.

Thermal Imaging Survey

Infrared thermography provides valuable information about the envelope's actual performance. Thermal imaging should be used to identify insulation deficiencies, thermal bridges, air leakage paths, moisture intrusion, and abnormal heat transfer through walls, roofs, and glazing systems. Thermographic findings should be correlated with visual observations and construction details.

Performance Evaluation and Recommendations

The collected data should be analyzed to determine the thermal performance of the building envelope and its compliance with applicable codes such as ECSBC or ECBC. Key indicators including wall and roof U-values, glazing performance, SHGC, VLT, WWR, airtightness, and daylighting effectiveness should be benchmarked against current best practices.

Based on the findings, the auditor should recommend practical Energy Conservation Measures (ECMs), such as:

Roof insulation enhancement or cool roof installation.

Wall insulation retrofits.

High-performance glazing replacement.

External shading improvements.

Air sealing and weather-stripping upgrades.

Daylighting optimization measures.

Reflective exterior coatings.

The final assessment should quantify the potential impact of each measure in terms of cooling load reduction, annual energy savings, implementation cost, and simple payback period, enabling building owners to prioritize envelope improvements that deliver the greatest energy efficiency benefits.

3.13 Sustainable Material

In the Energy Conservation and Sustainable Building Code (ECSBC 2024), sustainable material is addressed through embodied carbon. Embodied carbon is voluntary requirement using ($kgCO_2e/m^2$) as the metric. Embodied carbon refers to the greenhouse gas emissions associated with the materials used in a building before the building is occupied or operated. It includes emissions generated during the extraction of raw materials, transportation of materials, and manufacturing of construction products such as cement, steel, glass, bricks, blocks, aluminum, insulation, and other structural or envelope materials. In simple terms, embodied carbon is the "carbon footprint hidden inside building materials." For example, cement has embodied carbon because energy is consumed and carbon dioxide is released during limestone processing, clinker production, fuel combustion, and transportation. Similarly, steel, glass, aluminum, bricks, and blocks carry emissions from mining, processing, manufacturing, and delivery.

This is different from operational carbon, which refers to emissions from running the building after occupancy, such as electricity used for air-conditioning, lighting, equipment, pumps, and other services. As buildings become more energy-efficient through better design and renewable energy integration, embodied carbon becomes increasingly important because a large share of emissions may already be locked into the building at the construction stage.

Under ECSBC 2024, embodied carbon reporting is included under Appendix 6: Sustainable Materials. The Code requires reporting of embodied carbon in $kgCO_2$-eq/m^2, limited to the initial material life-cycle stages, i.e., A1 to A3, also known as the cradle-to-gate boundary.

These stages include raw material extraction and procurement, transport to the manufacturing plant, and manufacturing of construction materials (Rempher, Esau, & Weir, 2023). The provision is voluntary and applies mainly to materials used in structural and building envelope systems, such as foundations, columns, beams, walls, floors, roofs, staircases, ramps, and fenestration systems.

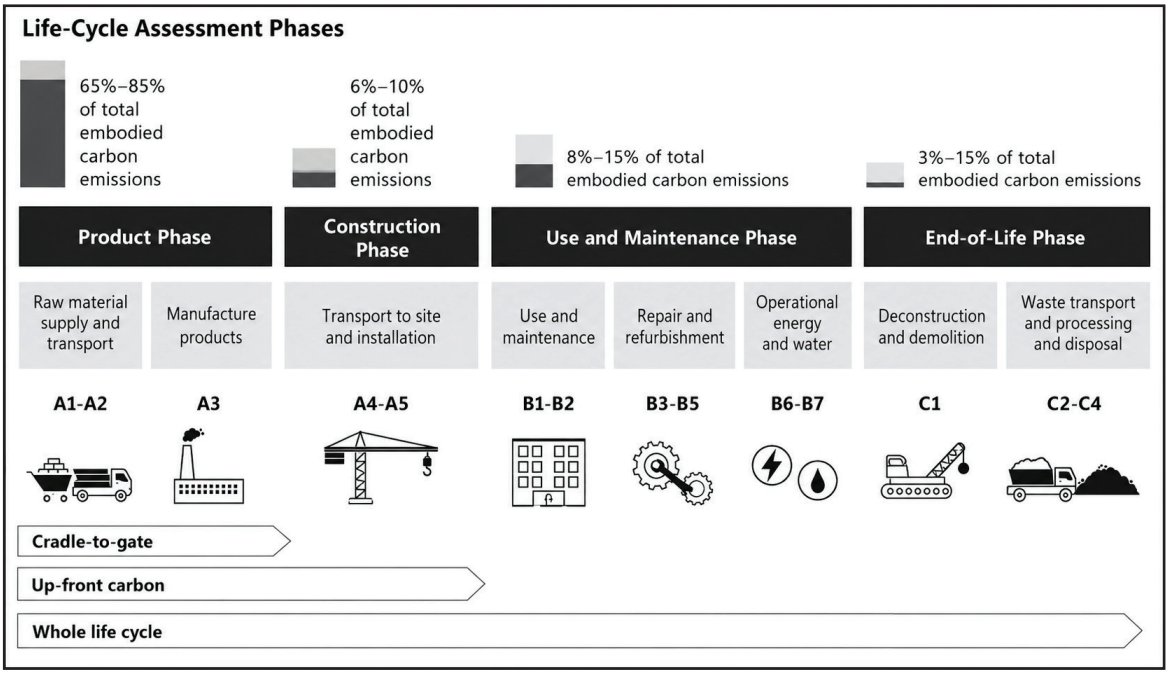


Figure 58 Life cycle assessment for embodied carbon

International standards and frameworks provide useful guidance for integrating embodied carbon assessment into building design. ISO 14040 and ISO 14044 establish the general methodology for life-cycle assessment (LCA), while EN 15978 defines system boundaries and calculation methods specifically for buildings. ISO 21930 and EN 15804 provide rules for developing Environmental Product Declarations (EPDs), which quantify environmental impacts, including GHG emissions, of construction materials and products. These declarations are essential for developing reliable, region-specific embodied carbon databases and enabling informed material selection.

In India, however, the adoption of embodied carbon assessment still faces several barriers. These include the limited availability of India-specific embodied carbon datasets for construction materials, low awareness among stakeholders, and insufficient financial incentives for disclosure and reduction of material-related emissions. Recent initiatives by the Bureau of Indian Standards (BIS), including guidelines for quantifying product carbon footprints based on ISO 14044, represent an important step toward standardizing life-cycle assessment practices in the country. Integrating life-cycle thinking, promoting low-carbon materials, improving data transparency, and encouraging voluntary disclosures under ECSBC can significantly reduce the environmental impact of the buildings sector and support India's long-term climate commitments.

Questions for Building Envelope

Section A: Objective Questions (MCQs) – 10 Nos

1. If WWR increases from 30% to 60% without improving glazing performance, in hot and dry climate then
A. Cooling load increases significantly
B. Cooling load decreases
C. Heating load increases
D. U-value decreases

2. Solar Heat Gain Coefficient (SHGC) affects:
A. Visible light only
B. Conductive heat transfer
C. Solar radiation admitted through glazing
D. Air infiltration

3. Continuous insulation in curtain wall systems helps to:
A. Improve aesthetics
B. Reduce infiltration
C. Eliminate linear thermal bridges
D. Both B and C

4. Thermal mass in hot-dry climate is beneficial for thermal comfort because:
A. It increases solar gain
B. It delays heat transfer
C. It increases infiltration
D. It increases Overall Thermal Transmittance Value

5. Cool roof effectiveness reduces when:
A. Insulation is added
B. Roof slope increases
C. Surface reflectance degrades over time
D. Roof area increases

6. In tropical climate, the ideal glazing selection for optimal visual comfort requires combination of:
A. High SHGC + High U-value
B. Low SHGC + Low VLT
C. Moderate SHGC + Low U-value
D. High WWR only

7. When infiltration of the room, increases from 0.5 ACH to 2 ACH, HVAC energy:
A. Decreases
B. Remains constant
C. Increases significantly
D. Becomes independent of envelope

8. In ECSBC envelope trade-offs can be validated through:
A. Overall Heat Transfer Value
B. Whole Building Energy Simulation
C. U-value comparison
D. Visual comfort evaluation

9. Airtightness testing at 50 Pa measures:

A. Envelope leakage rate

B. Solar Heat Gain Coefficient (SHGC)

C. Solar reflectance

D. Thermal mass

10. A façade optimized for cold climate may requires:

A. Low SHGC glazing with High U value

B. High SHGC glazing with High U Value

C. High SHGC with Low U value

D. Low SHGC with Low U value

Section B: Short Answer Questions- 5 Nos

1. Explain the glazing components and various types and properties of glazing.

2. Define between U-factor and SHGC with façade implications.

3. Explain the impact of Skylight on cooling load and daylight and the optimal design condition

4. What is thermal bridging? Explain mitigation strategies.

5. Discuss the importance of airtightness testing in ECSBC compliance.

Section C: Long Answer Questions – 2 Nos

Q1. Explain a comprehensive building envelope design strategy for achieving ECSBC compliance.

Q2. A commercial building located in a warm and humid climate zone must comply with the requirements of the ECSBC. The building envelope consists of a composite wall and roof assembly. Calculate and report if roof and wall assembly is compliant with ECSBC

Wall Assembly is made of the following layers: Layer 1 of Gypsum plaster with thermal Resistance of 0.08 m^2K/W, Layer 2 of Brick masonry with thermal Resistance of 0.35m^2K/W, Layer 3 of External plaster with thermal Resistance of 0.05 m^2K/W

Roof Assembly is made of the following layers: Layer 1 of Reinforced concrete slab with thermal Resistance of 0.2 m^2K/W, Layer 2 of Thermal insulation layer with thermal Resistance of 2.50 m^2K/W, Layer 3 of Roof screed with thermal Resistance of 0.12 m^2K/W

Assume the Interior surface resistance as 0.12 m^2K/W and Exterior surface resistance as 0.04 m^2K/W

Question

a. Determine the U-value of the wall and Check whether the wall assembly complies with ECSBC

b. Determine the U-value of the roof and Check whether the wall assembly complies with ECSBC

Answer Key for MCQs

1. A 2. C 3. D 4. B 5. C	6. C 7. C 8. B 9. A 10. A

Answer Key for Long Answer

1.

a. Wall U-value = 1.56 W/m²K → Not Compliant

b. Roof U-value = 0.336 W/m²K → Compliant

4. COMFORT SYSTEM AND CONTROLS

Comfort systems and controls form the backbone of modern building services, ensuring indoor environments that support occupant health, well-being, productivity, performance, safety, and the occupants' satisfaction. In India, the building sector accounts for about 34% of total energy consumption, out of which, domestic is 25% whereas commercial sector is 8% (Implementation, Energy Statistics 2022: Chapter 6 – Consumption of Energy Resources, 2022), and (United Nations Environment Programme, 2023). In commercial buildings, heating, ventilation, and air-conditioning (HVAC) systems account for the largest share of the total energy consumption in buildings, representing 40–50% of energy use for providing occupant comfort.

In the Indian context, as large-scale construction and rapid urbanization expand the built environment, the energy impact of comfort systems becomes even more significant. The introduction of codes such as the ECSBC reflects this imperative—requiring building designers, operators, and auditors to pay meticulous attention not only to equipment efficiency but also to the effectiveness of control systems, air and water distribution, and overall comfort delivery.Adopting energy-efficient materials and optimized glazing reduces operational energy demand and supports low-carbon, climate-responsive buildings.

Controls play a pivotal role in transforming high-efficiency equipment into smart, responsive systems that avoid energy waste from over-conditioning, poor scheduling, inactive set points, or sub-optimal distribution.

Thermal comfort principles were explained in Chapter 2. This chapter focuses on system-level methods to achieve comfort including natural and mechanical ventilation and active systems.

4.1 Ventilation Systems

Ventilation ensures adequate supply of outdoor air and removal of indoor pollutants to improve general environment of the building. This may be achieved in one of the following ways:

a) Natural ventilation

b) Mechanical ventilation

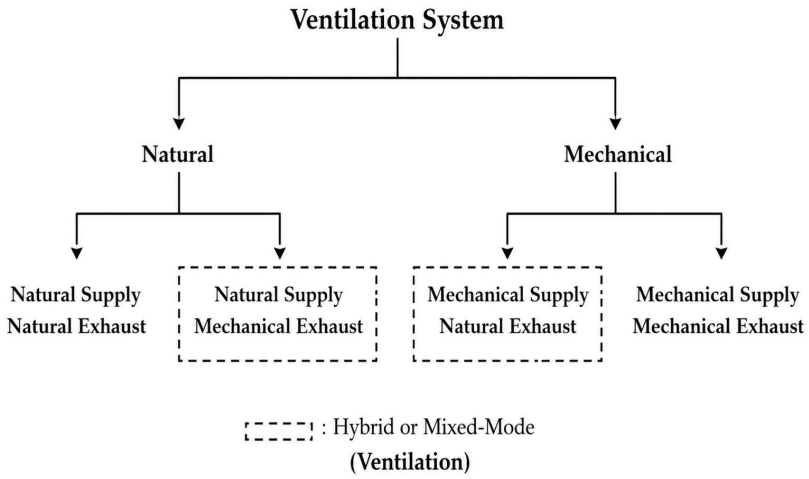


Figure 59 Classification of a ventilation system

A combination of natural ventilation and mechanical ventilation can be called as hybrid ventilation. Hybrid / Mixed Mode ventilation is a building ventilation strategy that combines natural ventilation (such as wind and buoyancy-driven airflow) with mechanical systems (fans, ducts, or HVAC equipment) to maintain indoor air quality and thermal comfort. The system dynamically switches between, or simultaneously uses, natural and

mechanical modes based on external climate conditions, indoor requirements, and control strategies, thereby optimizing energy efficiency while ensuring occupant comfort.

The standards of general ventilation are recommended/based on maintenance of required oxygen, carbon dioxide, and other air quality levels and for the control of body odours when no products of combustion or other contaminants are present in the air. The values of air changes for non-air-conditioned areas are prescribed in National Building Codes. The values of air changes for non-air-conditioned areas are prescribed in National Building Codes.

Table 19 Sample ventilation rates for non-air-conditioned areas from NBC, 2016

SI No. (1)	Application (2)	Air Change per Hour (3)	SI No. (1)	Application (2)	Air Change per Hour (3)
1	Assembly rooms	4-8	**28**	Hospitals-sterlizing	15-25
2	Bakeries	20-30	**29**	Hospital-wards	6-8
3	Banks/building societies	4-8	**30**	Hospital domestic	15-20
4	Bathrooms	6-10	**31**	Laboratories	6-15
5	Bedrooms	2-4	**32**	Launderettes	10-15
6	Billiard rooms	6-8	**33**	Laundries	10-30
7	Boiler rooms	15-30	**34**	Lavatories	6-15
8	Cafes and coffee bars	10-12	**35**	Lecture theatres	5-8
9	Canteens	8-12	**36**	Libraries	3-5
10	Cellars	3-10	**37**	Living rooms	3-6
11	Churches	1-3	**38**	Mushroom houses	6-10
12	Cinemas and theatres	10-15	**39**	Offices	6-10
13	Club rooms	12,Min	**40**	Paint shops (not cellulose)	10-20
14	Compressor rooms	10-12	**41**	Photo and X-ray dark room	10-15
15	Conference rooms	8-12	**42**	Public house bars	12, Min
16	Dairies	8-12	**43**	Recording control rooms	15-25
17	Dance halls	12, Min	**44**	Recording studios	10-12
18	Dye works	20-30	**45**	Restaurants	8-12
19	Electroplating shops	10-12	**46**	Schoolrooms	5-7
20	Engine rooms	15-30	**47**	Shops and supermarkets	8-15
21	Entrance halls	3-5	**48**	Shower baths	15-20
22	Factories and work shops	8-10	**49**	Stores and warehouses	3-6
23	Foundries	15-30	**50**	Squash courts	4, Min
24	Garages	6-8	**51**	Swimming baths	10-15
25	Glass houses	25-60	**52**	Utility rooms	15-20
26	Hair dressing saloon	10-15	**54**	Welding shops	15-30
27	Hair dressing saloon	10-15	**54**	Welding shops	15-30

Calculation of ventilation rate:

$$DF = \textit{Daylight internal (Ei) / Daylight external (Eo)} \times 100\%$$

Natural ventilation

Natural ventilation can be defined as ventilation provided by thermal, wind, or diffusion effects through windows, doors, solar chimneys, wind towers, trickle ventilators, or other intentional openings in the building. Natural ventilation can be divided into two categories which are:

a) Natural supply and natural exhaust of air

b) Natural supply and mechanical exhaust of air

Natural supply and natural exhaust of air

Natural supply and natural exhaust of air depend on natural forces like wind and temperature differences to **move fresh air in and stale air out of a building. The rate of ventilation depends on:**

Wind action: Wind plays a crucial role in natural ventilation by creating pressure differences around a building. When wind approaches a structure, the side facing the wind (windward side) experiences positive pressure, causing fresh air to be pushed into the indoor spaces through open windows or vents. At the same time, the opposite side (leeward side) experiences negative pressure, which helps draw indoor air out of the building. This simultaneous inflow and outflow of air enable effective cross-ventilation, improving indoor air quality, reducing heat buildup, and enhancing overall thermal comfort without relying on mechanical systems. Proper placement and orientation of openings ensure that the natural movement of wind can ventilate the building efficiently.

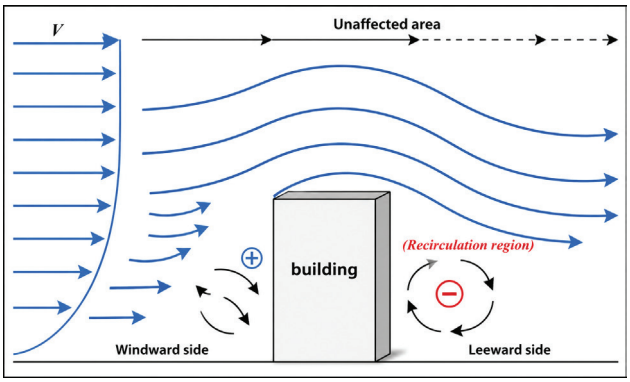


Figure 60 Ventilation due to pressure difference resulting from wind effect

Determining rate of Ventilation: For determining the rate of ventilation based on wind action, the wind may be assumed to come from any direction within 45° of the direction of prevailing wind. Ventilation due to external wind is given by the following formula:

$$Q = KAV$$

Where,

Q = Rate of air flow in m^3/h

K = Coefficient of effectiveness, which may be taken as 0.6 for wind perpendicular to openings and 0.3 for wind at an angle less than 45° to the openings

A = Free area of inlet openings in m^2

V = Wind speed in m/h

Note: For wind data at a place, the local meteorological department may be consulted.

Stack effect: Natural ventilation by stack effect occurs when air inside a building is at a different temperature than the air outside. Thus, in heated buildings or in buildings wherein hot processes are carried out and in ordinary buildings during summer nights and during pre-monsoon periods, when the inside temperature

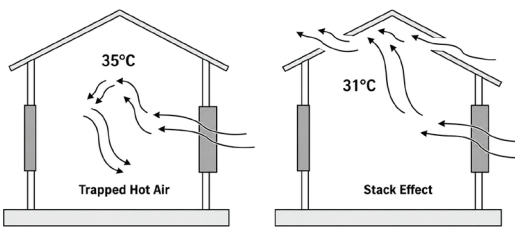


Figure 61 Principle of Stack effect

is higher than that of outside, cool outside air will tend to enter through openings at low level and warm air will tend to leave through openings at high level. It would, therefore, be advantageous to provide ventilators as close to ceilings as possible. Ventilators can also be provided in roofs such as, for example, cowl, vent pipe, covered roof and ridge vent.

Determining rate of ventilation: Ventilation due to convection effects arising from temperature difference between inside and outside is given by:

$$Q = 7.0\,A\sqrt{h(t_r - t_o}$$

Where,

Q = Rate of air flow in m^3/h

A = Free area of inlet openings in m^2

h = Vertical distance between inlets and outlets in m

t_r = Average temperature of indoor air at height h in °C

t_o = Temperature of outdoor air in °C

Notes: 1) The above equation is based on 0.65 effectiveness of openings. This should be reduced to 0.50 if conditions are not favorable.

2) When areas of inlet and outlet opening are unequal, the value of A may be calculated using the equation:

$$\frac{2}{A^2} = \frac{1}{A_{inlet}^2} + \frac{1}{A_{outlet}^2}$$

Solved Example

A room has inlet openings of area 1.8 m^2 and outlet openings of area 1.2 m^2. The vertical distance between the inlet and outlet openings is 4 m. The average indoor air temperature is 32°C, while the outdoor air temperature is 26°C. Calculate the rate of airflow due to stack effect ventilation.

Ans:

Since the inlet and outlet opening areas are unequal, the effective opening area is calculated using

$$: \frac{2}{A^2} = \frac{1}{A_{inlet}^2} + \frac{1}{A_{outlet}^2}$$

$$: \frac{2}{A^2} = \frac{1}{3.24} + \frac{1}{1.44}$$

$$: A = \sqrt{1.994} = 1.41\,m^2$$

The airflow rate due to convection is given by

$$: Q = 7.0A\sqrt{h(t_r - t_o)}$$

$$: Q = 7.0 \times 1.41 \times \sqrt{4(32 - 26)}$$

$$: Q = \frac{4836\,m^3}{h}$$

Natural Supply and Mechanical Exhaust of Air

'Natural supply and mechanical exhaust' is a type of ventilation system that uses openings like windows for fresh air intake and fans to actively pull stale air out of a building. This hybrid system combines the passive benefits of natural forces, such as wind and temperature differences, with the controlled removal of indoor air provided by mechanical means like fans (usually of the propeller, axial flow, or mixed flow type). It is effective in situations where controlling air quality and reducing moisture or pollutants is important, while still allowing for natural air intake.

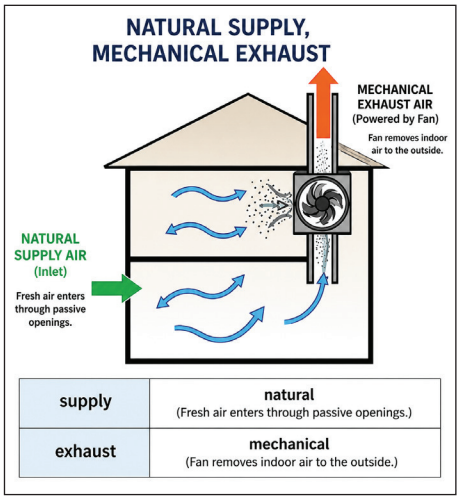


Figure 62 Natural supply and mechanical exhaust

Mechanical ventilation

Mechanical ventilation is a form of ventilation which usually consists of fans, filters, ducts, air diffusers, and outlets to move air into and out of a building, controlling indoor air quality by removing stale, contaminated air and replacing it with fresh outdoor air.

Mechanical ventilation can be divided into two categories which are.

1) **Mechanical supply and natural exhaust of air**

2) **Mechanical supply and mechanical exhaust of air**

Mechanical Supply and Natural Exhaust of Air

Mechanical supply and natural exhaust systems are arranged to deliver fresh air positively into the enclosed space. Such a system necessitates provision for the discharge of vitiated air by natural means. Where there is a requirement for the enclosed space to be at a slightly higher pressure than its surroundings (to exclude dust or smoke, for example), the discharge may be through natural leakage paths or balanced pressure relief dampers, as may be required.

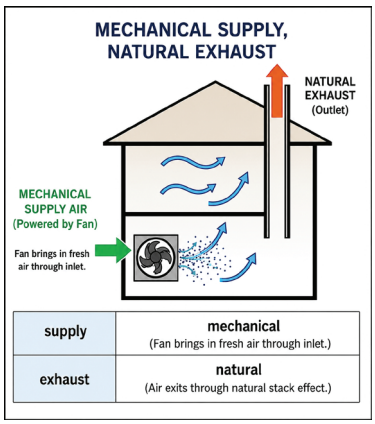


Figure 63 Mechanical supply and natural exhaust of air

Mechanical Supply and Mechanical Exhaust of Air

'Mechanical supply and mechanical exhaust system' is a combination of natural supply mechanical exhaust and mechanical supply natural exhaust system. This system may comprise supply and exhaust ductwork systems or may employ a common fan with a fresh air inlet on the low-pressure side..

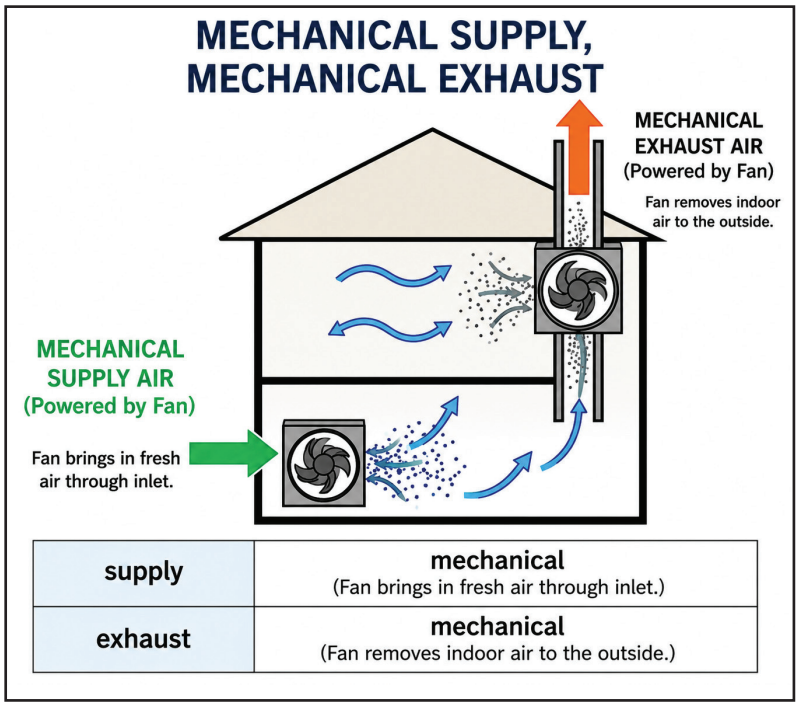


Figure 64 Mechanical supply and mechanical exhaust of air

Energy Conservation Strategies in Ventilation System

1) Maximum possible use should be made of wind-induced natural ventilation. This may be accomplished by following the design guidelines given below:

a. Adequate number of circulating fans should be installed to serve all interior working areas during summer months in the hot dry and warm humid regions to provide necessary air movement at times when ventilation due to wind action alone does not afford sufficient relief.

   i. The capacity of a ceiling fan to meet the requirement of a room with the longer dimension D metres should be about 55 D m3/min.

   ii. The height of fan blades above the floor should be (3H + W)/4, where H is the height of the room, and W is the height of work plane.

   iii. The minimum distance between fan blades and the ceiling should be about 0.3 metre.

2) Electronic regulators should be used instead of resistance-type regulators for controlling the speed of fans.

3) When actual ventilated zone does not cover the entire room area, then optimum size of ceiling fan should be chosen based on the actual usable area of room, rather than the total floor area of the room. Thus, smaller size of fan can be employed, and energy saving could be achieved.

4) Power consumption by larger fans is obviously higher, but their power consumption per square metre of floor area is less and service value higher. Evidently, improper use of fans irrespective of the rooms' dimensions is likely to result in higher power consumption. From the point of view of energy consumption, the number of fans and the optimum sizes for rooms of different dimensions are given in Table 13 below.

Table 20 Optimum size/number of fans for rooms of different sizes

Sl. No.	Room Width (m)	Optimum Size, mm/Number of Fans for room Length										
		4 m	5 m	6 m	7 m	8 m	9 m	10 m	11 m	12 m	14 m	16 m
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
i	3	1200/1	1400/1	1500/1	1050/2	1200/2	1400/2	1400/2	1400/2	1200/3	1400/3	1400/3
ii	4	1200/1	1400/1	1200/2	1200/2	1200/2	1400/2	1400/2	1500/2	1200/3	1400/3	1500/3
iii	5	1400/1	1400/1	1400/2	1400/2	1400/2	1400/2	1400/2	1500/2	1400/3	1400/3	1500/3
iv	6	1200/2	1400/2	900/4	1050/4	1200/4	1400/4	1400/4	1500/4	1200/6	1400/6	1500/6
v	7	1200/2	1400/2	1050/4	1050/4	1200/4	1400/4	1400/4	1500/4	1200/6	1400/6	1500/6
vi	8	1200/2	1400/2	1200/4	1200/4	1200/4	1400/4	1400/4	1500/4	1200/6	1400/6	1500/6
vii	9	1400/2	1400/2	1400/4	1400/4	1400/4	1400/4	1400/4	1500/4	1400/6	1400/6	1500/6
viii	10	1400/2	1400/2	1400/4	1400/4	1400/4	1400/4	1400/4	1500/4	1400/6	1400/6	1500/6
ix	11	1500/2	1500/2	1500/4	1500/4	1500/4	1500/4	1500/4	1500/4	1500/6	1500/6	1500/6
x	12	1200/3	1400/3	1200/6	1200/6	1200/6	1400/6	1400/6	1500/6	1200/7	1400/9	1400/9
xi	13	1400/3	1400/3	1200/6	1200/6	1200/6	1400/6	1400/6	1500/6	1400/9	1400/9	1500/9
xii	14	1400/3	1400/3	1400/6	1400/6	1400/6	1400/6	1400/6	1500/6	1400/9	1400/9	1500/9

4.2 Space-conditioning Systems

Space conditioning is the process of regulating the temperature and indoor air quality of an enclosed space through systems that provide heating, cooling, ventilation, and humidity control. These systems typically incorporate components such as chillers or compressors, fluid distribution networks (including air ducts, water piping, and refrigerant piping), pumps, air-handling units, cooling and heating coils, air- or water-cooled condensers, economizers, terminal units, and associated control systems. Together, these elements work to maintain comfortable and healthy indoor environmental conditions for building occupants.

Heating, ventilation, and air-conditioning (HVAC) refers to the equipment, distribution systems, and terminals that provide, either collectively or individually, the heating, ventilation, or air-conditioning requirement to a building or a portion of building. The HVAC systems also affect the health, comfort, and productivity of occupants.

Air-conditioning System

The refrigeration cycle in any air-conditioning system (DX or central chiller) works by continuously circulating a refrigerant through four key components—the evaporator, compressor, condenser, and expansion device. Together, they transfer heat from the indoor environment to the outdoors.

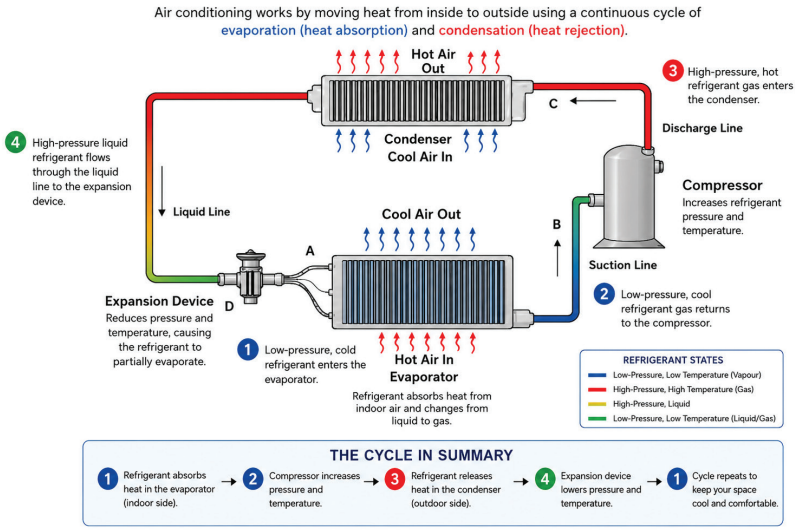


Figure 65 Refrigeration cycle

Evaporator – heat absorption: The cycle begins at the evaporator, where low-pressure, cold liquid refrigerant flows through coils. As warm indoor air (or chilled water, in central systems) passes over these coils, the refrigerant absorbs heat. This heat causes the refrigerant to evaporate into low-pressure vapour, cooling the air/water in the process.

Compressor – increasing pressure and temperature: The compressor pulls in the low-pressure vapour from the evaporator. It then compresses this vapour into a high-pressure, high-temperature gas. By increasing the pressure, the compressor raises the refrigerant's temperature above the outdoor air or cooling water temperature, allowing heat to be released in the next stage.

Condenser – heat rejection: The hot, high-pressure refrigerant vapour enters the condenser coil, where it releases the heat, it carried from the indoor space. Outdoor air (in DX systems) or cooling-tower water (in central systems) passes over the condenser, absorbing this heat. As the heat is removed, the refrigerant condenses into a high-pressure liquid.

Expansion Device – pressure and temperature reduction: The high-pressure liquid refrigerant then flows through the expansion device (such as a Thermostatic Expansion Valve (TXV), capillary tube, or Electronic Expansion Valve (EEV). The device creates a sudden pressure drop, causing part of the refrigerant to flash (evaporate slightly), bringing its temperature down significantly. This cold, low-pressure liquid is now ready to return to the evaporator and absorb heat again.

Heating System

Heating system types can be classified into boilers (oil and gas), furnaces (oil, gas, and electric), heat pumps, and space heaters.

Boiler-based heating systems have steam and/or water piping to distribute heat. Boilers can be self-contained units, or they can be packaged units which are factory-built systems, disassembled for shipment, and reassembled at the site. The heated water may serve preheat coils in air-handling units; reheat coils, and local radiators. Systems that circulate water or fluid are called hydronic systems. Heating water may also be used for heating service water and other process needs, depending on the building type. Some central systems have steam boilers rather than hot water boilers because of the need for steam for conditioning needs (humidifiers in air-handling units) or process needs (sterilizers in hospitals, direct-injection heating in laundry and dishwashers, etc.). The remaining heating systems include heat pumps and space heaters that heat directly and require little or no distribution.

Types of air-conditioning systems

There are primarily two main types of air-conditioning systems:

1) A direct expansion or DX type system

2) Central plant system

Direct expansion systems or DX systems

Direct expansion systems or DX systems are in the form of room air conditioners, split system air conditioners, and packaged air conditioners. Heat exchange takes place directly from the refrigerant within the copper tubes to the air being drawn across the finned coil by an evaporator fan. The DX type systems offer localized solutions for buildings' heating and cooling needs. These systems are typically appropriate for smaller (single zone) building.

Unitary air conditioners: Unitary air conditioners are self-contained, factory-assembled cooling systems designed to serve a single room or defined space. They include all major components—compressor, condensers, evaporators, expansion devices, and fans—within a single packaged unit or in two connected parts. Common

examples include window AC units and packaged AC units. These systems are easy to install, require minimal ductwork, and are ideal for small- to medium-sized spaces. Their compact design and plug-and-play nature make them a cost-effective option for residential and light commercial cooling applications.



Figure 66 Unitary air conditioner

Split-system air-conditioning systems : Split-system air conditioners consist of two main components: an indoor unit and an outdoor unit, connected by refrigerant piping and electrical wiring. The indoor unit houses the evaporator coil and fan, which cools and circulates air within the room, while the outdoor unit contains the compressor and condenser coil, responsible for releasing the absorbed heat to the outside environment. Because the compressor is located outdoors, split air conditioners operate quietly and offer higher efficiency compared to window units. They are commonly used in residential and small commercial spaces, providing reliable cooling, better aesthetics, and flexible installation.



Figure 67 Split air conditioner

Compliance:

Window and Split air-conditioners which are non- ducted and have a capacity up to 10499Wr and light commercial air conditioners from 10500 to 18000Wr (all air-cooled systems) shall comply with IS1391 Part 1 and Part 2 and shall meet or exceed the efficiency requirements as per BEE 3 Star rating.

Minimum efficiency requirements for window and split units as per the ECSBC Code

AC Type	ECSBC	ECSBC Plus	Super ECSBC
Window	BEE 3 star	BEE 4 star	BEE 5 star
Split	BEE 3 star	BEE 4 star	BEE 5 star

Packaged air conditioners: In a packaged air conditioner, the evaporator, condenser, and compressor are all located in one cabinet, which usually is placed on a roof or on a concrete slab adjacent to the building. This type of air conditioner is typical in small commercial buildings and in residential buildings. Air supply and return ducts come from indoors through the building's exterior wall or roof to connect with the packaged air conditioner, which is usually located outdoors. Packaged air conditioners often include electric heating coils or a natural gas furnace. This combination of air conditioner and central heater eliminates the need for a separate furnace indoors.



Figure 68 Packaged air conditioner

Ducted and packaged air conditioners of capacity above 3500 Wr for both air cooled and water-cooled systems, as per the ECSBC Code, the efficiency of system should be as follows:

Compliance:

Ducted and Packaged air conditioners of capacity above 3500 Wr shall comply with IS 8148 for both air cooled and water cooled systems and the minimum efficiency requirements as below:

Efficiency of water-cooled packaged air conditioners

Cooling capacity (Wr)	ECSBC	ECSBC Plus	Super ECSBC
≤ 10,499	NA	NA	NA
> 10,500	3.3 EER	3.7 EER	3.9 EER

Efficiency of air-cooled packaged air conditioners

Cooling capacity (Wr)	ECSBC	ECSBC Plus	Super ECSBC
≤ 10,499	BEE 3 star	BEE 4 star	BEE 4 star
> 10,500	2.8 EER	3.2 EER	3.4 EER

Variable refrigerant volume (VRV)/variable refrigerant flow (VRF): VRV and VRF refer to the same advanced air-conditioning technology developed to provide efficient, flexible, and zone-wise cooling and heating. These systems operate by continuously modulating the flow (or volume) of refrigerant supplied to multiple indoor units based on each zone's cooling or heating demand. A single outdoor unit can be connected to many indoor units, offering precise temperature control, energy efficiency, and ease of installation without the need for a chilled water network. Because of their ability to vary refrigerant flow, they consume less energy under part-load conditions and are widely used in commercial buildings, offices, hotels, and premium residences.



Figure 69 VRF System

Compliance: Efficiency for VRF air conditioners as per the ECSBC CodeEfficiency of water-cooled packaged air conditioners

For heating or cooling or both

Type	Size category (kWr)	For ECSBC ISEER (W/W)	For ECSBC Plus ISEER (W/W)	For ECSBC Super ISEER (W/W)
VRF air conditioners, air cooled	<40	5.4	6.4	7.4
	≥ 40 and < 70	5.5	6.5	7.5
	≥ 70	5.6	6.6	7.6

Heat pumps: A heat pump is same as an air conditioner except that the heat rejected in an air conditioner becomes the useful heat output. Heat flows naturally from a higher to lower temperature. Heat pumps, however, can force the heat flow in the other direction, using a relatively small amount of high-quality drive energy (electricity, fuel, or high temperature waste heat). In the example shown in the below figure, the heat pump takes three units of energy from the atmosphere and with an additional one unit by way of compressor work can provide four units of energy at a high temperature. Thus, heat pumps can transfer heat from natural heat sources in the surrounding, such as air, ground or water or form man-made heat sources such as industrial or domestic waste, to a building application.

To transport heat from a heat source to a heat sink, external energy is needed to drive the heat pump. Theoretically, the total heat delivered by the heat pump is equal to the heat extracted from the heat source, plus the amount of energy supplied. Electrically driven heat pumps for heating buildings typically supply 100 kWh or heat with just 20–40 kWh of electricity. The principle of operation of a heat pump is illustrated below:

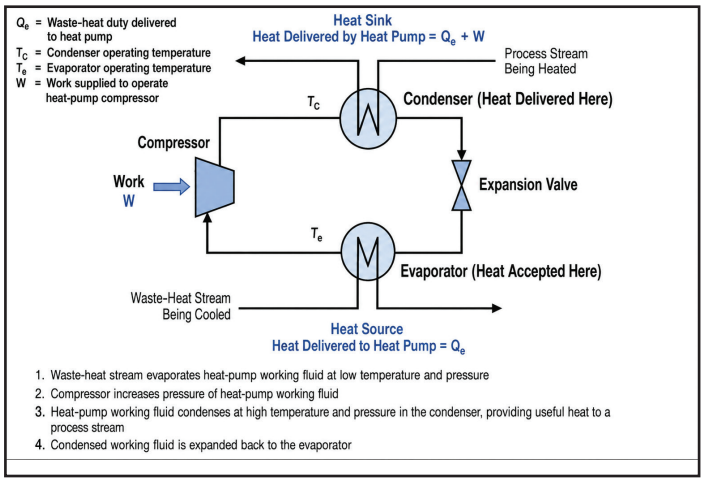


Figure 70 Working principle of a heat pump

(ref: Energy_Efficiency_In_Electrical_Utilities_Book_03_Final)

Space heaters: Space heaters are localized heating devices designed to warm a single room or a specific small area rather than an entire building. They generate heat through electricity, gas, kerosene, or other fuels and are typically used where central heating is unavailable or insufficient. Electric space heaters—such as fan heaters, convection heaters, radiant heaters, and oil-filled heaters—convert electrical energy directly into heat and distribute it through natural convection or forced airflow. Gas-based space heaters also serve as efficient point-source heating solutions but require proper ventilation for safe operation. Space heaters are commonly portable, easy to install, and provide rapid heating, making them suitable for spot heating, temporary heating needs, or supplemental heating in cold zones.

Central Plant Systems

A central plant system is a large facility within a building or campus that produces heating, cooling, or both from a single location and distributes it to various areas of the building. Instead of using multiple small air-conditioning or heating units in each space, the central plant generates thermal energy efficiently using shared equipment and distributes it through piping networks.

In cooling applications, a central plant typically consists of major components such as chillers, cooling towers, pumps, air-handling units (AHUs), and fan–coil units (FCUs). Cooling is generated in a central chilled water plant, where chilled water is produced and circulated using either primary-only or primary–secondary pumping configurations. These arrangements ensure stable flow through the chillers while enabling efficient chilled water distribution throughout the building. The AHUs and FCUs function as terminal units that transfer the cooling effect from the chilled water to the indoor air. Central plants may employ either air-cooled or water-cooled chillers, with water-cooled systems operating in conjunction with cooling towers to reject heat to the atmosphere.

Chiller: A chiller is a central cooling machine used in large air-conditioning systems to produce chilled water, which is then circulated to AHUs, FCUs, or process equipment for cooling. It operates on the vapour compression refrigeration cycle, where heat is absorbed from the chilled water and rejected to the environment either through air or water.

Wherever cooling water or recycled water is readily available, the use of water-cooled chillers is recommended due to their higher operational efficiency and suitability for larger cooling loads. In contrast, air-cooled or hybrid configurations (a combination of air-cooled and water-cooled chillers) are more appropriate for buildings with cooling loads below 530 kWr, where the scale of the system and site conditions may not justify a full water-cooled installation.

For buildings with cooling loads equal to or exceeding 530 kWr, air-cooled chillers should be limited to a maximum of 33% of the total installed chiller capacity (excluding standby units). However, this proportion may be modified if required by the local approving authority/authority having jurisdiction (AHJ) based on specific local conditions or regulatory considerations.

Air-cooled Chillers: Air-cooled chillers reject heat directly to the outdoor air using condenser coils and fans. These systems do not require a cooling tower or condenser water loop, making them simpler to install and maintain. They are commonly used in small to medium-sized commercial buildings, especially where water availability is limited or maintenance of cooling towers is not feasible. Air-cooled chillers are reliable and compact but may have lower efficiency in very hot climates.



Figure 71 Air-cooled chiller

Water-cooled Chillers: Water-cooled chillers reject heat through a condenser water loop connected to a cooling tower, where the heat is transferred to the atmosphere. These systems typically offer higher energy efficiency, better performance in high-ambient conditions, and are suitable for large commercial complexes, hospitals, hotels, and data centres. Although they deliver superior efficiency, they require more infrastructure, including cooling towers, pumps, and water treatment.

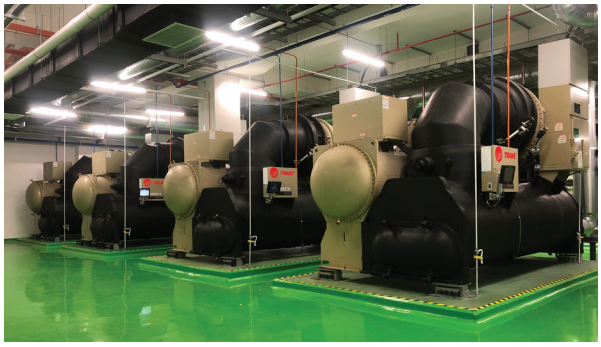


Figure 72 Water cooled chiller

Table 21 Minimum efficiency required for chiller system

Equipment Type	Size Category	Units	Path A	Path B	Test Procedure
Air-cooled chillers	<528 kW	COP (W/W)	≥2.985FL	≥2.866 FL	AHRI 551/591
			≥4.048 IPLV.SI	≥4.669 IPLV	
	≥528 kW		≥2.985 FL	≥2.866 FL	
			≥4.137 IPLV.SI	≥4.758 IPLV	
Air-cooled without condenser, electrically operated	All capacities	COP (W/W)	Air-cooled chillers without condenser must be rated with matching condensers and comply with air-cooled chiller efficiency requirements		AHRI 551/591

Water-cooled, electrically operated positive displacement	<264 kW	COP (W/W)	≥4.694 FL	≥4.513 FL	AHRI 551/591
			≥5.867 IPLV	≥7.041 IPLV	
	≥264 kW and <528 kW		≥4.889 FL	≥4.694 FL	
			≥6.286 IPLV	≥7.184 IPLV	
	≥528 kW and <1055 kW		≥5.334 FL	≥5.177 FL	
			≥6.519 IPLV	≥8.001 IPLV	
	≥1055 kW and <2110 kW		≥5.771 FL	≥5.633 FL	
			≥6.770 IPLV	≥8.586 IPLV	
	≥2100 kW		≥6.286 FL	≥6.018 FL	
			≥7.041 IPLV	≥9.264 IPLV	
Water-cooled, electrically operated centrifugal	<528 kW	COP (W/W)	≥5.771 FL	≥5.065 FL	AHRI 551/591
			≥6.401 IPLV	≥8.001 IPLV	
	≥528 kW and <1055 kW		≥5.771 FL	≥5.544 FL	
			≥6.401 IPLV	≥8.801 IPLV	
	≥1055 kW and <1407 kW		≥6.286 FL	≥5.917 FL	
			≥6.770 IPLV	≥9.027 IPLV	
	≥1407 kW and<2110 kW		≥6.286 FL	≥6.018 FL	
			≥7.041 IPLV	≥9.264 IPLV	
	≥2110 kW		≥6.286 FL	≥6.018 FL	
			≥7.041 IPLV	≥9.264 IPLV	
Air-cooled absorption, single effect	All capacities	COP (W/W)	≥0.600 FL	NA	AHRI 560
Water-cooled absorption, single effect	All capacities	COP (W/W)	≥0.700 FL	NA	AHRI 560
Absorption double effect, indirect fired	All capacities	COP (W/W)	≥1.000 FL; ≥1.050 IPLV.SI	NA	AHRI 560
Absorption double effect, direct fired	All capacities	COP (W/W)	≥1.000 FL; ≥1.000 IPLV.SI	NA	AHRI 560

Compliance:

Chillers in ECSBC, ECSBC+, and Super ECSBC buildings shall meet the minimum effiwciency requirements as per the table below. Additionally, chillers shall be rated at both full load and part load conditions in accordance with IS 16590.

Chiller Type	ECSBC	ECSBC Plus	ECSBC Super
Water Cooled	BEE 3 star	BEE 4 star	BEE 5 star
Air Cooled	BEE 3 star	BEE 4 star	BEE 5 star

Pumps : A chiller pumping system is the network of pumps and piping that circulates chilled water from the chiller to the building's cooling equipment (AHUs, FCUs) and brings the warmed water back to the chiller for re-cooling. It is a critical part of any central chilled water plant, ensuring stable flow, efficient heat transfer, and reliable cooling throughout the building. The system includes primary chilled water pump, secondary chilled water pump, and condenser water pump for cooling tower (if water- cooled chiller).

Primary chilled water pumps : Primary chilled water pumps are responsible for maintaining a constant and reliable flow of chilled water through the chiller evaporator. This flow is crucial because chillers require a minimum, steady water circulation rate to ensure stable heat exchange and to prevent operational issues such as evaporator freezing or low-flow trips. These pumps typically operate at constant speed, although variable-speed drives are increasingly being adopted in modern plants. The primary pumps draw warm return water from the distribution loop, push it through the chiller evaporator where heat is removed, and then deliver the chilled water to the system's distribution header or to the secondary loop through a decoupler. In essence, primary pumps ensure that the chiller functions safely, efficiently, and within its designed operating conditions.

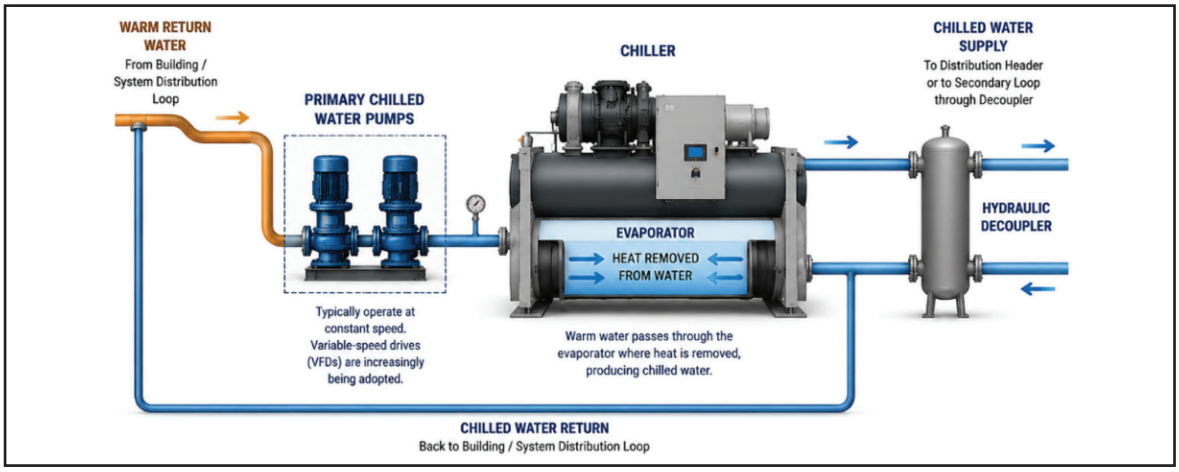


Figure 73 Operation of Primary chilled water pump

Secondary chilled water pumps : Secondary chilled water pumps are used to distribute chilled water from the central plant to various parts of the building, supplying air-handling units (AHUs), fan–coil units (FCUs), and other end-use cooling equipment. Unlike primary pumps, secondary pumps operate on a variable-flow basis and are typically equipped with variable frequency drives (VFDs), allowing them to modulate flow according to real-time cooling demands. This modulation is controlled using differential pressure sensors strategically located at the farthest point in the distribution network. By adjusting the pumping rate to match the actual cooling load, secondary pumps enable energy-efficient operation and ensure adequate cooling is delivered throughout the building. They return warmed water to the primary loop, completing the chilled-water circulation cycle.

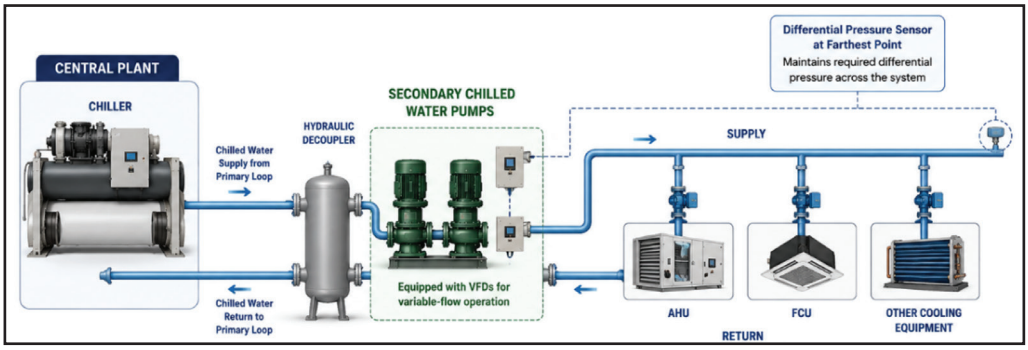


Figure 74 Operation of Secondary chilled water pump

Condenser water pumps : Condenser water pumps circulate water between the chiller condenser and the cooling tower and form an essential part of the heat-rejection loop in a water-cooled chiller system. These pumps supply water from the cooling tower basin to the condenser, where the water absorbs heat removed from the chilled water circuit. After passing through the condenser, the now-heated condenser water is returned to the cooling tower, where this heat is rejected to the atmosphere through evaporation and airflow. The flow provided by condenser water pumps must be steady and sufficient to maintain optimal condensing temperatures; otherwise, the chiller's efficiency drops significantly. While traditionally operated at constant flow, modern plants often use VFD-based control to improve energy performance. Overall, condenser pumps are critical for ensuring efficient heat rejection and smooth chiller operation.

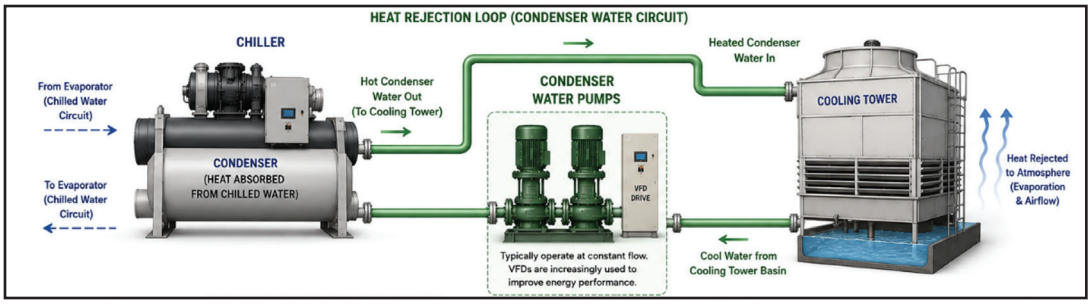


Figure 75 Operation of Condenser chilled water pump

Compliance: Pumps used in HVAC Systems shall meet or exceed the minimum energy efficiency requirements as per table below

Equipment	ECSBC	ECSBC Plus	ECSBC Super
building	Super ECSBC building	BEE 4 star	BEE 5 star
Chilled water pump (primary and secondary)	18.2 W/ kWr with secondary pump	16.9 W/ kWr with VFD on secondary pump	14.9 W/ kWr with primary pumping
Condenser water pump	17.7 W/ kWr	16.5 W/ kWr	14.6 W/ kWr
Pump efficiency (minimum)	70%	75%	80%
Motor efficiency (as per IS 12615)	IE3	IE4	IE4

Cooling Tower : A cooling tower is a heat-rejection device used in central air-conditioning systems—specifically in water-cooled chiller plants—to expel unwanted heat from the building into the atmosphere. It works by circulating warm condenser water (coming from the chiller condenser) and exposing it to ambient air. As this water flows over fill media inside the tower, air is drawn or forced across it using a fan. During this process, a small portion of the water evaporates, and this evaporation removes heat from the remaining water. The cooled water then collects in the tower basin and is pumped back to the chiller condenser to absorb more heat, completing the loop.

Cooling tower performance: The important parameters, from the point of determining the performance of cooling tower are:

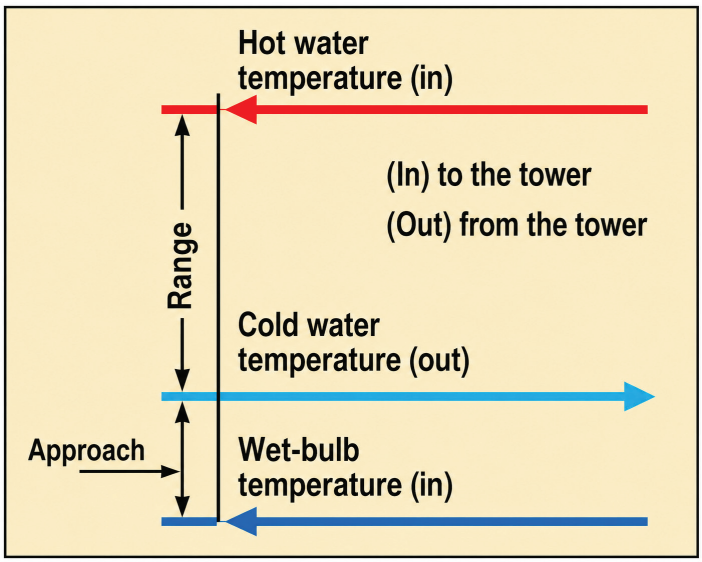


Figure 76 Schematics of cooling tower design parameters

1) **Range** is the difference between the cooling tower water inlet and outlet temperature.

2) Approach is the difference between the cooling tower outlet cold water temperature and ambient wet bulb temperature.

3) **Cooling tower effectiveness (in %)** is the ratio of range to the ideal range, that is, difference between cooling water inlet temperature and ambient wet bulb temperature, that is, range / (range + approach)

4) **Cooling capacity** is the heat rejected in kcal/hr or TR, given as product of mass flow of water specific heat and temperature difference, that is, TR = MCpΔT

5) **Evaporation loss** is the water quantity evaporated for cooling duty and theoretically, for every 10,00,000 kcal heat rejected, evaporation quantity works out to 1.8 m3. An empirical relation used often is:

   Evaporation loss (m3/hr) = 0.00085 x 1.8 x circulation rate (m3/hr) x (T1-T2)1 T1 – T2 = Temperature difference between inlet and outlet water

6) **Cycle of concentration (C.O.C)** is the ratio of dissolved solids in circulating water to the dissolved solids in make-up water.

7) **Blow down losses** depend upon C.O.C and the evaporation losses and is given by relation: Blow down = Evaporation loss / (COC -1)

Compliance: Pumps used in HVAC Systems shall meet or exceed the minimum energy efficiency requirements as per table below

Equipment type	ECSBC	ECSBC Plus building	Super ECSBC building
Open circuit	37.8°C entering water	36.7°C entering water	**35.6°C entering water**
cooling tower	32.2°C leaving water	31.1°C leaving water	**30.0°C leaving water**
Fans for Chillers ≤530 kWr	28.3 °C WB outdoor air	28.3 °C WB outdoor air	**28.3 °C WB outdoor air**
Efficiency	**0.35 kW/ (ltr- sec.)**	**0.35 kW/ (ltr- sec.)**	**0.35 kW/ (ltr- sec.)**

1 Perry's Chemical Engineers Handbook (Page: 12-17)

Air-handling Unit : An air handler is responsible for moving air throughout the duct work in an air-conditioning system. All air handlers contain a blower motor and squirrel cage blower housing which facilitates the movement of air. Most air handlers also include system controls, which are connected to the thermostat. Depending on the type of system, an air handler can also be integrated with gas, oil, electric furnace, heat pump, and cooling coils (or evaporator coil for the air conditioning).

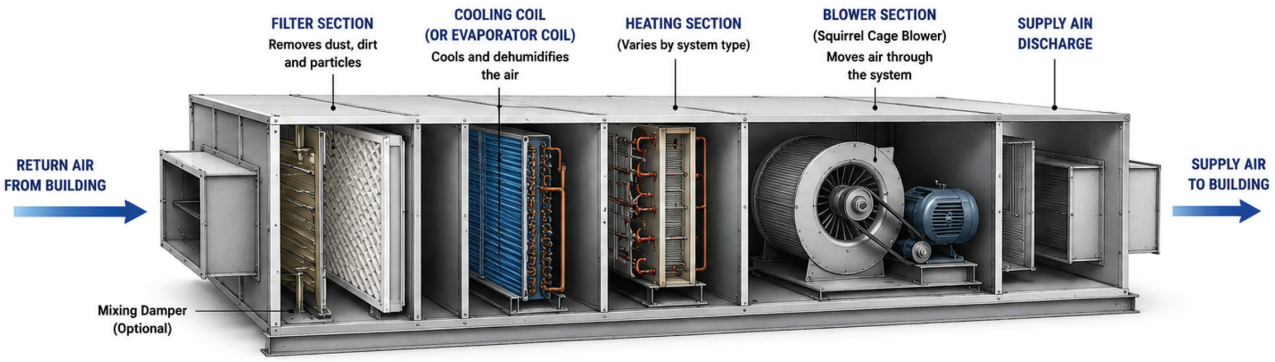


Figure 77 AHU System

Fan Coil Unit : A fan coil unit (FCU) is a smaller, localized air-conditioning unit that provides zone- level cooling or heating. It contains a fan and a coil connected to the chilled water or hot water supply. As the fan blows room air over the coil, the air is cooled or heated and then supplied directly to the occupied space. The FCUs are not typically connected to large ductwork systems; instead, they serve individual rooms or small areas, making them ideal for hotels, offices, residences, and small commercial spaces. The FCUs offer decentralized control, allowing occupants to independently regulate the temperature of their specific space. They are simpler and more compact than AHUs but rely on external ventilation systems (like fresh air units) to meet outdoor air requirements, whereas AHUs can integrate both cooling and ventilation in a single system.

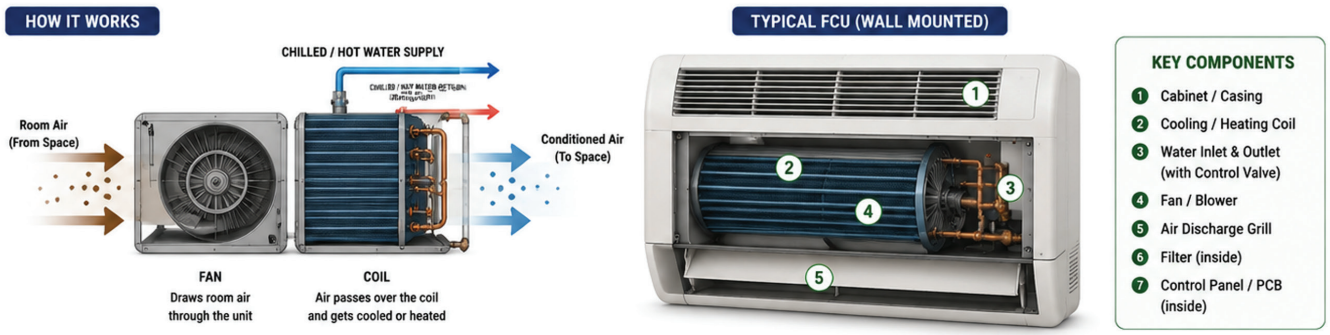


Figure 78 FCU System

Performance parameter of a refrigeration plant

Ton of refrigeration (TR): One ton of refrigeration is the amount of cooling obtained by one ton of ice melting in one day.

1 *ton* = 3024 kcal/hr **OR** 12000 Btu/h **OR** 3.516 thermal kW.

The refrigeration TR is assessed as:

$$TR = \frac{Q \; x \; C_p \; x \; (T_i - T_o)}{3024}$$

Where,

Q is mass flow rate of coolant in kg/hr Cp is coolant specific heat in kcal/kg/0C

Ti is inlet, temperature of coolant to evaporator (chiller) in 0C

To is outlet, temperature of coolant from evaporator (chiller) in 0C

In case of air-conditioning units, the air flow at FCU per the AHU can be measured with an anemometer. Dry bulb and wet bulb temperatures are measured at the inlet and outlet of AHU or the FCU and the refrigeration load in TR is assessed as,

$$TR = \frac{Q\ x\ \rho\ x\ (h_i - h_O)}{3024}$$

Where,

Q is air flow in m^3/hr

p is density of air kg/m^3

h_i is enthalpy of inlet air kcal/kg

h_o is enthalpy of outlet air kcal/kg

Net refrigeration capacity: A quantity defined as the mass flow rate of the evaporator water multiplied by the difference in enthalpy of water entering and leaving cooler, expressed in kcal/h, tons of Refrigeration. It means actual operating TR.

kW/ton rating: Commonly referred to as efficiency, but actually power input to compressor motor divided by tonnes of cooling produced, or kilowatt per ton (kW/ton). Lower kW/ton indicates higher efficiency.

$$kW/tonne = \frac{kW\ input}{tons\ refrigeration\ effect}$$

Coefficient of performance (COP): Chiller efficiency measured in W output (heating) divided by W input (electric power). The COP refers to heating efficiency of an air conditioner (heat pump).

$$COP = \frac{kW\ refrigeration\ effect}{kWinput}$$

Energy efficiency ratio (EER): Performance of small chiller and rooftop unit is frequently measured in EER rather than kW/ton. The EER is calculated by dividing a chiller's cooling capacity (in watts) by its power input (in watts) at full-load conditions. This definition of EER has been adopted in BEE star labelling programme.

$$EER = \frac{Watt\ refrigeration\ effect}{Watt\ input}$$

Relation between kW/ton, EER, and COP

$$kW/tonne = \frac{12}{EER} \qquad EER = \frac{12}{kW/tonne} \qquad COP = \frac{EER}{3.412}$$

$$kW/tonne = \frac{12}{COP\ x\ 3.412} \qquad EER = COP\ x\ 3.412 \qquad COP = \frac{12\ x\ 3.412}{kW/tonne}$$

Solved Example

A chilled water system supplies 18,000 kg/hr of water to an evaporator. The inlet water temperature to the evaporator is 12°C and the outlet water temperature is 7°C. The specific heat of water is 1 kcal/kg°C. The compressor power input is 42 kW.

Calculate:

1. Refrigeration capacity in TR
2. Chiller efficiency in kW/TR
3. Coefficient of Performance (COP)

Ans:

The refrigeration capacity is given by : $\boldsymbol{TR = \frac{Q \times C_p \times (T_i - T_o)}{3024}}$

$$\frac{18000 \times 1 \times (12 - 7)}{3024}$$

: $\boldsymbol{TR = \frac{Q \times C_p \times (T_i - T_o)}{3024}}$

: **29.76 TR**

The chiller efficiency is : $\frac{kW}{TR} = \frac{kW\ input}{TR}$

: $\frac{42}{29.76}$

: **1.41 Kw/TR**

Coefficient of Performance (COP) : **COP = kW refrigeration effect / kW input**

Refrigeration effect in kW : **29.76×3.516=104.64kW**

: $\boldsymbol{COP = \frac{104.64}{42}}$

$\boldsymbol{COP} = 2.49$

Energy and Water Efficiency in Cooling Towers

Water-based HVAC systems offer significant energy savings due to their ability to transport water to large quantities of heat over relatively long distances, more efficiently than air-based systems. Additionally, they offer advantages such as smaller equipment size and cost, along with reduced maintenance and extended life of

mechanical equipment. However, for water scarce urban centres in India, the viable installation and operation of cooling towers will require balancing needs for energy efficiency and water conservation simultaneously. Air-cooled chillers are a good option to conserve water; however, the trade-off is that these chillers consume more energy to provide the same amount of cooling when compared to water-cooled machines with cooling towers.

Energy efficiency measures

- Proper site selection and sizing of the tower can reduce fan speed, capacity, and sound and help to conserve energy.
- Centrifugal fans in favour of lower energy axial fans can reduce horsepower by 50% or more for the same capacity.
- Fan control through two-speed motors, pony motors, or variable speed motors can save energy as well.

Water efficiency measures

- An optimized bleed rate for the tower should be maintained to regulate water consumption. The evaporation rate is dependent on the load, which can vary widely and a constant bleed rate usually discharges more water than required. A properly operating conductivity meter can automatically control bleed to the proper amount required to always maintain the desired tower chemistry in the system.
- Contaminant induction should be minimized and a proper blow-down rate should be maintained. Water-treatment regimens are effective for water conservation, keeping the cooling loop cleaner, saving energy, reducing maintenance, and improving reliability of the entire cooling system.

New technological solutions like hybrid wet-dry cooling tower designs, which combine wet and dry cooling can be adopted to reduce water use, some as much as 70% compared to conventional towers. Typically, a dry-finned coil section is combined in series with an evaporative section in these units. The dry-finned section handles as much of the load as possible, with the unit able to operate completely dry at reduced ambient. Both open and closed-circuit versions are available

4.3 HVAC Controls

A control system in HVAC is the mechanism that monitors, regulates, and optimizes the operation of heating, ventilation, and air-conditioning equipment to maintain desired indoor conditions efficiently. It uses sensors, controllers, and actuators to continuously measure key parameters such as temperature, humidity, airflow, and pressure, and then adjusts system components—like valves, dampers, fans, pumps, and compressors—to achieve the set performance.

Modern control systems range from simple thermostats used for local control to advanced building management systems (BMSs) and direct digital controls (DDCs) that coordinate the entire HVAC plant. These systems ensure that equipment runs only as needed, prevents overcooling or overheating, optimizes energy use, and maintains indoor comfort and air quality. Control systems also support scheduling, monitoring, fault detection, and energy reporting, making them essential for efficient building operation.

Types of controls in HVAC systems

On–off control : On–off control is the simplest and most basic form of HVAC control. In this method, a device operates at full capacity when the measured parameter deviates from the set-point and completely shuts off once the set-point is reached. For example, a thermostat may switch an air conditioner ON when room temperature rises above the set-point and turns it OFF once the temperature falls to the desired level.

Although simple and low-cost, on–off control can lead to frequent cycling, temperature fluctuations, and higher energy use. It is generally used for small units such as window ACs, exhaust fans, and simple heaters where precision is not critical.

Proportional (P) control : Proportional control regulates HVAC equipment by adjusting output proportionally to the difference between the measured value and the set-point (the 'error'). This means that as the room temperature approaches the set-point, the controller gradually reduces the output to avoid overshooting.

Proportional control ensures smoother operation compared to on–off control and reduces rapid cycling. However, it may still result in a small steady-state error because the output never reaches 100% correction unless the error is large. Proportional control is commonly used for valve and damper actuation in AHUs, fan speed modulating dampers, and temperature control loops.

Proportional–integral (PI) control : PI control adds an integral action to proportional control, which eliminates the steady-state error. The integral component accumulates the past error over time and makes gradual adjustments until the controlled variable precisely matches the set-point.

PI controllers are widely used in HVAC because they provide accurate, stable control without excessive oscillation. Applications include chilled water valve control, hot water valve control, pump speed control, and VAV box temperature regulation.

Proportional–integral–derivative (PID) control : PID control is the most advanced form of loop control in HVAC systems. It combines:

- **Proportional action** to respond to the present error.
- **Integral action** to eliminate past cumulative error.
- **Derivative action** to anticipate future changes.

This combination ensures fast, stable, and precise control with minimal overshoot. The PID control is used in complex systems where tight regulation is necessary, such as chiller compressors, cooling tower fan control, supply air temperature control, and static pressure control in VAV systems.

Direct digital control (DDC) : DDC systems use microprocessor-based controllers to monitor sensors and adjust equipment using programmed logic. Data is communicated digitally, allowing precise and reliable control.

The DDC operates as the control backbone of modern buildings and is integrated into building management systems (BMSs). It allows centralized monitoring, remote operation, data logging, trending, alarm management, scheduling, and optimization.

The DDC manages all major HVAC equipment including chillers, pumps, AHUs, FCUs, cooling towers, and VAV terminals.

Time/Schedule-based control : Time-based control regulates HVAC operation based on predefined schedules, typically aligned with building occupancy. For example, HVAC systems may operate at full capacity during working hours and shift to reduced or off mode during nights and weekends. This control type significantly reduces energy use by ensuring equipment runs only when needed. It is commonly implemented via BMS schedules or programmable thermostats.

Demand-controlled ventilation (DCV): DCV adjusts ventilation rates based on real-time occupancy levels. Sensors—typically CO_2 sensors or occupancy sensors—measure concentration levels or presence of occupants and modulate outdoor air dampers accordingly.

When occupancy is high, fresh air supply increases; when fewer people are present, ventilation reduces, saving energy. The DCV is widely used in offices, auditoriums, conference rooms, malls, and educational buildings to balance indoor air quality and energy efficiency.

Variable air volume (VAV) control: VAV control modulates the amount of supply air delivered to different zones based on temperature demand. Each VAV box contains a modulating damper, reheat coil (optional), and a controller.

When a zone requires cooling, the damper opens to increase airflow; when cooling demand reduces, the damper closes partially.

The VAV systems significantly improve comfort, reduce fan energy through static pressure reset, and enable zone-level control in large buildings.

Variable frequency drive (VFD) control: VFDs regulate the speed of motors (fans, pumps, compressors) by controlling their electrical frequency. Instead of running motors at full speed, they operate only at the speed required to meet current load conditions.

The VFD control is highly energy efficient, especially in systems like chilled-water pumps, condenser water pumps, supply and return fans, and cooling tower fans. Benefits include reduced energy consumption, improved equipment life, and precise control.

Set-point reset control : Set-point reset strategies dynamically adjust system set-points to optimize energy use under varying load conditions. Examples include:

- Chilled water supply temperature reset based on outdoor air temperature
- Static pressure reset based on VAV box damper positions
- Supply air temperature reset based on return air conditions

These resets reduce unnecessary energy usage while maintaining occupant comfort. Reset controls are typically managed by a BMS.

4.4 Piping and Ductwork

Piping insulation

Piping work in HVAC systems deals with the distribution of chilled water, hot water, or condenser water to various components such as chillers, boilers, pumps, AHUs, and FCUs to prevent energy losses and ensure efficient system operation. In HVAC systems, especially chilled-water plants—insulation helps maintain the required fluid temperature by reducing heat gain (in chilled-water lines) or heat loss (in hot-water lines).

Proper insulation also prevents condensation on cold pipes, which can otherwise lead to water dripping, corrosion, mold growth, and damage to building finishes. Materials commonly used include elastomeric foam (e.g., NBR), polyethylene foam, glass wool, and rigid polyurethane (PUF). The insulation thickness depends on pipe size, temperature, and environmental conditions to ensure optimal thermal performance and long-term durability.

Piping for heating, space conditioning, and service hot-water systems shall meet the insulation requirements as per ECSBC 2024, given in the table below. Insulation exposed to weather shall be protected by aluminum sheet, painted canvas, or plastic cover. Cellular foam insulation shall be protected or be painted with water resistant paint.

Table 26 Recommended pipe sizes and insulation R-value as per ECSBC

Operating temperature (°C)	Pipe size (mm)					
Open circuit	**ECSBC**		**ECSBC Plus**		**Super ECSBC**	
	<40	≥40	**<40**	**≥40**	**<40**	**≥40**
	Insulation R-value (m2K/W)					
Heating system						
>94°C and ≤121°C	**0.9**	**1.2**	**1.1**	**1.3**	**1.5**	**1.5**
>60°C and ≤94°C	**0.7**	**0.7**	**0.8**	**0.8**	**1.0**	**1.3**
>40°C and ≤60°C	**0.4**	**0.7**	**0.5**	**0.9**	**0.7**	**1.1**
Cooling system						
>4.5°C and ≤15°C	**0.7**	**0.9**	**0.9**	**1.0**	**1.0**	**1.2**

Operating temperature (°C)	Pipe size (mm)					
< 4.5°C	**0.9**	**1.2**	**1.1**	**1.3**	**1.5**	**1.5**
Refrigerant piping (split systems)						
>4.5°C and ≤15°C	**0.4**	**0.7**	**0.4**	**0.9**	**0.7**	**0.9**
< 4.5°C	**0.9**	**1.2**	**0.9**	**1.3**	**1.5**	**1.5**

Where pipes are located within air-conditioned spaces or are buried in ground, the R-value indicated in Table 19 above be reduced by 0.2. Where pipes are located outside the building and in direct exposure to weather, the R-values given in Table 19 above shall be increased by 0.2.

Ductwork and plenum insulation

Ductwork insulation is applied to air-distribution ducts—such as supply, return, and fresh-air ducts—to prevent energy loss, reduce heat gain or heat loss, and avoid condensation. Insulating the duct ensures that the conditioned air maintains its temperature as it travels from the AHU/FCU to the occupied spaces. Common insulation materials include glass wool, mineral wool, elastomeric foam, and rigid boards. Insulation may be applied either externally (outside the duct) or internally (lining the duct) depending on acoustic and thermal performance needs.

Plenum insulation is used in areas where ceilings or building cavities serve as return-air plenums. Insulating plenums helps reduce heat transfer from surrounding spaces and minimizes noise transmission. Plenum-rated insulation materials must meet strict fire and smoke safety standards to ensure safe air circulation.

Together, duct and plenum insulation improves energy efficiency, prevents condensation, reduces airflow noise, and maintains indoor thermal comfort.

As per the ECSBC, Ductwork and plenum shall be insulated in accordance with the table below:

Table 27 Insulation requirements for supply and return ducts and plenum

Duct Location	**Required Insulation[a] (R-values in m^2.K/W**	
	Supply Ducts	Return Ducts
Exterior	R-1.4	R-0.6
Ventilated Attic	R-1.4	R-0.6
Unventilated Attic without Roof Insulation	R-1.4	R-0.6
Unventilated Attic with Roof Insulation	R-0.6	No Requirement
Unconditioned Space[b]	R-0.6	No Requirement
Indirectly Conditioned Space[c]	No Requirement	No Requirement
Buried	R-0.6	No Requirement

[a] Insulation R-value is measured on a horizontal plane in accordance with ASTM C518 at a mean temperature of 42 OC
(75 OF) at the insulated thickness.
[b] Includes crawlspaces, both ventilated and non-ventilated
[c] Includes return air plenum with or without exposed roofs above.

Table 28 Sample R-values for duct insulation materials

Installed R-value[1] ($h \cdot {}^{o}F \cdot ft^2$) / Btu	Required Insulation[a] (R-values in $m^2.K/W$
1.9	½ in. Mineral fiber duct liner per ASTM C 1071, Type 1 1 in. Mineral fiber duct wrap per ASTM C 1290
3.5	1 in. Mineral fiber duct liner per ASTM C 1071, Types I & II 1 in. Mineral fiber board per ASTM C 612, Types IA & IB 1 in. Mineral fiber duct board per UL 181 1 ½ in. Mineral fiber duct wrap per ASTM C 1290 1 in. Insulated flex duct per UL 181
6.0	1 ½ in. Mineral fiber duct liner per ASTM C1071, Types I & II 1 ½ in. Mineral fiber duct board per UL 181 1 ½ in. Mineral fiber board per ASTM C 612, Types IA & IB 2 in., 2 lb/ft^3 Mineral fiber duct wrap per ASTM C 1290 2 ½ in. 0.6 to 1 $lb./ft^3$ Mineral fiber duct wrap per ASTM C 1290 2 ½ in. Insulated flex duct per UL 181
8.0	2 in. Mineral fiber duct liner per ASTM C 1071, Types I & II 2 in. Mineral fiber duct board per UL 181 2 in. Mineral fiber board per ASTM C 612, Types IA & IB 3 in. ¾ lb/ft^3 Mineral fiber duct wrap insulation per ASTM C 1290 3 in. Insulated flex duct per UL 181
10.0	2 ½ in. Mineral fiber board per ASTM C 612, Types IA & IB`

[1] Listed R-values are for the insulation only as determined in accordance with ASTM C 518 at a mean temperature of 24 OC at the installed thickness and do not include air film resistance.

[2] Consult with manufactures for other materials or combinations of insulation thickness or density meeting the required R-Value.

Duct sealing

Duct sealing plays a vital role in ensuring that HVAC systems perform as intended by preventing unwanted air leakage. Air leaks can significantly reduce system efficiency, increase energy consumption, compromise indoor comfort, and place additional load on fans and cooling/heating equipment.

According to ASHRAE Standard 90.1, ductwork must be sealed to specific levels based on three key factors:

1. **Duct location:** Whether the duct is outside the conditioned space, within unconditioned zones, or inside conditioned areas.
2. **Static pressure classification:** Higher-pressure ducts require more stringent sealing to prevent leakage.
3. **Duct type:** Supply, return, and exhaust ducts have different sealing requirements due to their function and pressure characteristics.

ASHRAE classifies sealing levels (such as Seal Class A, B, or C) and mandates minimum sealing based on the above conditions to limit energy losses and ensure proper system performance. Proper duct sealing includes sealing all joints, seams, and penetrations using approved materials such as mastic, tapes, gaskets, or aerosol sealants.

Table 29 Minimum duct seal level

Minimum Duct Seal Level				
Duct Location	Supply Duct Supply		Exhaust Duct	Return Duct
Exterior	<= 498.2 Pa	>= 498.2 Pa		
Outdoors	A	A	C	A
Unconditioned Spaces	B	A	C	B
Conditioned Spaces	C	B	B	C
Duct Seal Level				
Seal Level	Sealing Requirements			
A	All transverse joints and longitudinal seams, and duct wall penetrations. Pressure-sensitive tape shall not be used as the primary sealant.			
B	All transverse joints and longitudinal seams. Pressure-sensitive tape shall not be used as the primary sealant.			
C	Transverse joints only.			

4.5 System balancing

System balancing is a process for maintaining the performance of an HVAC system, and for providing the occupants with a comfortable conditioned space. Balancing an air or water-based HVAC system of buildings will make it more energy-efficient, provide improved thermal comfort, extend the life of the building equipment, and reduce the cost of operating it. Balancing is achieved by optimizing the air/water distribution rates for the HVAC system.

Air system balancing

Air system balancing refers to the adjustment of airflow rates through air distribution system devices, such as fans and diffusers. This is done by adjusting the position of dampers, splitter vanes, extractors, etc., manually or by using automatic control devices, such as constant air volume or variable air volume boxes. Balancing is necessary to verify that each space served by a system receives the air volume designed for that space. Proper means for air balancing should be installed at each supply air outlet and zone terminal device. These include balancing dampers or other means of supply air adjustment provided in the branch ducts or at each individual duct register, grille, or diffuser. Installation in the duct system of all devices used for balancing, shown on the approved mechanical plans, typically, on the ductwork layout, should be verified.

High-efficiency air distribution systems can substantially reduce fan power required by an HVAC system, resulting in dramatic energy savings. The largest gains in efficiency for air-distribution systems are realized in the system design phase for new constructions or major retrofit projects. Passive or natural air transport systems have the highest efficiency, and successful, modern examples of this approach are steadily accumulating. For buildings that require mechanical ventilation, innovative design approaches and methodical examination of the entire air system can greatly improve efficiency and effectiveness.

Air-handling efficiency: The energy required to move air is calculated as follows:

$$\text{Air-handling efficiency: } = (\text{Flow} \times \text{static pressure}) / \text{Efficiency}$$

All these factors can be manipulated to reduce the energy consumption of the system. Air flow has a dominant effect on energy consumption because it shows up twice in the energy equation: as the first term and as a squared function in the second term (pressure). The pressure a fan must work against depends on two primary factors:

the flow and duct design features such as diameter, length, surface treatment, and impediments such as elbows, filters, and coils. Typical pressure losses are on the order of 2–6 inches water gauge (wg); an efficient system operates at less than 1.5" wg. A fan's duty factor is the number of hours per year that it operates, sometimes presented as a percentage. Many large fans spin at full speed continuously (8,760 hours per year). Using simple or complex controls, duty factors can often be reduced to about 3,000 hours per year or less by limiting fan operation to occupied periods. The mechanical efficiency of the fan and its drive system can typically be raised from the 40 to 60% range to the mid-80% range. Wire to air efficiency will need to be considered and is a function of motor efficiency × mechanical efficiency.

Design options for improving air-distribution efficiency include:

- Variable air-volume systems
- VAV diffusers
- Low-pressure-drop duct design
- Low-face-velocity air handlers
- Fan sizing and variable-frequency-drive motors
- Displacement ventilation system

Hydronic system and balancing : Hydronic system balancing refers to the adjustment of water flow rates through distribution system devices such as pumps and coils, by manually adjusting the position of valves, or by using automatic control devices, such as flow control valves.

When something is balanced, it is even on both sides. Therefore, a balanced hydronic system is one that delivers even flow to all the devices on that piping system. Each component has an effective equal length of pipe on the supply and return. And when a system is balanced, all the pressure drops are correct for the devices. When that happens, the highest efficiencies are possible in the system. One need not have to change system supply temperatures to accommodate one zone only. The system has the least amount of pressure drop possible, which translates into reduced pumping costs. A balanced hydronic system is one that is efficient. If a system that is not delivering the water to the right devices in the right amounts, then the system is out of balance.

4.6 Economizer

An economizer is an energy-saving control strategy used in HVAC systems that reduces mechanical cooling by utilizing favorable outdoor air conditions. Instead of relying solely on the chiller or compressor, the system brings in cool outside air to maintain indoor temperature—this process is often called 'free cooling'.

Air economizer

An air economizer is a duct and damper arrangement and automatic control system that together allow a cooling system to supply outdoor air to reduce or eliminate the need for mechanical cooling during mild or cold weather.

Water economizer

A water economizer is a system by which the supply air of a cooling system is cooled indirectly with water that is itself cooled by heat or mass transfer to the environment without the use of mechanical cooling.

Economizers allow the use of outdoor air to cool the building when the outside temperature is cooler than the inside. An economizer consists of dampers, sensors, actuators, and logic devices that together decide how much outside air is to be brought into a building

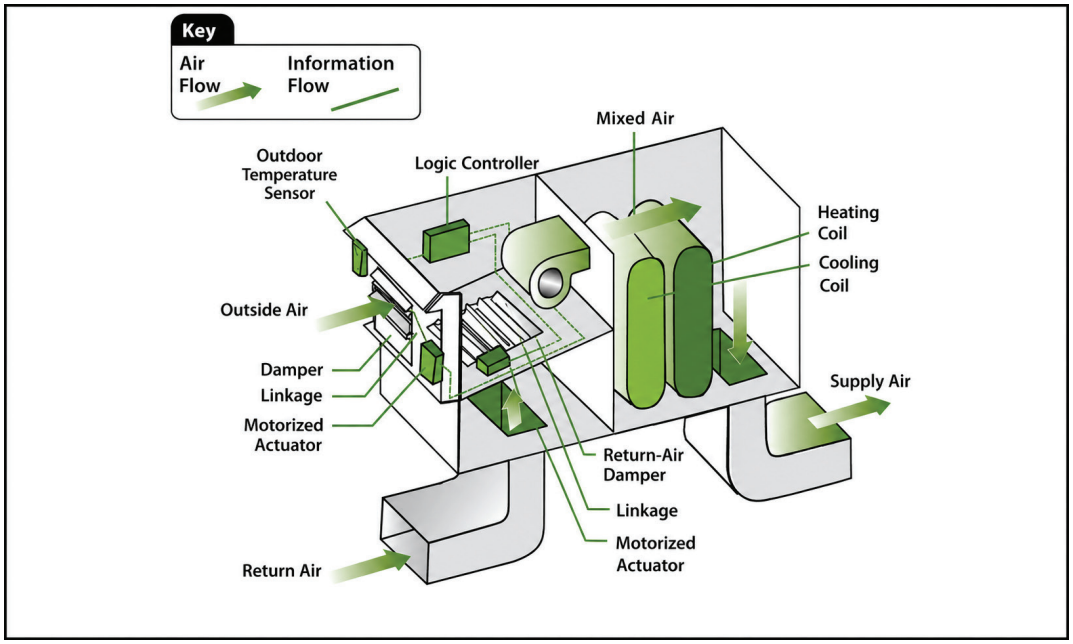


Figure 79 Basic components of economizer

Under the right conditions, sensors and controls shut down the compressor and bring in the outside air through the economizer louvers. A properly operating economizer can cut energy costs by as much as 10% of a building's total energy consumption, depending mostly on local climate and internal cooling loads.

4.7 Heat Recovery Wheel

A heat recovery wheel is a circular, rotating wheel made of a honeycomb-like matrix coated with a desiccant material (for moisture transfer). As the wheel rotates between the exhaust air stream and the incoming fresh air stream, it transfers sensible heat (temperature) and latent heat (moisture), depending on its type.

Air-to-air energy recovery involves transferring heat and in some cases, moisture between two separate air streams—exhaust air leaving the building and fresh outdoor air entering the building. This process helps maintain good indoor air quality (IAQ) without increasing energy consumption, because the heat energy in the exhaust air is reused instead of being wasted.

In a heat-recovery wheel (also called a rotary heat exchanger), a cylindrical wheel filled with heat- absorbing material rotates continuously between these two air streams. The supply air flows through one half of the wheel, while the exhaust air flows in the opposite direction through the other half. Because the two air streams move counter-flow, heat, and moisture transfer very efficiently.

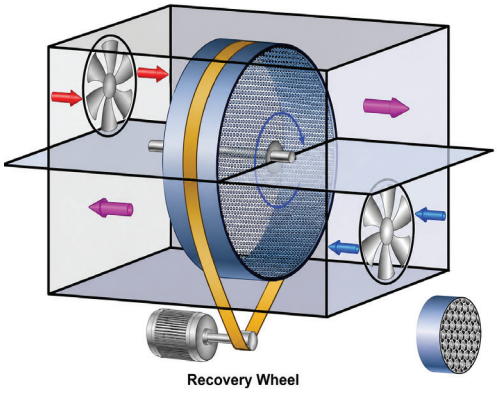


Figure 80 Heat-recovery wheel

Working of a Heat-recovery wheel

Exhaust air heats the wheel (energy absorption)

As the wheel rotates through the warmer exhaust air:

- The heat-storing matrix inside the wheel absorbs heat from the warm exhaust air.
- If the wheel has a desiccant coating, it also absorbs moisture from the humid exhaust air.
- This causes the matrix to become warm and, in some cases, moisture laden.

So, the wheel 'picks up' energy from the exhaust stream.

Wheel rotates into the incoming fresh air (energy release)

After absorbing heat from the exhaust air, the warmed section of the wheel rotates into the cooler incoming outdoor air stream:

- The stored heat is transferred to the cold fresh air.
- In moisture-transfer wheels, the stored moisture is also released into the fresh air.

The result is pre-warmed (and sometimes pre-humidified) supply air entering the HVAC system.

Similarly, during summer, the wheel helps cool and dehumidify the incoming hot and humid outdoor air by transferring this heat and moisture into the exhaust air stream.

This process operates on the principles of the second law of thermodynamics, which ensures that heat naturally flows from higher to lower temperatures and moisture moves from higher to lower vapour pressure. Because the supply and exhaust air streams flow in opposite directions across separate sections of the wheel, the energy transfer is highly efficient, enabling up to 70–90% recovery of heat energy. As the wheel rotates continuously, this exchange of heat and moisture occurs in a smooth, ongoing cycle, improving indoor air quality while significantly reducing the load on mechanical heating and cooling equipment and thereby lowering energy consumption.

Advantages of heat-recovery wheel

- High-heat-recovery performances
- Low-investment costs
- Less space requirements
- Less self-consuming energy
- Low-pressure drops
- Power for rotor drive is negligible
- Self-cleaning features

4.8 Variable Flow Hydronic System

Variable fluid flow refers to the ability of a hydronic system (chilled water or hot water) to adjust the amount of water circulating through pipes based on the actual cooling or heating demand. Instead of pumping a constant

quantity of water regardless of load conditions, the system reduces or increases flow rate dynamically. This is achieved using variable speed pumps and control valves that respond to signals from temperature sensors and building automation systems. During low-load periods—such as early morning, late evening, or mild weather, the flow rate automatically drops, significantly lowering pump energy consumption. This makes the system more energy efficient and improves temperature control across the building.

Automatic isolation valve

Automatic isolation valves are control valves installed on coils, heat exchangers, or equipment branches to automatically stop water flow when a specific zone or piece of equipment is not in use. When a fan coil unit, AHU coil, or heat exchanger reaches the desired temperature or switches off, the isolation valve closes, preventing unnecessary water circulation through that device. This helps maintain proper differential pressure in the hydronic network, allows pumps to reduce speed efficiently, and prevents energy waste by ensuring water only flows where it is required. Automatic isolation valves are essential for achieving true variable-flow operation.

Variable speed drives

Variable speed drives control the rotational speed of pumps and fans by adjusting the frequency of the electric motor. In hydronic systems, VSDs are typically installed on chilled water or hot water pumps to modulate pump speed based on demand. When the system requires less heating or cooling, the VSD slows the pump down, reducing both flow rate and energy use. Since pump power varies with the cube of speed (affinity laws), even a small reduction in speed results in substantial energy savings. The VSDs help maintain stable system pressure, improve comfort control, extend pump life, and significantly reduce operating costs.

4.9 District cooling system

District cooling is a centralized cooling network that distributes chilled water to a group of buildings for air-conditioning purposes. District Cooling Systems (DCS) use a network of underground insulated pipelines to supply cooling in the form of chilled water (or another cooling medium) from a central plant to multiple buildings for space conditioning and process cooling. It represents a modern, efficient approach to air-conditioning clusters of buildings in urban areas and institutional campuses.

In a district cooling system, a central plant produces chilled water and distributes it through a closed- loop piping network to connected buildings. Conventional air-conditioning systems can account for more than 50% of a building's peak electricity demand, often during periods of highest tariffs. District cooling helps reduce both peak electrical demand on the grid and overall energy consumption. Additionally, it eliminates the need for individual buildings to install chillers, cooling towers, and associated mechanical and electrical systems, thereby reducing capital costs and freeing up valuable rooftop and service space. By consolidating the cooling requirements of multiple users, district cooling achieves economies of scale. Such systems may serve a single large user (e.g., airports, campuses, malls, or hospitals) or supply cooling to a mix of building types within a development—such as high-density commercial zones, residential complexes, healthcare facilities, and educational institutions.

District Cooling Systems can also integrate renewable energy sources and recover waste or surplus energy, supporting the decarbonization of the cooling sector. The use of Thermal Energy Storage (TES)

further enhances system efficiency by shifting cooling loads and managing peak demand during hot periods, while also improving grid flexibility. This makes district cooling economically attractive from both regional and national energy planning perspectives.

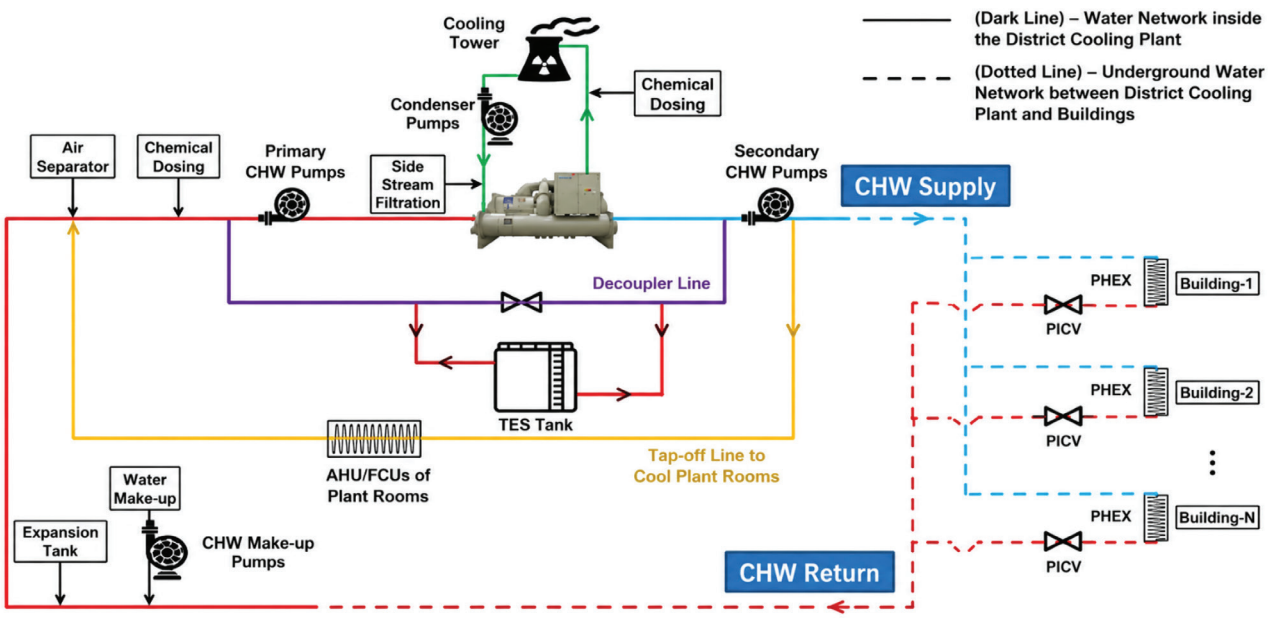


Figure 81 District cooling system mechanical layout

The scale of district cooling systems can vary significantly—from serving a small cluster of buildings to covering an entire city. These systems are particularly viable in areas with high cooling demand density and load diversity (i.e., non-coincident peak loads across different buildings).

In the Indian context, district cooling is particularly well-suited for a range of large-scale and high- density developments, including mixed-use or redevelopment projects that integrate residential and commercial spaces such as offices, retail, hotels, hospitals, convention centers, and entertainment facilities. It is also highly applicable in major infrastructure developments like Aerocities— encompassing airport terminals, logistics hubs, and commercial zones—as well as industrial clusters such as pharma cities. Additionally, district cooling can effectively serve large institutional campuses with academic and residential buildings, IT parks that house offices, call centers, and data centers, and smart city initiatives along with other similar large-scale real estate and industrial developments.

4.10 Low-energy Comfort System

Alternative HVAC systems which have low-energy use may be installed in place of (or in conjunction with) refrigerant-based cooling systems. The approved list of low-energy comfort systems is given below:

Evaporative cooling

Evaporative cooling works on the principle that when water evaporates, it absorbs heat from the surrounding air, thereby lowering the air temperature. In this system, warm outdoor air is passed over water-soaked pads or through a spray of fine water droplets. As the water evaporates, the air becomes cooler and more humid before it is supplied indoors. This method is highly energy efficient as it uses only fans and pumps, without compressors. Evaporative cooling is most effective in hot, dry climates where humidity levels are low, making it a popular alternative to traditional air conditioning in arid regions.

Desiccant cooling system

Desiccant cooling systems are heat-driven cooling units, and they can be used as an alternative to the conventional vapour compression and absorption cooling systems. The operation of a desiccant cooling system

is based on the use of a rotary dehumidifier (desiccant wheel) in which air is dehumidified. The resulting dry air is somewhat cooled in a sensible heat exchanger (rotary regenerator), and then further cooled by an evaporative cooler. The resulting cool air is directed into a room. The system may be operated in a closed cycle or more commonly in an open cycle in ventilation or recirculation modes. A heat supply is needed to regenerate the desiccant. Low-grade heat at a temperature of about 60–95°C is sufficient for regeneration, so renewable energies such as solar and geothermal heat as well as waste heat from conventional fossil-fuel systems may be used. The system is simple and thermal coefficient of performance (COP) is usually satisfactory. (Elsevier.)

Solar air conditioning

Solar air conditioning uses solar energy, either thermal or photovoltaic (PV), to drive the cooling process. In thermal solar systems, solar collectors heat water or refrigerant, which then powers absorption chillers to produce chilled water for cooling.

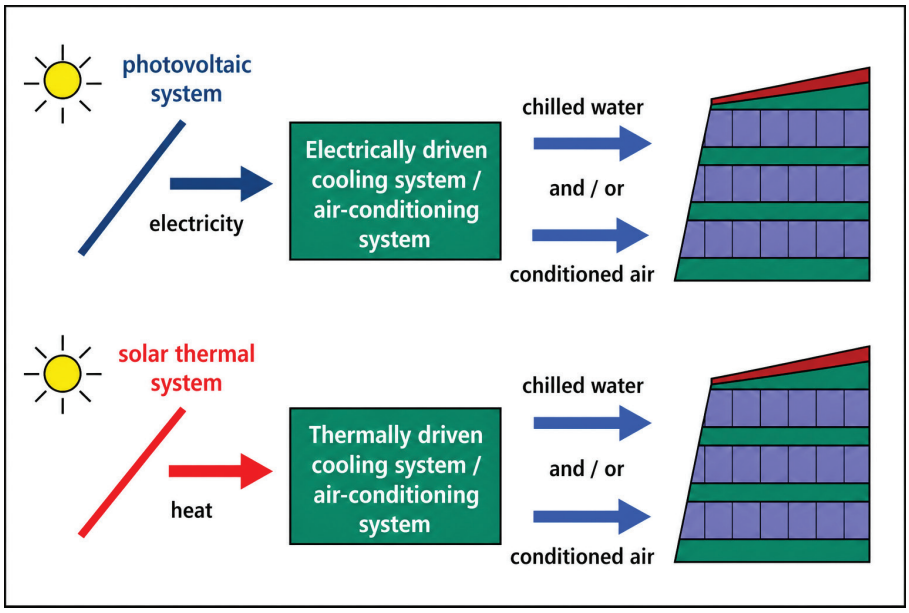


Figure 82 Solar air conditioning

In PV systems, solar panels generate electricity to run conventional air-conditioning systems, reducing dependence on the grid. Solar AC is ideal for locations with high solar radiation, helping reduce energy costs and carbon emissions. As cooling demand typically peaks during sunny days, solar AC aligns well with natural energy availability. (SHC)., 2011)

Tri-generation (waste-to-heat)

Tri-generation technology is a technology that can provide simultaneously three forms of output energy: electrical power, heating, and cooling. Tri-generation is also known as combined cooling, heating, and power (CCHP) or combined heating, refrigeration, and power (CHRP). In essence, tri-generation systems are combined heat and power (CHP) or co-generation systems, integrated with a thermally driven refrigeration system to provide cooling as well as electrical power and heating. The CHP systems consist of a power system which can be an internal combustion engine driven by a fossil fuel or a biofuel, an external combustion engine or other thermally or chemically driven systems coupled to a generator which produces electricity. A heat-recovery system recovers heat from the power system and exhaust gases to be used for heating applications. Effective operation of CHP systems requires maximum utilization of both electrical power and heat. Where there are seasonal variations in heat demand, the utilization efficiency of CHP systems can be increased if the excess heat is used to power thermally driven refrigeration technologies. Tri-generation systems can have

overall efficiencies as high as 90% compared to 33–35% for electricity generated in central power plants. (Conservation.)

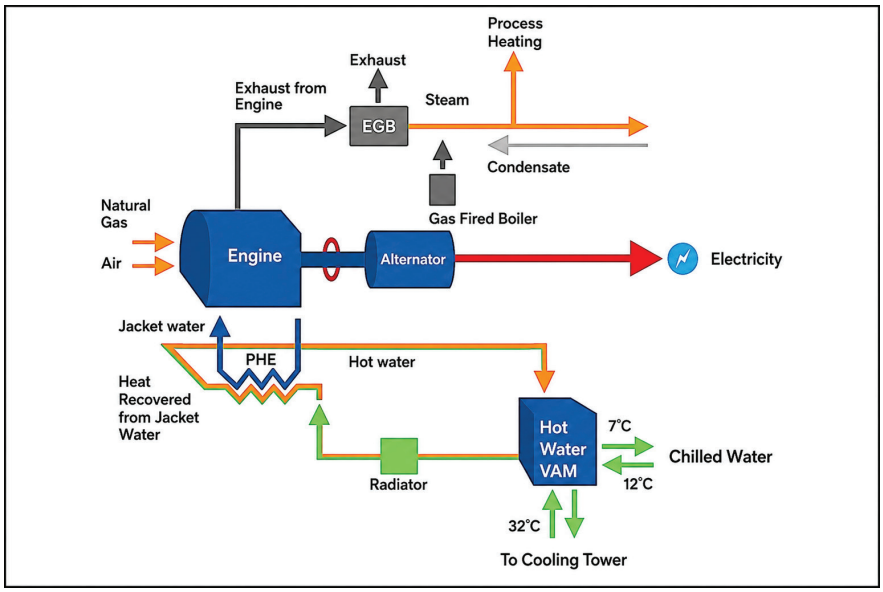


Figure 83 Schematic of tri-generation system

Radiant Cooling System

Radiant cooling uses chilled water circulated through ceiling panels, floors, or walls. These cooled surfaces absorb heat radiated from occupants and equipment, creating comfortable indoor conditions with reduced energy use. Since water transports heat more efficiently than air, radiant systems significantly lower fan and pump energy. Humidity management is critical to prevent condensation.

Coldwater flows through pipes embedded in the slab and cools the entire slab, resulting in the slab surface being maintained at about 20°C. Cooling inside the space is achieved when the cold slab absorbs the heat (radiation) generated by people, computers, lighting, and other equipment which are exposed to the slab. Fresh air is supplied through an air system to maintain a healthy indoor environment and to control the moisture inside the office space. In other words, the sensible heat load can be addressed by the cooled slab, and the latent heat load can be addressed by the dedicated outdoor air system (DOAS). ((IITH)., 2021)



Figure 84 Radiant cooling

Types of radiant cooling : Depending on the position of the piping in the building, the radiant system is usually classified into three types.

1. Embedded surface systems (pipes placed within a building layer (floor, wall, and ceiling) which is isolated from the main building structure).
2. Thermally activated building system (TABS) [pipes integrated into main building structure (ceiling, wall, floor)].
3. Radiant panel system (pipes integrated into light-weight panels)

Ground Source Heat Pump (Geothermal Heat Pump)

Geothermal means exchange of heat available inside the earth through convection and conduction. It has been experimentally proven that temperature of earth at a depth of 12ft is equal to average air temperature of that region and it doesn't vary much with further increase in depth. A geothermal (water to air based) heat pump which provides both heating and cooling, where the refrigerant exchanges heat with room air thus providing heating or cooling and in turn gains or rejects heat to or from the ground through the water being circulated through the geo-exchange loops. Apart from conservation of energy through high efficiency variable refrigerant volume heat pump, this system also addresses conservation of water which is another crucial resource that needs to be conserve.

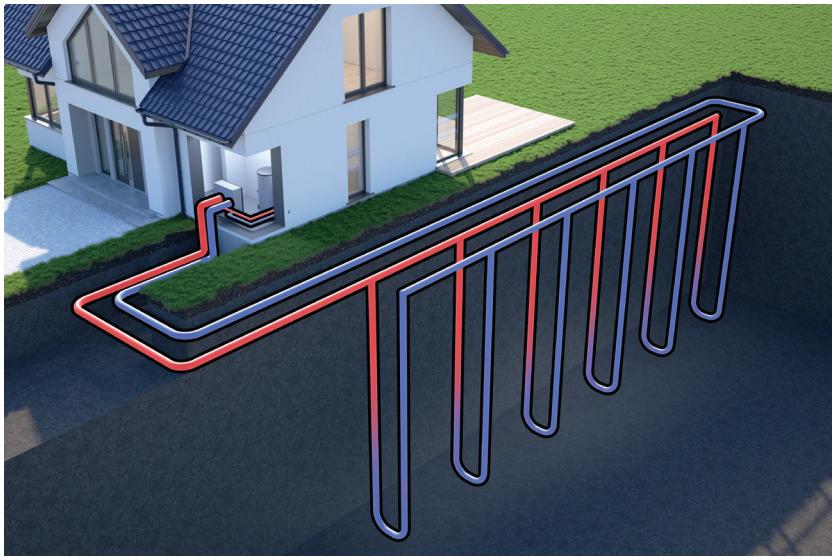


Figure 85 Geothermal heat pump

Adiabatic cooling system

Adiabatic cooling is a form of indirect evaporative cooling where air is cooled by reducing its temperature without adding moisture to the supply air. In this system, outside air passes through a heat exchanger whose other side is cooled by evaporation. As water evaporates on the secondary side of the exchanger, it cools the supply air indirectly without increasing humidity. Adiabatic cooling is energy efficient and ideal for data centres, HVAC pre-cooling, and industrial facilities where low humidity is essential. It provides significant cooling with minimal water consumption and no mechanical refrigeration.

Under-floor air distribution (UFAD) system

A UFAD system is an HVAC system that uses the open space (i.e., the underfloor plenum) between the structural slab and the underside of a raised floor to deliver conditioned air to supply outlets located at or near floor level within the occupied zone.

The UFAD systems supply conditioned air through an under-floor plenum, delivering air directly into the occupied zone through diffusers in the raised floor. Since cool air naturally settles, the UFAD uses stratification to remove heat effectively while using lower fan power. It provides improved ventilation, better temperature control, and flexibility for rearranging office layouts. The UFAD systems are widely

used in modern commercial buildings because of their energy efficiency, improved indoor air quality, and ease of integrating electrical and ICT systems below the floor.

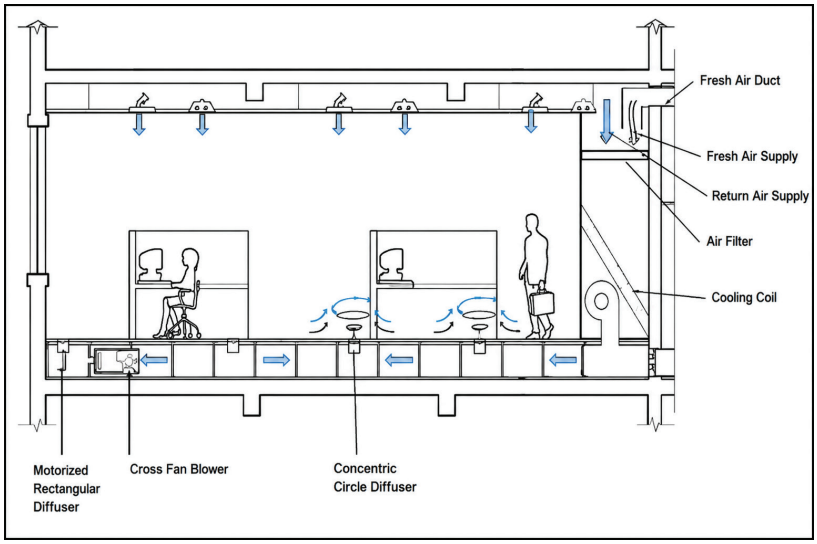


Figure 86 Under-floor air-distribution system

4.11 Service water-heating system

Service water-heating refers to the process of heating water for domestic or commercial use in buildings. This water is not used for space heating but for everyday end uses such as handwashing, bathing, dishwashing, laundry, cooking, and various industrial or institutional processes. The goal of a service water-heating system is to supply hot water at the required temperature, pressure, and flow rate while ensuring safety, reliability, and energy efficiency. This section is covered in detail in chapter 9 Water Management and Controls.

Questions for Comfort System and Control

Section A: Objective Questions (MCQs) – 10 Nos

1. **In natural ventilation due to wind action, the coefficient of effectiveness (K) for wind perpendicular to openings is**
   A. 0.3
   B. 0.4
   C. 0.5
   D. 0.6

2. **Which HVAC system modulates refrigerant flow based on zone demand?**
   A. Window AC
   B. Packaged AC
   C. VRV/VRF system
   D. Chilled water system

3. **In which space conditioning systems, the rejected heat becomes the useful heat output?**
   A. Air Conditioner
   B. Chiller
   C. Heat Pump
   D. Evaporative Cooling System

4. **Lower kW/TR value of a refrigeration plant indicates:**
   A. Lower cooling capacity
   B. Lower efficiency
   C. Higher efficiency
   D. Higher power consumption

5. **Which control strategy adjusts ventilation based on occupancy levels?**
   A. On–off control
   B. Demand-controlled ventilation
   C. Time-based control
   D. Proportional control

6. **Which factor has the greatest influence on fan energy consumption in an air distribution system?**
   A. Duct insulation thickness
   B. Airflow rate
   C. Fan motor efficiency
   D. Operating voltage

7. **Pump power consumption in a hydronic system varies approximately with:**
   A. Speed
   B. Square of speed
   C. Cube of speed
   D. Inverse of speed

8. Which device automatically stops water flow through an idle coil in a variable-flow hydronic system?

A. Balancing valve
B. Pressure relief valve
C. Expansion tank
D. Automatic isolation valve

9. Which insulation material is most commonly used to prevent condensation on chilled water piping?

A. Brick lining
B. Elastomeric foam
C. Cement plaster
D. Gypsum board

10. Which low-energy comfort system can achieve overall efficiencies up to 90% by producing power, heating, and cooling simultaneously?

A. Trigeneration (CCHP)
B. Solar air-conditioning
C. Radiant cooling
D. Evaporative cooling

Section B: Short Answer Questions- 5 Nos

Q1. Explain any 5 Low Energy Comfort system.

Q2. What is a Heat recovery wheel and explain its working.

Q3. What is the purpose of automatic isolation valves and variable speed drives in variable-flow hydronic systems?

Q4. Explain working of a refrigeration cycle in an air conditioning system.

Q5. A water-cooled chiller plant serving a commercial building operates under the following conditions:

Chiller Data:

- Chilled water flow rate = 60,000 kg/hr
- Chilled water inlet temperature = 12°C
- Chilled water outlet temperature = 6°C
- Specific heat of water = 1 kcal/kg°C
- Electrical power input to chiller = 210 kW

Cooling Tower Data:

- Hot water inlet temperature to cooling tower = 40°C
- Cold water outlet temperature from cooling tower = 33°C
- Ambient wet bulb temperature = 28°C
- Circulating water flow rate = 1,000 m^3/hr
- Cycle of Concentration (COC) = 5

Calculate:

a) Actual cooling capacity of the chiller (TR)
b) Chiller efficiency in kW/TR
c) Cooling tower range
d) Cooling tower approach
e) Cooling tower effectiveness

Section C: Long Answer Questions – 2 Nos
Q1. Explain different types of ventilation systems used in buildings (natural and mechanical). Discuss their working principles, advantages, and energy conservation measures adopted in ventilation design
Q2. Explain the working of a cooling tower. Define range, approach, effectiveness, evaporation loss, and blowdown. Discuss energy and water conservation measures adopted in modern cooling towers

Answer Key for MCQs

1. D	6. B
2. C	7. C
3. C	8. D
4. C	9. B
5. B	10. A

Answer Key for SAQs

a) Actual cooling capacity of the chiller (TR) = 119.05 TR

b) Chiller efficiency in kW/TR = 1.76 kW/TR

c) Cooling tower range = 7°C

d) Cooling tower approach = 5°C

e) Cooling tower effectiveness = 58.3%

5. BUILDING LIGHTING SYSTEM

The growing emphasis on architectural quality, energy efficiency, and visual comfort has significantly increased the importance of well-designed lighting systems in buildings. Today, a wide range of advanced light sources and luminaires are available, driven by rapid technological developments in lighting design and control. However, this diversity also makes it challenging for designers to select the most appropriate solutions for specific building requirements.

An effective lighting system must be tailored to the function of the space, ensuring a balance between aesthetics, performance, and energy efficiency. Good lighting design is not generic; it requires integration with architectural elements, careful placement of fixtures, and consideration of user needs, task requirements, and occupancy patterns.

Lighting in buildings is typically achieved through a combination of **daylighting and artificial lighting,** where the required illumination levels depend on the type, duration, and precision of visual tasks. Therefore, understanding the characteristics of different lighting sources, luminaires, and design strategies is essential for creating comfortable, efficient, and adaptable lighting environments.

5.1 Basic parameters and terms in lighting system

Luminous flux (I): It is the total quantity of visible light emitted by a light source in all directions per second. The unit of luminous flux is Lumen (lm). It indicates how much light a bulb produces, showing the brightness of the lamp regardless of how much energy (watts) it consumes. In simple terms, lumens tell us how much light we get from a light source.

Illuminance (E): Illuminance is the amount of light that falls on a surface and is a fundamental indicator of whether a space has adequate lighting for visual tasks. It is measured in lux (lumens per square meter) using a lux meter and is used to evaluate the effectiveness of both daylighting and artificial lighting in providing comfortable and functional illumination.

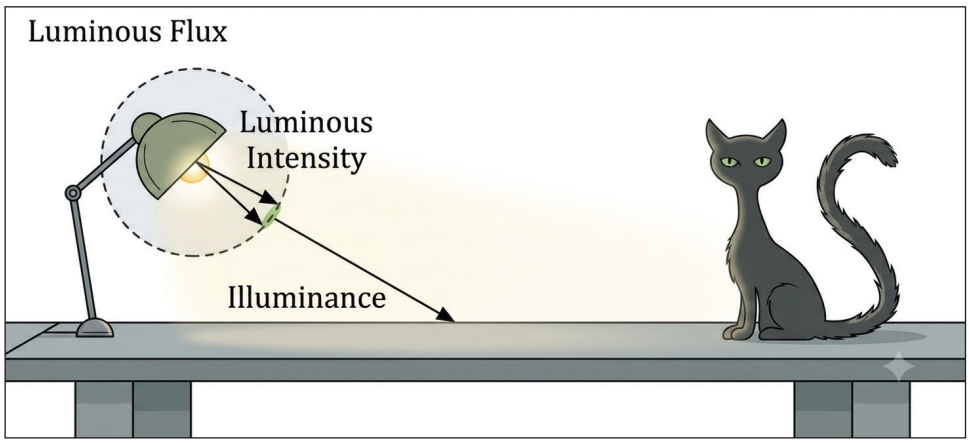


Figure 87 Luminous flux and Illuminance

The inverse square law: It defines the relationship between the illuminance from a point source and distance. It states that the intensity of light per unit area is inversely proportional to the square of the distance from the source (Essentially the radius).

The inverse square law: It defines the relationship between the illuminance from a point source and distance. It states that the intensity of light per unit area is inversely proportional to the square of the distance from the source (Essentially the radius).

$$E = \frac{I}{d^2}$$

Where,

E = Illuminance in lux (lm/m2)

I = Luminous intensity (I) is measured in candelas (cd)

d = distance from source in meters (m)

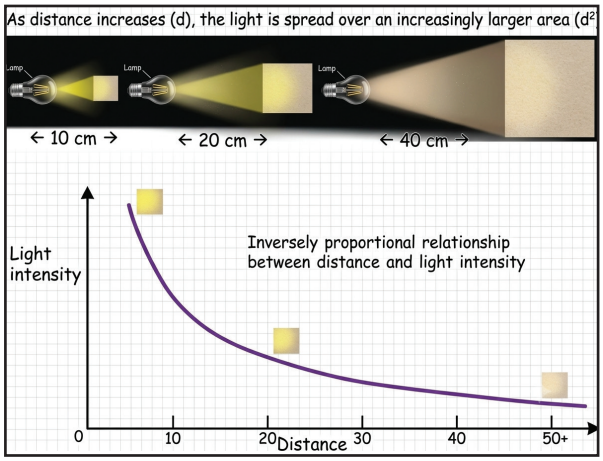


Figure 88 Illuminance v/s square of the distance from a light source

Glare: Glare refers to visual discomfort or reduced visibility caused by excessive brightness or high contrast within the field of view. It occurs when a light source—natural or artificial—is significantly brighter than the surrounding environment, leading to discomfort or impaired task performance.

Luminaire: Luminaire is the complete lighting unit that includes the lamp (light source) along with all other components like reflectors, ballasts, housings, and wiring. It is designed to safely connect to a power source, distribute light effectively, and control how the light spreads in a space. The efficiency and type of luminaire are key factors in meeting LPD requirements.

Lamp: A lamp is the primary light-emitting component of a lighting system. It is a device that produces visible light when powered, and includes sources such as incandescent bulbs, fluorescent tubes, and LED modules. The lamp is the core element responsible for generating illumination, while the luminaire houses and supports it.

Luminous efficacy (lm/W): Luminous efficacy is a measure of how efficiently a lamp converts the electrical energy it consumes into visible light. It is calculated as the ratio of the light output (luminous flux in lumens) to the electrical power input (in watts). Higher luminous efficacy means the lamp produces more light using less energy, indicating better efficiency.

Color-Rendering Index (CRI): The CRI is a measure of how naturally and accurately a light source shows the colors of objects compared to natural sunlight. A higher CRI means colors look truer and more vibrant, while a lower CRI makes colors appear dull or distorted.

Correlated color temperature (CCT): The CCT is a measure of the colour of light emitted by a source, expressed in Kelvins (K). It indicates whether the light appears warm (yellowish) or cool (bluish white) and is

used to create desired ambiance and mood in a space. The CCT is based on the colour a black body would emit if heated to the same temperature as the light source.

5.2 Daylighting

Daylighting refers to the controlled use of natural light to illuminate indoor spaces, reducing dependence on artificial lighting and enhancing visual comfort. It plays a crucial role in improving energy efficiency, occupant well-being, and overall building performance.

Since daylighting has already been discussed in detail in Chapter 3, this section briefly acknowledges its importance as a complementary component of building lighting systems. In practice, effective lighting design integrates daylight with artificial lighting through appropriate building orientation, window design, shading devices, and control strategies.

A well-balanced approach ensures adequate illumination levels while minimizing glare, heat gain, and energy consumption, thereby creating comfortable and sustainable indoor environments.

5.3 Artificial Lighting

Artificial lighting refers to the use of electric light sources to provide illumination within buildings, ensuring adequate visibility and functionality in the absence of or in supplement to daylight. It is a critical component of building design, enabling occupants to perform visual tasks efficiently regardless of time of day or external conditions.

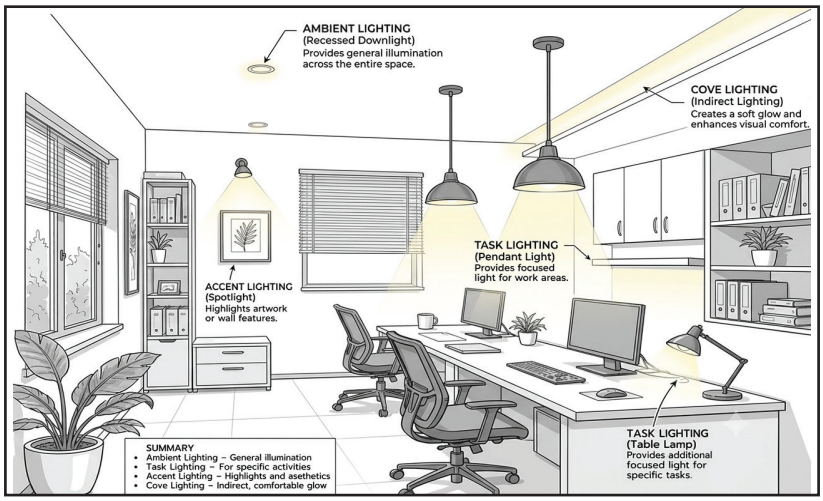


Figure 89 Type of Artificial Lighting

Modern artificial lighting systems include a wide range of light sources, luminaires, and control strategies that can be tailored to specific applications. Effective design focuses on achieving appropriate illumination levels, visual comfort, and energy efficiency while minimizing glare and uneven lighting.

Artificial lighting is often integrated with daylighting through smart controls and zoning, allowing for optimized energy use and improved indoor environmental quality

5.4 Lighting Design

Ambient Lighting: Ambient lighting, also known as general lighting, is the primary source of illumination in a space. It provides a uniform, comfortable, and glare-free light environment, forming the base layer upon which all other lighting types (task and accent) are built. In addition to ensuring adequate visibility, ambient lighting plays a key role in establishing the overall mood and brightness of a room.

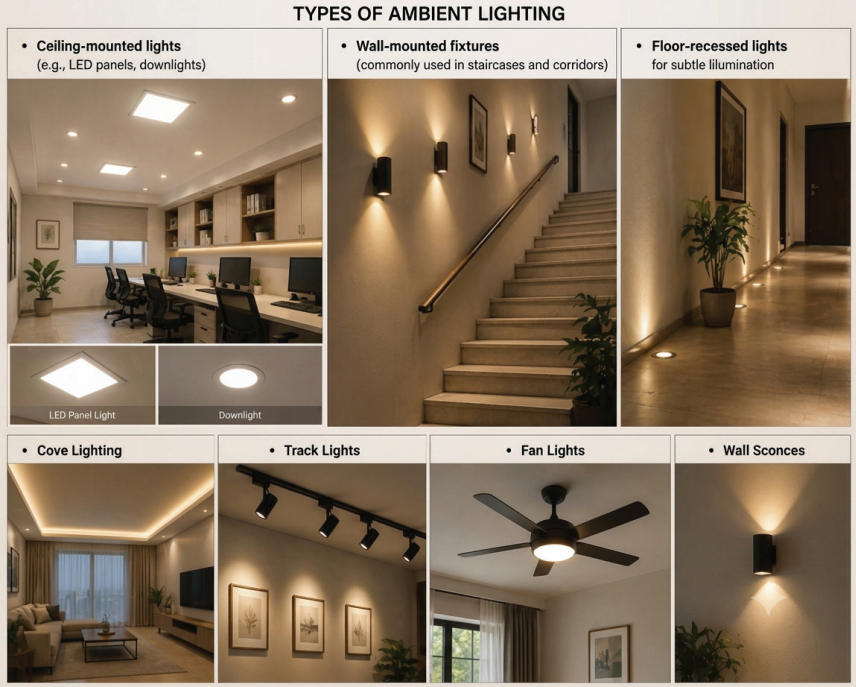


Figure 90 Type of Ambient Lighting Fixtures

The selection of ambient lighting depends on several factors, including:

- Size and layout of the room
- Availability of natural light (daylighting) and its contribution to indoor illumination A variety of fixtures can be used to achieve effective ambient lighting. These include:
- Ceiling-mounted lights (e.g., LED panels, downlights)
- Wall-mounted fixtures (commonly used in staircases and corridors)
- Floor-recessed lights for subtle illumination
- Cove lighting, track lights, fan lights, and wall sconces

These fixtures are typically designed to provide a wide and uniform beam distribution, ensuring consistent illumination across the space without harsh shadows or glare

Task Lighting: Task lighting refers to supplementary lighting provided in addition to ambient lighting to meet the requirements of specific visual tasks or work areas. It is designed to deliver focused and higher illumination levels exactly where needed, improving visibility, accuracy, and visual comfort.

It is important to note that different tasks require different illumination levels. For example, reading, writing, or computer work in an office may require localized lighting through desk-mounted luminaires or ceiling fixtures aligned with workstations, ensuring that only the task area is illuminated without affecting the entire space.

- Provides localized, focused illumination
- Enhances task performance and reduces eye strain
- Works in conjunction with ambient lighting
- Designed to avoid glare and shadows in the task area



Figure 91 Type of Task Lighting

Accent Lighting: Accent lighting is used to highlight specific objects, features, or areas within a space, making them visually prominent and creating focal points. Typically, accent lighting is brighter than ambient lighting (often up to three times) to effectively draw attention and enhance contrast.

It is commonly used to emphasize elements such as artwork, sculptures, planters, furnishings, or architectural details, adding depth, style, and visual drama to the space. Because of its focused nature, adjustable fixtures are preferred, allowing precise direction and control of light onto small or specific areas.

Accent lighting is especially effective in spaces like living rooms, entrances, gardens, and display areas, where highlighting design features is important. In addition to aesthetics, it also provides visual relief by reducing eye fatigue during prolonged tasks, creating a more comfortable visual environment.



Figure 92 Usage of Accent Lighting

5.5 Lighting Power Density

Lighting power density (LPD) is a key metric used to evaluate the energy efficiency of a building's lighting system influenced by multiple design factors, including the efficacy of light sources, type and efficiency of

luminaires, layout and spacing of fixtures, mounting height, use of reflectors or diffusers, and overall lighting design strategy. It is expressed in watts per square meter (W/m^2). Lower LPD values indicate a more energy-efficient lighting design achieved by using less electricity per unit of area.

Lighting power compliance applies to interior lighting systems and exterior lighting systems supplied by the building electrical service and must be calculated in accordance with the requirements specified for luminaires and associated equipment. ECSBC 2024 allows two compliance methods for determining the allowable interior lighting power

1) Building Area Method

2) Space Function Method

Building Area Method

The building area method is a simplified approach that establishes the lighting power allowance based on the overall function of building areas. In this method, the gross illuminated floor area is multiplied by the allowable lighting power density in W/m2 for a particular building area type to determine the maximum allowable lighting power installed.

$$P_{allowed} = A_{gross} \text{ X } LPD_{limit}$$

Where,

$P_{allowed}$ = Maximum allowable lighting power (W)

A_{gross} = Gross illuminated floor area (m2)

$LPD_{allowed}$ = Allowed lighting power density (W/m^2)

This method is suitable for projects with uniform space usage or where a quicker compliance approach is preferred.

Procedure:

1. Identify the applicable building area type.
2. Refer the following tables to determine the allowed LPD for each building area type:
   - o Table 28 for ECSBC 2024
   - o Table 29 for ECSBC Plus 2024
   - o Table 30 for Super ECSBC 2024
3. Calculate the gross illuminated floor area for each building area.
4. Multiply the gross illuminated area by the corresponding allowed LPD.
5. Add the lighting power allowances of all building areas to determine tshe total allowable interior lighting power.

Table 30 Interior lighting power for ECSBC buildings: building area method

Building Type	LPD (W/m2)	Building Area Type	LPD (W/m2)
Office Building	9.5	Motion picture theatre	**9.43**
Hospitals	9.7	Museum	**10.2**

Building Type	LPD (W/m2)	Building Area Type	LPD (W/m2)
Hotels	9.5	Post office	10.5
Shopping Mall	14.1	Religious building	12.0
University and Schools	11.2	Sports arena	9.7
Library	12.2	Transportation	9.2
Dining: bar lounge/leisure	12.2	Warehouse	7.08
Dining: cafeteria/fast food	11.5	Performing arts theatre	16.3
Dining: family	10.9	Police station	9.9
Dormitory	9.1	Workshop	14.1
Fire station	9.7	Automotive facility	9.0
Gymnasium	10.0	Convention center	12.5
Manufacturing facility	12.0	Parking garage	3.0
In cases where both a general building area type and a specific building area type are listed, the specific building area type shall apply.			

Table 31 Interior lighting power for ECSBC Plus buildings: building area method

Building Type	LPD (W/m^2)	Building Area Type	LPD (W/m^2)
Office Building	7.6	Motion picture theatre	7.5
Hospitals	7.8	Museum	8.2
Hotels	7.6	Post office	8.4
Shopping Mall	11.3	Religious building	9.6
University and Schools	9.0	Sports arena	7.8
Library	9.8	Transportation	7.4
Dining: bar lounge/leisure	9.8	Warehouse	5.7
Dining: cafeteria/fast food	9.2	Performing arts theatre	13.0
Dining: family	8.7	Police station	7.9
Dormitory	7.3	Workshop	11.3
Fire station	7.8	Automotive facility	7.2
Gymnasium	8.0	Convention center	10.0
Manufacturing facility	9.6	Parking garage	2.4
In cases where both a general building area type and a specific building area type are listed, the specific building area type shall apply.			

Table 32 Interior lighting power for Super ECSBC buildings: building area method

Building Type	LPD (W/m^2)	Building Area Type	LPD (W/m^2)
Office Building	5.0	Motion picture theatre	4.7
Hospitals	4.9	Museum	5.1
Hotels	4.8	Post office	5.3
Shopping Mall	7.0	Religious building	6.0
University and Schools	6.0	Sports arena	4.9
Library	6.1	Transportation	4.6

Building Type	LPD (W/m²)	Building Area Type	LPD (W/m²)
Dining: bar lounge/leisure	6.1	Warehouse	3.5
Dining: cafeteria/fast food	5.8	Performing arts theatre	8.2
Dining: family	5.5	Police station	5.0
Dormitory	4.6	Workshop	7.1
Fire station	4.9	Automotive facility	4.5
Gymnasium	5.0	Convention center	6.3
Manufacturing facility	6.0	Parking garage	1.5
In cases where both a general building area type and a specific building area type are listed, the specific building area type shall apply.			

Space Function Method

The space function method provides a more detailed and space-specific approach by assigning LPD limits based on the functional requirements of individual spaces rather than applying a single value to the entire building. This method recognizes that different spaces have varying lighting needs and therefore allows greater design flexibility which is recommended for buildings with diverse space functions and detailed lighting design requirements.

$$P_{i\ allawed} = A_i\ X\ LPD_i$$

Where,

$P_{i\ allowed}$ = Allowable lighting power for space i (W)

A_i = Area of Space i (m^2)

LPD_i = Prescribed LPD for that specific space type (W/m^2)

Procedure:

1. Design lighting layouts to meet lighting quantity and quality requirements as per IS 3646 (Part 1).
2. Identify the appropriate space type and corresponding allowed LPD from:
    - Table 31 for ECSBC buildings
    - Table 32 for ECSBC Plus buildings
    - Table 33 for Super ECSBC buildings

(Where both common and building-specific space types exist, the building-specific LPD shall apply)

3. Determine the gross-lighted floor area of each space enclosed by 80% partitions or greater than ceiling height by measuring to the centre of the partition wall.
    - Area of balconies and projections are included.
    - Retail spaces are exempted from the 80% partition height requirement.
4. Calculate the lighting power allowance for each space
5. Add allowances of all spaces to obtain the total allowable interior lighting power.

Table 33 Interior lighting power for ECSBC buildings: space function method

Building Type	LPD (W/m²)	Lamp category	LPD (W/m²)
Common Space Types			
Restroom	7.7	Stairway	5.5
Storage	6.8	Corridor/Transition	7.1
Conference/Meeting	11.5	Lobby	9.1
Parking Bays (covered/ basement)	2.2	Parking Driveways (covered/ basement)	3.0
Electrical/Mechanical	7.1	Workshop	17.1
Business			
Enclosed	10.0	Open Plan	10.0
Banking Activity Area	12.6	Service/Repair	6.8
Healthcare			
Emergency	22.8	Recovery	8.6
Exam/Treatment	13.7	Storage	5.5
Nurses' Station	9.4	Laundry/Washing	7.5
Operating Room	21.8	Lounge/Recreation	8.0
Patient Room	7.7	Medical Supply	13.7
Pharmacy	10.7	Nursery	5.7
Physical Therapy	9.7	Corridor/Transition	9.1
Radiology/Imaging	9.1		
Hospitality			
Hotel Dining	9.1	Hotel Lobby	10.9
For Bar Lounge/Dining	14.1	Motel Dining	9.1
For food preparation	12.1	Motel Guest Rooms	7.7
Hotel Guest Rooms	9.1		
Shopping Complex			
Mall Concourse	12.8	For Family Dining	10.9
Sales Area	18.3	For food preparation	12.1
Motion Picture Theatre	9.6	Bar Lounge/Dining	14.1
Educational			
Classroom/Lecture	13.7	Card File and Cataloguing	9.1
For Classrooms	13.8	Stacks (Lib)	18.3
Laboratory	15.1	Reading Area (Library)	10.0
Assembly			
Dressing Room	9.1	Seating Area – Performing Arts Theatre	22.6
Exhibit Space – Convention Centre	14.0	Lobby – Performing Arts Theatre	21.5
Seating – Gymnasium	4.6	Seating Area – Convention Centre	6.4
Fitness Area – Gymnasium	13.7	Seating ReligiousBuilding	16.4
Museum – General Exhibition	16.4	Playing Area – Gymnasium	18.8
Museum – Restoration	18.3		

Table 34 Interior lighting power for ECSBC Plus buildings: space function method

Building Type	LPD (W/m²)	Lamp category	LPD (W/m²)
Common Space Types			
Restroom	6.1	Stairway	4.4
Storage	5.4	Corridor/Transition	3.6
Conference/Meeting	9.2	Lobby	7.3
Parking Bays (covered/basement)	1.8	Parking Driveways (covered/ basement)	2.5
Electrical/Mechanical	5.7	Workshop	13.7
Business			
Enclosed	8.6	Open Plan	8.6
Banking Activity Area	9.3	Service/Repair	5.5
Healthcare			
Emergency	18.2	Recovery	7.0
Exam/Treatment	10.9	Storage	4.4
Nurses' Station	7.5	Laundry/Washing	6.0
Operating Room	17.5	Lounge/Recreation	6.4
Patient Room	6.1	Medical Supply	10.9
Pharmacy	8.5	Nursery	4.6
Physical Therapy	7.8	Corridor/Transition	7.3
Radiology/Imaging	7.3		
Hospitality			
Hotel Dining	7.3	Hotel Lobby	8.8
For Bar Lounge/Dining	11.3	Motel Dining	7.3
For food preparation	12.1	Motel Guest Rooms	6.1
Hotel Guest Rooms	7.3		
Shopping Complex			
Mall Concourse	10.2	For Family Dining	8.8
Sales Area	14.6	For food preparation	12.1
Motion Picture Theatre	10.3	Bar Lounge/Dining	11.3
Educational			
Classroom/Lecture	10.9	Card File and Cataloguing	7.3
For Classrooms	11.0	Stacks (Lib)	14.6
Laboratory	12.1	Reading Area (Library)	9.2
Assembly			
Dressing Room	7.3	Seating Area – Performing Arts Theatre	18.1
Exhibit Space – Convention Centre	11.2	Lobby – Performing Arts Theatre	17.2
Seating – Gymnasium	3.6	Seating Area – Convention Centre	5.1
Fitness Area – Gymnasium	7.9	Seating Religious Building	13.1
Museum – General Exhibition	11.3	Playing Area – Gymnasium	12.9
Museum – Restoration	11.0		

Table 35 Interior lighting power for Super ECSBC buildings: space function method

Building Type	LPD (W/m²)	Lamp category	LPD (W/m²)
Common Space Types			
Restroom	3.8	Stairway	2.7
Storage	3.4	Corridor/Transition	2.3
Conference/Meeting	5.7	Lobby	4.6
Parking Bays (covered/basement)	1.1	Parking Driveways (covered/ basement)	1.5
Electrical/Mechanical	3.5	Workshop	8.6
Business			
Enclosed	5.4	Open Plan	5.4
Banking Activity Area	5.8	Service/Repair	3.4
Healthcare			
Emergency	11.4	Recovery	4.4
Exam/Treatment	6.8	Storage	2.7
Nurses' Station	5.0	Laundry/Washing	3.8
Operating Room	10.9	Lounge/Recreation	4.6
Patient Room	3.8	Medical Supply	6.8
Pharmacy	5.3	Nursery	2.9
Physical Therapy	4.9	Corridor/Transition	4.6
Radiology/Imaging	4.6		
Hospitality			
Hotel Dining	4.6	Hotel Lobby	5.5
For Bar Lounge/Dining	7.0	Motel Dining	4.6
For food preparation	7.5	Motel Guest Rooms	3.8
Hotel Guest Rooms	4.6		
Shopping Complex			
Mall Concourse	6.4	For Family Dining	5.5
Sales Area	9.2	For food preparation	7.5
Motion Picture Theatre	6.5	Bar Lounge/Dining	7.0
Educational			
Classroom/Lecture	6.8	Card File and Cataloguing	4.6
For Classrooms	6.9	Stacks (Lib)	9.2
Laboratory	7.5	Reading Area (Library)	5.7
Assembly			
Dressing Room	4.6	Seating Area – Performing Arts Theatre	11.3
Exhibit Space – Convention Centre	7.0	Lobby – Performing Arts Theatre	10.8
Seating – Gymnasium	3.4	Seating Area – Convention Centre	3.2
Fitness Area – Gymnasium	3.9	Seating Religious Building	8.2
Museum– General Exhibition	5.7	Playing Area – Gymnasium	6.5
Museum – Restoration	5.5		

Exemptions from Interior Lighting Power Allowance

The installed interior lighting power for a building or a separately metered or permitted portion of a building shall not exceed the interior lighting power allowance determined in accordance with the building area method or space function method. Certain lighting applications are excluded from the interior lighting power allowance unless it is an addition to general lighting and is controlled by an independent control device. Exempted applications include (but are not limited to):

- Display or accent lighting in museums, galleries, and monuments
- Lighting integral to equipment, instrumentation, or medical systems
- Lighting for food warming/ food preparation and plant growth lighting
- Lighting for visually impaired users
- Retail display window lighting enclosed by full-height partitions
- Lighting in registered historic interior spaces
- Lighting for advertising and directional signage
- Exit signage
- Lighting for sale or educational demonstration
- Theatrical, stage, and film production lighting
- Lighting for athletic playing areas with permanent broadcast facilities

For calculating installed interior lighting power, the wattage of lighting equipment shall be determined based on the type of luminaire and its method of connection. Luminaires connected directly to the supply voltage shall be the manufacturer's-labelled-rated wattage. Where lighting equipment operates with remote ballasts, drivers, or similar auxiliary devices, the total input wattage of all associated components and accessories forming part of the lighting system shall be included.

For luminaire types not covered under the mentioned categories, the rated wattage marked on the luminaire or its packaging shall be used. In the case of lighting track systems, plug-in bus-ways, or flexible lighting systems that permit addition or relocation of luminaires without modifying the wiring, the assigned wattage shall be taken as the higher of the combined specified wattage of the connected luminaires or 135 W per metre of the lighting system length as per ECSBC 2024. Where such systems include integral overload protection, the wattage shall be based on 100% of the maximum rated capacity of the limiting device.

Exemptions from Exterior Lighting Power Limits

The connected lighting power of exterior lighting applications shall not exceed the lighting power limits specified in Table 7.1 for ECSBC buildings, Table 7.2 for ECSBC Plus buildings, and Table 7.3 for Super ECSBC buildings. Exterior lighting exemptions include:

- Lighting integral to equipment or instrumentation
- Theatrical and film production lighting
- Temporary, non-permanent lighting

- Industrial lighting with glare-control devices
- Lighting for monuments of national importance, flags, or statues

External luminaires (excluding lighting chains or direct view luminaires) emitting white light with CCT (correlated colour temperature) ranging from 2700–6500 K for all exterior applications (except decorative/ architectural) shall have efficacy not less than 100 lumens per watt, 110 lumens per watt, and 120 lumens per watt for ECSBC, ECSBC Plus, and Super ECSBC buildings, respectively.

The ECSBC specifies allowable exterior lighting power limits separately. These limits are defined for individual exterior lighting applications such as building façades, entrances and exits, parking areas, pathways, canopies, and other outdoor lighting categories. Trade-offs between different exterior lighting applications are not permitted, meaning each application must independently comply with its prescribed power limit.

The following tables from the ECSBC 2024 Manual present the maximum allowable exterior lighting power limits for different building performance levels. Designers must ensure that the connected load of each exterior lighting application does not exceed the corresponding limits specified in these tables.

Table 36 Exterior building lighting power for ECSBC buildings

Exterior lighting application	Power limits
Building entrance (with canopy)	10 W/m2 of canopied area
Building entrance (w/o canopy)	90 W/linear m of door width
Building exit	60 W/lin m of door width
Building façade	5.0 W/m^2 of vertical façade area
Emergency signs, ATM kiosks, Security areas façade	1.0 W/m^2
Driveways and parking (open/external)	1.6 W/m^2
Pedestrian walkways	2.0 W/m^2
Stairways	10.0 W/m^2
Landscaping	0.5 W/m^2
Outdoor sales area	9.0 W/m^2

Table 37 Exterior building lighting power for ECSBC Plus buildings

Exterior lighting application	Power limits
Building entrance (with canopy)	8.0 W/m2 of canopied area
Building entrance (w/o canopy)	72 W/linear m of door width
Building exit	48 W/lin m of door width
Building façade	4.0 W/m^2 of vertical façade area
Emergency signs, ATM kiosks, Security areas façade	0.8 W/m^2
Driveways and parking (open/external)	1.3 W/m^2
Pedestrian walkways	1.6 W/m^2
Stairways	8.0 W/m^2
Landscaping	0.4 W/m^2
Outdoor sales area	7.2 W/m^2

Table 38 Exterior building lighting power for Super ECSBC buildings

Exterior lighting application	Power limits
Building entrance (with canopy)	5.0 W/m^2 of canopied area
Building entrance (w/o canopy)	45 W/linear m of door width
Building exit	30 W/lin m of door width
Building façade	2.5 W/m^2 of vertical façade area
Emergency signs, ATM kiosks, Security areas façade	0.5 W/m^2
Driveways and parking (open/external)	0.8 W/m^2
Pedestrian walkways	1.0 W/m^2
Stairways	5.0 W/m^2
Landscaping	0.25 W/m^2
Outdoor sales area	4.5 W/m^2

5.6 Lighting Control

Lighting systems account for a significant share of a building's electricity consumption. Effective lighting controls are therefore a critical strategy for reducing energy use while maintaining visual comfort and operational efficiency. The primary function of lighting controls is to ensure that luminaires operate only when required and at appropriate light output levels, either by switching them off when spaces are unoccupied or by modulating light output based on occupancy and daylight availability.

Lighting control can be done at two levels in a building system.

1) Interior Lighting Control

2) Exterior Lighting Control

Interior lighting controls

Interior lighting controls are essential for improving energy efficiency, visual comfort, and operational flexibility in buildings. They ensure that lighting is used only when and where required, reducing unnecessary energy consumption while maintaining appropriate illumination levels. Modern control strategies integrate automation, sensors, and user-based controls to optimize lighting performance

Automatic lighting shutoff: Automatic light shut-off ensures that lights are turned OFF when not needed, reducing unnecessary energy consumption, hence, ECSBC 2024 requires that at least 90% of all interior lighting fixtures by wattage be equipped with automatic shutoff controls. These controls must function through either:

- **Scheduled controls** - Scheduled control operates on a time-based automation system, where lights are programmed to switch OFF (or ON) according to predefined schedules, such as after office hours. It is typically managed through centralized systems like timers or a Building Management System (BMS), allowing coordinated control across multiple spaces. This approach is especially suitable for areas with predictable occupancy patterns, ensuring energy savings without affecting functionality.

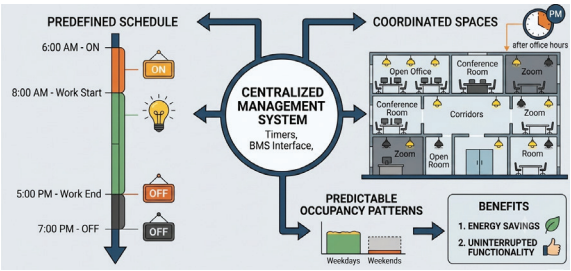


Figure 93 Scheduled control

- **Occupancy sensors –** Occupancy sensors automatically control lighting based on the presence or absence of people in a space. They operate by turning lights ON when occupancy is detected and switching them OFF or reducing the lighting output by at least 80% within 15 minutes when no movement is sensed. These systems use technologies such as Passive Infrared (PIR), ultrasonic, or dual-technology sensors to accurately detect occupancy. In addition to automated control, all luminaires connected to occupancy sensors are typically provided with wall- mounted manual switches, allowing users to turn lights ON or OFF as needed when the space is occupied. This combination of automatic and manual control eliminates dependency on constant user intervention, making it ideal for intermittently used spaces like corridors, restrooms, and meeting rooms. Overall, occupancy-based systems significantly enhance energy efficiency while maintaining user comfort and operational flexibility.



Figure 94 Occupancy Sensor

Note: Exceptions for automatic lighting shutoff apply to lighting that must operate continuously, lighting used in patient care areas, and lighting in spaces where it could affect safety or security.

Space control: Space control refers to the provision of independent lighting control within enclosed spaces, ensuring that lighting can be operated based on occupancy and user requirements. As per the requirements, each space enclosed by ceiling-height partitions must have at least one control device to independently manage general lighting. This control can be manual (switches/dimmers) or automatic (occupancy-based sensors). Each control device is designed to manage a maximum area of 250 m^2 for spaces up to 1,000 m^2, and 1,000 m^2 for larger spaces, ensuring effective zoning and control.

For offices larger than 30 m^2, additional zoning requirements apply: general lighting must be divided into control zones of not more than 60 m^2. These zones may automatically switch ON to full power upon occupancy, while lighting in other unoccupied zones can operate at not more than 20% of full power. Furthermore, no more than 50% of the total general lighting load may be automatically turned ON through scheduled controls, and the remaining lighting should not exceed 20% output when unoccupied. The system must also allow occupants to override automatic shut-off controls for up to 2 hours, and all control devices should be readily accessible and visible to users.

In addition, occupancy sensors are mandatory in specific spaces to enhance automation and energy savings. These include habitable spaces smaller than 30 m^2, storage or utility areas larger than 15 m^2, public toilets exceeding 25 m^2 (controlling at least 80% of lighting load), hospitality corridors (controlling 70–80% of lighting load), and all conference or meeting rooms. In cases where safety or security concerns prevent local installation, control devices may be installed remotely, provided they include a clearly labeled pilot indicator for user awareness.

Overall, space control ensures efficient lighting operation through zoning, automation, and user accessibility, leading to improved energy performance, flexibility, and compliance with building energy codes

Daylight Based Control: Daylight-based controls regulate artificial lighting based on the availability of natural daylight, ensuring efficient utilization of both light sources. Daylight sensors, a key component of this system, automatically dim or switch off electric lighting when sufficient daylight is available, thereby maintaining the required illumination levels for visual tasks. This approach significantly reduces dependence on artificial lighting, leading to energy savings and improved visual comfort by creating a more balanced and natural indoor lighting environment.

Luminaires installed within the daylight zone (as defined in Section 5.2.3 of ECSBC 2024) must be provided with appropriate controls. These can be either:

- A manual control device that allows users to switch off luminaires during periods of adequate daylight, or
- An automatic control device that operates based on daylight availability.

Automatic daylight controls must meet the following criteria:

- Incorporate a minimum time delay of 5 minutes to prevent frequent switching, and
- Be capable of switching off the luminaires or dimming/stepping down lighting levels to 10% or less of full power.

Additionally, when automatic daylight-responsive controls are installed, manual override is not permitted, ensuring that the system operates efficiently without user interference.

Overall, daylight-based controls are essential for integrating natural light with artificial lighting systems, enhancing energy efficiency, occupant comfort, and compliance with building energy codes.

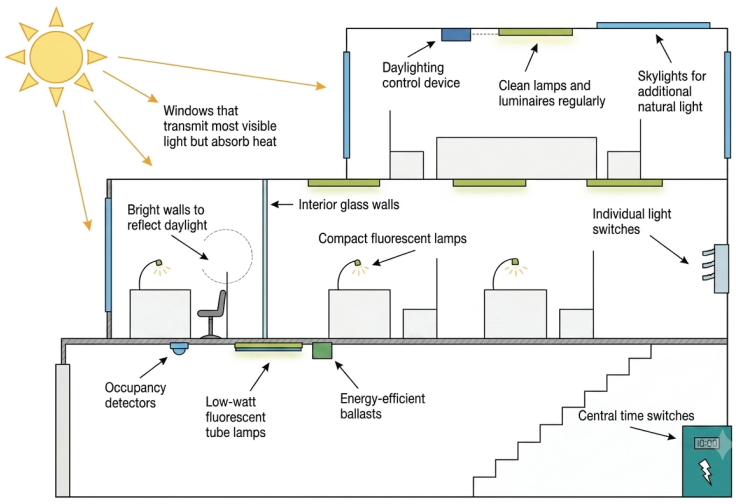


Figure 95 Daylight Based Lighting control for Interior Spaces

Exterior Lighting Controls

Exterior lighting control is essential for ensuring that outdoor lighting systems operate efficiently, safely, and only when required. These controls are designed to automatically regulate lighting based on daylight availability and time schedules, thereby minimizing energy wastage while maintaining adequate illumination for security, safety, and aesthetic purposes.

As per the requirements, all exterior lighting applications must be controlled using either a photosensor or an astronomical time control system. A photosensor detects the level of natural light and automatically switches OFF the exterior lighting when sufficient daylight is available. Alternatively, an astronomical time switch operates based on sunrise and sunset timings, ensuring that lighting is turned OFF during the day and ON only during required hours.

In addition, façade lighting and non-emergency façade signage lighting must be provided with separate time controls. This ensures that decorative or display lighting is operated independently and can be switched OFF during late hours when not needed, contributing to further energy savings.

It is important to note that exterior lighting systems designed for emergency and firefighting purposes are exempted from these control requirements, as they must remain operational at all times for safety reasons.

Overall, exterior lighting controls enhance energy efficiency, operational effectiveness, and compliance with building energy codes, while also supporting safety and visual requirements of outdoor spaces

5.7 Common Energy Savings Measures

Reducing lighting levels

Lighting level for a particular space depends on the tasks to be performed in the space and other visual requirements for the space. Generally, higher lighting levels lead to higher lighting energy consumption. Therefore, lighting levels shall be minimized and maintained based on the recommended values. For new installations, this can be achieved through good lighting design by optimizing factors such as lamp wattage, number of lamps, and spacing between lamps.

Use of energy-efficient lamps: The amount of light emitted by a lamp per unit of electrical power consumed is the luminous efficacy of a lamp. The higher the efficacy, the better the efficiency of the lamp. Since different types of lamps have different efficacy, lamps with low efficacy can be replaced with those having higher efficacy.

Use of task lighting: In many buildings/spaces, general lighting is provided uniformly at a higher level so that the required lighting level can be achieved on the work surfaces. However, since the quantity of light is inversely proportional to the square of the distance from the light source (inverse square law), a more intense lighting level is required for general lighting compared to task lighting to achieve the same lighting level at the working plane. In general lighting applications, energy savings can be achieved by installing the lighting fixtures in ceiling, directly over the work area.



Figure 96 Task Lighting

Lighting controls: Energy consumed by lighting can further be reduced by minimizing their usage and providing lighting controls. Various systems such as timers, occupancy sensors, and daylighting sensors can be installed to control lighting operations.

Optimized lighting power density (LPD) compliance: Designing lighting systems to strictly meet or perform better than the prescribed LPD limits encourages the use of efficient luminaires, optimal layouts, and appropriate spacing. This ensures that lighting energy consumption is minimized without compromising visual comfort or task requirements.

Integration of daylighting with lighting design: Effective integration of daylight with artificial lighting through proper building orientation, fenestration design, and daylight-responsive controls reduces reliance on electric lighting during daytime hours. Coordinated daylight and lighting design helps lower both lighting and cooling energy demand while maintaining visual comfort.

The ECSBC 2024 guidebook emphasizes an integrated approach to lighting design that balances visual comfort, energy efficiency, and operational effectiveness. By strengthening requirements for daylighting, artificial lighting performance, lighting power density, and advanced control strategies, the code moves beyond prescriptive limits toward performance-driven design. The inclusion of realistic daylight metrics such as UDI, refined LPD compliance methods, detailed control requirements, and differentiated pathways for ECSBC, ECSBC Plus, and Super ECSBC buildings encourages early-stage design integration and informed decision-making. Overall, ECSBC 2024 positions lighting as a key lever for reducing building energy consumption while enhancing occupants' comfort, productivity, and overall building performance.

Overall, while IoT provisions in ECSBC are not mandatory, they represent a forward-looking approach toward smart buildings. By adopting IoT-enabled controls, buildings can transition from static operation to dynamic, responsive systems that optimize performance, reduce energy consumption, and enhance occupant experience.

Controls and Internet of Things: The ECSBC 2024 recognizes the role of Controls and Internet of Things (IoT) in enhancing the performance and energy efficiency of lighting systems. Through the integration of sensors, controllers, communication networks, and software platforms, IoT-enabled lighting systems can support automated operation, real-time monitoring, and data-driven energy management.

In lighting applications, IoT facilitates the implementation of advanced lighting controls such as occupancy-based switching, daylight-responsive dimming, scheduling, and centralized monitoring. These controls help reduce unnecessary energy consumption while maintaining occupant comfort and visual quality.

ECSBC requires lighting controls to be provided in accordance with the building type and compliance level. Lighting Management Systems (LMS) can be used to monitor lighting energy use, control lighting zones, and track system performance. At higher levels of compliance, networked lighting controllers can be integrated into centralized platforms, enabling remote monitoring, data analytics, fault detection, and optimization of lighting operation.

The code also encourages the use of occupancy sensors and daylight sensors to automatically adjust lighting levels based on space utilization and available natural light. Such intelligent control strategies contribute to energy savings and support the development of smart, responsive building environments.

While IoT provisions for lighting are not mandatory under ECSBC, their adoption provides a pathway toward improved energy performance, operational efficiency, and enhanced occupant experience through intelligent lighting management

Smart Homes: ENS 2024 recognizes the growing importance of smart homes as an integral part of the evolving energy and technology landscape. smart homes play a crucial role in supporting demand response programs, helping utilities balance electricity demand and supply including share of renewable energy in the grid. Although the provisions related to smart homes are included in Annexure 6 of ENS 2024 it is not a mandatory requirement.

ENS 2024 also outlines the **minimum functional requirements** for smart homes to ensure a basic level of performance and user experience. These include essential monitoring devices (such as energy meters, temperature and occupancy sensors), controllable appliances (like ACs, geysers, and lighting systems), a unified user interface for interaction, and the ability to participate in grid-based demand response programs. Additionally, provisions for data sharing—such as periodic reporting of energy consumption patterns—are included to support broader energy management goals. The code emphasizes that all smart home components must adhere to standards of data privacy, cybersecurity, interoperability, safety, and energy efficiency

Questions for Building Lighting System

Section A: Objective Questions (MCQs) – 10 Nos

1. The primary objective of lighting provisions in ECSBC 2024 is to:

A. Maximize illumination levels
B. Reduce lighting fixtures count
C. Reduce energy consumption while ensuring visual comfort
D. Eliminate daylighting requirements

2. As per ECSBC 2024, lighting design must comply with which Indian Standard for illuminance and lighting quality?

A. IS 732
B. IS 456
C. IS 3646 (Part 1)
D. IS 875

3. Illuminance is measured in:

A. Lumens
B. Lux
C. Candela
D. Watts

4. Which metric represents the total visible light emitted by a lamp in all directions?

A. Lux
B. Candela
C. Lumen
D. CCT

5. As per ECSBC 2024, at least of interior lighting (by wattage) must have automatic shut-off controls.

A. 50%
B. 75%
C. 80%
D. 90%

6. In daylight zones, automatic daylight-responsive controls must be capable of dimming lighting to:

A. 50% of full power
B. 30% of full power
C. 20% of full power
D. 10% of full power

7. Which lighting control automatically adjusts switching times based on sunrise and sunset?

A. Occupancy sensor
B. Manual dimmer
C. Astronomical time control
D. Photo sensor

8. Which of the following lighting applications is exempted from Interior Lighting Power Allowance calculations under ECSBC 2024?

A. Office general lighting
B. Corridor lighting
C. Exit signage
D. Conference room lighting

9. External luminaires emitting white light for ECSBC buildings must have a minimum efficacy of:

A. 80 lm/W
B. 90 lm/W
C. 100 lm/W
D. 120 lm/W

10. Which lighting system is classified as non-visual lighting?

A. Office task lighting
B. Emergency exit lighting
C. Plant growth lighting
D. Corridor lighting

Section B: Short Answer Questions – 5 Nos

1. Define Lighting Power Density (LPD) and explain its significance in ECSBC compliance.
2. Differentiate between lumen, lux, with one practical example for each.
3. Write a short note on lighting design approach.
4. List any four spaces where occupancy sensors are mandatory under ECSBC 2024.
5. Explain the purpose of separate controls for non-visual lighting systems.

Section C: Long Answer Questions – 2 Nos

Q1. Describe the complete lighting design approach for a commercial building in compliance with ECSBC 2024.

Q2. Explain the design and implementation of lighting control systems in buildings to achieve ECSBC 2024, ECSBC Plus, and Super ECSBC compliance.

Answer Key for MCQs

1. C	6. D
2. C	7. C
3. B	8. C
4. C	9. C
5. D	10. C

6. BUILDING ELECTRICAL SYSTEM

Building electrical systems play a critical role in ensuring safe, reliable, and energy-efficient operation of modern buildings. As buildings become more technology-intensive and comfort expectations rise, optimizing electrical systems is essential to reduce energy demand, peak loads, operating costs, and associated greenhouse gas emissions.

A comprehensive building electrical system encompasses power generation (backup systems), power conditioning, power distribution, end-use equipment, and performance monitoring. Inefficiencies at any stage—such as low-power factor, oversized motors, high transformer losses, poor distribution design, or unmanaged plug loads—can lead to significant energy losses and increased stress on the grid. Studies indicate that electrical energy in buildings can be saved through efficient electrical system design, proper equipment selection, and effective monitoring and control strategies.

6.1 Power Distribution System

A power distribution system in a building is the integrated network that receives electrical power from the utility or on-site generation source and safely distributes it to various end-use loads such as lighting, heating, ventilation, and air-conditioning (HVAC) equipment, elevators, pumps, plug loads, data systems and life-safety services. It typically includes transformers, switchgear, bus ducts, line and cables, load-break switches, capacitors, distribution boards, and metering infrastructure.

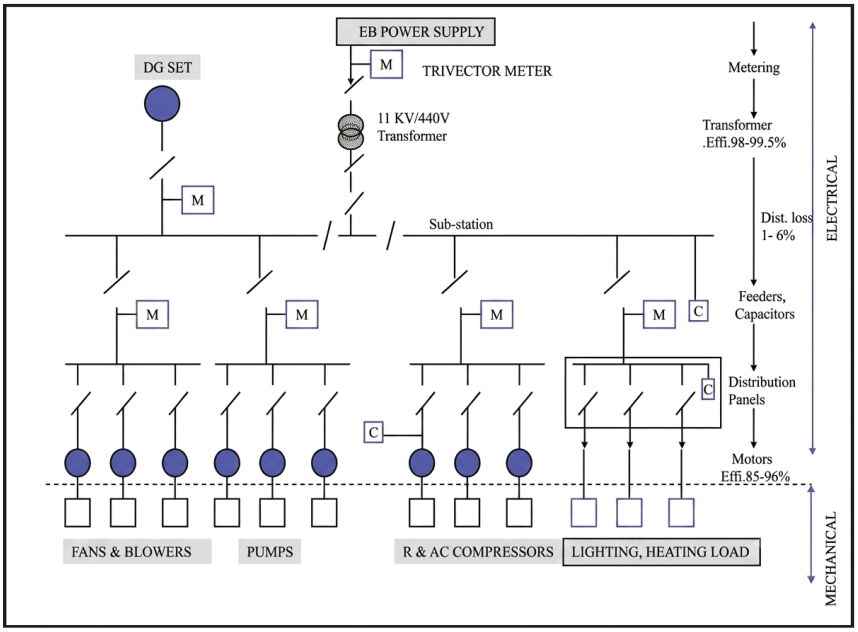


Figure 97 Electrical distribution system: SLD

An efficient and well-designed power distribution system is critical not only for operational safety and reliability but also for minimizing electrical losses and supporting overall building energy performance.

Distribution Losses in Electrical system

Losses in the power distribution **system** occur due to resistance in conductors, transformers, and switching equipment, as well as due to poor power quality, unbalanced loads, and low-power factor. The optimization of such losses is necessary and can be achieved via adopting the following strategies:

1) Relocating transformers and sub-stations near to load centres

2) Re-routing and re-conducting such feeders and lines where the losses/voltage drops are higher

3) Power factor improvement by incorporating capacitors at load end

4) Optimum loading of transformers in the system

5) Opting for lower resistance all aluminum alloy conductors (AAAC) in place of conventional aluminum cored steel reinforced (ACSR) lines

6) Minimizing losses due to weak links in distribution network such as jumpers, losses contracts and old brittle conductors. ((BEE)., Energy efficiency in electrical utilities (Book 3). 4th ed., 2015)

Table 39 Losses in electrical distribution equipment

S.No	Equipment Type	Building Area Type	LPD (W/m²)
		Minimum (%)	Maximum (%)
1	Outdoor circuit breaker (15 to 230 KV)	0.002	0.015
2	Generators	0.019	3.5
3	Medium voltage switchgears (5 to 15 KV)	0.005	0.02
4	Current limiting reactors	0.09	0.3
5	Transformers	0.4	1.9
6	Load break switches	0.003	0.025
7	Medium voltage starters	0.02	0.15
8	Bus ways less than 430 V	0.05	0.5
9	Low voltage switchgear	0.13	0.34
10	Motor control centers	0.01	0.4
11	Cables	1	4
12	Large rectifiers	3	9
13	Static variable speed drives	6	15
14	Capacitors (Watts / kVAr)	0.5	6

To ensure efficient delivery of electrical energy and to minimize technical losses within the building electrical distribution system, power cabling shall be designed and sized to limit distribution losses in accordance with the ECSBC compliance level. Proper conductor sizing reduces I^2R losses, improves voltage regulation, and enhances overall system efficiency

As per the ECSBC Code,

a) the total power losses in the building power distribution system, attributable to cables from the point of supply up to the final distribution panels, shall not exceed the following limits:
   - 3% of the total power usage in ECSBC-compliant buildings
   - 2% of the total power usage in ECSBC Plus-compliant buildings
   - 1% of total power usage in ECSBC Super-compliant buildings

b) Voltage drop for any feeders shall be maximum 2% at design load. Voltage drop for any branch circuit shall be maximum 3% at design load.

Design calculations for the losses shall be recorded and maintained. Load calculation shall be calculated up to the panel level.

As per the ENS 2024 code, for the residential sector,

a) The power cabling shall be sized so that the distribution losses shall not exceed 3% of the total power usage of the building. A record of design calculation for the losses with possible effects of harmonics shall be maintained and the load calculation up to the panel level shall be documented.

b) Voltage drop for feeders shall not exceed 2% at design load. Voltage drop for branch circuits shall not exceed 3% at design load.

c) The conductor used for fixed wiring shall be of class 2 as per IS 8130

6.2 Power Quality

Power quality refers to the degree to which the electrical power supplied to a building is stable, clean, and within prescribed limits of voltage, frequency, and waveform, ensuring proper and reliable operation of electrical equipment. Good power quality is essential for modern buildings where sensitive electronic equipment, variable-speed drives, IT systems, and automated controls are widely used. Poor power quality can lead to equipment malfunction, reduced efficiency, increased losses, overheating, premature equipment failure, and disruption of building operations.

In buildings, power quality issues commonly arise due to voltage fluctuations, voltage sags and swells, harmonics, unbalanced loads, poor power factor, and transient disturbances caused by switching operations or non-linear loads such as uninterrupted power supply (UPS) systems, light-emitting diode (LED) drivers, and variable frequency drives. These disturbances increase current flow, cause additional losses in cables and transformers, and adversely affect the performance and lifespan of electrical and electronic equipment.

Harmonics

A harmonic is a component of frequency of the signal that is an integer multiple of the fundamental frequency. Harmonics voltage and currents are an electric power system, a result of non-linear electric loads. The harmonic current represents energy that cannot be used by any devices on the network. It will be therefore converted to heat and is wasted.

The common sources of harmonics include variable frequency drives (VFDs) used in HVAC systems, UPS systems, IT and office equipment, LED lighting with electronic drivers, elevators, and battery chargers. These harmonic currents flow through the electrical distribution system and can cause several adverse effects, including overheating of transformers and cables, increased electrical losses, nuisance tripping of protective devices, malfunction of sensitive equipment, and distortion of supply voltage. Excessive harmonics also reduce system efficiency and available capacity, directly affecting power quality and energy performance.

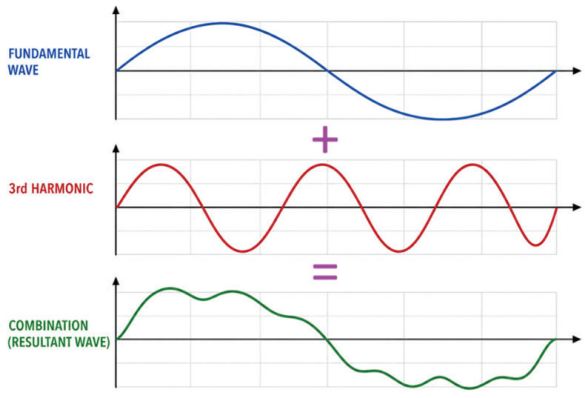


Figure 98 Harmonic Wave Pattern

Current distortion : Current harmonics could cause transformer heating or nuisance tripping by fuses, circuit breakers, and other protective devices since they are typically not rated for harmonically rich waveforms.

$$THD_{Current} = \sqrt{\sum_{n=2}^{n=n} \left(\frac{I_N}{I_1}\right)^2} \; X\ 100$$

Where,

I_1 = fundamental frequency current In = nth harmonic current component

Voltage Distortion: A distorted current has higher peak values that cause non-sinusoidal voltage drops across the distribution system. The resulting voltage drops add or subtract from the sinusoidal voltage supplied by the utility.

$$THD_{Voltage} = \sqrt{\sum_{n=2}^{n=n} \left(\frac{V_N}{V_1}\right)^2} \; X\ 100$$

Where,

V_1 = Fundamental frequency voltage

V_n = n^{th} harmonic voltage component

Table 40 Effects of harmonics

Observed problem/symptom	Underlying cause/power quality issue
Blinking of incandescent lights	Transformer saturation
Capacitor failure	Harmonic resonance
Circuit breakers tripping	Inductive heating and overload
Conductor failure	Inductive heating
Electronic equipment shutting down	Voltage distortion
Flickering of fluorescent lights	Transformer saturation
Fuses blowing for no apparent reason	Inductive heating and overload
Motor failures (overheating)	Voltage drop
Neutral conductor and terminal failures	Additive triplen currents
Electromagnetic load failures	Inductive heating
Overheating of metal enclosures	Inductive heating
Power interference on voice communication	Harmonic noise
Transformer failures	Inductive heating

Rectification of Harmonic in Power system

The harmonic mitigation can be done through the following methods:

1) Passive filters: Passive filters are the most used method for mitigating harmonic currents in power distribution systems. These filters are designed to present very low impedance at specific harmonic

frequencies, thereby providing a preferred path for harmonic currents. As a result, harmonic currents are diverted away from the main distribution network, reducing harmonic distortion in the system

2) Active filters: Active filters are connected in parallel with the power distribution system and operate by dynamically monitoring harmonic currents. They compensate for harmonics by injecting currents of equal magnitude but opposite phase to the detected harmonic components, effectively cancelling harmonic distortion and improving overall power quality.

3) Active front-end (AFE) rectifiers used in variable frequency drives (VFDs) offer significant advantages in harmonic mitigation without the need for external filters. These rectifiers enable near-unity power factor at the point of common coupling (PCC). The bidirectional power flow capability allows regenerative energy to be fed back to the mains instead of being dissipated, thereby improving overall system efficiency. Additionally, AFE rectifiers supply clean power to the grid without adversely affecting other connected loads and maintain a stable DC bus voltage irrespective of supply voltage variations.

Harmonics Limits

As per ECSBC 2024, maintaining good power quality is important not only for reliability and safety but also for achieving energy efficiency, as poor power quality results in hidden energy losses and oversized infrastructure.

Hence, it is necessary to limit harmonics as per below guidelines:

Voltage Distortion: At the main metering level of the building, utilities and/or distribution system operators shall limit line-to- neutral voltage harmonics as follows:

1. Daily 99th percentile very short time (3 sec.) values shall be less than 1.5 times the values given in below.
2. Weekly 95th percentile short time (10 min.) values shall be less than the values given in the table below.

Table 41 Prescribed requirements for individual and total harmonics

Bus voltage V at PCC	Individual harmonic (%) h ≤ 50	Total harmonic distortion THD (%)
V ≤ 1.0 kV	5.0	8.0
1 kV < V ≤ 69 kV	3.0	5.0
69 kV < V ≤ 161 kV	1.5	2.5
161 kV > V	1.0	1.5*

(ref. IEEE 519:2022)

Note: High-voltage systems are allowed to have up to 2.0% THD where the cause is an HVDC terminal whose effects are found to be attenuated at points in the network where future users may be connected.

Current distortion: The limits in this sub-clause shall be applicable to users connected to systems with the rated voltage at the PCC is from 120 V to above 161 kV. For individual non-linear load, these limits are not applicable. At the PCC, users shall limit their harmonic currents as specified:

1. Daily 99th percentile very short time (3 sec.) harmonic currents shall be less than 2.0 times the values given in the below tables of Current distortion limits for systems
2. Weekly 99th percentile short time (10 min.) harmonic currents shall be less than 1.5 times the value given in the below tables of Current distortion limits for systems
3. Weekly 95th percentile short time (10 min.) harmonic currents shall be less than the values given in in the below tables of Current distortion limits for systems.
4. Maximum allowable limit of current distortion for system design shall comply to below Table.

Table 42 Current distortion limits for systems rated 120 V through 69 kV

Maximum harmonic current distortion in percent of IL						
Individual harmonic order[2]						
ISC/IL	2 ≤ h < 11[3]	11 ≤ h < 17	17 ≤ h < 23	23 ≤ h <35	35 ≤ h ≤ 50	TDD
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>10004	15.0	7.0	6.0	2.5	1.4	20.0

ISC = Maximum short-circuit current at PCC

IL = Maximum demand load current at PCC under normal load operating conditions

Table 43 Current distortion limits for systems rated above 69 kV through 161 kV

Maximum harmonic current distortion in per cent of IL						
Individual harmonic order						
ISC/IL	2 ≤ h < 11	11 ≤ h < 17	17 ≤ h < 23	23 ≤ h <35	35 ≤ h ≤ 50	TDD
<20	2.0	1.0	0.75	0.3	0.15	2.5
20<50	3.5	1.75	1.25	0.5	0.25	4.0
50<100	5.0	2.25	2.0	0.75	0.35	6.0
100<1000	6.0	2.75	2.5	1.0	0.5	7.5
>1000	7.5	3.5	3.0	1.25	0.7	10.0

Table 44 Current distortion limits for systems rated > 161 kV

Maximum harmonic current distortion in percent of IL						
Individual harmonic order						
ISC/IL	2 ≤ h < 11	11 ≤ h < 17	17 ≤ h < 23	23 ≤ h <35	35 ≤ h ≤ 50	TDD
<25	1.0	0.5	0.38	0.15	0.1	1.5
25<50	2.0	1.0	0.75	0.3	0.15	2.5
≥5	3.0	1.5	1.15	0.45	0.22	3.75

Reference Standard: IEEE 519:202

6.3 Power Factor

Most commercial buildings are likely to have an overall load profile that is inductive. Both inductive and

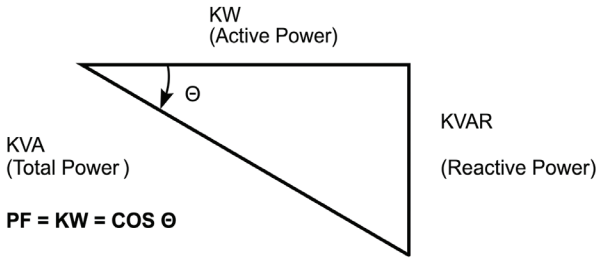


Figure 99 Power factor

capacitive loads are known as 'reactive loads' and, preferably, the goal should be to have almost zero-reactive currents (meaning that the current and voltage are in phase) at the point that the electrical supply enters the building.

Power factor is defined as ratio of active (real) power that performs useful work (measured in kilowatts, kW) to the apparent power supplied by the electrical system (measured in kilovolt-amperes, kVA). The vector sum of active power and reactive power make up the total power (apparent) power used. Power factor is a dimensionless quantity and varies between 0 and 1, where a value closer to 1 (unity power factor) indicates more efficient utilization of electrical power. It can be denoted by the formula:

$$Power\ Factor = \frac{ActivePower(kW)}{Apparent\ Power\ (kVA)}$$

$$Power\ Factor = \frac{Voltage\ x\ Current\ x\ Cos\theta}{Voltage\ x\ Current}$$

$$Power\ Factor = Cos\theta$$

Importance of Power Factor in Buildings

In building electrical systems, many common loads such as motors, transformers, lifts, escalators, air-conditioning equipment, and fluorescent/LED lighting with drivers are inductive in nature. These loads require both active power (to perform work) and reactive power (to establish magnetic fields). Reactive power does not perform useful work but increases current flow in the system, thereby lowering the power factor.

A low power factor leads to:

- Higher current draw for the same useful power
- Increased losses in cables and transformers
- Higher voltage drops
- Reduced capacity of electrical infrastructure
- Penalties from electricity distribution companies (DISCOMs)

Power Factor Improvement

To improve the power factor of an electrical system, it is necessary to add power factor correction capacitor. These capacitors act as reactive generators and provide the necessary reactive power to accomplish kW of work. This reduces the amount of reactive power and thus the power, generated by the utilities.

Automatic Power Factor Controller

An automatic power factor controller (APFC) is an intelligent electrical control device used to continuously monitor and maintain the power factor of an electrical system close to unity by automatically switching capacitor banks in response to varying load conditions. The APFC panels are installed at the main incomer or at major distribution points to dynamically compensate reactive power demand.

[2] Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed
[3] For h ≤ 6, even harmonics are limited to 50% of the harmonic limits shown in the table.
[4] Power generation facilities are limited to these values of current distortion, regardless of actual Isc/IL unless covered by other standards with applicable scope

The working principle of an APFC is based on real-time measurement of electrical parameters. The APFC relay continuously senses line voltage and load current through voltage inputs and a current transformer (CT) mounted on one of the incoming phases. Using these inputs, the controller calculates active power (kW), reactive power (kVAR), and the phase angle between voltage and current, from which the instantaneous power factor is determined. When the measured power factor falls below a predefined set value—typically between 0.95 and 0.99 lagging—the controller automatically switches ON appropriate capacitor steps to supply leading reactive power and counterbalance the inductive reactive power drawn by the load. Conversely, when the load reduces or the power factor exceeds the set limit, the controller switches OFF capacitor steps to prevent over-compensation and leading power factor conditions.

Selection of Capacitor

The capacitor can be selected based on the following relation:

$$kV\,Ar\,Rating = KW[\tan \phi 1 - \tan \phi 2]$$

Where,

kVAr rating = Size of capacitor needed

kW = Average power drawn

tanϕ1 = Trigonometric ratio of existing power factor

tan ϕ2 = Trigonometric ratio of required power factor

ϕ1 = Existing (cos-1 PF1)

ϕ2 = Required (cos-1 PF2)

Compliance:

As per the ECSBC 2024 code, all the three phases (of red, yellow, and blue) shall maintain their power factor at the point of connection as follows:

a) 0.97 for ECSBC-compliant building

b) 0.98 for ECSBC Plus-compliant building

c) 0.99 for Super ECSBC Super-compliant building

As per the ENS 2024 code, All 3 phase power systems shall be designed to maintain a power factor of 0.97 or respective DISCOM guidelines on power factor, whichever is more stringent shall be followed at the point of connection.

Solved Example:

An energy audit of a building was conducted. It has a contract demand of 400 kVA with the utility company. The average maximum demand recorded is 320 kVA/month at a power factor of 0.90. The maximum demand is billed at the rate of Rs.550/kVA/month. The buildings operators decides to improve the power factor from 0.90 to 0.99. Calculate the required capacitor kVAr.

Ans:

Calculate kW drawn	:	kW=kVA×PF
	:	kW=320×0.90=288” kW”
	:	kW=288 kW
Calculate capacitor kVAr required	:	kVAr=kW(tan θ_1–tan θ_2)
	:	θ_1= $\cos^{-1}$ (0.90)
	:	θ_2=$\cos^{-1}$ (0.99)

: $\tan \theta_1 = 0.484$

: $\tan \theta_2 = 0.142$

: $kVAr = 288\ (0.484\text{-}0.142)$

: $\boldsymbol{kVA}$=98.5 kVAr

6.4 Transformer

Transformer is static devices, which is used to either increase (step up) or decrease (step down) the input supply voltage depending on the application and requirement. Transformers consist of two or more coils that are electrically insulated but magnetically linked. The primary coil connected to the power source and secondary coil connects to the load.

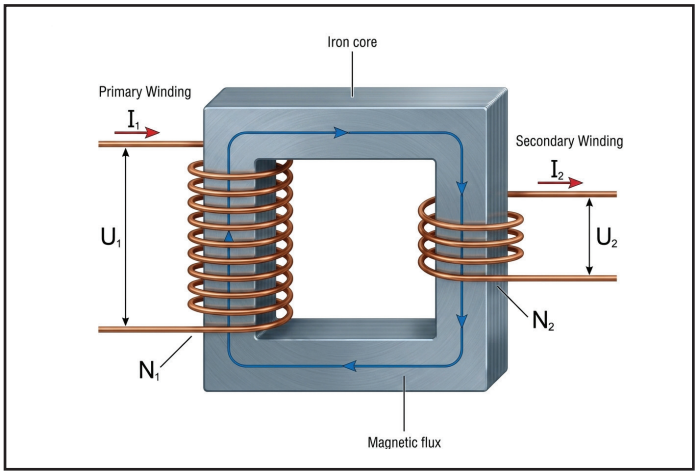


Figure 100 Transformer

In a building electrical system, transformers are used to step down high-voltage utility power to levels suitable for safe distribution and utilization within buildings. In most commercial and institutional buildings, transformers convert incoming medium voltage (typically 11 kV or 33 kV) to low voltage (415/240 V) for use by lighting, heating, ventilation, and air-conditioning (HVAC) systems, elevators, pumps, and plug loads. While transformers do not consume energy in the conventional sense, they are a continuous source of electrical losses and therefore play a significant role in overall building energy performance, particularly in large, continuously occupied facilities.

Types of Transformer Losses and Efficiency

Transformers are of two types: dry type and oil filled. Fire safety and environmental concerns associated with transformers are important. The oil-filled transformers are not installed at fire hazardous places. The dry-type transformer is used when it has to be located near the load centre which may be in a hazardous place. As there is no oil used in the transformer and special type of fire- resistant insulation is used for the windings, the fire risk is considerably reduced in these transformers

The efficiency varies anywhere between 96% to 99%. The efficiency of the transformers not only depends on the design, but also on the effective operating load. Transformer losses are broadly classified into no-load (core) and load (copper) losses.

The no-load losses occur whenever the transformer is energized and are independent of the connected load; these losses are primarily due to hysteresis and eddy currents in the magnetic core.

The load losses, on the other hand, vary with the square of the load current (P=I2R) and occur in the transformer windings due to resistive heating.

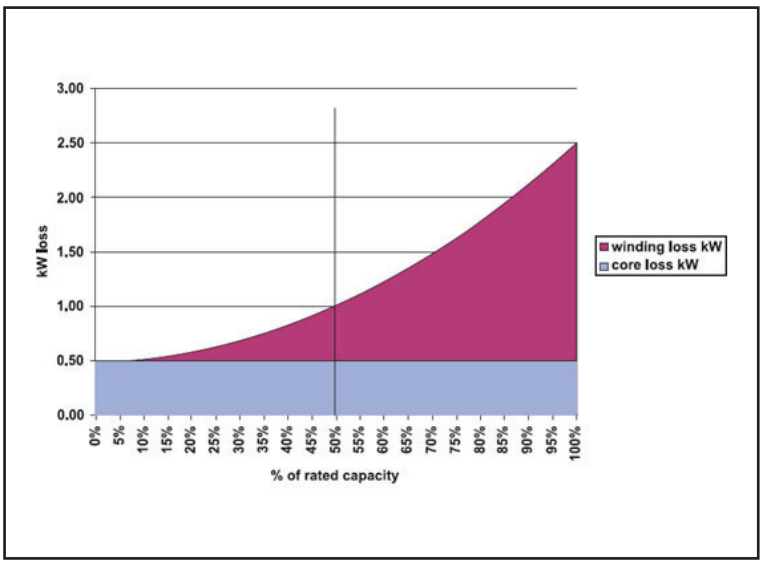


Figure 101 Transformer loss vs load (%)

The transformer loss, Ptotal, at any load level can be calculated as:

$$P_{total} = P_{no-load} + (\%\ Load/100)^2\ X\ P_{load}$$

$$P_{total} = No\ load\ loss + (\frac{kVA\ load}{Rated\ kVA})^2\ X|Full\ load\ loss$$

Note For no load and load losses, refer to the BEE Auditor Book. Energy Efficiency In Electrical Utilities Book 03

Modern energy-efficient transformers, including BEE Star-labelled transformers, are designed with improved core materials, optimized winding design and reduced stray losses to minimize total losses across the operating range. Oversizing of transformers, a common practice for future load growth, often results in prolonged operation at low load factors, increasing the proportion of no-load losses and reducing overall efficiency. Therefore, the ECSBC emphasizes appropriate transformer sizing, efficient design, and installation practices to reduce distribution losses and improve building electrical efficiency.

As per the ECSBC, the maximum allowable losses at 50% and 100% loading, shall be as follows:

Table 45 Allowable losses for dry-type transformers

Rating (kVA)	Impedance (%)	Max. total loss (W)					
		ECSBC buildings		ECSBC Plus buildings		ECSBC Super buildings	
		50% load	100% load	50% load	100% load	50% load	100% load
16	4.5	150	480	135	440	120	400
25	4.5	210	695	190	635	175	595
63	4.5	380	1,250	340	1,140	300	1,050
100	4.5	520	1,800	475	1,650	435	1,500

Rating (kVA)	Impedance (%)	Max. total loss (W)					
		ECSBC buildings		ECSBC Plus buildings		ECSBC Super buildings	
		50% load	100% load	50% load	100% load	50% load	100% load
160	4.5	770	2,200	670	1,950	570	1,700
200	4.5	890	2,700	780	2,300	670	2,100
250	4.5	1,050	3,150	980	2,930	920	2,700
315	4.5	1,100	3,275	1,025	3,100	955	2,750
400	4.5	1,300	3,875	1,225	3,450	1,150	3,330
500	4.5	1,600	4,750	1,510	4,300	1,430	4,100
630	4.5	2,000	5,855	1,860	5,300	1,745	4,850
1000	5.0	3,000	9,000	2,790	7,700	2,620	7,000
1250	5.0	3,600	10,750	3,300	9,200	3,220	8,400
1600	6.25	4,500	13,500	4,200	11,800	3,970	11,300
2000	6.25	5,400	17,000	5,050	15,000	4,790	14,100
2500	6.25	6,500	20,000	6,150	18,500	5,900	17,500
Total loss values given in above table are applicable for thermal classes E, B, and F and have component of load loss at reference temperature according to clause 17 of IS. An increase of 7% on the total for thermal class H is allowed.							

Table 46Allowable losses for power distribution transformers (Oil type)

Standard Losses in watts up to 11 KV Class (For ratings above 200 kVA)											
Rating (kVA)	% Impedance	1 Star		2 Star		3 Star		4 Star		5 Star	
	50% load		100% load	50% load	100% load	50% load	100% load	50% Load	100% Load	50% Load	100% Load
250	4.5	980	2930	920	2700	864	2488	811	2293	761	2113
315	4.5	1025	3100	955	2883	890	2681	829	2494	772	2319
400	4.5	1225	3450	1150	3330	1080	3214	1013	3102	951	2994
500	4.5	1510	4300	1430	4100	1354	3909	1282	3727	1215	3554
630	4.5	1860	5300	1745	4850	1637	4438	1536	4061	1441	3717

Standard Losses in watts up to 11 KV Class (For ratings above 200 kVA)											
Rating (kVA)	% Impedance	1 Star		2 Star		3 Star		4 Star		5 Star	
1000	5	2790	7700	2620	7000	2460	6364	2310	5785	2170	5259
1250	5	3300	9200	3220	8400	3142	7670	3066	7003	2991	6394
1600	6.25	4200	11800	3970	11300	3753	10821	3547	10363	3353	9924
2000	6.25	5050	15000	4790	14100	4543	13254	4309	12459	4088	11711
2500	6.25	6150	18500	5900	17500	5660	16554	5430	15659	5209	14813

As per ENS 2024, the maximum allowable losses at 50% and 100% loading, shall be as follows.

Table 47 Allowable losses for dry-type transformers (for ENS 2024)

Rating kVA	Max. losses at 50% loading W*	Max. losses at 100% loading W*	Max. losses at 50% loading W*	Max. losses at 100% loading W*
	Up to 22 kV class		33 kV class	
100	940	2,400	1,120	**2,400**
160	1,290	3,300	1,420	**3,300**
200	1,500	3,800	1,750	**4,000**
250	1,700	4,320	1,970	**4,600**
315	2,000	5,040	2,400	**5,400**
400	2,380	6,040	2,900	**6,800**
500	2,800	7,250	3,300	**7,800**
630	3,340	8,820	3,950	**9,200**
800	3,880	10,240	4,650	**11,400**
1,000	4,500	12,000	5,300	**12,800**
1,250	5,190	13,870	6,250	**14,500**
1,600	6,320	16,800	7,500	**18,000**
2,000	7,500	20,000	8,880	**21,400**
2,500	9,250	24,750	10,750	**26,500**

Table 48 Allowable losses for oil-type transformer (for ENS 2024)

Max. total loss (W)							
Rating (kVA)	Impedance (%)	BEE 3 Star		BEE 4 Star		BEE 5 Star	
		50% load	100% load	50% load	100% load	50% load	100% load
16	4.5	108	364	97	331	87	301
25	4.5	158	541	142	493	128	448
63	4.5	270	956	243	870	219	791
100	4.5	392	1,365	352	1,242	317	1,130
160	4.5	513	1,547	462	1,408	416	1,281
200	4.5	603	1,911	543	1,739	488	1,582
250	4.5	864	2,488	811	2,293	761	2,113
315	4.5	890	2,440	829	2,164	772	1,920
400	4.5	1,080	3,214	1,013	3,102	951	2,994
500	4.5	1,354	3,909	1,282	3,727	1,215	3,554
630	4.5	1,637	4,438	1,536	4,061	1,441	3,717
1,000	5.0	2,460	6,364	2,310	5,785	2,170	5,259
1,250	5.0	3,142	7,670	3066	7,003	2,991	6,394

Max. total loss (W)							
Rating (kVA)	Impedance (%)	BEE 3 Star		BEE 4 Star		BEE 5 Star	
		50% load	100% load	50% load	100% load	50% load	100% load
1,600	6.25	3,753	10,821	3547	10,363	3,353	9,924
2,000	6.25	4,543	13,254	4309	12,459	4,088	11,711
2,500	6.25	5,660	16,554	5430	15,659	5,209	14,813
Total loss values given in the above table are applicable for thermal classes E, B and F, and have component of load loss at reference temperature according to Section 17 of IS 1180, that is, average winding temperature rise as given in Column 2 of Table 8.2 plus 300C as per Sec-17 of IS 1180. An increase of 7% in the total for thermal class H is allowed.							
Permissible total loss values shall not exceed: - 5% of the maximum total loss values mentioned in IS 1180 for oil-type transformers in voltage class above 11 kV but not more than 22 kV - 7.5% of the maximum total loss values mentioned in above IS 1180 for oil-type transformers in voltage class above 22 kV and up to and including 33 kV							

6.5 Motor

Electric motors are the primary energy-consuming components in building electrical systems, driving equipment such as pumps, fans, compressors, elevators, and HVAC systems. The performance, efficiency, and control of motors therefore have a direct impact on overall building energy use and operating costs.

Motors convert the electrical energy into mechanical energy by the interaction between the magnetic fields setup in the stator and rotor winding. Electric motors can be broadly classified as induction motors, direct current (DC) motor or synchronous motors.

Type of Motors

On basis of the mentioned classification, motors can be of the following different types:

1. **Induction motor:** Induction motors are the most used motors in buildings applications due to their simple construction, ruggedness and low cost. They operate on the principle of electromagnetic induction, with rotor current induced by the stator magnetic field. These motors are widely used for pumps, fans, compressors, and HVAC equipment.

2. **Slip ring motor:** Slip ring motors are a type of induction motor equipped with external rotor resistance, which allows high starting torque and controlled starting current. They are typically used in applications requiring high starting torque, such as hoists, cranes, and heavy-duty drives.

3. **DC motor:** DC motors operate on direct current and provide excellent speed control and high starting torque. Although less common in modern buildings due to maintenance requirements and availability of AC drives, they are still used in specialized applications where precise speed regulation is required.

4. **Synchronous motor:** Synchronous motors run at a constant speed synchronous with the supply frequency, regardless of load variations. They are often used in large-capacity applications and can operate at leading power factor, thereby contributing to power factor improvement in the electrical system.

5. **Permanent magnet synchronous motor (PMSM):** The PMSMs use permanent magnets in the rotor instead of field windings, resulting in high efficiency, compact size, and excellent dynamic performance. These motors are increasingly used in high-efficiency HVAC systems, elevators, and variable-speed applications.

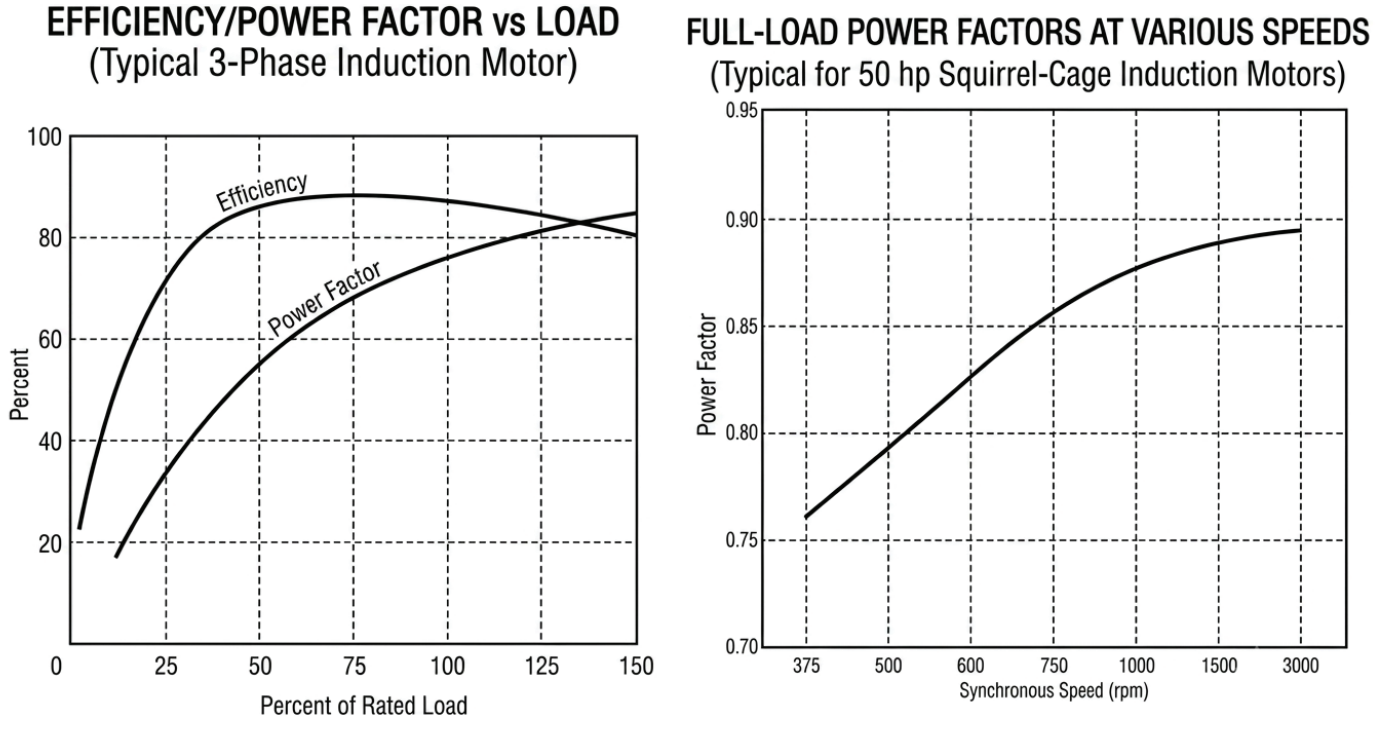
6. **Synchronous reluctance motor:** Synchronous reluctance motors operate based on the reluctance torque principle and do not use rotor windings or permanent magnets. They offer high efficiency, low-rotor losses, and robust construction, making them suitable for energy-efficient variable-speed applications when used with appropriate drives.

Motor Efficiency

Motor efficiency is the ratio of the useful mechanical power output to the total electric power input to the motor. Like all electromechanical equipment, motors consume some 'extra' energy to make the conversion. Efficiency reflects how much total energy a motor uses in relation to the rated power delivered to the shaft.

The efficiency of a motor is determined by intrinsic losses that can be reduced only by changes in motor design. Intrinsic losses are of two types: **fixed losses** (independent of motor load) and **variable losses** (dependent on load)

Fixed losses consist of magnetic core losses and friction and windage losses. Magnetic core losses (sometimes called iron losses) consist of eddy current and hysteresis losses in the stator. They vary with the core material and geometry and with input voltage. Friction and windage losses are caused by friction in the bearings of the motor and aerodynamic losses associated with the ventilation fan and other rotating parts.



% Load vs. Power factor, Efficiency **Speed vs. Power factor**

Figure 102 Impact on power factor due to percentage load and speed

Variable losses consist of resistance losses in the stator and in the rotor and miscellaneous stray losses. Resistance to current flow in the stator and rotor results in heat generation, which is proportional to the resistance of the material and the square of the current (I^2R). Stray losses arise from a variety of sources and are difficult to either measure directly or calculate but are generally proportional to the square of the rotor current.

Part load performance characteristics of a motor also depends on its design. Both efficiency and power factor fall to very low levels at low load. The figure below shows the effect of load on power factor and efficiency. Power factor drops sharply at part loads.

The efficiency of the motor is given by

$$\eta = \frac{P_{out}}{p_{in}} = 1 - \frac{P_{loss}}{P_{in}}$$

Where,

P_{out} = Output power of the motor

P_{in} = Input power of the motor

P_{loss} = Loss occurring in motor

Energy-efficient Motors

Energy-efficient motors, such as IE2, IE3 and IE4 class motors as per IEC standards, are designed with improved magnetic materials, optimized windings, and reduced losses. When combined with variable frequency drives (VFDs), motors can operate closer to actual load requirements, resulting in significant energy savings in variable-torque applications such as pumps and fans. The ECSBC encourages the use of high-efficiency motors and variable speed control to reduce building energy consumption and peak demand.

Compliance:

Three-phase induction motors shall conform to (IS) 12615 latest version as amended from time to time and shall fulfil the following efficiency requirements:

a) ECSBC buildings shall have motors of minimum IE 3 (high efficiency) class.

b) ECSBC Plus buildings shall have motors of minimum IE 4 (premium efficiency).

c) Super ECSBC buildings shall have motors of minimum IE 5 (super premium efficiency) class.

Notes

- IE5 efficiency class is as defined in IEC TS 60034-30-2.
- Motors of kW ratings different from those listed in the tables of IS 12615 shall have efficiency greater than that of the next listed kW motor.
- Motor kW ratings shall not exceed 20% of the calculated maximum load being served

EC Motors

An Electronically Commutated (EC) motor is a high-efficiency synchronous electric motor powered internally by direct current (DC) and operated using an integrated electronic commutation system. In industrial automation terminology, EC motors are often categorized as Brushless DC (BLDC) motors and are widely used in HVAC, refrigeration, ventilation, and pumping applications. These motors accept a conventional alternating current (AC) supply and internally convert it into controlled DC power for motor operation. Unlike conventional AC induction motors, which rely on electromagnetic induction and fixed line frequency to create

rotor motion, EC motors use solid-state electronics to precisely control the energization of stator windings. This electronic commutation enables highly efficient, reliable, and variable-speed operation while eliminating the need for mechanical brushes and commutators.

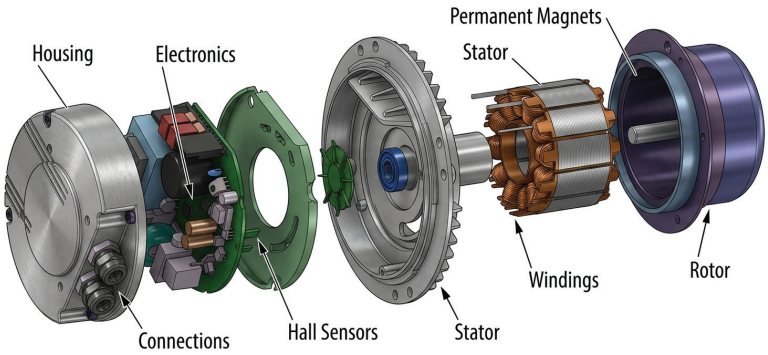


Figure 103 EC permanent magnet motor exploded view

An EC motor primarily consists of a rotor, stator, electronic controller, and rotor position sensing arrangement. The rotor is constructed using permanent magnets instead of copper windings, thereby eliminating rotor copper losses and significantly improving efficiency while reducing heat generation. The stator contains copper windings wound around a laminated steel core and is designed for sequential electronic energization. The integrated electronic control module typically includes an AC-to-DC rectifier, smoothing capacitors, inverter circuitry using MOSFETs or IGBTs, and a microcontroller or digital signal processor (DSP) responsible for electronic commutation, speed regulation, and protection functions. Rotor position is continuously monitored using Hall Effect sensors or sensorless back-EMF feedback algorithms to ensure accurate switching of the stator windings.

During operation, the controller energizes the stator windings in a controlled sequence based on the rotor position, generating a rotating magnetic field that drives the rotor synchronously. Since the rotor contains permanent magnets and no rotor current flows, rotor copper losses are eliminated, resulting in significantly higher efficiency compared to conventional squirrel-cage induction motors. The integrated controller also enables smooth speed variation, soft starting, overload protection, and thermal protection.

EC motors offer several operational advantages, including high energy efficiency, low noise generation, reduced vibration, lower heat dissipation, improved power factor, and reduced starting current. Since these motors do not use brushes, mechanical wear and maintenance requirements are considerably lower. Additionally, the integrated controller supports multiple speed control methods such as 0–10 V analog control, Pulse Width Modulation (PWM), and communication protocols including Modbus and BACnet, enabling seamless integration with Building Management Systems (BMS) and modern automation platforms

Concept of Variable Frequency Drives

The speed of an induction motor is proportional to the frequency of the AC voltage applied to it, as well as the number of poles in the motor stator. This relationship is expressed by the equation:

$RPM = (f \times 120) / p$

where f is the supply frequency in hertz (Hz), and p is the number of stator poles (always an even number).

Therefore, if the frequency applied to the motor is changed, the motor speed changes in direct proportion to the frequency variation. Controlling the frequency supplied to the motor is the primary function of a variable speed drive (VSD).

The basic principle of operation of a VSD is to convert the incoming electrical system voltage and frequency into the required voltage and frequency to operate a motor at a speed other than its rated speed. The two

fundamental functions of a VSD are, conversion of electrical power from one frequency to another, and control of the output frequency supplied to the motor.

In many flow control systems, mechanical control methods such as throttling valves, dampers, or vanes are commonly used to regulate flow. However, these methods lead to significant energy losses due to increased system resistance and also reduce the operational life of motors and control valves. In applications such as fans, blowers, and pumps, where the load power depends on motor speed, the torque varies proportionally to the square of the speed, while the power consumption varies proportionally to the cube of the speed. Therefore, implementing variable speed control can result in substantial energy savings. For example, reducing the motor operating speed by 20% from its rated speed can lead to nearly 50% reduction in motor input power consumption.

Fan Law (Affinity Law): The fan operates under a predictable set of laws concerning speed, power and pressure. A change in speed (RPM) of fan will predictably change the pressure rise and power necessary to operate it at the new RPM.

Flow 8 Speed	**Pressure 8 (Speed)^2**	**Power 8 (Speed)^3**
$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$	$\frac{SP_1}{SP_2} = (\frac{N_1}{N_2})^2$	$\frac{kW_1}{kW_2} = (\frac{N_1}{N_2})^3$
Varying the RPM by 10% decreases or increase air delivery by 10%	*Reducing the RPM by 10% decreases the static pressure by 19% and an increase in RPM by 10% increases the static pressure by 21%*	*Reducing the RPM by 10% decrease the power requirement by 27% and an increase in RPM by 10% increases the power requirement by 33%*

Q= Flow, SP = Static Pressure, kW = Power and N = Speed (RPM)

Consequences of Motor Oversizing

When motors are oversized and operate for extended periods at significantly less than full load, there are three significant operational penalties—reduced efficiency, reduced slip (important if the load is a cube-law type), and reduced power factor.

Depending on the motor, efficiency will typically peak at somewhere between 75% load and full load. The larger the motor and the higher its peak efficiency, the more likely it will have a relatively flat efficiency curve between 50% load and full load, with a hump at 75% load some 0.3 to 1% points higher than at full load. Efficiency drops precipitously below 50% load, with the average 100-hp energy- efficient motor losing over two points between 50% and 25% load and the average 100-hp standard efficiency induction motor dropping some 5.5 points over the same range. Smaller motors lose even more, particularly at lower efficiencies

A general rule-of-thumb is that a one percentage point increase in efficiency is equivalent to about a one-third point increase in slip—a decrease in slip—can therefore quickly negate even a significant energy efficiency improvement.

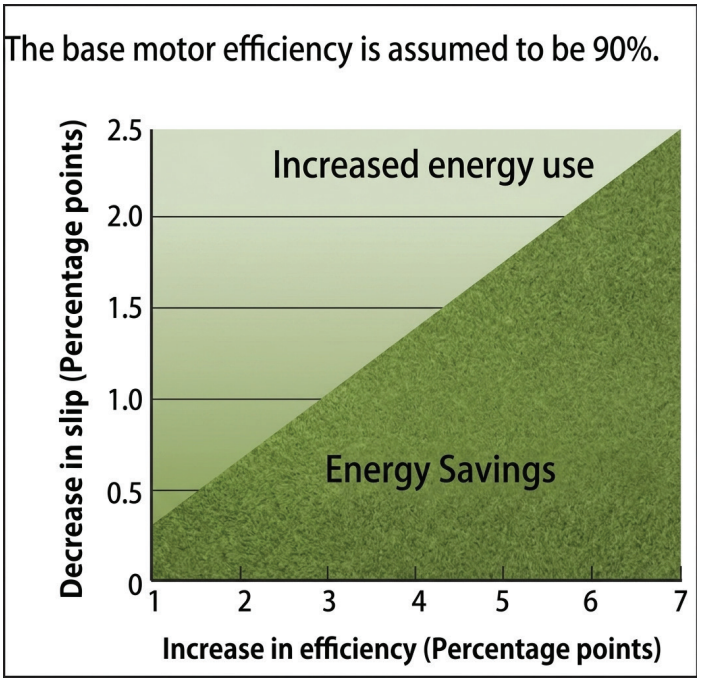


Figure 104 Impact of sizing of motor on efficiency

Motor Rewinding Versus Replacement

Motor failures are frequently caused by bearing failures and are often accompanied by the breakdown of the coils of insulated wire inside the motor (the stator windings) and other problems. When a motor fails, the owner is faced with deciding whether to rebuild it or replace it. Rebuilding, commonly called rewinding, usually entails a lower initial cost compared to a replacement motor, especially for larger motors. Rewinding can preserve and, in rare cases, slightly improve motor efficiency if skillfully done. However, the rewinding process provides many avenues by which the motor efficiency can be degraded, greatly increasing operating cost and energy consumption.

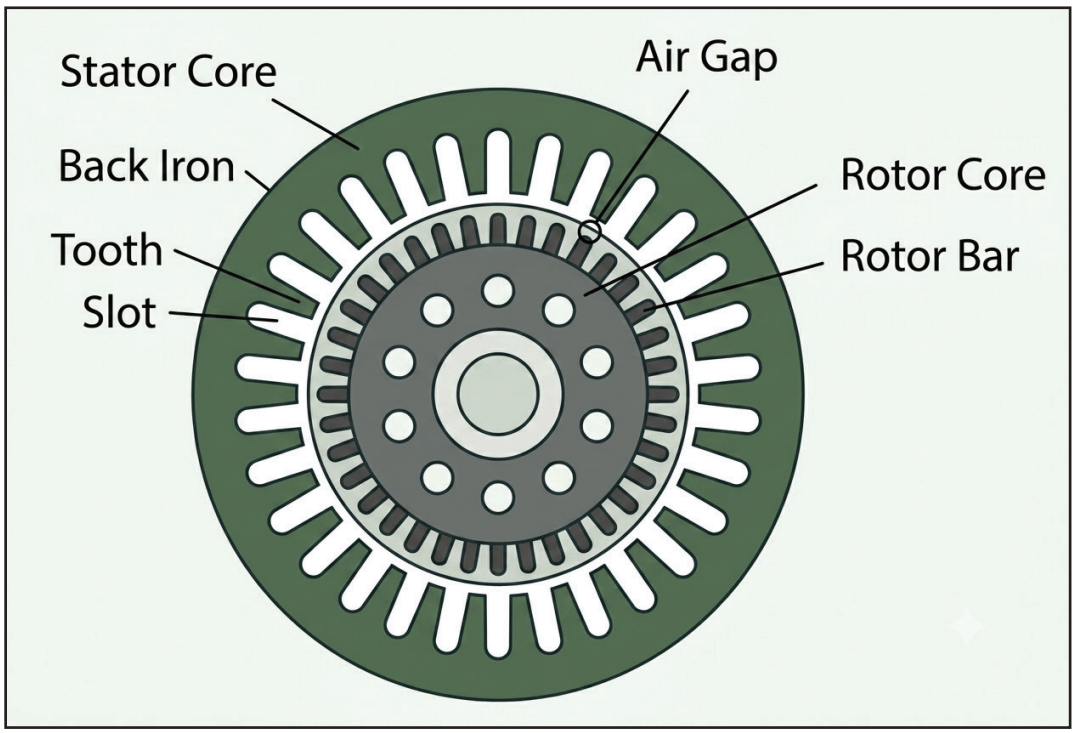


Figure 105 Schematic of motor section

To ensure the highest quality in repaired motors, the consistent use of test equipment and documentation procedures must be integral parts of the repair process, so that the efficiency of the motor and the quality of its components can be verified before the motor is put back into service. A critical task in most motor rebuilds is to remove the old windings without altering the adjacent laminated steel cores, and then to wrap new insulated wire around the old cores.

The old windings are commonly embedded in thick coats of varnish (used to glue the windings inside the core slots) which prevent their easy removal. Heat, chemicals, or mechanical force are commonly used to loosen and pull out old windings; excessive use of any of these can cause damage to the cores. Improper machining, replacement bearings, wire diameter, and winding technique can all compound, resulting in a rebuilt motor with poor performance and lower efficiency.

Although it is technically possible to rebuild a motor to its original specifications, survey results of actual rewind practices show that this is seldom the case. On the average, rewound motors are less efficient than they were before rewinding. The magnitude of this problem can vary widely from one rewind shop to another, and can only be properly identified when efficiency measurements are taken before and after rewinding

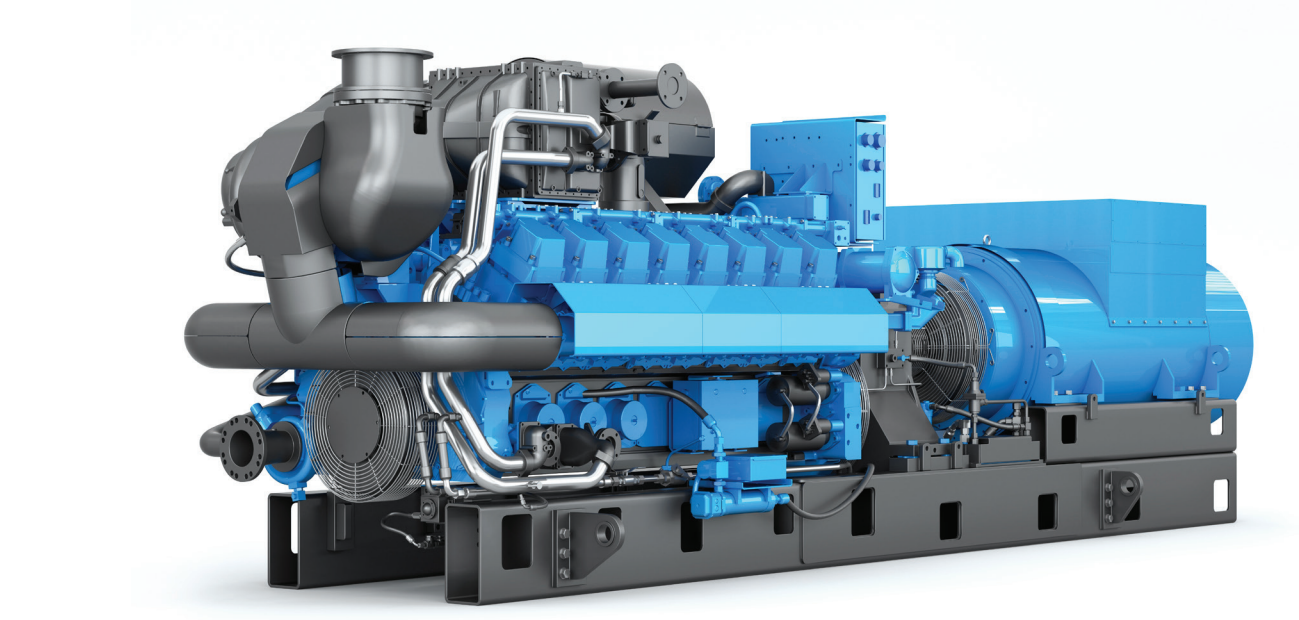


Figure 106 Diesel generator set

6.6 Diesel Generator Sets

A diesel generator (DG) set is a standby or backup power source used in buildings to supply electricity during grid outages or when the utility supply is unreliable. A DG set converts the chemical energy of diesel fuel into electrical energy through an internal combustion engine coupled with an alternator. In building applications, DG sets are essential for ensuring power continuity for critical loads such as life safety systems, elevators, emergency lighting, data centers, health care equipment, and essential services.

Diesel Engine Cycle

The diesel engine is the prime mover, which drives an alternator to produce electrical energy. In a diesel engine, air is drawn into the cylinder and is compressed to a high ratio (14:1 to 25:1). During this compression, the air is heated to a temperature of 700–900°C. A metered quantity of diesel fuel is then injected into the cylinder, which ignites spontaneously because of the high temperature. Hence, the diesel engine is also known as a compression ignition (CI) engine.

The DG sets can be classified according to cycle type as two-stroke and four-stroke engines. However, the bulk

of internal combustion engines used in the DG sets operate on the four-stroke cycle. The principle of operation of a four-stroke diesel engine is described below.

The four strokes in a diesel engine are:

First: Induction stroke: While the inlet valve is open, the descending piston draws in fresh air into the cylinder.

Second: Compression stroke: While both valves are closed, the air is compressed to a pressure of up to 25 bar.

Third: Ignition and power stroke: Fuel is injected while the valves remain closed (fuel injection starts at the end of the previous stroke). The fuel ignites spontaneously, and the piston is forced downward by the combustion gases, producing useful mechanical work.

Fourth: Exhaust stroke: The exhaust valve opens, and the rising piston discharges the spent gases from the cylinder.

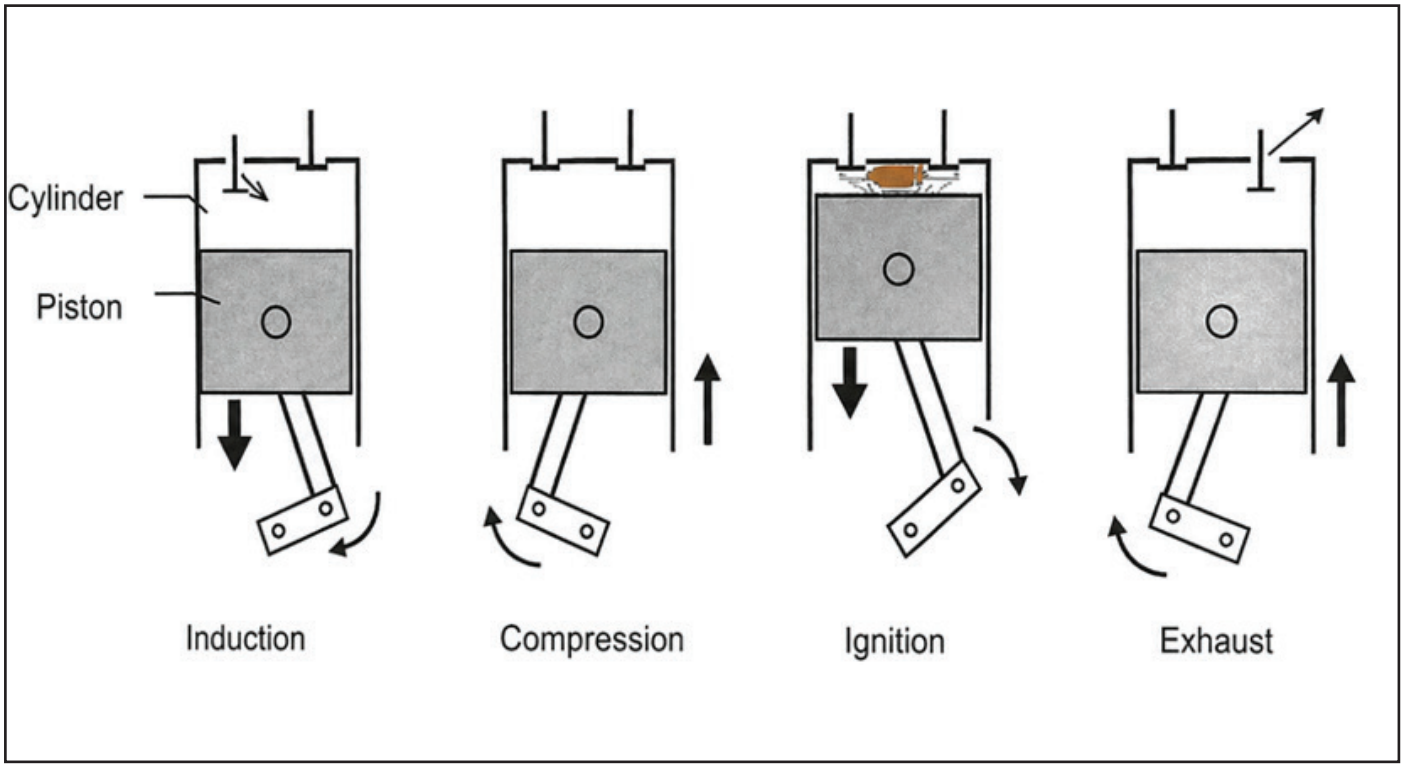


Figure 107 Schematic diagram of a four-stroke diesel engine

Gas Engine

In this process, the gas is mixed with air before the inlet valves. During the intake period, gas is also fed into a small prechamber, where the gas mixture is rich compared to the gas in the main cylinder. At the end of the compression phase, the gas–air mixture in the prechamber is ignited by a spark plug. The flames emerging from the nozzle of the prechamber then ignite the gas–air mixture in the entire cylinder. Combustion is rapid. After the working phase, the cylinder is emptied of exhaust gases and the process starts again. Reciprocating engines using modern lean-burn technology can achieve electrical efficiencies of up to about 45%.

From an energy efficiency and ECSBC perspective, the BEE star-rated DG sets shall be considered for the buildings. The DG sets in buildings greater than 20,000 m2 built up area (BUA) shall be BEE star- labelled as:

a) ECSBC-compliant building – Minimum BEE 3-star rating

b) ECSBC Plus-compliant building – Minimum BEE 4-star rating

c) ECSBC Super-compliant building – 5-star rating

Note: Provided standby generating sets, using any other fuels other than diesel, shall comply with BEE's star labelling programme as and when comes into effect. The buildings not using DG sets for captive power generation (no more than 15% of power requirement is being met using DG sets), BEE 3 star- rated DG sets shall be used for ECSBC Plus and ECSBC Super compliance.

Waste Heat Recovery in DG Sets

For combined heat and power applications, waste heat from reciprocating engines can be tapped mainly from exhaust gases and cooling water that circulates around cylinders in the engine jackets, with additional potential from oil and turbo coolers. While engines exhaust and cooling water each provide about half of the useful thermal energy, the exhaust is at much higher temperature (around 450 °C versus 100 °C) and hence is more versatile.

It would be realistic to assess the waste heat recovery (WHR) potential in relation to quantity, temperature margin, in kcal/hr as:

Potential WHR = (kWh output/ Hour) X (8 kg gases / kWh output)

X 0.25 kcal/kg °C X (t_g – 180 °C)

Where,

t_g = Gas temperature after turbocharger (the limiting gas exit gas temperature cannot be less than 180 °C to avoid acid dew point corrosion)

0.25 = Specific heat of flue gases

kWh output = Average unit generation form the set per hour

6.7 Uninterruptible Power Supply

An uninterruptible power supply (UPS) is an essential electrical system in modern buildings that ensures continuous, reliable, and high-quality power to critical loads. Unlike conventional backup sources such as DG sets, which require a finite start-up time, a UPS provides instantaneous power support without interruption. In addition to providing backup power, a UPS conditions the incoming electrical supply by delivering stable voltage and frequency, thereby protecting sensitive equipment from disturbances such as voltage fluctuations, surges, sags, harmonics, and short-duration outages. The UPS systems play a crucial role in maintaining the reliability of critical services while supporting overall energy efficiency and power quality objectives. Acting as an interface between the utility grid and sensitive electrical loads, a UPS ensures operational continuity during grid disturbances and maintains power quality during normal operation. By stabilizing voltage and frequency and minimizing power interruptions, the UPS systems help prevent equipment damage, data loss, operational downtime, and safety risks. The UPS systems are commonly deployed to serve critical and sensitive loads such as data centres and server rooms, IT and office equipment, building management systems (BMS), fire detection and alarm systems, health care facilities, and communication systems.

Major Components of UPS

A typical UPS system consists of four principal components: rectifier–charger, battery bank, inverter, and static bypass switch.

The rectifier converts incoming alternating current (AC) from the utility supply into direct current (DC). This DC power serves a dual purpose: it feeds the inverter and simultaneously charges the connected battery bank, ensuring that stored energy is available whenever required. In this manner, the rectifier also contributes to

stabilizing fluctuations in the input supply.

The battery bank, made up of multiple batteries connected in series and/or parallel, functions as the energy storage element of the UPS. Under normal operating conditions, electrical energy from the grid is stored in the batteries in chemical form. During a mains power failure or unacceptable voltage variation, the stored energy is released as DC power to support the inverter, thereby maintaining uninterrupted supply to the connected loads.

The inverter is responsible for converting DC power into high-quality AC power with regulated voltage and frequency. It typically comprises a power electronic switching bridge, control circuitry, and output filtering components to ensure a stable and distortion-free supply to sensitive equipment.

To enhance system reliability, a static bypass switch is incorporated within the UPS. This switch, constructed using antiparallel-connected thyristors, provides an alternate power path from the utility supply directly to the load. In situations such as inverter overload, fault, or maintenance conditions, the static bypass automatically transfers the load to the mains supply within a few milliseconds, ensuring continuity of power without mechanical switching.

Working Principle and Operating Condition of UPS

A UPS functions as a continuous power-conditioning and backup system. When the utility supply is available and within acceptable limits, the UPS regulates voltage and frequency while charging the batteries. In the event of a power interruption or disturbance, the UPS instantaneously supplies stored energy from the batteries through the inverter, preventing any disruption to the connected loads.

A UPS operates under three primary conditions: normal operation, power failure operation, and bypass operation.

Normal operating condition: Under normal conditions, when the utility power supply is available and within acceptable voltage and frequency limits, the UPS operates in normal mode. The incoming AC power is converted into DC by the rectifier. This DC power is used to supply the inverter and simultaneously charge the battery bank. The inverter then converts the DC power back into AC and delivers a clean, regulated output with constant voltage and frequency to the connected load. During this mode, the UPS also filters electrical disturbances such as voltage fluctuations, harmonics, and noise, ensuring high power quality while maintaining the batteries in a fully charged state

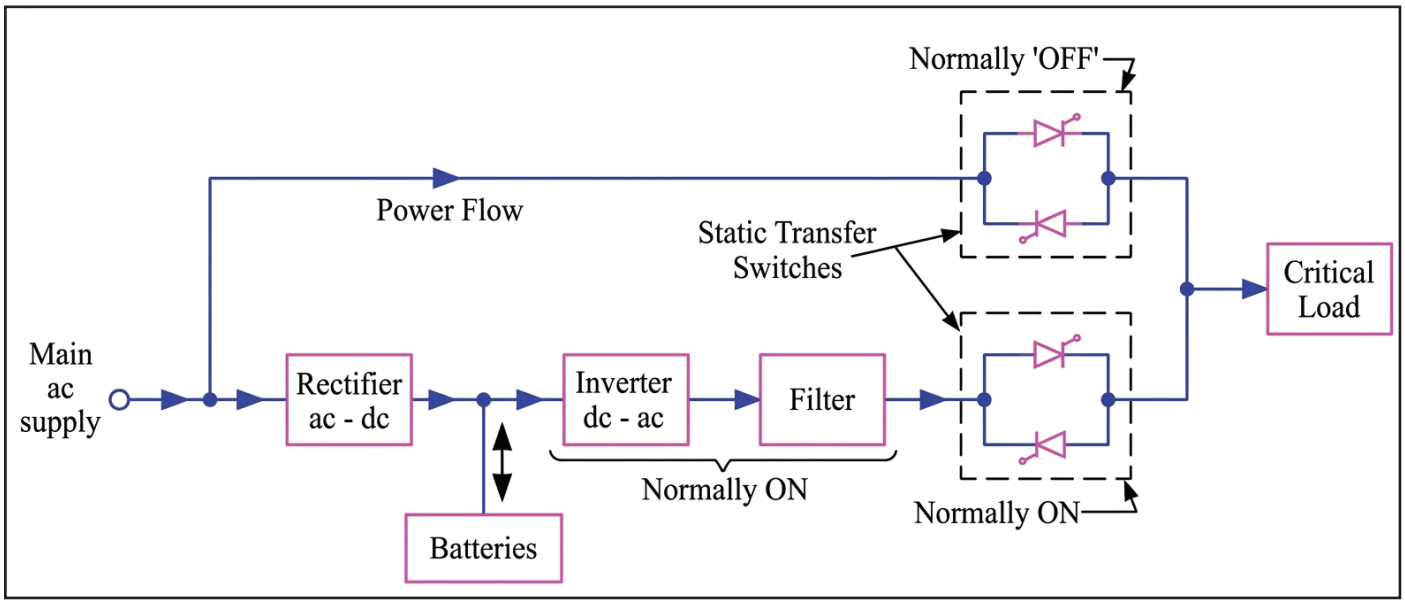


Figure 108 Working of UPS

Power failure condition: When the utility supply fails or deviates beyond permissible limits, the UPS immediately shifts to battery mode. In this condition, the battery bank supplies DC power directly to the inverter which continues to provide regulated AC power to the load without interruption. Since the inverter is already supplying power during normal operation (in online UPS systems), the transition is seamless, with zero or near-zero transfer time. This ensures that sensitive equipment continues to operate normally during power outages until the utility supply is restored or an alternate power source becomes available.

Bypass operating condition: The bypass mode is activated when the UPS inverter is unable to supply power due to conditions such as overload, internal fault, or maintenance requirements. In this mode, the static bypass switch transfers the load directly to the utility supply, bypassing the rectifier and inverter stages. The transfer occurs automatically within a few milliseconds, ensuring continuity of power to the load. While operating in bypass mode, power conditioning is limited, and the load receives power directly from the utility supply. Once the inverter becomes available and operating conditions are restored, the UPS automatically transfers the load back to normal operation

Battery System in UPS

UPS systems primarily use lead-acid (VRLA/SLA, VLA), lithium–ion batteries, and nickel–Cadmium batteries. Lead–acid is the most common for reliability and lower upfront cost, and lithium offers higher efficiency, longer life, and lower maintenance.

Valve-regulated lead–acid (VRLA) batteries: The VRLA batteries are the most used batteries in UPS systems. They are sealed, maintenance-free, and available in absorbed glass mat (AGM) and gel types.

The VRLA batteries have moderate energy density and relatively low-upfront cost, making them suitable for small to medium backup durations. However, they are sensitive to high temperatures and deep discharge, which can significantly reduce their service life.

Lithium–ion batteries: Lithium–ion batteries are increasingly being adopted in modern UPS systems due to their high energy density, longer service life, and faster charging capability. They offer higher efficiency, deeper depth of discharge, and significantly lower weight and space requirements compared to VRLA batteries. Although the initial cost is higher, lithium-ion batteries provide lower lifecycle costs due to reduced maintenance, longer lifespan, and better performance at partial loads.

Nickel–cadmium (Ni–Cd) batteries: Ni–Cd batteries are known for their robustness, tolerance to extreme temperatures, and long cycle life. They can withstand deep discharge and harsh operating conditions, making them suitable for industrial and mission-critical applications. However, they have lower energy density, higher cost, and environmental concerns due to the presence of cadmium, which limits their widespread use in commercial buildings.

Compliance with ECSBC (UPS)

In all buildings, energy efficiency of UPS shall be equal to or higher than energy efficiency requirements defined in Table 48.

Table 49 Energy efficiency requirements for UPS

UPS size	Energy efficiency requirements at 100% load
kVA< 20	93%
20<=kVA <=100	94%
kVA > 100	96%

Note: Standards and Labelling programme by BEE shall take precedence over requirements listed in table above.

6.8 Lift and Escalators

Lifts and escalators form an integral part of modern buildings by enabling efficient and safe vertical transportation of occupants and goods. As building heights, occupancy densities, and functional complexities increase, the dependence on vertical transportation systems has grown significantly. These systems directly influence building functionality, user comfort, accessibility, and operational efficiency. In energy-efficient and sustainable buildings, lifts and escalators must be designed not only for performance and safety but also for optimized energy use and reduced environmental impact, in line with the objectives of the Energy Conservation and Sustainability Building Code (ECSBC).

Lifts and escalators ensure seamless movement of people and materials within buildings, supporting daily operations and emergency functions. Lifts provide controlled vertical mobility across multiple floors, catering to occupants, visitors, goods, and emergency services. Escalators and moving walkways facilitate continuous passenger movement in high-traffic areas, reducing congestion and improving circulation efficiency. Together, these systems enhance building usability, accessibility for persons with disabilities, and compliance with safety and accessibility norms. In addition to mobility, lift and escalator systems influence building planning and space utilization, affecting core layouts, circulation patterns, and floor efficiency. Their reliability is critical in buildings such as hospitals, transit hubs, and high-rise commercial developments, where uninterrupted movement is essential for safety and operational continuity.

Vertical transportation systems used in buildings can be broadly classified into lift (Elevators) systems and continuous transportation systems such as escalators and moving walkways. The selection of each system depends on building height, occupancy, traffic pattern, energy performance requirements.

ECSBC Compliance (Vertical transportation)

a) Vertical transportation shall comply to the standard in table below.

Table 50 IS code compliance for vertical transportation

b) The lifts shall be of energy classification 'C' efficient for ECSBC buildings, energy classification 'B' efficiency for ECSBC Plus buildings and energy classification 'A' efficiency for ECSBC Super buildings. The energy classification values are as defined in table 7 of IS 17515 – Part 2.

Table 51 Classification of lifts as per IS 17515-part-2

Energy efficiency class	Energy consumption per day (Wh)
A	Ed ≤ 0.72 x Q x nd x Sav/1000 + 50 x tnr
B	Ed ≤ 1.08 x Q x nd x Sav/1000 + 100 x tnr
C	Ed ≤ 1.62 x Q x nd x Sav/1000 + 200 x tnr
D	Ed ≤ 2.43 x Q x nd x Sav/1000 + 400 x tnr
E	Ed ≤ 3.65 x Q x nd x Sav / 1000 + 800 x tnr
F	Ed ≤ 5.47 x Q x nd x Sav / 1000 + 1600 x tnr
G	Ed ≤ 5.47 x Q x nd x Sav / 1000 + 1600 x tnr

c) Lifts shall have variable frequency drives, permanent magnet gearless machines and energy- efficient lighting features with standby mode and prescriptive features like destination control system where applicable as per traffic analysis requirements, regenerative drives.

ECSBC Compliance for Escalators and Moving Walks

a) Energy calculations and classification for escalators and moving walks is based on Table 7.12 of IS 17515- Part 3

Table 52 Classification of escalators

Energy Performance ratio	**≤55 %**	**≤60 %**	**≤65 %**	**≤70 %**	**≤80 %**	**≤90 %**	**≤100 %**	**>100 %**
Energy performance class indicator	A+++	A++	A+	A	B	C	D	E

Note: If there are multiple lifts in a building with different classification as per table above, then the one with lowest class shall be taken for rating computation.

b) The escalators shall be energy classification 'A+ efficiency' for ECSBC buildings, energy classification 'A++ efficiency' for ECSBC Plus buildings and energy classification 'A+++ efficiency' for ECSBC Super buildings. The energy classification values are as defined in Table 7 of IS 17515 – Part 3.

Note If there are multiple escalators and /or moving walks in a building with different classification as per table above, then the one with lowest class shall be taken for rating computation.

c) Escalators and moving walks shall have variable frequency drives, load, and motion sensors for better efficiency and energy-efficient lighting features and soft start capabilities, regenerative drives shall be provided to recycle energy. All signals/signages used for these equipment's shall be of LED fixtures.

ENS Compliance for Escalator and Moving Walks

Elevators installed in the building shall meet all the following requirements:

a) Install high-efficacy lamps for lift car lighting having a minimum luminous efficacy of 95 lm/W.

b) Install automatic switch-off controls for lighting and fan inside the lift car when are not occupied.

c) Install minimum class IE 3 high-efficiency motors.

d) Group automatic operation of two or more elevators coordinated by supervisory control.

6.9 Metering and Monitoring

Metering and monitoring are essential tools for understanding how resources such as energy, water, and fuels are consumed within a building. These systems provide accurate, real-time, and historical data on resource usage, enabling effective management and informed decision-making. By quantifying consumption patterns, metering, and monitoring support performance assessment with a high degree of

accuracy and help improve accountability, operational efficiency, and cost-effectiveness. The growing ambition to reduce building energy consumption and associated greenhouse gas (GHG) emissions has acted as a strong catalyst for the increased deployment of advanced meters, sensors, and monitoring systems in both commercial and residential buildings. These systems not only track energy use but also monitor environmental conditions such as temperature, humidity, and indoor air quality, which directly influence building performance and occupant comfort. With the integration of advanced metering infrastructure, automation systems, and data analytics platforms, buildings can identify inefficiencies, detect abnormal consumption, optimize system operation, and verify the impact of energy-conservation measures. Consequently, both commercial and

residential buildings can achieve significant savings in energy and water resources while enhancing operational reliability, sustainability, and overall building performance.

Type of Meters

Analogue meter: Analogue meters are conventional measuring instruments that indicate the value of a measured quantity through the movement of a pointer over a calibrated scale. The pointer position varies continuously in proportion to the magnitude of the parameter being measured, such as voltage, current, power, or pressure.

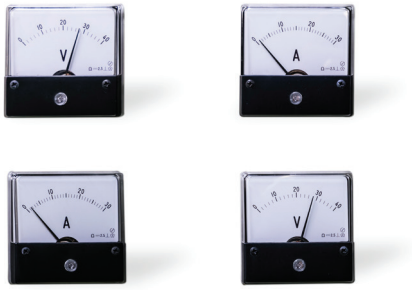


Figure 109 Analogue meter

Analogue meters operate on electromechanical principles, including magnetic deflection, electromagnetic induction, or electrostatic forces. The measured electrical or physical quantity produces a force that causes mechanical movement within the instrument, resulting in the deflection of the pointer. Common examples include analogue ammeters, voltmeters, pressure gauges, and electromechanical energy meters.

These meters are valued for their simple construction and ease of interpretation, particularly for observing trends or fluctuations in measured values. However, analogue meters have inherent limitations such as lower accuracy, susceptibility to parallax error, mechanical wear, and limited capability for data recording or remote monitoring. Owing to these constraints, their application in modern energy management and monitoring systems is increasingly limited.



Figure 110 Digital meter

Digital meters: Digital meters measure electrical or physical quantities and display the results in numerical form using electronic displays such as LCD or LED screens. Unlike analogue meters, digital meters rely on electronic sensors, signal conditioning circuits, and analogue-to-digital converters to process measurement inputs. A microprocessor then computes and displays the measured values with high precision.

Digital meters provide enhanced accuracy, stability, and repeatability, making them suitable for applications that require precise measurement and continuous monitoring. They eliminate parallax errors and do not involve moving parts, resulting in improved reliability and reduced maintenance requirements. In addition to

basic measurement, digital meters often support advanced features such as data logging, time-based recording, communication interfaces, and integration with building management and energy monitoring systems.

Owing to these advantages, digital meters are widely used for energy measurement, sub-metering, power quality analysis, and performance tracking in buildings, industries, and utility networks. Smart meters, a subset of digital meters, further enable remote data transmission and real-time monitoring, supporting informed decision-making and energy efficiency initiatives.

Smart meters: Smart meters represent an advanced evolution of conventional metering systems, enabling detailed, real-time measurement, and intelligent monitoring of resource consumption such as electricity, water, gas, and thermal energy. Unlike traditional meters that provide only cumulative consumption data, smart meters record time-based usage patterns and communicate this information automatically to centralized monitoring platforms, allowing for enhanced visibility and control over resource use, thus, identify inefficiencies, and respond proactively to abnormal consumption or system faults.

By integrating smart meters with building automation systems (BASs), energy management systems (EMSs), and data analytics tools, buildings can implement demand-side management strategies, optimize system operation, and verify the effectiveness of energy conservation measures. Smart meters also enhance transparency and accountability by enabling accurate sub-metering, benchmarking, and performance reporting at the equipment, system, and zone levels.

Compliance for ECSBC 2024 Code (Metering and Sub-Metering)

1. At building mains, installed meters shall monitor energy use (kWh, kVARh, kVAh), energy demand (kW/ kVA), THD (V and I) on a half-hour basis. The metering shall also be displaying current (in each phase and the neutral), voltage (between phases and between each phase and neutral).

   Note Reactive power influences the power factor of the system. 'Power factor' is a key indicator for an efficient energy delivery in AC electrical system. It is a measure of how effectively a specific load consumes electricity to produce work. Understanding of reactive power consumption in highly no linear load driven electrical system helps user to decide on efficient utilization of energy, avoid utility penalty and reduce MD in the system.

2. **Building services sub-meters shall comprise the following:**

   a. Services 1,000 kVA and above shall have permanently installed electrical metering to record demand (kVA), energy (kWh), and total power factor on half hourly basis. The metering shall also display current (in each phase and the neutral voltage (between phases and between each phase and neutral), and total harmonic distortion (THD) as a percentage of total current and voltage.

   b. Services 65 kVA to 1,000 kVA shall have permanently installed electric metering to record demand (kW/kVA), energy (kWh/kVAh), and total power factor (or kVARh) on half hourly basis.

   c. Services less than 65 kVA shall have permanently installed electrical metering to record energy (kWh) on hourly basis.

   d. Submetering for building services shall be as define in Table 51.

   e. Submetering for specific building types shall be as defined in Table 52.

All installed energy meters shall conform to IS 13779 and shall be Class 0.2s or higher accuracy for building-level metering and Class 1s for sub-metering and have an active RS-485 port, with industry standard modbus protocol. For power quality measurement at building level, the energy meter located in PCC shall be Class A as per IEC 61000-4-7 and IEC 61000- 4-30.

Sub-metering requirements for different services shall be as defined in Table 52 and additional sub-metering for specific building types shall be as defined in Table 53.

Table 53 Sub-metering: minimum requirement for separation of electrical load.

Building contract demand		
Particular	120 kVA to 250 kVA	**Greater than 250 kVA**
HVAC system and components	Required	**Required**
Interior and exterior lighting	Not required	**Required**
Domestic hot water	Not required	**Required**
Plug loads	Not required	**Required**
Renewable power source	Required	**Required**
Public health engineering (PHE) pumps	Not required	**Required**
Sewage treatment plant (STP)	Required	**Required**
Water treatment plant (WTP)	Required	**Required**

Table 54 Additional sub-metering requirements for specific building types

Mandatory requirement of sub- metering of services for specific building types	
Shopping complex	**Façade lighting, common area lighting and exterior lighting**
Shopping complex	**Elevator, escalators and moving walks**
Business	**Data centres and floor loads**
Hospitality	**Commercial kitchens, laundry, and total guest rooms**
Hospital	**Medical equipment, UPS power, total IPD rooms, kitchen, and laundry**
For tenant-based building, tenants must be provided with tap-off points to install electrical sub-meters.	

Questions for Building Electrical System

Section A: Objective Questions (MCQs) – 10 Nos

1. Which of the following best defines power factor?

A. Ratio of reactive power to apparent power
B. Ratio of active power to apparent power
C. Ratio of apparent power to reactive power
D. Ratio of voltage to current

2. As per ECSBC 2024, maximum allowable power distribution losses in ECSBC Plus buildings are:

A. 3%
B. 2%
C. 1%
D. 5%

3. Harmonics in electrical systems are mainly caused by:

A. Linear resistive loads
B. Balanced three-phase loads
C. Non-linear electronic loads
D. Capacitor banks

4. Which harmonic mitigation method injects equal and opposite harmonic currents?

A. Passive filter
B. Capacitor bank
C. Active filter
D. Isolation transformer

5. No-load losses in a transformer occur due to:

A. Copper resistance
B. Load current
C. Leakage reactance
D. Eddy current and hysteresis

6. Which motor type can operate at leading power factor?

A. Induction motor
B. DC motor
C. Slip ring motor
D. Synchronous motor

7. As per ECSBC, minimum motor efficiency class for ECSBC compliant buildings is:

A. IE2
B. IE3
C. IE4
D. IE5

8. Which UPS component converts DC back to AC supply?

A. Rectifier
B. Battery bank
C. Inverter
D. Static bypass

9. As per IS 17515, lifts in ECSBC Super buildings shall meet energy class:

A. A
B. C
C. D
D. B

10. Smart meters differ from conventional meters mainly because they:

a) Measure only kWh
b) Enable real-time data communication
c) Have lower accuracy
d) Operate without sensors

Section B: Short Answer Questions- 5 Nos

Q1. Define Harmonics and their method of rectification.

Q2. Explain the working principle of an Automatic Power Factor Controller (APFC)

Q3. What are the consequences of Motor Over Sizing ?

Q4. A commercial building has an average electrical load of 800 kW operating at a power factor of 0.82 lagging. The building intends to improve the power factor to 0.98 lagging to comply with ECSBC Plus requirements. Calculate the required capacitor bank size (kVAr).

Q5. A 1000 kVA transformer installed in the building has no load losses 2.5kW and full load copper losses are 10 kW. The transformer operates on 60% rated capacity, and then calculates the efficiency of the transformer.

Define power factor in building electrical systems. Explain two major consequences of operating a building with a low power factor.

Section C: Long Answer Questions – 2 Nos

Q1. Discuss how non-linear loads, power factor and total harmonic distortion (THD) on transformer losses affect the energy efficiency in the commercial building. What are the possible strategies to reduce these losses and improve the energy efficiency in the building?

Q2. Explain the logic of using IE4 Super Premium efficiency motors combined with Variable Frequency Drives (VFDs) in building pumping systems. Discuss the scientific superiority of VFD control over mechanical throttling and how the ECSBC's sub- metering framework ensures verifiable energy accountability for different building services.

Answer Key for MCQs

1. B	6. D
2. B	7. B
3. C	8. C
4. C	9. A
5. D	10. B

Short Answer Question 4 = Capacitor bank size =396kVA ~ 400kVA

Short Answer Question 5 = Transformer efficiency 99.0%

7. RENEWABLE ENERGY SYSTEM

Globally, studies have shown that if renewable energies (RE) are not implemented on a large scale, CO2 emissions that are related to the energy sector would increase 6% from 33 Gigatonnes (GT) in 2015 to 35 GT in 2050. To be able to keep the commitment of limiting the global surface temperature rise under 2°C, for compliance to the Paris Agreement, emissions need to fall to 9.7GT in 2050. The RE combined with energy efficiency, has the potential to reduce up to 95% emissions. From being a contributor of 14% in total primary energy supply in 2015, the share of RE would rise to 63% by 2050 (Gielen, et al. 2019).

The electricity consumption in India is projected to be 1,280 terawatt-hour (TWh) by 2040. India in its Intended Nationally Determined Contribution has committed to achieve 40% cumulative electric power installed capacity from non-fossil fuel-based energy resources, that is, RE by 2030 (SSIRU 2020). As of April 2026 , India had installed total of 283.46 GW of capacity from non-fossil fuel sources has been installed in the country as on 31.03.2026. This includes 274.68 GW Renewable Energy (150.26 GW Solar Power, 56.09 GW Wind Power, 11.75 GW Bio Energy, 5.17 GW Small Hydro Power, 51.41 GW Large Hydro Power) and 8.78 GW Nuclear Power capacity.

With the growing demand of energy and the concern about energy security, new and renewable sources of energy have been gaining increasing significance. After the oil shocks in the 1970s, the new and renewable sources of energy were majorly driven by energy self-sufficiency. The spike in the oil prices, unsurety about its supply, and the adverse impact on the balance of payments position led to the establishment of the Commission for Additional Sources of Energy in the Department of Science and Technology in March 1981.

Examples of RE technologies that can be incorporated with building energy systems include solar photovoltaic (PV) systems, solar thermal (domestic water heating and space heating), solar ventilation At preheating, geothermal heat pump, wind turbines, and biomass systems (Hayter and Kandt 2011).

7.1 Renewable Energy Technologies

Renewable energy, by definition, means energy generated using, natural resources, which are replenishable and have low negative impact on the environment. While the above-mentioned natural resources are available in abundance, especially in a long-term haul. However, their availability at a given point is restricted.

The Ministry of New and Renewable Energy (MNRE) classifies the following as renewable sources of energy.

Solar Energy

Solar energy is the energy derived from the sun in the form of electromagnetic radiation. It is the most abundant, inexhaustible, and clean source of RE available on earth. The sun emits enormous amounts of energy every second, a small fraction of which reaches the earth's surface and can be harnessed for useful applications such as electricity generation, heating, cooling, and industrial processes. In India, solar energy holds strategic importance due to high solar insolation, increasing energy demand, and the need to reduce dependence on fossil fuels.

Solar Photovoltaic System

When solar radiation falls on a PV cell, the energy from sunlight, in the form of photons, is absorbed by the semiconductor material of the cell, typically silicon. These photons transfer their energy to the electrons present in the material. As a result, some electrons gain sufficient energy to break free from their atomic bonds

and move from the valence band to the conduction band. This separation of charge creates an electric potential across the cell. Owing to the built-in electric field within the PV cell, the freed electrons begin to move in a specific direction, generating an electric current. This electricity is produced in the form of direct current (DC). Since most electrical appliances and the utility grid operate on alternating current (AC), the DC electricity generated by the PV cell is converted into AC using an inverter, making it suitable for practical applications such as household, commercial, and grid-connected use.

Type of Solar PV System

Grid-connected solar PV system: is a solar power system that is directly connected to the utility electricity grid. In this system, electricity generated by solar PV panels is first used to meet the on-site electrical demand of a building or facility, and any surplus electricity is exported to the grid. The system mainly consists of solar PV modules, a grid-tied inverter, mounting structures, and safety and metering equipment. The inverter converts the DC electricity produced by the solar panels into AC and synchronizes it with the grid in terms of voltage and frequency.

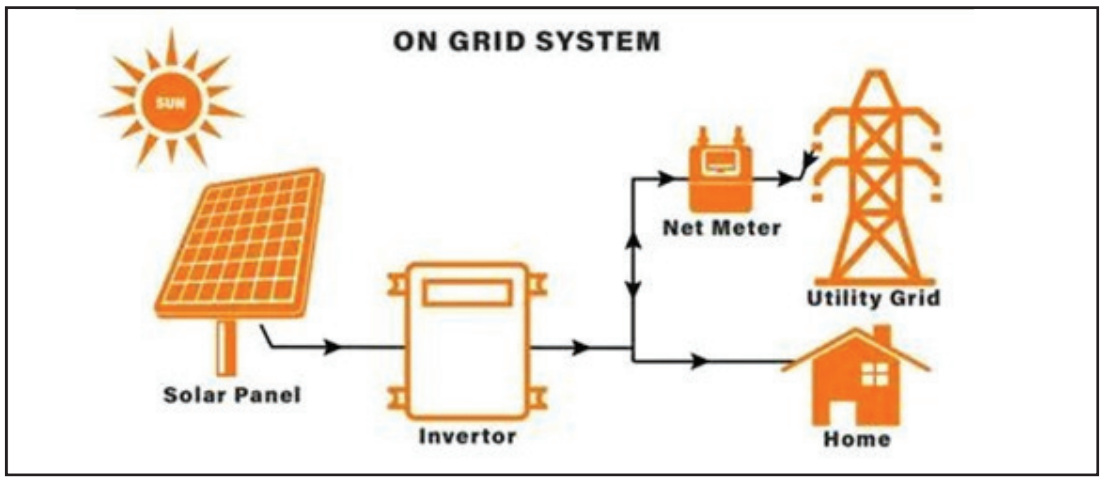


Figure 111 Components of a grid-connected solar PV system

Grid-connected systems generally do not require battery storage, which makes them more cost-effective and efficient compared to off-grid systems. Net metering or gross metering mechanisms are commonly used to account for the electricity exported to the grid, thereby reducing electricity bills. Grid-connected solar PV systems are widely used in residential, commercial, institutional, and utility-scale applications and play a significant role in promoting clean and sustainable energy generation.

Off-grid solar PV system: is a stand-alone power generation system that operates independently of the utility electricity grid. It is designed to supply electricity in remote, rural, or isolated locations where grid access

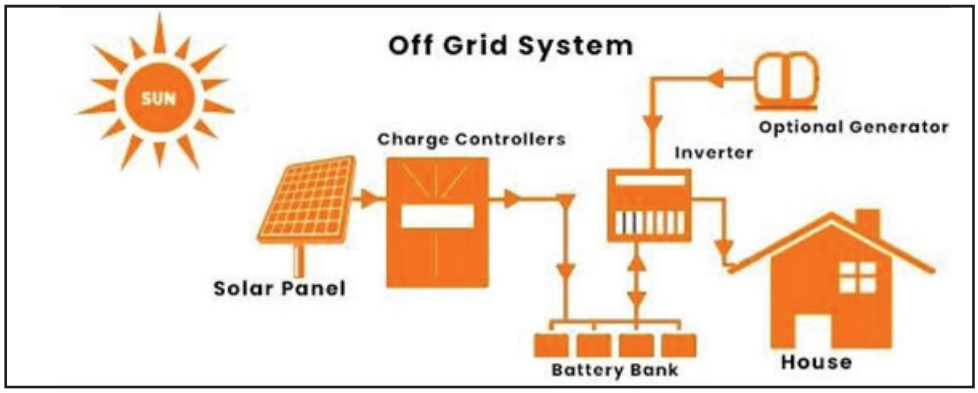


Figure 112 Components of an off-grid-connected solar PV system

is unavailable or unreliable. In this system, solar PV panels generate DC electricity from sunlight, which is regulated by a charge controller to protect the batteries from overcharging or deep discharge. The electricity is stored in batteries and later converted into AC using an inverter for use in household, commercial, or institutional applications. Since the system relies entirely on solar energy and stored power, careful system sizing and energy management are essential to ensure continuous supply. Off-grid solar PV systems provide a clean, reliable, and decentralized energy solution, particularly for rural electrification, telecom towers, water pumping, and emergency power needs.

Hybrid solar PV system: is a combination of a grid-connected system and battery-based energy storage, designed to provide both reliability and flexibility in power supply. In this system, solar PV panels generate electricity that can be used to meet on-site demand, stored in batteries for backup, or exported to the utility grid depending on availability and system configuration. During grid outages, the hybrid system can operate in island mode, supplying power from the batteries and solar panels to critical loads. The system uses a hybrid inverter that manages power flow between the solar panels, batteries, loads, and the grid. Hybrid solar PV systems are particularly suitable for applications where uninterrupted power supply is essential, such as hospitals, data centres, and commercial buildings, as they combine the benefits of energy savings, backup power, and efficient utilization of RE.

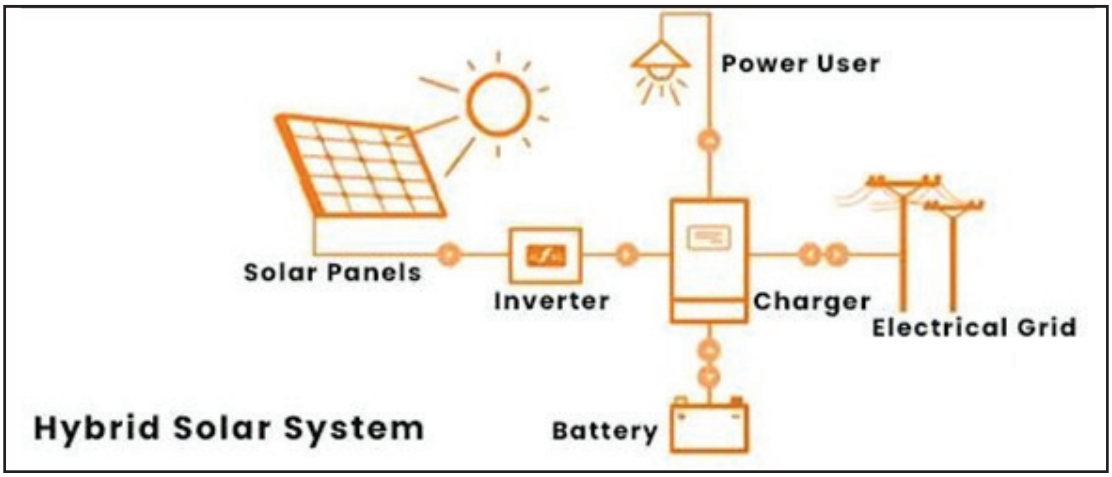


Figure 113 Components of hybrid solar PV system

ENS Code Compliance (Renewable Energy Generation Zone)

Mandatory: The Renewable Energy Generation Zone (REGZ) shall be free of any obstructions within its boundaries and from shadows cast by objects adjacent to the zone. It must adhere to the installation standards of solar PV systems and meet the requirements for a minimum BEE 3-star label. It shall comply with the requirements of installing solar PV: equivalent to at least 10% of the plot area.

Incremental points will be awarded in ENS if RE systems are equivalent to at least 13% or 16% of the plot area. 1 kWp = 10 m2 area as per MNRE guidelines

ECSBC Code Compliance

Renewable Energy Generation (REGZ): The building shall have onsite RE generation capacity in meeting at least 4% of the total contract demand of the building on annual basis or covering minimum of 50% of the available roof area, which ever feasible for ECSBC buildings.

In addition, the rooftop solar system considered for building, should give yield at least 0.46 kWh/sq. m/yr. or more Additional requirement for ECSBC Plus and Super ECSBC buildings are detailed in Table 53.

Table 53 Additional requirements as per ECSBC

Building type	Code	Minimum capacity to be installed in REGZ
All building types	ECSBC Plus	Minimum 7.5% of total contract demand
All building types	Super ECSBC	Minimum 15% of total contract demand

If states having open access policy, the buildings shall comply in meeting above demand by using combination of off- site green power procured from local energy company along with on-site installed renewable energy sources to meet the target mentioned above.

Building-integrated photovoltaic (BIPV)

It is a solar PV system in which PV modules are integrated directly into the building envelope, such as roofs, façades, skylights, windows, or shading devices, rather than being mounted separately.

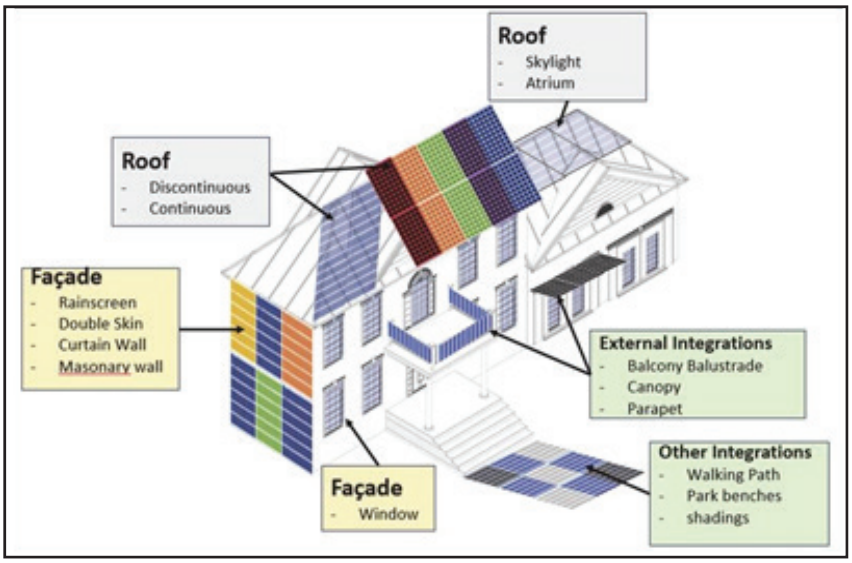


Figure 114 Different types of BIPV systems

In a BIPV system, the solar panels serve a dual function by acting as both a construction material and a power-generating unit. These systems generate electricity from sunlight and supply power to the building, either through a grid-connected, off-grid, or hybrid configuration. The BIPV enhances aesthetic appeal, optimizes space utilization, and reduces the need for conventional building materials, thereby contributing to energy-efficient and sustainable building design. Although the initial cost of BIPV systems is higher and requires careful architectural and electrical planning, they play an important role in green buildings and are increasingly promoted under sustainable building practices and rating systems.

BIPV Classification

Roof-integrated: In these systems PV modules are incorporated directly into the roof structure of a building, replacing conventional roofing materials such as tiles, shingles, or metal sheets. In this system, the PV elements serve a dual purpose by acting as the primary weatherproof roof covering while simultaneously generating electricity from solar radiation. Roof-integrated BIPV systems are designed to maintain structural integrity,

provide protection against rain and wind, and ensure thermal performance, while also contributing to the building's energy requirements. These systems are particularly effective because roofs receive high solar exposure, leading to improved energy generation efficiency. Although roof-integrated BIPV systems require careful architectural and electrical planning and have higher initial installation costs compared to traditional rooftop-mounted PV systems, they offer long-term benefits such as improved aesthetics, optimized space utilization, and reduced dependence on conventional energy sources, making them suitable for sustainable and green building applications.

Façade integrated: These systems involve the incorporation of PV modules into the external vertical or inclined walls of a building, forming an integral part of the building façade. In this system, PV panels replace conventional façade materials such as glass, cladding panels, or curtain walls, thereby performing both architectural and energy-generating functions. Façade-integrated BIPV systems contribute to electricity generation while also influencing the building's thermal and visual performance by providing shading, reducing heat gain, and enhancing façade aesthetics. Although their energy yield is generally lower than roof-integrated systems due to vertical orientation, they are particularly valuable in high-rise and dense urban environments where roof space is limited. With proper design and orientation, façade-integrated BIPV systems support sustainable building practices by improving energy efficiency, reducing reliance on fossil fuels, and integrating renewable energy seamlessly into building architecture.

Window and skylight integrated: These systems use semi-transparent photovoltaic modules that are incorporated into building openings such as windows, skylights, atriums, and glazed roofs. In these systems, the PV modules replace conventional glass while allowing a controlled amount of natural daylight to enter the interior spaces, thereby maintaining visual comfort. At the same time, they generate electricity from solar radiation, contributing to the building's energy supply. Window and skylight- integrated BIPV systems also help reduce glare and solar heat gain, which can lower cooling loads and improve indoor thermal comfort. Although their power generation efficiency is lower compared to opaque PV systems due to partial transparency, they offer significant architectural and environmental benefits. These systems are particularly suitable for commercial buildings, institutional facilities, and green buildings where daylighting, aesthetics, and energy efficiency are key design considerations.

Shading device integrated: These systems involve the installation of PV modules on architectural shading elements such as canopies, louvers, pergolas, and sunshades. In this configuration, the PV modules serve a dual purpose: they provide protection from direct sunlight, reducing solar heat gain and glare inside the building, while simultaneously generating electricity from solar radiation. By combining shading and energy generation, these systems enhance both thermal comfort and energy efficiency in buildings. Shading device-integrated BIPV is particularly effective on façades with high solar exposure or over windows and outdoor areas, where they can reduce cooling loads and improve occupants' comfort. Although the electricity yield may be moderate compared to roof-mounted systems due to the angle and partial shading, these systems are valued for their multi-functionality, aesthetic integration, and contribution to sustainable building design.

Solar Thermal Systems

Solar thermal energy systems operate by harnessing the heat from sunlight rather than converting it directly into electricity, as in PV systems. When solar radiation strikes a solar collector, it is absorbed by a working fluid (such as water, oil, or air) or a heat-absorbing surface, which increases the fluid's temperature.

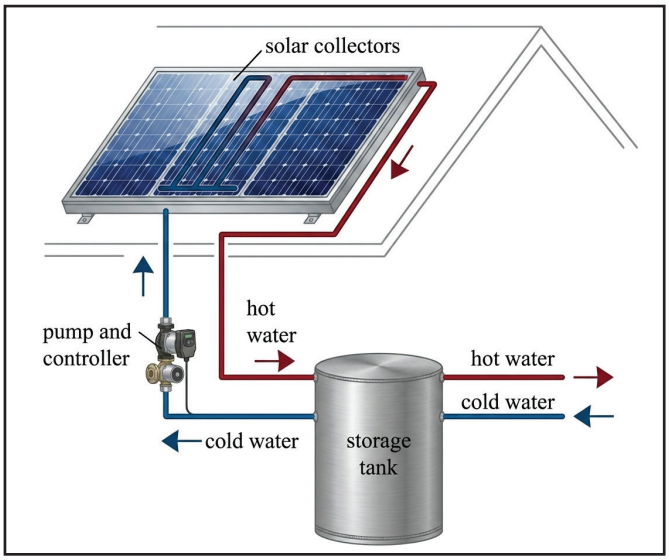


Figure 115 Components of solar water-heating system

This heat can then be directly used for thermal applications such as water heating, space heating, industrial process heat, or for generating steam to drive turbines in concentrated solar power (CSP) plants.

Categories of Solar Thermal System

There are two main categories of solar thermal systems based on their operating principle:

1. Low-temperature systems (e.g., solar water heaters)
2. High-temperature systems (e.g., concentrated solar power or CSP)

Low-temperature systems: Low-temperature solar thermal systems are designed to capture solar energy and convert it into heat for applications requiring temperatures typically below 100°C, such as domestic hot water, space heating, or swimming pool heating. The most common example of this category is the solar water heating system.

Solar water-heating system consists of three main elements:

1. Solar collector
2. Insulated piping
3. Hot water storage tank

Solar water heaters are typically described according to the type of collector and the circulation system.

High-temperature systems: Concentrated solar power (CSP) is a high-temperature solar thermal technology that generates electricity by concentrating direct solar radiation onto a receiver using mirrors or lenses. Unlike solar photovoltaic systems, CSP does not convert sunlight directly into electricity; instead, it converts solar energy into heat, which is then used to produce steam that drives a turbine connected to an electrical generator. The CSP systems are typically deployed in regions with high direct normal irradiance (DNI) and are suitable for large-scale, utility-level power generation. One of the key advantages of the CSP is the possibility of thermal energy storage, allowing electricity generation even after sunset

Basic technologies of concentrated solar power

1) **Parabolic trough system:** In this technology, long, curved mirrors shaped like a parabola concentrate sunlight onto a linear receiver tube placed at the focal line of the trough. A heat transfer fluid, usually

synthetic oil, flows through the receiver and absorbs the concentrated heat. The heated fluid is then used to produce steam in a heat exchanger, which drives a turbine to generate electricity. Parabolic trough systems are the most commercially mature CSP technology and have been widely deployed worldwide.

2) **Solar power tower (central receiver system):** A solar power tower system uses a large field of flat, sun-tracking mirrors called heliostats to reflect sunlight onto a central receiver located at the top of a tall tower. The concentrated solar energy heats a working fluid, commonly molten salt, to very high temperatures. This stored thermal energy is used to generate steam for power production. Power tower systems offer higher operating temperatures and better thermal storage capabilities compared to other CSP technologies.

3) **Linear fresnel reflector system:** The linear fresnel system uses multiple long, flat, or slightly curved mirrors arranged in parallel rows to concentrate sunlight onto a fixed elevated receiver. This system mimics the parabolic trough but uses simpler mirror designs, reducing cost and structural complexity. However, it generally has lower efficiency due to increased optical losses. Linear Fresnel systems are suitable for both power generation and industrial process heat applications.

4) **Parabolic dish system:** A parabolic dish system uses a dish-shaped mirror to concentrate sunlight onto a receiver located at the focal point of the dish. The concentrated heat is typically used to drive a Stirling engine or micro-turbine, producing electricity directly. Parabolic dish systems achieve the highest efficiency among CSP technologies but are usually deployed in small, modular units rather than large power plants.

Solar Thermal System Classification

Active solar water heater: Pumps are used to circulate water or a non-freezing heat transfer fluid from the storage tank through the collectors in the active solar water heater. Active systems are usually more expensive than the passive system, but they are also more efficient.

- **Direct circulation:** A pump is used to circulate water through the collectors and into the buildings; they work well in hot climate.
- **Indirect circulation:** Pumps are used to circulate a non-freezing heat transfer fluid through the collector and a heat exchanger, this heat water which then flows into the building. Indirect systems are popular in cold climates (Christensen 2003).

Passive direct solar water heater: Heat transfer fluid or household water is moved through the system without pumps and electricity in passive direct solar water heater. These systems work during power outages, but they should not be used in cold climates. Passive systems are typically less expensive to purchase and maintain than other types of solar water systems. They are also inherently more reliable and may last longer. However, passive systems are not usually as efficient as active systems.

- **ICS passive solar systems:** These systems may be best in cold climate. They are also good in households with significant daytime and evening hot-water need.
- **Thermosyphon system:** In these systems, water flows through the system when warm water rises as cooler water sinks. In these systems, the collector must be installed below the storage tank so that warm water will rise into the tank. These systems are reliable, but contactors must pay careful attention to roof design because the water in the storage tank is heavy. Thermosyphon passive solar systems are usually less expensive than active systems, but more expensive than ICS systems (Christensen 2003).

ENS Code Compliance (Solar Water Heater)

Mandatory: The installed solar water heater shall meet the minimum efficiency level mentioned in IS 13129 Part (1 and 2) and for the evacuated tube collector the storage tanks shall meet the IS 16542:2016, tubes shall meet IS 16543:2016 and IS 16544:2016 for the complete system, and shall comply with requirements as Solar water Heating system of minimum BEE 3-star label installed in at least 10% of the plot area.

Incremental points: Installing renewable energy systems, equivalent to at least 13% or 16% of the plot area having minimum BEE-3 star labelled solar water-heating system.

100 lpd= 3 m^2 area as per MNRE guidelines

ECSBC Code Compliance

Solar water-heating system shall comply with IS 12976 and shall be minimum BEE 3-star rated.

- **ECSBC:** hospitality and health care in all climatic zones shall have solar water-heating equipment installed to provide at least 40% of the total hot water design requirement, here, exceptions are buildings that install solar PV cells of capacity 5% of total contractual power demand or 200 W/sq. m whichever is less.
- **ECSBC Plus:** Hospitality and health care in all climatic zones shall have solar water-heating equipment installed to provide at least 60% of the total hot water design requirement and balance 40% to be provided by any other hot water-generating systems, here, exceptions are buildings that install solar PV system of capacity 7.5% of total contractual power demand or 300 W/ m^2 whichever is less.
- **Super ECSBC:** Hospitality and health care in all climatic zones shall have solar water-heating equipment installed to provide at least 100% of the total hot water design requirement, here, exceptions are buildings that install solar PV system of capacity 10% of the total contractual power demand or 400 W/ m^2 whichever is less.

In an active solar water-heating system, control systems are used to switch on a circulation pump whenever energy gain is possible through solar collectors. Otherwise, it automatically switches off the pump. A differential thermostat is recommended as it optimizes the energy gain for the system. Use of thermostatic mixing valves to avoid high-temperature water going out from solar panels

Wind Energy

Wind energy is a renewable source of energy that harnesses the kinetic energy of moving air and converts it into useful electrical power using wind turbines. Wind is generated due to the uneven heating of the earth's surface by the sun, which creates pressure differences and causes air to move from high- pressure to low-pressure regions. Wind energy is clean, inexhaustible, and plays a significant role in reducing greenhouse gas (GHG) emissions and dependence on fossil fuels.

When wind flows over the blades of a wind turbine, it creates lift due to the aerodynamic shape of the blades. This lift causes the rotor to rotate. The rotating rotor turns a shaft connected to a generator, either directly or through a gearbox, converting mechanical energy into electrical energy. The electricity produced is then conditioned and supplied to the grid or used locally. The size of wind turbines varies widely. The length of the blades is the biggest factor in determining the amount of electricity a wind turbine can generate. Small wind turbines that can power a single home may have an electric-generating capacity of 10 kilowatts (kW). The largest operating wind turbines have electric-generating capacity of about 15,000 kilowatts (15 megawatts).

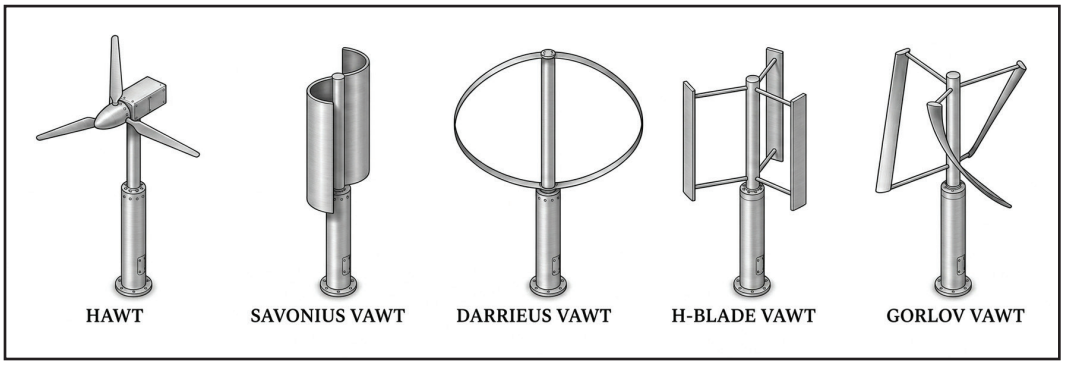


Figure 116 Different type of wind energy turbines that can be used in buildings for energy generation

Small Hydro Energy

Small hydro energy refers to the generation of electricity from flowing or falling water using hydroelectric plants of relatively small capacity, typically up to 25 MW, as classified by the Ministry of New and Renewable Energy (MNRE), Government of India. Unlike large hydro projects, small hydro schemes generally have minimal environmental and social impacts and are considered a renewable and sustainable source of energy.

Small hydro power plants operate by converting the potential and kinetic energy of water into mechanical energy using a water turbine. Water flowing from a higher elevation to a lower elevation is directed through a turbine, causing it to rotate. The turbine shaft is connected to a generator, which converts the mechanical energy into electrical energy. The generated electricity is then transmitted to the grid or used locally.

Types of Small Hydro Power Plants

Small hydro power plants are commonly classified based on their installed capacity, as this determines their scale, application, and level of infrastructure required.

Micro hydro power plants, with a capacity of up to 100 kW, are typically used for village-level or community-based electrification, especially in remote and hilly areas. These systems are often stand- alone, run-of-the-river installations that supply electricity to small settlements, schools, or local industries with minimal environmental impact.

Mini hydro power plants, having capacities ranging from 100 kW to 2 MW, serve small towns, institutional campuses, and localized grid networks. They offer a balance between power output and infrastructure requirements and are usually connected to local or regional grids.

Small hydro power plants, with capacities between 2 MW and 25 MW, are designed for commercial power generation and are generally grid connected. These plants can significantly contribute to regional power supply while still maintaining lower environmental and social impacts compared to large hydroelectric projects.

Waste to Energy

Waste-to-Energy refers to the process of converting waste materials into useful forms of energy, thereby reducing the volume of waste sent to landfills while recovering valuable energy resources. Waste to energy technologies utilize the energy content present in organic and combustible waste streams to produce electricity, thermal energy, biogas, or liquid fuels.

Various types of waste are generated from municipal, industrial, commercial, and agricultural activities. These wastes can be broadly classified into biodegradable and non-biodegradable fractions based on their decomposition characteristics and energy recovery potential.

- **Biodegradable wastes** include food waste, agricultural residues, animal manure, sewage sludge, and organic industrial waste. These materials can be converted into biogas through anaerobic digestion or into fuels through biochemical processes.
- **Non-biodegradable combustible** wastes such as wood waste, paper, cardboard, packaging materials, crop residues, bagasse, rice husk, and certain textile wastes can be used as fuel in combustion, gasification, or pyrolysis systems to generate heat and electricity.

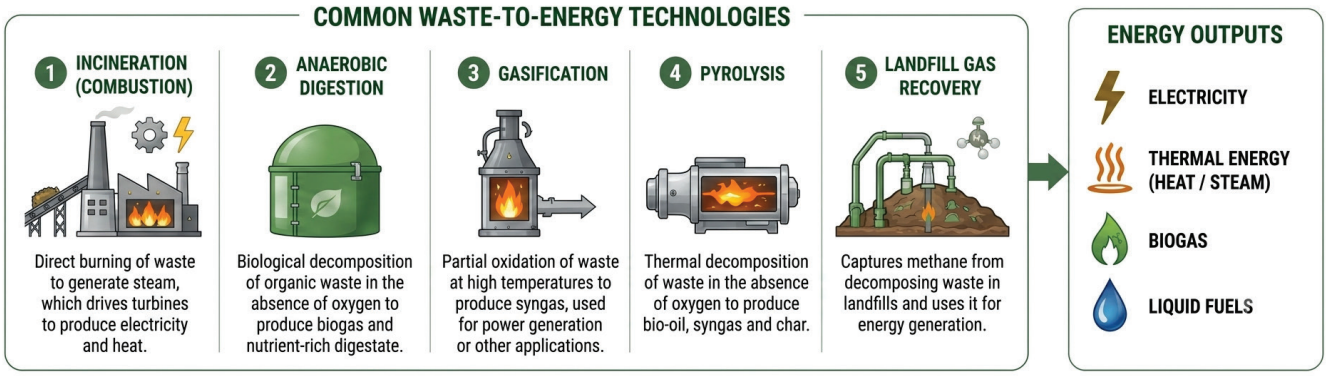


Figure 117 Common waste to energy technologies

Biomass Energy

Biomass is an important renewable source of energy, which is an organic material that comes from plants and animals. Plants absorb the sun's energy in a process called photosynthesis. When biomass is burned, the chemical energy in biomass is released as heat. Examples of biomass and their uses for energy are as follows (U.S. Energy Information Administration 2018):

- Wood and wood processing wastes—burnt to heat buildings to produce process heat in industry and to generate electricity
- Agricultural crops and waste materials—burnt as a fuel or converted to liquid biofuels
- Food, yard, and wood waste in garbage—burnt to generate electricity in power plants or converted to biogas in landfills
- Animal manure and human sewage—converted to biogas, which can be burnt as a fuel.

Geothermal Energy

Geothermal energy is heat derived within the sub-surface of the earth. The earth's shallow ground temperature is at a constant between 50 and 60°F and as we go deeper, it gets hotter. Water and/or steam carry the geothermal energy to the earth's surface. Geothermal energy can be used for heating and cooling purposes or harnessed to generate clean electricity. However, for electricity generation, high or medium temperature resources are needed. Geothermal resources in India have been mapped by the Geological Survey of India. Broad estimate suggests that there could be 10 GW geothermal power potential. Present efforts are towards establishing cost-competitive geothermal potential in India. Though it is not a new source of RE in the global scenario, India is yet to tap into this sector in a widespread manner, hence the MNRE lists it under this category.

Geothermal, energy applications are broadly categorized as follows (NREL, *n.d.*):

- Heat pumps: Heat pumps use the earth's shallow ground temperature for heating and cooling
- Electricity production: Electricity production generates electricity from the earth's heat

- Direct use: Direct use produces heat directly from hot water within the earth

Hydrogen Energy

Hydrogen energy comprises the use of hydrogen and/or compounds containing hydrogen to generate energy. This technology has overwhelming social, environmental, and economic benefits. The dawning of hydrogen energy is being experimented in all sectors including energy production, its storage and distribution, transportation, and heating and cooling of buildings and industry (Miranda 2019). With respect to transportation, major work is being carried out by Indian Institute of Technology (IIT) Delhi, Banaras Hindu University, and Mahindra & Mahindra, which has resulted in the development and demonstration of internal combustion engines run by hydrogen for two-wheelers, three-wheelers, and even mini buses.

Tidal Energy

Electricity can be produced using waves, tides, and currents. The energy contained in ocean waves is captured by converters and used to generate electricity. In the case of tidal, energy is produced by using a barrage to harvest power between high and low tides by tidal-range technologies. Temperature difference between warm surface water and cold deep water is used to produce electricity in the case of ocean thermal energy conversion (Ocean Energy, n.d.)

7.2 Policies and Initiatives of the Government

The national electric grid in India has an installed capacity of 370.106 GW as of 31 March 2020. Renewable energy-based power plants, which also include large hydroelectric plants, constitute 35.86% of India's total installed capacity. The gross electricity generated by utilities in India was 1,372 TWh and the total electricity generation (utilities and non-utilities) in the country was 1,547 TWh during the 2018–19 fiscal year. The gross electricity consumption in 2018–19 was 1,181 kWh per capita. In 2015– 16, electric energy consumption in agriculture was recorded as being the highest (17.89%) worldwide. The per capita electricity consumption is low compared to most other countries despite India having a low electricity tariff.

India has a surplus power generation capacity but lacks adequate distribution infrastructure. To address this, the Government of India launched a programme called 'Power for All' in 2016. The programme was accomplished by December 2018 in providing the necessary infrastructure to ensure uninterrupted electricity supply to all households, industries, and commercial establishments. Funding was made through a collaboration between the Government of India and its constituent states.

The Indian government revised the Solar Mission in 2014. It targets for 100 GW installed capacity of solar electricity by 2022. To reach this ambitious target, the government announced several policies to promote solar energy.

The MNRE is the nodal Ministry of the Government of India for all matters related to new and renewable energy. The broad aim of the Ministry is to develop and deploy new and renewable energy to supplement the energy requirements of the country. The following are some of the policies implemented by the MNRE:

The Electricity Act, 2003: The Electricity Act aimed at generating 10% of the power, supplied by suppliers and distributors to the consumers, using renewable and non-conventional sources of energy.

Tariff Policy, 2006: It is the mechanism of the renewable purchase obligation (RPO) to fix a minimum percentage of the purchase of energy consumption by the states from renewable energy sources.

National Solar Mission: Jawaharlal Nehru National Solar Mission 2010, also known as the Solar Mission, is part of India's National Action Plan on Climate Change. There are three phases to the mission: Phase I (2010–12), Phase II (2013–17), and Phase III (2017–22). Under Phase I, the Rooftop PV and Small-scale Generation

Programme aims to encourage the development of rooftop and ground- mounted solar systems. The Indian government revised the Solar Mission in 2014. It targeted for 100 GW installed capacity of solar electricity by 2022. To reach this ambitious target, the government announced several policies to promote solar energy.

Clean Energy Cess: The Clean Energy Cess was introduced in 2010 to levy the amount of ₹50 to every tonne coal used in the country. The Cess created the National Clean Energy Fund that aims to fund clean energy projects. It provides up to 40% of the total costs of renewable energy projects through the Indian Renewable Energy Development Agency (IREDA). The Cess has now grown to ₹400 per tonne of coal used.

National Offshore Wind Energy Policy: The National Offshore Wind Energy Policy was developed in 2015 to optimize the harnessing of energy from offshore wind. Some of the objectives under this policy are as follows:

- To explore and promote deployment of offshore wind farms in the exclusive economic zone of the country, including those under public–private partnership.
- To promote investment in energy infrastructure.
- To promote spatial planning and management of maritime renewable energy resources in the exclusive economic zone of the country through suitable incentives.
- To achieve energy security.
- To reduce carbon emissions.
- To develop coastal infrastructure and supply chain to support heavy construction and fabrication work and the operation and maintenance (O&M) activities.

Green Energy Corridor Project: The Green Energy Corridor Project aims to integrate electricity produced from renewable sources with conventional power stations in the grid. For evacuation of large- scale renewable energy, the Intra State Transmission System (InSTS) project was sanctioned by the Ministry in 2015–16. The project is being implemented in the eight states by the respective State Transmission Utilities. The Project includes approximately 9,400 km transmission lines and substations of a total capacity of 19,000 MVA. The purpose is to evacuate 20,000 MW of large-scale renewable power and improvement of the grid in the implementing states.

Policy for Repowering of the Wind Power Projects: This policy was released in 2016. Most of the wind turbines installed up to the year 2000 were of capacity below 500 kW and are at sites having high wind energy potential. It is estimated that over 3,000 MW capacity installations are from wind turbines of around 500 kW or below. To optimally utilize the wind energy resources, repowering is required. Repowering policy is aimed to promote optimum utilization of wind energy resources by creating a facilitating framework for repowering. For repowering projects, the IREDA will provide an additional interest rate rebate of 0.25% over and above the interest rate rebates available to new wind projects being financed by IREDA.

Small Hydropower Programme (SHP): The objective of the SHP programme is to encourage the state government entities and independent private producers (IPPs) to set up new small hydro projects to realize the entire 21,000 MW potential in a phased manner. The Programme was launched in 2017. The immediate objective was to encourage IPPs to start work on new projects of aggregate capacity of 1,000 MW, in addition to completing the ongoing projects, to reach a cumulative capacity of 6,000 MW by 2022. The scheme also envisages support to set up watermills for electrical and mechanical applications in remote and far-flung areas.

National Wind–Solar Hybrid Policy: The main objective of the Policy that was launched in 2018 is to provide a framework for promotion of large grid-connected wind–solar PV hybrid system for optimal and efficient utilization of transmission infrastructure and land, reducing the variability in renewable power generation, and

achieving better grid stability. The Policy also aims to encourage new technologies, methods, and ways of using combined operation of wind and solar PV plants. Under the category of wind–solar hybrid power plants, wind turbine generators and solar PV systems will be configured to operate at the same point of grid connection. The amendment replaced the limitation of energy storage in battery to any appropriate capacity of storage.

Programme on Energy from Urban, Industrial, Agricultural Wastes/Residues and Municipal Solid Waste: A total capacity of 56.34 MW has been set up for power generation from waste garbage/material during last three years and current year in the country. A total of 199 WTE projects for generation of biogas/Bio-CNG/ power based on urban, industrial, agricultural waste and MSW have been successfully established in the country. Under this programme, Central Financial Assistance in the form of back-ended subsidy is provided for installation of WTE projects for recovery of energy in the form of biogas/Bio-CNG/power from urban, industrial, agricultural waste/residues, and MSW. The following are the objectives of this programme:

- To promote setting up of projects for recovery of energy in the form of biogas/Bio-CNG/power from urban, industrial, and agricultural waste and captive power and thermal use through gasification in industries.
- To promote setting up of projects for recovery of energy from MSW for feeding power into the grid and for meeting captive power, thermal, and vehicular fuel requirements.
- To promote biomass gasifier for feeding power into the grid or meeting captive power and thermal needs of rice mills/other industries and villages.

Biogas-based Power Generation (Off-grid) and Thermal Application Programme (2017–18 to 2019–20): Biogas plants are reliable sources of decentralized renewable energy (DRE) for heating, cooking as well as generating electricity/power generation and thermal energy application alternatives in our country. To promote this decentralized renewable energy source (DRES) of power generation, specifically in the small capacity range (3–250 kW) and thermal energy for heating/cooling from the biogas produced from biogas plants of 30 m^3 to 2,500 m^3 size, operated based on the availability of required quantity of biodegradable organic waste(s).

The Biogas-based Power Generation (Off-grid) and Thermal Application Programme (BPGTP) is being implemented by the agriculture and rural development departments of the states and dairy cooperatives. However, the Programme is also implemented through the state renewable energy agencies, biogas development and training centres, Khadi and Village Industries Commission and National Dairy Development Board in states where agriculture and state rural development departments have not been able to implement.

The PM–Surya Ghar: Muft Bijli Yojana, is a flagship Government of India initiative aimed at accelerating the adoption of rooftop solar energy across residential households. The scheme seeks to provide up to 300 units of free electricity per month to one crore households by supporting the installation of rooftop solar photovoltaic (PV) systems through financial subsidies covering up to 40% of installation costs. By promoting decentralized renewable energy generation, the programme aims to reduce household electricity expenses, strengthen energy self-reliance, and decrease dependence on conventional energy sources.

Building Star Labeling Programme : The Building Star Labelling Programme of the Bureau of Energy Efficiency (BEE),is a performance-based initiative designed to promote energy efficiency in the building sector by providing a simple and transparent framework to rate buildings based on their actual energy consumption. Primarily applicable to commercial office buildings with at least one year of operational data, the programme evaluates buildings using the Energy Performance Index (EPI), defined as the annual energy consumption per unit of built-up area (kWh/m^2/year), where a lower EPI signifies higher efficiency. The rating system assigns buildings a star rating from 1 to 5 stars, with 5-star buildings representing the highest level of energy performance, and benchmarks are differentiated across India's various climatic zones—such as composite, hot and dry, warm and humid, temperate, and cold—to ensure fair comparison.

Shunya Labeling Programme : BEE's Shunya Labelling Programme recognizes Net Zero Energy Buildings (NZEB) and Net Positive Energy Buildings (NPEB). NZEB is one that relies on renewable sources to produce as much energy as it uses, usually as measured over the course of a year. NPEB is a net-positive energy building is one that relies on renewable sources to produce as much energy as it uses and supplies excess generated electricity to grid, usually as measured over the course of a year. Data required includes building's built-up area, conditioned and nonconditioned area, type of building, hours of operation of the building in a day, climatic zone in which building is located, and other related information of the facility.

Net Zero emissions target by 2070: The net zero target was articulated by Narendra Modi during his address at COP26 in Glasgow in November 2021. The announcement formed part of India's broader climate action framework known as the "Panchamrit" strategy. India's climate commitments are also aligned with the global framework established under the Paris Agreement, which aims to limit global temperature rise to well below 2°C above pre-industrial levels. As per report by Niti Ayog "Scenarios towards viksit bharat and net zero, several sectors are identified for approach to net zero including Power Sector, Transport, Industry, Buildings, Agriculture and waste. In Building sector this target is being pursued through several policies/ programmes including Improving energy efficiency; Implementing codes and standards for new construction; Managing cooling demand and; Embedding circularity and waste recovery.

Questions for Renewable Energy Systems

Section A: Objective Questions (MCQs) – 10 Nos

1. The primary reason for large-scale adoption of renewable energy is to:
- A. Reduce electricity tariffs
- B. Improve indoor comfort
- C. Mitigate climate change and reduce CO_2 emissions
- D. Increase fossil fuel reserves

2. As per India's Intended Nationally Determined Contribution (INDC), the target for non- fossil fuel-based installed electricity capacity by 2030 is:
- A. 40%
- B. 25%
- C. 30%
- D. 50%

3. Which renewable energy source contributes the largest potential for building-level electricity generation in India?
- A. Wind energy
- B. Solar energy
- C. Biomass
- D. Small hydro

4. In a grid-connected solar PV system, excess electricity generated is:
- A. Exported to the utility grid
- B. Stored in batteries
- C. Wasted as heat
- D. Converted to DC

5. Which component converts DC electricity generated by PV modules into AC electricity?
- A. Charge controller
- B. Battery
- C. Transformer
- D. Inverter

6. As per ECSBC 2024, the minimum onsite renewable energy generation requirement for ECSBC buildings is:
- A. 2% of total contract demand
- B. 4% of total contract demand
- C. 7.5% of total contract demand
- D. 10% of total contract demand

7. Building Integrated Photovoltaic (BIPV) systems differ from conventional PV systems because they:
- A. Are installed only on the ground
- B. Replace building envelope materials
- C. Always require battery storage
- D. Operate only off-grid

8. Which solar thermal system operates without pumps and electrical controls?

A. Active indirect system

B. Active direct system

C. Concentrated solar power system

D. Passive thermosyphon system

9. Which waste-to-energy technology produces biogas through anaerobic digestion?

A. Incineration

B. Pyrolysis

C. Gasification

D. Bio methanatio

10. The PM–Surya Ghar: Muft Bijli Yojana primarily promotes:

A. Utility-scale solar plants

B. Rooftop solar for residential buildings

C. Offshore wind farms

D. Biomass gasifiers

Section B: Short Answer Questions- 5 Nos

Q1. Differentiate between grid-connected, off-grid, and hybrid solar PV systems.

Q2. Explain Concentrated Solar Power and Its Technologies.

Q3. Describe biomethanation technology and its advantages in waste-to-energy applications

Q4. Discuss the role of Building Integrated Photovoltaic (BIPV) systems in sustainable building design.

Q5. Explain different type of biomas energy system.

Section C: Long Answer Questions – 2 Nos

Q1. Discuss the major renewable energy policies and initiatives implemented by the Government of India. Explain the objectives and significance of the National Solar Mission, Green Energy Corridor Project, and PM–Surya Ghar: Muft Bijli Yojana

Q2. Explain solar photovoltaic and solar thermal technologies in detail. Discuss the types of solar PV systems and elaborate on ECSBC 2024 and ENS 2024 code requirements related to solar PV and solar water heating systems in buildings

Answer Key for MCQs

1. C	6. B
2. A	7. B
3. B	8. D
4. A	9. D
5. D	10. B

8. WHOLE BUILDING PERFORMANCE

Evaluation of Energy performance through the Whole Building Performance (WBP) approach is a comprehensive compliance pathway under the ECSBC 2024 that evaluates the overall energy performance of a building rather than prescribing individual component-wise requirements. Unlike the prescriptive or system-based compliance methods, the WBP approach relies on building energy simulation to compare the annual energy performance of a proposed building against a baseline building that complies with ECSBC-defined reference parameters. Compliance is demonstrated when the proposed design achieves an energy performance index (EPI) or percentage energy savings (PESs) that is equal to or better than the ECSBC 2024 requirements for the applicable building typology and climate zone. This method encourages integrated design, innovation, and performance-driven decision-making from early design stages.

8.1 Whole Building Performance Approach

A thorough understanding of the WBP approach is essential, as it forms the basis for evaluating complex buildings, high-performance designs, and projects seeking optimization beyond minimum code compliance. This chapter explains the principles, methodology, modelling requirements, compliance criteria, documentation, and verification process prescribed in the ECSBC 2024 Manual. The effectiveness of the WBP simulation largely depends on the optimization of multiple integrated building systems and design strategies, each of which contributes to reducing overall energy consumption while maintaining occupants' comfort and functionality. Key strategies evaluated through whole building simulation include:

a) Building envelope (fenestration and opaque construction)

- Optimization of wall and roof assemblies to reduce conductive heat transfer.
- Selection of efficient fenestration with appropriate U-value, Solar Heat Gain Coefficients, & Visual Light Transmission for Daylighting.

b) Comfort systems and controls (natural/mechanical ventilation and temperature control)

- Efficient heating, ventilation, and air-conditioning (HVAC) system selection based on building type and climate zone.
- Integration of natural ventilation strategies where feasible to reduce mechanical cooling demand.
- Zoning of thermal systems to match occupancy and usage patterns.

c) Lighting systems and controls (interior and exterior)

- Use of high-efficacy lighting fixtures to reduce lighting power density.
- Optimization of lighting layout to meet illumination requirements with minimum energy use.
- Implementation of automatic lighting controls such as occupancy sensors, daylight sensors, and time scheduling to limit unnecessary operation.

d) Electrical and renewable energy systems

- Selection of energy-efficient transformers and motors with reduced losses.
- Use of variable frequency drives for motors and fans to match load conditions.
- Integration of on-site renewable energy systems, such as solar photovoltaic (PV) installations.

e) Water management and control systems

- Use of energy-efficient pumps for water supply and circulation
- Optimization of pump operation through proper sizing and control strategies.
- Selection of efficient water heating systems, including heat pumps or solar water heaters

f) Indoor environmental quality (thermal comfort)

- Maintenance of indoor thermal conditions within acceptable comfort ranges.
- Balancing energy-efficiency measures with occupants' comfort requirements.
- Consideration of air movement, temperature uniformity, and humidity control.

Compliance with ECSBC 2024 under the whole building performance (WBP) method is demonstrated by comparing the modified energy performance index (MEPI) of the proposed building with that of the ECSBC-defined baseline building. For ECSBC compliance, the MEPI of the proposed building is required to be equal to the baseline MEPI, whereas for ECSBC Plus and Super ECSBC, the proposed building must achieve a lower MEPI than the baseline, along with meeting the minimum percentage energy savings (PESs) requirements as specified in Section 12.6 of the ECSBC.

Annual Energy Consumption of a Building : Annual energy consumption, expressed as kilowatt-hours of electricity per year per unit floor area (kWh/m²·year), is adopted as the primary performance metric to enable a consistent, comparable, and climate-responsive assessment of building energy efficiency using approved simulation tools and standardized climatic data. This approach emphasizes a holistic evaluation of building energy performance, integrating the combined impact of:

- **Building envelope characteristics:** orientation, glazing, insulation, shading and thermal performance.
- **Building systems:** HVAC, lighting, electrical systems, and equipment efficiencies), and
- **Operational assumptions:** schedules, internal loads, and usage patterns as defined by the Code.

Energy sources other than electricity that are used in the building shall be converted to kWh of electric energy at the rate of 0.75 kWh per mega-joule as per ECSBC Section 12.2. By accounting for all energy sources through conversion to a common electrical energy equivalent, the WBP method ensures that design trade-offs are assessed on their net effect on annual energy use. The intent is to encourage integrated design strategies that optimize interactions between envelope and systems, leading to improved energy performance at the building level, while acknowledging that simulated results represent standardized compliance benchmarks rather than predictions of actual operational energy consumption.

8.2 Key Concepts

Whole building performance: A performance-based compliance method under ECSBC 2024 that allows buildings to demonstrate code compliance by comparing the simulated annual energy consumption of a proposed building against an ECSBC-defined baseline building. It serves as an alternative to prescriptive and system-based compliance paths.

Baseline building: A hypothetical reference building developed from the proposed design but modified to comply with mandatory and standardized ECSBC requirements. The baseline building serves as the benchmark against which the proposed building's energy performance is evaluated and remains the same across ECSBC, ECSBC Plus, and Super ECSBC compliance levels.

Proposed building: The building design submitted for approval, modelled in the energy simulation to reflect the actual design parameters, including envelope properties, HVAC systems, lighting systems, controls, and renewable energy systems, in accordance with ECSBC 2024 mandatory requirements and modelling rules.

Annual energy consumption: The total energy consumption of the building over one year, expressed in kWh/m²·year, calculated using an approved energy simulation program. All non-electric energy sources are converted to equivalent electrical energy using ECSBC-specified conversion factors.

Percentage energy savings (PESs): A metric used to quantify the energy performance improvement of the proposed building relative to the baseline building. The PES is mandatory for demonstrating compliance with ECSBC Plus and Super ECSBC levels and varies by building type and climate zone.

Modelled Energy Performance Index (MEPI): An energy performance indicator used to assess compliance under the WBP method, derived from simulated annual energy use and used for comparison between baseline and proposed buildings.

Energy simulation program: A computer-based software tool capable of performing hourly (8,760 hours) energy simulations, modelling thermal zones, HVAC part-load performance, economizers, schedules, and producing detailed end-use energy reports to evaluate and compare the energy performance of baseline and proposed buildings in accordance with ECSBC 2024 modelling rules.

Operational schedules: Time-dependent inputs that define hourly variations in occupancy, lighting use, equipment loads, thermostat set-points, and HVAC operation throughout the year, used in energy simulation. These schedules must be modelled identically for both the proposed and baseline buildings, except where ECSBC explicitly permits differences to represent specific energy efficiency measures.

Thermal zone: A thermal zone is a building area with uniform thermal conditions, internal loads, and control requirements, modelled as a single zone in the energy simulation. ECSBC 2024 specifies zoning rules based on perimeter/core location, orientation, usage, and HVAC system type as per ECSBC 2024 type to accurately capture thermal behavior and system performance.

Coefficient of performance (COP) and energy efficiency ratio (EER): The COP and EER are measures of HVAC equipment efficiency, representing the ratio of cooling or heating output to energy input, with higher values indicating better energy performance as required under ECSBC 2024.

Variable refrigerant flow (VRF): An HVAC system that varies the flow of refrigerant to multiple indoor units based on real-time load demand, enabling high part-load efficiency and precise temperature control, and commonly evaluated under the WBP approach.

Demand-controlled ventilation (DCV): A ventilation strategy that modulates outdoor air supply based on occupancy or indoor air quality indicators (such as CO_2 concentration), reducing unnecessary ventilation energy use while maintaining acceptable indoor air quality as per ECSBC 2024 intent.

8.3 Standards and Codes

To perform WBP simulation under the ECSBC 2024, several national and international standards must be followed to ensure that the modelling process is compliant with regulatory expectations. These standards collectively guide how building inputs are defined, how the baseline and proposed models are constructed, and how simulation tools are validated for accuracy and robustness. Together, they form the framework within which whole building energy simulation is conducted and evaluated. The following are the key codes and standards applicable for conducting whole building energy simulation as required:

ANSI/ASHRAE Standard 140: This is the primary and most direct standard required for WBP. The ECSBC mandates that any software used for WBP must be validated against ASHRAE 140. It ensures that the simulation

engine used for annual energy performance can reliably model loads, HVAC systems, schedules, and climate responsiveness which is the core performance-simulation standard.

National Building Code of India (NBC 2016): The NBC establishes the foundational indoor environmental and operational conditions that both the baseline and proposed building models must maintain. The NBC provides mandatory indoor temperature set-points, ventilation rates, humidity limits, and space-function-based occupancy densities. In the simulation, these requirements translate into indoor thermal set-points, minimum fresh-air quantities, occupancy schedules, and internal loads for activity-based spaces. The NBC ensures that the model reflects realistic building operation and that all energy use predictions are grounded in nationally accepted comfort and ventilation requirements.

Bureau of Indian Standards (BIS) specifications: The BIS supply the technical methods for determining material properties ensuring accurate and nationally consistent modelling inputs. The ECSBC 2024 references a limited set of BIS specifications, primarily for thermal insulation materials such as IS 3792, IS 8183 & IS 9842.

8.4 Design and Implementation Strategies

Building energy modelling (BEM): The BEM under the ECSBC 2024 WBP method involves developing two energy simulation models - a baseline building and a proposed building to evaluate compliance based on annual energy performance.

The baseline building model represents a standardized reference building with the same geometry, orientation, floor area, occupancy, and operating schedules as the proposed design, but with envelope properties, lighting power densities, HVAC system types, efficiencies, and control strategies set to the minimum prescriptive requirements of ECSBC 2024. It establishes a consistent benchmark for energy performance comparison.

The proposed building model reflects the actual design parameters, incorporating the as-designed envelope, lighting systems, HVAC configurations, efficiencies, and control strategies. Both models are simulated using identical climatic data, internal loads, ventilation rates, and schedules as prescribed by the Code.

Mandatory requirement: Compliance with the WBP method under the ECSBC 2024 requires that all mandatory provisions specified in Sections 5.2, 6.2, 7.2, 8.2, 9.2, and 11.2 of the ECSBC are fully met. These sections establish the minimum mandatory requirements related to key building components and systems and are prerequisites for demonstrating compliance through the WBP method. The mandatory provisions ensure that essential baseline levels of energy efficiency and operational performance are achieved for the building envelope, lighting systems, HVAC systems, electrical systems, service water heating, and other applicable energy-related components, as defined in the respective sections. Compliance with these requirements is non-negotiable and must be demonstrated independently of the energy performance results obtained.

Simulation requirement: Compliance with the WBP method under the ECSBC 2024 requires that building energy performance be demonstrated using approved computer-based energy simulation in accordance with the simulation requirements specified in the Code. These requirements establish the minimum technical criteria for energy modelling tools, climatic data, and calculation procedures for evaluating compliance using the WBP method. The energy simulation program shall be capable of accurately representing the dynamic inter

interaction between climate, building envelope, building systems, and operational characteristics over the course of a full year. To achieve this, the simulation software shall, at a minimum, include the capabilities described below:

a) **Hourly energy flow modelling (8,760 Hours):** The simulation program shall be capable of modelling energy flows on an hourly basis for all 8,760 hours of the year. This ensures that the simulation captures diurnal and seasonal variations in weather conditions, occupancy patterns, and system operation. Hourly simulation is essential for accurately estimating peak loads, part-load system performance, and cumulative annual energy consumption, which form the basis of compliance under the WBP method.

b) **ourly variations in internal loads and operations:** The program shall account for hourly variations in occupancy, lighting power, miscellaneous equipment loads, thermostat set-points, and HVAC system operation, with schedules defined separately for weekdays, weekends, and holidays. This capability allows the model to reflect realistic building usage patterns rather than assuming constant or average conditions. Accurate scheduling is critical for capturing fluctuations in internal heat gains and system response, particularly in commercial and mixed-use buildings.

c) **Thermal mass effects:** The simulation software shall be able to model thermal mass effects of building components such as walls, floors, and roofs. Thermal mass influences how buildings store and release heat, affecting indoor temperature stability, peak cooling and heating loads, and overall energy use. Accounting for thermal mass is especially important in climates with significant daily temperature variations and for buildings designed with passive or climate-responsive strategies.

d) **Multiple thermal zones:** The program shall be capable of modelling ten or more thermal zones, enabling accurate representation of buildings with varied space functions, orientations, occupancy densities, and internal load profiles. Zoning allows the simulation to capture differences in thermal behaviour across the building, such as perimeter versus core zones or conditioned versus semi-conditioned spaces, leading to more realistic energy performance results.

e) **Part-load and temperature-dependent equipment performance:** The simulation program shall model the part-load and temperature-dependent performance of heating and cooling equipment. The HVAC systems rarely operate at full capacity, and their efficiencies vary with load and ambient conditions. By capturing these performance characteristics, the simulation can more accurately estimate real-world system energy consumption and reflect the benefits of high-efficiency or variable-capacity equipment.

f) **Economizer modelling with integrated controls:** The software shall be capable of modelling air-side and water-side economizers with integrated control strategies. Economizers reduce energy use by utilizing favourable outdoor or condenser water conditions to meet cooling demands, either partially or fully. Proper modelling of economizer operation and controls is essential to accurately represent cooling energy savings and ensure fair comparison between baseline and proposed designs.

In addition to the above, the simulation tool shall be able to produce hourly reports of energy use by energy sources and shall have the capability to perform design load calculations to determine required HVAC equipment capacities, air, and water-flow rates for both the proposed and baseline building designs. Compliance with these

simulation requirements is mandatory and forms the foundation for credible assessment of annual building energy performance under the ECSBC framework.

Accurate representation of climatic conditions is also a critical component of the WBP method, as building energy consumption is directly influenced by local weather patterns. Under ECSBC 2024, the energy simulation program shall use hourly climatic data that are representative of the actual location of the proposed building, ensuring that the simulated energy performance reflects realistic environmental operating conditions.

The climate data used in the simulation shall include, at a minimum, hourly values of key weather parameters, such as ambient air temperature and humidity, over the full year. These hourly datasets enable the simulation to capture seasonal variations in climate, which significantly affect heating and cooling loads, HVAC system performance, and overall building energy use.

For cities or urban regions where multiple climate data files are available, the designer shall select the dataset that most accurately represents the climatic conditions at the construction site, taking into consideration factors such as geographic proximity, elevation, and prevailing weather characteristics. In cases where site-specific or city-level weather data are not available, the designer may use the nearest or most appropriate available climatic data that best approximates the local climate of the proposed site.

The selected climate data shall be applied consistently to both the baseline and proposed building models. This ensures that differences in simulated energy performance are attributable solely to design and system efficiency measures, rather than variations in weather assumptions. The intent of this requirement is to maintain fairness, consistency, and technical reliability in whole building energy performance evaluations under ECSBC 2024.

8.5 Compliance Under Whole Building Performance

Compliance under the WBP method of the ECSBC 2024 shall be determined through a comparative analysis of the proposed building design and the baseline building design. To ensure transparency and consistency in performance evaluation, both designs shall be calculated using uniform simulation inputs and assumptions, as prescribed by the Code. The proposed design and baseline design shall be calculated using the following:

i. The same energy simulation program shall be used to model both the proposed and baseline building designs. This requirement ensures that differences in simulation algorithms, calculation methodologies, or software-specific assumptions do not influence the compliance outcome. Using a single simulation platform establishes a consistent analytical framework and eliminates variability arising from tool selection.

ii. Both models shall also be simulated using the same weather data, as defined under the climate data requirements of the ECSBC 2024. Applying identical climatic conditions to the baseline and proposed designs ensures that variations in annual energy consumption are attributable solely to differences in building design and system efficiencies, rather than external environmental factors.

iii. In addition, the building operation assumptions used in the simulation shall be identical for both models, including but not limited to thermostat set-points, operating schedules, equipment and occupant loads, etc. Consistent operational assumptions are essential to isolate the impact of envelope performance, system selection, and efficiency measures on overall energy use. Any deviation from identical assumptions shall be permitted only where explicitly allowed by ECSBC 2024 for a specific building category or use case.

Energy Consumption calculation for Proposed Design and Baseline Design

The simulation model for calculating the proposed design and the baseline design shall be developed accordance

with the requirements in Table 12-1 of ECSBC document. The table describes the modeling requirements of proposed design and baseline design. While the design parameters of a proposed case is available to the project team , the approach for preparation of baseline case simulation model is detailed out. This include

- Preparation of simulation model aligned with thermal zones
- Space use classification
- Schedules for occupancy, lighting and HVAC systems etc.
- Building envelope specifications including limitations on WWR and SRR, modeling of shading devices etc.
- Lighting system LPDs and modeling of controls (Table 12-3 of ECSBC details out requirements for modeling of lighting controls.)
- HVAC Thermal Zones.
- HVAC System definition (Table- 12-2 of ECSBC details out System Map for the baseline design additionally section 12 .5.2 details out the other requirement of HVAC system including minimum outdoor air rates, fan schedules, fan power, design airflow rates, economizers, energy recovery , chiller efficiency, clilled water pumps , cooling tower, boilers, design supply temperatures, hot water pumps , District cooling etc.)
- Service Hot Water
- Miscellaneous Loads
- Modeling limitations of simulation programs
- Thermal comfort

The baseline design is based on the mandatory and standardized requirements of the ECSBC compliant building. The baseline design will be the same for all compliance levels (ECSBC, ECSBC Plus, and Super ECSBC).

The ECSBC Document clearly defines the requirements of whole building performance approach and is recommended for further reference for developing a through understanding of the whole building performance method.

Design optimization through simulation tools: Under ECSBC 2024, simulation-driven assessment enables designers to achieve higher efficiency benchmarks by evaluating multiple design alternatives before construction and refining system performance during operation. This helps identify the most effective combinations of passive and active measures, ensuring that energy efficiency is maximized throughout the building's lifecycle.

Form and orientation optimization: Building orientation is one of the most influential parameters affecting solar heat gain, thermal comfort, and daylight access. Simulation tools help analyze how different orientations expose building façades to varying solar intensities, allowing designers to identify configurations that minimize cooling loads while maximizing daylight utility. The ECSBC encourages early-stage orientation studies to improve envelope and glazing performance from the outset.

Façade strategy and glazing design: The façade—especially glazing—plays a decisive role in heat gain and daylight penetration. Optimizing window-to-wall Ratio (WWR) and glazing characteristics through simulation enables a balanced approach that enhances natural light while controlling thermal loads. Tools support iterative comparisons of glazing types, shading conditions, and WWR configurations across different orientations to determine the most efficient façade strategy aligned with ECSBC envelope requirements.

Thermal performance of envelope systems: The thermal transmittance (U-value) of walls, roofs, glazing assemblies, and floors significantly influences building energy demand. Simulation tools allow designers to test different material assemblies, insulation levels, and construction types to determine cost-optimal and performance-optimal U-values that meet or exceed ECSBC 2024 thresholds. Parametric studies help quantify the impact of envelope improvements on heating and cooling loads, making envelope design a cornerstone of optimization.

HVAC system selection and performance enhancement: The ECSBC promotes the use of efficient HVAC systems that minimize operational energy use. Whole-building simulation aids in evaluating system types, rated efficiencies, part-load behaviour, and operational strategies. Designers can test supply air temperature reset, chilled water temperature optimization, control sequences, and occupancy-responsive operation. Simulations support both fixed-parameter optimization (e.g., selecting a high-efficiency chiller) and dynamic operational optimization (e.g., fine-tuning control logic).

Integration of controls and smart operation: Advanced controls—such as demand-controlled ventilation, adaptive cooling strategies, and daylight-responsive lighting—can significantly reduce energy consumption. Simulation tools allow these strategies to be evaluated under realistic schedules and climatic conditions, enabling designers to forecast operational savings and verify compliance with ECSBC system requirements.

Renewable energy integration and on-site generation potential: The ECSBC 2024 permits on-site renewable energy—such as solar PV or solar water heating—to be incorporated into the proposed design model. Simulation tools assist in evaluating optimal system sizing, orientation, and hourly generation to determine how effectively renewable energy offsets delivered energy. This helps improve EPI performance, reduce peak demand, and identify strategies for maximizing solar potential within the whole building performance (WPB) method.

Parametric and comparative analysis: Simulation tools support parametric analysis—changing one variable at a time—to quantify the influence of orientation, insulation levels, glazing types, HVAC set-points, and WWR on overall energy use. The ECSBC allows such comparative modelling when justifying design enhancements or demonstrating compliance through the simulation pathway. This iterative approach ensures transparent, data-based decisions.

Under the ECSBC 2024, simulation-backed design and optimization strategies form the backbone of energy-efficient building development. By optimizing orientation, envelope performance, glazing design, HVAC systems, and operational controls through validated modelling, designers can ensure buildings achieve high performance, meet code requirements, and deliver long-term operational savings.

Building Energy Simulation Output

Building energy simulation tools generate a wide range of outputs that play a crucial role in compliance evaluation and informed design decision-making. The simulation not only computes the annual energy consumption, but also generates comprehensive output reports for loads, system performance, unmet hours, equipment sizing, and energy end-use breakdowns. These outputs enable a deeper understanding of how the building behaves under varying operations, helping stakeholders compare alternatives and optimize design strategies.

These outputs ultimately assist designers and code officials in evaluating energy performance, identifying inefficiencies, and validating full compliance with the Code while facilitating informed improvements to achieve higher efficiency outcomes.

Table 56 Key building energy simulation outputs under ECSBC 2024

Output category	Description
Annual energy Consumption (kWh/year per unit area)	Total annual energy use of proposed design and baseline design. Core metric for WBP compliance and percentage energy savings (PESs).
Energy end-use breakdown	Breakdown of energy use into key components: interior lighting, plug loads, service water heating, space heating, space cooling and heat rejection, fans, and other equipment.
Hourly energy use (8760-hour output)	Hourly simulation of energy use for all building systems across the year. Critical for understanding performance, peak periods, and system schedules.
Heating and cooling load profiles	Hourly and peak heating/cooling loads, including component-level breakdowns (solar, conduction, internal gains, ventilation). Used for system sizing and thermal analysis.
HVAC equipment sizing data	Design-day outputs for HVAC equipment: peak airflow, chiller/boiler capacity, pump flow rates, and cooling tower conditions. Ensure systems are sized correctly.
Unmet load hours	Total unmet heating and cooling hours for baseline and proposed cases. ECSBC limits: ≤300 hours and PD–BD difference ≤50 hours. Ensures comfort compliance and modelling validity.
Peak energy demand and time of peak	Highest annual cooling/heating demand and time of occurrence. Essential for electrical demand estimation and HVAC plant sizing.
Thermal comfort output (operative temperature)	Hourly operative temperature for each thermal zone to ensure comfort compliance.
Compliance summary output	Summary for annual energy use, modelling assumptions, and error messages from the simulation.

8.6 Best Practices for Whole Building Performance Evaluation

Simulation tools allow design teams to perform WBP analysis that reflects climatic variations, occupancy schedules, and system operation patterns. This high-resolution analysis helps predict annual energy use, peak demand, end-use consumption, and the overall energy performance, which is central to ECSBC performance pathways. Simulation tools typically include:

1. Modelling workflow and simplification strategy: Before running simulations, a simplified 3D representation of the proposed building is created. The intent is not to replicate every architectural detail, but to develop a model that accurately captures the thermal and operational characteristics relevant to energy analysis. Best practice emphasizes:
    - Using the simplest model that still maintains fidelity to ECSBC requirements
    - Avoiding unnecessary geometric or operational complexity
    - Ensuring all inputs correspond to actual design intent
2. Input parameters and data requirements: Tools may use default values, but ECSBC encourages replacing defaults with actual design data wherever possible to improve reliability. Under the ECSBC 2024, the accuracy of the model depends on clearly defined inputs, including:
    - Climatic and weather files compliant with the Code
    - Material properties (U-values, SHGC, insulation levels)
    - Internal loads such as occupancy, lighting, and equipment
    - HVAC system types, efficiencies, and control strategies

- Operational schedules for different spaces

3. **Technology features supporting the ECSBC 2024:** Modern simulation platforms offer several features that enhance modelling relevance and compliance. Such capabilities make simulation an iterative design tool rather than a mere compliance exercise such as:
   - BIM and 3D geometry imports to reduce manual errors
   - Automated baseline model generation to match ECSBC requirements
   - Library databases for materials, HVAC components, and lighting systems
   - Advanced output visualizations, including load profiles and end-use diagrams
   - Parametric analysis engines for scenario testing
4. **Best practices for effective simulation:** To ensure high-quality and code-aligned modelling outcomes, the following practices are recommended:
   - **Early design model development:** Introduce energy modelling during conceptual design to test massing, envelope strategies, and orientation options.
   - **Validation against ECSBC requirements:** Ensure that all mandatory parameters—such as baseline schedules, system efficiencies, and envelope performance match ECSBC modelling rules.
   - **Use of measured or manufacturer data:** Where available, input actual product specifications instead of generic defaults.
   - **Documentation and transparency:** Maintain modelling logs, assumptions, and data sources so compliance review becomes straightforward and defensible.

Output Interpretation and Decision Support

The ability to visualize hourly data, seasonal trends, and end-use breakdowns supports informed decision-making throughout the design process. Simulation outputs guide design decisions, helping identify:

- Cost-effective design improvements
- Optimal WWR and glazing strategies
- Efficient HVAC configurations
- Impact of control strategies such as occupancy sensors or daylight dimming
- Opportunities for renewable energy integration

Building simulation tools, when applied using best practices and ECSBC-compliant methodologies, serve as powerful platforms for both design optimization and performance verification. They enable iterative testing of various design strategies—such as envelope configurations, HVAC system options, and operational schedules—to understand their impact on energy performance. This iterative process helps project teams compare alternatives, refine system selections, and identify the most effective energy-efficiency measures. As a result, these tools ensure that buildings not only meet ECSBC code requirements but are also optimized for long-term operational efficiency, reduced energy consumption, and enhanced sustainability.

Table 57 Commonly used simulation tools and their purposes

Tool category / Simulation aspect	Purpose in design and energy performance optimization	Validated software
Whole-building energy simulation	Full-year (8,760 hr) energy modelling to evaluate building performance, load profiles, energy efficiency measures, operational schedules, and ECSBC compliance	EnergyPlus, eQuest, OpenStudio, DesignBuilder, IES VE
Site, solar, and climate analysis	Assess climate parameters, sun path, solar heat gain, shading, microclimate impacts, and site suitability for passive and renewable strategies	Ladybug Tools, SunCast (IES)
Passive design simulation	Evaluate daylight, natural ventilation, shading strategies, thermal mass, orientation impacts, and passive survivability scenarios	ClimateStudio, Sefaira, (Ladybug/ Honeybee),
Ventilation simulation	Analyse natural and mechanical ventilation, CO_2 concentration, pollutant dispersion, airflow patterns, and indoor air quality compliance	CFD tools (OpenFOAM, ANSYS Fluent), IES VE (MicroFlo), EnergyPlus (ventilation modules)
Envelope and thermal systems analysis	Study thermal transmittance, thermal bridging, envelope assemblies, glazing system behaviour, and material heat transfer	THERM, WUFI, HEAT3, WINDOW, EnergyPlus (envelope models)
Lighting and daylighting simulation	Evaluate daylight autonomy, glare, visual comfort, luminance distribution, artificial lighting energy use, and lighting control strategies	Radiance, ClimateStudio, DIALux, Velux Daylight Visualizer
HVAC and mechanical equipment Simulation	Model HVAC systems, plant equipment efficiency, part-load performance, heat pump/VRF behaviour, chilled water loops, and mechanical ventilation	TRNSYS, IES VE (HVAC module), EnergyPlus (HVAC templates), eQuest
Renewable energy system simulation	Analyse on-site renewable generation potential, PV sizing, solar thermal systems, hybrid renewable integration, and grid interactions	PVsyst, RETScreen

Ultimately, the strength of the WBP approach lies in its ability to transform simulation from a compliance requirement into a powerful decision-support framework—one that improves design quality, promotes passive and active efficiency strategies, and enables buildings to achieve measurable, verifiable performance outcomes throughout their lifecycle.

Compliance Thresholds for ECSBC-compliant, ECSBC Plus, and Super ECSBC Buildings

For buildings to qualify as ECSBC Plus and Super ECSBC buildings, the WBP method shall be followed for the baseline design. The proposed design for ECSBC Plus and Super ECSBC buildings shall meet the mandatory provisions of Sections 5.2, 6.2, 7.2 and 8.2 and 9.2. The PES for ECSBC Plus and Super ECSBC buildings shall be equal to or greater than the PES listed below under the applicable climate zone in the tables 12.7- 12.11 of ECSBC .

8.7 Documentation Required Whole Building performance

Compliance shall be documented prior submission. The information submitted shall include, at a minimum, the following:

1. Summary describing the results of the analysis, including the annual energy use for the proposed design and the baseline design, and software used.

2. Brief description of the project with location, number of stories, space types, conditioned and unconditioned areas, hours of operation.

3. List of the energy-related building features of the proposed design. This list shall also document features different from the baseline design.

4. List showing compliance with the mandatory requirements of this code.

5. The input and output report(s) from the simulation program including a breakup of energy usage by all the components: lighting, internal equipment loads, service water-heating equipment, space heating equipment, space cooling and heat rejection equipment, fans, and other HVAC equipment (such as pumps). The output reports shall also show the number of hours any loads which are not met by the HVAC system for both the proposed design and baseline design.

6. Explanation of any significant modelling assumptions made.

7. Explanation of any error messages noted in the simulation program output.

8. Building floor plans, building elevations, and site plan.

Daylight simulation: Daylight simulation within the ECSBC 2024 framework plays a key role in evaluating the building's capability to harness natural light effectively while balancing visual comfort and energy efficiency. Under the WBP method, compliance with daylighting requirements must adhere to the mandatory provisions of Section 5.2.3—through useful daylight illuminance (UDI) simulation method. The daylight simulation process helps quantify the quality, distribution, and usability of natural light across building spaces and its interaction with architectural design, glazing systems, and obstructions.

Natural ventilation simulation: The traditional approach of design natural ventilation is based on analysis and utilization of wind–rose diagram, the interpretation of climate zoning requirements, and the architect's experience.

The computational fluid dynamics (CFD) represents the combination of the modern fluid mechanics, numerical mathematics and computing models, computer graphics. The CFD modelling and simulation can assess air flow distribution inside the building, especially for the analysis of natural ventilation. In CFD simulation, computer model is developed incorporating architectural design to simulate the site while considering its surrounding and wind environment inside and outside of building and thus, CFD simulation supports in having simulated diagram for wind speed and pressure under natural ventilation. The CFD wind environment simulation can help architects to accurately project building wind environment patterns and conduct analysis to find out the strength and weakness of various design options and strategies and according revise the architectural design. Conducting CFD simulation and analyzing wind-flow patterns around building or air-flow distribution inside building requires three areas to cover

- Site planning
- Building form
- Building opening or deflectors.

In site planning, wind pattern around building depends upon external factor such as site terrain, surrounding building or building clusters or any obstacle bodies, prevailing wind direction and simulation can be performed to optimize natural resources and create better conditions for natural ventilation while at the same time, mitigate the impact of adverse wind environment on some areas to create an outdoor wind environment that is comfortable and safe. In this approach, buildings can then be reasonably positioned based on the analysis result of the wind environment, while other factors such as building coverage, elevation, orientation, spacing and configuration are addressed as well.

For analysis of building form, detailing of building form and floor plan are analyzed with respect to space depth from perimeter, elevation of the building, etc. In this way, with the help of simulation tool, suitable form of building along with its position can be designed to optimize natural ventilation inside space. Building opening plays an important role in facilitating natural ventilation by distributing outside wind into space. Again, the CFD simulation can help in assessing the building openings and its size for better natural ventilation (decide about indoor airflow paths, avoid blockage, and make sure that air flows smoothly through the use areas).

WINDOW/THERM simulation: Thermal bridge is basically a large local heat gain/loss caused by some elements which connect outside and inside surfaces of a building/space. These areas of intense local heat flow commonly can have a significant impact on the thermal performance of the building envelope and the overall building energy consumption. WINDOW/THERM simulation tool is used to analyze the local heat in complex building envelope components such as window frame, thermal bridge, etc. This tool works on a finite element numerical method (FEM) and incorporates sophisticated automated meshing and error estimation for rapid model generation and ensures accurate results. THERM's heat transfer analysis allows evaluation of a product's energy efficiency and local temperature patterns, which may relate directly to problems with condensation, moisture damage, and structural integrity. THERM has two-way interface to the WINDOW program and allows WINDOW to determine total window product U-factors, solar heat gain coefficients, visible transmittance and condensation resistance which account the impact of window frame.

8.8 Checklist for Whole Building Performance Method

Accurate and transparent documentation is critical for demonstrating compliance under the ECSBC Whole Building Performance (WBP) Method. Most issues encountered during simulation-based compliance reviews arise from incorrect interpretation of code requirements, inconsistent modeling assumptions, incomplete reporting, or lack of validation between simulation inputs and outputs. To improve the reliability and consistency of performance assessments, a structured quality-control process should be followed throughout model development and documentation.

The documentation review process for the ECSBC Whole Building Performance Method may be organized into three stages: (i) Input Quality Control, (ii) Output Quality Control, and (iii) Output–Input Consistency Verification. Together, these checklists help ensure that the proposed building model and the standard reference building are developed in accordance with ECSBC requirements and that the reported energy savings are technically sound, reproducible, and code-compliant.**1.**

Input Quality Control Checklist

The first stage of review focuses on validating the simulation inputs used for both the proposed building and

the standard reference building. The objective is to confirm that all modeling assumptions comply with ECSBC provisions, applicable standards, and approved simulation protocols.

The review should verify the completeness and correctness of the following aspects:

- Building geometry, orientation, zoning, and conditioned area;
- Envelope characteristics including wall, roof, glazing, shading, and thermal properties;
- Lighting power densities and lighting control assumptions;
- HVAC system selection, efficiencies, control strategies, and ventilation rates;
- Service hot water systems and associated efficiencies;
- Plug and process loads, occupancy schedules, and operational profiles;
- Renewable energy systems, if included;
- Weather file selection and climatic zone applicability;
- Baseline model assumptions as prescribed under ECSBC WBP methodology

Particular attention should be given to consistency between the information provided in architectural, electrical, and mechanical drawings and the assumptions incorporated in the simulation model. Common errors include incorrect baseline HVAC assignment, non-compliant envelope properties, unrealistic schedules, omission of mandatory controls, and mismatch between submitted drawings and modeled inputs.

All simulation inputs should be traceable to supporting design documents, manufacturer data sheets, or ECSBC-prescribed baseline criteria. The submitted documentation should include model input summaries, simulation reports, compliance forms, and supporting calculation sheets sufficient for independent technical review.

2. Output Quality Control Checklist

The second stage involves verification of simulation outputs to ensure that the model results comply with ECSBC performance requirements and accurately represent building operation.

The review should confirm:

- Annual energy consumption values for both proposed and baseline buildings;
- Modeled Energy Performance Index (MEPI) calculations, where applicable;
- End-use energy breakdowns including lighting, HVAC, pumps, fans, service water heating, and process loads;
- Compliance with unmet load hour limits;
- Proper accounting of renewable energy contributions;
- Correct reporting of demand and energy units;

- Consistency between compliance forms and simulation output reports;
- Appropriate treatment of exceptional calculations and non-standard systems.

Simulation outputs should demonstrate that the proposed design achieves the required percentage improvement over the baseline building as mandated under ECSBC. Reviewers should also ensure that savings are realistic and proportionate to the efficiency measures implemented in the design.

Special care should be taken to identify anomalies such as unusually low equipment loads, excessive renewable energy offsets, unrealistic operating schedules, or unexplained reductions in HVAC energy consumption. Any assumptions significantly affecting the results should be clearly documented and justified.

3. Output–Input Consistency Checklist

The final stage of quality assurance is to verify consistency between model inputs and simulation outputs. This step helps identify modeling errors, unintended assumptions, or discrepancies that may not be apparent during isolated input or output reviews.

The consistency review should examine whether:

- Changes in envelope performance correspond to expected reductions in cooling and heating loads;
- Improved lighting efficiency results in proportional reductions in lighting energy use;
- HVAC energy consumption aligns with system type, efficiency, and operating schedules;
- Occupancy and operating schedules are reflected appropriately in annual consumption patterns;
- Renewable energy generation values are reasonable for the installed system capacity and climatic conditions;
- Reported savings are technically achievable and consistent with implemented efficiency measures.

Order-of-magnitude checks and benchmarking against similar building types can be useful in identifying unrealistic simulation results. Comparative analysis between baseline and proposed models should also confirm that only permitted parameters differ between the two models, while all other assumptions remain consistent as required under ECSBC WBP methodology.

A robust documentation and verification process improves the credibility of simulation-based compliance submissions and minimizes delays during technical review and can be used as digital twin for evaluating appropriate energy efficiency measures in the future using simulation. Proper implementation of these checklists helps ensure that the Whole Building Performance Method accurately reflects the expected operational energy performance of the proposed building and supports transparent, reproducible, and code-compliant energy analysis.

8.9 Commissioning of Building Systems

Commissioning building systems is a critical process in ensuring that buildings perform as intended in terms of energy efficiency, functionality, and occupant comfort. Within the framework of the Bureau of Energy Efficiency

(BEE) and its ECSBC, commissioning is recognized as a structured and systematic methodology that verifies and documents that all building systems, subsystems, and equipment operate in accordance with the design intent and operational requirements. While global green building frameworks) emphasize commissioning as a pathway to sustainability, ECSBC integrates commissioning as a voluntary but strongly recommended process to ensure compliance with energy performance goals in Indian buildings.

ECSBC highlights that merely designing an energy-efficient building is not sufficient; it is equally important to ensure that the installed systems perform optimally in real operating conditions. Commissioning bridges the gap between design intent and actual performance. The key objectives of commissioning under ECSBC include:

- Ensuring that all building systems meet the Design Intent and Owner Project Requirements (OPR)
- Verifying proper installation, calibration, and integration of systems
- Identifying and resolving performance gaps before occupancy
- Enhancing energy efficiency, water efficiency, and system reliability
- Providing proper documentation and training for operation and maintenance

This approach ensures long-term performance and reduces lifecycle costs, aligning with national goals of energy conservation and sustainability.

As per ECSBC Appendix 5, commissioning provisions are applicable to:

- All building typologies covered under the code
- Buildings with a built-up area greater than 5000 m^2 (excluding non-air-conditioned basements)
- All climatic zones in India

The scope of commissioning may vary depending on project size, complexity, and owner requirements, but the process framework defined in ECSBC must be followed.

Systems Covered under Commissioning: ECSBC mandates that the commissioning process shall be applied to the following systems, wherever present:

- Building envelope systems
- Electrical systems including power distribution and standby generation
- On-site renewable energy systems
- Water supply, pumping, and hot water systems
- Water and sewage treatment and recycling systems
- Heating, ventilation, and air conditioning (HVAC) systems
- Vertical transportation systems (lifts, escalators)

- Solid waste management systems
- Building Management Systems (BMS) / Building Automation Systems (BAS)
- Lighting systems including controls and dimming

Key Requirements of Commissioning Process

Owner Project Requirements (OPR): The commissioning process begins with the development of the Owner Project Requirements (OPR). This document defines:

- Functional expectations of the building
- Energy performance targets
- Indoor environmental quality requirements
- Operational and maintenance considerations

The OPR is developed by the owner with inputs from architects, engineers, and other stakeholders, forming the foundation for all subsequent commissioning activities.

Commissioning Plan: Based on the OPR and project scope, a detailed commissioning plan is prepared for each applicable system. This plan outlines:

- Commissioning objectives and methodology
- Roles and responsibilities of stakeholders
- Documentation and reporting requirements included in Design Basis Report
- Timeline and integration with project phases

The commissioning plan acts as a roadmap for ensuring systematic implementation.

Construction Checklists and Installation Verification: During the construction phase, checklists are used to verify that:

- Equipment is installed as per design specifications
- Manufacturer guidelines are followed
- System components are properly integrated

This step ensures quality assurance and minimizes installation-related defects.

Functional Performance Testing: A core component of ECSBC commissioning is rigorous testing of systems. This includes:

- Testing of HVAC performance under different load conditions
- Verification of lighting control systems and energy efficiency measures
- Assessment of renewable energy system output
- Evaluation of water systems and pumping efficiency

Each test is documented, and results are compared with design expectations to confirm compliance.

Roles and Responsibilities: ECSBC requires clear assignment of responsibilities:

- Agencies responsible for conducting tests
- Authorities responsible for reviewing and approving results
- Coordination among design, construction, and commissioning teams

This accountability ensures transparency and reliability in the commissioning process. However it does not define scope of commissioning of a specific building as it may vary depending on the project size, complexity, specific requirements of the owner/end user or the local regulatory Authority Having Jurisdiction (AHJ)."

Building Management System (BMS) Integration: A key requirement under ECSBC is the installation of a Building Management System (BMS) or Building Automation System. The BMS must:

- Integrate data related to energy and water consumption
- Provide a centralized dashboard for monitoring

Enable control and optimization of building performance

This ensures that commissioning is not a one-time activity but supports continuous performance monitoring

Documentation, Training, and Handover: Commissioning concludes with:

- Preparation of comprehensive documentation (system manuals, test reports)
- Training of facility management personnel
- Smooth handover of systems to building operators

This ensures that the building continues to operate efficiently throughout its lifecycle.

Commissioning under ECSBC represents a critical step toward achieving high-performance buildings. By emphasizing a structured process—from defining Owner Project Requirements to performance testing and operational handover—ECSBC ensures that buildings do not just meet design expectations on paper but deliver real-world efficiency and sustainability.

As the ECSBC moves toward ambitious energy and climate goals, effective implementation of commissioning practices for projects exceeding 5000sqm will play a vital role in reducing energy consumption, improving occupant comfort, and enhancing the overall quality of the built environment for the large building construction projects. Integrating commissioning with tools like Building Management Systems further ensures continuous monitoring and optimization, making it a cornerstone of sustainable building operation.

8.10 Energy and Resource Efficiency Audit

As operational costs continue to rise and sustainability goals become increasingly important, energy and resource efficiency audits have become essential for commercial buildings seeking to improve performance,

reduce environmental impact, and comply with regulatory requirements. Modern buildings consume significant amounts of energy, water, and waste. An audit approach helps organisations identify inefficiencies across all major resource streams and develop strategies to optimise building performance in a holistic and sustainable manner.

An energy and resource efficiency audit is a systematic assessment of how a building consumes energy, water, and how waste is generated and managed. The audit identifies opportunities to reduce resource consumption, improve operational efficiency, minimise waste generation, and lower overall operating costs while enhancing occupant comfort and environmental performance.

While audits are mainly done for and existing building , the reference points of efficiencies and best practices can be derived from the codes such as ECSBC and ENS.

An energy and resource efficiency audit is a comprehensive evaluation of a building's resource consumption patterns, systems, operational practices, and maintenance procedures. The objective is to identify inefficiencies and recommend practical measures to optimise the use of:

- Energy
- Water and
- Improve waste management systems

The audit evaluates major systems such as HVAC, lighting, plumbing fixtures, pumping systems, water treatment systems, building envelope performance, waste segregation practices, and operational controls. The outcome is a structured action plan that supports cost savings, sustainability goals, operational resilience, and regulatory compliance.

One of the important aspect of conducting energy or other resources audit is to create a Clear and measurable goals. the American Society of Heating, Refrigerating and Air-Conditioning Engineers developed a three-tier audit framework consisting of Level 1, Level 2, and Level 3 energy audits.

Each audit level differs in scope, complexity, analytical depth, and intended application. The progression from Level 1 to Level 3 reflects an increasing degree of engineering analysis, data collection, financial evaluation, and implementation planning. Selecting the appropriate audit level depends on factors such as building size, project objectives, available budget, and the desired accuracy of results.

Level 1 Audit – Walk-Through Analysis

The Level 1 Audit, commonly referred to as a Walk-Through Analysis, is the most basic form of energy audit. Its primary objective is to provide a preliminary understanding of a facility's energy consumption patterns and identify obvious areas of energy waste and potential improvement.

This audit typically begins with a review of historical utility bills and basic operational data to establish overall energy consumption trends. A brief site inspection is then conducted to observe building systems, operating conditions, and maintenance practices. The assessment focuses on identifying low-cost or no-cost energy conservation opportunities that can be implemented with minimal investment.

During the walk-through inspection, the auditor examines major systems such as lighting, HVAC equipment, motors, pumps, and building controls. Visible inefficiencies—such as unnecessary lighting operation, poor thermostat settings, air leakage, inadequate maintenance, or outdated equipment—are documented. However, the analysis remains largely qualitative and does not involve extensive measurements or detailed engineering calculations.

The Level 1 Audit provides only approximate estimates of energy savings and implementation costs. Its findings are intended to help building owners determine whether more detailed analysis is justified.

Characteristics of a Level 1 Audit

- Review of utility bills and energy consumption history
- Basic walk-through inspection of the facility
- Identification of obvious inefficiencies
- Preliminary list of Energy Conservation Measures (ECMs)
- Rough estimates of costs and savings
- Limited or no monitoring and measurements

Although limited in detail, the Level 1 Audit serves as an important first step in establishing energy awareness and identifying immediate opportunities for savings.

Level 2 Audit – Energy Survey and Analysis

The Level 2 Audit, known as an Energy Survey and Analysis, provides a more comprehensive evaluation of building energy performance. It is the most commonly conducted audit for commercial and institutional buildings because it combines technical assessment with practical financial analysis.

Unlike the preliminary nature of a Level 1 Audit, the Level 2 Audit involves detailed examination of major energy-consuming systems and operational practices. The audit begins with a thorough review of utility data, occupancy schedules, maintenance records, and building characteristics. This is followed by an extensive field investigation and system-level analysis.

The auditor evaluates the performance and efficiency of HVAC systems, lighting systems, electrical distribution, motors, pumps, building envelope components, and control systems. Measurements may be taken using portable instruments, data loggers, thermal imaging devices, and other monitoring equipment to better understand operational conditions and system performance.

A significant feature of the Level 2 Audit is the quantitative evaluation of Energy Conservation

Measures(ECMs). Each recommendation is analysed in terms of implementation cost, projected energy savings, simple payback period, and potential return on investment. The audit may also include limited water efficiency assessment and resource management analysis in modern sustainability-oriented projects.

The Level 2 Audit produces actionable recommendations and forms the basis for planning retrofit projects and energy management strategies.

Characteristics of a Level 2 Audit

- Detailed utility and energy consumption analysis
- Comprehensive site investigation
- End-use breakdown of energy consumption
- System performance assessment
- Limited monitoring and data collection
- Financial evaluation of recommended measures
- Prioritised implementation roadmap

Because it balances technical detail with implementation practicality, the Level 2 Audit is often considered the standard audit level for most commercial building projects.

Level 3 Audit – Investment-Grade Audit

The ASHRAE Level 3 Audit, also known as an Investment-Grade Audit (IGA), represents the highest and most rigorous level of energy audit. It is intended for projects involving significant capital investment where accurate performance predictions and detailed engineering analysis are essential for financial decision-making.

A Level 3 Audit involves extensive data collection, advanced measurements, engineering calculations, and building performance modelling. Detailed sub-metering and monitoring are often conducted over extended periods to accurately capture system behaviour and operational patterns. Sophisticated energy simulation software may be used to evaluate building performance under varying conditions and to predict the impact of proposed improvements.

The audit examines all major building systems in depth, including HVAC systems, electrical infrastructure, lighting, controls, process loads, building envelope performance, renewable energy integration, and water management systems. Equipment testing and performance verification are frequently included.

One of the defining characteristics of a Level 3 Audit is its comprehensive financial analysis. Recommendations are evaluated using advanced economic methods such as lifecycle cost analysis, Net Present Value (NPV), Internal Rate of Return (IRR), and cash flow analysis. The audit often includes implementation specifications, project phasing strategies, risk assessment, and Measurement and Verification (M&V) plans.

Because of its high level of accuracy and engineering detail, the Level 3 Audit is commonly used to supportperformance contracting, major retrofit projects, decarbonisation initiatives, and external financing applications.

Characteristics of a Level 3 Audit

- Extensive engineering analysis
- Detailed monitoring and sub-metering
- Advanced energy simulation and modelling

- Equipment testing and performance verification
- Investment-grade financial analysis
- Lifecycle costing and risk assessment
- Detailed implementation planning
- Measurement and Verification (M&V) planning

The Level 3 Audit provides the highest confidence level for decision-making and serves as the technical foundation for major energy performance projects.

Expanding Scope of Modern Energy Audits

Traditionally, energy audits focused primarily on energy consumption and system efficiency. However, contemporary sustainability practices increasingly integrate broader resource efficiency considerations into the audit process. Modern audits may therefore include:

- Water consumption analysis
- Waste generation and diversion assessment
- Indoor Environmental Quality (IEQ) evaluation
- Carbon emissions analysis
- Renewable energy feasibility assessment
- Smart building and IoT-based monitoring strategies

This integrated approach supports comprehensive sustainability objectives and enables buildings to move toward low-carbon, resource-efficient, and resilient operations.

The benchmarks of ECSBC / ENS can provides a structured methodology for evaluating building performance and identifying opportunities for efficiency improvement. The evaluation may allows organisations to select an audit approach appropriate to their technical requirements, financial objectives, and sustainability goals. Detailed assessment of energy performance assessment of buildings and commercia establishments , and systems like HVAC system, Fans and Blowers, Pumps , Motors boilers and heat exchangers are included in the Book 3 of National Certification Examination for Energy anagers and Energy Auditors.

Whether used for preliminary benchmarking, retrofit planning, or investment-grade project development, audits play a critical role in reducing operational costs, improving building performance, and supporting long-term environmental sustainability.

Questions for Energy Optimization (Whole Building Performance)

Section A: Objective Questions (MCQs) – 10 Nos
1. The Whole Building Performance (WBP) method under ECSBC 2024 primarily evaluates: A. Individual system efficiencies B. Component-wise prescriptive compliance C. Overall annual building energy performance using simulation D. Only HVAC system performance
2. Under the WBP method, compliance is demonstrated by comparing the Proposed Building against: A. An existing reference building B. A utility benchmark C. An ECSBC-defined Baseline Building D. A building with maximum renewable integration
3. Which of the following best describes the Baseline Building in WBP? A. Replica of the proposed design B. Worst-case energy model C. Standardized ECSBC-compliant reference model D. Building with maximum renewable integration
4. The primary energy performance metric used in ECSBC WBP is: A. Peak electrical demand B. Monthly energy consumption C. Annual energy use per unit area (kWh/m²·year) D. Connected load
5. Which of the following is mandatory for energy simulation software used for WBP compliance? A. BIM integration capability B. Validation as per ASHRAE Standard 140 C. Real-time energy monitoring D. Cloud-based computation
6. Under WBP, operational schedules for the Proposed and Baseline models must be: A. Optimized independently B. Identical, unless explicitly permitted by ECSBC\ C. Based on actual user behavior D. Different to reflect efficiency measures
7. Percentage Energy Savings (PES) is mandatory for compliance with: A. ECSBC only B. ECSBC and ECSBC+ C. ECSBC+ and Super ECSBC D. Only Super ECSBC

8. Which of the following systems is explicitly evaluated through Whole Building simulation?
A. Fire detection system
B. Elevators and escalators
C. Building structural system
D. Acoustic insulation

9. Thermal zoning in WBP simulation is primarily required to:
A. Reduce modelling effort
B. Match electrical zoning
C. Accurately represent varied thermal behavior
D. Simplify HVAC design

10. Unmet load hours in Proposed and Baseline models must:
A. Be minimized without limits
B. Be zero
C. Not exceed 300 hours, with limited difference
D. Be ignored for compliance

Section B: Short Answer Questions- 5 Nos

1. Define the Whole Building Performance (WBP) approach under ECSBC 2024 and explain how it differs from the prescriptive compliance path.

2. What is meant by a Baseline Building in the context of WBP simulation, and why is it essential for fair comparison?

3. Explain the significance of using identical operational schedules in both Proposed and Baseline energy models.

4. What is Modified Energy Performance Index (MEPI), and how is it used for ECSBC compliance evaluation?

5. List down any four key building systems whose performance is integrated and assessed under the WBP method.

Section C: Long Answer Questions – 2 Nos

Q1. Explain the Whole Building Performance (WBP) compliance pathway under ECSBC 2024 in detail. Your answer should include:

Q2. Discuss how building energy simulation supports design optimization and ECSBC compliance under the Whole Building Performance method.

Answer Key for MCQs

1. C	6. B
2. C	7. C
3. C	8. B
4. C	9. C
5. B	10. C

9. WATER MANAGEMENT AND CONTROLS

This chapter presents the principles and requirements of water management and controls in buildings in a structured manner. It explains the major sources of water, water quality and treatment requirements, pumping and piping systems, metering and controls, service water heating, wastewater treatment and reuse, rainwater harvesting, water balance, fixture-level water efficiency, and irrigation planning. Taken together, these elements form the basis of a reliable, efficient, and sustainable building water system that is aligned with the objectives of ECSBC and ENS.

9.1 Sources of water

Water is the primary input for all building water systems, serving potable needs (drinking, cooking, hygiene) and non-potable uses (flushing, cleaning, landscaping, cooling). ECSBC requires that the water source be reliable over the building's life cycle and identifies five main sources: municipal supply, groundwater (bore/open wells), treated wastewater (STP), harvested rainwater, and desalinated high-TDS water (for non-potable use with approvals).

Water availability is governed by the hydrological cycle—evaporation, precipitation, runoff, infiltration, and recharge—which sustains rivers, reservoirs, and aquifers. At the building level, these are accessed through municipal networks, groundwater extraction, rainwater harvesting, reuse systems, and, where needed, desalination. National guidance (MoHUA/CPHEEO) treats source, treatment, storage, and distribution as integrated components of water planning.

In India, urban water supply is primarily managed by State agencies and Urban Local Bodies, making municipal supply the main source, while groundwater remains critical where supply is limited. ECSBC distinguishes fresh water (municipal, groundwater, tanker) from alternate sources (treated wastewater, rainwater, recycled water).

Selecting a water source is fundamental, as it affects treatment, storage, distribution, reuse potential, and reliability. Sources should be evaluated for quantity, quality, dependability, cost, regulatory compliance, and sustainability. A fit-for-purpose approach is recommended—using potable water only where necessary and alternate sources for non-potable uses—aligned with ECSBC and ENS provisions requiring separate storage and plumbing for reuse systems.

Municipal / Public Utility Water

Municipal or public utility water is generally the primary and preferred source for potable uses in buildings. ECSBC identifies municipal/public utility water supplying potable water as one of the primary sources of fresh water supply. This water is delivered through a centralized public distribution. system and is typically treated before reaching end users. Because it is regulated and monitored by the relevant authority, municipal supply forms the backbone of formal urban water supply in buildings. Even where municipal supply is available, buildings may still require storage and internal management because supply duration, continuity, and pressure may vary from one location to another. In many cities, water delivered through the municipal network may itself originate from groundwater sources, surface-water sources, or a combination of both.

Groundwater from Bore-Wells and Open Wells

Groundwater from bore-wells and open wells is a key water source for buildings, especially where municipal supply is inadequate or unreliable. ECSBC allows its use with prior approval from relevant authorities and supporting documentation.

While groundwater is locally available and can serve as a primary or supplementary source, its quality varies with hydrogeological conditions and often requires treatment, particularly for potable use. It should therefore be treated as a regulated and finite resource—requiring careful assessment, protection, and responsible use, rather than an unrestricted fallback option.

Reclaimed Used Water from Sewage Treatment Plants

Reclaimed used water refers to wastewater that has been treated to a suitable level and reused for appropriate applications. ECSBC explicitly recognizes reclaimed used water from sewage treatment plants as a valid source for non-potable usages. This source is particularly important for reducing dependence on fresh water and for promoting circular water management within the building premises. Typical uses include flushing, landscaping, cooling tower make-up, cleaning, and other non-potable applications. ECSBC further requires buildings to install on-site wastewater treatment plants capable of treating wastewater and to achieve treated water quality in accordance with applicable norms for reuse. ENS similarly requires separate storage tanks and plumbing lines for the reuse of treated water from on-site wastewater treatment systems. An important caution is also stated in ECSBC: reuse of reclaimed water in hospitals and outpatient health-care buildings is not recommended due to associated health hazards. This highlights that reclaimed water is a fit-for-purpose source and must only be used where its quality and risk profile are appropriate to the intended end use.

Harvested Rainwater

Harvested rainwater is another recognized source under ECSBC and is intended for non-potable use after treatment. At the building scale, rainwater may either be collected and stored for later use or diverted to recharge structures to augment groundwater. ENS gives a useful operational description of a rainwater harvesting system, which may include roof catchment, gutters, downpipes, rainwater or stormwater drains, filter chambers, storage tanks/pits/sumps, and groundwater recharge structures such as pits, trenches, and tube wells. ENS also requires that at least 80% of roof rainwater be harvested and stored for household reuse through separate tanks and pipelines to avoid mixing with potable municipal water supply, while the remaining harvested rainwater may be recharged back to groundwater after filtration. Rainwater harvesting is therefore not merely a conservation measure but a recognized technical strategy for reducing pressure on conventional water sources, improving local water resilience, and supporting groundwater recharge where appropriate.

Desalinated Water

In coastal or high-salinity regions, desalinated water may be considered as an alternative source where conventional freshwater sources are inadequate or unsuitable. Desalination can improve supply reliability by converting saline water into usable water, but it typically involves higher treatment cost, higher energy consumption, and greater operational complexity, along with the need for environmentally sound reject-water or brine disposal. It is therefore usually adopted only in context-specific situations rather than as a standard

source for ordinary buildings. Such decisions should be based on technical feasibility, environmental safeguards, and lifecycle considerations.

The source of water forms the foundation of the entire building water system. In ECSBC, the principal recognized sources are municipal/public utility water, bore-well or open-well water, reclaimed used water from sewage treatment plants, harvested rainwater, and desalinated high-TDS water for non-potable use with approvals. ENS reinforces this framework by promoting rainwater harvesting, groundwater recharge, on-site wastewater treatment, and separate storage and piping arrangements for non-potable reuse. A building should therefore select and combine water sources based on reliability, quality, treatment requirement, sustainability, and intended end use so that water is used safely and efficiently throughout the life of the building.

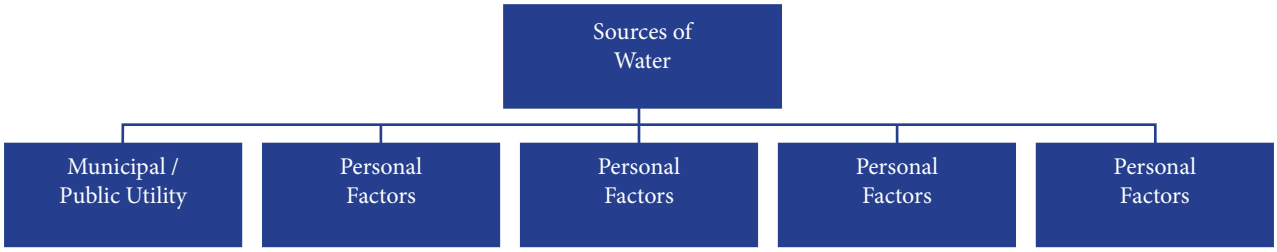


Figure 118 Sources of water

9.2 Water Quality

Water quality refers to the physical, chemical, and microbiological characteristics of water that determine whether it is suitable for a particular use. In buildings, this is a critical consideration because water is used for drinking, cooking, bathing, flushing, cleaning, landscaping, cooling, and several other functions, and each of these uses requires an appropriate level of quality. Water that is acceptable for one purpose may be unsafe or unsuitable for another. The concept of water quality in buildings is therefore inseparable from the concept of intended end use, following a fit-for-purpose approach. This approach is reflected in both ECSBC and ENS, which prescribe one benchmark for potable/domestic water and a separate benchmark for recycled water used in non-potable applications.

Major Water-Quality Parameters

Water quality is generally assessed through three groups of parameters: physical, chemical, and microbiological.

- **Physical Parameters:** Physical parameters such as turbidity, colour, odour, taste, and total dissolved solids affect the appearance and acceptability of water and often indicate inadequate treatment or contamination.
- **Chemical Parameters:** Chemical parameters such as pH, hardness, chlorides, sulphates, nitrates, fluoride, iron, manganese, and heavy metals influence both health and plumbing performance, since poor chemical quality may lead to toxicity, corrosion, or scaling.
- **Microbiological Parameters:** Microbiological parameters are especially important for water intended for human consumption or frequent contact, because the presence of coliforms or other microbial indicators suggests contamination and possible health risk. In building systems, these parameters matter not only for public health, but also for maintenance, equipment life, and operational reliability.

Potable and Domestic Water Quality Requirements

For potable and domestic uses, ECSBC requires water quality to comply with IS 10500:2012, Drinking Water – Specification, Tables 1 to 4, and ENS repeats the same requirement. This applies irrespective of the original source. Whether water is obtained from municipal supply, bore-wells, open wells, rainwater storage, or any other treated source, it must satisfy the same benchmark if it is intended for drinking, cooking, food preparation, or oral hygiene. IS 10500 further provides both acceptable limits and permissible limits in the absence of an alternate source, thereby serving as the formal benchmark for drinking-water quality.

Recycled and Reclaimed Water Quality Requirements

Recycled or reclaimed water, however, is not judged by drinking-water standards unless it is specifically intended for potable use. Instead, its required quality depends on where and how it will be reused. ECSBC states that treated used water reused for toilet flushing, vehicle exterior washing, non-contact impoundments, and landscape irrigation must comply with the requirements of the CPHEEO Manual on Sewerage and Sewage Treatment Systems, 2013, Chapter 7, Table 7.19, and ENS refers to the updated version of the same table circulated by CPHEEO. This reflects the fit-for-purpose principle: reused water must be treated to a quality appropriate to the risks associated with its intended application.

Water quality monitoring:

Water quality cannot be assured by assumption; it must be established through proper sampling, testing, and monitoring. ECSBC requires representative samples of water from all sources to be drawn for laboratory testing as prescribed in IS 1622 and BIS 3025 (Part 1 to Part 79). These samples are to be taken before installation of the water-treatment plant in order to establish the design basis, and thereafter during operation to ensure consistency in quality over time. This is an important engineering requirement, because treatment systems can only be designed correctly when the characteristics of the source water are known.

Water Quality Considerations for Different Water Sources

Water-quality concerns vary by source, so parameters must be source-specific rather than uniform. Municipal water is treated, but quality can degrade during distribution and storage; key parameters include turbidity, pH, residual disinfectant, taste, odour, and microbiological quality. Groundwater (bore/open wells) may appear clear but can contain hardness, iron, manganese, fluoride, nitrates, salinity, and other dissolved constituents, making chemical quality as critical as microbiological safety.

Harvested rainwater quality depends on air deposition, roof condition, first-flush systems, and storage; typical concerns are turbidity, suspended solids, pH, and microbes. Reclaimed water requires monitoring of BOD, COD, TSS, nutrients, odour, and pathogens, based on intended reuse. Desalinated water focuses on salt removal, but post-treatment checks for TDS, pH, and stability are still necessary. Thus, water quality assessment should align with the source, treatment, and end use.

ECSBC provides limited flexibility for small systems: if wastewater generation is below 10 kL/day, full compliance with CPHEEO recycled-water criteria may not be mandatory. However, this does not permit reuse of inadequately treated water.

Water Treatment

Water treatment is the set of physical, chemical, and biological processes used to make raw or contaminated water suitable for its intended use. In buildings, treatment is required because source water may contain suspended solids, dissolved salts, hardness, organic matter, colour, odour, or microorganisms. Without adequate treatment, such water can pose health risks, reduce usability, and damage plumbing systems and equipment. The objective is to achieve the required quality for potable or non-potable use—not just clear appearance.

The level of treatment depends on the source and the end use. Municipal water typically needs minimal conditioning or disinfection assurance, while groundwater may require iron removal, softening, or desalination. Harvested rainwater generally needs first-flush diversion, filtration, and disinfection. Recycled wastewater requires more advanced treatment to remove solids, organics, nutrients, and pathogens before reuse in applications such as flushing, landscaping, or cooling.

The type of treatment required depends on both the source of water and the purpose for which the water will be used. Municipal water may require only basic conditioning or disinfection assurance, whereas groundwater may need iron removal, softening, or desalination depending on its chemistry. Harvested rainwater usually requires first-flush diversion, filtration, and disinfection before domestic use. Recycled wastewater requires a higher degree of treatment because it contains organic matter, suspended solids, nutrients, and microorganisms, and must be treated to a level appropriate for reuse applications such as flushing, landscaping, or cooling tower make-up. This approach is based on the principle that water should be treated only to the level necessary for its intended use, but it must always be treated sufficiently to ensure safety and performance.

Common Water-Treatment Processes

Water treatment in buildings may involve a sequence of physical, chemical, and biological processes. Physical treatment processes include screening, sedimentation, and filtration. These processes remove floating matter, suspended solids, and visible impurities, and are often the first stage in the treatment train. Chemical treatment processes include coagulation, softening, pH correction, oxidation, and disinfection. These are used to improve chemical stability, reduce hardness, control dissolved contaminants, and destroy harmful microorganisms. Biological treatment processes are especially important in wastewater treatment, where microorganisms are used to break down organic matter and reduce pollution load. These processes are usually followed by tertiary or polishing treatment to improve the final quality of reused water. In practice, building treatment systems may use these processes singly or in combination, depending on the nature of the source water and the required quality of the treated water.

Nature-Based Treatment Approaches

In addition to conventional mechanical and compact treatment systems, some projects may adopt nature-based treatment systems for wastewater management where site conditions, land availability, and maintenance arrangements are suitable. These may include constructed wetlands, reed-bed systems, root-zone treatment systems, stabilization ponds, or other ecologically based processes that use natural physical, biological, and microbial interactions to improve water quality. Such systems can reduce operational energy demand, support.decentralized wastewater treatment, and contribute to landscape integration where properly designed.

However, the use of nature-based treatment systems in buildings should remain performance-based rather than technology-specific. This means that such systems are acceptable only when they are capable of achieving the required treated-water quality for the intended reuse or disposal application. In practice, nature-based systems may still need pre-treatment, post-treatment, or polishing units depending on the influent quality and the final reuse objective. Thus, while nature-based solutions offer a valuable treatment option, their suitability must be assessed in terms of capacity, land requirement, maintenance, climate response, and compliance with the applicable treated-water quality requirements.

Treatment of wastewater

Treatment of wastewater requires particular attention because reclaimed water is not intended for direct consumption unless specially treated for potable use. Its quality must therefore be matched to the intended non-potable application, such as flushing, landscaping, or cooling tower make-up. For this reason, wastewater is usually subjected to tertiary or polishing treatment after the main wastewater-treatment process so that suspended solids, residual organics, odour, colour, and microbial contamination are reduced to acceptable levels. Separate storage and conveyance are also important so that treated water does not mix with potable water within the building.

Operation, Monitoring, and Maintenance

A treatment system is effective only when it is properly operated, monitored, and maintained. Treatment performance can decline if filters are not cleaned, disinfectant dosage is not maintained, membranes foul, storage tanks are not hygienically managed, or treatment units are operated beyond their design capacity. Routine monitoring is therefore necessary to verify that treated water continues to meet the required quality. In building systems, this also means checking whether the quality remains suitable during storage and distribution, not just immediately after treatment.

ENS 2024 – Mandatory Provisions (Water quality , waste water treatment systems. reuse)

Clause 6.2.6.1 specifies that all potable or domestic water supplied to buildings must meet the quality standards outlined in IS 10500:2012, Drinking Water – Specification, as detailed in Tables 1–4. This ensures that water intended for drinking and household use is safe and compliant with national standards.

Under 6.2.6.2, the quality of treated recycled water intended for various non-potable applications—such as toilet flushing, vehicle exterior washing, non-contact impoundments, and landscape irrigation—must conform to the parameters provided in Table 7.19. These guidelines have been circulated to states and union territories by CPHEEO and are referenced under Section 9.2.2(c) of the Sewerage and Sewage Manual, published by the Ministry of Housing and Urban Affairs. This ensures safe and effective reuse of treated water across different applications, supporting sustainable water management practices.

ECSBC Plus Building Requirements

1. Separate treatment systems: Grey water and black water shall be treated through independent treatment systems.

2. Reuse of treated grey water: Properly treated grey water shall be reused for all non-potable applications, including HVAC cooling-tower make-up where water-cooled chillers are installed. 3. Reuse of treated black water: Treated black water shall be reused for toilet flushing and landscape irrigation. If additional demand arises, treated grey water shall supplement the requirement.
ECSBC Super Building Requirements 1. Grey water to be segregated and treated separately and reused.

9.3 Water–Energy Nexus in Building Water Systems

Water management in buildings is closely linked with energy consumption. Energy is required for pumping, pressurizing, treating, heating, circulating, and distributing water across different building systems. Similarly, several energy systems, such as cooling towers and hot water systems, depend on water for operation. This interdependence is referred to as the water–energy nexus.

In buildings, water-related energy use mainly occurs in domestic water pumping, flushing water distribution, cooling tower circulation, irrigation pumping, wastewater treatment, and service hot water generation. Inefficient water use therefore increases not only freshwater consumption but also electricity and thermal energy demand.

For example, leakage in a pressurized water supply system results in both water loss and additional pumping energy. Similarly, poor insulation in hot water pipelines causes heat loss, requiring additional energy input from the water heater. Therefore, water conservation measures such as leak prevention, low-flow fixtures, pressure optimization, water reuse, and efficient pumping can also reduce energy consumption.

An integrated water–energy approach should therefore be adopted during building design, operation, and maintenance. This includes efficient pump selection, demand-based pumping, VFD-based control, pipe insulation, water-efficient fixtures, reuse of treated water, and continuous monitoring of water consumption.

9.4 Pumping System

A pumping system is used to lift, transfer, and distribute water within a building or across a building site whenever gravity alone is insufficient to meet the required flow and pressure. Pumping systems represent one of the most significant links between water consumption and energy use in buildings. Water distribution for domestic supply, cooling systems, irrigation, and hot water circulation requires mechanical energy to transport water across varying elevations and pressure requirements. Consequently, inefficient water distribution not only increases water losses but also leads to unnecessary energy consumption.

The relationship between water and energy becomes particularly important in pumping applications because every unit of water moved through a building requires electrical energy for operation. Excessive pumping, oversized equipment, uncontrolled flow rates, and leakages collectively increase both operational costs and environmental impacts.

Water conservation measures such as demand reduction, leakage prevention, optimized pipe sizing, and water reuse therefore contribute indirectly to energy savings. Likewise, energy-efficiency interventions such

as efficient pumps, Variable Frequency Drives (VFDs), and pressure optimization reduce water wastage and improve system performance.

This interaction highlights the importance of adopting an integrated water–energy management approach during building design, operation, and maintenance.

Components of a Pumping System

A building pumping system generally consists of the pump, motor, suction and delivery piping, valves, controls, pressure gauges, and associated electrical and safety arrangements. In many cases, the system also includes storage tanks, pressure vessels, or hydro-pneumatic tanks that help regulate flow and pressure. The effectiveness of the system depends not only on the pump itself, but also on the proper integration of all these components.

Types of Pumps Commonly Used in Buildings

Different pump types are used depending on the application, required head, and flow rate.

- Centrifugal pumps are the most commonly used pumps in building water systems because they are simple, reliable, and suitable for a wide range of domestic and service-water applications.
- Submersible pumps are often used in bore-wells, open wells, or sumps where the pump operates below the water level.
- Booster pumps are used to increase pressure in water-supply networks, especially in multi-storey buildings.
- Hydro-pneumatic pumping systems combine pumps with pressure vessels and controls to maintain pressurized water supply without relying entirely on overhead tanks.

The selection of pump type depends on the source of water, the distribution arrangement, the required pressure, and the operational strategy of the building.

Important Pump Performance Parameters

- Pump selection is based on a few important hydraulic and performance parameters.
- Flow rate refers to the quantity of water the pump must deliver within a given time.
- Head refers to the height or pressure against which the pump must work, including suction head, delivery head, and friction losses in the pipe system.
- Efficiency indicates how effectively the pump converts electrical energy into hydraulic energy.
- Power requirement depends on the flow, head, and efficiency of the system.

A well-designed pumping system must balance all these factors so that it delivers the required quantity of water at the required pressure without unnecessary energy use.

Best Efficiency Point (BEP)

Every pump has a Best Efficiency Point (BEP), which is the operating condition at which it performs most efficiently. When a pump operates close to its BEP, energy use is lower, mechanical stress is reduced, vibration

is minimized, and service life is improved. If a pump operates too far away from this point, it may suffer from poor efficiency, overheating, excessive wear, noise, or unstable performance. For this reason, pumps in

Pump selection in buildings should be based on the nature of the source, daily and peak demand, building height, pressure requirements, storage arrangement, and the quality of the water being pumped. Water containing higher solids, corrosive constituents, or reused wastewater may require special pump materials or pump types suited to such conditions. Thus, a pump should not be selected merely on the basis of available capacity or nominal horsepower; it must suit the actual hydraulic and operational needs of the system.

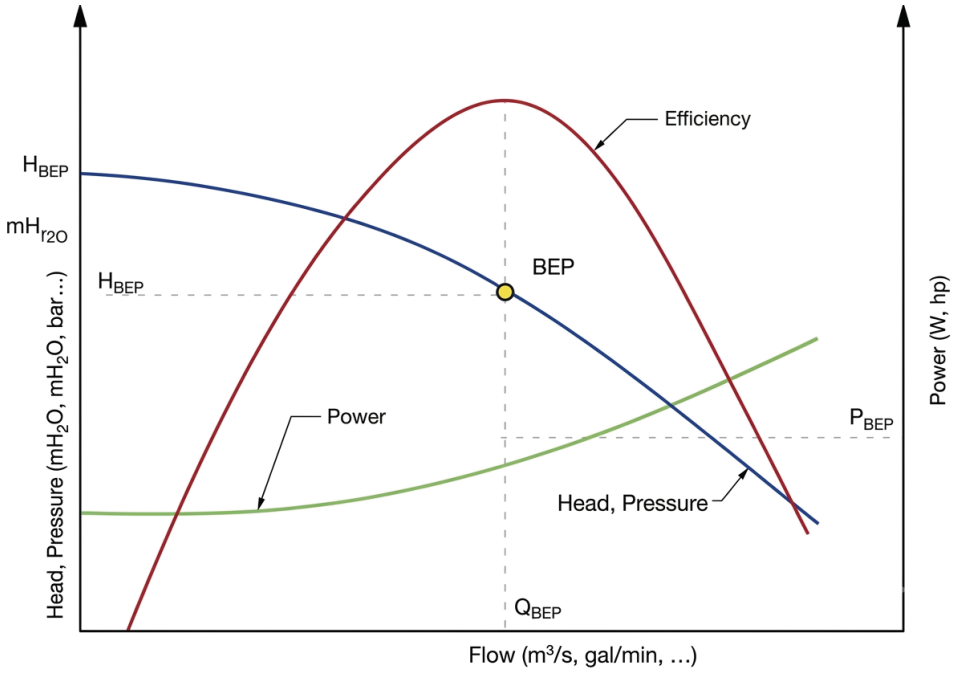


Figure 119 Pump's Best Efficiency Point

ECSBC also places importance on the efficiency of the pump–motor combination. For non-submersible pumps, the code requires at least IE3 efficiency motors, while submersible pumps are required to use at least IE2efficiency motors. Higher compliance tiers prescribe more stringent requirements. In addition, the combined overall efficiency of pump and motor must satisfy minimum values depending on the pumping application. In ECSBC-compliant buildings, domestic water pumps, flushing water pumps, and surface-water pumps are required to meet higher minimum efficiencies than wastewater, sewage, and hot-water circulation pumps, since the latter handle more difficult fluids and operating conditions. This approach ensures that pumping systems are selected not only for functional adequacy, but also for energy-efficient operation.

Efficiency in Pumping Systems

Pumping systems can account for a significant share of energy use in building water services, especially in large buildings or in systems with continuous recirculation and pressure maintenance. Their efficiency therefore depends not only on the pump itself, but also on proper selection, suitable operating conditions, reduced head losses, avoidance of over-pressurization, and good control strategies. In practice, energy performance can be improved by selecting pumps of appropriate size, using efficient motors, providing variable speed control

where suitable, and maintaining the system so that losses due to wear, clogging, air entrainment, or poor valve operation are minimized. Pumps are generally expected to perform best when operating close to their normal design condition rather than being consistently oversized or forced to operate under unstable hydraulic conditions.

ECSBC addresses pumping efficiency through both motor-efficiency class requirements and minimum overall pump–motor efficiency requirements. For non-submersible pumps, ECSBC requires motors of at least IE3 efficiency class, while for submersible pumps the minimum requirement is IE2 efficiency class. In addition, ECSBC prescribes minimum combined overall efficiencies for different pump applications. For domestic water pumps, flushing water pumps, and surface-water pumps, the minimum overall efficiency is 60% under ECSBC, increasing to 65% in ECSBC Plus and 70% in Super ECSBC. For wastewater pumps, sewage pumps, and hot-water circulation pumps, the minimum overall efficiency is 45% under ECSBC, increasing to 50% in ECSBC Plus and 55% in Super ECSBC. These distinctions recognize that cleaner-water pumps can generally operate at higher hydraulic efficiency, whereas pumps handling wastewater, sewage, or circulating hot water may experience greater hydraulic and mechanical losses under service conditions.

Compliance (Non submersible pumps)
ECSBC Plus Building Requirements
Minimum IE 3 efficiency All non-submersible pumps shall be coupled with minimum IE 3 and above-efficiency class motors.
ECSBC Super Building Requirements
Minimum IE 4 efficiency All non-submersible pumps shall be coupled with minimum IE 4 and above-efficiency class motors.

9.5 Piping system

A piping system is the network of pipes, fittings, valves, and accessories used to convey water from its source or storage location to the points of use within a building. In building water systems, piping is required not only for the distribution of potable water, but also for flushing water, treated wastewater, harvested rainwater, hot water, and other service-water applications. The piping system therefore forms the physical link between source, treatment, storage, pumping, and final use. ECSBC requires piping systems to comply with the guidelines of NBC 2016, Part 9, Section 1: Water Supply, and further requires hot-water piping to be insulated as per the relevant hot-water provisions.

A well-designed piping system must ensure that water reaches the required locations in adequate quantity, at suitable pressure, and without deterioration in quality. Poor piping design can result in leakage, excessive pressure loss, stagnation, contamination, water hammer, and increased maintenance. For this reason, piping systems should be designed with attention to hydraulic requirements, material compatibility, durability, accessibility for maintenance, and clear separation between potable and non-potable lines.

Functions of the Piping System

The primary function of a piping system is to transport water safely and efficiently throughout the building. In practice, the system may serve multiple purposes, such as carrying potable water to fixtures, distributing hot water to bathrooms and kitchens, supplying flushing water, conveying treated wastewater or reclaimed water for reuse, and transporting harvested rainwater to storage or reuse points. Thus, the piping system is not merely a set of pipes, but an organized distribution network that supports the entire building water infrastructure.

Types of Piping in Buildings

Different piping networks may exist within the same building depending on the type of water being conveyed. Common categories include cold-water supply piping, hot-water piping, flushing-water piping, reused-water piping, rainwater piping, and wastewater or drainage piping. Since these systems may carry water of different quality, they should be planned carefully to avoid cross-connection, contamination, and operational confusion. ENS specifically requires separate storage tanks and plumbing lines for reuse of treated water and also requires separate tanks and pipelines for stored harvested rainwater used in households so that it does not mix with potable municipal water supply.

Pipe Materials

The choice of pipe material depends on pressure requirement, water quality, temperature, durability, ease of installation, and expected service life. In building practice, different materials may be used for cold water, hot water, external distribution, or special-service water lines. The selected material should be compatible with the type of water conveyed and the conditions of use, since poor compatibility can lead to corrosion, scaling, leakage, or deterioration over time. Materials for hot-water piping should be able to withstand elevated temperature and pressure, while materials used for reclaimed or treated wastewater systems should be suitable for the chemical and biological nature of the water.

Hydraulic Considerations in Piping Design

Piping systems must be designed so that the required flow reaches all points of use at suitable pressure. This involves proper selection of pipe diameter, avoidance of excessive friction loss, and balanced distribution throughout the network. If pipes are undersized, pressure loss increases and the required flow may not be achieved. If pipes are oversized, water velocities may become unnecessarily low, increasing the risk of stagnation and avoidable material cost. Good piping design therefore seeks a balance between flow, pressure, velocity, and economy.

Zoning and Distribution in Buildings

In taller or larger buildings, piping systems are often divided into zones so that water can be distributed efficiently without excessive pressure at lower levels or inadequate pressure at upper levels. Pressure zoning helps maintain manageable operating conditions within the plumbing network and reduces stress on fixtures and fittings. Similarly, separate distribution systems may be needed for potable water, hot water, flushing water, and reused water. Such zoning and segregation improve operational control, reduce contamination risk, and support efficient maintenance.

Separation of Potable and Non-Potable Piping

One of the most important principles in building water systems is that potable and non-potable water must not be mixed. Piping carrying harvested rainwater, treated wastewater, or reclaimed water should therefore be kept separate from potable water lines. Separate piping, storage, and identification are essential to prevent accidental cross-connection and protect public health. This is especially important in buildings using alternate water sources for flushing, landscaping, or cooling-tower make-up, where multiple water networks may operate simultaneously. ENS reinforces this requirement by specifically requiring separate storage tanks and plumbing lines for reused water and separate tank and pipeline arrangements for harvested rainwater intended for household reuse.

Hot-Water Piping and Insulation

Hot-water piping requires additional care because temperature affects material performance, heat loss, safety, and energy use. ECSBC explicitly requires that hot-water piping be provided with the required insulation, and later sections of the code prescribe insulation levels for supply and return lines. Insulation helps reduce heat loss, improve delivery efficiency, reduce unnecessary reheating, and protect users from high external pipe temperatures. Proper insulation is therefore both an energy-efficiency measure and a system-performance measure.

Valves, Controls, and Pipe Accessories

A piping system includes not only pipes, but also valves and accessories that regulate flow, isolate sections, control pressure, and facilitate maintenance. These may include isolating valves, non-return valves, balancing valves, pressure-reducing valves, and strainers. Proper placement of these components improves reliability, ease of operation, and maintenance safety. Without adequate isolation and control, even a minor repair or fault may interrupt water supply to large parts of the building.

Leakage Prevention and Maintenance

Leakage is one of the major causes of water loss and system inefficiency in buildings. Poor jointing, corrosion, excessive pressure, mechanical damage, and lack of maintenance can all contribute to leakage. Piping systems should therefore be installed carefully, pressure-tested before commissioning, and inspected periodically during operation. Provision for access, repair, and replacement is important because concealed or inaccessible pipe failures can lead to prolonged losses, dampness, structural damage, and hygiene problems.should therefore be installed carefully, pressure-tested before commissioning, and inspected periodically during operation. Provision for access, repair, and replacement is important because concealed or inaccessible pipe failures can lead to prolonged losses, dampness, structural damage, and hygiene problems.should therefore be installed carefully, pressure-tested before commissioning, and inspected periodically during operation. Provision for access, repair, and replacement is important because concealed or inaccessible pipe failures can lead to prolonged losses, dampness, structural damage, and hygiene problems.

Water Metering

Water metering is the measurement of the quantity of water entering, leaving, or being used within a building water system. Accurate measurement of water volume is fundamental to effective water-resource management

because it enables accountability, efficient use, leak detection, performance assessment, and better control of different water streams within the premises. In buildings that use multiple sources and multiple distribution networks, such as potable water, flushing water, reclaimed water, and harvested rainwater, metering becomes especially important because it helps establish how much water is being supplied, consumed, reused, or lost.

Importance of Water Metering

Water that is not measured cannot be managed effectively. Without metering, it becomes difficult to determine whether high water demand is due to actual use, leakage, inefficient fixtures, or poor system operation. Metering helps in understanding demand patterns, identifying excessive consumption, verifying the performance of water-saving measures, and supporting water audits. It also helps compare incoming water with water distributed to various end uses, thereby improving overall water management within the building.

Types of Water Meters

Water flow may be measured using conventional mechanical meters or advanced digital technologies, depending on the application, pipe size, required accuracy, and the nature of the water being measured.

Conventional meters include positive-displacement meters and velocity meters such as multi-jet or turbine meters. These are commonly used in domestic and general building water-supply applications and are expected to conform to the relevant Indian standards for domestic water meters.

Advanced metering technologies may include electromagnetic meters, ultrasonic meters, and IoT-enabled smart meters. These systems are useful where real-time monitoring, remote reading, sub-metering, or integration with building management systems is required. In practice, advanced meters are particularly useful for larger buildings, complex water systems, treated-water networks, or applications where continuous performance monitoring is desirable.



Figure 120 Digital Water Meter

Inflow and Outflow Metering

For effective monitoring, meters should be installed at both major entry and distribution points in the building water system. Inflow metering measures water entering the building premises from sources such as municipal supply, groundwater, or external reclaimed-water supply.

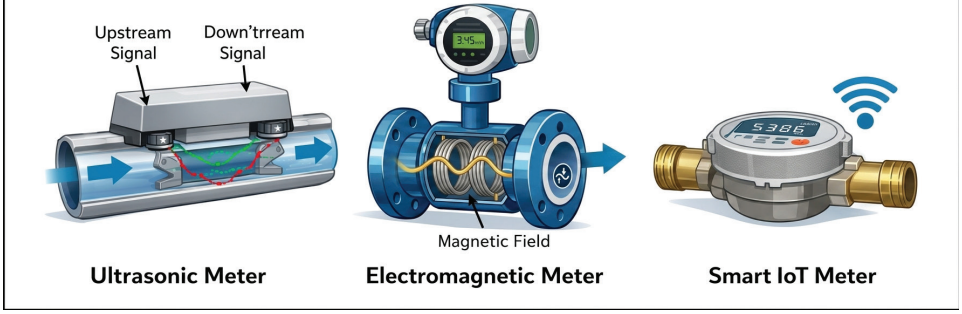


Figure 121 Types of water meter

Outflow metering measures water distributed from the supply point to the major internal water systems and end uses within the building. This approach allows the total incoming water to be compared with the water supplied to different systems, which helps in identifying losses, understanding demand distribution, and improving operational control.

Bulk Metering and Sub-Metering

Bulk metering records the total quantity of water entering or leaving the premises, while sub-metering records water use at selected branches, zones, or end-use systems. Sub-metering is particularly useful for monitoring potable water use, flushing demand, irrigation demand, cooling-tower make-up water, and reclaimed-water use. In larger residential, commercial, or mixed-use buildings, sub-metering improves accountability and helps identify areas of unusually high demand or hidden leakage.

Metering of Different Water Networks

Buildings using more than one type of water should provide separate metering for each major water network. Potable water, flushing water, harvested rainwater, and reclaimed water may serve different purposes and should therefore be monitored independently wherever feasible. Separate metering helps verify whether alternate water sources are actually reducing fresh-water demand and whether treated wastewater or harvested rainwater is being used effectively for intended non-potable applications.

Smart Metering and Monitoring Systems

Modern water-management systems increasingly use smart meters with digital or pulse outputs to support automatic meter reading, remote monitoring, leak detection, and data logging. Such systems can also be integrated with building management systems or utility dashboards to provide better visibility of water consumption trends. Although conventional meters remain widely used, smart metering can significantly improve monitoring and operational decision-making in buildings with complex or high-demand water systems.

Installation and Maintenance Considerations

The effectiveness of a water meter depends not only on the type of meter selected, but also on proper installation, calibration, accessibility, and maintenance. Meters should be installed in locations that allow accurate reading, easy inspection, and protection from physical damage or tampering. The selected meter should also be suitable for the quality of water being measured, since water containing suspended matter or impurities may affect the long-term accuracy and reliability of some devices. Regular inspection and maintenance are therefore necessary to ensure dependable performance over time.

Compliance (Water metering)

ENS 2024 – Mandatory Provisions Clause 6.2.3.1 requires that buildings exceeding the threshold specified in Section 2.2 of this code must install bulk flow meters on-site. These meters are intended to record overall water flow and demand for the entire residential premises as well as for individual dwelling units. The installation and operation of these meters should comply with the guidance provided in Chapter 13 of the "Manual on Water Supply and Treatment Systems (Drink from Tap), 2024", published by CPHEEO, MoHUA. This ensures accurate monitoring, effective water management, and helps in promoting water-use efficiency across the building.

IoT-Based Water Monitoring and Leak Detection

IoT-based water monitoring systems use smart meters, sensors, communication devices, and digital dashboards to monitor water consumption in real time. These systems help facility managers track water use, identify abnormal consumption, detect leakages, prevent tank overflow, and improve operational control.

A typical smart water monitoring system may include digital water meters, flow meters, pressure sensors, tank-level sensors, automated control valves, and integration with the Building Management System. These components provide continuous data on water flow, pressure, storage, and consumption at different end-use points.

Leak detection can be carried out using several methods. In the water balance method, total incoming water is compared with measured end-use consumption. Any unexplained difference indicates possible leakage or unmetered loss. In the minimum night flow method, water use during low-occupancy hours is monitored. Continuous flow during this period may indicate hidden leakage. In the pressure monitoring method, sudden pressure drops or abnormal fluctuations are used to identify possible pipe leakage or valve failure.

IoT-based systems can also generate automatic alerts when consumption exceeds defined thresholds. For example, if water flow continues in a toilet block after working hours, the system can notify the facility manager. This allows quick corrective action and reduces water wastage.

9.6 Water Controls

Water controls are the devices and control arrangements used to regulate the storage, movement, pressure, and operation of water within a building system. In practical terms, controls ensure that water is supplied when needed, that tanks do not overflow, that pumps do not run dry, and that pressure remains stable throughout the

network. Without proper controls, even a well-designed water-supply system may suffer from overflow losses, pressure fluctuations, inefficient pump operation, and unnecessary energy consumption.

In building water systems, controls are particularly important because water demand varies over time and because many buildings operate with multiple storage tanks, pumping arrangements, and separate water networks. Water controls therefore improve not only convenience and reliability, but also safety, efficiency, and resource management. ECSBC reflects this by requiring control arrangements for tanks, pumps, and hydro-pneumatic systems, with more advanced provisions introduced in higher compliance tiers.

Role of Water Controls in Buildings

The basic purpose of a control system is to maintain the desired operating condition automatically or with minimal manual intervention. In a building water system, this may include maintaining tank water levels, switching pumps on and off, controlling pressure in hydro-pneumatic systems, preventing dry running, and ensuring stable water delivery to fixtures and equipment. Effective controls reduce wastage, protect equipment, and improve the reliability of supply across the building.

Level Controls for Sumps and Tanks

Storage tanks and sumps should be provided with level-control arrangements so that pumping can be started or stopped automatically according to the water level. Float switches or equivalent level-sensing devices are commonly used for this purpose. These controls help prevent tank overflow, avoid dry running of pumps, reduce unnecessary pump cycling, and improve the service life of the equipment. In this way, level control contributes both to water conservation and to reliable system operation.



Figure 122 Float switch

Pressure Controls for Hydro-Pneumatic Systems

Where hydro-pneumatic systems are used, pressure controls are required to maintain consistent delivery pressure across the system. Pressure switches or pressure transmitters activate the pump when pressure falls below a set level and stop or regulate operation once the required pressure is restored. This helps ensure a steady supply to fixtures and equipment, especially in multi-storey buildings, and reduces pressure fluctuations that may damage fittings or affect user comfort. Proper pressure control also protects pumps from unstable operation and improves energy efficiency.

Auto-Changeover for Duty and Standby Pumps

In systems that include both duty and standby pumps, automatic changeover control is highly beneficial. Such arrangements allow the standby pump to take over automatically during failure, maintenance, or abnormal operation of the main pump. This improves reliability and continuity of supply, particularly in systems where uninterrupted water availability is important. Auto-changeover can also help distribute operating hours more evenly between pumps, thereby reducing uneven wear and extending service life.

Flow Monitoring as a Control Measure

Flow monitoring is an important control measure because it helps operators understand whether the system is performing as intended. Meters on key water-supply lines make it possible to identify abnormal demand, leakage, wastage, or imbalance between supply and use. In buildings with multiple water streams, such as potable water, flushing water, reclaimed water, and hot water, flow monitoring also supports better control of distribution and reuse. Thus, metering and controls work together to improve the overall management of the water system.

Advanced Control Systems

In larger or more complex buildings, water controls may be integrated into automated control panels, programmable logic controllers (PLCs), or building management systems (BMS). Such systems can provide centralized monitoring, alarm generation, remote operation, and better coordination between pumps, tanks, pressure systems, and metering devices. Although advanced controls may not be necessary for every building, they are particularly useful where multiple pumps, pressure zones, or alternate water networks operate together.

Importance of Proper Controls

Proper controls improve the overall performance of a building water system in several ways. They reduce water wastage from overflowing tanks, prevent pump damage from dry running, maintain stable pressure, reduce manual intervention, and support efficient energy use. They also make it easier to manage multiple water systems, such as potable water, flushing water, reclaimed water, and hot-water circulation networks. Thus, controls are not merely auxiliary accessories; they are an essential part of a safe, efficient, and reliable water infrastructure.

Compliance (Controls and Automation)

ECSBC Plus Building Requirements

01.Solenoid Based Level Controllers: All storage sumps and tanks shall be equipped with solenoid-based level controllers with automatic ON/OFF operation to prevent overflow and water wastage.

02.Hydro-pneumatic systems: Hydro-pneumatic systems, where installed, shall include pressure transmitters to maintain stable pressure at both suction and delivery manifolds—ensuring dry running is avoided at the suction side and enabling effective pressure monitoring on the delivery side.

03.Flow Meters: Flow meters shall be installed on all water supply lines.

ECSBC Super Building Requirements

01. Sump/Tank Level Control: All storage sumps and tanks shall be equipped with infrared level indicators and controllers with automatic ON/OFF functionality and alarm systems for pump operation.

02. Pumping System Automation: All pumping systems shall be operated through a PLC-based control setup integrated with the Building Management System (BMS), enabling data transmission for remote monitoring and management.

9.7 Service Water Heating

Service water heating refers to the heating of water for domestic and service purposes such as bathing, washing, cleaning, kitchen use, and other building functions that require hot water. In buildings, service hot water is different from space heating because its purpose is to supply heated water directly to occupants or service points rather than to condition indoor air. Since water heating can account for a significant share of building energy use, the selection of an appropriate system has an important influence on both energy performance and user comfort.

In many buildings, especially those with large and regular hot-water demand, centralized service water-heating systems are preferred because they improve operational control, reduce duplication of equipment, and allow integration with efficient technologies such as heat pumps, solar water-heating systems, and heat-recovery arrangements. ECSBC therefore places emphasis on centralized hot-water systems in covered buildings across climatic zones.

Heat Pump Requirements

A heat-pump water heater works by transferring heat from air, water, or ground to heat water, rather than generating all the required heat directly through resistance heating. Because of this, heat pumps can provide more useful heat per unit of electrical input than conventional electric water heaters and are therefore considered significantly more energy-efficient.

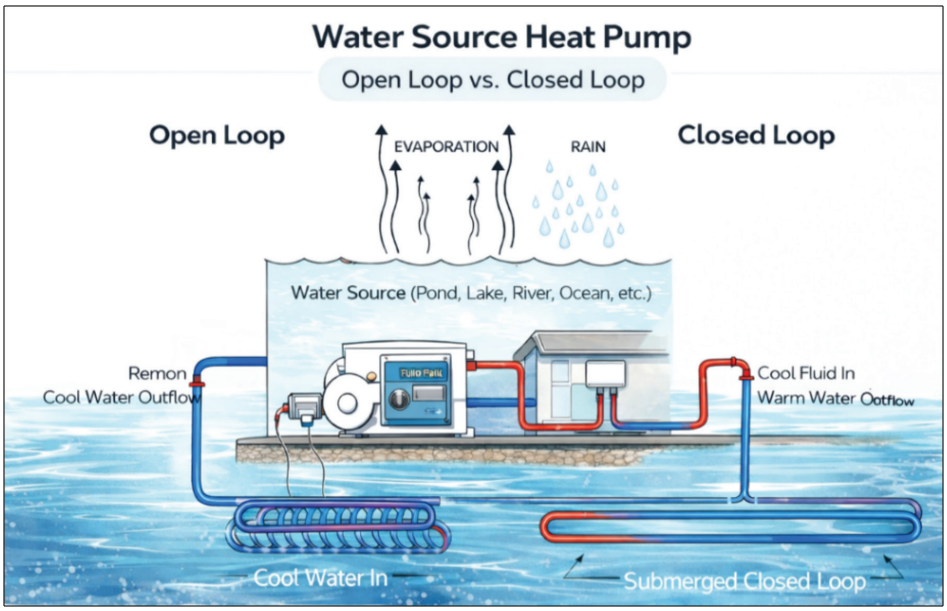


Figure 123 Water Source Heat Pump

ECSBC specifies minimum Coefficient of Performance (COP) values for centralized heat-pump-based service water heating. The minimum COP required is 3.5 for air-source heat pumps, 4.5 for water-source heat pumps, and 3.0 for ground-source heat pumps. These values represent the minimum performance level expected from the respective systems and help ensure that service water heating is achieved with lower energy consumption.

The choice of service water-heating system affects not only energy consumption, but also user comfort,

operating cost, and reliability. An inefficient system may increase electricity or fuel use, cause long waiting times for hot water, and lead to unnecessary standby losses. By contrast, a well-designed system can improve comfort, reduce wasted water and energy, and support better control of hot-water distribution within the building. In larger buildings, centralized high-efficiency systems are particularly beneficial because they can serve multiple demand points while reducing redundancy in equipment.

Exceptions and Alternative Pathways

ECSBC also provides specific exceptions to the general heat-pump requirement. In hospitality and healthcare buildings, solar water-heating equipment is required to provide at least 40% of the total hot-water design requirement. The code also provides exceptions where a building installs solar photovoltaic capacity equal to 5% of the total contractual power demand or 200 W/sqm, whichever is less, and where heat recovery from condensers or chillers is used to meet the required hot-water capacity.

These provisions indicate that the objective of the code is not tied to one rigid technology alone. Instead, it promotes efficient and renewable-energy-based pathways for meeting service hot-water demand while maintaining overall system performance.

Compliance (Solar Hot Water) **ECSBC Plus Building Requirements** 01.Solar Hot Water Requirement Hospitality and healthcare buildings across all climatic zones shall install solar water heating systems to meet at least 60% of the total hot-water design demand, with the remaining 40% supplied through other hot-water generation systems.
Exception to Clause 9.3.5(a) Buildings that install a Solar PV system with a capacity equal to 7.5% of the total contractual power demand or 300 W/m²—whichever is lower—are exempt from this requirement.
ECSBC Super Building Requirements 01.Solar Hot Water Requirement Hospitality and healthcare buildings in all climatic zones shall install solar water heating systems to meet 100% of the total hot-water design demand. Exception to Clause 9.3.5(b) Buildings that install a Solar PV system with a capacity equal to 10% of the total contractual power demand or 400 W/m²—whichever is lower—are exempt from this requirement.

9.8 Other Water-Heating Systems

In addition to centralized heat-pump-based systems, buildings may also use other water-heating systems depending on hot-water demand, available energy source, building type, and operational requirements. These systems may function either as primary hot-water systems in specific contexts or as supplementary systems used to support or back up the main service water-heating arrangement. Their suitability depends not only on the heating method, but also on efficiency, reliability, safety, maintenance needs, and compatibility with the overall building water and energy system.

ECSBC recognizes that service water heating may be supported by systems other than heat pumps in specific cases. These include condenser heat recovery, gas-fired water heaters, electric water heaters, electric coil heaters,

and solar-assisted systems. However, such systems should be selected and operated in a manner that maximizes energy efficiency and reduces unnecessary dependence on direct conventional heating.

Condenser Heat Recovery

Condenser heat recovery uses waste heat rejected from chillers, condensers, or other cooling equipment to heat water. This approach improves overall energy efficiency because it makes use of heat that would otherwise be rejected to the atmosphere. In buildings with continuous cooling loads, such as hotels, hospitals, and large commercial buildings, condenser heat recovery can be an effective way to meet part of the domestic hot-water demand while reducing dependence on standalone heating systems. It is particularly valuable because it links hot-water production with existing cooling operations, thereby improving the integrated performance of the building.

Gas-Fired Heaters

Gas-fired water heaters use combustion of gaseous fuel to heat water and may be used where piped natural gas or another suitable gas source is available. These systems are capable of rapid heating and may be suitable where reliable hot-water supply is required over short response times. They can also offer lower operating cost than electric resistance heating in locations where gas is economically and reliably available. However, their use requires proper combustion safety, exhaust venting, and temperature control. Gas-fired systems should therefore be selected with attention to safety, fuel availability, and operating efficiency.

Electric Coil Heaters

Electric coil heaters use resistive heating elements to raise the temperature of water. These systems are simple, compact, and easy to install, and they are often used as supplementary or backup heaters within larger hot-water systems. They may also be used where localized or limited hot-water demand exists. However, because they rely on direct resistance heating, they generally consume more electrical energy per unit of useful hot water than heat-pump-based systems. For this reason, electric coil heaters are best used selectively, such as for backup support, peak-load assistance, or in situations where other heating systems are unavailable or insufficient.

Selection Considerations

The selection of an alternative or supplementary water-heating system should consider hot-water demand, energy source availability, installation space, operating cost, maintenance requirements, and the need for backup or redundancy. In some buildings, a combination of systems may be the most practical solution—for example, a centralized heat-pump system supported by condenser heat recovery or electric backup. The choice should therefore be based not only on the type of heater, but also on its ability to provide the required quantity of hot water safely, reliably, and efficiently under actual building operating conditions.

Compliance (Solar hot water in Hospitality and health care)

ECSBC Plus Building Requirements Solar hot water requirement: Hospitality and health care buildings across all climatic zones shall install solar water-heating systems to meet at least 60% of the total hot-water design demand, with the remaining 40% supplied through other hot-water generation systems.

Exception to the Clause 9.3.5(a): Buildings that install a solar PV system with a capacity equal to 7.5% of the total contractual power demand or 300 W/m²—whichever is lower—are exempted from this requirement.

ECSBC Super Building Requirements Solar hot water requirement: Hospitality and healthcare buildings in all climatic zones shall install solar water heating systems to meet 100% of the total hot-water design demand.

Exception to the Clause 9.3.5(b): Buildings that install a Solar PV system with a capacity equal to 10% of the total contractual power demand or 400 W/m²—whichever is lower—are exempted from this requirement.

9.9 Service Water Heating Equipment Efficiency

The efficiency of water-heating equipment determines how effectively input energy is converted into useful hot water. In buildings, this is important because service water heating can account for a substantial share of total energy use, particularly in hotels, hospitals, hostels, residential complexes, and institutional buildings with regular hot-water demand. Efficient equipment reduces energy consumption, lowers operating cost, decreases standby and distribution losses, and improves overall system performance. For this reason, the selection of water-heating equipment should be based not only on initial cost or ease of installation, but also on long-term energy performance, safety, durability, and suitability for the intended application.

Different types of water-heating equipment express efficiency in different ways. In heat-pump-based systems, efficiency is represented through the coefficient of performance, which indicates how much useful heat is delivered for each unit of electrical input. In gas-fired systems, efficiency is generally understood in terms of how much of the fuel energy is converted into useful heating of water. In electric resistance systems, the conversion of electrical energy to heat is direct, but the overall system may still be less energy-efficient than heat pumps because of the higher electrical input required per unit of useful hot water delivered. Solar water-heating systems reduce dependence on conventional energy sources by using solar collectors and storage systems, while their performance depends on collector efficiency, solar availability, and system integration.

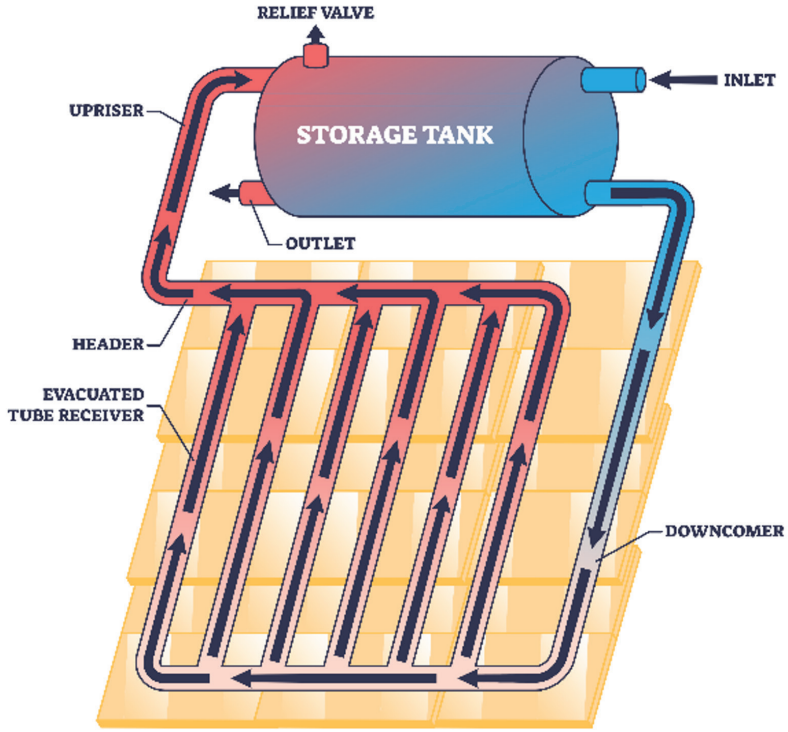


Figure 124 Solar water heater

ECSBC requires service water-heating equipment to comply with the relevant Indian Standards and applicable efficiency requirements. Solar water heaters are governed through the relevant BIS standards for solar water-heating systems and performance evaluation. Gas instantaneous water heaters are required to comply with the applicable Indian Standard, including minimum fuel-utilization efficiency requirements. Electric water heaters must conform to the relevant standard for electrical and thermal safety, and their energy performance

may also be linked to BEE star-labelling requirements where applicable. Evacuated tube collector systems are similarly required to comply with the relevant standards for storage tanks and evacuated tubes so that thermal performance and safety are maintained.



Figure 125 Evacuated tube collectors

In practical terms, equipment efficiency should not be considered in isolation. Actual performance depends on proper sizing, insulation of storage tanks and piping, control strategy, recirculation design, maintenance of heat-transfer surfaces, and water quality. For example, scale formation on heating surfaces can reduce heat-transfer efficiency, while poor insulation can increase standby losses and force the equipment to operate more frequently. Thus, efficient water-heating equipment performs best when it is integrated with a well-designed and well-maintained hot-water system.

9.10 Return recirculation line (centralized systems)

In a centralized hot-water system, a return recirculation line is provided to bring unused hot water back to the heating or storage unit so that hot water remains available near the points of use. Without a recirculation loop,

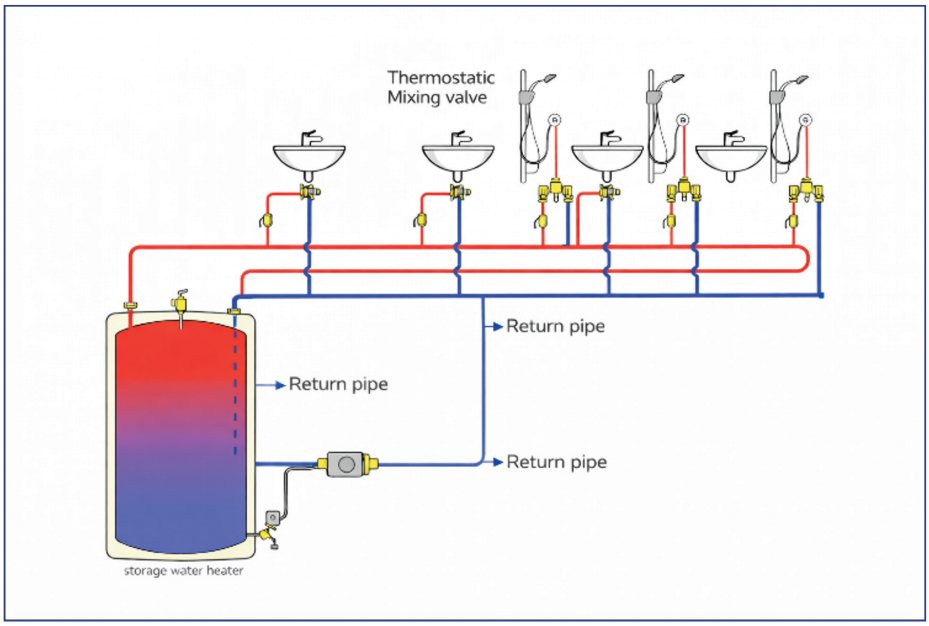


Figure 126 Recirculation system

water standing in long pipe runs cools down between uses, and users must discharge cold or lukewarm water before hot water reaches the fixture. This increases both water wastage and user waiting time, especially in large buildings, hotels, hospitals, hostels, and other facilities with long distribution networks. A properly designed return line therefore improves service quality by maintaining more stable water temperature throughout the hot-water system.

The effectiveness of a recirculation system depends on careful design and control. The return line should be used with insulated hot-water piping, balanced branch connections, and a circulation pump sized for the recirculation duty rather than for peak delivery demand. To avoid unnecessary energy use, the recirculation pump should not operate continuously unless required by the building's demand pattern. Instead, it may be operated through temperature-based, timer-based, or demand-based controls so that circulation occurs only when needed to maintain acceptable delivery temperature. When properly designed, a return recirculation line improves user comfort, reduces water wastage, limits temperature drop in the distribution network, and supports more efficient operation of centralized hot-water systems.

9.11 Water heating controls and safety controls

Effective control and safety arrangements are essential for the reliable and energy-efficient operation of service water-heating systems. In buildings, hot-water systems must not only deliver water at the required temperature, but must also protect equipment from damage, prevent unsafe temperatures, and ensure that the system operates only when needed. Without proper controls, water-heating systems may suffer from overheating, excessive cycling, unstable operation, unnecessary energy use, and safety risks to occupants.

The control requirements of a hot-water system depend on the type of equipment used. Gas-fired heaters, heat pumps, and solar water-heating systems each have different operating characteristics and therefore require different forms of monitoring, control, and protection. In all cases, the purpose of these controls is to maintain stable performance, improve efficiency, and protect both users and equipment.

Controls for Gas-Fired Water Heaters

Gas-fired water heaters require proper combustion safety and temperature regulation. Since gas combustion produces flue gases, safe exhaust or venting arrangements are necessary to discharge these gases and prevent unsafe indoor accumulation. In addition, gas-fired heaters should be provided with thermostat controls so that the outlet water temperature remains within the desired range and overheating is avoided. Proper temperature control improves user comfort, reduces excessive fuel use, and lowers the risk of scalding.

Controls for Heat-Pump Water Heaters

Heat-pump water-heating systems require several protective and operating controls to ensure stable performance under varying thermal conditions. These commonly include high- and low-pressure cut-offs, temperature cut-off and restart arrangements, and operating controls that prevent unstable cycling. Such controls protect the compressor and associated components from abnormal operating conditions, improve reliability, and help maintain energy efficiency. In water-source systems, control of the source-side temperature is especially important because very low or very high loop temperatures may affect performance or damage the equipment.

Controls for Solar Water-Heating Systems

Active solar water-heating systems rely on circulation controls to transfer heat from the collector to the storage tank. For this reason, solar systems are commonly operated using differential temperature controls that compare collector temperature with tank temperature and run the circulation pump only when useful heat gain is available. This prevents unnecessary pump operation and improves the net efficiency of the system. Because solar collectors can generate very high outlet temperatures under strong solar radiation, hot-water systems should also incorporate suitable temperature-control arrangements to avoid overheating and unsafe delivery temperatures.

Compliance: PLC- based control system

ECSBC Plus and Super Buildings' Requirements PLC-based system panel: ECSBC Plus and ECSBC Super buildings shall have heat pumps with PLC-based system panel, to give data to Central BMS of the building.

9.12 Swimming Pool Heating

Heated swimming pools can be major energy consumers, as water is maintained at elevated temperatures and continuously loses heat through evaporation, convection, radiation, and make-up water. Evaporation is typically the largest source of heat loss, making surface heat control critical to energy efficiency.

Effective pool heating therefore depends not only on the heating system but also on reducing heat loss, maintaining appropriate temperature, and minimizing reheating during non-use periods. A key measure is the use of vapour-retardant pool covers, which significantly reduce evaporation, lower energy demand, and improve overall efficiency. For pools operating at higher temperatures (above ~32°C), higher-performance covers are especially important.

Pool covers also help reduce humidity in indoor facilities, lowering ventilation and dehumidification loads. Overall, efficient pool heating combines appropriate equipment, thermal protection (covers), and good operational control to minimize energy use while maintaining comfort.

9.13 Water Balance

The concept of water balance evolved from the hydrologic principle of conservation of mass, where all water entering, leaving, and being stored within a system is systematically accounted for. As hydrology developed into a quantitative science, water balance methods became essential tools in watershed analysis, climatology, irrigation planning, and urban water management. The work of C. W. Thornthwaite and Thornthwaite & Mather significantly advanced practical water-balance analysis by formalizing methods for estimating water surplus, deficit, storage, and evapotranspiration.

In building and site planning, a water balance is used to account for all water inflows, storage, consumption, reuse, and discharge within a project. It helps align water demand with available sources, treatment systems, recycling strategies, and discharge management, thereby supporting efficient and sustainable water use. Since rainfall and water availability vary seasonally, ECSBC requires separate water balances for dry and wet seasons

to accurately assess source availability, especially from rainwater harvesting systems. Generally, the dry season is considered from October to May and the wet season from June to September, unless local meteorological data indicates otherwise.

Design Population and Water Demand

The preparation of a water balance begins with estimating the design population of the building. This is important because the quantity of water required for domestic use, flushing, and wastewater generation depends directly on the expected occupancy. The design population is to be determined in accordance with NBC 2016, Part 9, Section 1, based on the building type and occupancy characteristics. Where a building typology is not specifically covered, the actual occupancy may be adopted with appropriate certification and justification.

After determining the design population, the next step is to estimate the minimum water requirement using the consumption norms provided in NBC 2016. These norms establish standard daily water demand values for different building uses such as residential, commercial, institutional, and mixed-use developments. These values form the basis for estimating the total daily demand that must be met through municipal water, groundwater, rainwater, or recycled water sources.

Fixture Units and Simultaneous Demand

In addition to total daily demand, the water balance must also consider peak use and internal distribution requirements. For this purpose, fixture units are used to represent the relative demand imposed by different plumbing fixtures. The probable simultaneous demand is then derived using the relevant NBC provisions. This helps in sizing storage tanks, pumps, piping systems, and distribution arrangements so that the system remains functional during peak demand periods. Thus, the water balance is not only a planning document for water quantity, but also a practical input for hydraulic design.

Role of Efficient Fixtures and Alternate Water Sources

The water balance should also reflect the impact of water-efficient fixtures and alternate water sources. The use of efficient plumbing fixtures reduces per-capita water demand and lowers the total fresh-water requirement of the building. Similarly, rainwater harvesting and recycled-water reuse reduce dependence on fresh-water sources and improve overall water-use efficiency. Therefore, the water balance should clearly distinguish between fresh-water demand, alternate water availability, treated-water reuse, and final wastewater discharge.

Seasonal Adjustment and Planning Use

Seasonal preparation of the water balance is particularly important in Indian conditions, where rainfall patterns strongly influence water availability and reuse opportunities. In locations where the duration of wet and dry seasons differs from the general seasonal assumption, ECSBC allows projects to revise these periods based on authenticated rainfall records from the local meteorological authority. This makes the water balance more representative of local climatic conditions and improves the reliability of the water-planning exercise.

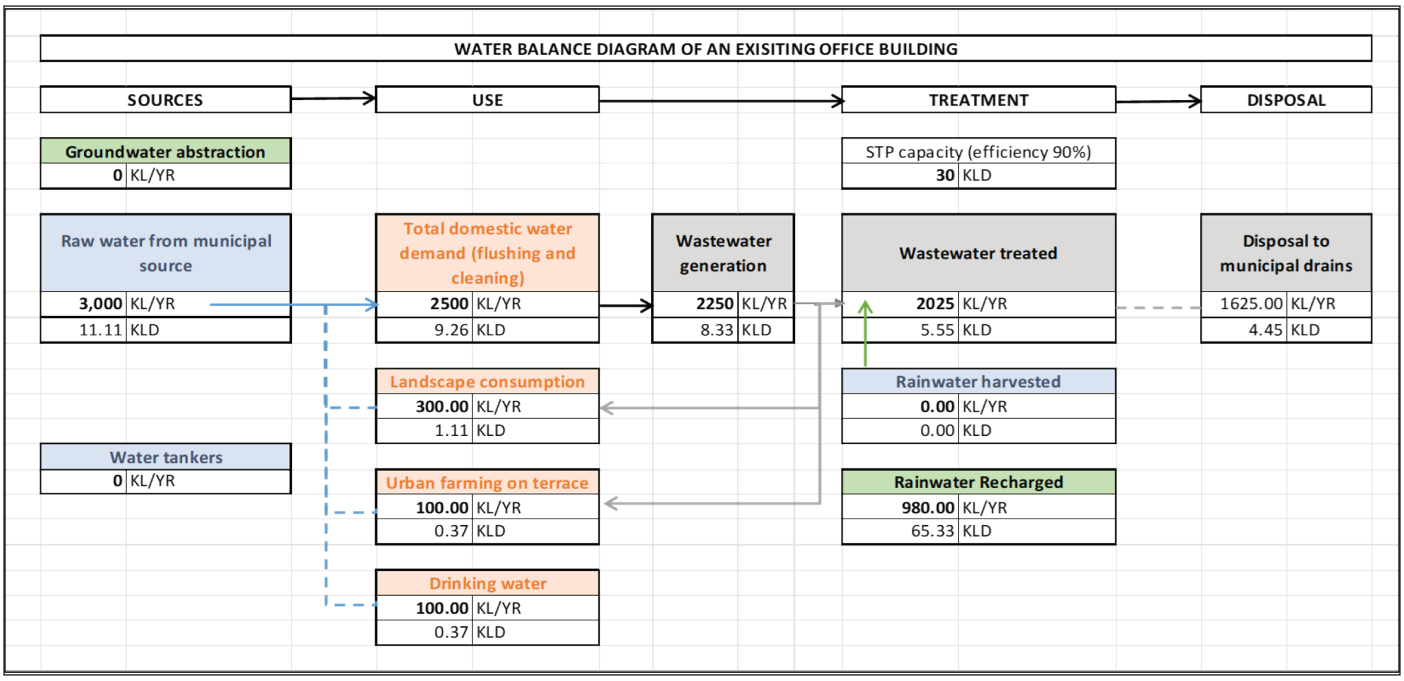


figure 127 water balance diagram

Water Balance with Example

A water balance is a systematic accounting of all water entering, used within, reused, discharged, and lost from a building. It helps identify inefficiencies, leakages, excessive consumption, and opportunities for water reuse.

The basic relationship is:

Total water input = Total water use + Total discharge + Total losses

Where water reuse is present, recycled water should be shown separately so that it is not double-counted as new freshwater input.

A building water balance generally includes:

Inputs

- Municipal water supply;
- Borewell water;
- Rainwater harvesting;
- Recycled treated water.

Uses

- Domestic fixtures;
- Flushing;
- Cooling tower make-up;
- Landscape irrigation;
- Cleaning;
- Hot water systems.

Outputs

- Wastewater;
- Treated wastewater;
- Reused water;

- Cooling tower evaporation;
- Blowdown;
- Leakage and losses.

Example

A commercial building has the following daily water demand:

Domestic use = 40 m^3/day

Flushing demand = 25 m^3/day

Cooling tower make-up = 20 m^3/day

Landscape irrigation = 10 m^3/day

Miscellaneous losses = 5 m^3/day

The building treats 20 m^3/day of wastewater and reuses it for flushing. Calculate the total water demand, freshwater demand after reuse, and percentage freshwater saving.

Total water demand:

40 + 25 + 20 + 10 + 5 = 100 m^3/day

Recycled water used for flushing:

20 m^3/day

Freshwater demand after reuse:

100 − 20 = 80 m^3/day

Freshwater saving:

20 m^3/day

Percentage freshwater saving:

20 / 100 × 100 = 20%

Therefore, by reusing 20 m^3/day of treated wastewater for flushing, the building reduces freshwater demand from 100 m^3/day to 80 m^3/day and achieves 20% freshwater saving.

9.14 Water Efficiency

Water efficiency in buildings is achieved not only through large system-level strategies such as recycling, rainwater harvesting, and reuse, but also through the selection of efficient sanitary fixtures and fittings. Fixtures such as water closets, urinals, taps, faucets, showers, and ablution sprays determine how much water is released each time a user activates them, and therefore have a direct influence on the building's daily water demand. ECSBC and ENS make this connection explicit by requiring sanitaryware and sanitary fittings to comply with the relevant star-rated performance thresholds under IS 17650 (Parts 1 and 2). In this way, the baseline water demand of the building is reduced at the point of use itself, even before alternate water sources or advanced reuse systems are considered.

Efficient fixtures are important because they reduce fresh-water consumption without compromising the essential function of the fixture. Lower discharge volumes and flow rates reduce the quantity of water drawn from municipal supply, groundwater, or other sources, and they also reduce the volume of wastewater generated. This improves the overall water balance of the building, reduces the size and load of pumping, storage, and treatment systems, and contributes to long-term savings in water and operating cost. Water-efficient fixtures are therefore among the most direct and cost-effective measures for improving building water performance.

Water-Efficient Sanitaryware

Sanitaryware such as water closets and urinals are major contributors to indoor water demand because they are used frequently and each use involves a defined flush volume. ECSBC and ENS therefore prescribe maximum flush volumes linked to the star-rating framework of IS 17650 Part 1.

For water closets, the minimum requirement under ECSBC and ENS is a 1-star dual-flush system with a maximum full flush of 6.0 litres per flush and a reduced flush of 3.0 litres per flush. More stringent limits are prescribed for higher compliance tiers. Under ECSBC Plus and ENS 2-star, the limits are 4.8 litres per full flush and 2.8 litres per reduced flush, while under Super ECSBC and ENS 3-star, the limits are 4.0 litres per full flush and 2.0 litres per reduced flush.

For urinals, the maximum flush volume permitted is 3.0 litres per flush under ECSBC and ENS 1-star, 2.0 litres per flush under ECSBC Plus and ENS 2-star, and 1.0 litre per flush under Super ECSBC and ENS 3-star.

These limits are important because water closets and urinals are high-frequency fixtures. Even modest reductions in flush volume lead to significant cumulative savings over the life of the building.

Water-Efficient Sanitary Fittings

Sanitary fittings such as taps, faucets, showers, and ablution sprays are governed mainly by flow rate or volume per use, because they release water continuously during operation. ECSBC and ENS adopt the relevant limits from IS 17650 Part 2 as the minimum compliance thresholds.

- For washbasin metered faucets, the maximum discharge is 1.0 litre per use under ECSBC and ENS 1-star, 0.8 litre per use under ECSBC Plus and ENS 2-star, and 0.6 litre per use under Super ECSBC and ENS 3-star.
- For urinal-metered faucets, the maximum volume is 3.0 litres per flush under ECSBC and ENS 1-star, 2.0 litres per flush under ECSBC Plus and ENS 2-star, and 1.0 litre per flush under Super ECSBC and ENS 3-star.
- For washbasin taps, the maximum flow rate is 8.0 litres per minute under ECSBC and ENS 1-star, 6.0 litres per minute under ECSBC Plus and ENS 2-star, and 3.0 litres per minute under Super ECSBC and ENS 3-star.
- For sink faucets, the corresponding limits are 8.0 litres per minute, 6.0 litres per minute, and 4.5 litres per minute.
- For overhead showers, the maximum flow rates are 10.0 litres per minute, 8.0 litres per minute, and 6.8 litres per minute under the three compliance tiers respectively.
- For handheld showers, the limits are 8.0 litres per minute, 6.0 litres per minute, and 4.0 litres per minute.
- For handheld ablution sprays, the limits are 6.0 litres per minute, 5.0 litres per minute, and 4.0 litres per minute.

Table 58 Water-efficiency criteria for sanitaryware

Unit	Water-consumption unit	ECSBC and ENS 1 star	ECSBC Plus – 2 star rating and ENS 2 star	ECSBC Super – 3 star rating and ENS 3 star
Water closet	Lpf full flush	≤6.0	≤4.8	≤4.0
	Lpf reduced flush	≤3.0	≤2.8	≤2.0
Urinal	Lpf	≤3.0	≤2.0	≤1.0

Table 57 Water-efficiency rating criteria for sanitary fitting

Unit	Water-consumption unit	ECSBC and ENS 1 Star	ECSBC Plus – 2 Star Rating and ENS 2 Star	ECSBC Super – 3 Star Rating and ENS 3 Star
Washbasin-metered faucet	Litres/use	≤1.0	≤0.8	≤0.6
Urinal-metered faucet	Lpf	≤3.0	≤2.0	≤1.0
Washbasin tap	Lpm	≤8.0	≤6.0	≤3.0
Sink faucet	Lpm	≤8.0	≤6.0	≤4.5
Overhead shower	Lpm	≤10.0	≤8.0	≤6.8
Handheld shower	Lpm	≤8.0	≤6.0	≤4.0
Handheld ablution spray	Lpm	≤6.0	≤5.0	≤4.0

These thresholds ensure that fittings remain functional and comfortable in use while controlling excessive discharge and unnecessary wastage.

Why Fixture-Level Water Efficiency Matters

The importance of fixture-level water efficiency lies in the fact that it creates a fixed upper limit on water consumption at the point of use. This improves the predictability of building water demand and strengthens water balance calculations. It also helps reduce the size and operating load of water-supply, pumping, storage, and wastewater-treatment systems. Where recycled water and rainwater are used, lower fixture demand also improves the feasibility of reuse by reducing the total fresh-water requirement that must be replaced. Because these limits are tied to IS 17650, they provide a standardized and nationally harmonized basis for evaluating fixture performance. This reduces ambiguity in design and makes it easier to compare, specify, and verify compliant products across building projects.

Compliance

ENS 2024 – Incremental Provisions

Clause 6.3.2.2 awards points for installing water-efficient sanitary fittings and sanitaryware that meet higher star-rating thresholds. As outlined in the table, faucets, taps, and showerheads that comply with the 2-star rating requirements of IS 17650 (Part 1): 2021 earn 5 incremental points. Upgrading these fixtures to the 3-star rating provides 8 incremental points, recognizing significantly improved water efficiency.

Similarly, sanitaryware—including water closets, squatting pans, flushing cisterns, flush valves, and urinals—can also contribute to point scoring. According to Table 33, providing units that meet the 2-star rating criteria under IS 17650 (Part

2): 2021 earns 5 points, while opting for 3-star rated products yields 8 points. This incentivizes the adoption of high-efficiency fixtures across the building to reduce overall water consumption.

9.15 Irrigation

Irrigation in a building project should be treated as an integral part of the overall water-management system rather than as an isolated landscape activity. The amount of water required for irrigation depends on climate, soil conditions, plant species, landscape area, and the efficiency of the irrigation method used. In an efficient building water system, landscape demand should be planned in relation to the site water balance so that outdoor water use does not unnecessarily increase dependence on fresh water sources.

ENS promotes the use of alternate water sources for irrigation wherever feasible, particularly recycled treated wastewater and harvested rainwater. Treated wastewater from an on-site sewage-treatment plant can provide a dependable source of irrigation water linked to building occupancy, while harvested rainwater can supplement irrigation demand during suitable periods. This approach reduces the use of potable water for landscaping and supports a more circular and resource-efficient water system within the premises.

Source of Irrigation Water

The first step in planning an irrigation system is to determine the quantity of water required and the source from which it will be supplied. Where available, recycled water should be preferred for irrigation because it reduces the demand on municipal and groundwater sources. Harvested rainwater may also be used, particularly where storage is available and the seasonal rainfall pattern supports such use. Fresh water should be used only where alternate sources are not sufficient or not feasible.

Irrigation Methods

The efficiency of irrigation depends greatly on the method of water delivery. Drip irrigation is generally preferred for planting beds, shrubs, and trees because it delivers water directly to the root zone and reduces evaporation, runoff, and deep percolation losses. Sprinkler irrigation may be used where turf or lawns require more uniform surface wetting. The selection of irrigation method should therefore be based on the type of vegetation, soil condition, and water-use efficiency of the system.

Water Quality for Irrigation

The quality of irrigation water is important because poor-quality water can affect soil condition, plant health, and long-term landscape performance. Recycled water used for irrigation should be treated to the quality appropriate for the intended use, while harvested rainwater stored for use should be protected from contamination and monitored as required. The use of suitable filtration, safe storage, and proper separation from potable-water systems is therefore essential.

Integrated Irrigation Planning

An efficient irrigation system works best when it is integrated with the building's broader water infrastructure, including treatment systems, storage, pumping, metering, and seasonal water planning. When irrigation demand is linked with recycled-water availability, rainwater harvesting, and efficient delivery methods, the

landscape becomes part of the building's overall water-efficiency strategy rather than an additional consumptive load.

ENS 2024 – Mandatory Provisions

6.2.1.1: A minimum of 40% of the total irrigation water demand shall be met using recycled water or rainwater harvested on-site.

6.2.1.2: In accordance with the National Building Code, irrigation systems shall be designed to supply 8 litres of water per square metre per day to all landscaped areas.

6.2.1.3: To minimize evaporative losses, drip irrigation must be installed in at least 70% of all landscaped planting beds. 6.2.1.4: A minimum of 60% of planted turf areas shall be irrigated using sprinkler systems, applicable only after meeting the provisions of Clause 4.2.3.2 of this code.

ENS 2024 – Incremental Provisions

To encourage efficient irrigation practices, projects can earn up to 17 points by incorporating recycled water and adopting high-efficiency irrigation systems.

Under 6.3.1.1, projects are required to meet a portion of their total irrigation demand using recycled or harvested water. Points are awarded based on performance: supplying at least 60% of the irrigation requirement earns 5 points, while meeting at least 80% of the requirement earns 8 points.

Clause 6.3.1.2 focuses on drip irrigation for planting beds. Installing drip systems across a minimum of 80% of the total planting bed area awards 3 points, and extending this coverage to 90% of the planting bed area awards 5 points.

Finally, 6.3.1.3 addresses irrigation of turf areas. After satisfying the provisions of Clause 4.2.3.2, projects may receive additional points for providing sprinkler systems. Installing sprinklers across at least 70% of turf areas earns 2 points, while extending coverage to 80% or more earns 4 points.

9.16 Wastewater treatment and reclamation

Wastewater treatment and reuse is a central component of sustainable building water management because it reduces dependence on fresh-water sources and converts wastewater from a disposal burden into a usable resource. In buildings, wastewater is generated from toilets, bathrooms, kitchens, washing areas, and other domestic or service activities. If this water is collected, treated, and reused appropriately, it can substantially reduce the demand on municipal supply and groundwater while also lowering the volume of wastewater discharged from the site. Both ECSBC and ENS support this approach by requiring on-site wastewater treatment and reuse for suitable non-potable applications.

The underlying principle is that wastewater generated within the premises should, as far as practicable, be treated on site and reused for applications that do not require potable-quality water. This reflects the broader fit-for-purpose approach adopted throughout the code framework. It also aligns with the CPHEEO guidance

that treatment processes and final water quality should be selected according to the intended reuse application rather than by applying a single generic standard to every use.

Need for On-Site Wastewater Treatment

On-site wastewater treatment is important because it gives the building direct control over wastewater quality, reuse potential, and overall water efficiency. Instead of relying entirely on external sewerage systems for disposal and fresh-water sources for supply, the building can create an internal reuse loop in which treated wastewater offsets part of the non-potable demand. This is particularly valuable in water-stressed locations and in larger buildings where flushing, landscaping, and cooling demand can be substantial.

Under ECSBC, the wastewater treatment plant is required to be capable of treating 100% of the wastewater generated within the premises. This means that the treatment system must be designed for the full wastewater load expected from the building rather than for only a portion of the flow.

Treatment Process and Treatment Levels

Wastewater treatment generally involves a sequence of stages designed to progressively improve water quality. In broad terms, these may be understood as primary, secondary, and tertiary or polishing treatment.

- Primary treatment mainly removes settleable and floating solids.
- Secondary treatment reduces organic matter and biological load, usually through biological processes.
- Tertiary or polishing treatment improves the final quality further through filtration and disinfection so that the treated water becomes suitable for reuse.

ECSBC explicitly requires tertiary and/or polishing treatment where necessary, including processes such as dual media filtration, activated carbon filtration, and disinfection, so that the treated water meets the required quality for reuse and environmental compliance. Where higher quality is needed, additional treatment such as softening or membrane filtration systems may also be used.

Reuse of Treated Wastewater

The purpose of on-site wastewater treatment in these codes is not treatment alone, but treatment linked to reuse. Properly treated wastewater can be reused for a range of non-potable applications within the building premises. ECSBC identifies suitable reuse applications such as landscaping, flushing, and cooling-tower make-up water, while ENS also supports reuse through separate storage and plumbing arrangements for treated water.

In practical terms, treated wastewater may be used for:

- toilet and urinal flushing,
- landscape irrigation,
- cooling-tower make-up,
- floor and external cleaning,
- and other non-potable service uses where the water quality is appropriate.

This reuse reduces fresh-water demand and improves the overall water balance of the building.

Water Quality for Reuse

Treated wastewater intended for reuse must meet the quality requirements appropriate to its end use. Reuse water is not judged by potable-water standards unless it is specifically intended for potable application. Instead, the required quality is determined by the risk and sensitivity of the intended reuse.

ECSBC states that treated used water reused for toilet flushing, vehicle exterior washing, non-contact impoundments, and landscape irrigation must comply with the relevant criteria of the CPHEEO Manual on Sewerage and Sewage Treatment Systems, Chapter 7, Table 7.19. ENS refers to the updated version of the same reuse criteria.

This means that treatment technology and final polishing must be matched to the reuse application. Where reuse involves applications with greater sensitivity, additional conditioning may be required to control suspended solids, organic matter, hardness, dissolved salts, odour, or microbial content.

Monitoring and Instrumentation

Wastewater treatment and reuse systems cannot be managed effectively without monitoring. ECSBC therefore requires flowmeters at the inlet and outlet of the sewage treatment plant and a water-quality monitoring system at the outlet for key parameters such as pH, TSS, BOD, COD, and TDS. These measurements are important because they show whether the plant is operating within design limits, whether the treated water is suitable for reuse, and whether the system is producing the expected quantity of reusable water.

Monitoring transforms the treatment plant from a hidden utility into a controlled and measurable part of the building water system. It also supports better operation, record-keeping, and compliance management.

Design, Operation, and Maintenance

A wastewater treatment and reuse system is effective only when it is properly designed, operated, and maintained. Design must consider the expected wastewater quantity, peak loading, treatment objective, reuse application, and sludge management requirements. Operation and maintenance must include

regular inspection of pumps, blowers, filters, disinfection systems, and other process units, together with routine monitoring and record-keeping.

In practice, long-term performance depends on:

- regular maintenance of mechanical and electrical equipment,
- timely desludging and sludge handling,
- consistent monitoring of inlet and outlet quality,
- upkeep of filters, disinfection units, and reuse lines,
- and proper operation of storage and distribution systems for treated water.

Thus, wastewater treatment and reuse should be understood not as a one-time installation, but as an ongoing managed system.

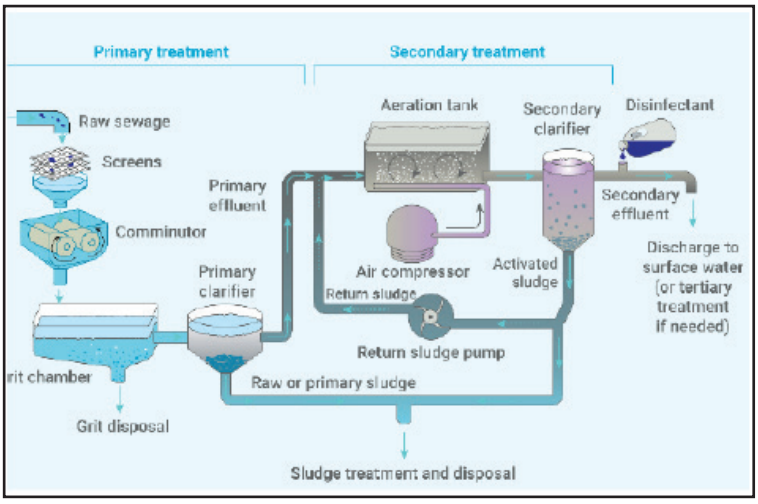


Figure 128 Wastewater treatment

Compliance (Additional Mandatory Requirements)

ECSBC Plus Building Requirements

Rooftop rainwater: Collect rooftop rainwater in a storage tank sized for at least one day's use (or as per stricter local rules). Treat it so the water meets IS 10500:2012 drinking-water standards if used for potable purposes.

Treated used water: Reuse treated wastewater from the STP for all non-drinking needs such as flushing, irrigation, and cleaning.

HVAC condensate: Collect condensate from HVAC systems and use it for washbasins, showers, pantry needs, flushing, landscaping, car washing, floor cleaning, or swimming pool makeup water.

Grey and black water management: Keep greywater and blackwater separate and treat each appropriately so they meet the required quality for their intended reuse.

Water-quality monitoring: A system must be installed to measure flow, pH, TSS, and TDS, and these parameters should be checked after treatment.

RO recovery requirement: If TDS exceeds IS 10500:2012 limits and RO treatment is needed; the RO system must deliver at least 75% recovery.

Grey water reuse: Adequately treated grey water shall be reused for all non-potable purposes along with HVAC cooling tower make up (if water cooled chillers are installed).

Black water reuse: Treated Black water shall be reused for flushing and landscape irrigation. In case of deficit, treated grey water shall be used to augment the demand.

Water-quality monitoring: A system must be installed to measure flow, pH, TSS, and TDS, and these parameters should be checked after treatment.

RO recovery requirement: If TDS exceeds IS 10500:2012 limits and RO treatment is needed; the RO system must deliver at least 75% recovery.

Grey water reuse : Adequately treated grey water shall be reused for all non-potable purposes along with HVAC cooling tower make up (if water cooled chillers are installed).

Black water reuse: Treated Black water shall be reused for flushing and landscape irrigation. In case of deficit, treated grey water shall be used to augment the demand.

ENS 2024 – Mandatory Provisions

Clause 6.2.5.1 requires that residential complexes with a plot area of 100,000 sq. ft (1.0 lakh sq. ft) or more, which generate substantial quantities of untreated sewage or wastewater, must install on-site wastewater treatment systems if no centralized sewerage system is available. At least 50% of the total wastewater generated in such complexes must be recycled and reused within the premises. Smaller residential complexes are also required to provide on-site treatment systems to manage and treat both grey and black water generated at the household level.

Under 6.2.5.2, the reuse of treated water must be facilitated through separate storage tanks and dedicated plumbing lines, following the specifications outlined in Section 2 of the National Building Code of India. This ensures safe and efficient redistribution of treated water for non-potable uses within the premises, supporting water conservation and sustainable water management practices.

ENS 2024 – Incremental Provisions

Clause 6.3.2.1 encourages the on-site recycling and reuse of wastewater to promote sustainable water management. Points are awarded based on the proportion of wastewater reclaimed, as outlined in Table 31 of ENS 2024. Projects that reclaim at least 70% of the total wastewater generated are awarded 6 incremental points, while those achieving 90% or more reclamation earn 10 incremental points. This system incentivizes efficient treatment and reuse of wastewater within the premises, reducing dependence on freshwater sources and supporting overall water conservation goals.

9.17 Rainwater Harvesting

Rainwater harvesting is the planned collection, conveyance, filtration, storage, and recharge of rainwater falling on a building site. In buildings, rainwater is mainly harvested from rooftops and, where appropriate, from paved areas after suitable pretreatment. Instead of allowing rainfall to leave the site as uncontrolled runoff, rainwater harvesting captures part of this water for beneficial use or for groundwater recharge. In this way, it helps reduce dependence on municipal supply and groundwater, improves local water security, and supports better stormwater management.

In the context of ECSBC and ENS, rainwater harvesting is not merely a supplementary sustainability measure but an important part of building water planning. It contributes to source diversification, reduces peak runoff, and supports the broader goal of using water more efficiently within the premises. The design of a rainwater-harvesting system should therefore be integrated with the site water balance, the building's non-potable demand, and local hydrogeological conditions.

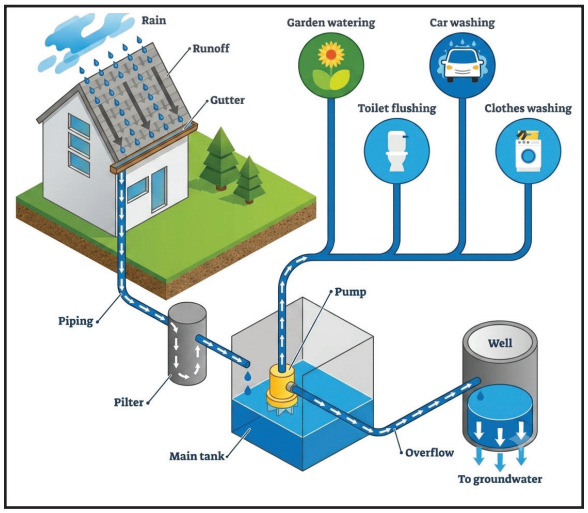


Figure 129 Rainwater harvesting system

Basic Components of a Rainwater-Harvesting System

A typical rainwater-harvesting system includes a catchment area, conveyance network, first-flush arrangement, filtration unit, and either a storage system or a groundwater recharge structure. Rooftops generally provide the most suitable catchment because the runoff is relatively cleaner than runoff from paved or traffic-prone surfaces. Water collected from paved areas may also be used or recharged, but only after suitable removal of silt, grit, and other contaminants.

The conveyance system usually consists of gutters, downpipes, channels, and fittings that transfer rainwater from the catchment to the filtration or storage point. Proper sizing of these components is important so that the system can safely carry runoff during rainfall events without overflow, backflow, or blockage.

First-Flush and Filtration

One of the most important steps in rainwater harvesting is the removal of the first flush. The first portion of runoff from a rainfall event often carries accumulated dust, leaves, bird droppings, and other pollutants deposited on the roof or paved surface during the dry period. A first-flush arrangement diverts this initial contaminated runoff away from the storage or recharge system, thereby improving the quality of the harvested water and reducing maintenance load.

After first-flush diversion, rainwater should pass through suitable filtration before it is stored or recharged. Filtration may include silt traps, grit chambers, media filters, modular inline filters, or other suitable arrangements. The purpose of filtration is to reduce suspended solids, organic matter, and debris so that the water does not contaminate storage tanks, clog recharge structures, or deteriorate in quality during subsequent use.

Storage of Rainwater

Where rainwater is intended for later use, it may be stored in above-ground or below-ground tanks. The size of storage depends on roof area, rainfall pattern, runoff coefficient, and intended demand. Stored rainwater may be used for suitable non-potable purposes such as flushing, cleaning, or landscaping, and where intended for more sensitive use it should be treated appropriately before application. Storage tanks should be provided with access for cleaning, overflow arrangements, bottom scour or drain valves, and protection against contamination.

Groundwater Recharge

Where storage is not the primary objective, harvested rainwater may be directed to groundwater recharge structures. Common recharge arrangements include recharge pits, trenches, soakaways, dug wells, percolation

structures, and recharge bores, depending on site conditions. The purpose of these structures is to allow filtered rainwater to infiltrate into the ground and augment local groundwater resources.

Groundwater recharge should be undertaken only where site conditions are suitable. Soil permeability, groundwater level, and contamination risk should all be considered before selecting the recharge method. Poorly designed recharge systems may fail hydraulically or create water-quality concerns, whereas a properly designed system can reduce runoff while supporting local aquifer replenishment.

Design Considerations

The design of a rainwater-harvesting system should consider catchment type, rainfall intensity, runoff quantity, filtration needs, storage or recharge objective, available space, maintenance access, and local bye-laws. Because local regulations may prescribe mandatory rainwater-harvesting provisions, the system should also comply with the requirements of the relevant municipal or development authority. In practice, the governing principle is that the design should satisfy the most stringent applicable requirement while remaining technically sound and maintainable.

Role in Building Water Management

Rainwater harvesting supports the building water system in multiple ways. It supplements water availability, reduces pressure on fresh-water sources, lowers runoff from the site, and can improve the feasibility of non-potable water use and seasonal water balancing. In buildings with wastewater reuse and efficient fixtures, rainwater harvesting further strengthens the overall strategy of reducing fresh-water demand and building greater resilience into the site water cycle.

ECSBC Plus and ECSBC Super Building Requirements

Rooftop rainwater : All rooftop rainwater shall be completely collected, appropriately treated, and reused, including for potable purposes where feasible.

Recharge percolation pits: Groundwater recharge shall be implemented through percolation pits designed and sized in accordance with the site's soil conditions and infiltration suitability.

ENS 2024 – Mandatory Provisions

Clause 6.2.4.1 requires that all buildings incorporate rainwater harvesting through either recharge or storage, following the guidelines prescribed by the local byelaws/authority or the Model Building Byelaws, whichever imposes stricter requirements. For residential buildings, the harvested rainwater—especially when intended for potable use—must be regularly tested in accordance with BIS 10500:2012.

A typical residential rainwater harvesting system may include roof catchments, gutters, downpipes, stormwater drains, filter chambers, storage tanks or pits, and groundwater recharge structures such as trenches, pits, tube wells, or a combination of these components.

Clause 6.2.4.3 further emphasizes water quality management, requiring that harvested rainwater stored in tanks, pits, or sumps within the site be tested once every three months as per BIS 10500:2012, particularly when used for drinking or other potable applications. Finally, 6.2.4.4 specifies that all remaining harvested rainwater, including runoff from non-roof areas, should be filtered and then recharged into the ground using appropriate methods such as tube wells, recharge pits, trenches, or other approved on-site recharge techniques.

9.18 Water Audit Procedure and Key Performance Indicators

A water audit is a systematic assessment of water use in a building. It helps identify major water-consuming systems, quantify losses, assess reuse potential, and recommend conservation measures.

The audit begins by defining the boundary of the water system. This includes municipal supply, borewell water, rainwater harvesting, domestic water, flushing water, cooling tower make-up, irrigation, hot water systems, treated wastewater, and discharge.

The next step is data collection. Water bills, meter readings, occupancy details, fixture inventory, pump operation schedules, cooling tower records, and wastewater treatment plant data should be collected. After this, major end uses should be identified and a water balance should be prepared.

The water balance compares total water input with water consumption, reuse, discharge, evaporation, blowdown, and losses. This helps detect leakage, excessive consumption, and inefficient operation.

Key performance indicators used in water audits include:

Indicator	Formula	Unit
Water Use Intensity	Annual water use / Built-up area	L/m²/year
Occupant Water Use	Daily water use / Number of occupants	L/person/day
Recycled Water Fraction	Recycled water use / Total water use × 100	%
Leakage Rate	Water loss / Total water input × 100	%
Cooling Tower Cycles of Concentration	TDS in circulating water / TDS in make-up water	Ratio

Regular water audits support efficient operation, reduce operating costs, and improve compliance with water efficiency objectives.

Questions for Water Management and Control

Section A: Objective Questions (MCQs) – 10 Nos
1. Under ECSBC, which of the following is an acceptable water source for building use? a) Bore-well water extracted without approval where adequate municipal supply exists b) Reclaimed wastewater from sewage treatment plants for suitable non-potable use c) Rainwater collected from rooftop runoff directly mixed with potable supply d) High-TDS saline water used directly for drinking purposes
2. The fit-for-purpose approach in building water management means that: a) all water supplied within a building must meet potable-water standards b) each source of water should be used only after matching its quality to the intended end use c) groundwater is always preferred over municipal supply d) non-potable water may be used for any purpose if filtered once
3. For drinking, cooking, food preparation, and oral hygiene, ECSBC and ENS require compliance with: a) IS 456 b) IS 10500 c) IS 1172 d) IS 3025 only
4. Which of the following is most directly associated with microbiological water quality? a) Hardness and alkalinity b) Colour and turbidity only c) Coliforms and microbial contamination d) Total dissolved solids and chlorides
5. In a typical wastewater-treatment plant, tertiary or polishing treatment is mainly intended to: a) Treat raw sewage b) improve final quality for reuse through filtration and disinfection c) replace biological treatment entirely d) eliminate the need for monitoring
6. Which of the following is the best example of a nature-based treatment approach? a) Activated carbon filter b) Reverse osmosis membrane c) Constructed wetland or reed-bed system d) Pressure sand filter

7. The Best Efficiency Point (BEP) of a pump refers to the condition at which the pump:

a) produces minimum noise with maximum vibration

b) operates at its highest hydraulic efficiency

c) reaches its maximum shut-off head

d) must always run at full motor load

8. Under ECSBC, the minimum motor-efficiency class generally required for non-submersible pumps is:

a) IE1

b) IE2

c) IE3

d) IE4

9. In a building using both potable and reclaimed water, the most important piping principle is:

a) equal pipe diameters for all systems

b) minimizing the number of valves

c) clear separation of potable and non-potable lines

d) routing all lines through a common storage tank

10. The main purpose of water metering in buildings is to:

a) increase pumping head

b) measure and manage supply, use, reuse, and losses

c) eliminate the need for water-quality testing

d) standardize pipe material selection

Section B: Short Answer Questions – 5 Nos

1. Explain the fit-for-purpose approach in building water management.

2. Why is water-quality monitoring necessary before and during operation of a building water-treatment system?

3. What is the importance of keeping potable and non-potable piping systems separate in a building?

4. State the role of a return recirculation line in a centralized hot-water system.

5. Why is a water balance considered an important planning tool in ECSBC and ENS?

Section C: Long Answer Questions – 2 Nos
1. Discuss the major sources of water used in buildings under ECSBC and ENS. In your answer, explain the characteristics, suitability, and typical applications of municipal water, groundwater, reclaimed used water, harvested rainwater, and desalinated water.
2. Explain how wastewater treatment and reuse, rainwater harvesting, fixture-level water efficiency, and water balance together contribute to sustainable building water management. Illustrate how these measures reduce freshwater demand and improve overall building performance.

Answer Key for MCQs

1. B 2. B 3. B 4. C 5. B	6. C 7. B 8. C 9. C 10. B

10. WASTE MANAGEMENT

Waste management is a critical component of sustainable development, directly influencing resource efficiency, environmental quality, public health, and climate resilience. With rapid urbanization and rising consumption patterns, cities are generating increasing amounts of solid waste, placing immense pressure on municipal systems and natural ecosystems. Effective waste management in buildings helps reduce pollution, lower greenhouse gas (GHG) emissions, support material circularity, and minimize the burden on landfills.

This chapter introduces the foundational concepts of waste management, including key definitions, global and national trends, and the composition of urban waste streams. Understanding these fundamentals enables building professionals to interpret regulatory requirements, integrate waste-minimization strategies into project planning, and strengthen compliance with Indian waste management codes.

In the sections that follow, the classification of construction waste and post-occupancy municipal waste is explained in detail, along with their regulatory frameworks and management practices prescribed under the ECSBC 2024 and Eco-Niwas Samhita for Residential Buildings (ENS 2024).

10.1 Composition of Urban Solid Waste

Urban solid waste in India includes waste generated during both the construction phase and post occupancy phase of urban development. This comprises municipal solid waste from residential, commercial, and institutional areas, along with construction and demolition (C&D) waste generated during construction, renovation, and demolition activities. Other waste streams include horticulture waste, street sweepings, sanitary waste, domestic hazardous waste, and recyclable dry waste.



Figure 130 Urban solid waste

During construction, waste mainly includes concrete, bricks, metal scrap, wood, tiles, glass, plastics, packaging materials, excavated soil, and hazardous materials such as paints, adhesives, sealants, and chemical containers. In the post-occupancy phase, waste primarily consists of biodegradable kitchen waste, recyclable dry waste such as paper, plastic, metal, and glass, along with sanitary and domestic hazardous waste.

Typically, 40–60% of MSW is biodegradable, 10–20% is recyclable, and 20–30% is non-recyclable or inert (Affairs, 2021). However, these proportions vary significantly across locations. For example, vegetable and wholesale markets generate a much higher share of organic waste, while commercial zones such as offices and shopping malls produce predominantly dry, inorganic waste. Residential neighborhoods generally have larger quantities of biodegradable kitchen waste.

Waste composition is also closely linked to income levels, with high-income areas generating more packaging waste, plastics, paper, and disposables, whereas low-income communities tend to produce more organic and low-volume waste.

A clear understanding of waste composition is important for designing effective segregation systems, selecting treatment technologies, and planning storage and collection infrastructure within buildings and campuses.

10.2 Challenges in Construction and Municipal Waste Management in Buildings

India faces several barriers that limit effective waste management:

- **Poor segregation at source:** Most construction and municipal waste is mixed, making recycling and safe disposal difficult.
- **Weak enforcement:** Despite national rules, monitoring and compliance by local bodies remain limited.
- **Inadequate recycling infrastructure:** Few cities have functional C&D recycling or waste-processing facilities, and many operate below capacity.
- **Low awareness:** Generators often lack incentives or knowledge to segregate waste or adopt recycled materials.
- **Inefficient collection systems:** Gaps in collection and transport lead to littering, open dumping, and burning.
- **Limited market for recycled products:** Perceived quality issues and weak procurement norms reduce demand.
- Urban space constraints: Rapid urbanization limits space for processing facilities and scientific landfills.

10.3 Relevance to Building Sustainability

Waste management is a critical component of building sustainability and directly influences the environmental performance of developments across their entire lifecycle from construction and operation to renovation and demolition. Efficient waste management systems help reduce environmental pollution, minimize landfill dependency, improve material recovery, conserve natural resources, and enhance long-term operational efficiency of buildings and urban development.

The building sector generates substantial quantities of both construction and demolition (C&D) waste during project execution, as well as municipal solid waste during occupancy. Improper handling and disposal of these waste streams can lead to resource loss, increased greenhouse gas emissions, soil and water contamination, and adverse impacts on public health and urban environmental quality. Integrating sustainable waste management practices at the planning and design stage is therefore essential for achieving resource-efficient, low-impact, and climate-responsive development.

Waste-to-Energy and Circular Economy Opportunities

Integrating waste-to-energy (WtE) approaches and circular economy principles within buildings and townships can significantly reduce waste sent to landfills while promoting resource recovery and energy generation. During both construction and post-occupancy phases, several waste streams possess potential for reuse, recycling, recovery, or decentralized energy generation when managed through an integrated waste management framework.

During the construction phase, circular economy strategies can focus on minimizing material wastage and promoting reuse and recycling of construction materials such as concrete, metal, wood, bricks, glass,

excavated soil, and packaging waste. Recovered materials can be reused within site development, road sub-base preparation, landscaping, backfilling, and non-structural applications, thereby reducing the demand for virgin materials and lowering embodied carbon impacts.

In the post-occupancy phase, biodegradable municipal waste generated from households, kitchens, food courts, and landscaping activities can be processed through composting or biomethanation systems for generation of compost, biogas, or energy. Recyclable dry waste such as paper, plastic, metal, and glass can be channelized to authorized recyclers to support material recovery and circular resource utilization.

Potential waste-to-energy and resource recovery opportunities include:

- Organic waste composting and decentralized biomethanation systems
- Biogas generation from food and biodegradable waste
- Refuse-derived fuel (RDF) recovery from non-recyclable combustible waste
- Recycling and reuse of construction and demolition waste
- Recovery of recyclable dry waste through authorized recycling systems
- Reuse of treated organic manure for landscaping and green areas

Adoption of circular economy principles within buildings and townships can contribute towards:

- Reduction in landfill waste generation
- Conservation of natural resources and raw materials
- Lower transportation and waste disposal costs
- Reduction in greenhouse gas emissions and environmental impacts
- Improved material efficiency and resource recovery
- Enhanced long-term sustainability and operational resilience

Integrating waste segregation, recovery, recycling, and resource circulation mechanisms at the planning stage can significantly strengthen sustainable building performance and support the transition towards low-waste and resource-efficient urban development.

Policy and Regulatory Relevance

Sustainable waste management practices are increasingly being emphasized within national policies, building regulations, and green building frameworks in India. The Energy Conservation and Sustainable Building Code (ECSBC) 2024 and Eco Niwas Samhita (ENS) 2024 mandate structured waste management interventions at both construction and post-occupancy stages, making it essential for project teams to integrate waste management planning early in the design phase.

In addition, the Solid Waste Management Rules, 2016 and Construction and Demolition Waste Management Rules, 2016 issued by the Central Pollution Control Board and the Ministry of Environment, Forest and Climate Change emphasize source segregation, recycling, material recovery, decentralized waste processing, and scientific disposal of waste streams. National initiatives such as the Swachh Bharat Mission and the principles of circular economy promoted under India's resource efficiency and climate action strategies further reinforce the importance of integrated waste management within sustainable urban development.

Green building rating systems such as GRIHA Council and Indian Green Building Council also encourage construction waste reduction, on-site waste processing, recycling infrastructure, and circular material use as part of sustainable building assessment frameworks.

10.4 Key Concepts and Classification of Waste

The purpose of this section is to standardize understanding of waste categories according to the ECSBC 2024 and ENS 2024, their types, regulatory frameworks, and classification. Two main types of waste in the Indian built environment are construction and demolition waste and post-occupancy solid waste.

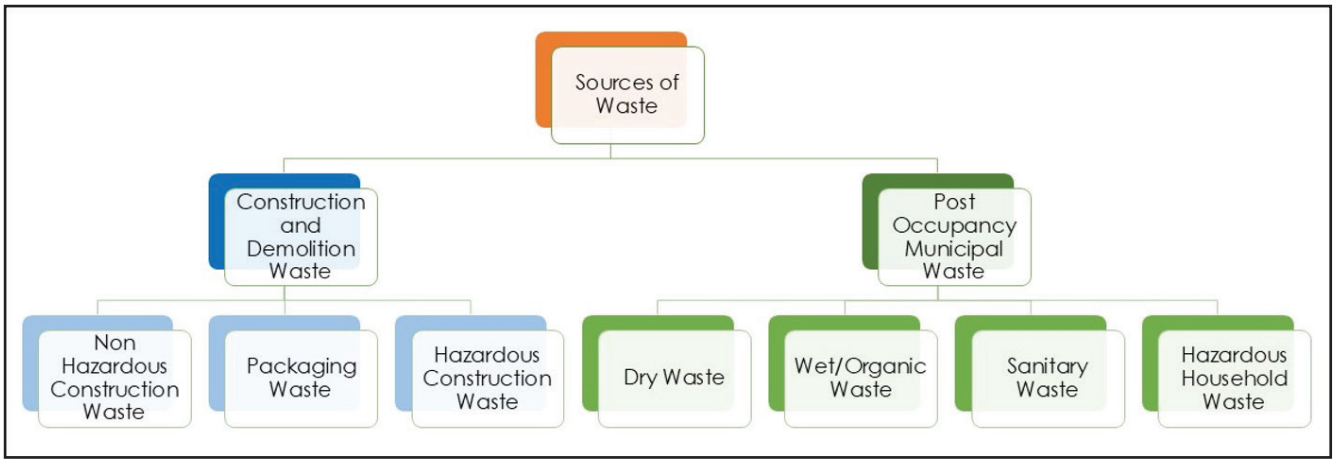


Figure 131 Classification of waste

10.5 Construction Waste

What is construction waste?

Construction and Demolition Waste Management Rules 2025 (Board, Waste management rules and guidelines., 2025) define construction waste often referred to as construction and demolition (C&D) waste as the waste generated due to construction, demolition, remodelling, renovation, repair, and maintenance activities of buildings, roads, and other infrastructure. It comprises soil, sand and gravel, bricks and masonry, concrete, metal, wood, plastic, ceramic, and such other items arising from site activities.

Why does it need to be managed?

According to a report by CSE (Environment., 2020), India generates over 150 million tonnes of C&D waste annually, yet only a fraction is formally collected or processed. Poorly managed C&D waste leads to:

- Illegal dumping in drains, water bodies, and vacant plots
- Urban flooding due to clogged stormwater channels
- Air pollution from dust and particulate matter
- Loss of recyclable resources like concrete aggregates, metals, and soil
- Higher embodied carbon when new materials are produced unnecessarily



Figure 132 Debris dumping in rivers, urban flooding, and dust pollution from demolition

Effective management can create circular-economy pathways, reduce environmental pollution, and support India's low-carbon, resource-efficient development goals.

Classification of Construction Waste in India

Construction activities generate diverse waste streams, and their proper classification is essential for effective handling, resource recovery, and compliance with India's C&D Waste Management Rules (2016 and 2025). Construction waste can broadly be categorized into the following type as ECSBC and ENS 2024: Non-hazardous Construction Waste, Packaging Waste and Hazardous Construction Waste.

Non-hazardous Construction Waste

Non-hazardous construction waste represents the largest and most common waste stream generated on construction sites. These materials are typically inert, recyclable, reusable, or suitable for repurposing, and therefore have high-resource recovery potential. Non-hazardous waste does not pose chemical or toxic risks, but if unmanaged, can contribute to land degradation, excessive landfill burden, and inefficient material use. Non-hazardous construction waste includes but is not limited to:

Excavated Soil (Excluding the top 150 – 200 mm of Fertile Top Soil)	Land Clearing Debris such as stones, sand and vegetation	Metals
		
It is the subsoil that is removed during excavation activities for foundations, basements, or trenches. The top layer of fertile soil is excluded as it is usually reused for landscaping or agricultural purposes.	These are the materials generated during the preparation of a construction site, including rocks, sand, tree roots, branches, and other natural vegetation cleared from the land.	Ferrous and non-ferrous metallic construction materials include reinforcement bars (rebar), structural steel sections, beams and girders, aluminum frames for doors and windows, electrical wires, and fasteners like nuts and bolts.

Cement and Concrete waste from batching, spillage and rejected mixes	Masonry Materials	Flooring Materials
		

It is the leftover or unusable cement, concrete slurry, and partially mixed or spilled concrete generated during material handling and construction processes.	These are the construction debris from brickwork, blockwork, or stonework, including broken bricks, autoclaved aerated concrete blocks (AAC), stone fragments, and leftover mortar.	These are the waste generated from installation, cutting, removal of floor finishes, including ceramic tiles, marble, granite, vitrified tiles, and timber or engineered wood flooring.

Ceiling Materials	Roofing Materials	Insulation Materials
		
These are the waste generated from ceiling works such as dismantled false ceiling panels, gypsum boards, or ceiling tiles.	These are the waste arising from roofing activities, including removed galvanised iron (GI) sheets, broken roofing tiles, and damaged roofing panels.	These are waste insulation products that do not pose chemical or health hazards, such as fibreglass batts, mineral wool, or foam boards, typically used for thermal or acoustic insulation.

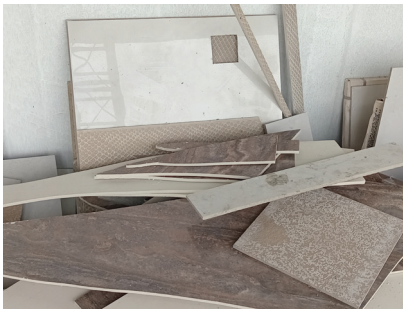
Cladding Materials	Glass	Wood
		
These are the waste generated from ceiling works such as dismantled false ceiling panels, gypsum boards, or ceiling tiles.	These are the waste arising from roofing activities, including removed galvanised iron (GI) sheets, broken roofing tiles, and damaged roofing panels.	These are the wood wate generated from formwork (shuttering plywood), timber framing, doors, wooden pallets, or other wooden components used in construction.

Figure 133 Typical non-hazardous construction waste

Packaging Waste

Packaging waste forms a significant portion of construction waste streams due to the extensive use of packaged materials such as cement, tiles, paints, fixtures, HVAC equipment, electrical items, and modular components. Packaging materials are typically highly recyclable, but their recovery depends on proper sorting, handling, and storage to prevent contamination by cement slurry, soil, or wet waste. Key characteristics of the packaging waste are:

- Usually lightweight but bulky
- Often clean and suitable for recycling
- Generated continuously throughout the construction phase
- Includes multiple material streams (paper, plastic, wood, metal)
- Needs dedicated storage and trained workforce to prevent mixing

Packaging waste includes but is not limited to:

Cement Bags (Paper or HDPE)	Wooden Crates, Pallets, and Boxes	Cardboard Boxes
		
They are generated in large quantities. Paper cement bags can be recycled if not contaminated with cement residue. HDPE (High-Density Polyethylene) cement bags are recyclable through authorized plastic recyclers.	They are used for heavy equipment, tiles, glass, sanitary ware, and fragile components. They can be reused, repaired, or repurposed on-site (temporary platforms, storage racks, shuttering support) and are fully recyclable as wood waste through authorized vendors.	It is common for packaging electrical fixtures, lighting appliances, and hardware. It is easily recyclable if kept dry and uncontaminated.

Plastic Wrapping, Shrink Wrap, and Stretch Film	Foam Sheets, Bubble Wrap, and Cushioning Material	Strapping Bands (Plastic or Steel)
		
It is widely used for moisture protection and bundling of materials. It must be segregated from rigid plastics. It can be sent to plastic recycling units capable of handling LDPE (Low-Density Polyethylene) and LLDPE (Linear Low-Density Polyethylene).	It is typically used for fragile material packaging such as glass fixtures etc. Expandable polystyrene (EPS) is recyclable but requires special handling. Bubble wrap can be recycled with LDPE waste streams.	It is used for securing boxes, pallets, tile bundles etc. Steel bands have high recycling value. Plastic strapping (PET/PP) must be separated from film plastics.

PE Film or Plastic Sheeting	Plastic or Metal Drums, Buckets, and Containers	Corrugated Plastic Sheets
		
It is often used for chemicals, paint, waterproofing compounds, and adhesives. It must be empty and clean before being sent to recyclers. Metal drums can be refurbished and reused.	They are used for temporary floor protection and packaging equipment. They are durable and reusable multiple times before recycling.	This can include items such as thermocol moulds for sanitaryware, moulded cardboard inserts, technical packaging for HVAC/electrical panels, anti-static packaging for electronics.

Figure 134 Typical packaging waste

Specialized packaging for fragile or equipment components: This can include items such as thermocol moulds for sanitaryware, molded cardboard inserts, technicals packaging for HVAC/electrical panels, anti-static packaging for electronics. Special handling is required to maintain recyclability of these items.

Hazardous Construction Waste

Hazardous construction waste includes materials generated during construction, renovation, or demolition that can pose chemical, environmental, health, or safety risks if not handled, stored, or disposed of properly. These wastes may be toxic, flammable, corrosive, reactive, or capable of causing injury (such as sharp or contaminated items).

Hazardous construction waste must never be mixed with non-hazardous waste streams, as contamination can render recyclable materials unusable and create significant environmental and occupational health risks. Such waste should be segregated at source, stored in designated labelled containers or isolated storage areas, and disposed of only through authorized recyclers, treatment facilities, or hazardous waste disposal agencies in accordance with applicable regulations and safety protocols.

Lead-Based Materials	Tar and Bituminous Materials
	
Materials such as lead-containing pipes, paints, solder, plumbing fixtures, batteries, and electrical components are toxic in nature and require careful handling using appropriate personal protective equipment (PPE). These materials should be stored separately in labelled containers and disposed of through authorized hazardous waste recyclers, e-waste handlers, or Treatment, Storage, and Disposal Facilities (TSDFs).	This category includes bitumen sheets, asphalt mixes, waterproofing tar, and retained bituminous residues. Such materials can release harmful fumes and may become hazardous when contaminated with chemicals or mixed waste. These should be properly contained, stored away from heat sources and drains, and disposed of through authorized hazardous waste handlers or approved construction and demolition waste facilities, as applicable.
Broken or Laminated/Toughened Glass	**Adhesives, Sealants, Resins, and Chemical Additives**
	
Although not chemically hazardous, broken glazing glass, laminated façade panels, and toughened safety glass fragments present significant injury and handling risks. These materials should be collected separately in puncture-resistant containers or designated storage areas and sent to authorized glass recyclers or approved disposal facilities.	This includes construction adhesives, epoxy resins, tile adhesives, polyurethane (PU) sealants, bonding agents, curing compounds, paints, solvents, and related chemical additives. Many of these materials may be flammable, chemically reactive, or corrosive in nature. Residual containers, unused materials, and contaminated packaging should be securely sealed, stored separately, and disposed of through authorized hazardous waste collection agencies or TSDFs.

Disposal and Management Requirements

Hazardous construction waste must be strictly segregated at source and stored in designated, labelled, covered, and leak-proof containers to prevent contamination and environmental damage. All handling, transportation, and disposal activities should be carried out using appropriate safety measures and PPE, with proper

documentation and waste records maintained for regulatory compliance. Such waste must only be disposed of through CPCB/SPCB-authorized hazardous waste recyclers, handlers, or Treatment, Storage, and Disposal Facilities (TSDFs). Open dumping, burning, or mixing with municipal or recyclable waste streams must be strictly prohibited. Regular worker training and awareness programs should also be conducted to ensure safe handling practices and compliance with environmental regulations.

10.6 Post-Occupancy Municipal Waste

What is post-occupancy municipal waste?

Post-occupancy municipal waste refers to all solid waste generated during the operation and everyday use of a building whether residential, commercial, institutional, or mixed-use. This waste stems from routine human activities and must be managed responsibly to minimize environmental impacts, safeguard public health, and comply with India's waste management regulations. The MSW includes solid or semi-solid domestic waste, sanitary waste, commercial and institutional waste, market and catering waste, non-residential waste streams, street sweepings, silt from surface drains, horticulture waste, agricultural and dairy waste, and treated biomedical waste.

Why does it need to be managed?

Urban India generates over 1,60,000 tonnes of MSW per day (Gupta, 2022), projected to double by 2030. Buildings, especially residential societies, offices, hotels, and malls contribute a major share. Improper segregation, limited recycling, and inadequate collection systems lead to:

- Landfill overflow and methane emissions
- Public health hazards
- Air, land, and groundwater pollution
- Loss of recyclable material value

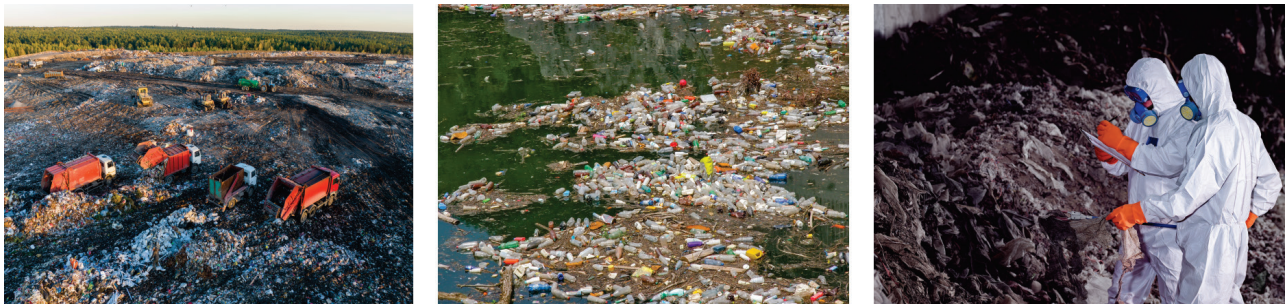


Figure 136 Municipal solid waste

Effective post-occupancy waste management enables circularity, reduces emissions, and supports Swachh Bharat Mission and Solid Waste Management Rules.

Regulatory framework for post-occupancy municipal waste management in India

India's Solid Waste Management (SWM) Rules, 2016, notified by the Ministry of Environment, Forest and Climate Change (MoEFCC), provide the overarching regulatory framework for managing MSW generated during the occupancy and operational phase of buildings. These rules apply to all urban local bodies, institutions, commercial buildings, residential complexes, special economic zones, railway premises, airports, industrial townships, and large waste generators across the country.

The framework emphasizes source segregation, door-to-door collection, decentralized processing, recycling, safe disposal, and integration of the informal waste sector. It clearly delineates the roles and responsibilities of all stakeholders' waste generators, local authorities, state agencies, pollution control boards, bulk waste generators, manufacturers, and brand owners to ensure systematic and environmentally sound waste management.

Classification of Post-occupancy Municipal Waste in India

Post-occupancy municipal waste refers to the waste generated during the operation and use phase of a building by occupants, visitors, facility management activities, housekeeping services, and retail/office operations within the premises. The following categories represent the primary waste streams expected in residential, commercial, institutional, and mixed-use buildings: dry waste, wet/organic waste, sanitary waste, and hazardous household waste.

Dry waste

Dry waste comprises non-biodegradable materials that have high potential for recycling, repurposing, or material recovery. This waste stream must be kept clean and moisture-free to maintain recyclability. Dry waste is generated daily in both household and commercial settings. It includes but is not limited to:

Plastics	Paper	Cardboard and Corrugated Board
		
PET bottles, plastic containers, Plastic packaging films, wrappers, detergent bottles, shampoo containers, takeaway container, disposable plates/cups (non-compostable), stationery plastics such as pens, folders, covers.	Newspapers, magazines, office paper, printed sheets, paper bags, pamphlets, flyers, books, notebooks	Cartons and boxes, packaging cardboard sheets, food delivery packaging (clean and dry) packaging

Metals	Glass	Electronic
		
Aluminium cans, tin cans, foils, trays, metal lids, small household metal items, old utensils, pots, pans.	Glass bottles, jars, broken or intact households glass items (non-toughened decorative glass materials.	E waste accessories (small quantities), chargers, cables, earphones, computer accessories (mice, USB devices), remote controls, and small batteries.

Figure 137 Typical images of dry waste

Note: Large e-waste (appliances, electronics) must be managed as per E-Waste Management Rules 2022 and not mixed with routine dry waste.

Wet/organic waste

Wet waste consists of biodegradable, moisture-rich waste generated from kitchens, food processing, gardens, and household organic matter. This waste must be collected daily to prevent odour, pests, and microbial growth. Under the ECSBC/ENS, organic waste treatment is a major requirement, with thresholds for on-site composting based on built-up area. Includes but not limited to:

Kitchen Food Waste	Horticulture/Garden Waste
	
Vegetable peels, fruit scraps, cooked food leftovers, used tea leaves, coffee grounds, eggshells	Dry leaves, trimmed branches, grass clippings, flower waste

Figure 138 Typical images wet/organic waste

Sanitary waste

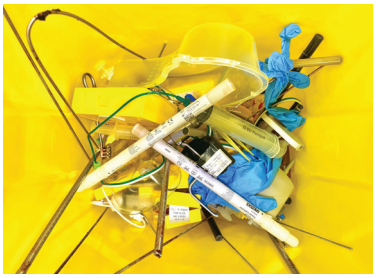
Sanitary waste contains body fluids, hygiene products, and absorbent materials, and requires careful handling to avoid health and environmental risks. It must be collected in sealed, clearly labelled bags and disposed of through authorized municipal channels. It includes but is not limited to:

Sanitary and Personal Care Waste	Personal Hygiene Items	Medical-Type Domestic Waste
		
Includes feminine hygiene products such as sanitary pads, tampons, disposable menstrual cups, an sweat pads, as well as infant and adult care items like diapers and incontinence pads	Used tissue paper, wet wipes, cotton buds, cotton balls	Masks, gloves, bandages, gauze, swabs, home used personal care disposables

Figure 139 Typical images wet/organic waste

Hazardous household waste

Hazardous household waste includes items that are toxic, flammable, corrosive, chemically reactive, infectious, or capable of causing environmental and health risks. Although generated in relatively small quantities, these wastes require strict segregation, safe storage, and environmentally sound disposal to prevent contamination and human exposure. Hazardous household waste must never be mixed with general municipal waste or recyclable streams and should be managed separately through authorized collection and disposal systems.

Batteries	Expired medicines and pharmaceutical waste	Used syringes/needles waste
		
AA/AAA cells, rechargeable batteries, lithium-ion batteries from gadgets, and lead-acid inverter batteries. These contain heavy metals and hazardous chemicals and should preferably be returned to vendors, e-waste collection centres, or authorized recyclers.	Expired tablets, syrups, blister packs, unused ointments, medical creams, and other pharmaceutical products that may pose contamination risks if disposed of with regular waste. These should be returned through medicine take back programs, pharmacies, hospitals, or disposed of through authorized biomedical or pharmaceutical waste handlers.	Used syringes, needles, lancets for home medical testing, insulin injectors, and broken thermometers (including mercury-containing devices), which can pose infection, injury, and toxic exposure risks. These should be collected in puncture-proof containers and handed over to authorized biomedical waste collection agencies or healthcare facilities.

Chemical containers and bottles	Aerosol and pressurized containers	Hazardous light waste
		
Pesticide containers, cleaning acid bottles, bleach containers, phenyl bottles, disinfectant bottles, solvents, and containers with residual hazardous chemicals that may remain reactive or toxic even after use. These should be rinsed only where permitted, stored separately, and disposed of through authorized hazardous waste or municipal collection systems.	Deodorant cans, insect spray cans, air fresheners, paint sprays, and other pressurized containers that may be flammable or explode if punctured or exposed to heat. These should never be incinerated or crushed and should be disposed of through authorized dry waste or hazardous waste collection channels.	CFL bulbs, fluorescent tube lights, mercury-containing lamps, certain disposable and hygiene contaminated or household requiring careful items handling and disposal. These should be stored carefully to avoid breakage and handed over to authorized e-waste recyclers or hazardous waste collection centres.

Disposal and Management Requirements

Hazardous household waste should be segregated at source and stored separately in labelled, leak-proof, and secure containers away from children, food, and general waste streams. Disposal should be undertaken only through authorized municipal collection systems, e-waste recyclers, biomedical waste handlers, producer take-back systems, or CPCB/SPCB-authorized facilities, depending on the waste type. Open dumping, burning, flushing into drains, or mixing with municipal solid waste must be strictly avoided. Public awareness and responsible disposal practices are essential to minimize environmental contamination, safeguard public health, and ensure compliance with waste management regulations.

10.7 Construction and Post Occupancy Municipal Waste Management

Construction and post-occupancy waste management form the backbone of sustainable building practices in India. Sound waste management reduces environmental impact, enhances material efficiency, and supports circular economy principles by ensuring that resources remain in productive use for as long as possible. The ECSBC 2024 and the Eco-Niwas Samhita for Residential Buildings (ENS 2024) make waste management a mandatory requirement for all compliant buildings. This section presents the fundamental concepts and implementation steps necessary for effective waste management throughout the building lifecycle.

Construction Waste Management

Construction waste management begins with the understanding that waste generated during excavation, structural works, finishing, and site operations is not merely a by-product but a resource stream that must be handled efficiently. Waste segregation, reduction, recycling, and diversion form the core pillars of sustainable construction practices. The ECSBC and ENS require all projects to adopt structured systems that protect environmental quality, reduce landfill loads, and improve resource recovery.

Best Practices for Construction Waste Management

- Plan Waste Management Early: Integrate waste handling, storage areas, and recycling strategies into the project's design, tender documents, and contractor agreements from the outset.
- Establish a Site Waste Management Plan (SWMP): Define material flows, segregation protocols, documentation procedures, and waste diversion targets aligned with ECSBC/ENS requirements.
- Demarcate Segregation Zones: Create labelled zones for non-hazardous waste, hazardous waste, packaging waste, concrete debris, soil, metals, timber, and recyclables, ensure they are weather protected.
- Preserve Topsoil: Stockpile the top 150–200 mm of fertile soil separately, maintain moisture, and reuse it in landscaping or site restoration.
- Maximize On-Site Reuse: Reuse excavated earth for backfilling, masonry debris for sub-base layers, and timber for temporary structures to reduce dependence on new materials.
- Prevent Cross-Contamination: Keep recyclable waste streams separate from wet waste, soil, cement slurry, and hazardous materials to preserve their recyclability.
- Document All Waste Movements: Maintain daily logs, weighbridge slips, recycler invoices, and photographic records to demonstrate compliance during audits.
- Train Construction Workers: Conduct toolbox talks and periodic training on segregation protocols, safety handling, and legal obligations under C&D Waste Rules.
- Engage Authorized Recyclers Only: Partner with certified recyclers and municipal processing facilities, avoid informal handlers to ensure environmental safety and traceability.
- Monitor and Review Performance: Periodically evaluate waste quantities generated, reuse rates, and compliance with diversion targets, adjust strategies as required.

Segregation and Storage of Waste

Segregation at source is the most fundamental step in construction waste management. It ensures that waste

materials, once generated, retain their quality and potential for reuse or recycling. This process involves setting up clearly demarcated spaces within or adjacent to the construction site where different categories of waste can be separated immediately after they are produced. Such areas must be designed to prevent contamination from rain, runoff, or soil, and should protect materials from leachate formation that can degrade recyclability.

Proper segregation enables non-hazardous materials such as masonry debris, metals, and wood to be reused in construction activities, while hazardous items are safely isolated to avoid risks. It also prevents mixing of packaging waste with concrete debris, ensuring each waste stream can be efficiently channelled to recyclers or processors. Indian regulations strictly prohibit the littering or dumping of construction waste in public spaces or drains, making controlled storage not just a sustainability requirement but a legal one.

Compliance (Segregation and designated storage)

Segregation and designated storage areas are mandatory under the ECSBC 2024 and ENS 2024 and must follow the C&D Waste Management Rules, 2016, which prohibit littering and require controlled handling of all construction debris.

Minimization of Non-Hazardous Waste

Minimizing non-hazardous construction waste is essential for reducing costs, improving material efficiency, and ensuring that the environmental footprint of the building remains low. Many construction materials such as excavated soil, broken masonry, concrete offcuts, stone pieces, timber elements, and metal scrap are inherently reusable or recyclable. When these materials are handled with care, they can be reintegrated into the project, reducing the need for virgin materials and thereby conserving natural resources.

For example, excavated soil can be redeployed for site levelling or landscape contouring; broken bricks and concrete fragments can serve as sub-base layers in road or pavement construction; and timber pieces can be repurposed for temporary formwork or safety barriers. These internal reuse mechanisms not only reduce waste volumes but also save transportation and disposal costs. Beyond on-site reuse, a thriving ecosystem of authorized recyclers can process metals, concrete, wood, plastic, and glass into valuable secondary materials.

Compliance (Construction waste)

A minimum 50% diversion of non-hazardous construction waste is mandatory under ECSBC 2024 and ENS 2024, while 75% and 95% diversion are required for ECSBC Plus and Super ECSBC levels and for scoring incremental ENS points.

Recycling of Packaging Waste

Packaging waste is a prominent and continuous waste stream in construction due to the significant use of packaged materials such as cement bags, plastic wrapping, cardboard boxes, insulation sheets, pallets, and containers. This waste category has high recyclability but is often contaminated due to poor-handling practices. The fundamental principle for managing packaging waste is segregation now of unpacking, followed by proper storage in clean, dry areas.

When packaging materials remain free from cement slurry, paint, or soil, they can be easily channeled to authorized recyclers. Paper packaging such as cardboard, kraft paper, and cement bags can be recycled into

paper products; plastic films can be converted into pellets for secondary applications; and wooden pallets can be reused or refurbished. Clean handling of packaging waste is therefore essential not only for sustainability but for complying with national waste regulations that mandate full diversion of recyclable packaging.

Compliance (Recyclable packaging waste)

Recycling 100% of recyclable packaging waste is mandatory under the ECSBC 2024 and ENS 2024 and is aligned with the C&D Waste Management Rules, 2016, which require strict segregation and recycling of packaging materials.

Diversion of Construction Waste from Landfills

The ultimate objective of sustainable construction waste management is to ensure that no recoverable or recyclable material ends up in landfills. This involves a systematic approach in which all construction waste whether reusable on-site or recyclable externally is tracked, handled, and processed through appropriate channels. Diversion includes the reuse of materials in the project, repurposing for ancillary construction needs, recycling through authorized facilities, and finally, the safe transfer of residual waste to municipal C&D processing centres.

A critical component of this process is the maintenance of accurate documentation. Projects must maintain records of the quantities of waste generated, the volumes reused on-site, transportation logs, recycler receipts, and municipal handover slips. These records demonstrate compliance and help project teams monitor their waste diversion performance throughout the construction cycle.

By actively diverting materials from landfill disposal, projects reduce their environmental impact, conserve resources, and align with national sustainability targets.

Compliance (Diversion of construction waste)

Achieving 100% diversion of construction waste from landfills through reuse, repurposing, recycling, or authorized municipal disposal is mandatory for the ECSBC 2024 and ENS 2024 and must be supported by complete documentation as per the C&D Waste Management Rules, 2016.

Example for Estimation of Construction Waste Diversion

The example below illustrates how construction waste generation and diversion are calculated for compliance with the ECSBC 2024.

Based on the CPCB (2016) guidelines, new construction projects typically produce 40–60 kg of waste per square metre of built-up area, and the example assumes a benchmark of 50 kg/sq.m. Using this value, the total estimated construction waste for the project is 2,57,621.5 kg.

This total is then broken down into different types of waste such as soil, sand, gravel, brick and masonry debris, concrete fragments, metals, wood, packaging materials, and a small portion of hazardous waste like bitumen. For each category, the table presents the quantity generated, its proportion in the total waste stream, and the corresponding volume derived using standard material densities.

Table 60 Construction waste diversion estimation

Classification of waste	Type of waste	Quantity (kg)	Percentage of total waste	Density (kg/m³)	Volume (m³)	Diverted from landfills (kg)	Method of diversion
Total construction waste quantity		2,57,621.5 (Considering 50 kg of waste per sq.m of built-up area)					
Non-Hazardous	Soil, sand, and gravel	66,981.6	26%	1600	41.86	66,981.6	**Reused/ repurposed on site**
	Brick and masonry	82,438.9	32%	1900	43.39	82,438.9	**Reused/ repurposed on site**
	Concrete	72,134.0	28%	1200	60.11	72,134.0	**Reused/ repurposed on site**
	Metals	1,54,57.3	6%	7850	2.0	15,457.3	**Sold to recycler**
	Wood	7,728.6	3%	400	19.3	7,728.6	**Sold to recycler**
Packaging	others	7728.6	3%			7,728.6	**Sold to recycler**
Hazardous	**Bitumen**	**5,152.4**	**2%**	**1,040**	**5.0**	**5,152.4**	**Handover to municipal authority**

The table further shows how each waste type is diverted from landfill through reuse, recycling, or authorized disposal. Most non-hazardous waste such as soil, bricks, masonry, and concrete—is reused or repurposed onsite for backfilling, leveling, or other construction needs. Recyclable materials like metals, wood, and packaging are sent to authorized recycling units. Hazardous waste, including bitumen, is handed over to authorized municipal facilities following regulatory requirements. When summarized as per the ECSBC provisions, the results show that all non-hazardous waste is either reused or sent for recycling, packaging waste is fully recycled, and hazardous waste is safely handed over to the municipality.

Table 61Construction waste diversion estimation

Classification of waste as per the ECSBC provisions	Quantity (kg)	Percentage of diversion
Non-hazardous	2,44,740.4	
Sent to recycling units	23,185.9	
Reused/repurposed on site	2,21,554.5	
Hazardous	5,152.43	
To municipalities	5,152.4	
Packaging	7,728.645	
Sent to recycling units	7,728.6	
Minimization of non-hazardous waste (reused on site, to recycling units)	2,44,740.4	**100%**
Recycling of packaging waste	7,728.6	**100%**
Total waste diverted from landfills (kg)	**2,57,621.5**	**100%**

The outcome demonstrates that **100% of the total construction waste generated is diverted from landfill,** which fully meets and exceeds the mandatory waste-diversion requirements of the ECSBC 2024 and ENS 2024.

This example serves as a model for project teams to understand how waste quantities are estimated, categorized, and reported, and how proper segregation and planning can enable complete landfill diversion.

Post-occupancy Municipal Waste Management

Post-occupancy municipal waste management refers to the systems and practices used to handle the waste generated after the building becomes operational. This includes household or commercial waste from residents, tenants, visitors, building operations, and support services. Effective management of municipal waste is essential for maintaining hygiene, ensuring environmental safety, and enabling resource recovery. It also ensures that buildings continue to meet sustainability goals throughout their lifecycle, not merely during construction. The ECSBC 2024 and ENS 2024 establish structured requirements for waste segregation, collection, storage, transportation, and treatment particularly for organic waste, which constitutes a major proportion of municipal solid waste in India.

Best Practices for Post-occupancy Municipal Waste Management

- Segregate at source: Provide colour-coded bins for dry, wet, sanitary, hazardous, and e-waste in all units and common areas.
- Maintain a centralized waste room: Ensure a clean, ventilated, pest-proof space for category-wise storage and easy access for collectors.
- Follow a daily collection routine: Collect wet, sanitary, and hazardous waste daily; keep dry waste clean and dry for recycling.
- Avoid mixing of waste streams: Keep all categories strictly separate to maintain hygiene and recyclability.
- Train staff and educate occupants: Conduct regular awareness sessions and provide clear pictorial signage to guide proper segregation.
- Use authorized recyclers only: Hand over dry, sanitary, and hazardous waste to licensed agencies or municipal bodies.
- Reduce Waste at Source: Promote alternatives to single-use plastics and encourage low-packaging products.
- Document waste handling: Maintain logs of quantities collected, compost produced, and disposal receipts for compliance.
- Treat organic waste on-site: Install composting systems sized as per the ECSBC/ENS requirements and use compost in landscaping.
- Monitor and improve performance: Conduct periodic segregation audits, ensure cleanliness, and address odour/pest issues promptly.

Waste Collection Segregation and Storage

A central principle of post-occupancy waste management is maintaining segregation at source, ensuring that waste generated within the building is immediately sorted into the appropriate categories. This reduces contamination, preserves recyclability, and ensures that waste is directed to the correct downstream processing route whether composting, recycling, or safe disposal.

To facilitate this, every building must provide a dedicated centralized waste collection and storage area,

designed to receive segregated waste from individual units or floors. This area must contain clearly labelled, colour-coded bins representing at least five primary categories: dry waste, organic (wet) waste, sanitary waste, hazardous household waste, and e-waste. The centralized facility must be easily accessible to housekeeping personnel and to authorized waste collection agencies.

Daily waste collection schedules play an essential role in maintaining hygiene and preventing waste buildup. Wet and sanitary waste must be collected frequently to prevent odours, pests, and health hazards, while dry waste can be stored longer if kept clean and dry. Once collected, dry, hazardous, and sanitary waste must be transferred only to authorized recyclers or municipal corporations, ensuring compliance with national waste management rules.

Compliance (Waste collection , segregation and storage)

Provision of a centralized waste collection area with category-wise segregation and proper storage is mandatory under the ECSBC 2024 and ENS 2024, in alignment with the Solid Waste Management Rules, 2016.

The given-below example illustrates the calculation of waste generation quantity and area required for storage.

Example for waste generation quantity calculation

To estimate post-occupancy municipal waste generation lets, take in an office building, we begin with the basic building and occupancy details. Consider an office building with a plinth area of 30,000 sq. m. The occupancy density is 10 people per 100 sq. m, which means the total number of occupants is calculated by applying this ratio to the built-up area. Using this value, the building accommodates 3,000 people. Post-occupancy waste generation in office buildings generally ranges between 0.1 and 0.2 kilograms per person per day. Taking an illustrative mid-range value, the total waste generated in the building is estimated at 600 kilograms per day.

Municipal waste is typically composed of both organic and inorganic fractions. For office buildings, a commonly used assumption is that 40% of the total waste stream consists of organic waste primarily food waste and horticulture waste while the remaining 60% consists of inorganic materials such as paper, plastics, and packaging waste. Applying these percentages to the total waste generated, the organic waste quantity is calculated as 240 kilograms per day and the inorganic waste quantity as 360 kilograms per day. These values help determine the size of the waste storage facility, collection frequency, and capacity of on-site waste treatment systems such as composting units, as required under ECSBC 2024 and ENS 2024.

Example for waste storage area required calculation

The storage volume required for organic waste depends primarily on its density, which varies with moisture content, composition, and degree of compaction. Organic waste can have a density ranging from 0.2 kg/L to 0.8 kg/L, but for calculation purposes a typical average value of 0.5 kg/L is often used.

To estimate the volume needed to store a known mass of organic waste, the standard formula: Volume = Mass ÷ Density is applied.

Using this approach, 1 kilogram of organic waste with a density of 0.5 kg/L will occupy approximately 2 litres of volume (1 kg ÷ 0.5 kg/L = 2 L). Since 1,000 litres are equivalent to 1 cubic metre, this translates to 0.002 cubic

metres per kilogram of organic waste. This '0.002 m^3 per kg' value is often used as a practical thumb rule for estimating storage capacity.

Thus, to determine the area or volume required for waste storage in a building, the daily organic waste generation (in kilograms) is multiplied by this conversion factor. This ensures that the central waste storage room is adequately sized to hold the expected quantity of organic waste before it is treated on-site or handed over for collection.

Organic waste treatment

Organic waste primarily food scraps, kitchen waste, and horticulture greens constitutes the largest fraction of municipal waste in Indian residential and commercial buildings. Managing this waste stream sustainably is crucial because untreated organic waste creates methane emissions and contributes to landfill overload. The ECSBC and ENS therefore place strong emphasis on on-site organic waste treatment, particularly in medium- and large-scale developments.

For projects with a built-up area of 5000 sq. m or more, the codes require a designated area on-site to treat at least 50% of projected organic waste, using either manual composting, mechanized composters, or vermicomposting systems. The calculation of expected organic waste generation is formula-based and must follow the methodology outlined in the code. By treating organic waste on-site, buildings can significantly reduce municipal waste transportation needs and produce nutrient-rich compost that can be used for landscaping.

For smaller projects those below 5000 sq. m built-up area direct on-site treatment is not mandatory, provided the local municipal body has an efficient collection system specifically for organic waste. In cases where the municipality lacks such capacity, the building developer or association must engage a professional waste management agency. As an alternative or supplement, smaller buildings must install organic waste composters or vermiculture pits sized at a minimum capacity of 1 kg per 150 sq. m of built-up area per day. This ensures that even smaller developments contribute to reducing organic waste loads.

Compliance (Organic Waste)

Under the ECSBC 2024 and ENS 2024, projects with a built-up area of ≥5,000 sq. m must treat at least 50% of on-site organic waste through approved processing systems. Smaller projects may comply through municipal collection or appropriately sized composting units. Enhanced ECSBC compliance levels require:

- ECSBC Plus: 75% on-site organic waste treatment
- ECSBC Super: 95% on-site organic waste treatment

For calculating organic waste generation, the below example can facilitate understanding.

Example for organic waste calculation (vermicomposting method)

To design an on-site vermicomposting system, it is important to estimate the total amount of organic waste that must be processed, the volume of composting beds required, and the area needed for installation. Vermicomposting relies on a defined retention time, suitable bed dimensions, and appropriate worm density to ensure efficient processing.

From Section 3.2.2.1, the building generates 240 kg of organic waste per day. For vermicomposting, this waste must be accumulated and processed over a fixed retention period. In this example, a 60-day retention time is used, which is a typical duration for complete decomposition under controlled conditions. Over 60 days, the total quantity of organic waste that the system must accommodate is therefore:

Total waste = 240 kg/day × 60 days = 14,400 kg

To estimate the volume of vermicomposting beds, the storage density of organic waste is applied. Using the thumb rule of 0.002 m^3 per kg of organic waste, the total volume required becomes:

Total vermi-bed volume = 14,400 kg × 0.002 m^3/kg = 28.8 m^3

Vermicomposting beds must be shallow to maintain aeration and worm activity. A bed depth of 0.6 m is recommended, as deeper beds reduce decomposition efficiency. Dividing the required volume by the bed depth gives the total plan area needed:

Vermi-bed area = 28.8 m^3 ÷ 0.6 m = 48 m^2

The width of individual beds is usually limited to 1.5 m, allowing easy turning and maintenance. Using this width, the required length of the vermi bed is calculated as:

Length = 48 m^2 ÷ 1.5 m = 32 m

Thus, the size of one continuous vermi-bed needed to process the full 60-day load would be:

0.6 m (depth) × 1.5 m (width) × 32 m (length)

For operational convenience, multiple smaller beds are often preferred instead of a single long bed. In this example, the total requirement is split into two beds, each occupying half the calculated area.

Compliance area requirements (ECSBC 2024)

Using the calculated vermicomposting area of 48 m^2 for processing 50% of waste, the required area increases proportionally for higher ECSBC compliance levels:

- 50% mandatory requirement: 48 m^2
- 75% (ECSBC Plus): 72 m^2
- 95% (ECSBC Super): 91.2 m^2

The project has provided 93 m^2 of space for organic waste processing, which meets the 100% compliance requirement, including ECSBC Super-level performance.

Questions for Waste Management

Section A: Objective Questions (MCQs) – 10 Nos
1. As per CPCB benchmarks adopted in ECSBC 2024, typical construction waste generation for new buildings is:
A. 10–20 kg/m² B. 20–30 kg/m² C. 40–60 kg/m² D. 80–100 kg/m²
2. Under ECSBC 2024, the minimum mandatory diversion of non-hazardous construction waste is: A. 25% B. 40% C. 50% D. 100%
3. Packaging waste generated during construction must be: A. Disposed in landfills B. Partially recycled C. Incinerated D. 100% recycled through authorised recyclers
4. Which of the following is classified as hazardous construction waste? A. Brick masonry debris B. Excavated soil C. Bitumen waste D. Timber off-cuts
5. Under ECSBC/ENS, on-site organic waste treatment becomes mandatory when built-up area is: A. ≥ 2,000 m² B. ≥ 3,000 m² C. ≥ 5,000 m² D. ≥ 10,000 m²
6. Landfill diversion rate is best defined as: A. Waste sent to landfill ÷ total waste B. Waste reused and recycled ÷ total waste C. Hazardous waste ÷ total waste D. Organic waste ÷ total waste
7. Typical bulk density assumed for organic waste in ECSBC calculations is: A. 0.2 kg/L B. 0.35 kg/L C. 0.5 kg/L D. 0.8 kg/L
8. Which greenhouse gas is primarily emitted from landfills due to organic waste decomposition? A. Carbon monoxide B. Nitrous oxide C. Methane D. Sulphur dioxide

9. Which rule governs post-occupancy municipal solid waste management in India?
A. Environmental Protection Act, 1986
B. C&D Waste Management Rules, 2016
C. Solid Waste Management Rules, 2016
D. Hazardous Waste Rules, 2016

10. ECSBC Super level requires on-site treatment of ___ of organic waste.
A. 50%
B. 60%
C. 75%
D. 95%

Section B: Short Answer Questions – 5 Nos

1. Define Construction and Demolition (C&D) waste as per C&D Waste Management Rules.

2. What is meant by segregation at source, and why is it critical for waste recyclability?

3. List any four categories of post-occupancy municipal waste in buildings.

4. State the minimum on-site organic waste treatment requirements under ECSBC 2024.

5. Mention any three environmental impacts of improper construction waste management.

Section C: Long Answer Questions – 2 Nos

Q1. Construction Waste Estimation and Diversion Calculation
A commercial building project has a built-up area of 5,150 m^2.
Assume:
- Construction waste generation factor = 50 kg/m^2
- Waste composition: Non-hazardous waste = 95%, Hazardous waste = 5%
- Of the non-hazardous waste: 90% is reused or recycled, 10% is sent to landfill

Tasks:
1. Calculate total construction waste generated (kg and tonnes).
2. Calculate quantities of non-hazardous and hazardous waste.
3. Calculate total waste diverted from landfill.
4. Determine landfill diversion percentage.
5. Assess ECSBC compliance.

Q2. Describe the design, implementation, and compliance assessment of an on-site organic waste management system for a building with built-up area greater than 5,000 m^2 in accordance with ECSBC 2024 and Solid Waste Management Rules, 2016.

Answer Key for MCQs

1. C	6. B
2. C	7. C
3. D	8. C
4. C	9. C
5. C	10. D

11. INDOOR ENVIRONMENT QUALITY

Indoor environmental quality (IEQ) represents one of the most critical dimensions of building performance, directly influencing the health, well-being, comfort, and productivity of occupants. As buildings evolve towards higher energy efficiency and sustainability standards, the importance of creating healthy indoor environments has intensified. The IEQ encompasses the physical, chemical, and environmental conditions inside buildings—conditions that determine how people experience the spaces where they live, work, learn, and heal.

This chapter provides a comprehensive understanding of the IEQ, its key parameters, and the factors that influence comfort and indoor health. It serves as a technical guide for designers, engineers, building professionals, students, and practitioners involved in shaping the built environment.

The IEQ is integral to sustainable and energy-efficient building design. It establishes the guidelines and performance criteria required to ensure that buildings not only minimize energy use but also promote wellness and comfort. The IEQ plays a pivotal role in occupants well-being as described below:

- **Protecting occupant health:** Avoiding exposure to pollutants, allergens, pathogens, and inadequate ventilation.
- **Enhancing user satisfaction and comfort:** Through appropriate thermal, visual, and acoustic performance.
- **Balancing energy efficiency with human needs:** Designing for natural ventilation, daylight, and efficient mechanical systems.
- **Reducing long-term operational costs:** By minimizing sick building complaints and improving system performance.
- Supporting sustainable development: Aligning built spaces with environmental, social, and governance (ESG) objectives.
- Buildings optimized for the IEQ not only reduce energy loads but also ensure environments that support physiological and psychological well-being.

The IEQ also determines compliance with national building codes, workplace safety legislation, environmental standards, and rating system requirements. Poor IEQ can lead to building-related illnesses (BRI), sick building syndrome (SBS), and operational disruptions. Hence, the IEQ forms the backbone of healthy building design and management protocols.

11.1 Key parameters of indoor environmental quality

The IEQ comprises several interrelated parameters, this guidebook focuses on the four most widely recognized:

Indoor air quality (IAQ)

Refers to the presence of clean, breathable air free from harmful pollutants, odours, allergens, volatile organic compounds (VOCs), and particulate matter. The IAQ depends on ventilation strategies, filtration efficiency, outdoor air quality, and the selection of building materials and equipment.

Visual comfort

Addresses the adequacy and quality of lighting—both natural daylight and artificial illumination. It considers glare control, luminance balance, color rendering, and uniformity to create comfortable and visually supportive spaces.

Thermal comfort

Represents a state of mind where individuals feel satisfied with the surrounding temperature, humidity, air movement, and radiant conditions. Thermal comfort results from environmental factors and personal variables such as clothing and metabolic rate.

Acoustics

Concerns the control of noise levels within indoor spaces to avoid discomfort, distraction, or health impacts. Acoustic comfort includes reducing external noise intrusion, controlling internal noise sources, and optimizing reverberation.



Figure 141 Key parameters of indoor environment quality

11.2 Components Influencing Indoor Environmental Quality

The IEQ is governed by a combination of design parameters, material selection, operational practices, and environmental characteristics. The following components play a central role in shaping IEQ outcomes:

Ventilation potential

Proper ventilation dilutes indoor contaminants and maintains oxygen-rich indoor environments. Ventilation potential depends on:

- Building orientation
- Wind patterns and natural airflow pathways
- Mechanical ventilation design and efficiency
- Air distribution strategies

Energy-efficient buildings should balance fresh air supply with low-energy systems such as demand-controlled ventilation or hybrid approaches.

Low-emitting materials

Materials such as adhesives, paints, coatings, sealants, flooring, furniture, MDF boards, and carpeting often emit VOCs and formaldehyde. Selecting low-emitting, certified materials:

- Reduces risks of respiratory irritation
- Prevents long-term chemical exposure
- Improves IAQ in sealed, conditioned spaces

Material compliance with recognized emission standards is essential for healthy interiors.

Air quality in car parking

Vehicular emissions contribute significantly to indoor pollutants such as CO, NO_2, and particulate matter. Measures to maintain air quality include:

- Exhaust systems and CO sensors
- Adequate cross-ventilation in open parking areas
- Segregation of parking zones from habitable spaces
- Avoiding direct openings from parking into buildings

Controlling pollutants from parking ensures safer, cleaner adjacencies and prevents cross-contamination.

Spaces such as kitchens and toilets generate moisture, odours, and pollutants. Adequate ventilation is essential to:

- Prevent mold growth
- Remove excess humidity
- Control odours and chemical exposure
- Maintain hygiene standards



Figure 142 Air-quality issues in enclosed parking areas

Effective strategies include natural ventilation, mechanical exhaust systems, and ensuring airflow pathways that do not compromise overall building performance.

Daylight availability

Daylighting is key to visual comfort, circadian health, and energy savings. Adequate daylight reduces dependence on artificial lighting and contributes to improved mood, productivity, and visual acuity.

Daylight design considers:

- Window placement and size
- Glazing type and visible light transmittance
- Shading devices to avoid glare
- Daylight factor and illuminance levels

Balanced daylighting reduces energy loads while enhancing occupant comfort.

Lighting adequacy for common areas and exterior lighting

Lighting in circulation areas, lobbies, staircases, and outdoor zones is essential for safety, security, and functionality.

Key criteria include:

- Minimum lux levels for tasks and movement
- Uniformity of illumination
- Avoiding over-lighting and unnecessary energy use
- Ensuring safe illumination of entrances, ramps, pathways, and parking areas

Guidelines should follow national lighting standards and good practice recommendations.

Lighting quality

Lighting quality goes beyond basic illumination and includes:

- Glare management
- Colour rendering (CRI)
- Correlated colour temperature (CCT)
- Flicker control
- Luminance diversity

High lighting quality supports visual comfort, enhances spatial perception, and reduces visual strain.

Thermal comfort

Thermal comfort integrates multiple factors:

- Air temperature
- Radiant temperature
- Relative humidity
- Air movement

- Metabolic heat generation
- Clothing insulation

This section is covered in detail at chapter 2 Building Physics

Appropriate design features include insulation, shading, passive cooling strategies, efficient HVAC systems, natural ventilation potential, and adaptive comfort approaches suitable for the Indian climate.

11.3 Occupant Comfort and Building Performance

Modern buildings must balance sustainability with occupant comfort. Research by Dodge, Daly, and others defines well-being as the ability of individuals to meet psychological, physical, and social challenges. Building comfort contributes significantly to this well-being, affecting:

- Cognitive clarity
- Emotional stability
- Productivity levels
- Occupant satisfaction and retention

Sick building syndrome (SBS) and building-related illness (BRI) have drawn global attention. The World Health Organization (WHO) in 1984 highlighted that nearly 30% of new or renovated buildings worldwide experience IAQ-related complaints. Symptoms include:

- Eye, nose, and throat irritation
- Headaches and fatigue
- Dizziness and nausea
- Skin irritation
- Respiratory difficulties

Indian studies have documented similar trends, especially in centrally conditioned office buildings. Poor ventilation, lack of daylight, excessive recirculation, and pollutant buildup are key contributors.

Indoor air quality (IAQ) refers to the quality of air within buildings and enclosed spaces, particularly in relation to the health, comfort, and well-being of occupants. Human survival depends on a continuous and substantial intake of air—typically in the range of 10–20 cubic metres per person per day. Unlike food or water, air intake is involuntary and uninterrupted, making the quality of inhaled air a critical determinant of both short-term comfort and long-term health outcomes. Poor indoor air quality has been widely associated with adverse health effects, reduced productivity, and diminished quality of life, particularly in densely occupied and mechanically conditioned buildings.

Inadequate IAQ is a major contributor to BRI and SBS. While BRI refers to clinically diagnosable illnesses directly attributable to indoor environmental conditions, SBS is characterized by a collection of symptoms—such as headaches, fatigue, respiratory irritation, and skin discomfort—that cannot be traced to a specific disease but are clearly linked to time spent within a building. Recognizing the fundamental importance of clean air, the United Nations declared access to acceptable air-quality standards a basic human right in 1999, and the WHO subsequently affirmed the right of all individuals to healthy indoor air.

In India, the burden of indoor and outdoor air pollution is particularly severe. Studies indicate that air pollution contributed to approximately 2.2 million deaths in 2017 alone, accounting for nearly 12% of the national health burden. These figures highlight the urgency of integrating IAQ considerations into building planning, design, construction, and operation, especially in urban and peri-urban contexts where ambient air quality is often compromised.

Harmful Pollutants and Substances

A wide range of harmful pollutants contribute to poor indoor air quality. In India, the continued use of solid fuels such as wood, charcoal, crop residue, and dung for cooking and heating results in the emission of numerous toxic substances due to incomplete combustion. These include carbon monoxide, particulate matter, sulphur dioxide, nitrogen dioxide, volatile and semi-volatile organic compounds, ammonia, benzene, benzo(a) pyrene, and various heavy metals.

Carbon monoxide is a colourless, odourless gas produced by incomplete combustion and poses serious health risks by reducing oxygen delivery to vital organs. Particulate matter, especially $PM_{2.5}$, is a major contributor to respiratory and cardiovascular diseases. Sulphur dioxide and nitrogen dioxide irritate the respiratory system and contribute to secondary pollutant formation. Ground-level ozone, formed through photochemical reactions involving nitrogen oxides and VOCs, exacerbates respiratory conditions and damages lung tissue.

Other pollutants such as ammonia, benzene, benzo(a)pyrene, and heavy metals present additional health risks, including carcinogenic, neurological, and developmental effects. Children are particularly vulnerable to heavy metal exposure due to their developing nervous systems. Given their prevalence and severity, carbon monoxide and particulate matter are considered priority pollutants for indoor air quality management in the Indian context.

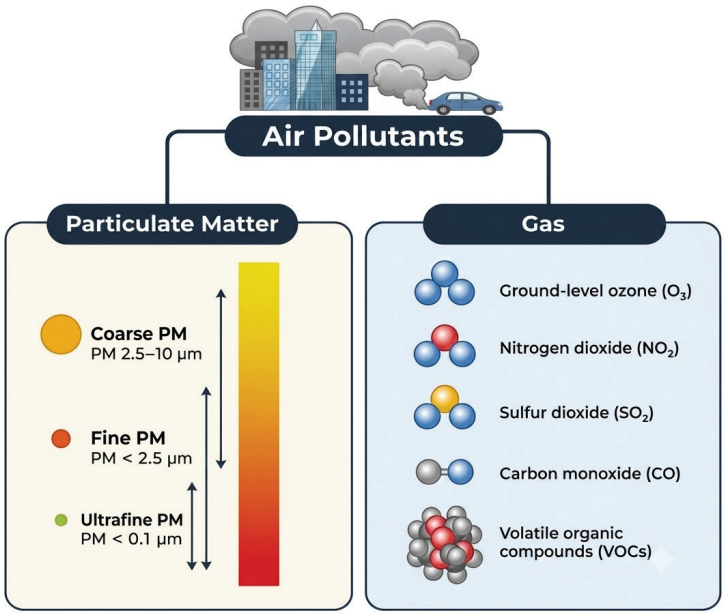


Figure 143 Parameters for evaluating air quality index

Designing for Air Quality

The HVAC system shall be designed with appropriate filtration measures to maintain indoor pollutant levels within the prescribed limits. The threshold values for Indoor Air Quality (IAQ) pollutants shall be in accordance

with Table provided below. Buildings and indoor spaces shall be categorized into Class A, Class B, and Class C, where Class A represents aspirational performance, Class B represents acceptable performance, and Class C represents the minimum acceptable performance level.

Table 62 Threshold Values for IAQ Pollutants (NBCS-2026)

Sl No.	Pollutants	Units	A	B	C
i)	CO_2	ppm	ambient + 350	ambient + 500	ambient + 700
ii)	$PM_{2.5}$	ug/m^3	< 15	< 25	< 25
iii)	PM_{10}	ug/m^3	< 50	< 100	< 100
iv)	O_3	ug/m^3	< 50	< 100	-
v)	TVOC (equivalent to isobutylene)	ug/m^3	< 200	< 400	< 500
vi)	CH_2O	ug/m^3	< 30	< 100	-
vii)	SO_2	ug/m^3	< 40	< 80	-
viii)	NO_2	ug/m^3	< 40	< 80	-
ix)	CO	ppm	< 2	< 9	< 9

Control of Particulate Matter and Carbon Dioxide

Among the various indicators of IAQ, particulate matter and carbon dioxide are of primary concern due to their prevalence, health impacts, and strong relationship with ventilation effectiveness. Effective IAQ management requires controlling these pollutants at the source and ensuring adequate dilution through ventilation.

Source Control for PM_{10} and $PM_{2.5}$

Particulate matter (PM) consists of solid particles and liquid droplets suspended in the air. PM_{10} refers to particles with an aerodynamic diameter of 10 micrometres or less, while $PM_{2.5}$ refers to fine particles with a diameter of 2.5 micrometres or less. The health implications of $PM_{2.5}$ are particularly severe, as these fine particles can penetrate deep into the lungs and enter the bloodstream, contributing to respiratory and cardiovascular diseases.

Indoor particulate matter originates from both external and internal sources. In polluted urban environments, outdoor air infiltration is a significant contributor, especially when buildings are located near traffic corridors, industrial zones, or construction sites. Indoor sources include combustion activities such as cooking, smoking, use of incense or candles, dust resuspension due to poor housekeeping, and infiltration from basements or parking areas. Given the high ambient PM concentrations in many Indian cities, source control becomes a critical strategy for maintaining acceptable IAQ.

Effective control of PM requires a combination of architectural and mechanical measures. These include careful placement of air intakes away from pollution sources, sealing of the building envelope to minimize uncontrolled infiltration, provision of appropriate filtration systems in heating, ventilation, and air-conditioning (HVAC) installations, and maintenance of clean indoor surfaces. Reducing indoor dust generation through proper material selection and regular cleaning also plays an important role in controlling particulate levels.

Compliance (source control for PM10 and PM2.5)

- ECSBC (mandatory requirements):
  - o The HVAC system of building shall use air filter conforming to IS/ISO 16890 Part 1 to Part 4

Source control for carbon dioxide

Carbon dioxide is primarily generated indoors through human respiration, and to a lesser extent, through combustion processes. Although CO_2 is not toxic at concentrations typically encountered in buildings, elevated levels are widely recognized as an indicator of inadequate ventilation and excessive occupancy. High indoor CO_2 concentrations are associated with drowsiness, reduced concentration, headaches, and diminished cognitive performance.

Controlling CO_2 levels requires ensuring sufficient outdoor air supply in proportion to the number of occupants and the nature of activities taking place within the space. Strategies such as demand-controlled ventilation, which adjusts air supply based on real-time CO_2 concentrations, are increasingly adopted in energy-efficient buildings. Adequate space planning, avoidance of overcrowding, and continuous or periodic monitoring of CO_2 levels in high-occupancy areas are essential to maintaining both comfort and acceptable indoor air quality.

Compliance (source control for CO2))

- ECSBC (mandatory requirements):
  - o Buildings shall be designed to operate their ventilation systems according to design ventilation rates for perceived air quality, in accordance with Section 6.2.1.
- ECSBC (additional mandatory requirements):
  - o In addition to ECSBC requirements, the ECSBC Plus-compliant buildings shall install devices to measure and control HVAC equipment to regulate and maintain the ventilation rate for non-residential building excluding health care and industrial buildings as defined in Chapter 6 – Section 6.2.1.(C) of the Code.
  - o In addition to ECSBC requirements, in super ECSBC-compliant buildings, sensors shall be integrated with the controls to consistently monitor and regulate ventilation rates, maintaining comfort levels in non-residential buildings (excluding health care and industrial buildings), as outlined in Clause 6.2.1-(c)

Source control of volatile organic compounds and aldehydes Emissions

Volatile organic compounds (VOCs) are a broad class of organic chemicals that readily evaporate at room temperature and are emitted as gases from numerous building materials, finishes, furnishings, and household products. Common indoor sources include paints, varnishes, coatings, adhesives, sealants, composite wood products, furniture, cleaning agents, disinfectants, and personal care products. Among VOCs, formaldehyde and other aldehydes are of particular concern due to their strong irritant properties and established links to cancer and respiratory disorders.

Indoor concentrations of VOCs are often significantly higher than outdoor levels, especially in newly

constructed or recently renovated buildings. In tightly sealed, air-conditioned buildings, these pollutants tend to accumulate, leading to prolonged exposure. Effective control of VOCs therefore relies heavily on source control through material selection. The use of low-VOC or zero-VOC certified materials, elimination of urea-formaldehyde–based resins in furniture and finishes, and strict adherence to prescribed VOC limits are essential measures. Adequate ventilation during construction and post-occupancy flushing further helps in reducing indoor VOC concentrations.

Table 63 Prescribed VOC limits of selected paints

Type of material (paints)	VOC Limit (g/L less water)
Flat paints Non-flat paints	50 50
Compliance (Source control of VOCs and aldehydes emissions) • ECSBC (additional mandatory requirements): o All ECSBC Plus and Super ECSBC buildings, the construction materials like gypsum board, wood, paint, varnish, adhesives, furniture, carpet, etc., shall be with low VOC emissions, complying to standards listed below: ▪ The electronic equipment shall be tested as per ISO/IEC 28360 -1 or ISO/IEC 28360-2: ▪ Information technology: Determination of chemical emission rates from electronic equipment o The building material shall be tested as per ISO 16000-9: Determination of the emission of VOCs from building products and furnishing-emission test chamber method. o UL 2818: Building materials, finishes, and furnishings. o UL 2819: Emissions for electronic equipment. o ANSI/BIFMA X7.1-2011(R2021) standard for formaldehyde and TVOC o Emissions of Low-emitting office furniture and seating.	
Compliance (source control of VOCs and aldehydes emissions) • ENS (mandatory points): o Paints used on the interior side of the building envelope shall comply with the VOC content limits as per Table 38.	

11.4 Ventilation strategies for indoor air quality

Ventilation is the primary mechanism for diluting indoor pollutants and maintaining acceptable indoor air quality. An effective ventilation strategy must balance occupant health, thermal comfort, and energy efficiency.

Openable Window-to-floor Area

The effectiveness of operable windows depends not only on the size of the openings but also on their placement, height, orientation, and relationship to prevailing wind directions. Properly designed window openings facilitate cross-ventilation, allowing fresh air to enter and stale air to exit efficiently. Single-sided ventilation is generally less effective, especially in deep-plan spaces, and should be supplemented with additional ventilation measures where required.

Operable windows provide a simple and effective means of achieving natural ventilation, particularly in residential and mixed-use buildings. Minimum window-to-floor area ratios are prescribed to ensure sufficient

air exchange, removal of indoor contaminants, and provision of fresh air. These ratios are influenced by climatic conditions, building typology, occupancy patterns, and external environmental quality and often are included in the building byelaws.

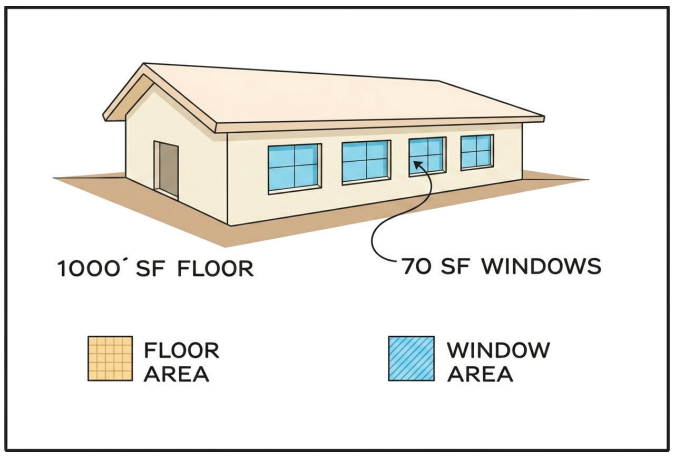


Figure 144 Window to floor area ratio

Natural Ventilation

Natural ventilation utilizes wind pressure and thermal buoyancy to drive airflow through buildings without mechanical assistance. When properly designed, it offers significant benefits, including reduced energy consumption, improved perceived air freshness, and enhanced occupant comfort. However, its effectiveness is highly dependent on outdoor air quality, climatic conditions, and architectural planning. In polluted urban contexts, natural ventilation strategies must be carefully evaluated to avoid introducing outdoor contaminants into indoor spaces.

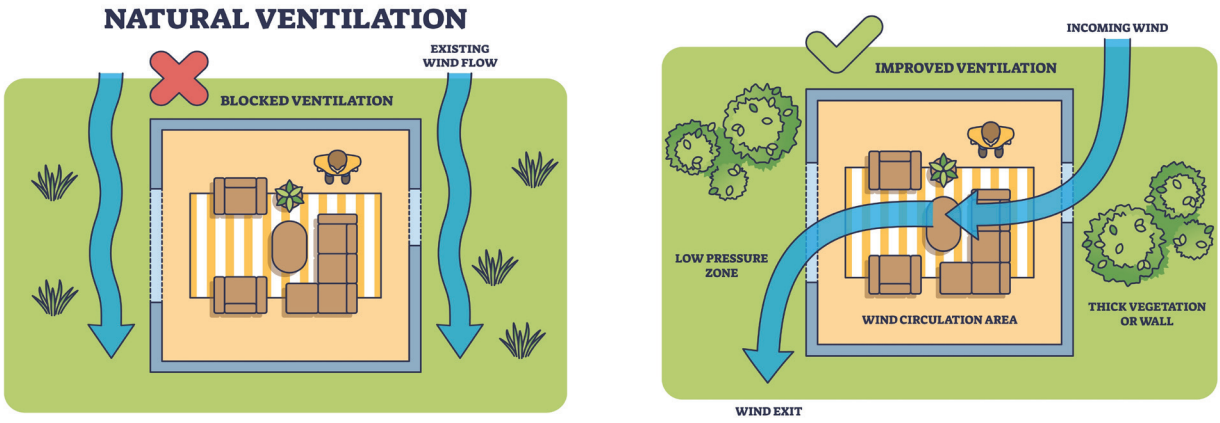


Figure 145 Cross-ventilation

Table 64 Prescribed VOC limits of selected paints

Provision	Incremental points
50% of regularly occupied spaces have cross-ventilation	2
75% of regularly occupied spaces have cross-ventilation	3
90% of regularly occupied spaces have cross-ventilation	4

Compliance (cross-ventilation)

- ENS (incremental points provision):
  o Cross-ventilation is ensured in regularly occupied spaces (kitchen, bedrooms, living, dining areas) with openable doors, windows, or ventilators as per Annexure 6. Incremental points are calculated as per the formula below and points as per Table 41.

  o Percentage of cross-ventilation area = Cross-ventilation area/total regularly occupied area × 100

Air Quality in Parking Areas

Parking areas, particularly enclosed or semi-enclosed ones, are significant sources of indoor air pollutants such as carbon monoxide, nitrogen dioxide, and particulate matter due to vehicular emissions.

Well-designed Ventilation



Figure 146 Car park ventilation

Adequate ventilation in parking areas is essential to prevent the accumulation of harmful gases and protect both occupants and adjacent indoor spaces. Ventilation systems must be designed to maintain pollutant concentrations within permissible limits and to prevent migration of exhaust gases into habitable areas of the building.

Exhaust System

Mechanical exhaust systems are commonly employed in enclosed parking structures to remove vehicular emissions. These systems must be designed for peak usage conditions, with exhaust outlets located to ensure safe dispersion of pollutants away from air intakes and occupied spaces. Regular maintenance and testing are critical to ensure reliable operation.

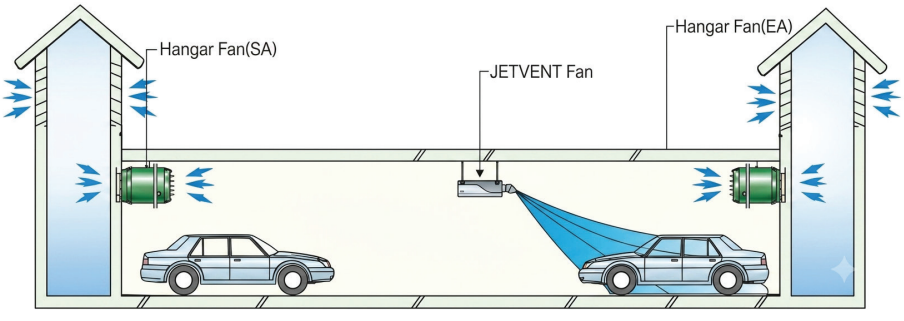


Figure 147 Smoke-extraction system in parking areas

Demand-controlled ventilation systems

Demand-controlled ventilation systems use pollutant sensors, typically carbon monoxide sensors, to regulate exhaust rates based on real-time air-quality conditions. Such systems enhance energy efficiency by operating at reduced capacity during periods of low-vehicle activity while ensuring adequate ventilation during peak usage.

Compliance (air quality in parking spaces)

- ENS (mandatory requirements)
  o For enclosed parking areas, a well-designed ventilation and exhaust system shall be installed that provides a minimum of six air changes per hour, as per the National Building Code (NBC), to effectively eliminate vehicle exhaust fumes and pollutants.
  Air change per hour = Q / V where,
  Q = airflow rate (m^3/h)
  V = volume of the space (m^3)

Provision	Incremental points
CO sensors are installed to control the ventilation system to limit CO level	2

Compliance (air quality in underground parking spaces)

- ENS (mandatory requirements) Install a demand control ventilation system to limit CO levels in the underground parking area to ensure safety and air quality. The location of sensors should be followed as prescribed by the NBC 2016, Volume 2, Part 8, Section 3 and Section 11.5.4. Incremental points can be achieved as per Table 43.

11.5 Ventilation in Kitchens and Sanitary Spaces

Exhaust systems in the kitchen and bathrooms/toilets

Kitchens and sanitary spaces are major sources of indoor pollutants, moisture, and odours. Cooking activities generate particulate matter, carbon monoxide, nitrogen dioxide, and grease aerosols, while bathrooms and toilets produce excess humidity and biological contaminants. Dedicated exhaust ventilation systems are therefore essential in these spaces to remove pollutants at the source, prevent moisture-related problems such as mold growth, and maintain hygienic indoor conditions. Exhaust air from these areas must be discharged directly outdoors and should not be recirculated into occupied spaces.

Compliance (exhaust systems in the kitchen and bathrooms/toilets)

- ENS (mandatory requirements)
  o An opening and/or ventilator shall be provided, in addition to the window, for the installation of exhaust systems in the kitchen and bathrooms/toilets.

11.6 Visual Comfort

Visual comfort refers to the degree of satisfaction experienced by occupants with respect to the quantity, quality, and distribution of light within an indoor space at any given time. It is a critical component of indoor environmental quality, as it directly affects visual performance, comfort, health, mood, and productivity. An appropriately designed lighting environment enables adequate retinal illumination, reduces glare and excessive contrast, and supports the wide range of visual tasks performed by occupants. Both insufficient lighting and

excessive illumination can lead to discomfort, eye strain, headaches, and reduced efficiency, making visual comfort a key design consideration in buildings.

The human visual system is highly adaptive and capable of functioning under a variety of lighting conditions and visual tasks. However, long-term exposure to poorly designed lighting environments—characterized by inadequate illuminance, excessive glare, or improper spectral quality—can result in visual fatigue and adverse physiological and psychological effects. Lighting in indoor spaces, whether natural or artificial, influences not only visual perception but also circadian rhythms, alertness levels, emotional well-being, and cognitive performance. Research has consistently established strong links between lighting conditions and human well-being, emphasizing the importance of careful lighting design in buildings.

Compliance (visual comfort)

- ECSBC (mandatory requirements)
  - o Following requirements shall be met:
    - For all interior spaces, lighting quantity and quality parameters shall conform to IS 3646 (Part 1).
    - For sustainability and energy efficiency aspects of the lighting system, Chapter 7.0 (Lighting and Controls) of this code shall be referred.
- ECSBC (additional mandatory requirements)
  - o For all interior spaces, lighting quantity and quality parameters shall conform to IS 3646 (Part 1).

Interior Lighting Quantity and Quality

Interior lighting design must address both the quantity and quality of light to ensure visual comfort. Lighting quantity refers to the amount of light available on a given surface, while lighting quality relates to how that light is distributed, its spectral composition, glare characteristics, and interaction with interior surfaces.

Lighting quantity is typically measured in terms of illuminance, expressed in lux, which represents the amount of light falling on a working plane. Adequate illuminance levels are essential for performing visual tasks comfortably and efficiently the details of illumination level requirements are provided in IS 3646 (part1) and National Building codes 2016, Part 8: Building services, Section 1: Lighting and Natural Ventilation. However, illuminance alone does not guarantee visual comfort. Lighting quality parameters such as uniformity, contrast, glare control, and colour characteristics play an equally important role in shaping visual perception.

Surface reflectance significantly influences the distribution of light within a space. Interior finishes with higher reflectance values help distribute light more evenly, reducing the need for higher artificial lighting levels. Conversely, dark, or highly absorbent surfaces can lead to uneven lighting and increased energy consumption.

Lighting quality is also strongly influenced by the spectral characteristics of the light source. The 'human visual and perceptual system' has evolved under natural daylight conditions, which exhibit a broad spectral distribution with peak wavelengths between approximately 530 and 580 nanometres. The visible spectrum ranges from about 380 to 780 nanometres, and light within this range is perceptible to the human eye. Artificial lighting systems that approximate the spectral performance of daylight are generally better suited to supporting visual comfort and overall well-being.

Useful daylight illuminance

Useful daylight illuminance (UDI) is a climate-based daylight performance metric that quantifies the percentage of occupied time during which daylight illuminance at the work plane falls within a desirable range, typically between 100 and 2000 lux. Unlike traditional daylight metrics, UDI recognizes that both insufficient and excessive daylight can cause discomfort. Illuminance levels below the lower threshold are considered inadequate and require supplementation with artificial lighting, while levels above the upper threshold may cause glare and visual discomfort.

Table 65 Prescribed daylighting requirement as per ECSBC

Provision	Incremental points
40% of the regularly occupied spaces meeting the UDI requirement	2
50% of the regularly occupied spaces meeting the UDI requirement	3
60% of the regularly occupied spaces meeting the UDI requirement	4
Compliance (useful daylight illuminance) • ENS (mandatory requirements) o The building shall comply with the UDI requirement as prescribed by the ECSBC 2024 (for commercial buildings), Section 5.2.3-(a) Ensure above-grade floor areas shall meet or exceed the UDI area requirements listed in Table 56 for 90% of the potential daylit time in a year (Refer to Chapter 9: Calculations and Formula). Incremental points can be achieved as per Table 42.	

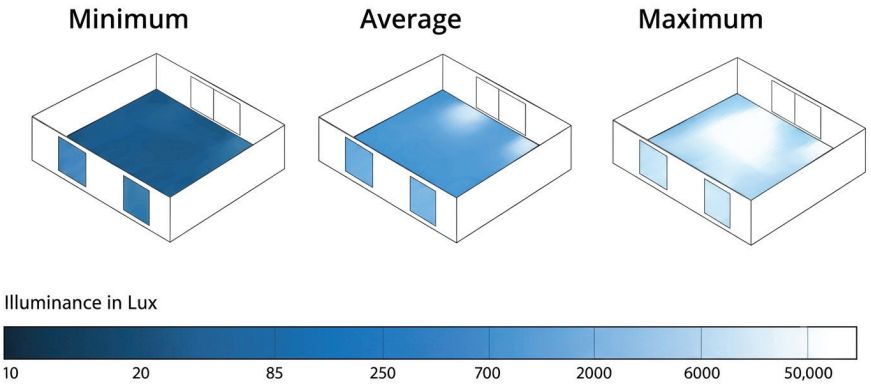


Figure 117 Useful Daylight Illuminance (UDI)

Lighting Adequacy and Colour Quality

Lighting adequacy is achieved when lighting levels are sufficient for the intended tasks and evenly distributed across the space, while colour quality ensures accurate color perception and visual clarity.

Colour-rendering index as per space type

The Colour-rendering index (CRI) indicates how accurately a light source reveals the colours of objects compared to a reference light source, typically natural daylight. Higher CRI values are essential in spaces where accurate colour perception is important, such as offices, classrooms, healthcare facilities, and retail environments. Poor colour rendering can lead to visual fatigue and misinterpretation of visual information, even when illuminance levels are adequate.

Table 66 Required CRI as per space type as per ENS 2024

Area name	Ra (general CRI)
Corridor lighting and stilt parking	80
Basement lighting	70
Exterior lighting areas	
Driveways and parking (open/ external) pedestrian walkways stairways	70 70 80
Indoor lighting (If applicable)	
Kitchen Bathroom Reading/study	90 80 90
Compliance (CRI, as per space type) • **ENS (mandatory requirements)** o The CRI values for each zone within the building shall comply with requirements as per Table 40.	

11.7 Thermal Comfort Evaluation

Thermal comfort principles are explained in Chapter 2. This chapter focuses on thermal comfort evaluation and compliance.

Thermal comfort is one of the most critical determinants of occupant well-being, health, and productivity within buildings. From a biological standpoint, thermal comfort is intrinsically linked to the concept of homeostasis, which refers to the ability of the human body to maintain a stable internal condition despite variations in the surrounding environment. For optimal physiological functioning, the human body must regulate its core temperature at approximately 37°C. While this core temperature remains relatively constant, the body allows greater variability at the skin and extremities, enabling heat exchange with the surrounding environment. Indoor environments that support this balance help reduce physiological stress and enable occupants to perform effectively.

The widely accepted definition of thermal comfort provided by EN ISO 7730 describes it as 'that condition of mind which expresses satisfaction with the thermal environment'. This definition highlights the subjective nature of thermal comfort, emphasizing that it is not solely determined by measurable physical parameters but also by human perception and adaptation. Discomfort arises when the indoor environment deviates from conditions that occupants perceive as acceptable. Excessively warm environments can lead to lethargy, fatigue, dehydration, and reduced cognitive performance, while excessively cool environments may result in restlessness, distraction, and muscular discomfort. Persistent exposure to uncomfortable thermal conditions can adversely affect health, satisfaction, and productivity.

Thermal comfort is the cumulative result of a delicate balance between multiple environmental variables—air

temperature, mean radiant temperature, relative humidity, and air movement—along with personal variables such as metabolic rate and clothing insulation. These factors interact continuously, and comfort is achieved only when they are appropriately aligned rather than optimized in isolation. Because of this complexity, numerous theoretical and empirical thermal comfort models have been developed to evaluate and predict comfort conditions across different climates, building types, and occupancy patterns.

Compliance (thermal comfort)

- ECSBC (mandatory requirements)
  o In conditioned building spaces, the values for quality of thermal environment parameters for representative occupant of a space shall conform to Table 11.1. Notes:
    - Conditions for special purpose buildings such as operation theatres, clean rooms shall be governed by norms prescribed by appropriate authorities.
    - Clothing insulation is expressed in clo units. The clo has the units as m2k/W.
    - 1 clo = 0.155 K·m2·W−1. One clo is the amount of insulation that allows a person at rest to maintain thermal equilibrium in an environment at 21°C in a normally ventilated room (0.1 m/s air \ movement).
- ECSBC (additional mandatory requirements)
  o In addition to mandatory requirements of Section 11.2.2, ECSBC Plus, and Super ECSBC buildings shall comply with following details: ECSBC Plus and Super ECSBC-compliant buildings shall be designed to have relative humidity control within the range of 30% to 70% in summer.
  o Super ECSBC buildings shall be designed to have relative humidity control within the range of 30–70% during summer as well as winter conditions. Super ECSBC buildings shall also meet the additional design conditions as given in Table 11.3.

Compliance (thermal comfort)

- ENS (mandatory requirements):
  o Buildings in all climate zones except cold climate shall comply with the following provisions of the Code:
    - Maximum residential envelope transmittance value (RETV) (except the roof) as per Provision 5.2.1.4.
    - Minimum openable window-to-floor area ratio (WFRop) as per provision 5.2.1.1.
    - Maximum thermal transmittance of roof (Uroof) as per Provision 5.2.1.3.
  o Buildings in cold climates, shall comply with the following provisions of the Code:
    - Thermal transmittance value of the building envelope (UEnvelope.Cold) (except the roof) as per Provision 5.2.1.5.
    - Maximum thermal transmittance of roof (Uroof) as per Provision 5.2.1.3.

Thermal Comfort Measurements

Thermal comfort measurements are undertaken to objectively assess the environmental conditions that influence human thermal perception. These measurements typically include air temperature, relative humidity, air velocity, and mean radiant temperature, which together describe the thermal state of the occupied zone. Measurements are taken at heights corresponding to the typical position of occupants—such as seated or standing levels—to ensure that recorded values reflect actual exposure conditions.

In practice, thermal comfort assessment often combines physical measurements with subjective occupant feedback. Surveys and occupant responses provide valuable insights into perceived comfort and help identify discrepancies between measured conditions and human experience. This combined approach is particularly

important in naturally ventilated and mixed-mode buildings, where occupant behavior and adaptation significantly influence comfort outcomes.

Table 67 Conditions for thermal comfort measurement (Source: Table 4 Conditions for Thermal Comfort, NBCS, 2026)

Air velocity	Weather condition	Level of activity	Reference table
Up to 0.2 m/sec	Summer/winter	Met value ≤ 1.2	Table 11.2
Above 0.2 m/ sec	Summer/winter	Met value ≤ 1.2	Table 11.2

Table 68 Acceptable range of operative temperature (Source: Table 5 Acceptable Range of Operative Temperature with Air Velocity up to 0.2 m/s, NBCS, 2026)

Level of activity	Operative temperature (°C)	
	Summer (cooling season) ~0.5 clo	Winter (heating season) ~1.0 clo
1.0 < Met ≤ 1.2	23.0 ± 3.0	19.0 ± 4.0
Met ≤1.0	24.5 ± 2.5	22.0 ± 3.0

Table 69 Additional requirements for thermal comfort in Super ECSBC buildings

Parameter	Unit		Super ECSBC
Radiant temperature asymmetry	°C	Warm ceiling	<7
		Cool wall	<13
		Cool ceiling	<18
		Warm wall	<35
Vertical air temperature difference	°C		4
Floor surface temperature (only for floor-based cooling/heating)	°C		17–31

Method of Calculating Operative Temperature

Operative temperature is a key indicator used in thermal comfort analysis, as it represents the combined effect of air temperature and mean radiant temperature on the human body. Unlike air temperature alone, operative temperature accounts for the influence of surrounding surface temperatures, which can significantly affect thermal sensation through radiant heat exchange.

Operative temperature is calculated as a weighted average of air temperature and mean radiant temperature, with the weighting dependent on air velocity. At low-air speeds, radiant temperature has a stronger influence on thermal perception, whereas at high-air speeds, convective heat transfer becomes more dominant and air temperature plays a greater role. Because it reflects the integrated thermal experience of occupants, operative temperature is widely used in comfort standards and compliance assessments.

For air velocity up to 0.2 m/s the operative temperature shall be calculated as below:

Operative temperature = $((Tr + (Ta \times \sqrt{10v})))/(1+\sqrt{10v})$

Where,

Ta = Air temperature

Tr = Mean radiant temperature (MRT)

v = Air speed (m/s)

It is also acceptable to approximate this relationship for occupants engaged in near sedentary physical activity (with metabolic rates between 1.0 met and 1.3 met), not in direct sunlight, and not exposed to air velocities greater than 0.20 m/s.

Operative temperature = (*Tr* + *Ta*) / 2

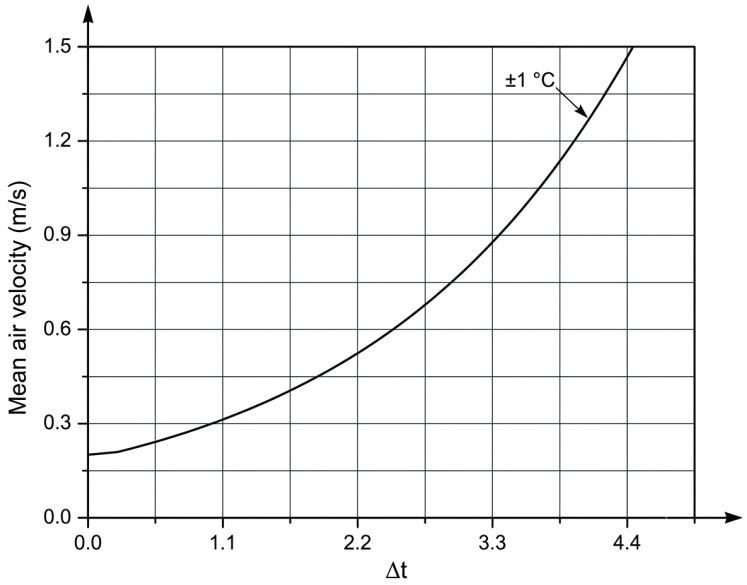


Figure 148 Required air speed to offset increased operative temperature (in degree Celsius)

The above image (based upon the methodology from ISO 7730) can be used to find increase in acceptable operative temperature at elevated air speed above 0.2 m/s.

Example: If in a given room, an occupant is involved in the moderate level of activity, air speed in room is 0.9 m/s and operative temperature is 27°C, then by using above-mentioned graph, Δt is 3.3°C. It makes acceptable room air temperature of 27°C + 3.3°C.

For the purpose of showing compliance, representative sample locations shall be the locations where most extreme values of the thermal parameters are observed or likely to occur (e.g., potentially occupied areas near windows, diffuser outlets, corners, and entry/ exit).

Thermal comfort compliance through Standardized Compliance Method (SCM) of ECSBC

The Standardized Compliance Method (SCM) of ECSBC compliance evaluates thermal comfort under prescribed indoor environmental conditions for conditioned buildings.

For demonstrating compliance, representative sample locations shall be selected at positions where extreme values of thermal parameters are observed or likely to occur, such as areas near windows, supply air diffusers, corners, and entry or exit points.

When using the SCM, the mean radiant temperature (MRT) shall be assumed equal to the air temperature.

Thermal comfort compliance through Integrative Compliance Method (ICM) of ECSBC

The Integrative Compliance Method (ICM) of ECSBC compliance evaluates thermal comfort using simulation-based assessment of operative temperature.

For demonstrating compliance, representative sample locations shall be selected at positions where extreme values of thermal parameters are observed or likely to occur.

When using the ICM, the operative temperature shall be determined through a simulation program and shall conform to the following reporting requirements:

- Climate data file used
- Report demonstrating compliance with thermal comfort criteria
- Simulation report, including input and output files, confirming that thermal comfort conditions are met

Local Thermal Discomfort Parameters

Even when overall thermal comfort conditions are satisfied, occupants may experience discomfort due to localized thermal effects. These local discomfort parameters can strongly influence occupant satisfaction and must be addressed through careful design and system operation.

Radiant temperature asymmetry

Radiant temperature asymmetry occurs when there is a significant temperature difference between opposing surfaces within a space, such as a cold-glazed façade or a sun-exposed roof. This imbalance causes uneven radiant heat exchange between different parts of the body and the surrounding surfaces, leading to localized discomfort. Effective insulation, appropriate glazing selection, and external shading help minimize radiant temperature asymmetry and improve comfort.

Vertical air temperature difference

Vertical air temperature difference refers to the temperature gradient between head and ankle levels within an occupied space. Excessive stratification can cause discomfort, particularly in mechanically conditioned spaces with inadequate air distribution. Maintaining acceptable vertical temperature gradients through proper HVAC system design ensures that occupants experience uniform thermal conditions across the occupied zone.

Floor surface temperature (only for floor-based cooling/heating)

In buildings employing radiant floor heating or cooling systems, floor surface temperature has a direct impact on occupants' comfort. Floors that are excessively cold or warm can cause discomfort through direct contact, particularly for occupants who are barefoot or lightly clothed. Proper system design and control are essential to maintain floor surface temperatures within comfortable limits.

Building envelope parameters affecting thermal comfort

A building envelope acts as the primary moderator between indoor and outdoor environments and plays a crucial role in determining indoor thermal conditions. Envelope performance influences heat gain, heat loss, and thermal stability, all of which directly affect occupant comfort further explanations are provided in the Chapter 2: Building Physics and Chapter: 3 Building Envelope.

Residential envelope transmittance value

Residential envelope transmittance value (RETV) is a composite performance metric used in ENS 2024 to assess the overall thermal transmittance of residential building envelopes. It accounts for heat transfer through walls, windows, and roofs. Lower RETV values indicate reduced heat gain, improved indoor comfort, and lower cooling energy demand. The ENS prescribes maximum allowable RETV values to ensure thermally efficient residential buildings.

11.8 Acoustic Comfort

Acoustic comfort refers to the psycho-physiological state in which building occupants experience satisfaction with the sound environment within enclosed spaces. It is a critical component of indoor environmental quality because unwanted sound and excessive noise have direct and measurable impacts on human health, cognitive performance, communication, learning outcomes, sleep quality, and overall well-being. Sound itself is a form of mechanical energy that propagates through air and solid materials as pressure waves, and its perception depends on intensity, frequency, duration, and the sensitivity of the listener.

Noise within buildings originates from a wide range of sources. External noise commonly arises from vehicular traffic, railways, aircraft, construction activity, and neighbourhood functions, while internal noise is generated by human speech, audio-visual equipment, plumbing systems, appliances, fans, elevators, and heating, ventilation, and air-conditioning (HVAC) systems. Indoor noise can be classified into airborne noise, which travels through air, and structure-borne noise, which is transmitted through vibrations in building elements. Poor acoustic environments can interfere with verbal communication, increase stress levels, reduce concentration, and significantly impair productivity in workspaces and educational settings.

Long-term exposure to elevated noise levels has serious health implications. Continuous or repeated exposure to sound levels above approximately 85 dB is known to cause permanent hearing damage. Noise-induced hearing loss (NIHL) is among the most prevalent irreversible occupational health hazards worldwide, with global studies estimating that more than one-quarter of hearing loss cases are attributable to prolonged noise exposure. Occupational health guidelines generally recommend that exposure to noise should not exceed 75 dB over an eight-hour period to minimize risk. Beyond hearing impairment, excessive noise contributes to sleep disturbances, cardiovascular stress, anxiety, and fatigue, making acoustic comfort a public health concern rather than merely an architectural issue.

Children are particularly vulnerable to the effects of noise. Research has shown that students exposed to high levels of traffic or classroom noise experience reduced memory retention, impaired reading ability, and diminished sustained attention. Similarly, adults living or working in noisy environments report higher levels of annoyance, stress, and poorer self-reported physical health outcomes. These findings reinforce the need for acoustic considerations to be integrated into building design, rather than treated as secondary or corrective measures.

The acoustic quality of an interior space depends on the characteristics of noise sources, the transmission paths through which sound travels, and the acoustic performance of building elements. Effective acoustic design therefore requires a comprehensive approach that addresses sound transmission through building components, the acoustic performance of partitions and openings, and the level of noise isolation required for different space functions.

Compliance (junction between the separating wall/ floor)

- ECSBC (additional mandatory requirements)

  o The controlling of noise in and around buildings is essential. The new buildings and the refurbished buildings shall demonstrate compliance as defined below:

  - Isolation between building elements depends upon the following factors:
    - Junction between the separating wall/floor
    - Mass of flanking elements
    - Transmission through floor voids, loft spaces, service ducts, mullions and similar paths. The building material shall be selected based on acoustic insulation properties of the material as specified in Table 11.4. The standard laboratory measurements of airborne sound insulation in accordance with BS EN ISO 10140-2 and impact sound insulation in accordance with BS EN ISO 10140-3 or any other equivalent standard should be considered as a guide to the performance of an element in the field.

  o In case of Super ECSBC, post-building construction, field tests for sound insulation shall be conducted in accordance with BS EN ISO 140-4 and BS EN ISO 140-

  o From these measurements, single-number ratings can be calculated according to BS EN ISO 717-1, for airborne insulation, and BS EN ISO 717-2, for impact insulation.

  o The threshold noise isolation class (NIC) depending on type of spaces shall be as per Table 11.7.

  o The transmission loss of wooden, metal Doors along with acoustical louvers are defined in Table 11.5.

  o Transmission loss for acoustical louvers is defined in Table 11.6.

  o Table 11.4 gives default sound insulation values of the different walls and glazing.

Sound Transmission Through Building Elements

Sound transmission in buildings occurs not only directly through walls, floors, and ceilings but also indirectly through connected structural elements and concealed cavities. These indirect transmission routes, known as flanking paths, can significantly compromise acoustic performance if they are not adequately controlled.

Table 70 Default sound insulation values of the different walls and glazing

S. No.	Partition (dry and wet walls)	Rw/STC
1	100 mm thick low-density block work 214 approx. density 52 kg/m2) with 12 mm thick plaster on both sides	35–37
2	Metal stud partition, 50 mm studs 600 mm centres, clad both sides with 12.5 mm plasterboard of minimum density 750kg/m3 joints filled and perimeters sealed	
3	100 mm thick medium density block work 214 approx. density 140 kg/m2 with 12 mm thick plaster on both sides	38-40
4	Metal stud partition, 50 mm studs 600 mm centres, clad both sides with 12.5 mm plasterboard of minimum density 750kg/m3, cavity filled with 50 mm thick mineral wool and joints filled and perimeters sealed	
5	100 mm thick medium density block work 214 approx. density 140 kg/m2 with 12 mm thick plaster on both sides	

6	115 mm brickwork 214 approx. density 190 kg/m2 with12 mm thick plaster on both Sides	
7	Metal stud partition, 70 mm studs 600 mm centres, 2 x 12.5 mm plasterboard of mini- mum density	40-45
8	225 mm brickwork 215 approx. density 440 kg/m2 with12 mm thick plaster on both Sides	45-50
9	Double-stud metal stud partition, 70 mm studs placed 10 mm apart and studs fixed at 600 mm centres, 2 x 12.5mm plasterboard of minimum density 900 kg/m3 cavity filled with 2 x 50 mm thick mineral wool each side of a metal stud	
10	200 mm block work 215pprox.. density 400Kg/m2with 15mm thick plaster on both sides	
11	100 mm block (high density 200 kg/m2) with 12 mm plaster on one side and 1 x 12.5 mm plasterboard on metal frame with a 50 mm cavity filled with glass fiber/mineral wool on other side	50-55
12	Double-stud metal stud partition, 70 mm studs placed 10 mm apart and studs fixed at 600 mm centres, 2 x 12.5 mm plasterboard of minimum density 990–1000 kg/m3 cavity filled with 2 x 50 mm thick mineral wool each side of a metal stud	
	Glazing combinations	
13	4 mm single float (sealed)	25
14	6 mm single float (sealed)	28
15	4 mm glass/12 mm air gap/4 mm glass	
16	10 mm single float (sealed)	30
17	6 mm glass/12 mm air gap/6 mm glass	
18	12 mm single float (sealed)	33
19	16 mm glass/12 mm air gap/8 mm glass	
20	10 mm laminated single float (sealed)	35
21	4 mm glass/12 mm air gap/10 mm glass	
22	12 mm laminated single float (sealed)	38
23	6 mm glass/12 mm air gap/10 mm glass	
24	19 mm laminated single float (sealed)	40
25	10 mm glass/12 mm air gap/6 mm laminated glass	
26	10 mm glass/50 mm air gap/6 mm glass	

27	10 mm glass/100 mm air gap/6 mm glass	43
28	12 mm laminated glass/12 mm air gap/10 mm glass	
29	**17 mm laminated glass/12 mm air gap/10 mm glass**	45

Table 71 Transmission loss of wooden, metal door along with acoustic louvers

a. Solid-core wood doors				
TL (transmission loss), DB				
Description		Solid-core wood door (24 kg/m2)]; no seals around perimeter	Solid-core wood door [(24 kg/m2)]; foam-type seals around perimeter	Solid-core wood door [(24 kg/m2)]; magnetic seals around perimeter
STC		22	26	30
Rw	63	16	18	20
	80	19	20	23
	100	16	19	22
	125	19	22	25
	160	20	24	26
	200	21	25	27
	250	22	25	29
	315	24	28	31
Frequency H	400	16	25	29
	500	16	25	30
	630	17	26	31
	800	17	26	31
	1000	17	26	30
	1250	17	28	29
	1600	18	29	31
	2000	18	30	36
	2500	17	32	38
	3150	19	33	40
	4000	20	34	39

Table 72 Transmission loss for acoustical louvers

Depth of acoustical louver single blade (mm)	63	125	250	500	1000	2000	4000	8000
100	5	4	5	6	9	13	14	**13**
150	6	6	8	10	14	18	16	**15**
300	6	7	10	12	18	18	14	**13**
600	**7**	**9**	**12**	**24**	**31**	**33**	**29**	**30**

Calculating acoustical transmission loss:

Normalized transmission loss shall be calculated using the equation below:

Normalized transmission loss TLn,

$$TL_N = 10\log\{1 + (\pi \times F \times \frac{S}{So * Co})\}^2$$

Where, F = centre frequency, S = surface density, ($\mathbf{S_o} \times \mathbf{C_o}$) = characteristic impedance, random transmission loss is then calculated using normalized transmission using the below mentioned formula,

$TLR = TLN - (10 \log 0.23 \times TL_N)$

Table 73 Transmission loss for acoustical louvers

S. No.	Building	Type of space	Dw/NIC		
			Super ECSBC	ECSBC Plus	ECSBC
1	Office	Between two enclosed offices	45	40	**40**
		Between enclosed office and circulation area	40	35	**30**
		Between two meeting or conference rooms	50	45	**45**
		Between meeting or conference room and circulation area	40	35	**30**
		Between two training rooms	50	45	**45**
		Between training room and circulation area	40	35	**30**
2	Hospitality	Walls and floor between banquet halls and guestrooms/suites	55	50	**50**
		Between banquet hall and circulation area or pre functions	45	40	**40**
3	Entertainment	Walls of cinemas, auditoriums, studios, pubs	60	55	**50**
4	Education	Between classrooms, labs, lecture halls	50	50	**45**
5	Hospital and health care	Between two patient rooms and circulation area	40	40	**35**
		Between patient room and circulation area (with entrance)	35	30	**25**
		Between patient room and service area	50	45	**45**
		Between consultation room and patient room,	40	40	**40**
		patient room, public space			
		Between consultation room and circulation area (with entrance)	**35**	**30**	**25**

Junction Between the Separating Wall/Floor

The junctions between separating walls and floors are particularly critical points for sound transmission. Even when individual walls or floor slabs provide sufficient sound insulation, rigid or poorly detailed junctions can allow vibrations to bypass the primary separating element. This flanking transmission enables sound energy to travel through the structure and re-radiate into adjacent spaces. Proper acoustic detailing at junctions is therefore essential and may include resilient connections, discontinuities in rigid materials, and continuous sealing to prevent sound leakage. Without careful treatment of these junctions, the effective acoustic performance of the building may fall far short of its design intent.

Mass of Flanking Elements

The mass of flanking elements such as adjacent walls, floors, and ceilings plays a significant role in determining how much sound is transmitted through the building structure. Lightweight elements tend to vibrate more readily when excited by sound waves, thereby transmitting noise to connected spaces. Increasing the mass of these elements improves sound insulation by reducing vibration amplitudes and shifting resonance frequencies. In practice, layered constructions that combine mass with damping and resilient connections are particularly effective in limiting sound transmission and improving overall acoustic comfort.

Transmission Through Floor Voids, Loft Spaces, Service Ducts, Mullions and Similar Paths

Sound can also propagate through concealed pathways such as floor voids, ceiling plenums, loft spaces, service ducts, mullions, and other interconnected cavities. These paths can unintentionally link acoustically separate spaces, allowing noise to travel laterally and vertically across large portions of a building. Poorly sealed service penetrations and unlined ducts are common sources of acoustic leakage. To mitigate this, all penetrations should be acoustically sealed, ducts should be internally lined or fitted with acoustic attenuators, and cavities should be compartmentalized to prevent the spread of sound.

Acoustic Performance of Partitions and Openings

Partitions and openings are the primary elements responsible for separating spaces acoustically. Their design and construction must be tailored to the acoustic sensitivity of the spaces they divide.

Partition (dry and wet walls)

Both dry partitions, such as gypsum board systems, and wet partitions, such as masonry or concrete walls, can provide effective sound insulation when properly designed and constructed. Wet walls rely primarily on mass and continuity to resist sound transmission, while dry walls achieve acoustic performance through layered assemblies, cavity insulation, and resilient fixings. In noise-sensitive applications, enhanced partition systems such as double-stud walls or staggered framing may be required to reduce sound transmission and prevent vibration transfer. The effectiveness of any partition system depends not only on its materials but also on workmanship and detailing.

Solid-core wood doors

Doors often represent the weakest point in an acoustic barrier. Solid-core wood doors provide significantly

better sound insulation than hollow-core alternatives due to their higher mass and reduced susceptibility to vibration. However, even a high-quality door will perform poorly if gaps exist around the frame. Proper sealing with acoustic gaskets, drop seals, and well-fitted frames is essential to prevent sound leakage and maintain the overall integrity of the acoustic separation.

Hollow-core steel doors

Hollow-core steel doors generally offer limited acoustic insulation because their lightweight construction allows sound to pass through and induce vibration. While they may be suitable for certain functional or fire-safety applications, their use in acoustically sensitive areas should be carefully evaluated. Where hollow-core doors are unavoidable, additional acoustic treatments or alternative door constructions may be required to achieve acceptable noise isolation.

Noise Isolation Performance

Noise isolation performance refers to the ability of building elements and assemblies to reduce sound transmission between spaces and is typically quantified using standardized indices such as the sound transmission class (STC) or equivalent metrics.

Thresholds noise isolation class depending on type of spaces

Different types of spaces have different acoustic requirements depending on their function and sensitivity to noise. Spaces such as bedrooms, classrooms, libraries, health care facilities, and meeting rooms require higher levels of noise isolation to support rest, learning, confidentiality, and concentration. In contrast, spaces such as corridors, lobbies, and service areas can tolerate higher noise levels. Establishing appropriate noise isolation thresholds based on space function ensures that acoustic design supports the intended use of the building and enhances occupant satisfaction.

Planning, mitigation, and compliance for acoustic comfort

The National Building Code (NBC) 2016 provides guidance on planning and design strategies to limit indoor noise arising from both external and internal sources. One of the most effective noise-mitigation strategies is careful site selection and planning. Locating buildings away from major noise sources such as airports, highways, railway lines, and industrial areas significantly reduces exposure to external noise. Where avoidance is not possible, screening strategies may be employed, such as positioning less noise-sensitive buildings or spaces to shield more sensitive areas.

Landscape design also contributes to noise control. Dense vegetation helps absorb and scatter sound, while excessive hard paving tends to reflect and amplify noise. Breaking up large paved areas with planting and avoiding narrow hard-surfaced courtyards between tall buildings can improve the acoustic environment. In residential areas, road layouts that discourage high-vehicle speeds further reduce traffic noise.

Interior layout planning is equally important. Noise-sensitive spaces such as bedrooms, classrooms, and libraries should be located away from external noise sources or buffered by less sensitive spaces such as corridors,

staircases, or service zones. Where windows face busy roads, increased setbacks, enhanced glazing, or acoustic window systems should be provided to limit noise ingress.

To verify compliance, indoor noise levels must be measured using appropriate instruments. Measurements are typically conducted using a sound level meter (SLM) at locations representative of occupant exposure, usually at least one metre away from inward-facing façades. The SLM detects air pressure variations caused by sound waves and converts them into electrical signals that are processed and displayed as sound pressure levels in decibels. Measured noise levels must comply with the limits specified in NBC 2016, Volume 2, Part 8, Section 4, which prescribes acceptable indoor noise levels for various building types and occupancies. Where measured values exceed permissible limits, mitigation measures must be implemented to ensure safe, healthy, and comfortable acoustic environments for building occupants.

11.9 IEQ Audit

IEQ audit of an operational building should be carried out through a structured process involving document review, site inspection, environmental measurements, occupant interaction, and reporting. The objective of the audit is to evaluate indoor environmental performance, identify deficiencies, and recommend measures for improving occupant comfort, health, and operational efficiency.

The audit shall begin with a review of relevant documents to understand the building design, system operation, and maintenance practices. The review may include HVAC drawings, Building Management System (BMS) trends, maintenance records, filter replacement logs, and previous IEQ or IAQ audit reports. The document review helps in identifying operational patterns, recurring issues, and areas requiring detailed investigation during the site assessment.

Site Inspection

A physical inspection of the building and associated systems shall be conducted to assess actual operating conditions and identify factors affecting indoor environmental quality.

The inspection should include HVAC systems, occupied spaces, Air Handling Units (AHUs), ventilation systems, toilets, pantry areas, and other common spaces. Key observations may include ventilation effectiveness, thermal conditions, housekeeping practices, moisture ingress, odor sources, occupant density, and cleanliness of HVAC components.

Instrument Measurements

Environmental parameters shall be measured using calibrated instruments under normal operating conditions at representative indoor locations.

Measurements may include indoor air quality parameters, illumination levels, sound levels, temperature, and relative humidity. Depending on project requirements, monitoring may also include carbon dioxide (CO_2), particulate matter ($PM_{2.5}$ and PM_{10}), total volatile organic compounds (TVOC), and air velocity.

The measured values should be compared with applicable standards and recommended IEQ performance criteria of ECSBC and ENS 2024.

Occupant Interaction

Feedback from occupants and facility management personnel should be collected to understand user experience and identify recurring environmental concerns.

The interaction may include occupant surveys, interviews, and review of complaint records related to thermal comfort, indoor air quality, lighting, noise, odors, and general workplace comfort.

Analysis and Reporting

Based on the site observations, measurements, and occupant feedback, an assessment of the overall IEQ performance shall be carried out.

The audit report should include compliance status, identified gaps, risk areas affecting occupant wellbeing, and recommended corrective measures. The report may also provide guidance on operational improvements, maintenance practices, and opportunities for enhancing energy efficiency and occupant comfort.

Questions for Waste Management

Section A: Objective Questions (MCQs) – 10 Nos
1. Indoor Environmental Quality (IEQ) primarily refers to: A. Structural stability of buildings B. Indoor environmental conditions affecting occupant health and comfort C. Building energy consumption levels D. External environmental impacts of buildings
2. Which of the following parameters is NOT considered a key component of Indoor Environmental Quality (IEQ)? A. Indoor air quality B. Thermal comfort C. Structural load capacity D. Acoustic comfort
3. Indoor air quality problems such as headaches, irritation, and fatigue experienced by occupants without a specific diagnosable illness are commonly referred to as: A. Building-related illness (BRI) B. Sick Building Syndrome (SBS) C. Occupational hazard syndrome D. Environmental fatigue disorder
4. As per ECSBC requirements, HVAC systems in buildings shall use air filters conforming to which standard for particulate matter control? A. ISO 9001 B. IS/ISO 16890 C. ISO 14001 D. IS 456
5. Elevated indoor carbon dioxide (CO_2) levels are primarily an indicator of: A. Excess lighting levels B. Poor acoustic insulation C. Inadequate ventilation D. High humidity levels
6. As per ENS requirements, enclosed parking areas must provide a minimum ventilation rate of: A. 3 air changes per hour B. 4 air changes per hour C. 6 air changes per hour D. 10 air changes per hour
7. Useful Daylight Illuminance (UDI) represents the percentage of occupied time during which daylight illuminance falls within which range?

A. 50 - 500 lux
B. 100 - 2000 lux
C. 200 - 5000 lux
D. 500 - 10000 lux

8. The Colour Rendering Index (CRI) of a light source indicates:
A. The energy consumption of the lighting system
B. The ability of a light source to accurately render colours
C. The brightness of the light source
D. The temperature of the light source

9. Thermal comfort, as defined by EN ISO 7730, refers to:
A. The temperature maintained inside buildings
B. A condition where HVAC operates efficiently
C. A state of mind expressing satisfaction with the thermal environment
D. The ability of buildings to maintain energy balance

10. Long-term exposure to continuous noise levels above approximately ___ dB can cause permanent hearing damage.
A. 60 dB
B. 75 dB
C. 85 dB
D. 100 dB

Section B: Short Answer Questions – 5 Nos

1. Define Indoor Environmental Quality (IEQ) and explain its importance in sustainable building design.

2. What are volatile organic compounds (VOCs), and how can their emissions be controlled in buildings?

3. Explain the concept of Useful Daylight Illuminance (UDI) and its role in improving visual comfort in buildings.

4. What are the main environmental and personal factors influencing thermal comfort?

5. Define acoustic comfort and mention two common sources of indoor noise in buildings.

Section C: Long Answer Questions – 2 Nos

Q1. Ventilation Requirement Calculation for Enclosed Parking, an enclosed basement parking area has the following characteristics:

Parking area = 1,200 m^2
Average ceiling height = 3 m

Assume the following:

ENS requirement: Minimum 6 air changes per hour (ACH) Air change formula:
Air change per hour = Q / V
Where:
Q = airflow rate (m^3/h)

V = volume of space (m^3)

Tasks

1. Calculate the total volume of the parking area.
2. Calculate the **minimum airflow rate required** to achieve 6 air changes per hour.

Explain why adequate ventilation in parking areas is critical for indoor air quality

Q2. Explain the major parameters of Indoor Environmental Quality (IEQ) and their role in improving occupant health and comfort in buildings.

Your answer should include discussion on:

- Indoor air quality and pollutant control
- Ventilation strategies and CO_2 management
- Daylighting and visual comfort
- Thermal comfort parameters and adaptive comfort approaches
- Acoustic comfort and noise control strategies

Discuss how these strategies contribute to healthier indoor environments and improved building performance.

Answer Key for MCQs

1. B	6. C
2. C	7. B
3. B	8. B
4. B	9. C
5. C	10. C

Recommended further reading from BEE:

- Energy Conservation & Sustainable Building Code 2024 (ECSBC 2024)
- Eco-Niwas Samhita (ENS) 2024
- Energy-Efficient Retrofit Manuals: Transforming Existing Buildings residential 4 climates
- Energy Efficiency Solutions for Existing Buildings Commercial 4 climates
- Energy Efficient Retrofit Manuals: Transforming Existing Buildings Commercial Cold Climate
- Energy conservation building code user guide

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