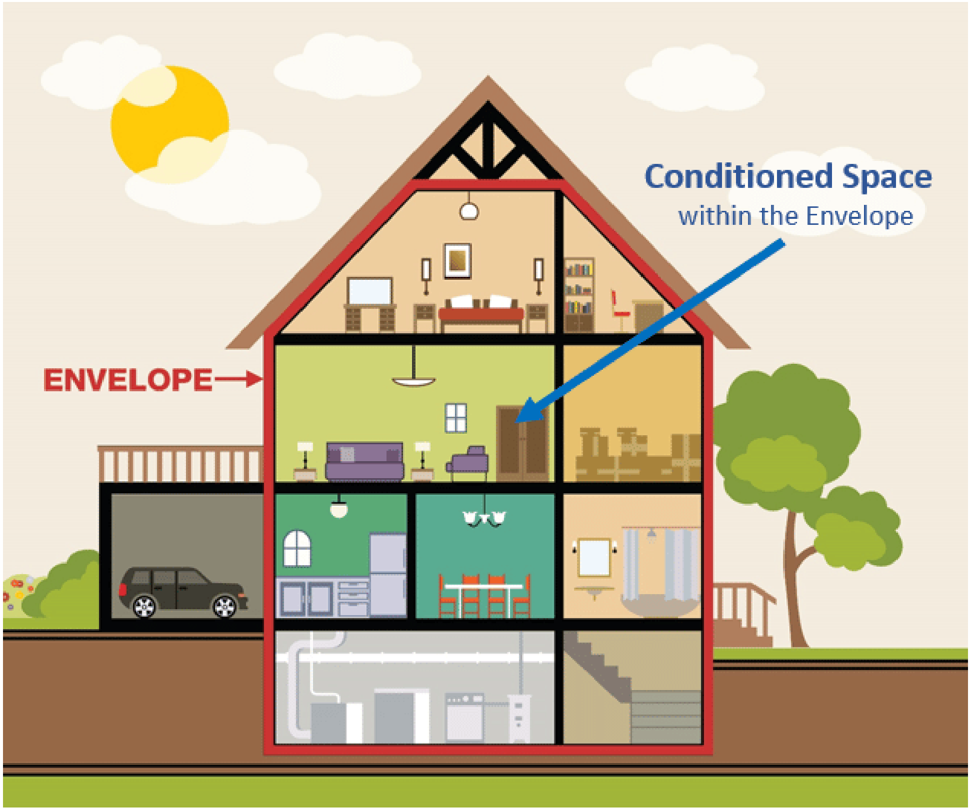
Erasmus+ Project ID: 2023-1-ES01-KA220-HED-000156652

This Erasmus+ Project has been funded with support from the European Commission. This publication reflects the views only of the authors, and the European Commission and Erasmus+ National Agencies cannot be held responsible for any use which may be made of the information contained therein

BIM4Energy Project

Title: Properties and behaviour of the building thermal envelope



Summary

1 – Aims

The main aim of this tutorial is to show what the thermal envelope of a building is and how it works in the task of maintaining comfort in the interior spaces of the building. The primary objectives of such a tutorial typically include:

The objectives of this tutorial about the building thermal envelope are as follows:

- Knowledge of the definition of thermal envelope of buildings.
- Knowling the elements of thermal envelope of buildings and how they work.
- Knowing examples of various types of facades, party walls, roofs-
- Understanding the different mechanics of Heat transfer through the thermal envelope: conduction; convection; radiation
- Knowing the different materials used in the thermal insulation layer of an element of a building's thermal envelope.
- Understanding the thermal properties of walls (transmittance and thermal inertia)
- Understanding the thermal properties of windows (solar factor, transmittance, light transmission).
- Knowing the technical requirements of energy saving standards in buildings on the thermal envelope.

2 - Learning methodology

The teacher will give an explanation about the thermal envelope of a building of about 30 minutes.

Students will read this tutorial and follow the steps shown in the tutorial, namely:

- The building envelope
- Common types of facades, walls and roofs
- Heat transfer through the thermal envelope
- Thermal conductivity and insulation products for buildings
- Thermal properties of a wall
- Thermal properties of windows
- Thermal Envelope Code Requirements

In order to evaluate the success of the application, a questionnaire will be held for the students.

3 - Tutorial duration

The implementation described in this tutorial will be carried out through the BIM4ENERGY Project website by self-learning.

3 lesson hours are suitable for this training.

4 – Necessary teaching recourses

Computer room with PCs with internet access.

Required software: Microsoft Office.

5 – Contents & tutorial

5.1 – The building envelope

The **building thermal envelope** (also referred to as the heat-flow control layer) comprises those elements of a building—such as basement walls, exterior walls, floors, roofs, insulation layers, windows, doors, air and vapor barriers—that separate the conditioned interior space from unconditioned or outdoor environments and control heat, air, and moisture transfer [1].

Another definition:

The term "**building thermal envelope" is defined as being "the basement walls, exterior walls, floor, roof and any other building elements that enclose conditioned spaces**." This boundary also includes the boundary between conditioned space or provides a boundary between conditioned space and exempt or unconditioned space.

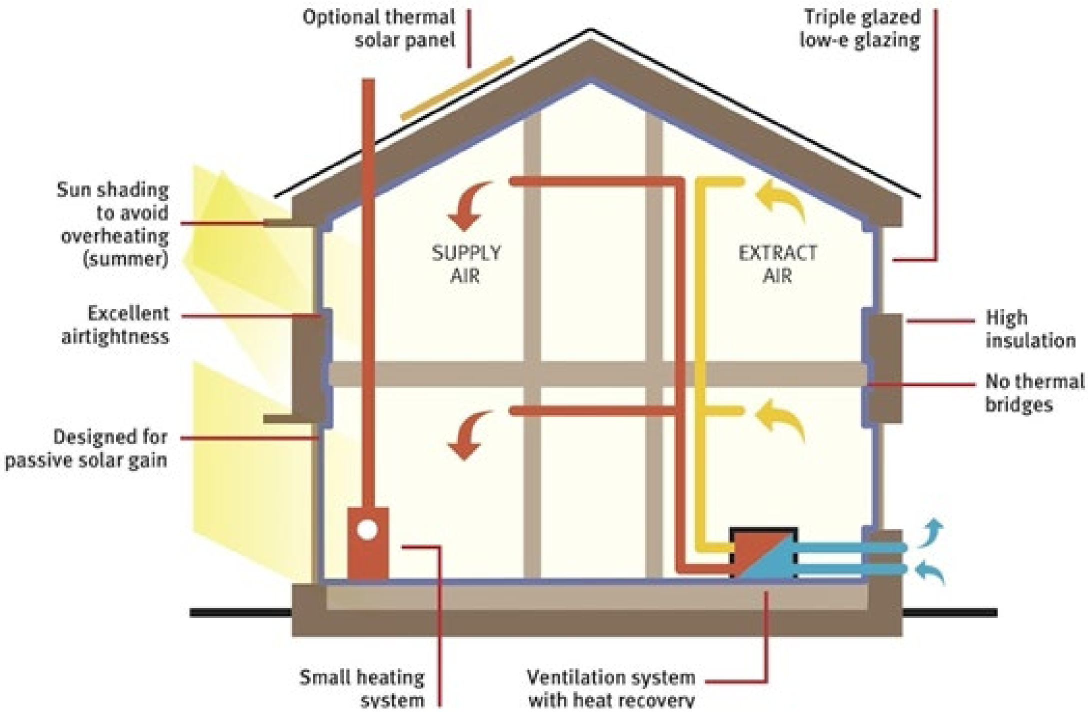
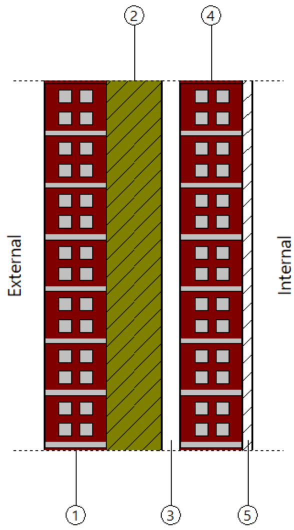


Figure 1. Building thermal envelope

5.2– Common types of facades, walls and roofs

5.2.1 Facade type I: Facade with double brick wall

A double brick wall façade consists of two separate layers of masonry—an outer and an inner brick wall—separated by a cavity that typically includes both an air gap and a layer of thermal insulation. The insulation layer, placed against either the inner or outer wall, reduces heat transfer through conduction, helping to maintain a stable indoor temperature and improve energy efficiency. The air cavity acts as a buffer zone, limiting moisture penetration and allowing any water that infiltrates the outer wall to drain or evaporate. This combination of materials and layers provides excellent thermal and acoustic performance, while also enhancing the durability and weather resistance of the building envelope.



Layers
1 - M01 - 100 mm brick: 10.16 cm
2 - I04 - 89 mm batt insulation: 8.94 cm
3 - F04 - Wall air space resistance: 3.00 cm
4 - M01 - 100 mm brick: 10.16 cm
5 - G01 - 16 mm gyp board: 1.59 cm
Total thickness: 33.85 cm
Thermal description
Heat transfer coefficient (U): 0.39 W/(m²·K)
Thermal capacity: 51975.29 J/m²·K

Figure 2: Facade with double brick wall

5.2.2 Facade type II: Ventilated Facade

A ventilated façade with an outer skin of limestone panels functions as a high-performance building envelope system that enhances thermal regulation and moisture control. The exterior limestone cladding acts as a protective and aesthetic skin, shielding the structure from direct weather exposure. Behind it, a ventilated air cavity allows for continuous airflow, which helps remove moisture, reduces thermal bridging, and prevents heat buildup in warmer climates. Inside the cavity, a layer of thermal insulation minimizes heat transfer between the building's interior and the external environment, improving energy efficiency. The interior structure consists of a brick wall that provides mechanical support and structural integrity, followed by an interior finish layer that completes the building's inner envelope. This multi-layered system offers excellent durability, thermal comfort, and protection against environmental elements.

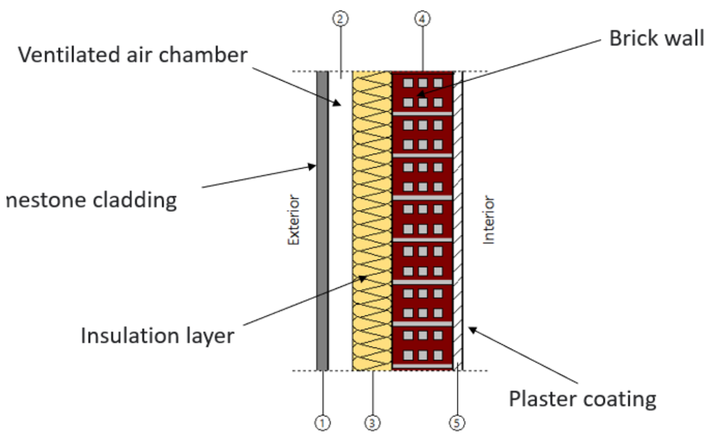


Figure 3: Ventilated facade

5.2.3 Facade type III: Facade with timber wall

This façade system features a massive timber structure using Cross-Laminated Timber (CLT) wall boards, which serve as both the primary structural and load-bearing elements. On the exterior side of the CLT wall, a layer of mineral wool insulation is installed, providing excellent thermal and acoustic performance while maintaining vapor permeability to avoid moisture issues. Wooden battens are fixed within the insulation layer, serving as intermediate structural elements that create a ventilated cavity and a support grid for the outer cladding. A vertical seal is integrated to ensure wind-tightness, reducing air infiltration and improving energy efficiency.

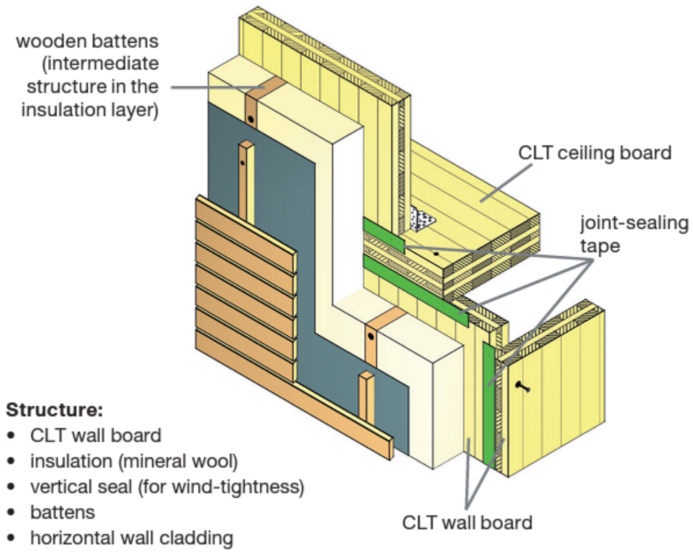


Figure 4: Façade with timber wall

On top of the battens, horizontal wooden cladding panels are mounted as the exterior finish, offering protection against weather and contributing to the façade's aesthetic appeal. The system includes joint-sealing tape between CLT panels and at connections to ensure airtightness and minimize thermal bridging. The CLT ceiling board seamlessly connects with the wall elements, maintaining the continuity of the thermal and airtight layers. This multi-layered design combines the natural beauty and sustainability of wood with high thermal performance, resulting in a modern, energy-efficient, and durable building envelope.

5.2.4 Party wall: Wall with interior insulation and plasterboard covering

An example of party wall construction features an existing structural wall made of concrete or brick, which serves as the primary support and separation between adjacent spaces or dwellings. A framework of galvanized steel profiles (C studs) is anchored to the inner face of this structural wall, creating a cavity where a thermal insulation layer—typically mineral wool or rigid foam panels—is installed. This insulation improves the thermal performance of the wall, reducing heat loss or gain between units and contributing to acoustic insulation. The system is completed by a layer of gypsum cardboard (drywall) screwed onto the steel profiles, forming a smooth, paint-ready interior finish.

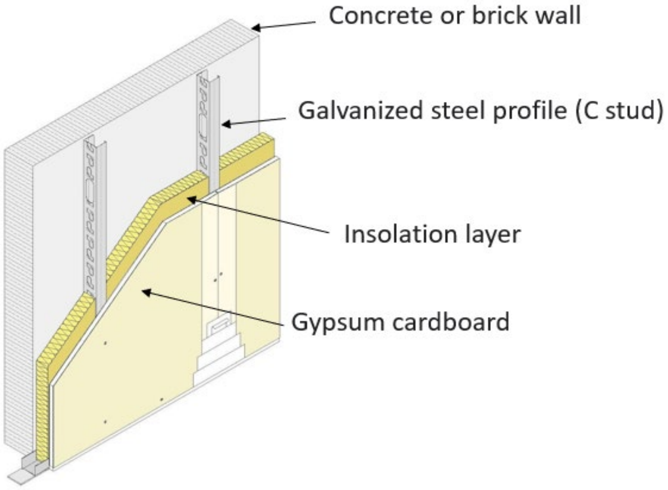


Figure 5: Party wall with interior insulation and plasterboard covering

To prevent condensation and moisture problems inside the wall assembly, it is essential to place a **vapor barrier** on the warm side of the insulation layer—that is, directly behind the gypsum cardboard but before the insulation—especially in climates with cold winters. This placement stops warm, humid indoor air from penetrating into the cooler insulation layer, where it could condense and cause mold or structural damage. By keeping moisture out of the insulation, the vapor barrier ensures the longevity and performance of the wall system.

5.2.5 Roof type I: Inverted flat roof

This flat roof system (Figure 6) is composed of several layers installed over a structural concrete slab. First, a screed with slope (screed to falls) is applied to direct water towards drainage points, preventing ponding. On top of the screed, a waterproofing layer protects the building against water ingress. Above the waterproofing, extruded polystyrene (XPS) insulation boards are installed to provide excellent thermal resistance and minimize heat loss through the roof. A water flow reducing layer is then placed to slow down water movement across the roof surface. Finally, the system is finished with either gravel ballast or paving slabs set on spacer pads, which protect the layers below from UV exposure and mechanical damage while providing a walkable or usable surface.

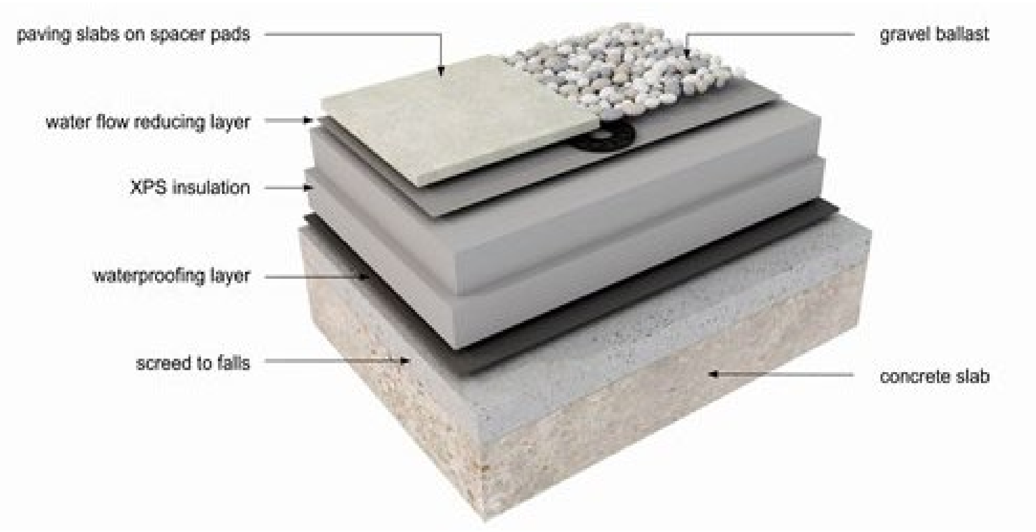


Figure 6: Inverted flat roof

Hydrothermally, this is an **inverted roof system** (also called a protected membrane roof), where the thermal insulation sits above the waterproofing layer. This arrangement keeps the waterproofing layer at a more stable temperature, minimizing thermal cycling and extending its lifespan. The XPS insulation's closed-cell structure resists water absorption, maintaining insulation performance even in wet conditions. The ballast or paving layer prevents wind uplift and shields the insulation from sunlight and mechanical impacts. Moisture that penetrates the ballast or joints can drain through the water flow reducing layer, while the slope directs it towards drainage outlets. This hygrothermal design efficiently manages heat and moisture, ensuring energy efficiency and protecting the roof structure from water-related damage.

5.2.6 Roof type II: Tiled roof with brick walls

A tiled roof over brick walls (Figure 7) typically begins with a structural concrete slab serving as the main load-bearing component of the roof system. On top of this slab, a layer of thermal insulation is installed to reduce heat transfer and improve the building's energy efficiency. Above the insulation, lightweight hollow brick partitions are constructed to create the pitched framework of the gable roof. These partitions support a ceramic board, which acts as a rigid base for the screed layer. A ventilated air cavity is incorporated above the ceramic board, allowing airflow beneath the tiles.

A mortar screed layer is applied over the ceramic board to create a smooth surface and provide the necessary slope for drainage along the pitched roof. Clay or concrete tiles are then laid on top of the ventilated cavity and screed, completing the outer waterproof layer of the roof. The ventilated air cavity turns the system into a ventilated roof, enabling hot air to escape and reducing heat buildup under the tiles. This multi-layered, ventilated design not only ensures thermal performance and structural stability but also provides effective weather protection.

Figure 7: Tiled roof with brick walls

In warm climates, a ventilated tiled roof offers significant advantages: the ventilated air cavity allows continuous airflow, which helps dissipate heat accumulated on the roof surface before it can reach the interior. This reduces indoor temperatures and cooling loads, improving comfort and energy efficiency by minimizing the need for air conditioning. Additionally, the ventilation helps remove moisture, reducing the risk of condensation and prolonging the lifespan of the roofing materials.

5.2.7 Roof type III: Tiled roof with timber structure

A gable roof with a timber structure (Figure 8) typically consists of a wooden framework of rafters and beams forming the two inclined planes of the roof. Between the wooden ribs, insulation is installed on or between the structural decking boards, providing an effective thermal barrier directly within the timber structure. Over the insulation and decking, additional wooden boards or battens are fixed horizontally or diagonally to create a support surface for the roof tiles. Clay or concrete tiles are then laid on top of these battens, completing the pitched, ventilated roof assembly. This timber structure allows for lightweight, flexible construction that can be easily adapted to various spans and architectural styles.

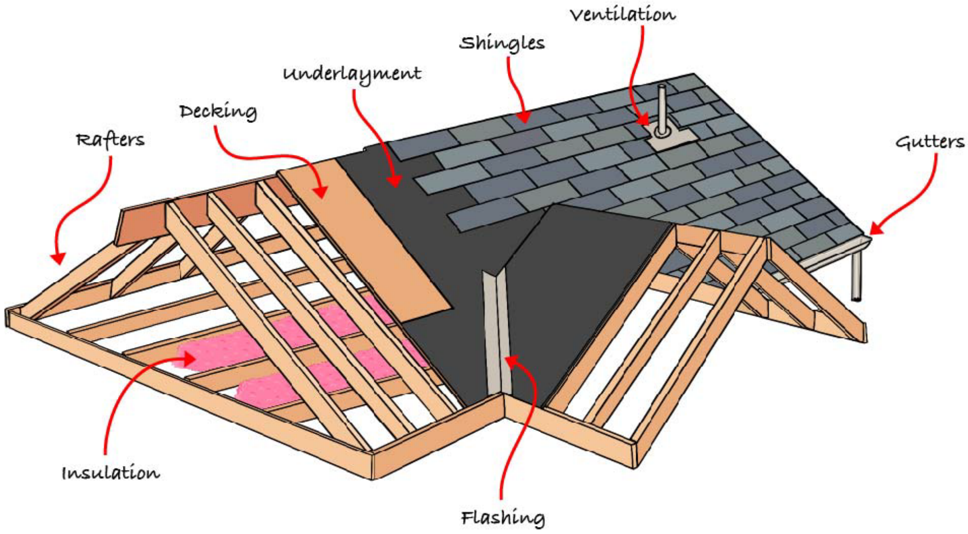


Figure 8: Tiled roof with timber structure

Compared to tiled roofs over brick walls, timber-structured gable roofs offer faster construction, reduced weight on the building's load-bearing walls, and greater flexibility for complex roof geometries. The use of wood simplifies the formation of dormers, skylights, or other roof features. Additionally, by placing the insulation within or above the timber structure, the thermal envelope can more easily follow the roof's shape, reducing thermal bridges and improving energy performance. These advantages make timber gable roofs particularly suitable for residential buildings in areas where lightweight construction and design flexibility are priorities.

5.3– Heat transfer through the thermal envelope

The ability to hold indoor air temperature at the desired level is affected by all three methods of heat transfer:

- Conduction
- Convection
- Radiation

5.3.1 Conduction

Thermal conduction is the process by which heat is transferred through a solid material from a region of higher temperature to a region of lower temperature, without any movement of the material itself. This occurs as the more energetic (hotter) particles within the material collide with neighbouring, less energetic (cooler) particles, passing on their thermal energy. The efficiency of this process depends on the material's thermal conductivity—metals, for example, are good conductors of heat, while insulating materials like mineral wool or polystyrene have low thermal conductivity and significantly slow down heat transfer by conduction.

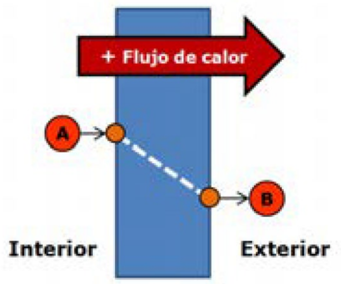


Figure 9: Conduction heat flow

- Requires that surfaces touch for solid-solid heat transfer.
- Because the different materials in an insulated assembly touch each other, conduction heat loss occurs through solid components of the building envelope.
- For example, heat flows by conduction from warm areas to the cooler areas of concrete slabs, window glass, walls, ceilings, and other solid materials.

5.3.2 Convection

Thermal convection is the process of heat transfer through a fluid (liquid or gas) caused by the movement of the fluid itself. It occurs when warmer, less dense regions of the fluid rise while cooler, denser regions sink, creating a continuous circulation pattern known as a convection current. This movement distributes heat throughout the fluid. Convection can be natural, driven by temperature differences alone (such as warm air rising in a room), or forced, where an external mechanism like a fan or pump moves the fluid. Convection is a key mechanism in heating, ventilation, and many natural phenomena like ocean currents and atmospheric circulation.

In short:

- Transferring heat from one place to another by molecular movement through fluids such as water or air.
- Heat loss by convection commonly results from exfiltration or air leakage.
- Convective heat loss occurs when warm air is forced out, usually from the building (exfiltration), by cold incoming air, usually in the lower part (infiltration).
- The rate of transfer is increased when the wind blows against the building or when the temperature difference between the inside and outside increases.

Figure 10: Air leaking into/out of the house[3].

5.3.3 Radiation

- Radiation is the heat transfer by electromagnetic waves from a warmer to a cooler surface.
- The transfer of the sun's heat to a roof or the warmth of a standing near a glass furnace are examples of radiant heat transfer.

Solar radiation can significantly affect thermal comfort inside a home by directly increasing indoor temperatures, especially through windows and poorly insulated walls or roofs. When sunlight enters through glazing, it can heat interior surfaces, causing a rise in ambient temperature and creating localized overheating, particularly in summer or in buildings with large south-facing openings. Without adequate shading, thermal insulation, or reflective materials, this heat gain can lead to discomfort, increased reliance on air conditioning, and higher energy consumption. Controlling solar radiation with external shading devices, reflective coatings, and proper orientation is essential to maintaining a stable and comfortable indoor climate.

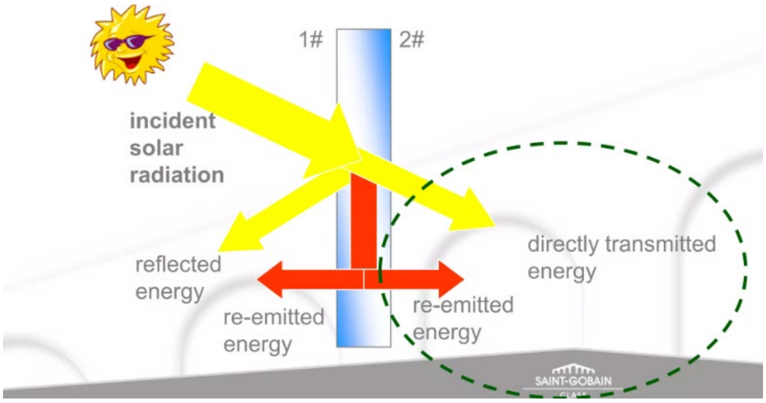


Figure 11: Solar radiation through windows [4].

5.4– Thermal conductivity and Insulation products for buildings

The **thermal conductivity** of a material is a measure of its ability to conduct heat. It is commonly denoted by ***k***, ***λ*** or ***κ*** and is measured in W/m·K.

This property is **independent of the thickness** of the material. Heat transfer occurs at a lower rate in materials of low thermal conductivity than in materials of high thermal conductivity.

Table 1 shows the thermal conductivity of various building materials.

Table 1: Thermal Consistency of Building Materials.

No	Building Material	Density (kg/m3)	K (W/m.K)
1	Concrete	2.400	1,448
2	Aerated Concrete	960	0,303
3	Plastered Clay Brick	1.760	0,807
4	Exposed Clay Brick		1,154
5	Glass	2.512	1,053
6	Gypsum board	880	0,170
7	Steel	7.840	47,6
8	Granite	2.640	2,927
9	Marble/Ceramic/Terazzo	2.640	1,298
Source: SNI 03- 6389- 2000			

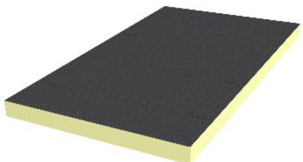
The **products** to be used **in the thermal insulation layer** of a building's thermal envelope are characterised by having very low conductivity. All products have a similar conductivity so when choosing a material the main factors to take into account are: thickness, price and sustainability.

The following list shows the most commonly used materials to thermally insulate a building:

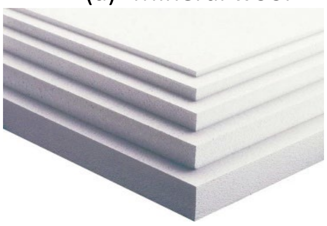
- Mineral wool insulation (high bulk density range) λ = 0.038 W/m·K
- Insulation board with a core of rigid polyurethane (PIR) λ = 0.022 W/m·K
- Polyurethane thermal insulation spray foam λ = 0.02 - 0.03 W/m·K
- Expanded polystyrene foam (EPS) λ = 0.035-0.037 W/m·K
- Extruded Polystyrene or Styrofoam (XPS) panels λ = 0.024 W/m·K
- Cellulose fibre insulation λ = 0.04 W/m·K
- Cork-based thermal insulation panels λ = 0.037 – 0.040 W/m·K

Figure 12 show images of these insulating materials.


(a) Mineral wool


(b) Rigid polyurethane


©Polyurethane spray foam


(d) Expanded polystyrene foam (EPS) or Extruded Polystyrene or Styrofoam (XPS)


(e) Cellulose fibre insulation


(f) Cork-based panels

Figure 12: Thermal insulation materials

5.5– Thermal properties of a wall

The two fundamental properties that explain the thermal behaviour of a wall are **thermal transmittance** and **thermal inertia**.

5.5.1 Conductance (or thermal transmittance, or U-value) of an element (wall or window).

Thermal transmittance (also known as the **U-value**) of a wall or a windows is the rate of heat transfer through the wall per unit area and per unit temperature difference between the inside and outside environments. It is expressed in **watts per square**

meter per kelvin (W/m²·K), and lower values correspond to better insulation performance.

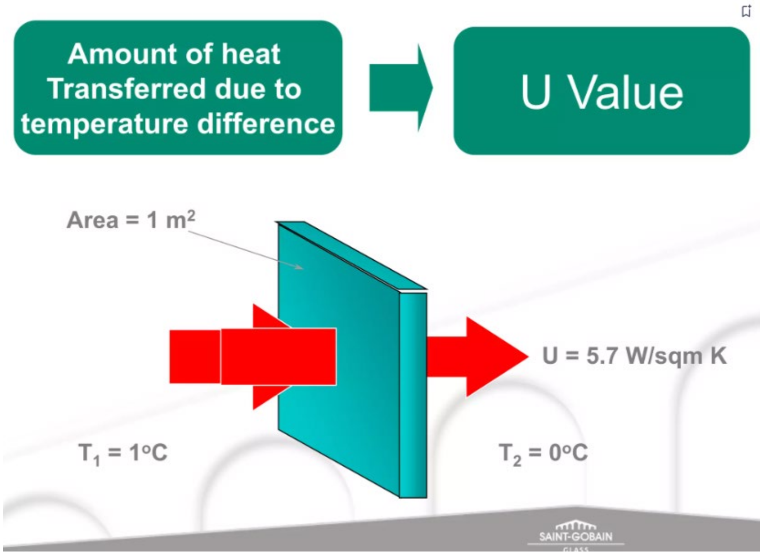


Figure 13: U value definition [4].

How to calculate the **U-value** of a wall:

The thermal transmittance U (W/m² -K) is given by the following expression:

$$U = \frac{1}{R_T} \qquad (1)$$

R_T the total thermal resistance of the wall [m²·K/W]:

$$R_T = R_{si} + R_1 + R_2 + \ldots + R_n + R_{se} \qquad (2)$$

R_1, R_2 ...R_n the thermal resistances of each layer defined according to expression (3) [m² -K/ W];

R_{si} and R_{se} are the surface thermal resistances corresponding to indoor and outdoor air respectively, taken from codes according to the position of the enclosure, direction of heat flow and its location in the building [m² -K/ W].

$$R = \frac{e}{\lambda} \qquad (3)$$

R thermal resistance of a layer; e thickness of the layer; λ conductivity of the layer material

5.5.2 Thermal inertia

Thermal mass is a property of the mass of a building that enables it to store heat and provide inertia against temperature fluctuations.

Thermal inertia refers to a wall's **ability to absorb, store, and gradually release heat over time**, which plays a crucial role in improving a building's energy efficiency. Walls with high thermal inertia—typically made of dense materials like concrete, brick, or stone—can moderate indoor temperatures by delaying the transfer of external heat into the building during the day and releasing stored heat during cooler periods, such as at night. This buffering effect helps reduce reliance on heating and cooling systems, maintaining thermal comfort with less energy consumption. As a result, buildings with well-designed thermal mass can achieve more stable indoor climates and lower energy demands, particularly in climates with large daily temperature fluctuations.

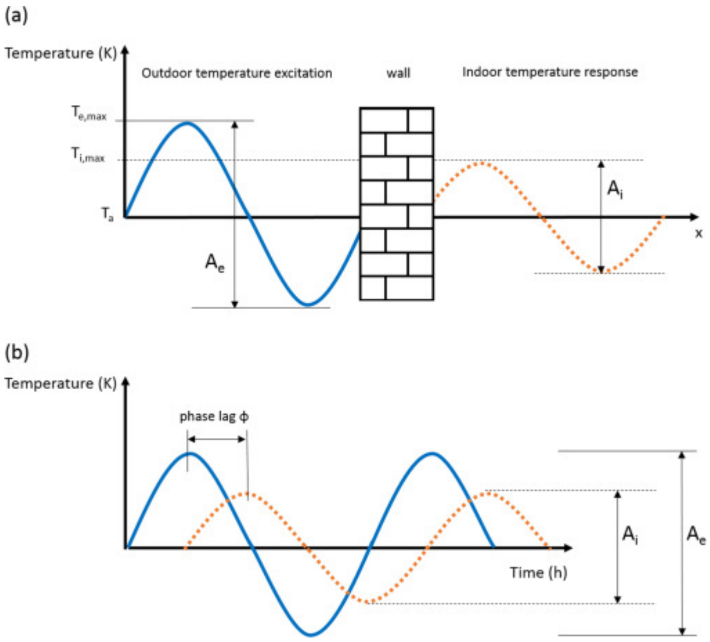


Figure 14: Effect of the thermal inertia of the wall on the indoor temperature [4].

The following equation (4) shows the parameters on which the thermal inertia *P* depends

$$P = \sqrt{C\ \lambda} = \sqrt{c\ \rho\lambda} \tag{4}$$

P: thermal Inertia, C: Volumetric heat capacity, c: specific heat, λ : thermal conductivity

5.6– Thermal properties of windows

Key Performance Factors in windows are the following:

- Total Heat Gain / Heat Transmission
    - SHGC or SF: Solar Heat Gain Coefficient or Solar Factor
    - U Value
- Light Transmission: percentage of incident light transmitted

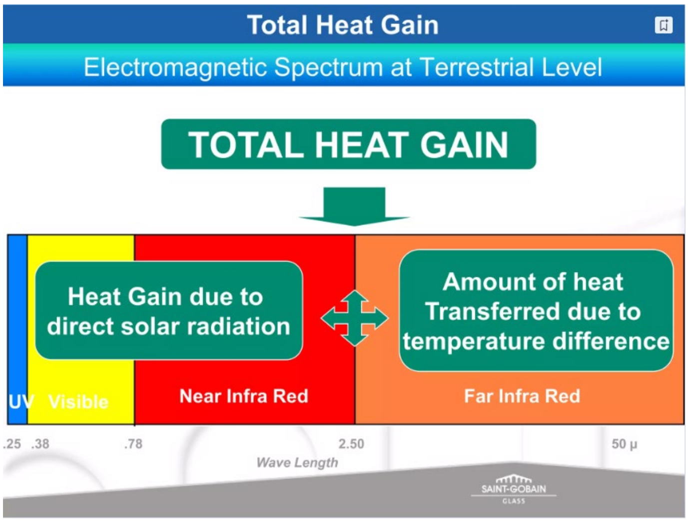


Figure 15: Heat gain – electromagnetic spectrum.

The **Solar Heat Gain Coefficient (SHGC)**, also known as the **Solar Factor**, is a measure of how much **solar radiation** passes through a window—both directly transmitted and absorbed then released inward—relative to the total solar energy striking the window. It is expressed as a number between **0 and 1**, where a **lower SHGC** means less solar heat enters the building, and a **higher SHGC** allows more solar gain. In terms of **energy efficiency**, the ideal SHGC depends on climate: in **hot climates**, windows with **low SHGC** help reduce cooling loads by minimizing unwanted heat gain, while in **cold climates**, a **higher SHGC** can be beneficial by maximizing passive solar heating and reducing the need for mechanical heating. Therefore, choosing the right SHGC is key to optimizing a home's **thermal performance and energy consumption** throughout the year.

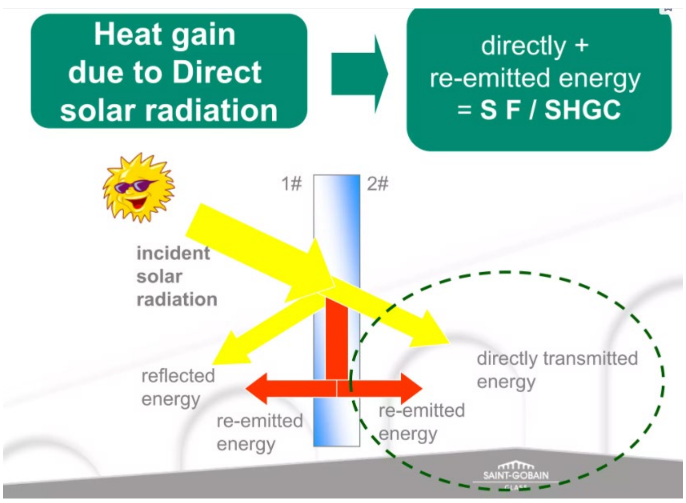


Figure 16: Concept of solar factor (SF or SHGC).

The **U-value** has been explained in section 5.5.1.

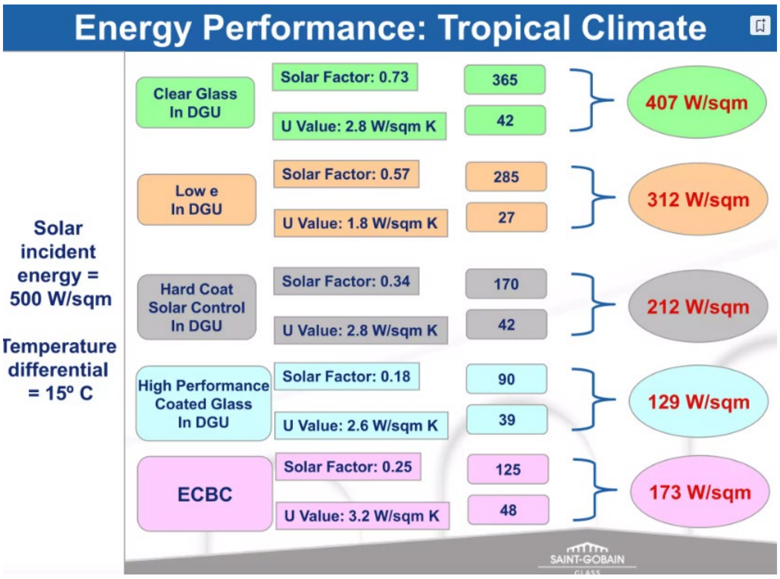


Figure 17: Examples of heat gains with various types of windowpanes, in tropical climates

Light Transmission, often referred to as **Visible Light Transmittance (VLT)**, is the percentage of **visible light** that passes through a window into a building's interior. It is expressed as a value between **0 and 1** (or 0% to 100%), where higher values mean more natural light enters the space. In residential settings, an optimal level of light transmission is essential to ensure **visual comfort, reduce the need for artificial lighting**, and create a pleasant, functional environment for **living, working, or relaxing**. Too little light transmission can make interiors feel dim and require more electric lighting, increasing energy use. Conversely, very high transmission might cause **glare** or overheating, particularly in sunny climates. Therefore, selecting windows with an appropriate VLT helps balance **daylight access, energy efficiency, and occupant comfort**.

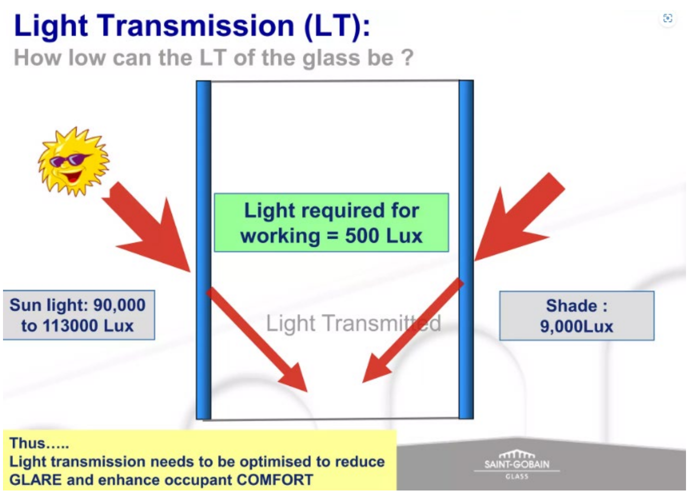


Figure 18: Concept of correct light transmission [4].

There are several devices and technologies designed to **optimize light transmission** through building windows, enhancing both **natural lighting** and **energy efficiency**. **Smart glazing** or **electrochromic windows** can automatically adjust their tint based on sunlight intensity, reducing glare and heat while maintaining adequate daylight. **External shading systems**, such as **louvers, awnings, or brise-soleils**, can block excessive sunlight during peak hours while allowing diffused light in. **Internal solutions** like **light shelves** and **reflective blinds** help redirect natural light deeper into interior spaces. Additionally, **low-emissivity (low-E) coatings** on glass can control the amount of visible light transmitted while minimizing heat gain. Together, these devices enable dynamic control over daylight, helping to create comfortable, well-lit environments and reduce reliance on artificial lighting and HVAC systems.

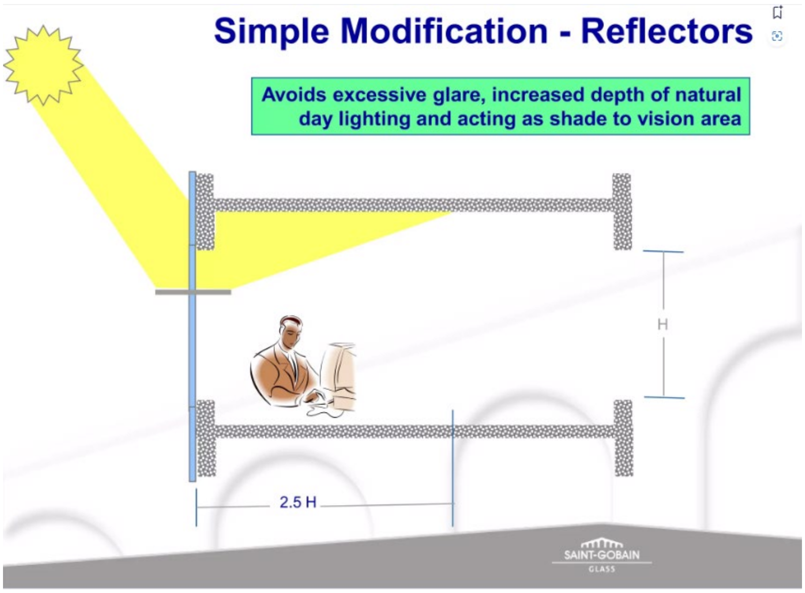


Figure 19: Reflectors [4]

Recommendation about walls, windows, shading and solar gains.

- Wall should be designed to have insulation
- Window area should be limited to 10-30% of the wall area
- Windows should be highly efficient, particularly if more than 25% of the wall area (both thermal protection and solar protection).
- Shading with overhangs should be designed based on solar angles (i.e. typically overhangs are more effective on North and South walls)
- Shading with movable external shades can be highly effective for optimized daylighting and controlling solar gains.
    - Shutters
    - Movable blinds.

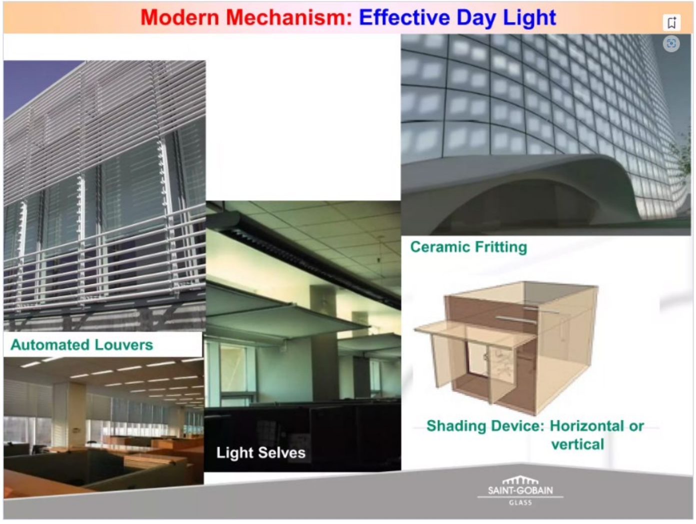


Figure 20 Shading systems [4].

5.7– Thermal Envelope Code Requirements

According to the Spanish Technical Building Code, buildings must have a thermal envelope that limits their primary energy needs according to the climatic zone, its use and its compactness.

In order to comply with these aims, it is necessary to check five aspects:

1. Limitations in the **global transmittance** of the thermal envelope (K) and **transmittances by elements** (U_{lim})
2. Solar Control of the Thermal Envelope ($Q_{sol;Jul}$)
3. The **Air Permeability** of the thermal envelope (Q_{100} and n_{50})
4. Limit **imbalances between units of use** (U_{lim} interior partitions)
5. **Condensation control**.

5.7.1. Example of a thermal envelope that complies with the Spanish building code.

This section describe two examples of a thermal envelope of a buildings in Cartagena (Spain) [5]. Cartagena is located in climate **zone B3** according to the Spanish technical building code.

In the context of the Spanish Building Code, climate zone B3 refers to a moderate Mediterranean climate characterized by mild winters and warm to hot summers. The letter “B” indicates the winter climate severity, with B representing mild winter conditions, while the number “3” refers to summer climate severity, with 3 being among the warmest summer categories.

The first example consists of a newly built single-family house with the following characteristics in the elements of the envelope:

Description of the facades:

Layers in WALLS:

Cement mortar

Perforated brick

Insulation (λ=0.032 W/m2)

Double hollow brick

Description of the Roof

Layers in COVERS:

Ceramic tiles

Cement mortar

Insulation (λ=0.032 W/m2)

Lightweight aggregate concrete

Description of Floors

Layers in FLOORS:

Ceramic tiles

Cement mortar

Insulation (A=0.032 Wm2)

Reinforced concrete floor

For a new residential building located in a B winter climate zone, with the materials described in the thermal envelope, according to the Spanish Technical Building Code (CTE), the thermal envelope elements should meet the following characteristics (Table 2):

- walls and floors in contact with outside air must have a thermal transmittance (U-value) of 0.38 W/m^2·K (at least 7 cm of insulation);
- roofs in contact with outside air should achieve a U-value of 0.33 W/m^2·K (at least 8.5 cm of insulation);
- walls, floors, and roofs in contact with non-habitable spaces or the ground, as well as interior partitions within the thermal envelope, should meet a U-value of 0.69 W/m^2·K (al least 3 m of insulation);

- and openings such as windows and doors should have a maximum U-value of 2.0 W/m²·K. This requirement is archived with windows with metallic carpentry with thermal bridge breaking, and low emissive double glass (4,10,6 mm).

These specifications ensure compliance with energy efficiency requirements for winter climate zone B.

Table 2: Guideline table for new construction. Example 1.[5]

Guideline table for new construction or interventions on the building as a whole:

Table a - Annex E Thermal transmittance of the element as a guideline for compliance with K, U [W/m²K].

Element	Winter climate zone α	A	B	C	D	E
Walls and floors in contact with outside air (US, UM)	0,56	0,50	0,38	0,29	0,27	0,23
cm of insulation	4	5	7	9,5	10,5	12,5
Covers in contact with outside air (UC)	0,50	0,44	0,33	0,23	0,22	0,19
cm of insulation	5,5	6	8.5	13	13,5	16
Walls, floors and roofs in contact with non-habitable spaces or with the ground (UT) Partition walls or interior partitions belonging to the thermal envelope (UMD)	0,80	0,80	0,69	0,48	0,48	0,48
cm of insulation	2	2	3	5	5	5
Openings (frame, glass and, if applicable, louver box) (UH)* (UH)* (UH)* (UH)	2,7	2,7	2,0	2,0	1,6	1,5
glass composition and metallic carpentry, without roller shutter drawer	BE4/8/6 SinRPT	BE4/8/6 SinRPT	BE4/10/6 RPT	BE4/10/6 RPT	BE4/12Ar/ RPT	BE4/14Ar/6 RPT

The second example consists of the energy rehabilitation of an existing building. This building has the same characteristics of materials in the thermal envelope as the one in example 1. It is also located in climate zone B3. In this case, the thicknesses of the insulation layers to be installed and the limit transmittances to be respected according to the Spanish technical building code are shown in Table 3.

Table 3: Guideline table for interventions in existing buildings. Example 2. [5]

Table for interventions in existing buildings:

Table 3.1.1.a - HE1 Thermal transmittance limit values, U_{lim} [W/m²K].

Element	Winter climate zone					
	α	A	B	C	D	E
Walls and floors in contact with outside air (U_S, U_M)	0,80	0,70	0,56	0,49	0,41	0,37
cm of insulation	2.5	3	4	5	6.5	7
Covers in contact with outside air (U_C)	0,55	0,50	0,44	0,40	0,35	0,33
cm of insulation	5	5.5	6.5	7	8	8.5
Walls, floors and roofs in contact with non-habitable spaces or with the ground (U_T) Partition walls or interior partitions belonging to the thermal envelope (U_{MD})	0,90	0,80	0,75	0,70	0,65	0,59
cm of insulation	1.5	2	2.5	2.5	3	3.5
Openings (frame, glass and, if applicable, louver box) (U_H)* (UH)* (UH)* (UH)	3,2	2,7	2,3	2,1	1,8	1,80
glass composition and metallic carpentry, without roller shutter drawer	4/16/6 SinRPT	BE4/8/6 SinRPT	BE4/8/6 RPT	BE4/10/6 RPT	BE4/20/6 RPT	BE4/20/6 RPT
Doors with semi-transparent surface equal to or less than 50%.	5,7					

*The window openings in *units of use* with commercial activity can increase the value of the $_{HU}$ by 50%.

For an intervention in an existing building located in a B winter climate zone, with the materials described in the thermal envelope, according to the Spanish Technical Building Code (CTE), the thermal envelope elements should meet the following characteristics (Table 3):

- walls and floors in contact with outside air must have a thermal transmittance (U-value) of 0.56 W/m²·K (at least 4 cm of insulation);
- roofs in contact with outside air should achieve a U-value of 0.44 W/m²·K (at least 6.5 cm of insulation);
- walls, floors, and roofs in contact with non-habitable spaces or the ground, as well as interior partitions within the thermal envelope, should meet a U-value of 0.75 W/m²·K (al least 2.5 m of insulation);

- and openings such as windows and doors should have a maximum U-value of 2.3 W/m²·K. This requirement is archived with windows with metallic carpentry with thermal bridge breaking, and low emissive double glass (4,8,6 mm).

References

[1] American Society of Heating, Refrigerating and Air-Conditioning Engineers. (n.d.). Building thermal envelope. In ASHRAE Terminology. Retrieved August 3, 2025, from https://terminology.ashrae.org/?entry=building+thermal+envelope.

[2] BPC Green Builders. https://www.bpcgreenbuilders.com/blog/your-homes-thermal-envelope-most-important-element-for-an-energy-efficient-home/

[3] The importance of the Building Envelope. Retrieved August 3, 2025, from The Importance Of The Building Envelope | Eco Spray Insulation

[4] 'IEA – International Energy Agency', IEA. Accessed: Jun. 23, 2024. [Online]. Available: https://www.iea.org

[5] Ministerio de Transportes, Movilidad y Agenda Urbana. (2020). *Guía de aplicación del Documento Básico DB-HE Ahorro de Energía del Código Técnico de la Edificación (CTE)*. https://www.codigotecnico.org/images/stories/pdf/ahorroEnergia/DBHE/GuiaDBHE.pdf

6 - Deliverables

In order to evaluate the success of the application, we suggest a questionnaire to be held for the students.

7- What we have learned

- The definition of thermal envelope of buildings.
- The elements of thermal envelope of buildings and how they work.
- Examples of various types of facades, party walls, roofs-
- Heat transfer through the thermal envelope: conduction; convection; radiation
- Materials used in the thermal insulation layer of an element of a building's thermal envelope.
- The main thermal properties of walls and windows
- Technical requirements in building codes about the thermal envelope.