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Integrative design of the building envelope — General principles

Conception intégrée de l'enveloppe du bâtiment — Principes généraux

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Foreword

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This document was prepared by Technical Committee ISO/TC 205, *Building environment design*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The building envelope is either a boundary or a space, or both, separating the indoor and outdoor environments of a building. It is comprised of roofs, walls (above grade and under grade), windows, doors and foundation. Windows and other openings for daylighting and ventilation are deemed to be an interface between the indoor and outdoor environments. They transfer physical environment elements such as air, heat and cold, light, sound and water. A good building envelope secures high environmental performance in the building with low energy use as well as structural soundness and an aesthetically pleasing appearance.

The building envelope bears a direct relationship to the design and construction of the building. Designing the building envelope requires a wide range of considerations covering structural, environmental and aesthetic functions. A comprehensive approach is essential and achieved through an integrated design process for buildings. This document focuses on the environmental factors and provides design principles for the quality and energy-efficient building envelope.

The building envelope can also meet structural and safety requirements including earthquake protection, wind resistance, flood resistance, fire resistance, durability, maintainability and security. However, those requirements are out of the scope of this document, and can be found in other international standards, guides and reports.

Integrative design of the building envelope — General principles

1 Scope

This document provides an overview of the design principles for the building envelope in order to achieve a high quality and energy efficient built environment. The design principles include:

— thermal performance;

— daylight and visual environment;

— air quality;

— provisions of natural and mechanical ventilation;

— air barrier (airtightness);

— watertightness;

— moisture proof;

— soundproofing;

— sustainability and integration with technical building systems and controls.

This document is applicable to new buildings and the retrofit of existing buildings.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
building envelope
elements of a building as a boundary or barrier separating the interior volume of a building from the outside environment

[SOURCE: ISO 12569:2017, 3.5, modified — The words “elements of a building as a” have been added to the beginning of the definition.]

3.2
building envelope commissioning
BECx
process of enhancing the delivery of the design and construction of a building envelope by verifying and documenting the building envelope concepts, designs, materials, components, assemblies and systems that have been designed, installed and performance tested, and are maintainable, in accordance with the owner's project requirements

[SOURCE: ISO 21105-1:2019, 3.5, modified — The words "enclosure" and "OPR" have been replaced by "envelope" and "owner's project requirements" respectively.]

3.3
daylight sensing control
device that automatically regulates the power input to electric lighting near the fenestration to maintain the desired workplace illumination, thus taking advantage of direct or indirect sunlight

[SOURCE: ISO 16818:2008, 3.54]

3.4
design team
group of people who are responsible for building design

Note 1 to entry: The design team can consist of an architect, an interior designer, a lighting designer, a landscape designer, engineers in electrical engineering, illuminating engineering, HVAC systems, structural engineering and construction management and other specialists.

[SOURCE: ISO 19454:2019, 3.5]

3.5
heat island effect
phenomenon of elevated temperatures in urban and suburban areas compared to their outlying rural surroundings

Note 1 to entry: The temperatures can be influenced by various aspects, including the presence of denuded landscaping, impermeable surfaces, massive buildings, heat-generating vehicles and machines and pollutants.

[SOURCE: ISO 21929-1:2011, 3.14]

3.6
heat transfer coefficient
U-value
heat flow rate divided by the temperature difference between two environments

Note 1 to entry: Expressed in $W \cdot m^{-2} \cdot K^{-1}$.

3.7
HVAC system
system that provides heating, ventilation or air conditioning for buildings

[SOURCE: ISO 16814:2008, 3.18]

3.8
rooflight
daylight opening on the roof or on a horizontal or near horizontal area of a building

[SOURCE: ISO 16817:2017, 3.19, modified — The words "or near horizontal" have been added.]

3.9
solar heat gain coefficient
SHGC
ratio of the solar heat gain entering the space through the fenestration area to the incident solar radiation

Note 1 to entry: Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which is then reradiated, conducted or convected into the space.

[SOURCE: ISO 16818:2008, 3.216]

3.10
technical building system
technical component for heating, cooling, mechanical ventilation (filtration and exhaust), humidification, dehumidification, domestic hot water, water supply, drainage and sanitary equipment, lighting, building automation and control, and electricity production on site

Note 1 to entry: A technical building system can refer to one or to several building services (e.g., heating, cooling, lighting and domestic hot water).

Note 2 to entry: Lifts and fire extinguishing systems can be included in technical building systems.

Note 3 to entry: A technical building system is composed of different sub-systems.

Note 4 to entry: Electricity production can include cogeneration, wind power and photovoltaic systems.

[SOURCE: ISO 16813:2024, modified — The words “on site” have been added.]

3.11
thermal mass
materials with mass heat capacity storing or releasing heat as the interior or exterior temperature, or both, convective and radiant conditions fluctuate, and affecting building thermal load

Note 1 to entry: Expressed in $J \cdot K^{-1}$.

3.12
thermal resistance
R-value
ratio of the temperature difference between the two faces of a material to the rate of flow of heat unit area normal to the faces

Note 1 to entry: Expressed in $m^2 \cdot K \cdot W^{-1}$.

3.13
ventilation rate
magnitude of air flow to a room or building through the ventilation system, device or building elements

Note 1 to entry: Expressed in h^{-1}.

3.14
window-to-wall ratio
WWR
ratio of the net glazing area to the gross exterior wall area above the ground

[SOURCE: ISO 16818:2008, 3.249, modified — The word “fenestration” has been replaced with “net glazing” and the words “above the ground” have been added.]

4 Design philosophy and principles for the building envelope

4.1 General

Both the client and the designer can have a philosophy and set ethics concerning building environment in general terms. They can also rely on ideas related to architectural and environmental design. Philosophy and ethics are a base on which the target level of each environmental element is determined and the design strategies are planned. A building is evaluated from different aspects. Clients and designers can wish to decide which aspect is crucial or less critical on the basis of their own philosophy and ethics. This consideration is possible, provided it does not violate the environment design criteria. Philosophy and ethics relate to the aspects which are determined on more than the others. The theories also encourage a designer to employ a particular design strategy and work as the rationale on which the behaviours and functions of a building from its structure are based.

This document introduces Gero's theory in design[9] and expands it. Four classes of variables can be defined to describe different aspects in designing buildings as follows:

— function (F) variables that describe the teleology of the object, i.e. for what it is;

— behaviour (B) variables that describe the attributes that are derived or expected to be derived from the structure (S) variables of the object, i.e. what it does;

— structure (S) variables that describe the components of the object and their relationships, i.e. what it is;

— experience (E) variables that describe the interaction between the object and users, i.e. how it is utilized.

The notion of function (F) refers to the teleological characteristics of an artefact. The purpose of designing is to transform function (F; where is a set) into a design description of structure (S) in a such a way that the artefact being described is capable of producing the functions. The design description is expressed and documented in the form of drawings and notes.

The notion of behaviour (B) refers to the characteristics of an artefact or mechanisms of an artefact that are deterministically derived or expected to be derived from the structure (S) of the artefact and that articulate the functions (F) of the artefact. The physical properties of an artefact are classified into behaviour (B).

The notion of structure (S) refers to the substantial characteristics of an artefact that can be determined directly in designing. The structure (S) represents an artefact's elements and their relationships, and determines the behaviours of the artefact.

The notion of experience (E) refers to the interactive characteristics between an artefact and users. Humans build connections between the function (F), behaviour (B) and structure (S) through experience (E) and development of causal models based on interactions with an artefact.

For example, consider designing a library. One of the objectives of a library is to provide a built environment where occupants can read books comfortably. This objective can be expressed in terms of functions of the library, that is, visual performance, visual comfort and visual safety. The functions are articulated in terms of values of behavioural variables such as luminance, illuminance and colour temperature of light. The structural variables – form and materials – are determined to meet the requirements of the above variables.

Since the structure of a building envelope can enhance the behaviour of a certain environmental element and detract from the behaviour of another environmental element, to design a building envelope is to solve a multi-objective optimization problem. However, the problem definition is not so easy in the sense that the formulation of its evaluation function depends on the requirements for the building envelope. The requirements are co-defined by the clients, architects, engineers and other specialists involved in the design.

Each of the diverse functions of a building can be articulated as a combination of the behaviours of certain environmental elements. The behaviour of each environmental element is affected by the structure of the building environment. Therefore, the relationship between the structure and the behaviour of each environmental element is meant to be clarified prior to designing the building envelope.

4.2 One thing increases, another decreases

Philosophy 1: There are trade-offs between function variables in a project definition, and more than one optimum solution exist. There is no logical method to select an optimum solution.

Principle 1: A design team determines what is crucial and what is less crucial among the function variables.

4.3 One structure variable relates to several function and behaviour variables

Philosophy 2: A structure variable determines behaviour variables. For example, the dimensions of a window determine how deeply daylight enters a room and how much heat transfers through the window.

Principle 2: Experts in different fields are involved in designing a component of the building envelope.

4.4 Appropriate balance among the behaviours of environmental elements

Philosophy 3: An appropriate balance among the behaviours of the environmental elements is maintained during a lifetime of a building, especially post-occupancy.

Principle 3: A plan of operations of the building envelope is taken into consideration in order to maintain the balance among the behaviours of the environmental elements.

5 Functions of the building envelope

5.1 General

The building envelope physically separates conditioned indoor spaces from the unconditioned outdoor environment. However, it concurrently introduces useful elements of the outdoor environment into the indoor environment selectively. The fundamental role of the building envelope is to make enclosed spaces that are safe, comfortable and healthy. Functions of the building envelope can be classified into the following three categories:

— structural robustness and safety;

— environmental quality and energy efficiency;

— aesthetically pleasing property.

The building envelope provides structural support against external and internal loads and forces. It controls the exchange of physical environment elements such as water, air, heat, light, sound and electronic waves between the indoor and outdoor environments. Systems of the building envelope can enhance energy efficiency of the building and reduce environmental burdens. Since the design of the building envelope has a big impact on the external appearance of the building, the building envelope has symbolic and social value. Building envelopes contribute to town and street landscapes. The building envelope design reflects the period. A good building envelope enhances the economic value of the building. A building envelope with an impression of character or dignity or class can be a reflection of higher status of the occupants.[10]

Daylight openings in the building envelope have an important function of providing views out and information on the outdoor environment including the weather and time changes. Openable windows and rooflights also serve as ventilation. In addition, daylight openings practically function as emergency egress or aid in identifying one's location in the building in case of emergency.

Façade systems with photovoltaic (PV) modules, often called building integrated photovoltaics (BIPV), can generate electricity. There are a variety of PV façade systems, e.g. PV cladding, curtain walls, spandrels, PV tiles, PV glazing, exterior PV blinds or PV louvers.

A part of the building envelope can function as a sensor for outdoor environmental conditions. Outdoor sensing or monitoring is utilized to control technical building systems such as daylight-responsive lighting controls.

5.2 Flexibility

In designing a sustainable building, an important consideration is to secure the functional flexibility of the building, i.e. the ability to adapt to individual user requirements, changes in user requirements, technical changes or changes in use of some areas[7]. The design team is expected to consider the asset value over time. It includes maintainability, flexibility and adaptability of the building to keep its economic performance high in changing market conditions or in response to changes in user requirements. It also includes minimizing obsolescence of the design and technical building systems. A well-designed building envelope guarantees adaptability.

However, replacement of envelope components is extremely difficult for some types of building when attaching importance to the strength and durability. A long-term perspective is essential for design. The design team needs to consider the design on the premise that a major part of the building envelope is unalterable.

5.3 Adaptability

Adaptability for different uses is an important factor of the sustainable building. Buildings are subject to changes in use during their long service life. It is desirable to consider a certain range of versatility, convertibility and expandability in designing the building envelope as well as the building. Some parts are removed or upgraded without adverse effects on the performance of the other parts. ISO 20887 provides an overview of design for disassembly and adaptability principles and potential strategies for integrating those principles into the design process for all types of building. ISO 20887 includes requirements that are mandatory for implementation of specific principles.

Another perspective, i.e. adaptability to climate change, is also an important consideration.

5.4 Reusability

Reusability of building elements and materials is an important factor of the sustainable building. The notion of reusability is defined in ISO 20887 as ability of a material, product, component, or system to be used in its original form more than once and maintain its value and functional qualities during recovery to accommodate reapplication for the same or any purpose. Some building elements and materials are replaced to meet the new requirements for buildings. It is preferable for the sustainable building to reuse both removed ones and replacing ones.

6 Structure of the building envelope

6.1 General

The performance of the indoor environment depends on the construction, materials and assembly of the building envelope. Major components of the building envelope are as follows:

— roof system;

— wall system above the ground (above grade);

— windows, rooflights, doors and other openings;

— wall system underground (below grade);

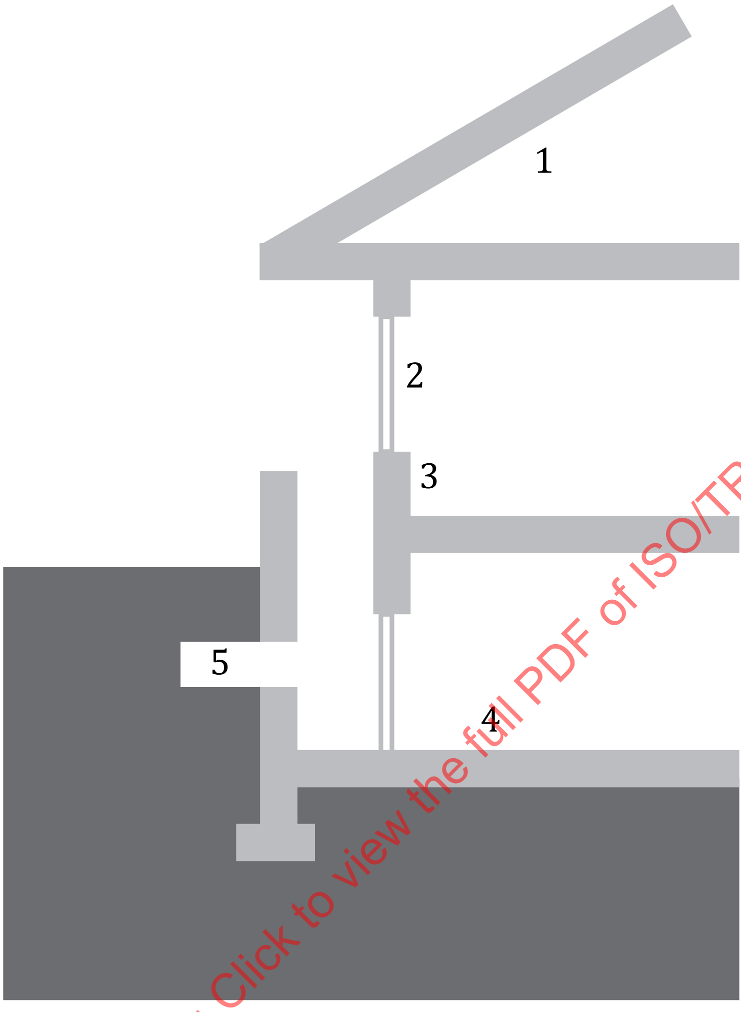
— base floor system.

Figure 1 shows basic components of the building envelope.

Masonry construction is available with different materials such as stone, brick and concrete. The thermal performance of masonry walls differs depending on the materials and composition. The dimensions of openings are determined by masonry units and, in general, the opening area is comparatively small. Box-frame construction with concrete also limits the opening area in the walls but can have wide openings on non-bearing sides.

Framed construction is available with different materials and methods such as wood, steel, reinforced concrete, steel reinforced concrete and concrete filled steel tube. It allows a large opening within a frame making up the roof and façades. The thermal performance depends on materials infilling the frames. However, the framed construction can separate the outer envelope from the load-bearing structure.

The structure of a building is selected according to, for example, conditions of the site and ground, the building scale and form, the construction period, or the budget. Prerequisites, constraints and requirements for a project define the building design and influence the structure of the building.



Key

1 roof system
2 windows, doors, other openings
3 wall system above the ground
4 base floor system
5 wall system underground

Figure 1 — Basic components of the building envelope

6.2 Roof system

Roof systems are roughly classified into three types, i.e. flat roofing, low-slope roofing and steep-slope roofing. The slope or pitch of a roof is a critical factor in making decisions on the roof system. Typical styles of roof are as follows:

— A-frame roof;

— butterfly roof;

— flat roof or deck roof;

— gable roof;

— gambrel roof;

— hip roof;

— mansard roof;

— M-shaped roof or double pitched roof;

— parapet roof;

— pyramid hip roof;

— saltbox roof;

— shed roof;

— winged gable roof.

Roof materials include asphalt shingles, slate shingles, wood shake, metal, tile, membrane and thatched roofing materials. Protection against rain and snow is the most fundamental requirement for the building envelope. Flat roofs contain a slope. Moisture proofing is also essential.

Since roofs receive solar radiation directly, thermal insulation is important to prevent rooms at the top from being heated up, especially in hot climates. Cool roofs (sometimes called reflective roofs) are a roof system that reflects more sunlight and absorbs less heat than standard designed roofs. They are made of a highly reflective paint, a sheet covering, or highly reflective tiles or shingles. They function to decrease roof temperatures, reduce cooling loads and improve indoor comfort for spaces that are not air conditioned. Green roofs (also known as "vegetated roofs") are a roof system that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane. They function as absorbing rainwater, providing insulation, creating a habitat for wildlife, providing a more aesthetically pleasing landscape and helping to lower urban air temperatures and to mitigate the heat island effect.

The roof can have rooflights. Rooflights can illuminate interiors as top lighting such as luminaires on the ceiling. Depending on the number and arrangement of rooflights, rooflights can illuminate a room relatively uniformly. A luminous ceiling system can be constructed in combination with rooflights. It gives diffused daylight evenly within a room.

6.3 Wall system above the ground

The wall system consists of components that fulfil the support, control and finish function of the building envelope. Typical components of the walls above the ground (above grade) are:

— exterior cladding;

— exterior sheathing membrane;

— exterior sheathing;

— insulation;

— structural components;

— vapour retarder;

— interior sheathing.

Daylight openings and other openings are an interface between the indoor and outdoor environments. They bring information on the external world into a building by the medium of environmental elements such as heat, light and sound. People perceive changes in time, weather and surrounding circumstances through daylight openings. Walls often have architectural shading or attachments such as eaves, awnings, fins, overhangs, balconies or recesses. Ventilation openings provide fresh air inside and remove pollutants outside.

Providing daylight openings in the building envelope means creating holes for the masonry construction in building design, whereas it means saving openings for the framed construction. Maximum dimensions of the windows are structurally limited for the masonry construction, but, by contrast, a minimum requirement for the dimensions is considered for the framed construction.

Windows are a key component of the building envelope. Their dimensions, positions and structure have a direct impact on the façade impression and attractiveness as well as the indoor environmental conditions.

Exterior doors are comparatively large openings in the building envelope. Windbreak rooms are often provided as means to buffer the wind, rain, and heat or cold. Common types of exterior doors are:

— swing doors;

— revolving doors;

— sliding doors;

— industrial doors or overhead doors.

Glazing is a major component in the wall system. It is used in windows and doors, and even makes up walls. Pre-glazed windows, doors and wall components have advantages of maintaining quality control, faster installation, and simplified fabrication.

Curtain walls are an exterior wall system that does not support loads other than its own weight. Curtain walls are attached to the building structure. Seismic and wind forces on a curtain wall are transferred to the supporting structure of the building. A curtain wall usually consists of aluminium-framed wall and infills of glass, metal panels or thin stone. Extruded aluminium is typically used for the framing members. They are effective in daylighting. However, control of solar heat gain is difficult when using a large amount of glass infill. ISO 12631 specifies a method for calculating the thermal transmittance of curtain walls consisting of either glazed or opaque panels, or both, fitted in, or connected to, frames.

Double-skin façades are a system of building consisting of two skins placed in such a way that air flows in the intermediate cavity. The distance of the intermediate cavity ranges from 0,2 m up to 2 m in many instances. It is typically about 0,6 m. Some façades have a shallow cavity less than 0,2 m. However, shallow double skins must have special control of airflow in the intermediate cavity to achieve the expected performance.

A variation of the double-skin façade is a double envelope system that consists of an outer glazed enclosure and an inner semi-enclosed wall. The inner wall can exhibit the building framework to the outside.

Atria enclosed by glazed walls act as either a thermal buffer space or a light well, or both.

Reflectance of glass is no small matter. Since the amount of sunlight is enormous, even reflected sunlight from a glass façade is intense. Reflected sunlight often causes glare or visual annoyance to people walking or driving a car on neighbouring streets. Its direction changes with time. A concave glass façade focuses the reflected sunlight and will possibly cause melting or ignition of objects in focus.

6.4 Wall system underground

The wall system underground (below grade) is subjected to different forces and loads. The underground walls support the following functional requirements:

— structural stability;

— water protection;

— moisture protection;

— durability;

— insulation.

The underground walls can be a cast-in-place concrete or reinforced masonry. Durability of design and materials is mandatory for the underground enclosure systems. The underground walls are subjected to high pressure from the ground. They must resist lateral loads to maintain the stability of the wall. The underground walls are braced or constructed robustly enough to cope with the stresses involved.

Moisture influences durability of the underground walls. Underground walls are waterproofed and moisture-proofed. In order to exclude moisture, the following can be considered:

— use materials with low porosity;

— provide water proofing membranes or moisture proofing;

— provide proper water drainage systems.

Porous materials absorb moisture from the ground and expand on freezing, causing spalling and friability of the material. Non-porous materials do not transfer moisture through capillarity. Insulation to the underground walls helps to reduce the expansion and contraction that occur in the wall membranes. It also reduces the potential for cracking and helps in terms of durability of the wall membranes.

6.5 Base floor system

Base floors are subjected to under-surface loads from ground and water table pressure. Environmentally, they are subjected to thermal and moisture problems, insects and soil gas from the outside. The base floor can be a cast-in-place concrete slab with considerations for structural support and environmental control. Underground slabs are often a source of water leakage with slab cracking of concrete materials. In order to prevent it, a layer of gravel is provided beneath the slab covered by a vapour retarder.

7 Behaviour of the building envelope

7.1 General

The building envelope can be either tight or loose. A tight envelope restricts air flow between the indoor and outdoor environments. A loose envelope allows it. Traditional buildings are vernacular and follow the local climate, culture and materials available. For example, well-insulated buildings have been made in cold regions. In contrast, well-ventilated airy buildings have been made in humid regions. Modern technology offers more options of construction with technical buildings systems.

Passive building design maximizes the use of natural energy sources for heating, cooling, lighting and ventilation to make interiors comfortable without mechanical or electrical building systems. It includes considerations of the location, surrounding environment, orientation, massing, form of the building, room layout, material selection, shading, insulation, thermal mass and positioning of openings.

Active building design means use of technical building systems. Use of PV panels is included. Buildings generally take both passive and active measures. The building envelope is a crucial component for successful passive design.

7.2 Thermal performance

Heat transfer through a building envelope is a combination of heat conduction, heat radiation, heat convection, and moisture movement and its phase change. The U-value referred to as heat transfer coefficients measures how effective elements of a building envelope are as insulators, i.e. how effectively they prevent heat from transmitting between the inside and the outside of a building. The R-value measures thermal resistance and is often expressed as the reciprocal of the U-value.

The lower the U-value of an element of a building envelope, the less heat transmits through it. Lower U-values mean better thermal insulation performance. Countries can have recommendations or regulations on the U-value for specific building types. Thermal insulation means separating the indoor temperature from the outdoor temperature. This leads to reduced heating loads in cold climates and, in many cases, reduced cooling loads in hot climates.

Thermal capacity describes the ability of a material to store heat. Thermal mass that has higher heat capacity can be used to store heat gains by solar radiation and then release it when external conditions are cooler. For example, concrete floor slabs can be used to absorb heat gains during the day and to release them during the night. Types of thermal mass include water, rock, earth, brick, concrete, fibrous cement and ceramic tile. Masonry and concrete have a high heat capacity, a high density and moderate thermal conductivity. Heat moves between the surface of the material and its interior at a rate that roughly matches the building's daily heating and cooling cycle. The thermal capacity of wood is relatively low, even though its thermal conductivity is relatively low. Therefore, it is unsuitable for thermal mass.

Factors of the exterior environment that influence heat transfer through the building envelope are:

— temperature of the ground, air or snow with which the building is in contact;

— direct and indirect solar radiation incident on the building;

— cloud amount;

— direction and speed of winds blowing on the building which affect convective heat transfer from the surface of the building envelope, ventilation, and infiltration;

— rain, snow, and other forms of precipitation;

— relative humidity levels in the air.

Building shape influences heat loss and gain of a building. Surface area to volume (S/V) ratio is an important factor for the environmental performance of a building. The larger the surface area, the greater the potential heat gain or loss through it. In order to minimize heat transfer through the building envelope, a compact shape is desirable.

Solar heat gain coefficient (SHGC) is the fraction of solar radiation admitted through a window, door or rooflight. The SHGC is expressed as a number between 0 and 1. The lower the SHGC of a window, the less solar heat it transmits and the greater its shading ability. A product with a high SHGC is more effective at collecting solar heat during the winter. A product with a low SHGC is more effective at reducing cooling loads during the summer. How to best balance solar heat gain with an appropriate SHGC depends on, for example the climate, orientation, shading conditions.

The SHGC is rated for the whole window including effects of the frame or alternatively, for the centre of glazing. The centre-of-glazing SHGC shows the effect of the glazing alone. ISO 19467 specifies a method to measure the SHGC of complete windows and doors. ISO 19467-2 specifies a method to measure the SHGC for the centre of glazing in fenestration systems, i.e. windows, doors or curtain walls with or without shading devices.

7.3 Daylight and visual information

Daylight performance for illumination first depends on how much skylight enters the interior through daylight openings. Sunlight also affects the indoor environment depending on the window orientation. Although sunlight can cause an unwanted glare for visual tasks and excessive heat, it is fundamental to health in terms of the biological effects of light. Bright daylight in the morning is essential for resetting human circadian rhythms. Exposure to bright daylight during winter months helps in maintaining a positive mood. To ensure a comfortable visual environment, control of glare from direct sunlight is a consideration in window design.

The amount of indoor daylight depends on the dimensions and the position of the daylight opening. The potential of windows can be first assessed with the window-to-wall ratio (WWR). A 0,3 WWR to 0,4 WWR is considered good.[15] As an estimation, a moderately strip-glazed building has a 0,35 WWR. It is 0,5 WWR for larger windows or curtain walls, and 0,25 WWR for smaller punched windows. Outdoor obstructions that block daylight influence daylight availability in interiors. In urban areas where buildings are densely built, it is difficult to obtain sufficient daylight if the windows cannot see the sky. A detailed daylight analysis is necessary to properly predict daylight availability.

Light flows in a room almost horizontally from a window, whereas it flows vertically from a rooflight. In general, rooflights potentially introduce more daylight into a room than windows of the same dimensions when a reference plane is horizontal. The depth of a daylight effective zone from a window wall is 1,5 to 2 times the window head height. It can be found from calculations of the configuration factor of the window. For unilateral daylighting, the daylight effective area from the window wall is determined by the ceiling height even if the whole window wall is open with no obstruction outside the window.

Visual information through daylight openings gives building users a sense of contact with the external world and environmental changes. The visual information is primarily recognized as views out from the inside. View quality is a key element in designing a building and its daylight openings. However, any sight of the outside environment is useful. The visual information through daylight openings functions as a cue for identifying the location of oneself in the building and for finding the way around.

Wide and deep views of scenes including nature are preferred in general.[16] EN 17037 on daylighting gives information on how to assess the outside view. View availability at a reference point in a room is first determined by the size and number of daylight openings. View quality depends on the horizontal view angle, the outside distance of view and encompassed elements such as the sky and vegetation. The surroundings of a building can be a constraint condition for the view quality, especially in dense urban areas.

Transparency of windows gives an opposing function, i.e. views from the outside in, which is often disliked for privacy or security concerns. In emergencies, inside views can be helpful for rescuers. Curtains, blinds, screens or shutters can be attached to windows to adjust the visibility. Even if users keep curtains or blinds always closed, it does not mean that windowless rooms are preferred.[16]

Visible transmittance of glazing determines daylight performance. It is an important behaviour variable regarding daylighting. The range of 0,4 to 0,7 is moderate.[15] Glazing with a high visible transmittance looks clear. However, it can cause glare in some circumstances. Special glazing is capable of changing visible transmittance between clear and tinted states. Ceramic printing on glass enables light transmittance distribution of a sheet of glass depending on printed patterns.

Window glass hardly transmits ultraviolet B radiation (UV-B) but transmits UV-A. Although it is not as severe as outdoors, even indoors, UV-A through the windows causes discoloration and fading over a long period of time. In particular, flooring, wallpaper, and furniture in areas exposed to sunlight are subject to deterioration. One option to avoid this problem is to choose window glass that does not transmit much ultraviolet radiation, such as laminated glass.

7.4 Ventilation

Ventilation is indispensable to maintain acceptable indoor air quality. Use of natural ventilation is very common for good hygiene in a room. Well air-conditioned buildings with fixed windows have increased in urban areas. However, several infectious outbreaks and natural disasters demonstrated the importance of natural ventilation to prevent infection, to keep the hygienic environment in shelters or to continue business in offices after a natural disaster.

Natural ventilation is driven by pressure differences to move air through a building. Pressure differences are caused by the wind force or buoyancy force made by temperature differences (stack ventilation) or humidity differences (cool tower ventilation). Stack ventilation is effective when the outdoor temperature is lower than the indoor temperature, especially in winter. Cool tower ventilation is effective only in places where outdoor humidity is very low.

The amount of natural ventilation is determined by a balance between the ventilatory drive and pressure loss. It depends on the size and placement of openings in the building. Considerations in planning natural ventilation are:

- climate characteristics;
- conditions of location;
- compatibility with the building plan, including floor and sectional plans;
- unity with the façade plan;

- specifications of air vents and prevention of drafts in rooms;
- noise control measures;
- performance of air vents, such as airtightness, watertightness, wind pressure resistance and controllability;
- prevention of moisture and condensation on routes of natural ventilation.

ISO 16814 specifies methods of expressing the indoor air quality for human occupancy. ISO 16814 intends to allow several acceptable target levels of the indoor air quality depending on local requirements, constraints and expectations. The document covers commercial and institutional buildings but not residential buildings, industrial buildings and hospitals. National codes, standards or regulations can specify minimum ventilation rates and other requirements to minimize adverse health effects.

7.5 Sound proofing

Sound insulation is an ability of the building envelope to reduce the sound that goes through it. It is measured in terms of sound transmission. The performance of sound proofing is given in a single unit number that expresses effectiveness in limiting sound transmission. The single unit number is a summary of the sound insulation performance of a material over a range of frequencies. Requirements for preventing sound transmission through building elements are given in national building codes or regulations.

There are two types of sound transmission in buildings:

- airborne;
- impact.

The building envelope limits noise from outside of the building. Wall materials and assembly influence sound transmission. Windows and other openings in the building envelope can be a source of airborne noise. Sound insulation is relevant to airtightness of the building envelope. Double glazing is slightly better than single glazing for sound insulation.

7.6 Airtightness

Airtightness is defined as the resistance of the building envelope to inward or outward air leakage. The air leakage is driven by differential air pressures across the building envelope. Airtightness is effective in reducing a heating load in winter and a cooling load in summer due to less heat loss. It also reduces drafts. An airtight building envelope can enhance the overall energy efficiency of the building. But an appropriate ventilation system is necessary to ensure that enough fresh air comes into the building and that excessive moisture and particulate matter are discharged to the outside.

The performance is measured by air leakage rates. The air leakage rate is an airflow rate per hour through the building envelope at a given reference pressure (usually 50 $N \cdot m^{-2}$) divided by the heated building volume or the envelope area or the floor area. Lower air leakage rates mean better airtightness. Most European countries require or recommend minimum airtightness levels in their regulations. In the United States, the International Energy Conservation Code (IECC) sets air leakage requirements for all new construction and additions according to the climate zones.[18]

7.7 Moisture protection

Moisture gets into buildings in various ways. Rainwater can penetrate through gaps, cracks, or poorly sealed joints in cladding. Water can be drawn into porous materials like masonry by capillary action. Water vapour can move through materials due to differences in vapour pressure from high humidity to low humidity. When warm, moist air comes into contact with a cold surface, condensation forms, and moisture accumulates. Condensation also forms inside walls. Airtight building envelopes block unwanted moisture penetration from the outside and reduce the chances of mould and rot. Excessive moisture produced in interiors needs to be exhausted by some appropriate ventilation system.

Effective moisture management strategies can avoid damages caused by vapor condensation. To prevent condensation in interiors, a moisture-proof membrane is placed between the interior material and insulating layer, and an air layer is made between the exterior wall and insulating layer.

7.8 Sustainability and integration with technical building systems

Floor area growth accompanied by population and economic growth inevitably increases global building energy use.[19, 20] The current growth is strong enough to negate improvements in building envelopes and systems. Further building envelope measures are required to offset the influences. Promising measures are improvements in windows and insulation.[21] Retrofitting existing buildings is a key issue. Many existing buildings have single glazed windows with insufficient thermal performance. Motivational strategies are needed along with research and development for highly insulated window technologies.

An International Energy Agency (IEA) report on sustainable buildings lists building envelope technologies based on economy, climate and construction type (new or retrofit).[22] The main considerations in hot climates are windows with low SHGCs, reflective wall/roof coatings and architectural shading. Considerations in cold climates are, for new construction, highly insulated windows and passive heating gain, and for retrofit, low-E storm panels and window films, insulated shades and other attachments, and exterior insulating wall systems.

Sustainable envelope design supports building sustainability. The base of the environmental performance and energy efficiency can be obtained by the passive design approach. An active design approach can enhance the base performance. Passive designs closely relate to the size and costs of HVAC systems as well as energy use. In addition to adopting appropriate building equipment, the active design approach includes use of renewable energy technologies integrated with the building envelope for energy efficiency. Examples are PV systems for solar electric generation, solar water heater and solar powered ventilation and heating.

The sustainable building envelope is realized when each element is appropriately designed with proper materials and composition and when all the elements are properly assembled. Integration of the building envelope with HVAC and lighting systems has a crucial role during the operation phase of a building. A typical example is integration of a façade system and the daylight sensing control for office buildings. LED lights enable power saving in electric lighting in comparison with prior discharge lamps. Lighting performance is optimized with controls both of daylight and electric light while minimizing heating and cooling loads. LED lights that radiate less heat and tend to slightly increase the heating load in comparison with discharge lamps. Another example is integration of operable windows and HVAC systems. Operable windows allow natural ventilation. Users can open a window when the mechanical HVAC systems are not operating. An option is available to provide HVAC systems with window status feedback. It automatically switches off local HVAC components when windows are open.

Building operation as well as construction has a significantly negative impact on the environment, for example in terms of consumption of resources and energy, greenhouse gas emission and waste generation. Proper controls and commissioning of technical building systems can mitigate this. Investment in better building envelopes will allow for greater economic efficiency by reducing costs associated with space heating and cooling systems.[23]

8 Relationship, synergies and trade-offs

The building envelope is the boundary between the indoor and outdoor environments. Conditions of the boundary determine not only one environmental performance but synergies and trade-offs between different environmental performances.

Large windows and rooflights allow daylight into a room, provide wide views out and if operable, are good for ventilation. Daylighting can reduce energy use for electric lighting with proper lighting controls. Since daylight accompanies solar heat, daylight openings on the sunny side contribute to passive heating in the cold season. However, they increase cooling needs in warm circumstances and can cause overheating without proper shading or sun control. Windows with poor insulation take heat away from warm interiors and let in the cold, especially in the cold season. It will lead to an increase in heating load. Poorly insulated or large windows also tend to cause radiative heat loss from human skin to cold window surfaces or create cold drafts, and consequently deteriorate the indoor thermal environment.