Environmental Impact and Energy Efficient Result when Using Passive House

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Abstract: Passive houses are those that make the most of bioclimatic architecture to create a building with high energy efficiency whilst ensuring suitable comfort throughout the year**.** These are homes designed to use minimally active heating or cooling systems, leading to near-zero energy consumption. A passive house is not just a set of high-quality windows or insulation materials but a complete approach to sustainable living. People took these currents of thought into account and began to consider the idea of buildings that used as little energy as possible without economizing on the comforts of the people living in them. The goal of a passive house is to attain near-zero energy consumption, significantly reducing utility bills and lessening the home's impact on the environment. Unlike traditional buildings that rely heavily on active heating and cooling systems, a passive house utilizes natural resources like sunlight and airflow to maintain a comfortable interior climate.

Key-Words: affordable, benefits, comfortable, energy efficient, healthy, passive house, versatile.

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1 Introduction

The Passive House Institute defines a passive house as "a building in which a comfortable interior climate can be maintained without active heating and cooling systems". According to Wolfgang Feist and Bo Adamson (founders of the Passivhaus Institute), passive house is basically defined as a building that does not need any form of active heating and cooling systems to keep the climate inside the building at comfortable levels. The name "Passive house" is given by the concept passive heating or cooling. A Passive House needs less energy to maintain constant temperature throughout the building. It means that these buildings are almost "Passive", since they hardly need any active heating/cooling for the purpose of staying comfortable throughout the year.

This concept ultimately does not mean that the heating/cooling operations are carried out without using any energy at all. It is just about intelligent design, which includes reaching the desired amount energy usage within the minimal usage of complex systems. To add to this, non-renewable resources can also be used.

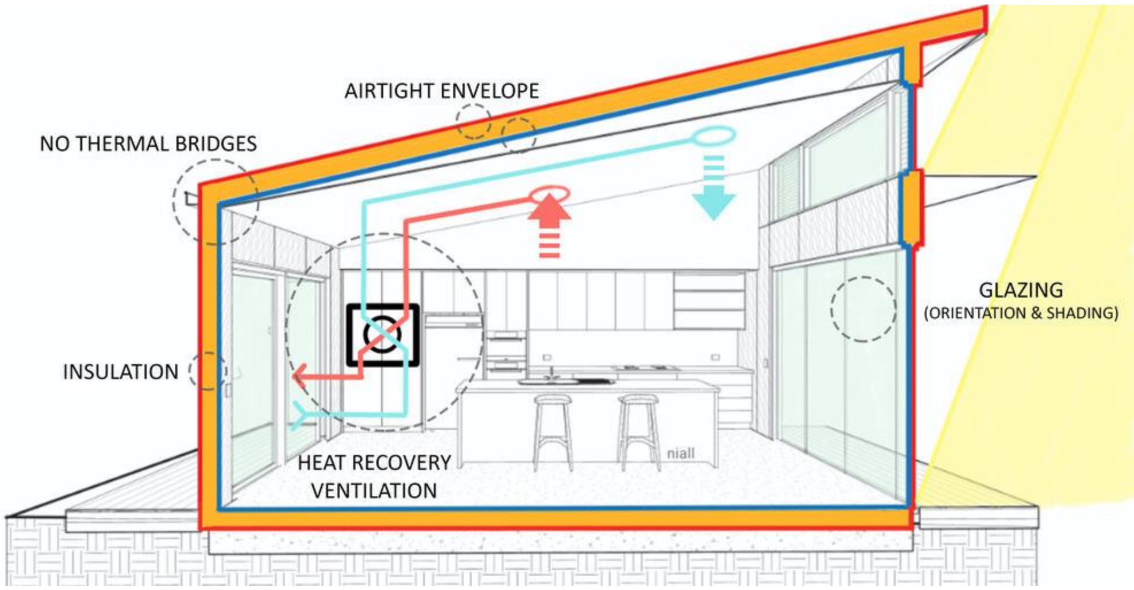


Fig.1 Passive house principles.

2 The Core Principles of Passive House

1. High Levels of Insulation: One of the cornerstones of a Passive House is the use of superior insulation. Walls, roofs, and floors are meticulously insulated to prevent heat from escaping during winter or entering during summer. This creates a stable indoor environment that requires minimal energy to maintain a comfortable temperature.

2. Airtight Construction: Airtightness is crucial in preventing drafts and reducing heat loss. In a Passive House, great care is taken to seal all joints and penetrations to ensure that the building envelope is as airtight as possible. This not only improves energy efficiency but also enhances indoor comfort by eliminating cold spots and drafts.

3. High-Performance Glazing: Windows, doors and rooflights are often the weakest link in a building's thermal envelope. Passive Houses use high-performance glazing, typically triple-glazed, to minimize heat loss. These systems also incorporate advanced framing materials and gas-filled panes to provide excellent insulation without compromising on natural light.

4. Heat Recovery Ventilation (HRV): Maintaining good indoor air quality is essential in an airtight building. Passive Houses use mechanical ventilation systems with heat recovery to provide a constant supply of fresh air without significant heat loss. The HRV system captures heat from outgoing stale air and transfers it to incoming fresh air, ensuring that the indoor environment remains healthy and comfortable.

5. Thermal Bridge-Free Design: Thermal bridges are areas in a building where heat can easily flow through materials, by passing insulation. Passive Houses are designed to eliminate these bridges, ensuring that the thermal envelope remains unbroken. This involves careful detailing at junctions and connections to prevent heat loss.

3 Benefits of Passive Houses

The advantages of building to the Passive House standard are numerous:

1. Energy Savings: Passive Houses can reduce energy consumption for heating and cooling by up to 90% compared to traditional buildings. This translates into lower utility bills and a smaller carbon footprint.

2. Comfort: The combination of high insulation, airtightness, and controlled ventilation ensures a consistently comfortable indoor environment, free from drafts and temperature fluctuations.

3. Indoor Air Quality: With a constant supply of fresh, filtered air, Passive Houses provide superior indoor air quality, which is particularly beneficial for occupants with allergies or respiratory issues.

4. Sustainability: By significantly reducing energy demand, Passive Houses contribute to a more sustainable future. They lower greenhouse gas emissions and reduce dependence on fossil fuels.

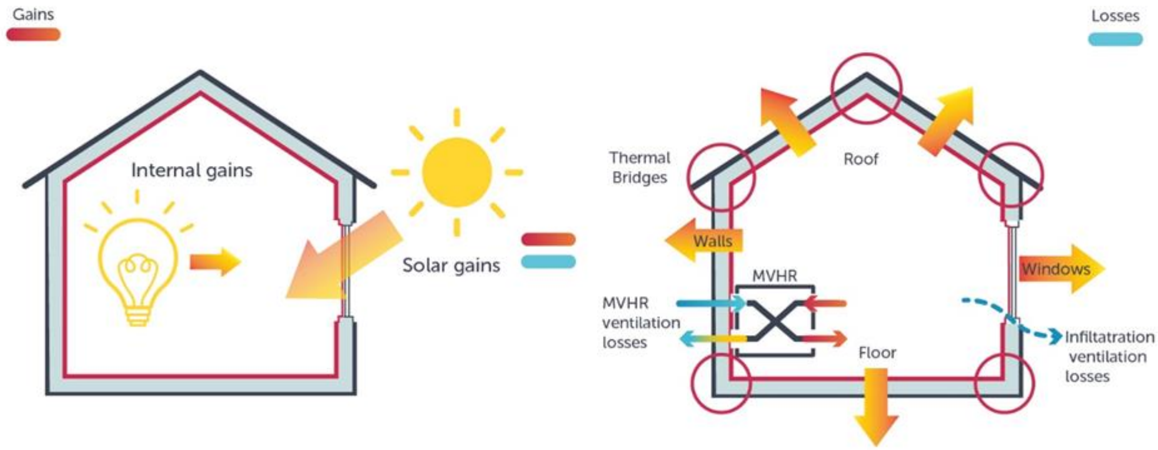


Fig.2 The heat gains and losses balanced in a Passive House home.

4 Principles of Passive House

4.1 Airtight Construction

Heat can also be lost through the envelope via air leakage. A building's air barrier is a layer of material (membrane, tape, seals) around the envelope that restricts the movement of air in and out of the building. Gaps in the air barrier can allow air to move in and out of the building uncontrolled; they occur when there is insufficient detailing during construction, when there are numerous ducts or other penetrations in the air barrier, or when construction is of generally poor quality.

High volumes of uncontrolled air exchange with the exterior can lead to a whole host of problems, including increased energy use from having to repeatedly reheat the air, discomfort from cold air drafts near the walls, and localized moisture and condensation problems.

Airtight construction on a Passive House project will further reduce space-heating costs and localized condensation problems and will provide better comfort inside the building. In a Passive House building these advantages cannot be achieved by tightening the building envelope alone but must be coupled with a suitable ventilation strategy to deal with excess humidity in the building.

4.1.1 Air pressure test

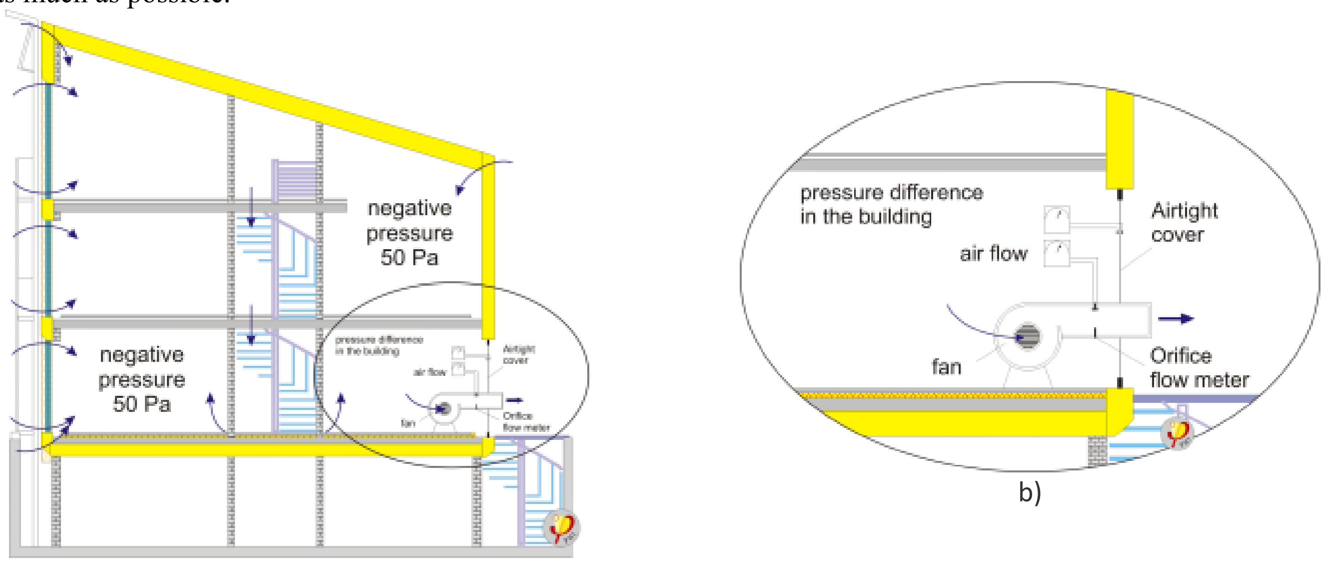
The **air pressure test**, or the **n_{50}-value** measures the total leakage through the building envelope. The n_{50}-value (in h^{-1}) describes the air changes at a differential pressure of 50 Pa. A differential pressure of 50 Pa (equivalent to 5 mm water column) is created between the inside of the building and the outside by means of a blower door test. The blower door consists if a compressor built into an opening in the envelope (e.g. a door) creating underpressure inside the building in order to detect leakages. The actual test involves a series of underpressure and overpressure measurements determining the leakage rate at a differential pressure of 50 Pa in relation to the air volume V_{n50}.

The n_{50} leakage rates **may not be greater than 0.6 h^{-1}** to comply with the certification criteria. In fact, values between 0.2 and 0,6 h^{-1} were achieved with built Passive Houses.

The air volume V_{n50} within the heated building envelope is the volume that will be used for calculating the n50 air leakage value. Air change rate at 50 Pa [h^{-1}].

4.1.2 Glazing

While the walls typically make up the largest area of a building's façade, the glazing systems (windows and glazed doors) can play an even bigger role when it comes to contributing to space-heating energy. Due to their function (providing light and visibility), glazing systems cannot be insulated to the same degree as a wall, resulting in the windows being the weakest areas of the envelope in terms of heat-flow resistance. Therefore, it is very important that high-performance glazing systems, such as Passive House-certified windows, are used to reduce that heat flow as much as possible.



a) b)

Fig.3 a) Procedure of the pressurisation test with air flows due to leakages with underpressure; b) testing procedure with devices for measuring the differential pressure.

Some key characteristics of a high-performance Passive House glazing system, as shown in Fig.2, include:

- **Triple or Double Glazing:** Units with two or three panes of glass, often with low-emissivity (Low-E) coatings, provide the best thermal performance.
- **Inert Gas Fills:** Spaces between panes are filled with argon or krypton gas, which are denser than air and reduce thermal transfer.
- **Warm-Edge Spacers:** Advanced spacers between glass panes reduce heat loss around the edges and minimize condensation.
- **Insulated Frames:** High-performance frames made of materials like vinyl, fiberglass, or wood-aluminum composites minimize conductivity.
- **Vacuum Insulation:** Emerging technology like vacuum insulated glass (VIG) offers superior insulation in a much slimmer profile, similar to triple glazing.
- **Low-emissivity** (low-e) glass is coated with a microscopic layer of metallic material that reflects thermal energy back inside during winter and repels it outside in summer.
- It is important not only to make sure to specify high-performance windows, but also to carefully consider how they are incorporated into the building design. Passive House designs take advantage of free passive heating from the sun. Solar heat gain through appropriately placed windows can help offset the amount of heat a building needs during colder months. During the summer months, this needs to be counteracted with shading to prevent too much heat from the sun from getting into the building, causing overheating. For each Passive House project, there will be an ideal number of windows that can balance the advantage of free heat from the sun with minimizing the heat loss from having too many windows.

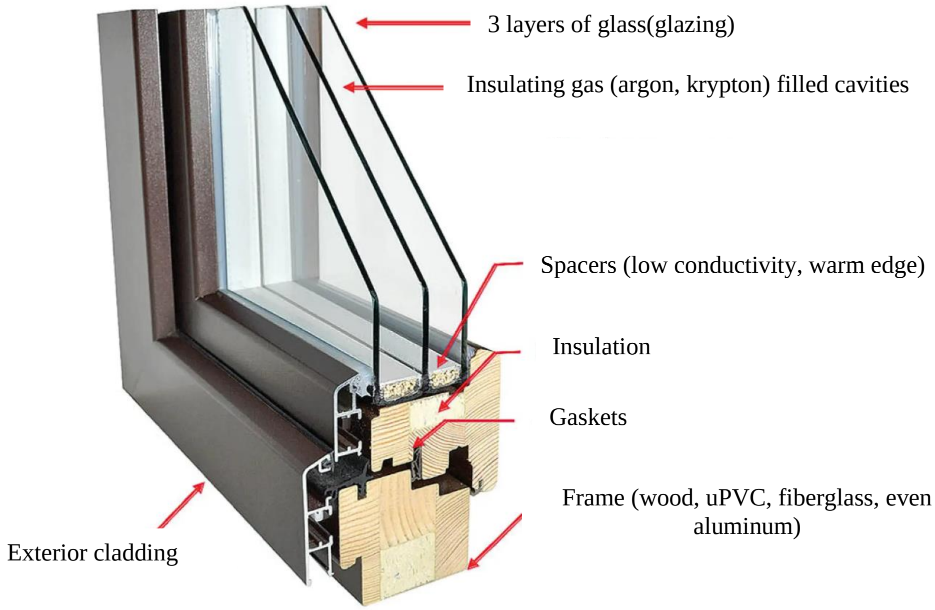


Fig.4 Triple glazed windows.

4.1.3 Heat recovery ventilation

HRV is arguably the most important component in a Passive House. Natural ventilation can be unreliable because of natural factors, particularly unpredictable weather conditions. A heat recovery ventilation device can recover heat from the extracted air and transfer it to the supplied air, ensuring minimal heat energy loss and good indoor air quality.

Attaining great air quality in Passive Houses is not as simple as opening the window to let air in, as buildings near industrial zones or in certain climates can have poor natural conditions. Passivhaus overcomes this by using a mechanical ventilation system, which allows for 100% fresh air to be provided all year round. Filtered fresh air is constantly supplied to living areas or bedrooms, while exhaust air is simultaneously extracted from areas like the bathrooms and kitchens. This mechanical ventilation system is the same one that enables the heat recovery process mentioned above, further increasing the building's design efficiency.

4.1.4 Supply and exhaust air systems with heat recovery

Ventilation will only work properly if used air is continuously removed from the kitchen, bathroom, toilet and other rooms with high pollution and humidity. In return, fresh, unused external air is supplied to the living room bedrooms and functional rooms.

The principle behind convenient home ventilation: used air (brown) is continuously being removed from the rooms with high levels of pollution and humidity. Fresh air (light blue) is supplied to the living areas. Good quality air is an important prerequisite for a healthy and comfortable living climate. Just the right quantities of fresh air that are required for the good health and comfort of the occupants are supplied. Only untreated air enters the living areas, there is no recirculated air, thus providing a hygienic air quality.

Passive Houses only work if a highly efficient heat recovery system is also present**.** This recovers the heat from the exhaust air and, using a heat exchanger, transfers it back into the supply air without mixing the air flows. Today, modern ventilation technology allows a heat recovery rate of between 75 and 95 %. This is possible due to counterflow heat exchangers and special energy-efficient fans (with so-called EC motors with a particularly high effectiveness), so that the recovered heat is 8 to 15 times the electricity consumed.

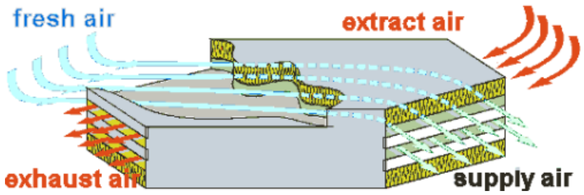


Fig.5 Heat exchanger.

This is how a heat exchanger works: The stale extract air (red) flows through a duct and transfers its heat to the plates above and below. It cools down and exits as exhaust air (orange). Unused fresh air streams in through separate ducts on the other side of the plates. It takes up the heat and is available as warm (but still fresh) supply air (light turquoise). The counterflow principle makes up for almost 100% of the temperature difference. Saving energy by using heat recovery is not only cost-effective and environmentally friendly but also healthy fresh air is provided constantly without having to keep opening the windows. This applies for all buildings, not just for Passive Houses.

Due to this principle of directed air flow, fresh air is optimally utilized: it provides high quality air in the living areas, removes any bad air from the air zones transferred (e.g. odors from clothes), and finally dehumidifies the humid areas.

The devices ensure the separation of exhaust air and supply air, don't consume much electricity and are very silent.

With such a heat recovery system, the remaining ventilation losses are insignificant: they are only between 2 and 7 kWh/(m²a), which is a good prerequisite for a functioning Passive House.

Thus, due to the heat recovery, the temperature of the supply air is raised to near room air temperature, therefore the air entering the room is not "cold" anymore. Together with very good insulation of the building envelope and the windows, it is possible to get along with very little heating power and reduce the effort for installation.

4.1.5 Thermal Insulation of Passive Houses

Good insulation aims to keep the interior at a comfortable and stable temperature. It prevents heat from escaping and prevents cold air from affecting the inside temperature. As mentioned above, one of the selling points of the Passive House is its thermal comfort, where good thermal insulation retains the temperature from foundations and walls to the roofs (thick yellow line in the below image). The building also must account for another layer of air leakage, as most insulation materials are not airtight (red line).

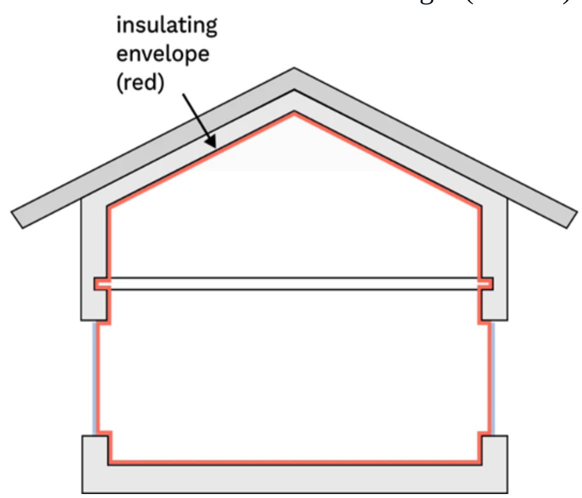


Fig.6 Passive House Envelope.

The heat losses though a standard building component, i.e. external wall, floor, top floor ceiling or roof, are defined by the **U-value** or **overall heat transfer coefficient**. This value indicates the **rate of heat transfer through a specific component over a given area** if the temperature difference is one degree (1 Kelvin). The measurement unit of the U-value is therefore "W/(m²K)". The smaller the U-value the better the level of insulation.

To calculate the **heat loss** through a wall, one must multiply the U-value with the area and temperature difference. In Central Europe, the average temperatures measured during severe winter periods are –12 °C outside and 21 °C inside.

The heat losses through a standard building component, i.e. external wall, window, floor, roof, are defined by the **U-value** also known as the **heat transfer coefficient, or thermal transmittance coefficient**. This value indicates the **rate of heat transfer through a specific component over a given area** if the temperature difference is one degree (1 Kelvin). The measurement unit of the U-value is therefore "W/(m²K)". Thus, the lower the U-value, the lower the rate of heat transfer, and the better the insulating property of the element! In other words, the more slowly heat moves through the material.

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

We can alternatively think of the thermal 'quality' of the element in terms of the **R-value**, also known as

the **thermal resistance**. The R-value is simply the reciprocal of the U-value and describes how much resistance a material or element presents to heat flow.
To calculate the **annual heating losses**, one must multiply the U-value with the average temperature difference in the heating period with the duration of the heating period, or in other terms, multiply the U-value by the heating degree hours – which is 78,000 degree hours for an average Central European climate.
Table 1 presents the typical heat losses for different external walls based on a typical European single-family house with an external wall area of 100 m². Winter temperatures of -12 °C outside and 21 °C at the inside are used as they are typical of Central Europe.

Table 1. Typical heat losses for an average climate

U-value [W/m^{2}K]	**Heat loss rate [W]**	**Annual heating losses [kWh/yr]**
1.00	3,30	7,80
0.80	2,64	6,20
0.60	1,98	4,70
0.40	1,2	3,10
0.20	660	1,60
0.15	495	1,20
0,10	330	800

The heat loss is a significant factor in the energy balance of a building. Any heat loss must be compensated for by a corresponding heat gain, otherwise the temperature inside the house will drop. For typical Central European buildings, U-values of Passive House walls should range between 0.10 and 0.15 W/(m²K); depending on the climate, these figures may be somewhat higher or lower.
Table 2 shows the thickness needed of an exterior construction, if that is solely built from the material given, to meet a typical passive house U-value of 0,13 W/(m²K).
Table 1 shows thermal conductivity of common building materials and thickness required to obtain a U-value = 0.13 W/(m^{2}K).

Types of thermal bridges

In general, a distinction is made between linear and point thermal bridges. Linear thermal bridges include ceiling junctions, projecting balcony slabs, outer corners, verges and eaves.

Table 2. Thermal conductivity and thickness

Material	**Thermal conductivity [W/mK]**	**Thickness required for U = 0.13 W/(m^{2}K) [m]**
Reinforced concrete	2.3	17.30
Solid brick	0.80	6.02
Softwood	0.13	0.98
Porous brick/concrete	0.11	0.83
Straw	0.055	0.41
Typical insulation material	0.040	0.30
Vacuum insulation material	0.002	0.015

From this table a reasonable thickness of components is available only if quite good insulation material is used.

4.1.6 Thermal bridge

Thermal bridges are thermally weak points or interruptions in the building envelope. More heat is lost here than in areas without interruptions. Due to this, the temperature of the interior surface near the thermal bridge is lower. If this spot becomes too cold, there will be increased moisture and mould may even form, potentially damaging the building structure. A better level of thermal protection generally leads to higher temperatures, including near thermal bridges, therefore highly energy efficient buildings are always less problematic in this regard. In general, a distinction is made between linear and point thermal bridges. Linear thermal bridges include ceiling junctions, projecting balcony slabs, outer corners, verges and eaves. Point thermal bridges are single penetrations in the thermal envelope of the building. Examples of these include mounting brackets for canopies, penetrations by electrical cables, sub-constructions for ventilated façades and insulation fasters.

Point thermal bridges are single penetrations in the thermal envelope of the building. Examples of these include mounting brackets for canopies, penetrations by electrical cables, sub-constructions for ventilated façades and insulation fasteners. Let's look at one for

the most common examples of a thermal bridge: the projecting balcony slab.
If the concrete slab continues through the insulation as a balcony, then the thermal building envelope will be completely penetrated by the heat-conducting concrete, resulting in a significant thermal bridge. In existing buildings, mould growth often occurs at this point. However, if the balcony is placed in front of the building instead, the insulation can continue uninterrupted and a thermal bridge will not occur. However, this is not always possible (e.g. with highrise buildings).

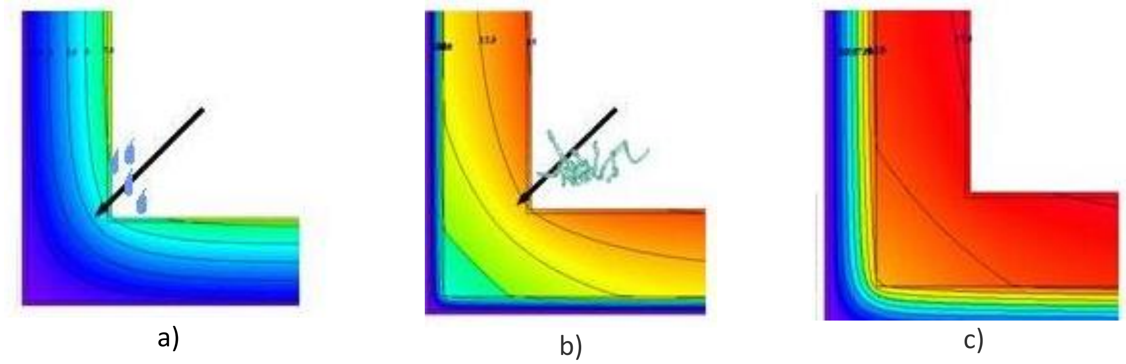


Fig.7 Heat flow simulations of a thermal bridge for outer corners of different insulation levels: a) uninsulated; b) conventional; c) highly efficient

One way to handle this is to use a "thermal break". Instead of the slab passing directly through the insulation, thermal breaks are used, which allow for cantilevers of a certain length, while also reducing the linear heat loss. Using certified Passive House components, these thermal breaks can reduce the thermal bridge by up to 75%, and the indoor temperatures remain unproblematic.

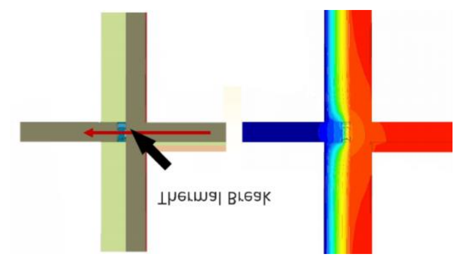


Fig.8 Example of a balcony with a thermal break

It is important to note that the total heat loss is considerably reduced by the insulation measure and the temperature of the interior surface is increased so much so that it is higher than the critical level of 12.6° C, as mould growth can occur below this level with normal indoor air humidity levels.
While it may not seem obvious, the thermal bridges caused by window-to-wall interfaces can have a very large impact. The total perimeter of all the window-to-wall connections can add up to several kilometers on some projects, so how a window is installed into an opening plays an important role in minimizing the heat flow. Reducing thermal bridging at this connection involves positioning the window to line up with the insulation layer, overinsulating in front of the frame, and minimizing how far closure flashings penetrate the rough opening while still maintaining adequate drainage paths

The easiest way to avoid thermal bridging is by making architectural design changes (where possible), such as using self-supported decks and canopies for low-rise buildings or reducing the number of cantilevered balconies and articulating architecture (lots of corners) on larger buildings. This is not always realistic or achievable, and in these cases, special attention needs to be paid to these interfaces. Reducing direct conductive connections between the interior and exterior is important. Examples include installing intermittent connections for shelf angles, overinsulating in front of certain connections around the foundation, wrapping insulation around protruding details, or using special materials such as thermal breaks.

5 Insulated Concrete Forms (ICF)

Insulated concrete forms (ICF) are a building system to create reinforced concrete walls or floors with integral insulation. They are dry-stacked (without mortar) and filled with concrete. The units interlock somewhat like Lego bricks and create the formwork for reinforced concrete that becomes the structural walls, floors or roofs of a building. The forms stay in place after the concrete is cured and provide a permanent interior and exterior substrate for finishes. The forms come in different shapes, sizes and are made from different materials depending on the manufacturer.

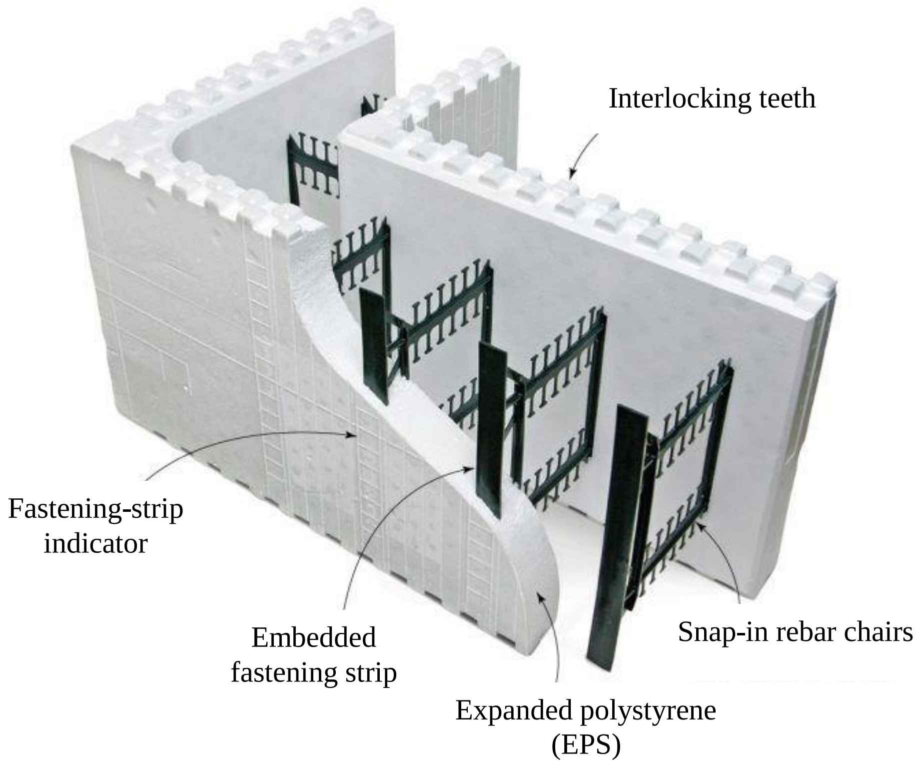


Fig.9 Structure of an ICF

5.1 Construction

Reinforcing steel bars (rebar) are usually placed inside the forms before concrete is poured to give the concrete flexural strength, similar to bridges and high-rise buildings made of reinforced concrete. Like other concrete formwork, the forms are filled with concrete.

After the concrete has cured, the forms are left in place permanently to provide a variety of benefits, depending on materials used:

- High thermal resistance (R-value) typically above 3 $K \cdot m^2/W$
- Soundproofing. ICF walls have much lower rates of acoustic transmission. Standard thickness ICF walls have shown sound transmission coefficients (STC) between 46 and 72 compared to 36 for standard fiberglass insulation and drywall.
- Good surface burning characteristics rating. ICF walls can have four- to six-hour fire resistance rating and negligible surface burning properties.
- Continuous insulation without thermal bridges or "insulation gaps
- Space to run electrical conduit and plumbing. The form material on either side of the walls can easily accommodate electrical and plumbing installations.
- Backing for drywall or other finishes on the interior and stucco, brick, or other siding on the exterior
- Improved indoor air quality

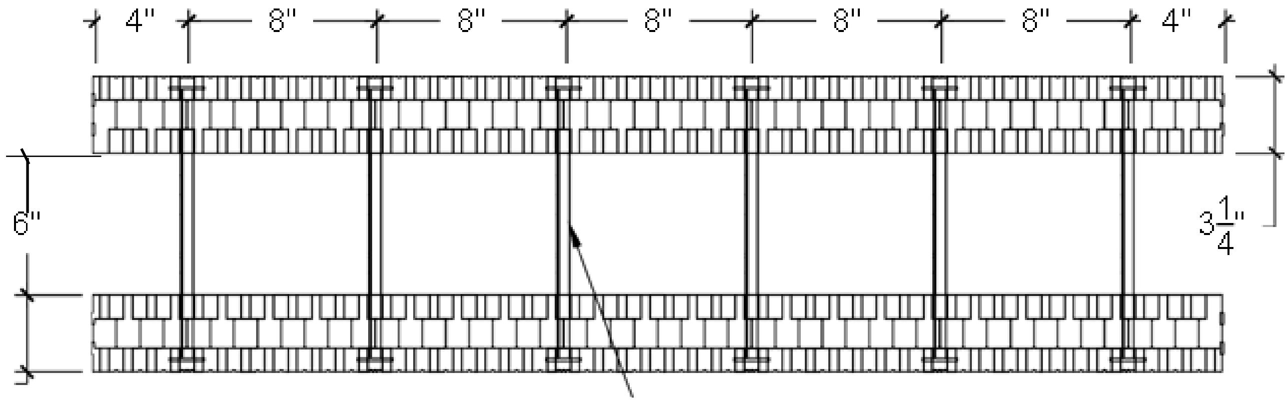


Fig.10 Typical straight ICF block.

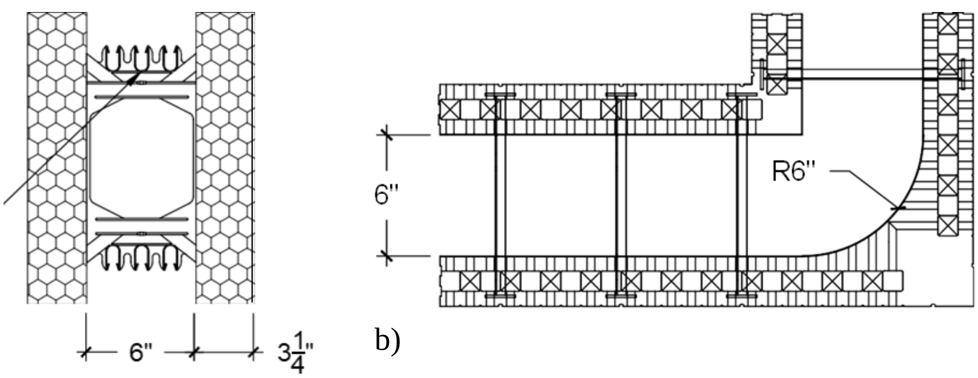


Fig.11 a) Cross section of ICF block; b) Typical ICF corners.

5.2 Different shapes of ICF

ICF **Straight** Forms serve as a mold for pouring and curing concrete. Once the concrete hardens, it provides the primary structural support for the home. The ICF wall minimizes thermal bridging effectively by incorporating dual layers of continuous insulation forming a remarkably airtight enclosure, significantly decreasing unwanted air leakage. The combination of superior thermal resistance, air-sealing properties, and thermal mass contributes to the creation of a highly energy-efficient home. This exceptionally energy-efficient envelope not only reduces the carbon footprint of your home but also reinforces the structure, ensuring long-term resilience against nature's inevitable challenges.
No need to glue, tape, tie or hook the blocks together, and webs have built-in rebar clips which can hold 2 layers of reinforcing steel

ICF **Radius** forms enable the construction of curved or rounded walls, which can add architectural interest and unique design elements. This is often seen in modern and contemporary architectural designs, as well as in structures like swimming pools, and curved facades. ICF radius forms, when properly designed and installed, maintain the structural integrity and stability of the wall - engineered to withstand the loads and stresses associated with the curved walls they create.

ICF **90 Degree Corner** forms facilitate the creation of sharp right-angle corners. The corner forms are a fundamental part of any structure and need to be structurally sound and well-insulated. ICF Corner Forms serve as a mould for pouring and curing concrete. Once the concrete hardens, it provides the primary structural support for the home. The same caracteristics are for ICF **ICF 45 Degree Corner** Forms.

a) b) c) d)

Fig.12 Different forms of ICF: a) ICF Straight Form; b) ICF Radius Form; c) ICF 90 Degree Corner Form; d) ICF ICF 45 Degree Corner Forms.

5.2.1 Short corners using 90° corner blocks with a stack joint

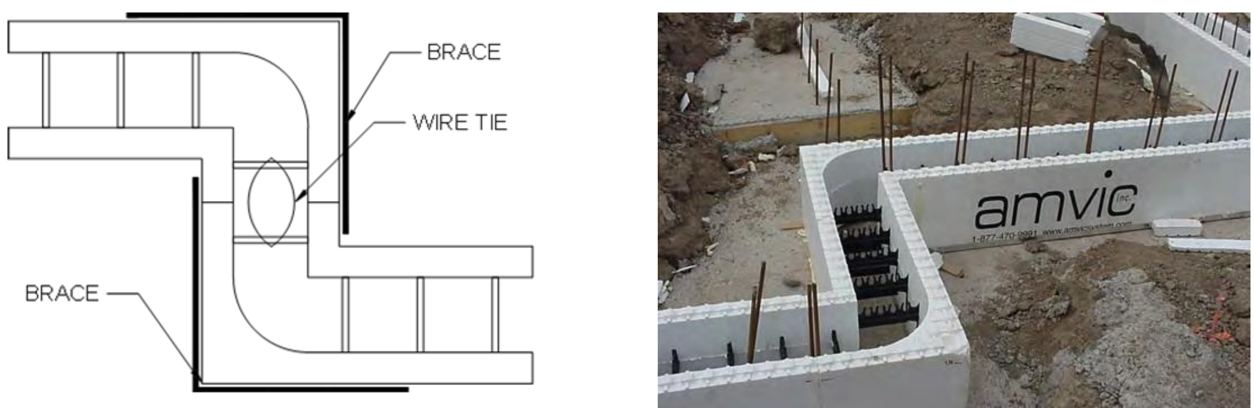
A short corner can be constructed using at least two (2) 90° corner blocks. Recommended steps are given below.

• Install the first course so that the short legs on both blocks are adjoining each other as illustrated in Fig. a.

• Install second and consecutive courses of corner blocks in the same manner without alternating forms. This will create a stack joint.

• Ensure stack joints are adequately braced on both sides of forms and at every course.

• Failure to brace a stack joint adequately may lead to a blowout during the concrete pour. Make sure to use additional bracing if necessary.



a) b)

Fig.13 a) Short corner made of 90^0 form with a stack joint; b) Short corner made of 90°.

5.2.2 Short corners made of straight ICF

Corners shorter can be achieved by using **straight** ICF blocks. The recommended steps are given below:

1. Start with two straight ICF blocks.
2. Cut off the L dimension (Fig.14a).
3. Setting the two cut forms into position (Fig.14b).
4. Using cut off pieces to close the open ends and create a corner (Fig.14c).
5. Construct two 90^0 wood forms made of lumber and place them on each of the formed EPS corners (Fig.14d).
6. Drill a 13 mm hole through the wood forms and the EPS panels starting about 300 mm from footing or slab. Insert a 10 mm threaded rod through holes in both wood forms. Use plate washers and nuts on both sides to hold rod securely (Fig.14e).
7. Continue to cut and stack the block to the desired wall height. Place the threaded bolts approximately 400 mm on center vertically. When the concrete has been poured and has set for a few hours, remove the wooden forms and cut the threaded rod so that it is

flush with the concrete surface. Use foam adhesive to fill the holes in the EPS panels (Fig.14f).

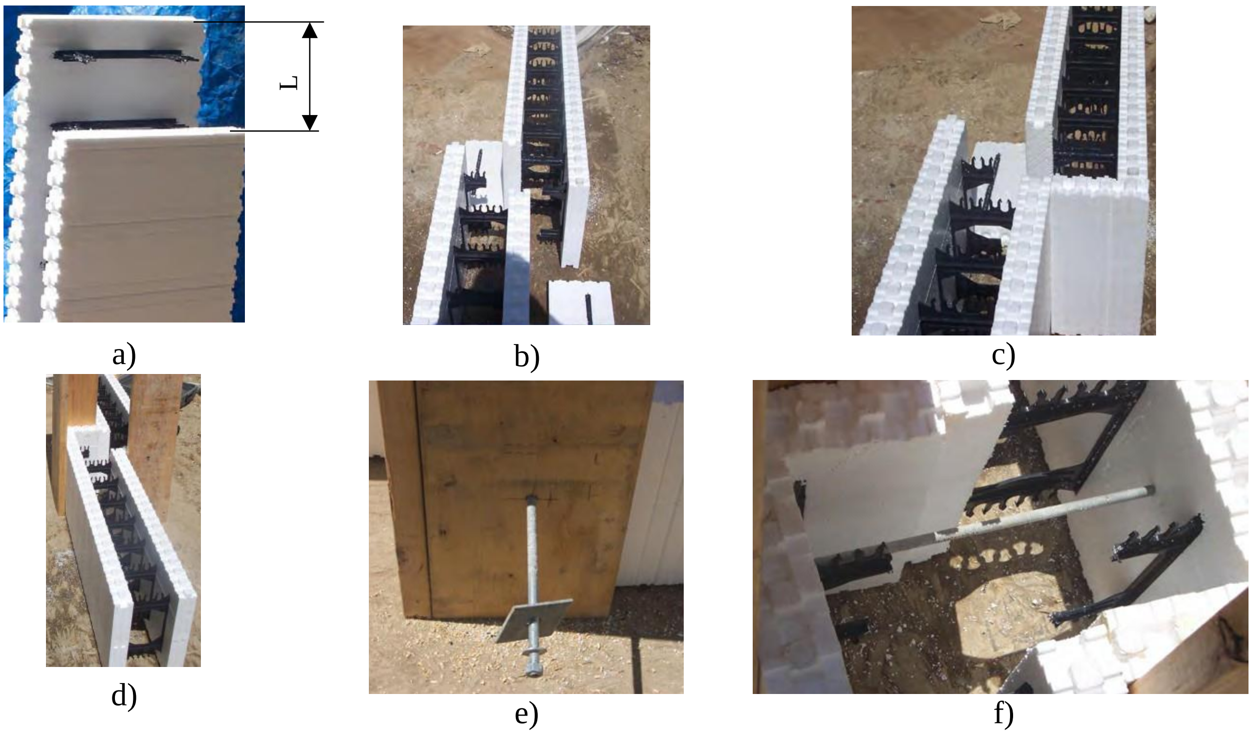


Fig.14 Steps for short corners made of straight ICF.

5.2.3 Radius Wall Construction

Radius forms can also be constructed by the contractor on site using straight ICF. Manufacturing facilities provide pre-cut radius forms which ensure that courses fit together easily, and installation goes smoothly with minimal labor costs. Pre-cut radius forms are tongue and groove cut on the inside EPS panel and slit cut on the outside EPS panel.

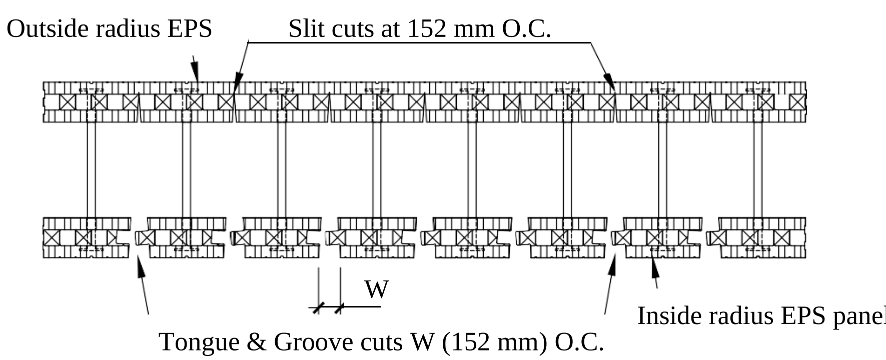


Fig.15 Radius wall tongue & groove and slit cut details.

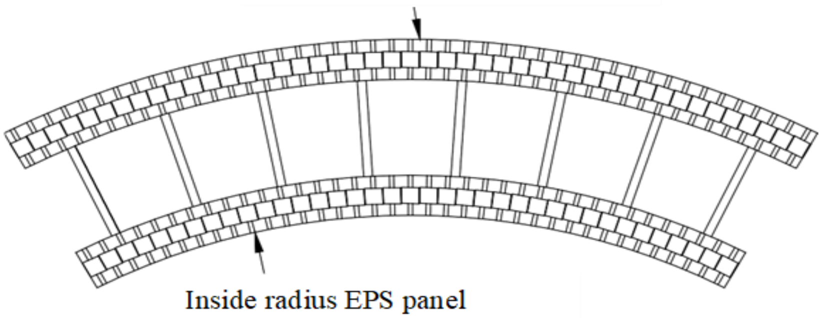
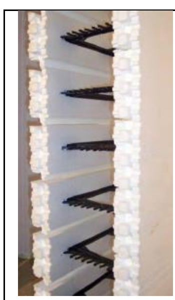


Fig.16 Radius wall bent to shape.

Installing Radius Forms:
1. On the footings/slab, set a template or guide board to match the desired radius.
2. Apply a bead of spray foam to the bottom of the form along the tongue and groove cut (for pre-cut forms), bend the form into shape and install it.
3. After laying the first course, install the horizontal rebar as per engineering requirements and/or local building codes.
4. Support the outside of the form using bracing or plumbers pipe strapping.
5. Brace the wall adequately before pouring concrete.



a)

b)

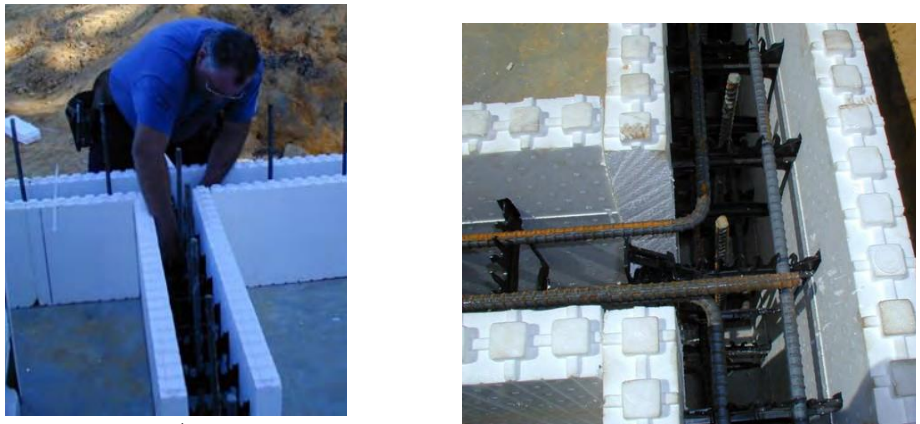
c)

Fig.17 a) Pre-cut radius blocks. Tongue and groove cut on the inside and slit cut on the outside; b) Bending securing the radius form into place; c) Several courses of radius blocks installed.

5.2.4 T-wall Construction

T-walls require special attention before the concrete pour. Proper bracing and alignment are essential.
Constructing T-Walls:
1. Locate the T-wall intersection as you lay the first course.
2. Cut ICF blocks appropriately and put them together to form the T-intersection. Use zip ties (or equivalent) to secure the blocks together (Fig. a).
3. Install horizontal reinforcing steel bars including bent 90° corner bars with proper lap splice length as per engineering requirements and/or local building code (Fig. b).
4. Continue stacking subsequent courses of block until the full wall height is achieved.
5. Check walls for level. If the walls are level, run a bead of spray foam down along each side of the forms on the T-wall.
6. For below grade and main floor level walls, additional bracing must be installed on the exterior side of the intersection. Failure to brace properly may cause a blowout during the concrete pour.
7. For above grade levels where there is no ground surface to anchor the exterior bracing, insert zip ties (or equivalent) through the forms around to each side of the intersecting T-Walls. Do not tighten the zip ties yet.
8. Once the wall is formed to desired height, slide a 2x6” (38x140mm) lumber down the backside of the wall that runs straight through in between the forms and the tie wire. Tighten the wire tie to hold the

lumber in place. Make sure the wire ties are at every cours



a) b)

Fig.18 T-wall construction.

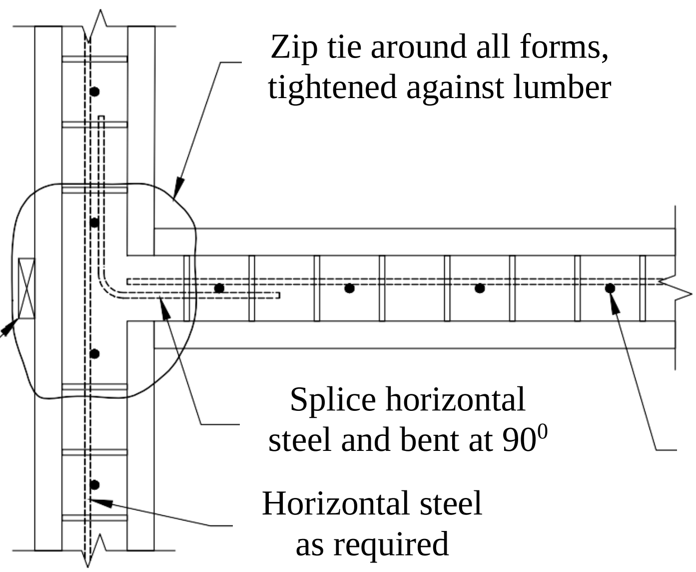


Fig.19 Securing T-wall forms together with 38x140mm lumber and zip tie.

6 Exemples of Passive Houses in Romania

6.1 Passive House in Bragadiru

The single-family house in Bragadiru is the second Passive House in Romania certified by the Passive Haus Institute dr. Wolfgang Feist, Darmstadt, Germany. The house is realized from CLT (Cross Laminated Timber) with structural elements cut in the factory on CNC machines and built on site in 4 days.

To meet the energy efficiency required by the Passive House standards, a continuous thermal envelope has been realized, from foundation to roof, with a heat transfer coefficient of 0.11W/m^{2}k. Also, the energy efficiency standards have been attained through PHPP calculation, attention to window details (heat transfer coefficient U = 0.85W/m^2 k), air tightness, no thermal bridges and by using a heat recovery ventilation. The insulation has been realized from solid wooden fibred panels and blown cellulose

Fig.20 Passive House in Bragadiru.

The air tightness test (Blower Door Test) showed a heat transfer coefficient n50 of 0.14 (the standard is 0.6) for which the energy consumption of the house is 10kwh/m^2/year (the required standard is 15kwh/m^2/year)

The building site also had an educational goal. Over 40 architects and engineers had the opportunity to experiment with new materials and technologies and understand the details specific to Passive House standards.

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In Fig.21 is shown on-site assembly of Cross Laminated Timber.

Fig.21 Sequences from on-site assembly of Cross Laminated Timber.

6.2 Passive House – Corbeanca

The architecture of the house was inspired by the traditional way of living, adapting it to modern needs. In the traditional house, daily activities take place outdoors, around the kitchen and the yard (the vegetable garden and the animal yard). In the project, the exterior (the utility yard, the kitchen) is incorporated into the interior, in a large, comfortable and bright space with a generous green space and a permanent visual connection with the exterior (windows and zenithal light – skylight).

Wooden elements from old buildings were reused as functional pieces (the structure that separates the living room from the kitchen, the steps of the staircase). The spaces are designed to be easy to maintain over time and adaptable. The home is the first Premium Passive certified house in Romania.

Fig.22 Passive House in Corbeanca.

6.3 The Cherry House

The Cherry House is an energy-efficient single-family residential building to passive standards, certified by the Passive House Institute in Darmstadt. In a typical subdivision for the suburbs of the capital, with medium-sized lots, narrow streets, no consideration for public space and the needs of a developing community, without decent utilities, the beneficiary seeks to achieve the comfort that the public authority refuses – maximizing green space, reducing consumption and minimal impact on the environment.

The building's conformation is the result of a sun exposure analysis, so that the solar input is maximum to reduce energy consumption and increase indoor comfort. The option for CLT (cross laminated timber) and the construction systems emerged from the "CAP-ul case" experiment. 3 different beneficiaries with land in nearby areas, with similar design themes (passive houses, wooden, modern, sustainable) chose the same design team. From here the step was simple, to get to know each other and combine their site management efforts in a way that would be mutually beneficial. Construction partnerships are a useful lesson and still in their early stages.

Fig.23 The Cherry House.

7 Conclusions

In summary, a passive house is not just a building; it's a long-term investment in energy efficiency and sustainability. With key features like effective insulation, high-quality windows, and well-designed ventilation systems, these houses are built to last and save you money in the long run. Not only do they drastically reduce energy consumption, but they also minimize your carbon footprint.

These buildings tend to provide a superior, more stable and more comfortable indoor environment than traditional construction. They remain warm in the winter and cool in the summer, and they do this amazingly without the need to use large heaters or air conditioning units. This brings us to advantage number two – not only are they consistently comfortable, but Passive House buildings use up to 90% less energy than traditional buildings, meaning greater comfort with much lower energy bills, and less damage to the environment. As the International Passive House Association puts it, passive houses are sustainable, affordable, comfortable and versatile

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