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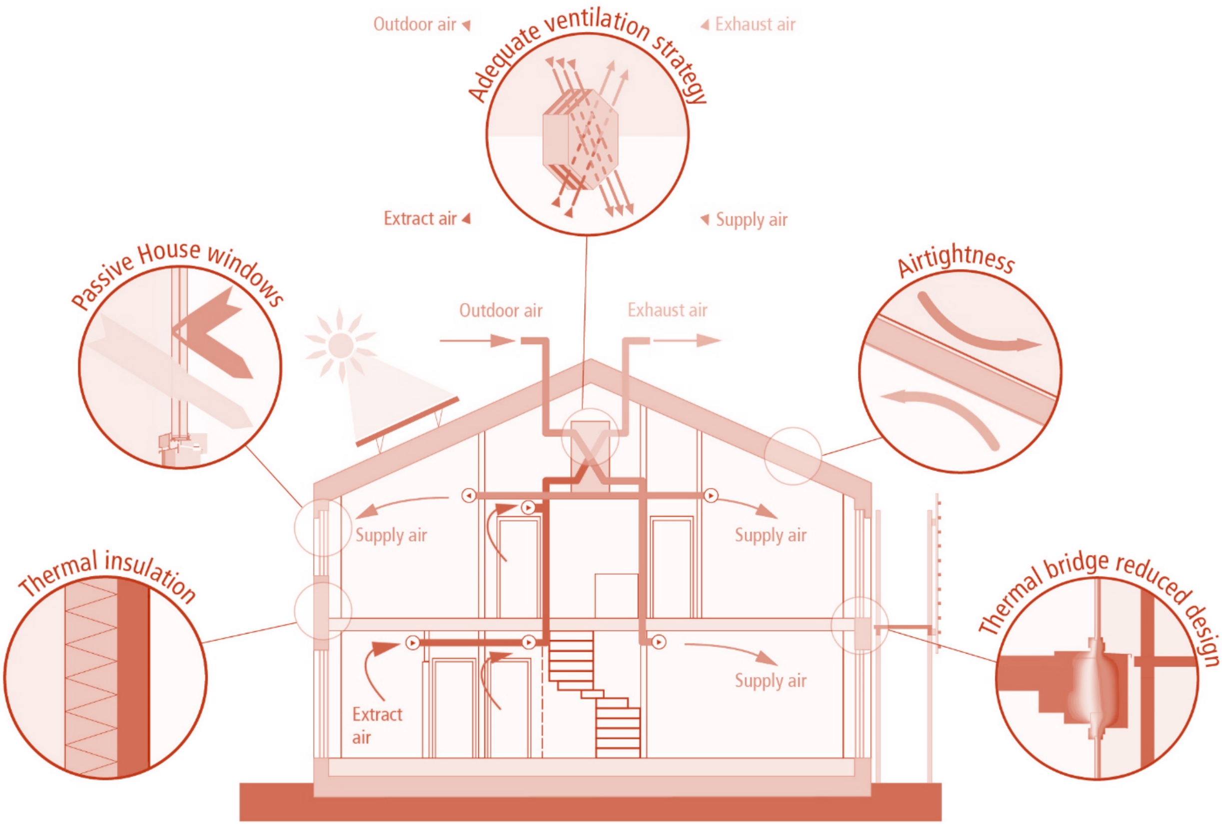
BIM4Energy Project

Title: Passive houses



1 – Aims.

The objectives of this Passive house's tutorial are as follows:

1. Understand Passive House Principles – gain knowledge of the fundamental principles of Passive house design and operation, their impact on energy efficiency and occupant comfort.
2. Identify Key Components – learn to recognize and understand the essential elements of a Passive house, such as thermal insulation, airtightness, heat recovery ventilation, solar energy utilization and thermal bridging prevention.
3. Recognize Energy-Saving Opportunities – analyse how Passive House technologies help to reduce heating, cooling and electricity costs and evaluate their economic benefits.
4. Promote Sustainable Construction – to introduce environmentally friendly construction technologies and renewable energy solutions to reduce the climate impact of buildings.
5. Practical Application – to develop the ability to assess building energy performance, select appropriate materials and technologies and apply Passive house principles to real construction projects.

2 - Learning methodology.

The teacher will give an explanation about Passive houses for about 1 hour.

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

- Introduction to Passive houses
  - Concept of Passive house
  - Historical context of Passive houses
- Why build a Passive house?
  - Energy savings
  - Comfort
  - Long-term sustainability
  - Reducing the impact of climate change
- Passive House principles
  - Thermal insulation
    - Importance of heat conservation
    - Insulation material types
    - Importance of the heat transfer coefficient (U-value)
  - Airtightness
    - Building airtightness
    - Airtightness testing
    - Practical measures to ensure airtightness
    - Efficient ventilation with heat recovery
    - The importance of air quality for health and comfort
    - Energy recovery efficiency

- Windows and doors
  - Triple glazing
  - Solar energy through proper building orientation
- Eliminating thermal bridges
  - Impact of thermal bridges on energy losses
  - Structural solutions

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

3 - Tutorial duration.

The implementation of this tutorial will be carried out through the BIM4ENERGY Project website www.bim4energy.eu by self-learning.

The tutorial is structured to be delivered over:

Total duration: 3 hours.

4 – Necessary teaching recourses.

Computer room with PCs with internet access.

Required software: Microsoft Office.

5 – Contents & tutorial.

5.1 – Introduction to Passive houses.

5.1.1. Concept of Passive house.

For the last few decades, the world has been talking and discussing about preserving nature, and in recent years, there has been a lot of work to reduce the use of energy resources, which has led to the increasing popularity of energy-efficient homes.

A Passive house is an energy-efficient building designed to provide the highest level of comfort, using the minimum amount of energy for heating and cooling, and using efficient insulation, air-tightness and ventilation technologies. A Passive house is based on the principle that most of the energy demand is met by passive sources such as solar energy and human heat, while the missing part of the energy gap is made up by renewable sources, resulting in extremely low running costs.

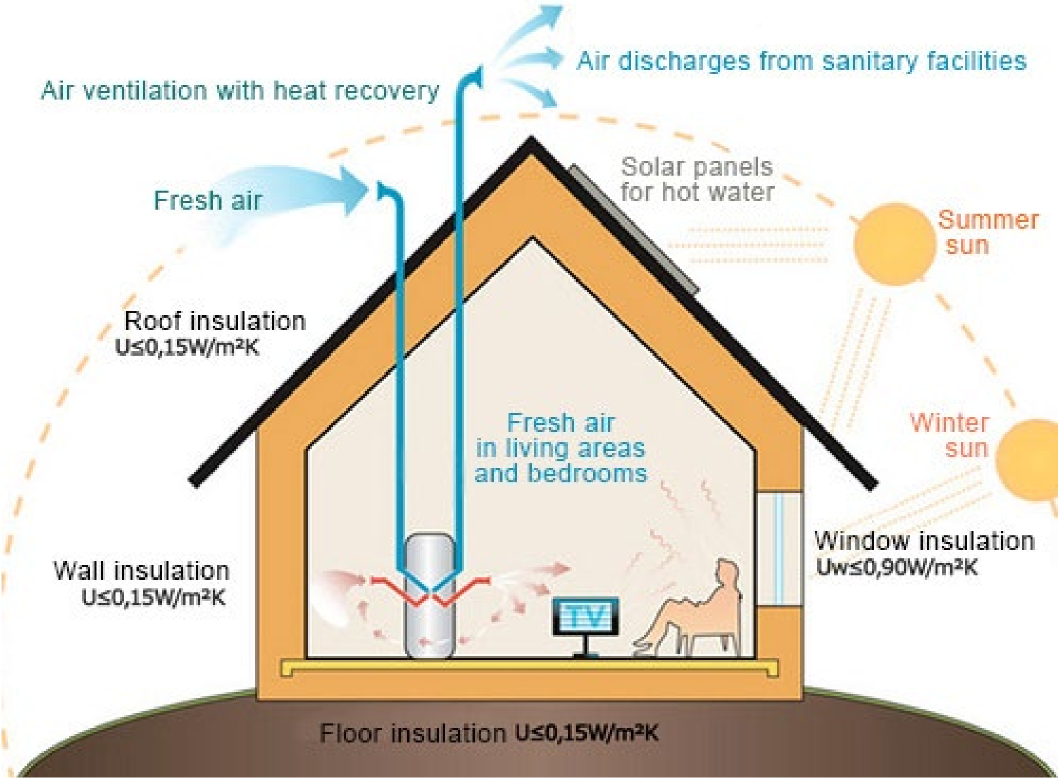


Figure 1. The five key principles of Passive House.

5.1.2. Historical Context of Passive houses

The Passivhaus concept was developed in Germany in 1990 in collaboration between Professor Wolfgang Feist (founder of the Passivhaus Institute) and Swedish researcher Bo Adamson. The aim of these two experts was to develop a building standard that minimises energy consumption while ensuring maximum living comfort. The first Passive house was built in Darmstadt, Germany, in 1990, with all the basic principles: efficient thermal insulation, efficient windows, most of them south-facing, mechanical ventilation with heat recovery and airtightness. The building is still functioning as a demonstration project and proof of concept for a Passive house. 1996 - Wolfgang Feist founds the Passivhaus Institute, which aims to standardise and promote the Passive house principle. The Institute developed clear technical criteria for Passive houses and started to provide training for architects, engineers and building professionals. Since 2000, the Passive house concept has been spreading in Europe and later worldwide. Many model Passive buildings have been developed, including schools, offices and apartment blocks. The Passivhaus Institut has developed PHPP, a software for modelling and planning the energy needs of Passive houses. The Passive House standard has become one of the world's most important energy-efficient construction methods. In many countries, it is used as the basis for developing national energy efficiency standards. In today's world, Passive House is not just a standard for residential buildings. It is now being applied to many different types of buildings, including schools, offices and even industrial facilities. The Passivhaus Institut continues to research and develop new technologies that contribute to even greater energy efficiency and reduce the impact of climate change.

5.2. – Why build a Passive house?

5.2.1. Energy savings

Passive houses are designed to use very little energy for heating, cooling and other everyday needs. Here are the main energy-saving benefits:

- ✓ **Minimal energy consumption:** a Passive house uses up to 90% less energy for heating and cooling than a conventional building. The average heating energy consumption is just 15 kWh/m² per year, which can be achieved with only a small additional heating or cooling source.
- ✓ **Lower maintenance costs:** reducing energy demand reduces monthly bills for electricity, gas or other heating fuels. In the long run, a Passive house pays for itself in cost savings.
- ✓ **Use of renewable energy sources:** it is easier to integrate renewable energy systems, such as solar panels or geothermal heating, in Passive houses because the energy demand is very low.
- ✓ **Energy efficiency:** due to its efficient insulation, airtightness and heat recovery system, the Passive House maintains a constant internal temperature without high energy costs, even in extreme weather conditions.
- ✓ **Energy security:** low energy demand reduces dependence on external energy suppliers and fluctuations in fossil fuel prices.
- ✓ **Sustainability:** energy saving contributes to reducing carbon emissions and mitigating the effects of climate change. It is the perfect choice for those seeking a greener lifestyle.

Passive House is not only a solution to reduce costs, but also a step towards long-term energy sustainability and comfort.

5.2.2. Comfort

Passive House provides exceptional living comfort by being designed to maintain a constant temperature, excellent air quality and a maximum sense of well-being. The main aspects of comfort are:

- ✓ **Consistent indoor temperature:** a Passive House maintains the same temperature in all rooms, without large fluctuations, whatever the season. Thanks to efficient insulation, heat recovery and airtightness, the indoor temperature stays above 21 degrees Celsius even in the cold season and stays cool in the summer without rising above 24 degrees Celsius.
- ✓ **Excellent air quality:** the heat recovery ventilation system ensures a constant supply of fresh air, removing excess CO_2 and moisture. There are no draughts or air movement in the rooms that could cause discomfort.

- ✓ **Soundproofing:** a thick layer of insulation and quality windows provide excellent protection against external noise, creating an atmosphere of peacefulness.
- ✓ **Natural light:** the windows are largely south-facing to maximise the use of sunlight, making the living space in a Passive house bright and cosy.
- ✓ **Pleasant humidity balance:** sealing and ventilation help maintain an optimal humidity (40-60%) that is healthy for skin, respiratory and general health.
- ✓ **Wall surface comfort:** well-insulated building components ensure that walls, floors and ceilings are as warm as the air, so there are no "cold spots" or discomfort.
- ✓ **No noisy heating or cooling systems:** due to minimal mechanical equipment, passive houses do not have noisy heating boilers or air conditioners, which further contributes to comfort.

Passive House not only saves energy, but also provides the highest level of comfort, allowing you to live in a healthier, calmer and more pleasant environment. It is an investment not only in energy efficiency, but also in everyday quality of life.

5.2.3. Long-term sustainability

Passive houses are designed to be not only energy-efficient, but also long-lasting, sustainable and environmentally friendly. This standard ensures that homes contribute to the environment and remain economically viable for many years.

Reduced environmental impact

- Reduced CO_2 emissions: a Passive House consumes up to 90% less energy than a conventional building, thus contributing less to climate change.
- Reduced need for fossil fuels: the low energy demand makes it easier for a Passive house to switch to renewable energy sources such as solar panels or geothermal heating.

Longevity

- Quality materials: Passive houses use high-quality insulation materials, windows, doors and efficient building solutions that last for decades.
- Durable design: structures without thermal bridges ensure that the building remains resistant to moisture, mould and temperature fluctuations and therefore requires less maintenance.

Economic sustainability

- Lower running costs: low energy consumption for heating, cooling and other uses means lower costs in the long run.
- Long-term value: Passive houses retain a higher real estate value because they are attractive for their energy efficiency and comfort.

Adapting to meet future requirements

- Resilience to energy price fluctuations: the very low energy demand makes Passive house owners less vulnerable to rising energy prices.
- Climate resilience: Passive houses are designed to maintain comfort in extreme weather conditions, from cold winters to hot summers.

Promoting sustainable solutions

- Passive House is an example of a long-term sustainable living philosophy that ensures lower environmental impact, greater sustainability and financial stability. It is an investment not only in the present but also in the future of our planet.

5.2.4. Reducing the impact of climate change

Passive houses make a significant contribution to reducing the impact of climate change because they are designed to minimise energy consumption and associated CO_2 emissions.

Key aspects of how a passive house helps fight climate change

Reduced energy demand

- Up to 90% lower energy consumption: a Passive House consumes very little energy for heating and cooling (just 15 kWh/m^2 per year), reducing the need to use fossil fuels, which are a major source of greenhouse gases (GHG).
- Energy efficiency in all areas: modern technologies such as heat recovery are used to help retain heat and cool while reducing heat loss.
- Use of renewable energy: In passive houses, the energy demand is so low that it can be fully covered by renewable sources such as solar panels, geothermal heating or wind power. Renewable energy not only reduces GHG emissions but also ensures energy self-sufficiency.

Reducing CO_2 emissions

- Minimal CO_2 emissions: low energy demand and resilience to energy loss mean that a passive house has significantly lower carbon emissions than conventional buildings.
- Long-term impact: Over its lifetime, a passive house significantly reduces overall emissions, contributing to climate change mitigation.

Use of sustainable materials

- Environmentally friendly and recyclable materials: passive houses are often built with materials whose production process emits less CO_2.
- Durability: Passive house structures are resilient and long-lasting, requiring less maintenance and renovation, which reduces the need for additional resources.

A role model for others

- Promoting climate awareness: passive houses become a model for living responsibly, using natural resources sustainably and reducing the impact of climate change.
- Raising standards: Passive House serves as a benchmark for other building standards, promoting the integration of energy-efficient technologies and sustainable solutions.

Passive House is a responsible choice that reduces the environmental impact of human activity. It contributes to mitigating the effects of climate change by reducing energy demand, GHG emissions and promoting the use of sustainable solutions. It is an important step towards climate change mitigation and a cleaner future.

5.3 – Passive house principles

5.3.1. Thermal insulation

5.3.1.1. Importance of heat conservation

Conservation of heat is a key principle of passive house design, ensuring low energy consumption, comfort and sustainability. This is achieved by minimising heat loss through the building fabric and making efficient use of natural heat sources.

Conserving heat in a passive house is the key to energy efficiency, comfort and sustainability. It ensures that heating energy is maximised and heat loss is kept to a minimum, creating long-term benefits for both occupants and the environment.

5.3.1.2. Insulation material types

Insulation materials are an essential part of building a passive house as they help to reduce heat loss and maintain a constant internal temperature. The materials chosen must be highly efficient and meet the heat transfer (U-value) requirements of a passive house.

Mineral insulation materials
Mineral wool (Fig. 2) Made of stone or glass fibre. Advantages: good thermal and acoustic insulation, fire resistant, environmentally friendly. Use: For wall, ceiling and floor insulation. Glass wool Lightweight and elastic, suitable for complex shaped structures. Resistant to moisture, but requires a suitable vapour barrier system.

Figure 2 Insulation with mineral wool insulation materials.

Polymer insulation materials
Polyurethane foam (PUR) (Fig. 3) Used as a spray or in panel form. Advantages: high acoustic insulation, extremely low thermal conductivity. Creates a sealed layer without thermal bridging. Use: for insulation of floors, roofs and complex structures.

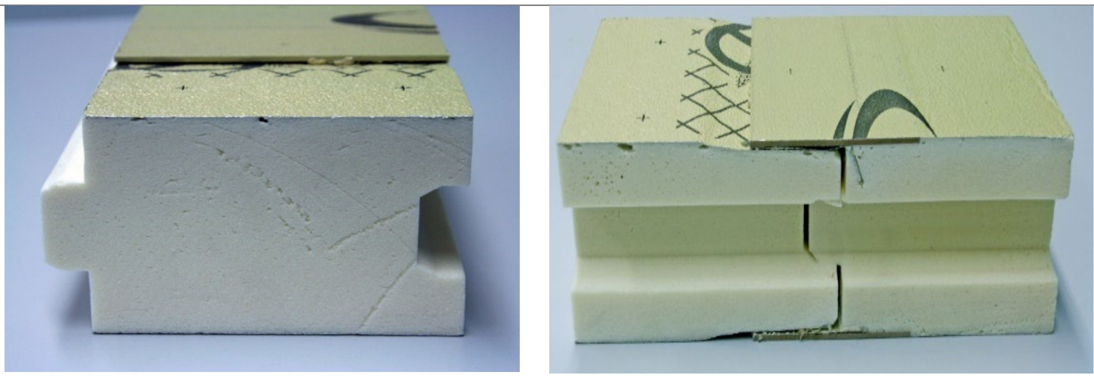


Figure 3 Polyurethane foam (PUR) panels.

Polystyrene foam (EPS and XPS) (Fig. 4)

EPS (expanded polystyrene)

Very lightweight, used for wall and ceiling insulation.

Advantages: lightweight, cost-effective, good thermal performance.

XPS (extruded polystyrene)

Stronger, moisture-resistant, suitable for foundations and floors.

Advantages: resistant to moisture and mechanical stress, enhanced durability, suitable for various applications. Effective thermal insulator.

Figure 4 Insulating the walls of a building with polystyrene foam (Neopor) panels.

Natural insulation materials

Fibreboard (Fig. 5)

Advantages: eco-friendly, easy to recycle. Good sound insulation.

Uses: insulation of roofs, walls, floors.

Straw

Used in eco-construction as a wall insulation material.

Advantage: low cost and recyclability.

Felt and sheep wool

Used for internal insulation, good moisture control.

Cork (cork material)

Advantages: Natural material, excellent insulator. Resistant to moisture and mould. Use: For floor and wall insulation.

Figure 5 Fibreboard.

Innovative insulation materials
Aerogel
Highly efficient, light and thin material.
Advantages: low thermal conductivity even in thin layers.
Low heat insulation with low thermal insulation.
Vacuum Insulation Panels (VIP) (Fig. 6)
Advantages: Extremely thin but highly efficient.
Use: for special projects where space saving is important.

Figure 6 Insulating floors with vacuum insulation panels.

Bulk and sprayable materials
Ekowool Made from recycled paper. Advantages: eco-friendly, easy to fill cavities. Use: for filling cavities in walls and roofs. Spray foam (polyurethane) Ensures airtightness and eliminates thermal bridging.

Insulation selection criteria

THERMAL CONDUCTIVITY COEFFICIENT	• The lower the value, the better the material insulates.
MOISTURE RESISTANCE	• Important for floor and foundation insulation.
FIRE RESISTANCE	• Particularly relevant for the insulation of residential buildings
ECO-FRIENDLY	• Whether the material is environmentally friendly and recyclable
EASE OF INSTALLATION	• Is the material easy to install.

The right combination of insulation materials ensures the energy efficiency, comfort and durability of a passive house.

5.3.1.4. Importance of the heat transfer coefficient (U-value)

The heat transfer coefficient (U-value) is a property of a building structure that describes how much heat is lost per square metre of surface per unit time when the temperature difference between the inside and outside of the building is 1 Kelvin (W/m^2K). This value is very important in passive houses as it directly determines energy consumption, comfort and sustainability.

U-value in Passive houses

Effective thermal insulation indicator

A low U-value means that the building's structure (walls, roof, floors, windows) effectively traps heat and reduces heat loss.

Reducing energy costs

Low U-value designs allow passive houses to maintain a minimum heating demand of only 15 kWh/m² per year.

U-value requirements in a Passive house

A passive house must meet strict U-value standards to ensure energy efficiency:

Construction	Required U-value (W/m²K)
External walls	≤ 0,15
Roof	≤ 0,15
Floors (contact with ground)	≤ 0,15

Advantages of low U-value

- Reducing heat loss: less heat transfer means that more heat is retained inside the building during winter.
- Comfort: surfaces such as walls, floors and windows remain warm and pleasant to the touch, while indoor temperatures are uniform.
- Lower running costs: better thermal insulation saves energy for heating and cooling.

Effect of U-value on structures

- External walls: a lot of heat is lost through the walls, so special attention needs to be paid to their insulation.
- Windows: windows are one of the weakest points in terms of heat loss, so triple glazing with efficient thermal insulation is used in passive houses.
- Floors and foundations: heat can be lost through floors if there is no proper insulation. Insulation materials must ensure that heat is retained inside the building.

Sustainability aspect

- Reduced energy consumption: low U-value designs reduce fossil fuel use and CO_2 emissions.
- Longevity: properly insulated buildings last longer and require less maintenance.

Example of U-value calculation

If the structure consists of several layers (e.g. insulation, bricks, plaster), the U-value is calculated as the sum of the thermal resistances of the layers:

$$U = \frac{1}{R_{\text{insolation}} + R_{\text{structure}} + R_{\text{other}}}$$

The higher the thermal resistance (R), the lower the U-value.

The heat transfer coefficient (U-value) is an important indicator for assessing the energy efficiency of a building. A low U-value ensures reduced heat loss, comfort and lower heating and cooling costs, and is therefore one of the main requirements of the Passive House standards.

5.3.2. Airtightness

The airtightness of a building is the ability to prevent the uncontrolled movement of air through the building's structures, joints and junctions. It is one of the key principles of Passive House, as it directly affects energy savings, comfort and the longevity of the building.

5.3.2.1 Building airtightness

Airtightness ensures that air does not enter or leave through leaks (e.g. cracks, leaking joints, doors or windows). The aim is to reduce air leakage, which can lead to heat loss and increased energy demand.

Why is building airtightness important?

Energy efficiency

- Uncontrolled air leakage leads to heat loss in winter and heat penetration in summer. Airtightness reduces the need for heating and cooling.

Comfort

- Prevents draughts, so the internal temperature remains uniform and pleasant.

Air quality

- The airtight building, combined with an efficient ventilation system, ensures that the air is clean and properly humidified.

Durability

- Airtightness protects structures from moisture and mould, which can be caused by air movement and condensation.

How is airtightness measured?

Blower Door Test

This is a standard method used to assess the airtightness of a building. The test uses a special fan to create a pressure differential (50 Pa) inside the building and measures how much air enters or leaves through leaking areas.

The requirement for a passive house is an air leakage rate (n50) ≤ 0.6 air changes per hour.

How to ensure the airtightness of a building?

Structural solutions

- proper sealing of wall, ceiling and floor joints. Sealed doors and windows with high quality gaskets.

Use of materials

- vapour barrier films, sealing tapes, polyurethane foams.

Installation quality

- ensuring that materials are properly installed and that all connections are tight.

Airtightness and ventilation balance

Efficient ventilation

- sealed buildings use a mechanical ventilation system with heat recovery to provide fresh air without heat loss.

Controlled air exchange

- airtightness allows you to control how much air enters the building and how it enters, unlike uncontrolled air leakage.

Problems when a building is not airtight enough

- Increased heat loss leading to higher energy costs.
- Draughts that reduce comfort.
- Moisture, mould and condensation which can damage structures.
- Noise transmission, as leaks can allow external sounds to enter.

Building airtightness is an essential feature of a passive house, ensuring reduced heat loss, indoor comfort and structural durability. A properly implemented airtightness solution combined with a ventilation system allows passive houses to be a model of energy efficiency and comfort.

5.3.2.2. Airtightness testing

An airtightness test is a standardised method used to assess the airtightness of a building by determining how much air enters or leaves uncontrolled through leaky areas. It is an essential step in the certification of a Passive house to ensure that the building meets energy efficiency and comfort requirements.

Figure 7 Types of Blower Door test equipment according to the power required.

Purpose: to check that the building structure (walls, windows, doors, joints) is airtight.

The airtightness test is carried out using a special device - the Blower Door system. A pressure difference (50 Pa) is created between the inside and the outside of the building and measures how quickly air enters or leaves the building.

- ✓ Installing the fan: a fan with an adjustable airtight frame is installed in the door or window.
- ✓ Pressure generation: the fan reduces or increases the pressure of the building's internal air to create a pressure difference of 50 Pa.
- ✓ Measuring air leakage: measuring equipment records how much air passes through leaky areas.
- ✓ Leak detection: additional tools such as thermal imaging, smoke generators or ultrasonic detectors are used to pinpoint leaky areas.

Airtightness requirements for Passive house

Indicator n50 (number of air changes) shows the number of times per hour the total air volume of the building is changed due to leakage.

Passive House Standard: n50 ≤ 0.6 air changes per hour (50 Pa pressure difference). Requirement value: a lower value means better airtightness, lower heat loss and higher energy efficiency.

Benefits of airtightness tests

Saving energy

- Leaks are identified and the heat loss is reduced.

Comfort

- It ensures even temperature distribution and eliminates draughts.

Protection of structures

- A sealed building protects structures from moisture, mould and condensation.

Certification

- The airtightness test is a necessary step in the certification process for Passive houses.

Additional testing methods

Smoke test	Thermal imaging	Ultrasonic test
• Smoke is used to visually identify leak locations.	• Thermal imaging cameras are used to see areas of heat loss.	• Ultrasonic detectors identify air movement in leaking areas.

When is the airtightness testing performed?

- During construction: the test is carried out before the structures are covered to allow leaks to be repaired.
- After construction: the final test ensures that the building meets Passive House standards.

Figure 8 Thermal imaging during a leak test and an image using a smoke generator to locate leaking areas.

Airtightness testing is a necessary process to ensure that a building meets energy efficiency, comfort and durability requirements. They allow you to identify and eliminate weak points in the structure that could lead to heat loss or other deficiencies.

5.3.2.3. Practical measures to ensure airtightness.

The use of the right materials, solutions and careful installation are essential to ensure that the building is airtight and to minimise air leakage. This is particularly important in a Passive House, as airtightness directly determines the energy efficiency, comfort and longevity of the building.

Materials to ensure airtightness

- sealing tapes resistant to temperature fluctuations and humidity, vapour barrier films needed to prevent uncontrolled air movement, polyurethane foams, sealants and mastics, special installation foams.

Sealed connections

- Ensure that all joints in walls, floors and ceilings are tight.
- Joint sealing systems shall be used to eliminate cracks and thermal bridging.

Installation of windows and doors

- Special sealing tapes and properly adapted installation foams are used.
- The frames shall be mounted in such a way as to avoid thermal bridging.

Sealing of engineering networks

- The passageways for pipes, wires and ventilation ducts through walls or roofs must be thoroughly sealed.

Installation quality

- Careful work: ensuring airtightness depends not only on the materials, but also on the precision of the work. Even the smallest leaks can lead to significant heat loss.
- The right combination of materials: vapour barriers, films, foams and tapes need to be matched to avoid condensation or other problems.
- Control during construction: leakage tests can be carried out between construction phases to correct deficiencies in time.

The most common air leakage points and their solutions

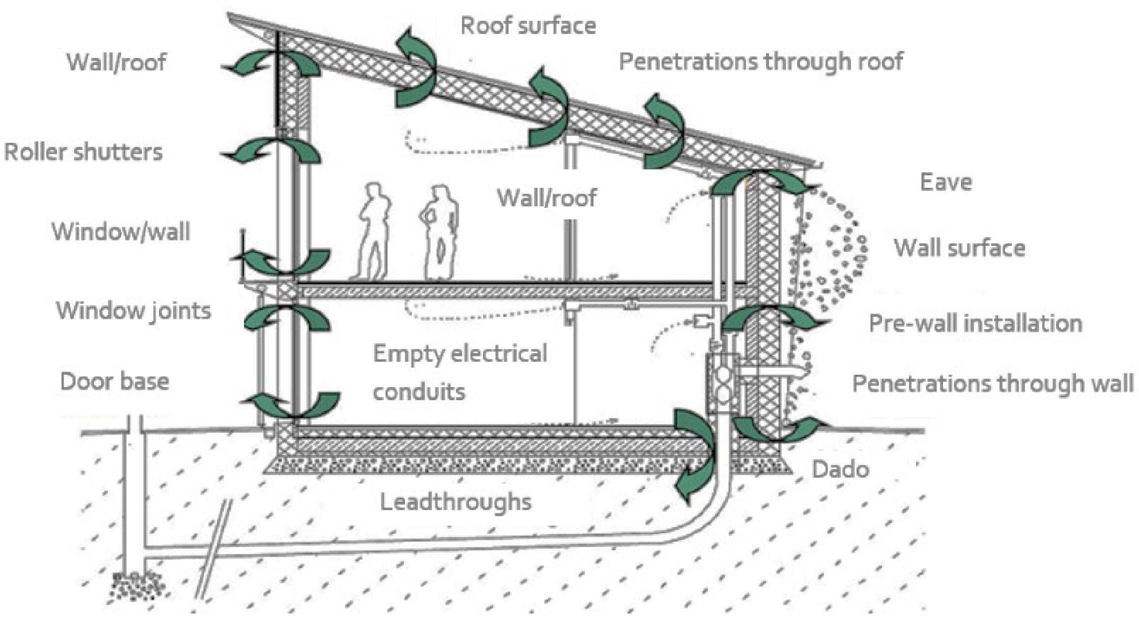


Figure 9 The most common air leak points found during the leak test.

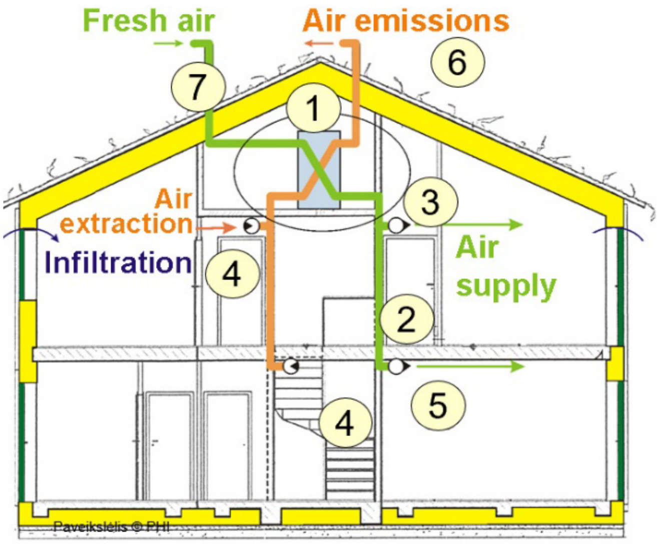
The choice of the right materials, quality construction solutions and diligent workmanship ensure a tight seal. A sealed building not only reduces energy loss, but also improves comfort and durability.

5.3.2.4. Efficient ventilation with heat recovery

Operating principle of the recuperator	• A heat recovery ventilator is a mechanical ventilation system designed to provide fresh air to a building while retaining most of the heat in the exhaust air. This process reduces heating and cooling costs and ensures a healthy indoor microclimate.

How a recuperator works:

- Heat recovery: heat is transferred from the building's exhaust air to the fresh air supply.
- Efficient ventilation: a constant supply of fresh air is provided, preventing the build-up of carbon dioxide, moisture or other harmful substances.



Characteristics

Centrally installed ventilation unit with fan and heat recovery.
Air supply and extract through separate ducts.

Main components

1. Ventilation unit with fan, control, heat recovery, filter.
2. Ductwork with sound attenuator.
3. Air supply valve
4. Air extraction valve
5. Air transfer
6. Air exhaust device.
7. Air intake device.

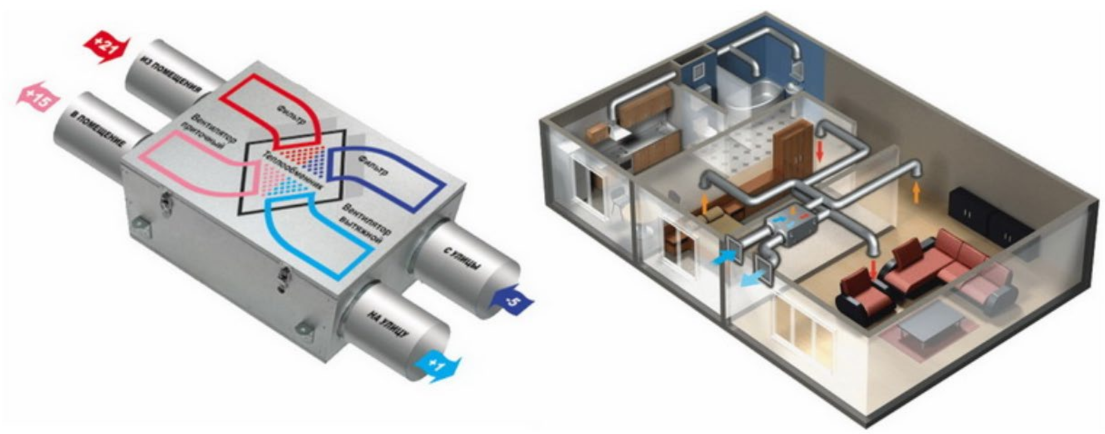


Figure 10 Principle diagram and 3D visualisation of the heat recovery system.

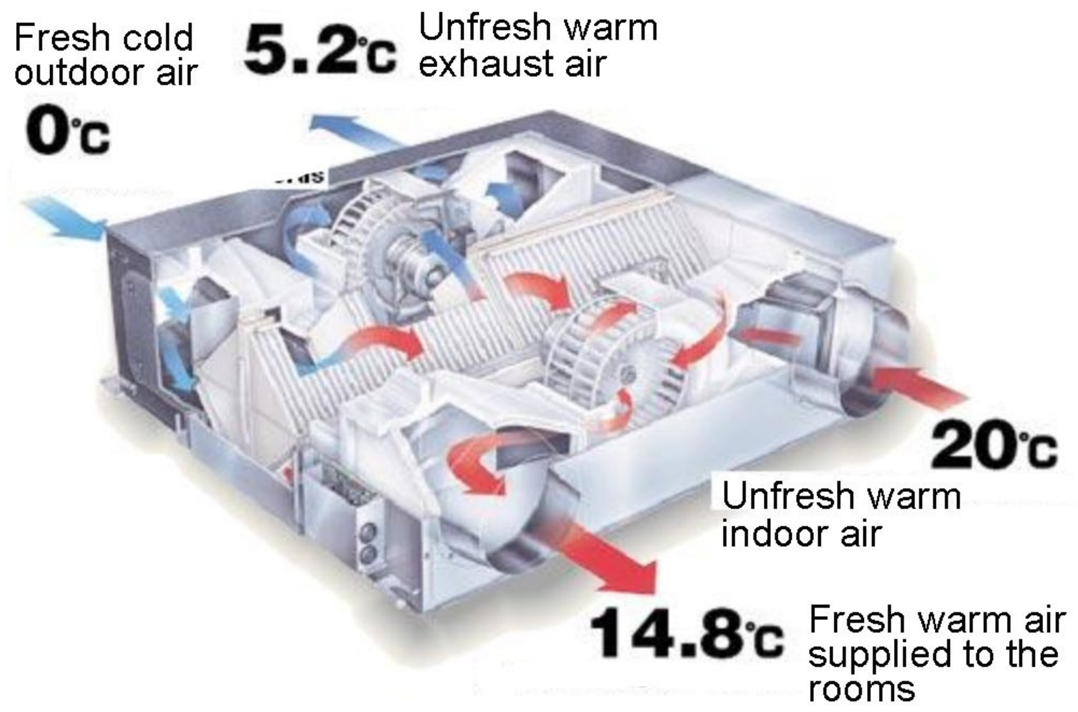


Figure 11 Operating principle of the recuperator.

Exhaust air collection

- Warm and humid air is extracted from rooms (e.g. bathrooms, kitchens, living rooms).

Heat exchange

- The exhaust air passes through a heat exchanger where its heat is transferred to the cold outside air, preventing direct mixing of these air streams.

Fresh air supply

- Outdoor air that has gained heat from the exhaust air is supplied to the building's living spaces (e.g. bedrooms, living room).

Air flow management

- The recuperator ensures that exhaust and supply air move separately, thus avoiding the transfer of pollutants or odours.

Main parts of the recuperator

Heat exchanger

- The main component where heat is exchanged. May be plate, rotary or counterflow.

Fans

- One fan draws in exhaust air and the other supplies fresh air.

Filters

- Clean both the supply and exhaust air to ensure a healthy indoor climate.

Control system

- Allows you to control airflow, temperature and humidity.

Types of recuperators

Plate heat exchanger: exhaust and supply air pass through plates where heat is exchanged.
Advantages: Simple, efficient, no moving parts.

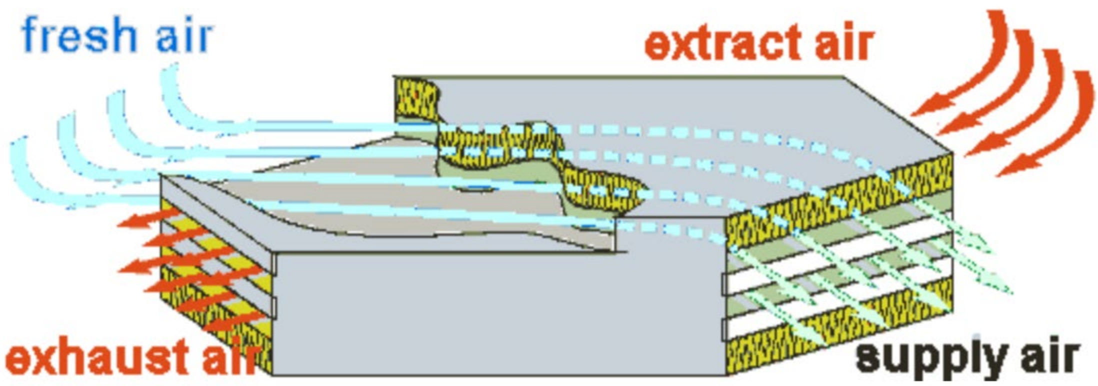


Figure 12 Principle diagram of a plate heat exchanger.

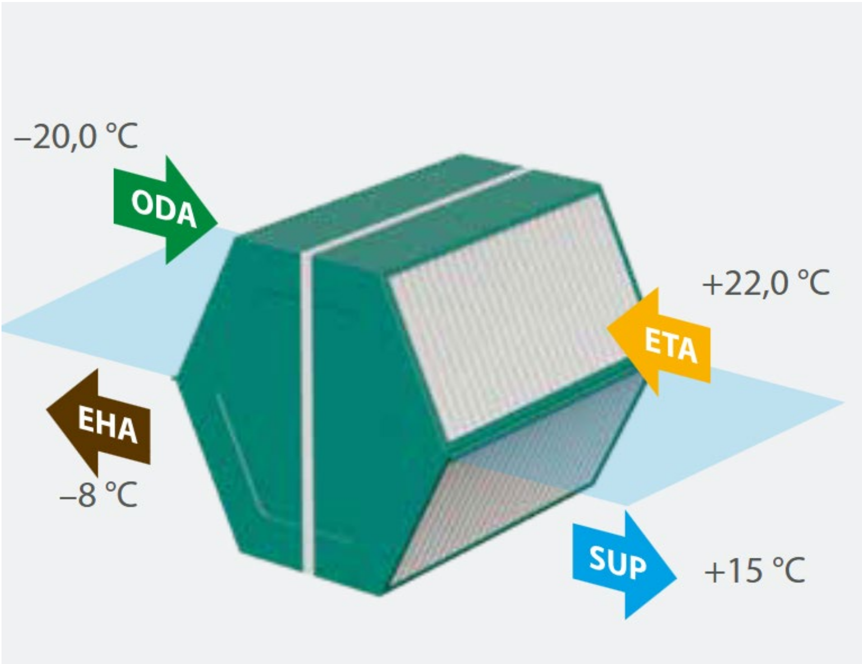


Figure 13 Principle diagram of a cross-flow heat exchanger.

Rotary heat exchanger: a rotating disc collects heat from the exhaust air and transfers it to the supply air.

Advantages: more efficient moisture retention.

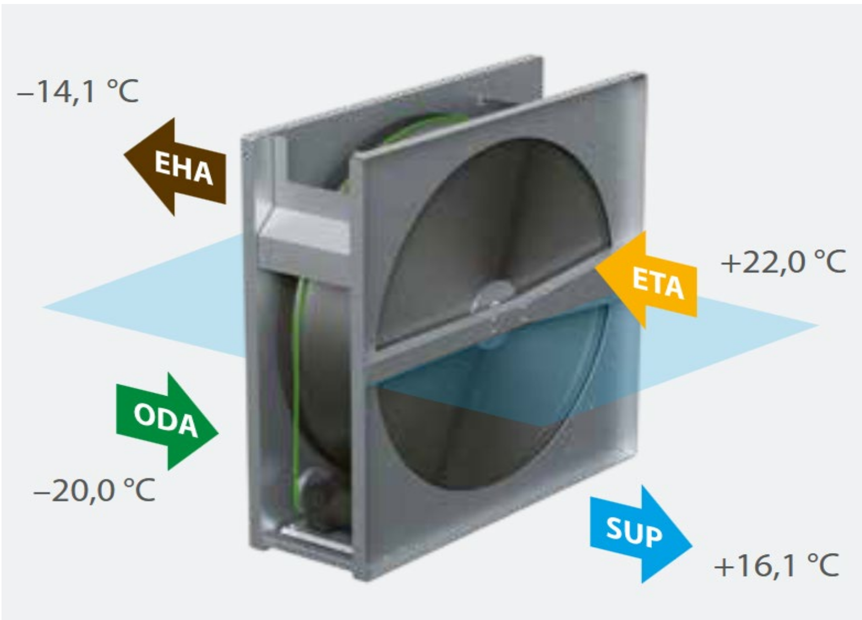


Figure 14 Principle diagram of a rotary heat exchanger.

Counter-flow heat exchanger: the air flows move in opposite directions for maximum heat transfer efficiency.

Advantages: high heat recovery efficiency.

The recuperator can recover up to 90% of the heat from the exhaust air. This reduces heating costs and energy demand. Some heat recovery ventilators are also able to transfer some of the humidity, providing a comfortable indoor climate. In summer, the recuperator can use the coolness of the exhaust air to lower the supply air temperature.

The principle of a heat recovery ventilator is based on efficient heat exchange, which reduces energy consumption while ensuring a healthy and comfortable indoor microclimate. It is an essential part of a passive house, helping to achieve high energy efficiency and comfort.

5.3.2.5. The importance of air quality for health and comfort

Good indoor air quality is essential for both physical and emotional health, as the air we breathe indoors has a direct impact on our respiratory system, our energy levels and our overall comfort. In a passive house, special attention is paid to ensuring air quality through efficient ventilation systems such as heat recovery ventilators.

The main determinants of air quality

- Level of oxygen
  Oxygen is essential for a healthy respiratory system and energy production. Inadequately ventilated rooms can have reduced oxygen concentrations.
- Carbon dioxide (CO_2)
  Excess CO_2 causes drowsiness, headaches and reduced work capacity.
- Pollutants
  Dust particles, mould, bacteria and other air pollutants can cause respiratory diseases, allergies and other health problems.
- Moisture levels
  Too high humidity encourages the growth of mould and dust mites, while too low humidity dries out the skin and respiratory tract and causes discomfort.

The importance of air quality for health

- Prevention of respiratory diseases
  Clean air reduces the risk of infectious diseases such as colds and flu by removing harmful particles and germs.
- Allergy and asthma control
  Clean and properly filtered air reduces exposure to allergens (e.g. dust, pollen), which is important for allergy sufferers or asthma sufferers.
- Sense of well-being
  Adequate air quality improves sleep, energy levels and concentration.
- Cardiovascular health Well-ventilated rooms reduce harmful air pollutants that can have a negative impact on blood pressure and overall heart health. Adequate air quality improves sleep, energy levels and concentration.

The importance of air quality for comfort

- Temperature balance
  Efficient ventilation ensures that the air is at the right temperature without the discomfort of heat or cold.
- Moisture balance
  An optimum humidity of 40-60% is maintained to ensure comfort and health.
- Freshness
  Fresh air supply eliminates stagnant air odours and provides a pleasant living environment.
- Noise reduction.
  Heat recovery systems allow rooms to be ventilated without opening windows, which reduces exposure to external noise.

Ensuring good air quality in a passive house

- Heat recovery ventilation systems
  A constant supply of fresh air and the removal of polluted air ensure high air quality.
- Air filtration
  High-quality filters (e.g. HEPA) are used to remove dust, allergens and other pollutants.
- Airtightness
  Passive houses are airtight, so air quality can be fully controlled by ventilation systems.
- Humidity control
  Recuperators maintain optimum humidity, preventing excessive dryness or mould growth.

Good air quality is an integral part of a healthy and comfortable life. In passive houses, fresh air supply and proper filtration ensure that occupants breathe clean, healthy air and maintain a pleasant indoor microclimate. This not only contributes to health but also improves quality of life.

5.3.2.6. Energy recovery efficiency

Energy Recovery Efficiency (or Heat Recovery Efficiency) is an indicator of how much heat from the exhaust air is recovered by the recuperator and transferred to the supplied fresh air. This principle is a key part of the mechanical ventilation system in passive houses, allowing to reduce energy consumption and ensure comfort.

What is energy recovery efficiency?

Definition:

The energy recovery efficiency refers to the percentage of the heat from the exhaust air that is recovered by the recuperator and transferred to the supply air.

Meaning:

Efficiency directly determines how much additional heating or cooling energy is required to maintain the space at the required temperature.

Energy recovery efficiency of the recuperator

- Efficiency range: modern heat recovery units achieve 75-95% heat recovery efficiency. This means that only 5-25% of the heat is lost in the exhaust air.
- Example: if the room temperature is 22 °C and the outside air temperature is 0 °C, a recuperator with an efficiency of 90% will heat the supply air to about 20 °C using only the exhaust air heat.

Factors determining efficiency

- Plate: Efficiency about 75-85%. Air flows are not mixed, heat is transferred through the plates.
- Rotary: Efficiency about 80-90 %. Some moisture can also be transferred.
- Counter-flow: Efficiency up to 95%. The air streams move in opposite directions, maximising heat transfer.
- Insulation: well-insulated ducts and unit reduce heat loss.
- Air filtration: proper filters not only clean the air but also reduce energy losses due to airflow resistance.
- Proper maintenance: regular filter changes and cleaning of the ventilation system ensure optimum performance.

Benefits of energy recovery efficiency

- Energy savings: most of the heat is returned to the building, reducing heating and cooling energy demand.
- Comfort: the supply air is already at a near-adequate temperature, so rooms do not freeze and there are no sudden temperature fluctuations.
- Environmental protection: efficient use of energy reduces CO_2 emissions, contributing to reducing the effects of climate change.
- Lower running costs: less energy is used for heating and cooling, which reduces electricity or heating fuel bills.

Calculating energy recovery efficiency

The efficiency is expressed as a percentage and is calculated according to the formula:

$$\eta = \frac{T_{supplied\ air} - T_{outdoor\ air}}{T_{air\ emissions} - T_{outdoor\ air}} \times 100$$

η – *energy recovery efficiency*

$T_{supplied\ air}$ – *temperature of the preheated fresh air*

$T_{outdoor\ air}$ – *temperature of outdoor air entering the recuperator*

$T_{air\ emissions}$ – *temperature of the exhaust air from the room*

The importance of energy recovery efficiency in passive houses

A high-efficiency heat recovery ventilator is an essential component of a passive house, ensuring minimum heat loss and energy demand.

It allows passive houses to meet the heating energy requirement of 15 kWh/m² per year.

Energy recovery efficiency is a key performance indicator for achieving the energy efficiency, comfort and sustainability goals of a passive house. High heat recovery efficiency results in lower energy consumption, a better microclimate and a lower environmental impact.

5.3.3. Windows and doors

5.3.3.1. Triple glazing

Triple glazing is an essential component of a passive house, as it provides high thermal insulation, energy savings and comfort. Such windows and doors meet the strict Passive House standards and help reduce heat loss through building openings.

What is triple glazing?

Structure: a triple glazing unit consists of three layers of glass with two layers of air or an inert gas (e.g. argon, krypton) between them. The gaps are filled with this gas to increase thermal insulation.

Coatings: glass surfaces are coated with a low-emissivity (Low-E) coating, which reflects heat back into the room and reduces heat loss.

Thermal insulation properties

- Low U-value: triple glazing has a very low heat transfer coefficient (U-value), often ≤ 0.5 W/(m²K),
- The total U-value of the whole window with frame is ≤ 0.8 W/(m²K), which meets the requirements of a passive house.
- Efficiency: they are twice as efficient as double glazing, with minimal heat leakage.

Saving energy

- Heat retention: triple glazing helps to retain heat indoors, reducing the need for heating in winter.
- Heat penetration protection: in summer, the windows prevent too much heat from the sun from entering the room, reducing the need for cooling.
- Solar transmittance: windows with the right choice of glass make optimal use of natural sunlight and heat.

Ensuring comfort

- Uniform temperature: triple glazing eliminates the feeling of cold zones at the windows, as the glass remains warm even in winter.
- Sound insulation: thanks to the extra layer of glass and the gas filler, the windows have a high level of sound insulation, reducing noise from outside.
- Anti-condensation: the warm inner surface of the glass reduces the risk of condensation forming on the windows.

Sustainability

- Energy saving: reduced heating and cooling demand helps reduce CO_2 emissions and contributes to environmental protection.
- Durability: triple glazing is durable and resistant to temperature fluctuations, so it retains its properties over time.

Additional features

- Security: windows can be reinforced with toughened glass or laminate to provide impact resistance.
- Aesthetics: different frame types (wood, aluminium, plastic) and glass shades are available to match the building design.

Triple glazing is the ideal choice for passive houses because of its thermal insulation properties, energy saving potential and comfort. They are indispensable for modern sustainable and energy-efficient buildings.

5.3.3.2. Solar energy through proper building orientation.

Proper building orientation is one of the key design principles for passive house design. It allows efficient use of the sun's natural energy for heating, lighting and overall energy savings. By optimising the position of the building according to the movement of the sun, heating, cooling and lighting needs can be reduced.

Key principles	
Window orientation	• the majority of windows should be oriented towards the south to maximise absorption of solar heat and light during winter. A minimum of windows on the north side to minimise heat loss.
Shape of the building	• a compact and simple building form reduces heat loss.
Shadow management	• canopies, curtains or protruding structures prevent excessive solar heat in summer but allow winter sunlight to reach the interior of the building.

Benefits of solar energy through proper orientation

- Reducing heating demand: south-facing windows allow the sun's heat to warm rooms during the cold season, reducing the need for additional heating energy.
- Natural light: the orientation ensures maximum natural light penetration, reducing the need for artificial lighting.
- Energy saving in summer: proper shade management prevents overheating, reducing the need for air conditioning.

Practical orientation solutions

- South orientation
  Maximum absorption of solar energy and light in winter.
  Windows should be large enough to take advantage of the sun's heat, but at the same time protect against overheating in summer.
- North orientation
  Reduced number of windows to avoid heat loss.
  Suitable for ancillary or less used rooms.
- East and west orientation
  Eastern windows let in the morning sun, providing warmth and light early in the morning.
  On the west side, protection against afternoon overheating is needed, e.g. blinds or plants.

Optimising solar energy capture

- Roofs and solar panels: roofs with a southern slope are ideal locations for solar panels or photovoltaic panels, allowing additional energy generation.
- Solar heat storage: massive internal structures (e.g. concrete or masonry walls) can store solar heat during the day and slowly release it at night.

Sustainability aspects

- CO_2 reduction: efficient use of solar energy reduces dependence on fossil fuels.
- Cost-effectiveness: lower heating and cooling costs due to optimal orientation and use of natural solar energy.

Example

- In a passive house with windows on the south side, the sun's rays warm the floors and walls in winter, while in summer, canopies or trees block the direct rays to prevent overheating. This ensures constant comfort in all seasons.

Proper building orientation is one of the key factors in the energy savings of a passive house. Making optimal use of solar energy reduces heating and cooling demand, ensures comfort and contributes to sustainable building goals.

5.3.4. Eliminating thermal bridges

5.3.4.1. Impact of thermal bridges on energy losses

Thermal bridging is one of the main reasons why a passive house can lose heat and reduce energy efficiency. Thermal bridges are areas of a building where the insulation is weaker due to design or material features, and where heat escapes more quickly.

What are thermal bridges?

They are parts of a structure that transfer heat faster than the rest of the building due to:

- Connections between different materials with different thermal conductivities.
- Leaks in the installation or design.
- Improperly designed insulation layers.

Main locations of thermal bridges

Windows and doors:

- Joints between window and door frames and the wall.
- Improperly installed sealing materials.

Foundations and walls:

- Transition zones between walls and foundations.

Roof-to-wall joints:

- Poor insulation termination at joints.

Balconies:

- Structures that extend from the inside to the outside transfer heat.

Piping and wiring:

- Passageways through walls and ceilings without proper sealing.

Effect of thermal bridges on energy losses

Increased heat loss:

- Thermal bridges act as heat "leakage pathways", increasing the overall energy consumption of the building.

Increased heating demand:

- Even small thermal bridges can lead to significant increases in energy costs, especially in winter.

Reduced comfort:

- Thermal bridges create areas of cold surfaces which can cause discomfort and draughts in rooms.

Mould and moisture problems:

- Cold surfaces tend to condense moisture, which can lead to the formation of mould and eventually damage the structure.

How significant can the effect of thermal bridges be?

Although thermal bridges are only a small part of the surface area of a building, they can be responsible for 20-30% of all heat loss.

Passive House standards pay special attention to thermal bridges in order to minimise energy losses.

How to reduce the effects of thermal bridges?

Design solutions

- Avoid external structures that extend from inside to outside (e.g. balconies).
- Use continuous layers of insulation without gaps.

Selection of materials

- Use materials with lower thermal conductivity (e.g. polystyrene, mineral wool).
- Continue the insulation layer through all joints of the structure.

Structural solutions

- Insulate foundations and walls without interruption.
- Install window and door frames so that the insulation covers the sides of the frame.

Installation quality

- Ensure careful installation work to avoid leakage.
- Use sealing tapes and mastic at joints.

Passive House requirements for thermal bridges

In the Passive House standard, the influence of thermal bridges must be minimised:

The thermal bridging coefficient (ψ\psiψ) shall be as close to zero as possible.

The design of passive houses uses specific simulations and calculations to identify and eliminate potential sources of thermal bridging.

Reducing thermal bridges is a critical aspect of passive house design. Avoiding them not only reduces energy costs, but also increases comfort, protects structures from moisture and extends the life of the building. The right design, material and installation solutions are key to success.

5.3.4.2. Structural solutions

Preventing thermal bridging is an essential part of efficient building design and construction, especially in passive houses. Properly selected design solutions can reduce heat loss, improve energy efficiency, prevent moisture build-up and increase overall living comfort.

Foundations and floors

- Insulation under floors: use high-density insulation boards (e.g. XPS or PIR) under floor and foundation slabs to prevent heat transfer through the ground.
- Thermal insulation blocks for foundations: install thermal insulation blocks in the transition zones between foundations and walls to reduce heat transfer.
- Continuity of insulation is crucial: insulation should cover the foundation and the edges of the floor to avoid breaks between insulation layers.

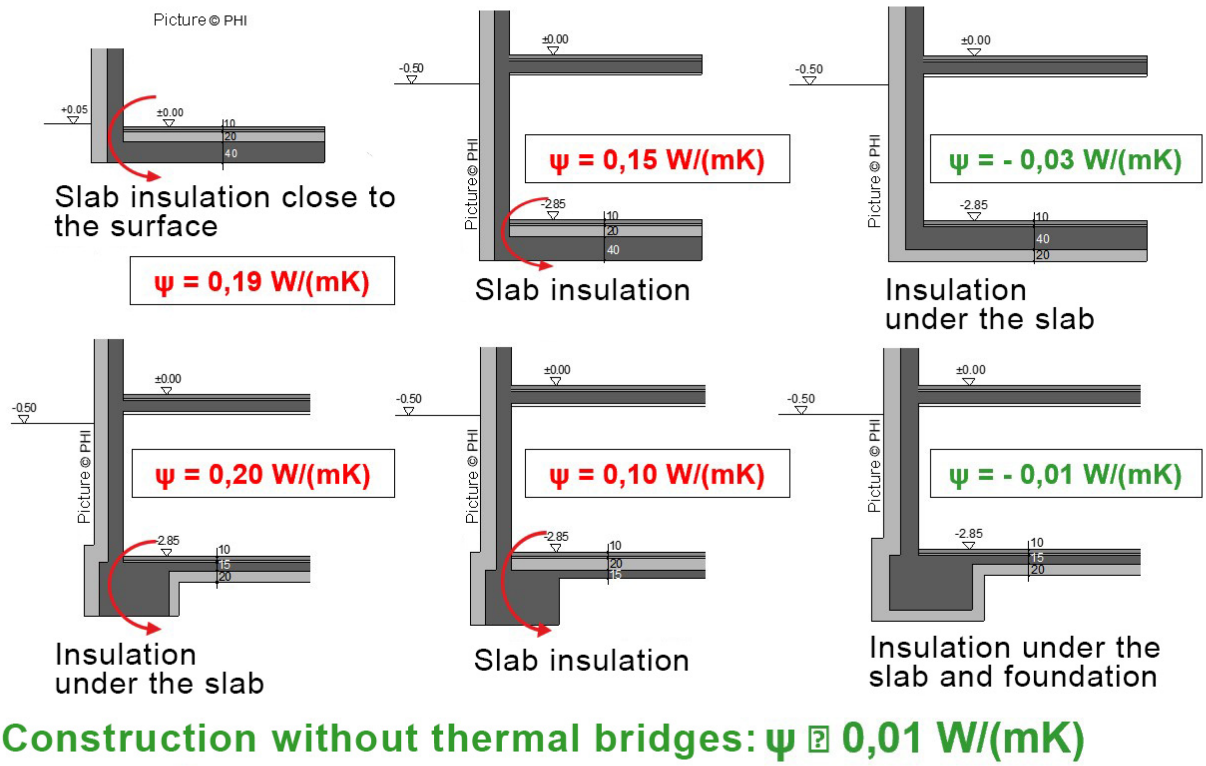


Figure 15 Structural solutions with and without thermal bridges.

Walls and their connections

- Single layer of insulation: ensure that the insulation covers the entire external surface of the building, including corners and joints, without interruption.
- Insulation of wall and ceiling joints: avoid open corners of structures; use external insulation layers that extend across all joints.
- Multi-layered structures: use external insulation layers with appropriate diffusion membranes to ensure thermal conductivity reduction and moisture removal.

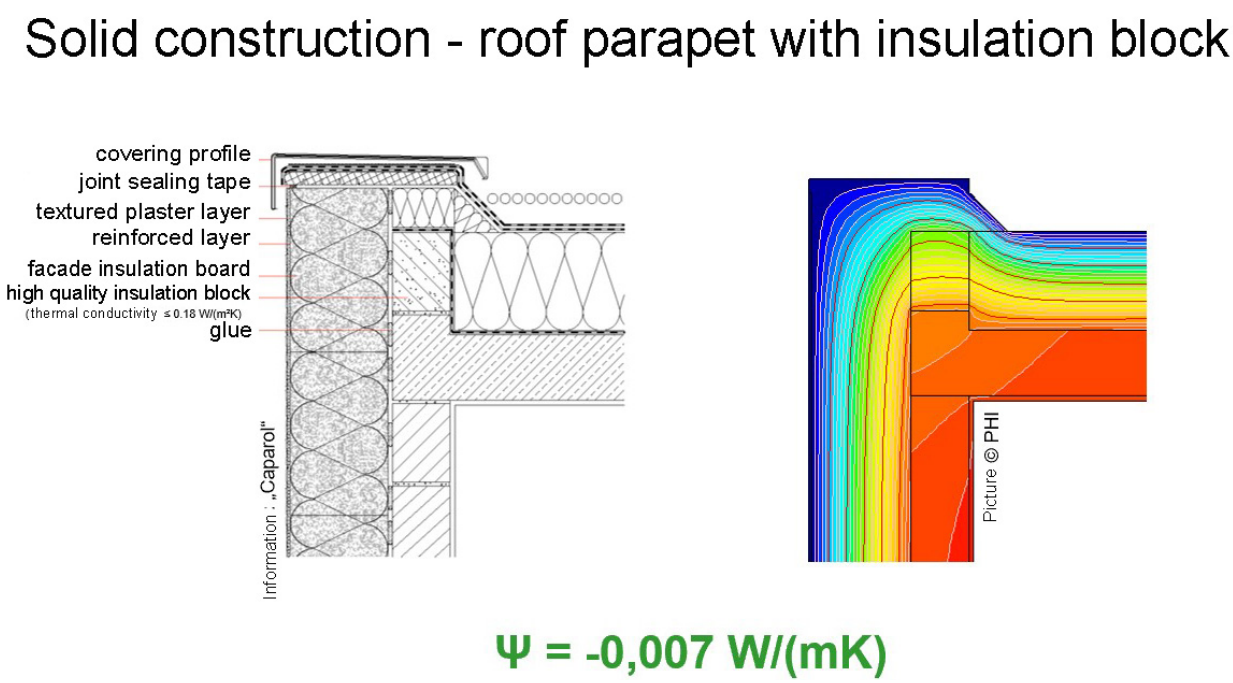


Fig. No. 16 Roof parapet assembly without thermal bridge.

Windows and doors

- Installation of windows in the insulation layer: windows should be installed in the external insulation layer to prevent heat loss through the window frames.
- Use of sealing strips: install special sealing strips between window/door frames and walls to prevent air and heat leakage.
- Low U-value windows: use triple glazing with low thermal conductivity frames.

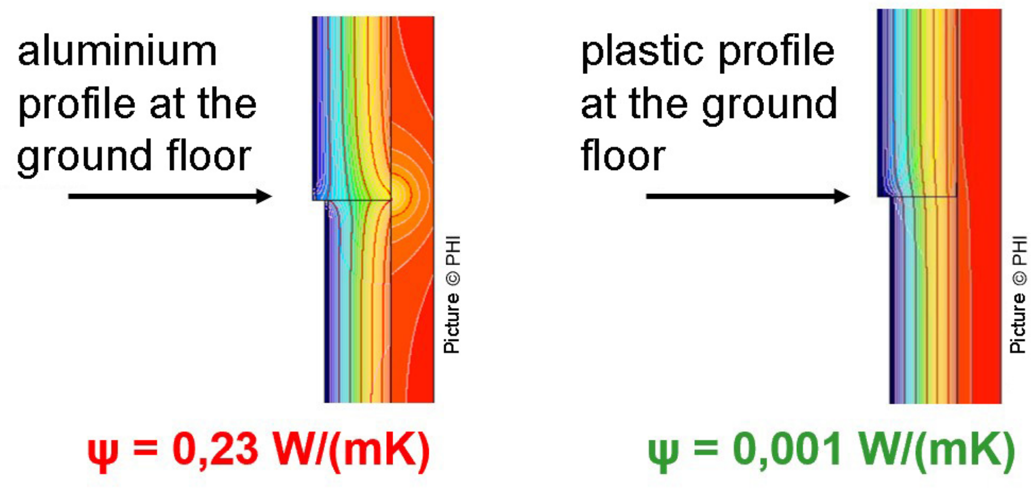


Figure 17 Thermal bridging with different materials.

Balconies and other external structures

- Thermal insulation joints: balcony panels should be separated from the building by thermal insulation joints which reduce heat loss.
- Separate structural elements: where possible, balconies should be constructed as separate from the building to avoid heat transfer.

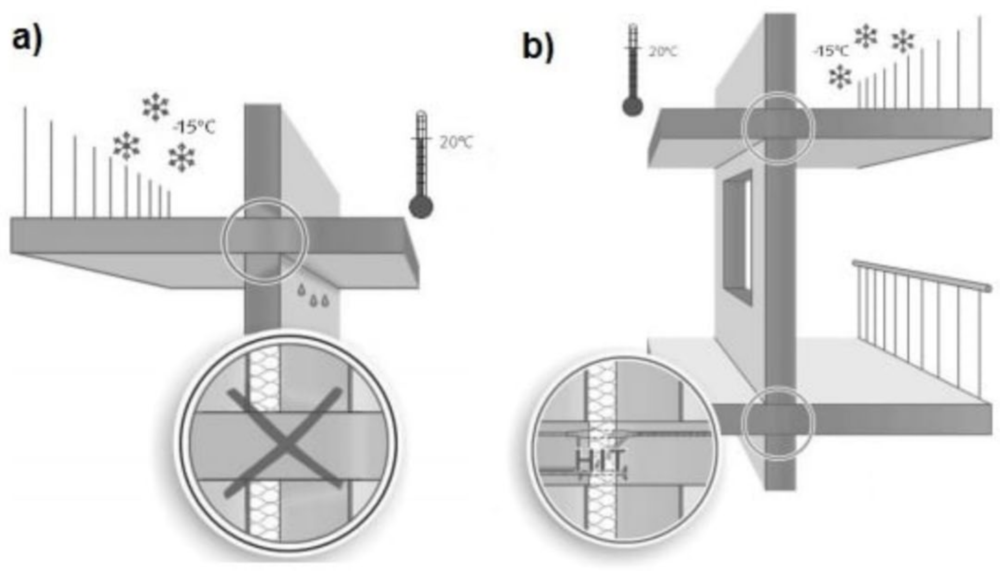


Figure 18 Balcony panel installation solution without thermal bridge.

Roofs and overlays

- Thermal insulation at roof joints: the roof insulation shall be continuous and cover the entire joint between the walls and the roof.
- Avoid heat loss through the ridge: roof ridges shall be properly insulated using sealed insulation boards or spray insulation.

Transitions for pipelines and engineering systems

- Sealed penetrations: use special sealing devices for pipe and cable penetrations through walls, floors or roofs.
- Insulate piping: heating and cooling pipes must be insulated even in internal structures to reduce heat loss.

Materials used

- Insulation materials: use low thermal conductivity materials such as polyurethane (PUR), extruded polystyrene (XPS) or mineral wool.
- Thermal insulation blocks: incorporate thermal insulation blocks in structural joints to reduce heat transfer.
- Diffusion membranes: membranes protect against moisture but allow vapours to escape.

Ensuring airtightness

- Vapour barrier films: proper installation of vapour barriers to ensure airtightness and moisture control.
- Sealing tapes and mastics: use sealing materials at all joints to eliminate cracks and air leaks.

Structural solutions to prevent thermal bridging are an essential part of passive house construction. Properly selected materials, design methods and careful installation can minimise energy loss, improve comfort and ensure the longevity of the building.

Summarising the benefits of Passive House

An energy-efficient house has many environmental, economic and social benefits. There are also undoubtedly a number of benefits for the occupants of the passive house itself.

- Compared to other similar types of energy-efficient buildings, a passive house is much more durable and requires less maintenance.
- Higher quality of life and comfort.
- Reduced CO_2 emissions - An average sized house emits up to 6,000 kg of CO_2 per year. Living in a passive house of the same size reduces atmospheric pollution by up to 2,100 kg CO_2 per year.

- Noise reduction - Thicker and well-insulated envelopes provide better protection against external noise, which simply means quieter rooms and better relaxation in areas close to noise areas.
- Thermal comfort (also in summer).
- Better indoor air quality. Fresh, clean air.
- Consistent humidity and temperature.
- Easier maintenance.
- Low heating costs - A Passive House saves at least 75% of the energy needed for heating per year.
- Low running costs.
- Higher and stable building value - The sale price of an energy-efficient house will be up to 30% higher than that of a conventional house.
- Design freedom.
- Less technical equipment.
- Less dependence on imported energy resources.

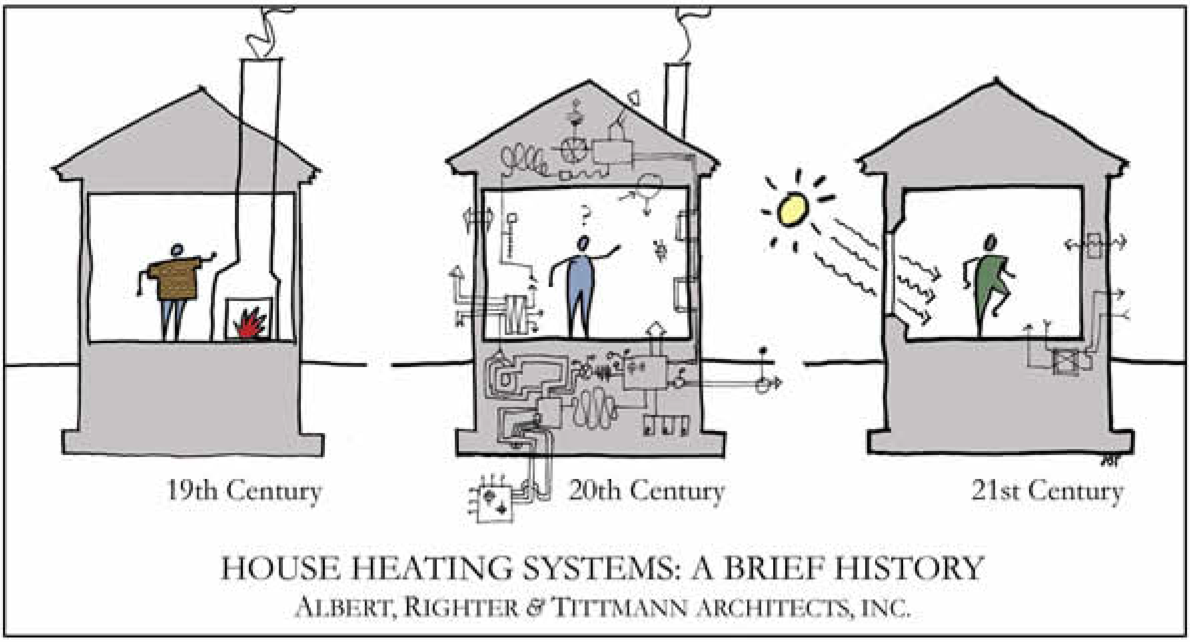


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Figure 10 https://smartair.lt/rekuperatoriaus-balansavimas

Figure 11 http://www.manevras.lt/index.php?id=39&print=1

Figure 13 https://www.komfovent.lt/lt/atsisiuntimai

Figure 14 https://www.komfovent.lt/lt/atsisiuntimai

Figure 18 https://denia.lt/balkonai-be-salcio-tiltelio-halfen-konstrukciniai-sprendiniai/

Recommended reading:

„The Passive House: Fundamentals, Design, Construction“ (Jürgen Schnieders).

„Passive House Design“ (Emma Walshaw).

Useful links:

Passivhaus Institute: www.passiv.de

International Passive House Association: www.passivehouse-international.org

https://smartair.lt/rekuperatoriaus-balansavimas

https://i1.wp.com/www.aterma.lt/wp-content/uploads/2019/05/dumai.jpg

http://www.manevras.lt/index.php?id=39&print=1

https://www.komfovent.lt/lt/atsisiuntimai

Useful tools:

PHPP (Passive House Planning Package) – passive house energy calculation software.

6 - Deliverables

To evaluate the success of the application, we suggest students to answer an online questionnaire.

7- What we have learned

Basic understanding about Passive houses.

Various passive and active solutions applied in the building to achieve passive house standards.