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BIM4Energy Project

Catalogue of best alternatives for improving the Building Energy Efficiency: Improvement of the Thermal Envelope

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1 – Aims

A Catalogue of best alternatives for improving Building Energy Efficiency: Improvement of the thermal envelope tutorial aims to equip participants with a comprehensive understanding of measures to improve the properties of the building's thermal envelope. The objectives of this Catalogue of best alternatives for improving the thermal envelop of Buildings are as follows:

- Understanding what the thermal envelope of a building is.
- Understanding the physical properties of a building's thermal envelope.
- Strategies to optimize the thermal enveloped of a building.
- Understanding the Components of the Thermal Envelope.
- To learn about examples of highly energy-efficient windows and doors.
- To learn about examples of highly energy-efficient facades and roofs.
- To know measures to improve the insulation of the façades and walls of the thermal envelope.

2 - Learning methodology

The teacher will give an explanation about best alternatives for improving Building Energy Efficiency of the thermal envelop of about 30 minutes.

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

- How the building's thermal envelope works
- Strategies to optimize the thermal envelope of a building
- Examples of highly energy-efficient windows and doors
- Examples of highly energy-efficient façades and roofs
- Alternatives to improve the insulation of facades of existing buildings.

In order to evaluate the success of the application, we suggest a questionnaire to 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 – What is the thermal envelope of a building

Before diving into specific measures to improve the thermal envelope, it's essential to understand what the Thermal Envelope of a Building is.

The **thermal envelope** of a building is the physical barrier that separates the conditioned interior spaces from the external environment. It plays a crucial role in regulating heat flow, air infiltration, and moisture transfer, which directly affects a building's energy performance, indoor comfort, and durability. A well-designed thermal envelope helps maintain a consistent indoor temperature, reduces energy consumption, and lowers greenhouse gas emissions [1].

The main components of the thermal envelope include the **walls**, **roof**, **floor**, **windows**, and **doors**. Each part contributes to controlling thermal exchange and should be constructed with appropriate **insulating materials**, **air barriers**, and **moisture control layers**. For example, exterior walls typically contain insulation and an airtight layer to minimize heat loss in winter and prevent heat gain in summer. Roofs often include ventilation layers and reflective surfaces, while floors—especially those in contact with the ground—require thermal breaks and moisture protection. Windows and doors are considered thermal weak points; thus, modern designs include **double or triple glazing**, **low-emissivity (low-E) coatings**, and thermally broken frames to enhance their performance.

There are different types of thermal envelopes based on design intent and efficiency standards. **Conventional envelopes** follow standard building codes and provide basic thermal protection. In contrast, **high-performance envelopes**, such as those used in **Passive House** design [2], aim to minimize energy demand through airtight construction, superior insulation, and thermal bridge-free detailing. **Dynamic or adaptive envelopes** use technology or smart materials to respond to external conditions, such as ventilated façades that allow air circulation between cladding layers to improve thermal behaviour.

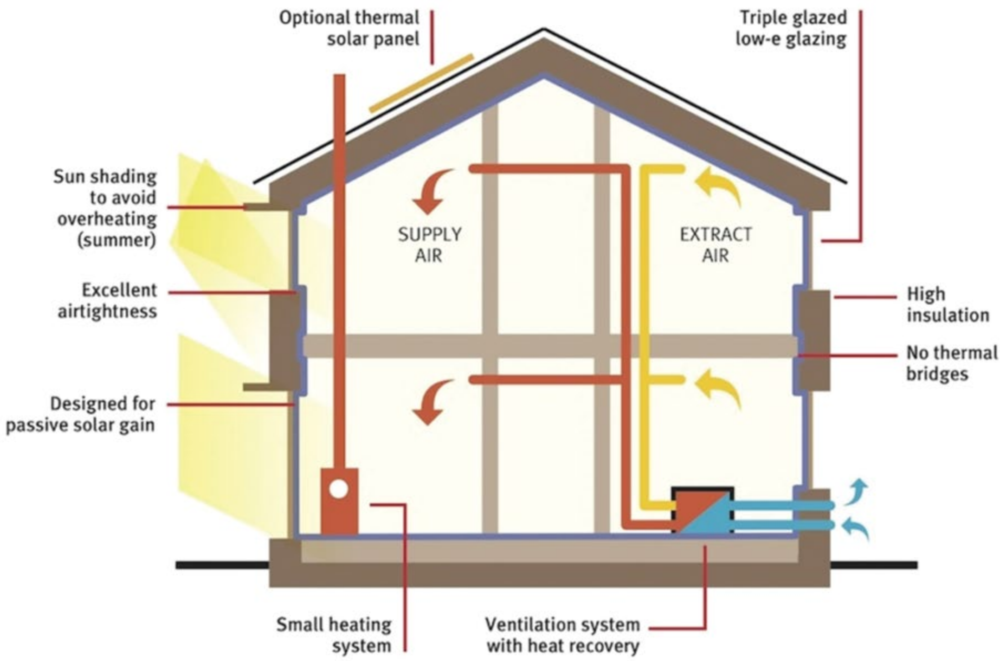


Figure 1: Passivhaus standards in action. (Image Source John Gilbert Architects.)

Improving a building's thermal envelope is one of the most effective strategies for reducing energy use. Common improvement measures include **retrofitting insulation** in walls, attics, and floors; replacing outdated windows with **energy-efficient units**; and sealing air leaks around joints, pipes, and electrical outlets. More advanced strategies involve installing **green roofs**, **external shading devices**, or **ventilated façades**, all of which contribute to better temperature regulation and moisture control.

5.2 – How the building's thermal envelope works

The thermal envelope of a building functions as a protective shell that manages the transfer of heat, air, and moisture between the interior and exterior environments. It is composed of structural and insulating elements—such as walls, roofs, floors, windows, and doors—that collectively reduce energy loss and help maintain thermal comfort. By limiting unwanted heat gains in summer and heat losses in winter, the envelope significantly reduces the need for mechanical heating and cooling systems [1].

Key properties of an effective thermal envelope include **thermal resistance (R-value)**, **air tightness**, and **moisture control**. High R-values indicate better insulation performance, which slows down heat flow through building elements. Air tightness prevents uncontrolled air leakage, enhancing energy efficiency and indoor air quality. Moisture control layers, such as vapor barriers and drainage planes, protect the building materials from deterioration due to condensation or infiltration [3]. Each component must work together as an integrated system to optimize thermal performance and durability.

Advanced building standards, such as **Passive House**, emphasize the importance of a high-performance thermal envelope. These designs use thick insulation, high-performance windows, and meticulous air sealing to drastically lower heating and cooling demands [2]. Improving the envelope—either through new construction or renovation—can lead to substantial energy savings and a longer lifespan for building materials. Ultimately, the thermal envelope is one of the most critical factors in sustainable and energy-efficient building design.

5.3 – Strategies to optimize the thermal envelope of a building.

One of the most effective strategies to improve a building's thermal envelope is to **upgrade the insulation** in the roof, walls, and floors. Insulation slows down heat transfer, helping maintain comfortable indoor temperatures year-round while reducing energy consumption. In cold climates, such as northern Europe, high R-value materials like mineral wool or spray foam are often used in thick layers to minimize heat loss [1]. In hot, arid regions (e.g., southern Spain), reflective insulation or radiant barriers are added under roofs to reflect solar radiation [4]

Another key area for improvement is the **performance of windows and doors**, which are responsible for a large portion of heat loss or gain. Replacing outdated units with **double or triple-glazed windows** equipped with **low-emissivity (low-E) coatings** and argon gas filling significantly enhances thermal performance [2]. In colder regions, south-facing windows can be designed to capture passive solar heat, while in tropical climates, it's essential to limit window size and use shading devices to reduce overheating. Thermal breaks in aluminium frames and insulated exterior doors also contribute to maintaining a tighter thermal boundary [3].

Air sealing is a critical improvement that applies across all climate zones. Air leaks can account for up to 30% of heating and cooling losses in a typical building [1]. Sealing gaps with caulks, foams, and weatherstripping reduces infiltration and improves energy efficiency. In humid climates, it also prevents warm, moist air from entering and condensing within the walls, which can lead to mold. A **blower door test** is often used to detect leakage points.

Lastly, climate-responsive **passive strategies** can significantly enhance the thermal envelope. In warm, humid regions, **ventilated façades** help remove solar heat and moisture, keeping the building cooler. **Green roofs** are effective in both temperate and hot climates, providing insulation and reducing urban heat island effects. **External shading devices**, such as louvers or pergolas, block direct sunlight in summer but allow it in during winter in seasonal climates. These elements not only improve the thermal envelope's performance but also contribute to occupant comfort and environmental sustainability.

5.4 – Examples of highly energy-efficient windows and doors

5.4.1. Types of Windows: Glazing and Frame Materials

Windows are a key part of the thermal envelope and significantly affect a building's energy efficiency, especially in heating- or cooling-dominated climates. The two most important factors that determine a window's thermal performance are the type of glazing (glass) and the frame material. Together, they influence the U-value, which measures the rate of heat transfer—the lower the U-value, the better the insulation.

Glazing types vary from single-pane glass (rarely used today) to double-glazed and triple-glazed units. Double glazing consists of two panes of glass with an air or gas-filled space (argon or krypton), while triple glazing adds a third pane, further improving insulation. Approximate U-values are:

- Single glazing: 5.0–6.0 $W/m^2 \cdot K$ (very poor insulation)
- Double glazing (air-filled): 2.7–3.0 $W/m^2 \cdot K$
- Double glazing (argon-filled, low-E): 1.4–1.6 $W/m^2 \cdot K$
- Triple glazing (argon/krypton, low-E): 0.8–1.0 $W/m^2 \cdot K$ [5]

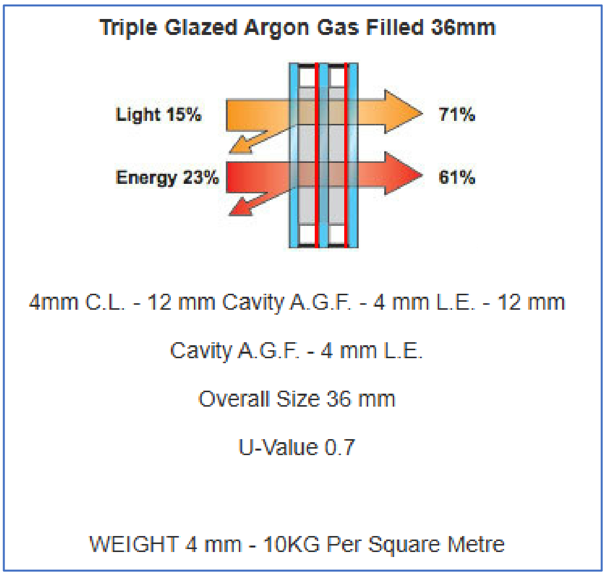


Figure 2: Features of Triple glazed argon gas filled 36 mm

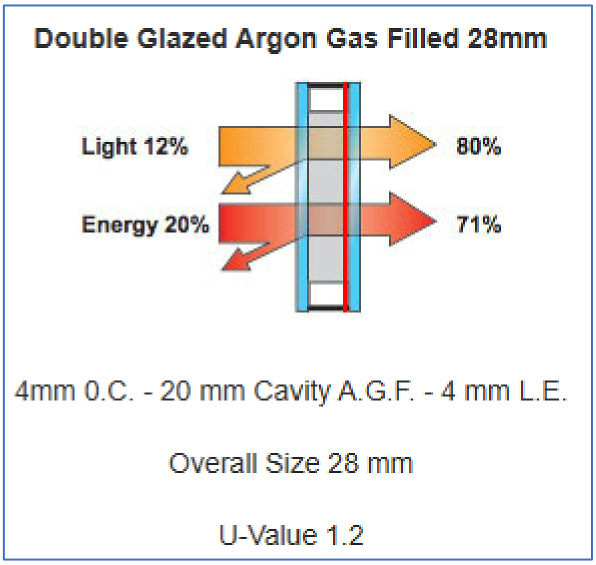


Figure 3: Features of Double glazed argon gas filled 28 mm

Frame materials also play a major role in heat transfer. Common types include:

- Aluminum (non-thermally broken): High conductivity; U-values around 5.5–6.0 W/m²·K
- Thermally broken aluminum: With thermal barriers, values drop to 1.8–2.5 W/m²·K

- PVC/vinyl frames: Good insulation; U-values between 1.2–1.6 W/m²·K
- Wood frames: Naturally insulating; U-values from 1.4–1.8 W/m²·K
- Wood-aluminum composite: Combines aesthetics and performance; ~1.0–1.4 W/m²·K [6]

Figure 4: PVC, Aluminium and Wood window frames.

5.4.2. Recommended U-values for windows by Climate Zone

The recommended thermal transmittance (U-value) of windows depends heavily on the local climate and building regulations:

- Cold climates (e.g., Scandinavia, Canada): Recommended U-value is ≤ 1.0 W/m²·K for windows; Passive House standards suggest ≤ 0.8 W/m²·K for extreme cold [2].
- Temperate climates (e.g., Central Europe, Northern US): Target ≤ 1.4 W/m²·K for good performance.
- Warm climates (e.g., Mediterranean, Southern US): Slightly higher U-values up to 1.8–2.0 W/m²·K may be acceptable, but solar heat gain coefficient (SHGC) becomes more critical here to reduce overheating.

It's also important to consider **solar orientation and shading**: In colder climates, south-facing windows with higher SHGC can help heat the interior naturally, while in hot climates, low-SHGC glazing and external shading are preferred.

To ensure high energy efficiency, window systems should be chosen according to both U-value and SHGC, and adapted to the local climate conditions. Triple-glazed, low-E windows with thermally broken or composite frames offer excellent performance in cold climates. In warmer areas, double-glazed low-E windows with solar control coatings and shading systems are often more appropriate and cost-effective.

5.4.3. Window Catalogs

Below are some of the main websites in English where you can access high-efficiency window catalogs, including PDFs and brochures:

- **Alpen High Performance Products**

  Alpen specializes in custom triple- and quad-pane windows certified for Passive House and ENERGY STAR standards. Their catalogs highlight advanced glazing, insulated frames, and integrated shading options.

  windowsbertrand.comthinkalpen.com+3thinkalpen.com+3thinkalpen.com+3

- **Marvin (Essential & Ultrex® Series)**

  Offers comprehensive catalogs featuring ENERGY STAR-certified low-E glass, argon fills, and Ultrex fiberglass frames. Catalogs include performance data like U-factors and solar heat gain coefficients.

  prioritydoorwindow.com+6irp.cdn-website.com+6energy.gov+6

- **REHAU**

  Polished PDF brochure showcasing **WER A-rated polymer window systems** with excellent thermal and acoustic insulation, tailored to UK/EU climates. window.rehau.com

- **SUNCE Marinkovic**

  English PDF catalog providing energy-efficient **PVC windows** featuring security mechanisms and thermal properties. en.wikipedia.org+12suncemarinkovic.com+12windowsbertrand.com+12

- **SILKA**

  English info for triple-glazed aluminium windows using **Thermafill® insulated frames**, boasting U-value as low as 0.8 W/m²K—one of the market's top performers. silkawindows.com

5.4.4. Thermal Properties of Main Entrance Doors for Residential Homes

The thermal performance of main entrance doors varies significantly depending on their materials and internal structure. Solid wood doors, while naturally insulating and visually appealing, typically offer U-values between 0.35 and 0.70 W/m²·K, which is less efficient compared to insulated alternatives [7]. Steel and fiberglass doors that incorporate polyurethane foam cores provide superior insulation, achieving U-values as low as 0.15–0.30 W/m²·K [8]. Additionally, glazed entry doors can offer good thermal resistance when equipped with double or triple low-emissivity (Low-E) glazing and gas fills such as argon [9]. The use of weatherstripping, insulated cores, and thermal breaks is critical to minimize air leakage and maintain energy efficiency [9].

Regulatory standards define maximum allowable U-values based on regional energy efficiency goals. In colder European regions, regulations typically require door U-values below 1.4–1.8 W/m²·K, depending on whether the door is new or a replacement [7]. More demanding certifications, such as Passive House, require U-values of ≤1.0 W/m²·K to minimize thermal loss [2]. In North America, ENERGY STAR guidelines also emphasize full door assembly performance, with maximum U-values of approximately 0.28 W/m²·K depending on the climate zone and door-glass ratio [9].

For cold and alpine climates, doors should ideally have U-values of ≤1.0 W/m²·K to reduce heating demands and improve thermal comfort [2]. In temperate regions, U-values up to 1.4 W/m²·K strike a practical balance between insulation and cost-effectiveness [1]. In warmer climates, such as Mediterranean or tropical areas, U-values up to 1.8 W/m²·K may suffice, especially when paired with low solar heat gain features [9]. Regardless of location, selecting doors with proper seals, thermal breaks, and certified insulation materials is essential to ensure long-term energy savings and indoor comfort [8].

Here are several high-performance, energy-efficient main entrance doors, along with their approximate thermal transmittance (U-values):

- **Insulated Fiberglass with Low-E Glazing** – Typically features a foam-core fiberglass door with double-pane, low-E glass inserts and argon gas fill. These doors usually achieve **U-values between 0.17 and 0.30 W/m²·K**, offering excellent insulation and modern aesthetics.
- **Steel Door with Polyurethane Core** – A durable steel exterior combined with a polyurethane-insulated core. These models often include thermal-break frames and weatherstripping, with **U-values ranging from 0.15 to 0.25 W/m²·K**, making them among the most thermally efficient.

- **Solid Wood with Composite Core** – This style maintains an elegant wood appearance but includes a composite or insulated core for improved performance. Their typical **U-values fall between 0.30 and 0.50 W/m²·K**, which is better than solid wood alone but higher than fully insulated designs.
- **Full-Glazed Door with Triple Low-E Panels** – A sleek, modern design using triple-pane low-E glass with inert gas filling (e.g., argon or krypton). These doors often reach **U-values around 0.70 to 1.20 W/m²·K**, depending on glass specifications and frame quality.

These mentioned examples highlight how different materials—fiberglass, steel, composite wood, and glazing—combine aesthetics with advanced thermal efficiency.

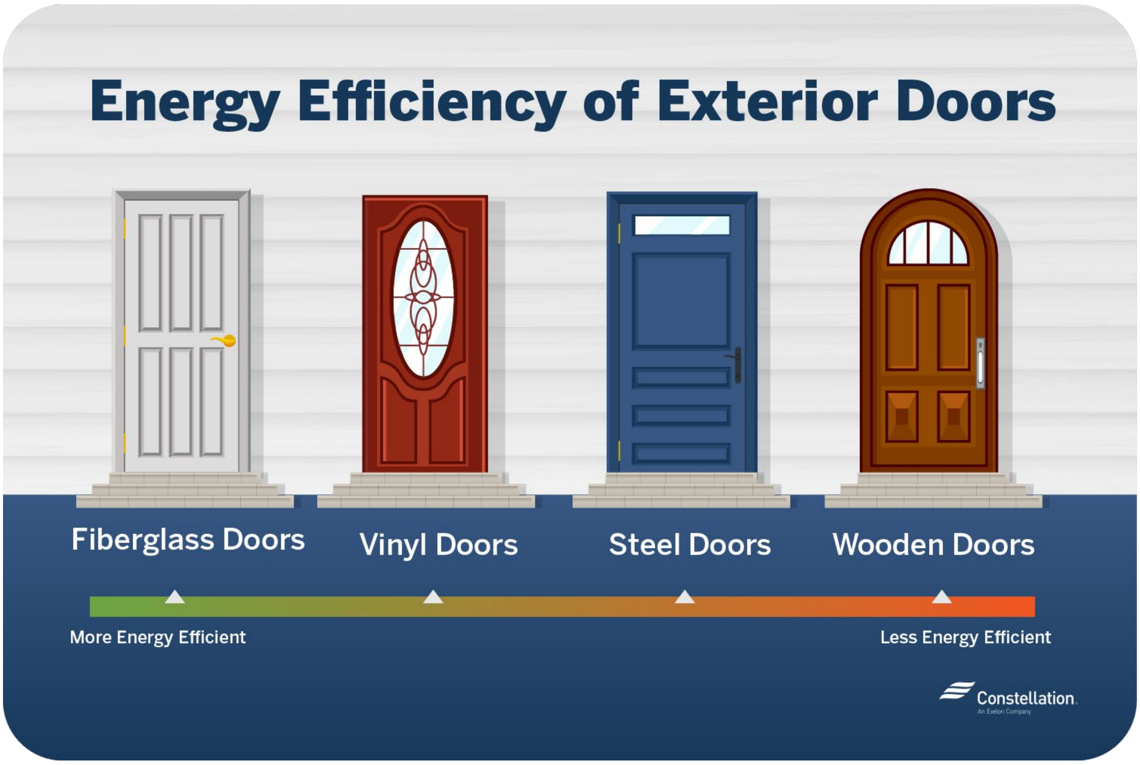


Figure 5: Examples of front doors of houses (Source: Constellaion.com)

5.5 – Examples of highly energy-efficient façades and roofs

5.5.1. Ventilated Facade vs Conventional Facade

Ventilated façades (also known as rainscreen or double-skin façades) work by incorporating an external cladding, an air gap, and insulation on the structural wall. The airflow in the cavity (often driven by the "chimney effect") reduces heat gains in summer and moisture build-up in winter, improving thermal performance. Studies have shown ventilated façades can reduce cooling loads by **20–55%** and improve U-value by approximately **30–40%** over conventional insulation systems [10].

A case study of residential buildings in Alicante, Spain, compared a north-facing ventilated façade (brick, 3 cm continuous insulation, 7 cm cavity, porcelain stoneware cladding) (Table 1) with a conventional insulated wall (Table 2). The ventilated system achieved a U-value around **0.20 W/m²·K**, compared to the conventional façade at **0.33 W/m²·K**, indicating a **40% improvement** in thermal transmittance [11].

Table 1: Constructional features of the housing façade. [11]

F_1_ Ventilated façade _Total thickness = 0.355 m		
Vertical construction and horizontal flow / Inside environment		Thickness (m)
1	Trim and plaster	0.015
2	Hollowed ceramic brick	0.115
3	Perforated ceramic brick	0.115
4	Thermal insulation: PUR projection [0.033 W/[mK]]	0.03
5	Metallic structure	–
6	Air gap ventilated	0.07
7	Outer discontinuous ceramic façade	0.01
Outside environment		

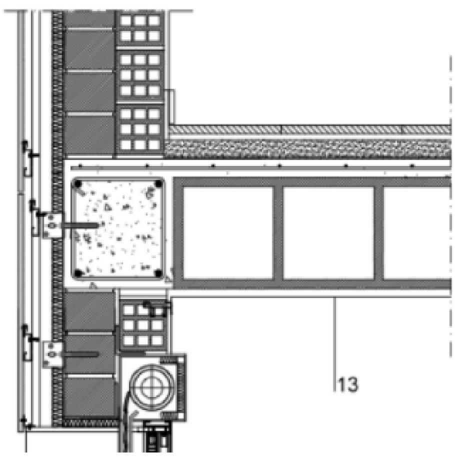
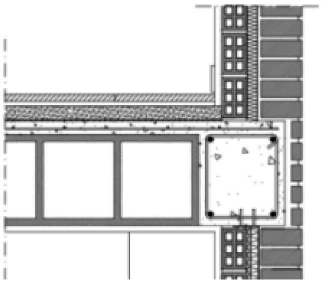


Table 2: Constructional features of the conventional façade. [11]

F_2_ Conventional façade _Total thickness = 0.24 m		
Vertical construction and horizontal flow / Inside environment		Thickness (m)
1	Trim and plaster	0.015
2	Hollowed ceramic brick	0.07
3	Thermal insulation: mineral wood [0.033 W/[mK]]	0.03
4	Mortar bed	0.01
5	Perforated ceramic brick	0.115
Outside environment		



Other examples of ventilated façade and conventional façade are shown in the following figures:

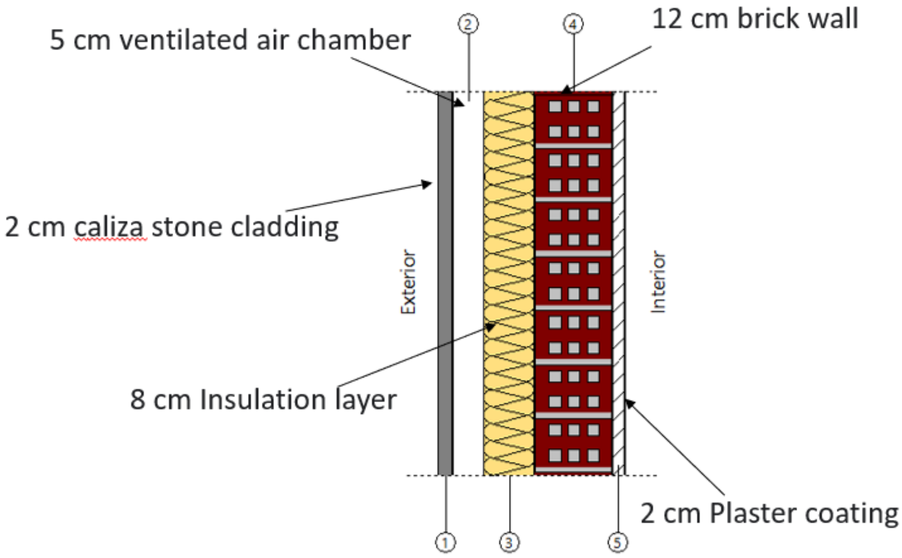


Figure 6: Ventilated facade (U = 0.33 W/m^2·K)

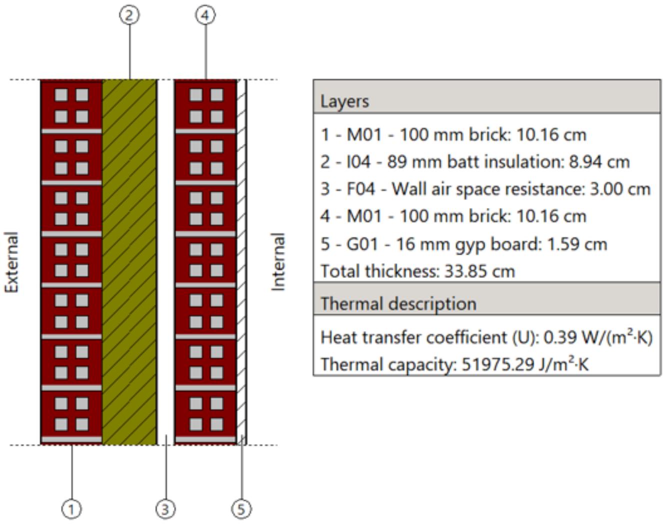


Figure 7: Conventional facade (U = 0.39 $W/m^2 \cdot K$)

5.5.2. Other type of facades

Another real-world example is the Indira Paryavaran Bhawan, a Net Zero Energy Buildings (NZEB) in Delhi. The building envelope construction comprises heavy weight construction. The external wall consists of 30 cm thick Autoclave Aerated Concrete (AAC) block, 7 cm thick mineral wool insulation, 12 cm thick air gap and 12 cm thick 'Fal-G' [proprietary blend of fly ash (Fa), lime (L) and gypsum (G)] block brick, and has a U-value of **0.22 W/m^2K** [12].

Figure 8: Indira Paryavaran Bhawan [12]

Another case to highlight is the double-skin facades. High-performance double-skin façades with glass skins and ventilated cavities—like those on Pearl River Tower or 30 St Mary Axe—enhance U-values to the range of **0.40–0.80 W/m²·K**, depending on cavity width and glazing type [13]. While glazed, these façades intelligently use natural or mechanical ventilation to manage solar radiation and control airflow.

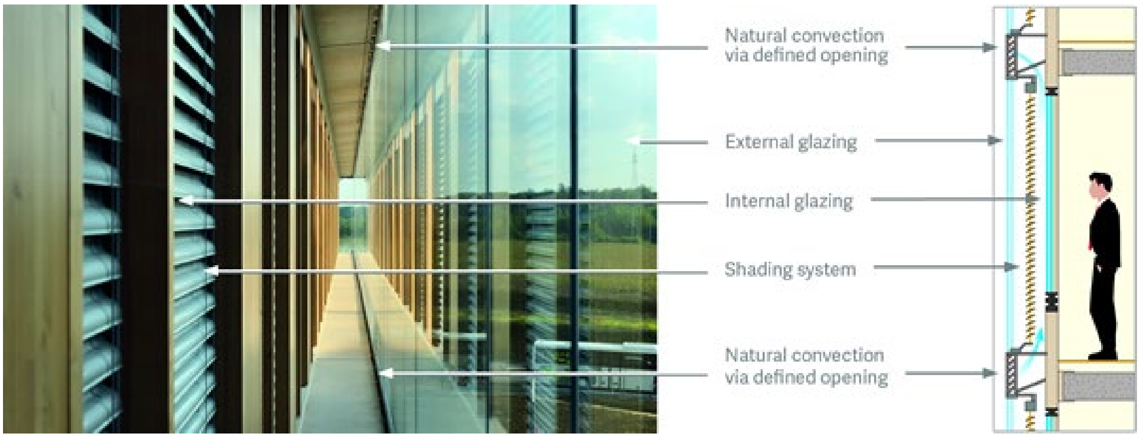


Figure 9: Doble skin facade

5.5.3. Examples of high-energy efficiency building roofs

Flat roof

A **flat roof** is a type of roof characterized by its minimal slope—usually less than 5%—and is commonly used in modern and commercial buildings due to its simple structure and efficient use of space. A typical flat roof system includes multiple layers: a structural deck, vapor barrier, thermal insulation, waterproof membrane, and sometimes a protective or finishing layer such as gravel, tiles, or vegetation.

Thermal Insulation Properties:

1. **Continuous Insulation Capability:** Flat roofs allow for continuous and uninterrupted installation of thermal insulation, minimizing thermal bridging. Common insulation materials include polyisocyanurate (PIR), extruded polystyrene (XPS), and mineral wool. Well-designed systems can achieve **thermal transmittance (U-values)** between **0.15 and 0.25 W/m²·K**, depending on insulation type and thickness.
2. **High Energy Efficiency:** The flat, uniform surface makes it easier to ensure consistent insulation thickness, which improves the overall thermal resistance. This helps reduce heat losses during winter and overheating in summer, enhancing indoor thermal comfort and reducing HVAC energy demand.

3. **Compatibility with Passive Systems:** Flat roofs are ideal platforms for integrating additional energy-efficient systems, such as green roofs, solar panels, or reflective coatings (cool roofs). Reflective flat roofs, for example, can reduce solar absorption by more than 70%, complementing the thermal insulation and improving performance in hot climates.

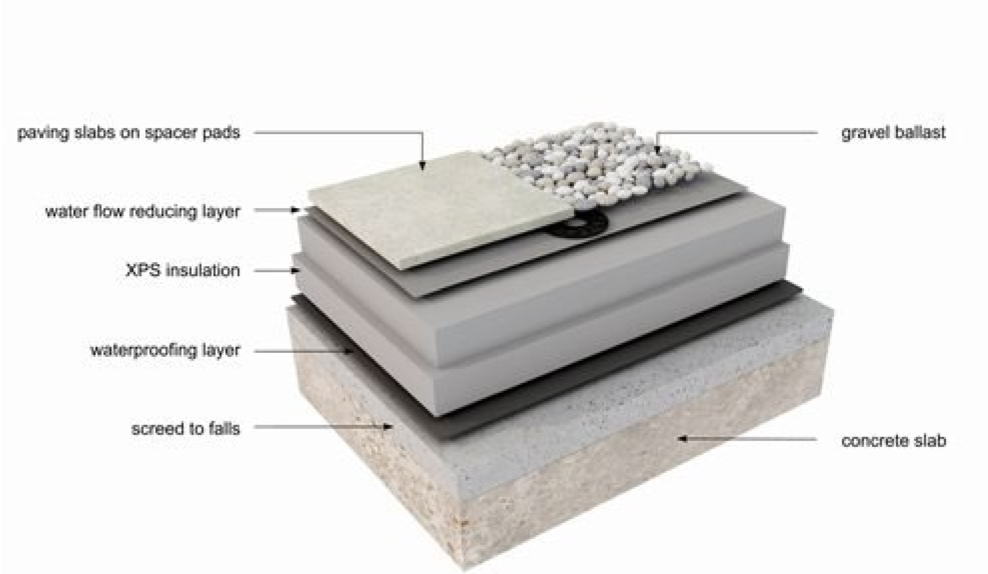


Figure 10: Flat roof

Ventilated cool roofs.

Definition and Mechanism: Ventilated cool roofs combine a **high-reflectivity outer layer** (solar reflectance between 0.65 and 0.85) with a **ventilated air cavity** beneath it. This configuration enables natural airflow where heated air escapes through high vents while cooler air enters from lower intakes, effectively **reducing thermal transmission** into the interior space [14]. This passive ventilation process also helps maintain a more stable roof temperature throughout the day.

Typical Structure and Thermal Transmittance (U-Value): A standard assembly consists of a **roof deck**, **vapor barrier**, **thermal insulation layer**, and a **ventilated cavity** approximately 25–50 mm deep, topped by the external roofing material (tiles, metal sheets, etc.). The insulated layer typically achieves **U-values ranging from 0.20 to 0.30 W/m²·K**, depending on the insulation type and thickness [15]. The ventilated layer contributes an additional thermal benefit, effectively reducing the **overall U-value by approximately 0.1 W/m²·K** through decreased conductive and convective heat transfer [15].

Cooling Effect and Energy Efficiency: Due to the combined effect of solar reflectance and ventilation, ventilated cool roofs can maintain **surface temperatures up to 30–40 °C**

cooler than dark, non-ventilated roofs [16]. This thermal performance results in **cooling energy savings of 30–50%**, depending on climate, roof configuration, and building type. In single-story buildings, reductions of **up to 15% in HVAC demand** have been documented when switching to ventilated reflective roofs [16].

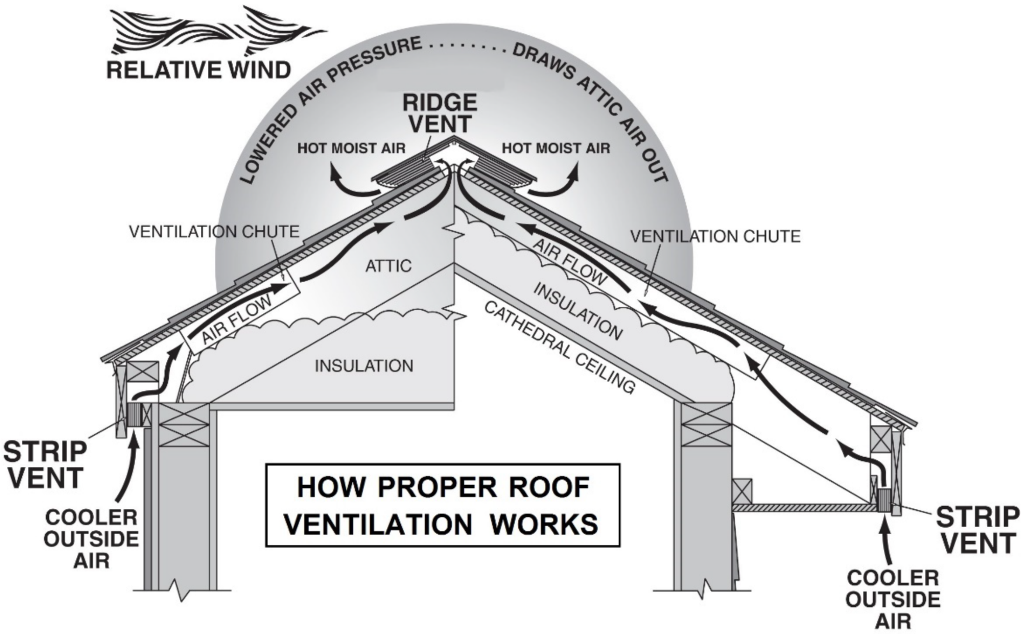


Figure 11: How ventilated roof works

Other advantages: Aside from energy efficiency, ventilated cool roofs offer several additional benefits:

- **Prolonged material lifespan**, as lower surface temperatures reduce thermal stress and degradation.
- **Moisture control**, minimizing the risk of condensation and mold development through continuous airflow [15].
- **Reduced urban heat island effect**, since these roofs emit less thermal radiation to the surroundings [14].

Figure 12: Tilled roof with brick walls (ventilated roof).

Green roofs

Figure 13: Geen roof.

Definition and Components: Green roofs consist of a **multi-layer system** installed on top of conventional roofs, incorporating waterproof membranes, root barriers, drainage layers, a growing medium (soil), and vegetation. They can be classified as **extensive** (6–20 cm depth, low-maintenance, lighter load) or **intensive** (20+ cm depth, supports trees and shrubs, heavier and more complex) [17]. These systems provide insulation and climate regulation, while adding aesthetic and ecological value to urban structures.

Thermal Transmittance and Performance: Green roofs act as natural thermal buffers. In summer, **evapotranspiration and shading** reduce heat transfer, and in winter, **soil mass and retained moisture** slow down heat loss. Measured U-values for green roofs vary, but typically range from **0.25 to 0.35 W/m²·K** depending on thickness and saturation [18]. Compared to traditional flat roofs (U ≈ 0.50–0.60 W/m²·K), green roofs can improve insulation by **up to 50%**, especially in summer.

Energy Efficiency and Indoor Comfort: In warm climates, green roofs can reduce indoor temperatures by **2–5 °C**, lowering air conditioning loads by **30–70%** during peak summer [18], [19]. In temperate climates, overall energy savings of **5–10% annually** have been reported. During winter, insulation gains are smaller but still relevant—studies show heating energy use reductions of **up to 10%** [18].

Environmental and Durability Benefits: Beyond thermal advantages, green roofs offer:

- **Stormwater retention** of up to 80% of rainfall, easing drainage systems.
- **Urban Heat Island mitigation**, reducing ambient air temperatures by up to 2–3 °C in dense areas [17].
- **Extended roof life**: by protecting waterproof membranes from UV radiation and thermal cycling, green roofs can **double the roof's lifespan**, reaching 40–50 years [20].

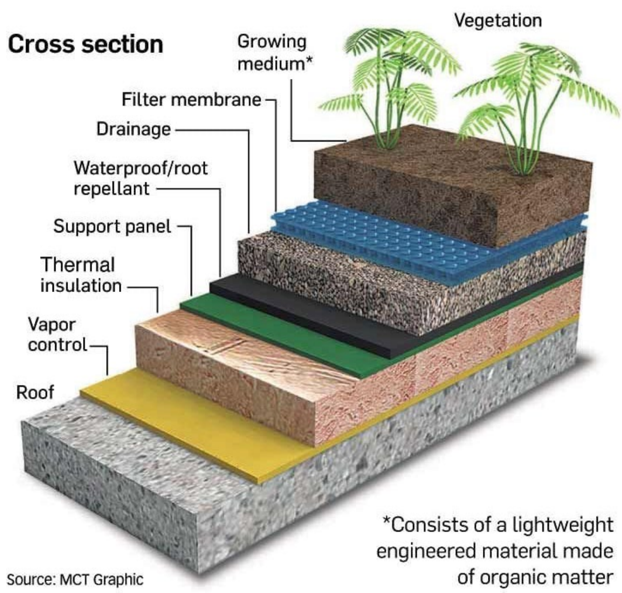


Figure 14: Geen roof. Source MCT graphic

5.6 Alternatives to improve the insulation of facades of existing buildings.

5.6.1. Introduction and Context

Improving the insulation of building facades is one of the most effective strategies for reducing energy consumption and increasing indoor comfort in existing structures. Facades often account for **20–35% of heat losses** in buildings, especially in cold and temperate climates [21]. Retrofitting these envelope elements can significantly reduce the building's U-value and energy demand without requiring major structural changes.

5.6.2. External Thermal Insulation Composite Systems (ETICS)

ETICS, also known as external wall insulation systems, involve applying **insulation panels (e.g., expanded polystyrene, mineral wool, or PIR)** on the exterior of walls, then covering them with mesh and finishing plaster. These systems can reduce wall U-values from around **1.0 W/m²·K (uninsulated masonry)** to as low as **0.20–0.25 W/m²·K**, depending on the material and thickness used [22]. ETICS also help prevent thermal bridging and improve façade durability by shielding the structure from weathering and UV radiation [22].

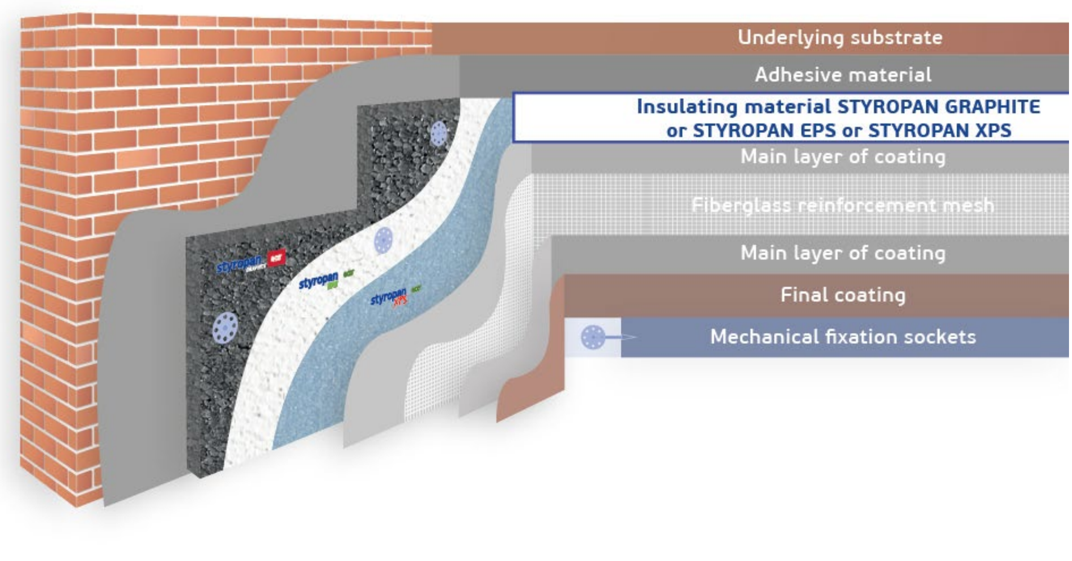


Figure 15: ETIC. Source: Styropan

Advantages of rehabilitating with ETICS

- **Improved Thermal Performance:** ETICS can reduce the **thermal transmittance (U-value)** of typical masonry walls from around **1.2–1.5 W/m²·K** (uninsulated) to **0.20–0.30 W/m²·K**, depending on insulation thickness and material. This improves indoor comfort and reduces heating and cooling demands by up to **40%** in temperate climates.

- **Minimized Thermal Bridges:** As the insulation is continuous over the wall surface, ETICS helps **eliminate linear thermal bridges** (e.g., at floor slabs or window lintels), which are frequent sources of heat loss in older buildings.
- **Preserved Interior Space:** Since insulation is applied externally, **no interior surface area is lost**, and the occupants are not displaced during installation.
- **Enhanced Façade Durability:** ETICS shields the underlying structure from **weathering, temperature fluctuations, and UV radiation**, extending the lifespan of walls and reducing maintenance costs.
- **Aesthetic Renovation:** The system allows for a wide variety of **finishes, textures, and colours**, providing an opportunity to modernize the building's appearance along with improving performance.

Disadvantages of ETICS:

- **Façade Modifications Required:** The added thickness (typically **8–20 cm**) may require adaptations at **window reveals, sills, eaves, and balconies**, increasing labour complexity and cost.
- **Mechanical Vulnerability:** Despite a reinforced outer layer, ETICS can be **susceptible to mechanical damage** (e.g., impact, vandalism), especially in ground-floor areas, and may require periodic repairs or reinforcements.
- **Regulatory or Heritage Constraints:** In historic or architecturally protected buildings, **external alterations may be restricted**, making ETICS an unsuitable or prohibited option.
- **Initial Investment:** The upfront cost, including scaffolding, skilled labour, and detailing, is **relatively high** compared to some other solutions, though long-term savings often justify the expense.

5.6.3. Ventilated Facades (Rainscreen Cladding Systems)

Ventilated façades involve a **layered wall system** with an exterior cladding (e.g., ceramic, metal, fiber cement), an air cavity, and an underlying layer of thermal insulation. This setup enables **airflow between the insulation and cladding**, enhancing hygrothermal performance and reducing moisture buildup. The ventilated air layer acts as a thermal buffer and can reduce U-values to **0.15–0.30 W/m²·K**, depending on the insulation material and cavity depth [23]. These systems are widely used in both energy retrofits and aesthetic façade upgrades.

Figure 16: Energy rehabilitation of the façade. Ventilated façade

5.6.4. Interior Insulation Solutions

When external insulation is not feasible (e.g., heritage buildings), **internal wall insulation** is a viable alternative. Materials such as **vacuum insulation panels (VIPs)**, aerogels, or mineral wool boards are applied to the internal face of the wall. While these systems are easier to install from within, they may slightly reduce usable space and require vapor control layers to prevent condensation. Depending on the product, interior retrofits can reduce U-values to **0.30–0.45 W/m²·K** [24].

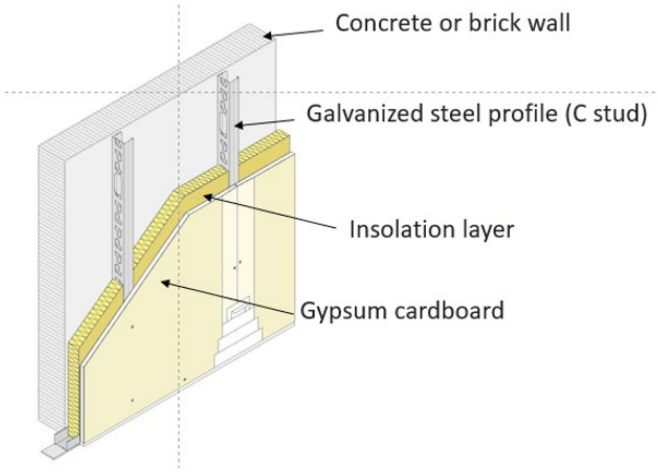


Figure 17: Interior insulation solution.

Internal wall insulation is often used when insulating the exterior of a building is not possible—typically due to urban restrictions, architectural preservation requirements, or budget limitations. These systems involve applying insulation materials (such as mineral wool, polyurethane boards, aerogels, or composite panels) to the inner surface of existing external walls.

Advantages of internal insulation solutions:

- **Preservation of the Building's Exterior:** One of the main benefits is that the building's outward appearance remains unchanged. This makes internal insulation particularly suitable for **heritage buildings**, where modifications to the façade are often restricted.
- **Simplified Installation:** Internal insulation can usually be installed **room by room**, allowing for **phased renovation**. This is helpful in residential settings where occupants may continue to use parts of the building during the works.
- **Lower Initial Cost:** Compared to external insulation systems, internal solutions can be **less expensive**, especially in buildings with complex façades, ornamentation, or difficult access for scaffolding.
- **Improved Indoor Comfort:** Properly applied, internal insulation can significantly **reduce heat loss**, **increase surface temperatures**, and **reduce condensation** on interior walls, improving thermal comfort during winter months.

Disadvantages of internal isolation solutions

- **Reduced Interior Space:** One notable drawback is the **loss of usable floor area**, especially when thicker insulation is used to meet thermal requirements. This can be a concern in smaller rooms or apartments.
- **Thermal Bridging Risks:** Internal insulation does not cover structural junctions such as floor slabs or internal partitions. This creates **thermal bridges**, which may reduce overall energy performance and lead to **localized condensation or mold growth**.
- **Condensation and Moisture Risks:** If not properly designed with **vapor control layers** or breathable materials, internal insulation systems can trap moisture within the wall, leading to **interstitial condensation** and degradation of the building fabric.
- **Disruption to Occupants:** Installing insulation internally involves working inside the building, which may require **moving furniture, electrical work,** and **redecorating**. This can disrupt occupants during renovation.
- **Complex Detailing Required:** Proper execution is critical, especially around **window reveals, sockets, radiators,** and **junctions**. Poor detailing may compromise both thermal performance and moisture control.

5.6.5. Other system: Hydronic Shells

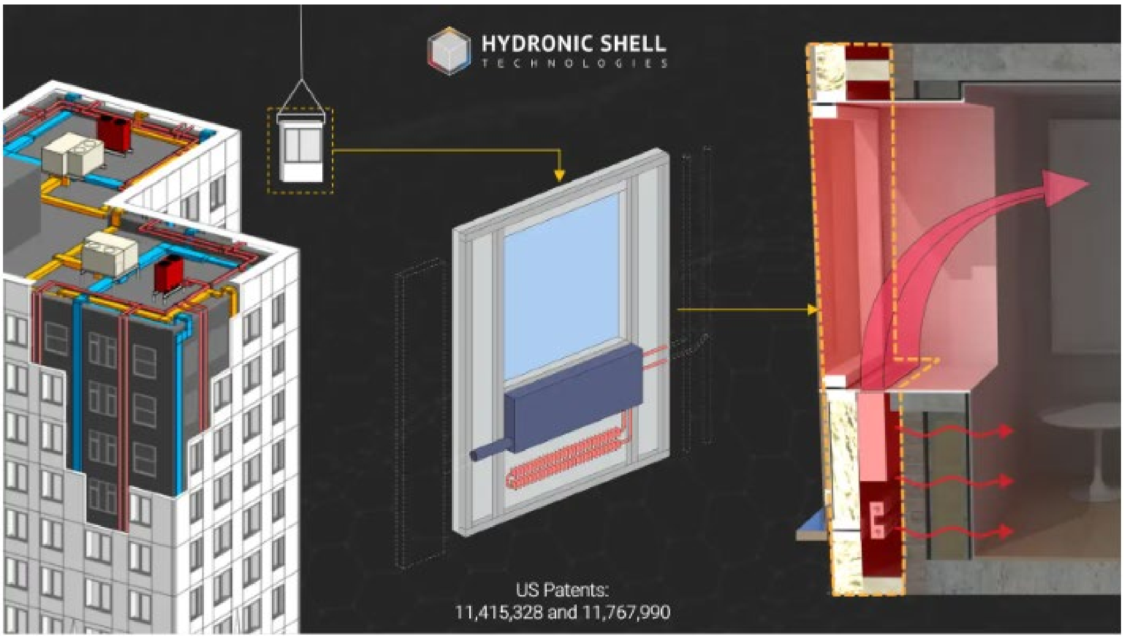


Figure 18: Hydronic shell system [25]

The **Hydronic Shell System** is an innovative façade-integrated solution designed for the **deep energy retrofit** of existing buildings, particularly those with limited insulation and outdated heating systems. It consists of a prefabricated external envelope that incorporates high-performance insulation and an integrated **hydronic radiant heating and cooling network**. This network circulates water through embedded pipes or panels within the façade, enabling low-temperature heating in winter and passive or active cooling in summer. The system not only improves thermal insulation (with U-values typically below **0.20 W/m²·K**) but also replaces or supplements traditional HVAC systems, resulting in significant energy savings and improved indoor comfort.

One of the key advantages of the Hydronic Shell is that it allows for a **non-invasive retrofit**, as the modules are mounted externally and can be installed with minimal disturbance to building occupants. In addition to improving energy performance, the system provides a new ventilated façade with potential architectural renewal. Its compatibility with renewable energy sources (like heat pumps or solar thermal) further enhances its sustainability. Although still an emerging solution in terms of large-scale implementation, it represents a promising strategy for achieving **near-zero energy buildings (nZEB)** standards in the existing building stock.

References

[1] U.S. Department of Energy, "Building Envelope," Energy.gov. [Online]. Available: https://www.energy.gov/energysaver/design/energy-efficient-home-design/building-envelope

[2] Passive House Institute, "What is a Passive House?" [Online]. Available: https://passivehouse.com

[3] American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), *ASHRAE Handbook – Fundamentals*, Atlanta, GA: ASHRAE, 2021.

[4] L. Pérez-Lombard, J. Ortiz, and C. Pout, "A review on buildings energy consumption information," *Energy and Buildings*, vol. 40, no. 3, pp. 394–398, 2008.

[5] U.S. Department of Energy, "Types of Windows," *Energy Saver*, https://www.energy.gov/energysaver/types-windows

[6] NFRC (National Fenestration Rating Council), "Window Performance Ratings," https://www.nfrc.org

[7] Urban Front, "U Values and your front door: A guide," *Urban Front*, 2025. [Online]. Available: https://www.urbanfront.com/blog/u-values-and-your-front-door/

[8] King Locksmiths, “Best R-value and U-factor Comparison for Doors,” *King Locksmiths Blog*, 2024. [Online]. Available: https://www.kingdoorandlock.com/r-value-vs-u-factor-door-insulation/

[9] A. Biro, “A Guide to Energy-Efficient Doors in 2025,” *Green Building & Design (gb&d)*, Apr. 22, 2025. [Online]. Available: https://gbdmagazine.com/energy-efficient-doors/

[10] Camila Prieto, “Ventilated Facades for Energy-Efficient Building Rehabilitation,” *ArchDaily*, June 2023. [Online]. Available: <archdaily.com>

[11] A. Espinosa-Fernández et al., “Energy Efficiency of Ventilated Façades,” *WIT Transactions on The Built Environment*, vol. 171, pp. 41–52, 2017.

[12] “Indira Paryavaran Bhawan,” *Wikipedia*, Apr. 2025. [Online]. Available: <wikipedia.org/wiki/Indira_Paryavaran_Bhawan>

[13] “Double-skin facade,” *Wikipedia*, 2023. [Online]. Available: <wikipedia.org/wiki/Double-skin_facade>

[14] U.S. Department of Energy, “Cool Roofs,” *Energy.gov*, 2021. [Online]. Available: https://www.energy.gov/energysaver/cool-roofs

[15] AIVC, “The Thermal Performance of Ventilated Roofs,” *Air Infiltration and Ventilation Centre*, 2006. [Online]. Available: https://www.aivc.org/sites/default/files/members_area/medias/pdf/Inive/epic2006/Volume_1_Epic06/E06/040_Borg.pdf

[16] M. Singh et al., “A comparative review of cool roof thermal performance,” *Journal of Building Engineering*, vol. 43, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2666123321000209

[17] U.S. Environmental Protection Agency, “Using Green Roofs to Reduce Heat Islands,” *EPA*, 2022. [Online]. Available: https://www.epa.gov/heatislands/using-green-roofs-reduce-heat-islands

[18] A. Niachou, K. Papakonstantinou, M. Santamouris, A. Tsangrassoulis, and G. Mihalakakou, “Analysis of the green roof thermal properties and investigation of its energy performance,” *Energy and Buildings*, vol. 33, no. 7, pp. 719–729, 2001. [Online]. Available: https://doi.org/10.1016/S0378-7788(01)00062-7

[19] Living Roofs, “Green Roofs and Energy Conservation,” *LivingRoofs.org*, 2023. [Online]. Available: https://livingroofs.org/energy-conservation/

[20] Urban Greening, “Benefits of Green Roofs,” *Green Roofs for Healthy Cities*, 2023. [Online]. Available: https://greenroofs.org/resources/benefits-of-green-roofs/

[21] European Commission, “Energy performance of buildings,” *European Union*, 2023. [Online]. Available: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings_en

[22] Baumit, “ETICS External Thermal Insulation Composite System,” *Baumit Technical Datasheets*, 2022. [Online]. Available: https://www.baumit.com/products/facade/etics

[23] Knauf Insulation, “Ventilated Façade Systems,” *Knauf Technical Guide*, 2023. [Online]. Available: https://www.knaufinsulation.com/en/products-solutions/facades

[24] Historic England, “Energy Efficiency and Historic Buildings: Internal Wall Insulation,” 2016. [Online]. Available: https://historicengland.org.uk/images-books/publications/eehb-internal-wall-insulation/

[25] Hydronic Shell, “How It Works — Hydronic Shell,” *HydronicShell.com*, accessed Jun. 2025. [Online]. Available: https://www.hydronicshell.com/

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

What the thermal envelope of a building is.

The physical properties of a building's thermal envelope.

Strategies to optimize the thermal enveloped of a building.

Components of the Thermal Envelope.

Types of high-energy efficient windows and doors.

Examples of highly energy-efficient windows and doors.

Examples of highly energy-efficient facades and roofs.

Measures to improve the insulation of the façades and walls of the thermal envelope.