Higher quality of life – lower heating costs

Up to 90 % energy savings by renovation

A Technical Guide to the
Thermal Renovation of old buildings.

Responsible building – Comfortable living

The construction of new buildings provides an opportunity to apply state-of-the-art building materials and methods. But just as important is the enormous opportunity to renovate existing buildings so that they reflect the highest standards of energy efficiency.

It is an opportunity for architects, engineering firms and all building professionals to create considerable value as we enter a new era of environmental awareness. It should in fact be possible to save between 60 and 90 % energy if all heated buildings were refurbished according to the standard that is technologically feasible today. The advantages of a well-planned renovation don't stop at lower energy bills and a reduction of the CO_2 output. Enhancing the protective shell of a building has a direct impact on its lifetime and overall value. And by creating an interior climate that is more balanced, with improved temperature distribution and noise reduction, the residents' comfort is also enhanced. Energy prices are projected to rise continuously over the coming decades in response to the worldwide growing demand. There can be no doubt that we need to reduce our energy consumption drastically – for environmental reasons but also for economic reasons. Energy-saving buildings will therefore provide immediate benefits for their users.

Renovation projects: towards an immediate and significant reduction of CO_2

The reality of climate change can no longer be doubted. The consequences can already be observed around the planet. The accelerated rate at which glaciers are melting and the consequent rise in sea levels the dramatic increase and violence of cyclones, storms, heat waves and droughts … all these phenomena point to the changes in the delicate balance of the Earth's ecosystems.

This is not an easy issue. Our modern world is more than ever dependent on energy. And this trend is set to continue for the unforeseeable future. Europe's energy needs are expected to grow by 30 % by the year 2030. It is imperative that energy use goes hand in hand with the reduction of greenhouse gases.

Climate change is directly related to the increase in these gases and notably CO_2. The greenhouse effect, which prevents heat from escaping the Earth's atmosphere, is caused by the increase in carbon dioxide which accounts for about 70 % of all greenhouse gases. The increase in CO_2 is primarily caused by the combustion of fossil fuels such as coal, oil and gas.

A large part of the CO_2 generated comes from the energy consumed by buildings for heating, air-conditioning and other energy-dependent functions. If we ensure that our homes are well insulated, we can rapidly and significantly reduce the amounts of carbon dioxide released into the atmoshphere.

Comfort comes first!

Renovation with the ISOVER Multi-Comfort House Concept - this stands for environmental protection, energy savings and a very low space heating demand comparable to that of passive houses. The Multi-Comfort house offers a pleasantly stable indoor climate and excellent conditions for working and living – thanks to snugly warm indoor air temperatures without drafts and no cold walls, competent noise control, sound absorption and low-energy day lighting.

Ecology and sustainability

The beneficial effects of insulation on our environment need not be explained. Experts have calculated that the effective renovation and insulation of existing buildings can result in energy savings of 60 to 90 %. At the same time, the principles of ecology and sustainability can be applied to the choice of building materials and processes. The primary ingredient of ISOVER glass wool is sand, a material that is available in virtually unlimited quantities. Product life cycle issues can have a profound effect on the environment as well. Raw materials for ISOVER products are procured from small, open-air sources and then reconditioned using state-of-the-art processes that ensure minimal environmental impact. Up to 80 % of the contents of ISOVER glass wool come from recycled glass. The energy used in producing glass wool is saved in less than two heating months.

Moisture and air tightness

A continuously airtight building envelope is an essential factor in reducing energy losses and ensuring comfort. A building envelope with leaky joints can have highly undesirable consequences, including heat loss, uncontrolled air exchange, poor sound insulation and progressive structural degradation caused by condensate, mould or corrosion. For this reason, most building codes require airtight building envelopes. ISOVER – having recognized the importance of airtight envelopes for decreasing energy consumption and increasing comfort – has developed VARIO KM, a flexible climatic membrane system that adjusts itself to the challenges of every season and climate.

Ease of installation

ISOVER ensures that all of its products provide comfort and efficiency in installation. ISOVER glass wool features a compression rate of 6:1 or even higher, thus minimizing the volume for transportation to and on the construction site. Highly compressed rolls can be handled in narrow corridors, staircases and attic accesses, making your job on the renovation site easier. Once unwrapped, the glass wool recovers its full thickness. The installation of ISOVER insulation materials is extremly easy, fast and convenient. The coating used for the ISOVER Comfort products reduces skin irritation and dust. ISOVER is committed to inventing products and systems that enable efficient work on the job site, facilitate the application of best installation practices and reduce the volume of waste.

Content

Sources:
The concept and the majority of text, photos, tables and drawing have been made available by the Low-Energy-Institute, D-32756 Detmold (www.NEI-DT.de).
Some of the thermographic pictures come from InfraTec GmbH, D-0217 Dresden (www.infratec.de).
The picture of vacuum panels originates from the manufacturer Va-Q-Tec AG in D-97080 Würzburg (www.va-q-tec.de).
The climate map in chapter II has been made available by the Wetterzentrale, D-76332 Bad Herrenalb (www.klimadaten.de).

I. Introduction

I.1. High energy costs but a low comfort level – a growing problem.

We speak of "thermal comfort" when it is neither too cold nor too warm and when there is enough fresh air but without disturbing drafts. A comfortable temperature feeling results from the low difference between indoor air temperature and the temperature of the inner surfaces of outer walls and windows. Under these conditions, one can enjoy a homogeneous air temperature in the whole house and the absence of annoying drafts. Most older houses were built at a time when the building mentality was very different from today and when there were no efficient thermal insulation materials available. Although a lot of energy is used in heating old houses, their floors, walls and ceilings often do not really get warm in winter. And although the residents pay high energy bills for heating in winter and cooling in summer, there is only limited thermal comfort. In view of the fast increasing energy prices, living in older houses can become a very expensive "pleasure". Not to forget the high consumption of natural resources and the emissions that burden our environment.

I.2. Thermal comfort at lower heating costs: achieved by thermal renovation.

When carefully insulating the building envelope and installing modern heating and ventilation systems, the energy consumption of older houses can be reduced by up to 90 %. After their thermal renovation, such buildings can offer even higher thermal comfort than some newly built houses that comply only with minimal requirement of the current building regulations. At the same time, the heating costs decrease. When making use of the proper insulation materials, also a higher level of acoustic comfort can be reached. Last but not least, an adapted ventilation system ensures a real improvement of indoor air quality. The aim of this Technical Guide is to show how these improvements of quality and comfort can be achieved.

I.3. The key to success: avoid thermal transmission through the building envelope.

The amount of energy needed for heating and cooling a building depends directly on the thermal insulation of walls, roof, ceilings and base slab, the thermal performance of windows as well as ventilation losses and gains. Special attention must be paid to thermal bridge free construction and an airtight, leak-free building envelope. When following these principles, you obtain controlled conditions that ensure a high comfort level in your home. Only minimum energy will be needed then to maintain the desired temperature and comfort level.

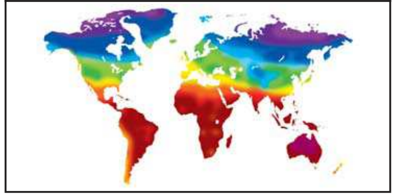
II. Climate-adequate thermal insulation

The heating and/or cooling demand greatly depends on the local climatic conditions. The three maps on the right show the middle temperatures in January and July as well as the annual middle temperatures worldwide. It is obvious that almost all regions of the world need heating and/or cooling. Cost is the decisive factor. And since thermal insulation reduces thermal transmission through the building envelope, it can thus reduce the heating and/or cooling costs in almost all regions of the world.

Construction details need to take the different directions of thermal transmission, radiation, airflows and moisture diffusion into account (see next chapter). It is not enough to simply set off the energy losses against the gains and to come up with a positive energy balance. Moreover, a sufficiently high level of comfort needs to be ensured, both in winter and in summer. It is therefore recommended to always use glass with a high thermal resistance and to make sure that the window area of a house is not too large. Airtightness has top priority so that residents can control the ventilation inside their homes. Airtightness and ventilation are the best means to protect the building structure from condensation and moisture.

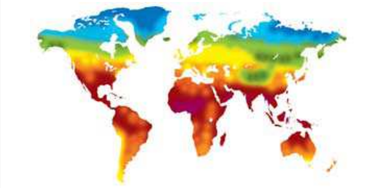
In moderate climatic zones like Central Europe or the major part of North America, India and China, there are strong fluctuations in temperature and moisture over the year. For this reason, the building envelopes in these zones need to be well insulated. Good thermal insulation is the precondition for comfortable living all year round.

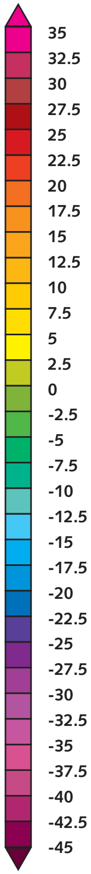
Middle temperature 1961-90 in °C in January



Middle temperature 1961-90 in °C in July

Middle temperature 1961-90 in °C in a year





If best practice is used to construct and insulate a building, its heating and cooling demand can be reduced to less than 15 kWh/m^{2}a. For a detailed description refer to the technical chapters of the Multi-Comfort House Brochure. Since in our moderate climatic zone the sun radiation is of medium strength also in the cold season, a well designed solar system can help reduce heating costs. In summer, immission caused by the high-standing sun needs to be reduced by externally installed shading systems. With state-of-the-art windows and solar shading, houses can be opened to the south and thus benefit from the low-standing winter sun. In summer, they have enough sun protection to avoid overheating. Airtightness and controlled ventilation systems are necessary to fulfil the building physical requirements, especially with respect to the level of humidity.

In the hot regions of the world, efficient thermal insulation of the building envelope is crucial to control heat transmission into the building. Furthermore, airtightness and protection against solar radiation are necessary to control the indoor climate. Especially in desert regions with high day and very low night temperatures, thermal insulation helps ensure comfortable temperature levels around the clock.

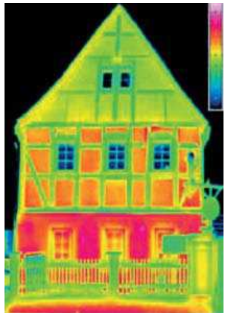
Although the requirements of airtightness and ventilation are comparable in almost all regions of the world, the positioning of the water vapour barrier and of the different airtight layers needs to follow special physical requirements. The local climatic conditions must always be kept in mind. Especially in tropical zones, the ventilated air needs to be kept cool and dry to maintain comfortable conditions.

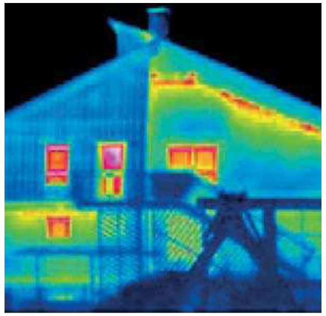
The table below shows the range of U-value: from building elements in old houses with very high energy losses to Multi-Comfort houses with a very low energy consumption.

Thermal insulation quality levels (U-values in W/m^{2}K)	**Very high energy losses**	**High energy losses**	**Insufficient insulation**	**New house level**	**Low-energy house level**	**Multi-Comfort house level**
Base slab	3.5	1.5	0.6	0.4	0.30	0.15
Cellar ceiling	1.8	1.5	0.6	0.4	0.30	0.18
Outer wall	2.5-1.0	1.0-0.5	0.5-0.35	0.35-0.25	0.25-0.15	< 0.15
Window, door	5.0	3.0	2.5	1.6	1.30	0.80
Loft ceiling (concrete)	3.5	1.0	0.6	0.2	0.15	0.09
Pitched roof	2.9	1.0	0.6	0.2	0.15	0.11
Flat roof	3.2	1.0	0.6	0.2	0.12	0.09

III. Heat flows in old houses

In the cold season, thermal energy flows out and in the hot season into the building. This takes place in three different ways: by transmission, by radiation and by airflows. The influence of these heat flows differs. They depend on the geometry of the house, the insulation of the building envelope, the quality, size and orientation of its windows, on its airtightness and the efficiency of the ventilation system. The next chapter explains the direction of the different heat flows, their importance and how they can be influenced.

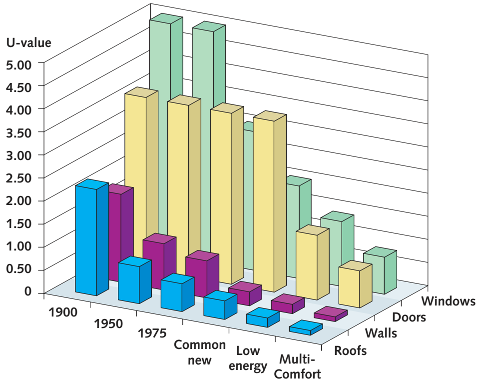




III.1. Thermal transmission

Usually, the heat flows through the outer envelope account for the major part of the overall heat losses of an old building. This applies to both hot and cold seasons. Technically speaking, these heat flows are either transmission losses or transmission gains. They depend on the thickness and the thermal conductivity of the materials that the building envelope is made of. The thermal transmittance of walls, roofs, floors and windows is expressed in U-values. The lower the U-value, the lower the energy loss.

The U-values of common building components are between 6.0 W/m^{2}K (metal frame windows or aluminium house doors with single glazing) and 0.1 W/m^{2}K (for a very well insulated roof). For a non-renovated old house built in 1900, the average U-value of the complete envelope is approx. 2.0 W/m^{2}K. By contrast, recently renovated houses on passive house level have an average U-value of the complete envelope of 0.14 W/m^{2}K.



U-values of different old building components

The largest areas of the thermal envelope of a normal family house are its outer walls, the different parts of the roof and the floors. Apart from these areas, also the windows, outer doors and the walls between heated rooms and non-heated parts of the house need to be taken into account. The thermal performance of the building envelope does not only depend on the thermal insulation and ventilation, but also on the ratio between heated volume and surface area of the heated volume. This is why bungalows with relatively large surfaces have higher energy consumptions than buildings with a more compact form.

Bungalows: large roof and floor areas, fewer walls

High houses: large wall areas

Old houses: often small window areas

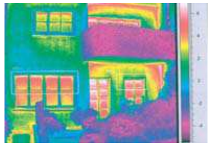
Since 1970: often large window areas

The U-values of building elements exposed to the outside air should be about 50 % lower than those of building elements in contact with the ground. The thermal transmissions through old external walls, roofs and floors can be reduced by 50 to 95 %, provided their thermal insulation is optimized (see the following chapters). The heat lost through older windows and doors in winter can be reduced by 60 to 85 % when using coated double or triple glazing as well as special frames with lower heat transmission and airtight sealing.

Better thermal protection of the envelope also results in higher indoor comfort. Take, for example, the cold season. After installing additional insulation, the air temperature inside the room may be the same, but the inner surface temperature of the outer walls, roofs and floors above cellars will be up to 10°C higher. This mitigates the "cold wall" feeling and prevents uncomfortable drafts in the room. During hot periods, a well-insulated building envelope reduces the risk of overheated rooms (especially under the roof). In old houses, a significant part of the heat loss is caused by thermal bridges.

With older houses, thermal bridges are frequently caused by load-bearing structures that penetrate the building envelope from inside, for example connections to balconies, flat roofs and terraces. Further critical components include wall edges, stone windowsills below window frames and very thin walls behind radiators or around roller shutter boxes. Another type of thermal bridge is created when using construction materials of high thermal conductivity such as steel, concrete and others. These thermal bridges must be avoided by overlapping the external thermal insulation. Before starting hands-on thermal renovation, the problems caused by existing thermal bridges should be checked, eliminated or reduced as much as possible.

Thermal bridges caused by concrete components (wall / balcony)



Thermal bridges caused by doors and windows

Thermal bridges caused by wooden rafters

Thermal bridges do not only occur in solidly built houses, but also in timber-framed houses despite the use of materials with a low thermal conductivity. The stripes formed by the melting snow on the round roof (see photo on the right) show the effect of such a thermal bridge. It is caused by the difference in thermal conductivity between the wooden rafters and the insulation material used for the space in-between. This happens when roofs are insufficiently insulated.

III.2 Thermal radiation

In practice, all materials with a positive temperature difference between surface and surroundings emit thermal radiation. The amount is nearly proportional to the temperature difference. In winter, houses without thermal insulation have a much higher surface temperature than the outer air. This is caused by high transmission losses through the building envelope (see thermographic pictures). The results: high heating costs.

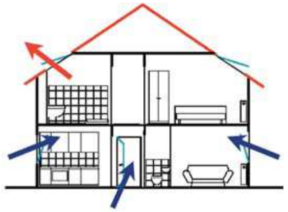
Sunshine heating up the surface of the outer wall can contribute to reducing the energy losses. And sunshine entering through windows provides energy gains that are similar to those produced by solar systems. One should, however, keep in mind that these gains cannot fully compensate the losses (high heating demand in cold winter nights). On the other hand, too much sun radiation in summer may also overheat a house.

The unwanted overheating of the house in summer by solar radiation can be avoided. How? By the installation of adjustable outer shading systems and good thermal insulation of walls and roofs. These are preconditions for reducing radiation heat flows. But in winter this is more complex. Winter sunshine through windows is usually wanted as it warms the interior. But this warmth should not leave the house through the windows again. Modern coated windowpanes can separate wanted from unwanted radiation flows. Their coating allows solar radiation to enter the house without the infrared radiation of the heated space escaping through the windows. This selection is possible because these radiations have different wavelengths. Wintertime heat losses through such coated window glazing are about 60 % lower compared to uncoated glazings. Radiation heat flows are not only important on the outer surface, but also inside houses and materials. Heat distribution inside a room thus takes place by reciprocal radiation of all warmed surfaces to all others. If shading furniture (e.g. a cupboard) blocks the heat transport, temperatures in the shaded parts of the room will be lower.

III.3. Airflows and ventilation

The absolute amount of ventilation loss is partly due to house construction and partly to resident behaviour. This aspect is often underestimated in energetic calculations. Heat loss by ventilation is due to the volume of exchanged air and the temperature difference between incoming and outgoing air. The volume of exchanged air depends on:

- the airflows caused by the residents' active opening of windows/doors or use of ventilation devices
- the airflows through leaky joints or cracks in the building envelope, moved by wind and thermal effects
- the airflows from chimneys, fireplaces and other heating systems inside the heated part of the building if they are provided with fresh air directly from the room and not via an air channel from outside.



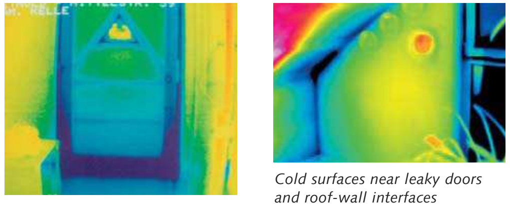
Airflows through windows

The heat losses caused by active ventilation, i.e. by opening windows and doors, depend on resident behaviour. Human beings do not have sufficient sensors for the slowly decreasing oxygen content or the increasing concentration of CO_2 or other pollutants in indoor air. What we mainly feel is warmth or cold and fast changing odours. Rooms which we want to be warm are often not aired enough, other rooms more than necessary, and this causes unwanted heat losses. During the day or night, working people do not have the opportunity to air the room every two to three hours. Airing should be done briefly but intensively to ensure comfort and hygiene with small heat losses. Windows that are tilt-open for long periods cause high heat losses. These conflicting interests can be solved, also in old houses, by the installation of mechanical ventilation systems. They supply each room with the exact quantity of fresh air needed and extract humidity and bad smells from kitchen, bathroom and toilet with no need for the presence or discipline of the inhabitants. If combined with a heat exchanger, these mechanical ventilation systems can reduce the ventilation heat loss by up to 85 % while at the same time highly improving indoor air quality. In older houses, the high heat loss is often caused by airflows through gaps in the building envelope. Airtightness was never duly considered – or does no longer exist because the building (and also its air barrier materials) aged with time. Most old window frames, front doors, doors leading down to the cellar or up to lofts, wooden ceilings above cellars or below lofts are not equipped with a continuous airtight layer. In winter, air flows through these gaps due to the external wind pressure and the "chimney effect". Since warm, wet air has a lower specific weight than cold air, it flows upwards. The pressure at the top of the house is a little higher than outside whereas it is a little lower at the bottom of the house. This pressure difference causes warm air to flow out and cold air to flow into a heated house through gaps in the building envelope.

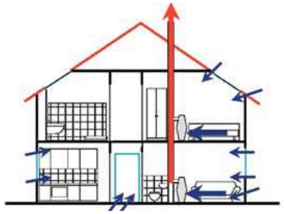
Airflows through gaps

The so-called chimney effect causes a vertical airflow through the whole house. Consequence: considerable heat losses and uncomfortable cold drafts on ground floor level. This can only be avoided by a properly insulated and airtight building envelope.

In the past, stoves and other systems with an open fire were used for heating. It was not possible to avoid the heat losses caused by the demand for fresh air as long as these stoves had no separate supply channels for fresh air from outside. Today, it is no longer allowed for new houses in Germany to install stoves or other heating systems that use up indoor air. They have to draw the fresh air from outside by separate channels. Existing stoves or fireplaces in old houses that work with inside air can be used as long as they also draw enough air from outside.



Cold surfaces near leaky doors and roof-wall interfaces



Airflows caused by air supplied for a stove

The cooling effect of the fresh air diminishes the feeling of comfort and therefore needs to be compensated by additional heating. If this discomfort is not wanted, stoves and other heating systems with flames should be removed, placed outside the heated space or replaced by types that draw fresh air from outside. This increases security and reduces both the uncomfortable cooling effect and the heating demand.

Airtightness and mould formation

In some old houses mould begins to grow in the corners or behind cupboards after new windows were built in, former air gaps were closed or indoor-air supplied stoves were replaced. What triggers this mould growth? Usually, it's the increasing moisture in the rooms that condensates on cold surfaces. Two strategies can help prevent this unhealthy growth of mould. The first is to reduce the moisture content by raising the rate of ventilation. The second is to raise the inner surface temperature by installing thermal insulation preferably on the outside of the external walls. Both measures are helpful and enhance comfort, so it's best to implement them both. Controlled ventilation, which supplies fresh air and removes moisture and odours, is beneficial for both comfort and health. By improving the insulation of floors, walls and roofs of existing houses, you can save energy, increase thermal comfort and reduce the risk of mould. The next chapter shows how the heat losses of a typical old house can be reduced by different ways of thermal renovation.

IV. How much energy can be saved in old houses?

Let's compare the energy consumption of two common house types in Germany. In how far do they differ when changing the construction and renovating them with different qualities of thermal insulation? The first house type is a typical single-family house built in 1955, the second a 24-family house built in 1952 with four staircases leading to 6 flats each.

It was calculated for both houses which heat losses and gains they would have when built in 1900, 1950 and 1975 using the typical construction (see description below as well as the technical data table). The main differences lie in the quality of thermal insulation, ventilation, airtightness and the solar gains through windows.

Based on the 1950 construction, it was then calculated how much heating energy can be saved in both house types if they are renovated on three different levels of thermal quality:

- complying with minimal legal requirements
- with the aim of reaching low-energy house level
- with the aim of reaching Multi-Comfort house level.

The values assumed for these six thermal levels are indicated in the technical data table and described below.

Technical data	As built in 1900	As built in 1950	As built in 1975	Minimal renovation	Low-energy house level	Multi-Comfort house level
Cellar ceiling	Beams and cinder U = 0.73 W/m^{2}K	Concrete + subfloor U = 2.20 W/m^{2}K	Concrete, 1.5 cm ins. U = 1.13 W/m^{2}K	Concrete, 4 cm ins. U = 0.63 W/m^{2}K	Concrete, 10 cm ins. U = 0.30 W/m^{2}K	Concrete, 24 cm ins. U = 0.14 W/m^{2}K
Outer walls	40 cm nat.stone U = 1.72 W/m^{2}K	30 cm brick U = 1.12 W/m^{2}K	30 cm light brick U = 0.99 W/m^{2}K	6 cm insulated U = 0.35 W/m^{2}K	14 cm insulated U = 0.20 W/m^{2}K	30 cm insulated U = 0.11 W/m^{2}K
Windows	Wood, single glazed U = 4.90 W/m^{2}K	Wood, single glazed U = 4.90 W/m^{2}K	PVC, double glazed U = 2.93 W/m^{2}K	PVC, double ins. glass U = 2.00 W/m^{2}K	PVC, double coated glass U = 1.40 W/m^{2}K	PVC, triple coated glass U = 0.80 W/m^{2}K
Outer doors	Wood 58 mm U = 3.50 W/m^{2}K	Wood 58 mm U = 3.50 W/m^{2}K	Wood 58 mm U = 3.50 W/m^{2}K	PVC + ins. glazing U = 3.50 W/m^{2}K	PVC + coated glass U = 1.50 W/m^{2}K	Insulated door U = 0.80 W/m^{2}K
Roofs	Only plastered U = 2.13 W/m^{2}K	3 cm insulated U = 0.86 W/m^{2}K	5 cm insulated U = 0.70 W/m^{2}K	10 cm insulated U = 0.40 W/m^{2}K	26 cm insulated U = 0.17 W/m^{2}K	40 cm insulated U = 0.11 W/m^{2}K
Ventilation and airtightness	Gaps + windows $n_{(50)}$ = 4.5 1/h	Gaps + windows $n_{(50)}$ = 4.5 1/h	Windows + gaps $n_{(50)}$ = 4.5 1/h	Windows $n_{(50)}$ = 3.0 1/h	Ventilation without heat exchangers $n_{(50)}$ = 1.5 1/h	Ventilation with heat exchangers $n_{(50)}$ = 0.6 1/h
Heat demand of a single-family house	496 kWh/m^{2}a	376 kWh/m^{2}a	280 kWh/m^{2}a	165 kWh/m^{2}a	86 kWh/m^{2}a	28 kWh/m^{2}a
Heat demand of a multi-family house	384 kWh/m^{2}a	314 kWh/m^{2}a	260 kWh/m^{2}a	123 kWh/m^{2}a	66 kWh/m^{2}a	15 kWh/m^{2}a

Comparison of the technical data assumed for six energetic levels

Built in 1900: The cellar ceiling is made of wood with a 6 cm layer of filling material. The outer walls of 40 cm thickness are made of natural stones. The windows have unsealed wooden frames and are single-glazed. The wooden front door was not sealed. Roof and upper ceiling below the unheated loft are without insulation; the inner surface only consists of plaster. The cover under the hatch to the loft is made of unsealed plywood. Ventilation takes place via building gaps and windows.
The heating demand of the 100 m^2 single-family house is **approx. 500 kWh/m^{2}a**.
The heating demand of the 1000 m^2 24-family house is **approx. 380 kWh/m^{2}a**.

Built in 1950: The cellar ceiling is made of concrete but has no insulation. The 30 cm thick outer walls are made of bricks. The windows have unsealed wooden frames and are single-glazed. The front door is made of wood and without sealing. The roof and the loft ceiling are only insulated with 3 cm.
The heating demand of the 100 m^2 single-family house is **approx. 380 kWh/m^{2}a.**
The heating demand of the 1000 m^2 24-family house is **approx. 310 kWh/m^{2}a.**

Built in 1975: The cellar ceiling is made of concrete with a 1.5 cm insulation layer. The 30 cm thick outer walls are made of lightweight bricks. The windows are equipped with PVC frames, all-round sealing and double glazing. The front and cellar doors are made of wood and unsealed. Roof and upper ceiling were insulated with a 10 cm layer of aluminium-coated glass wool which cannot take full effect due to the lack of airtightness.
The heating demand of the 100 m^2 single-family house is **280 kWh/m^{2}a.**
The heating demand of the 1000 m^2 24-family house is **260 kWh/m^{2}a.**

Minimal renovation: The cellar ceiling was additionally insulated on its bottom side with a 4 cm layer. The outer walls received an external insulation layer of 6 cm thickness. New windows were installed with cheap PVC frames (only two divisions) and one surrounding seal, but double glazing. New front doors with one seal were installed. The pitched roof and the upper ceiling were insulated from outside with a 10 cm layer. The inner airtight plaster was left in place. A new sealed hatch to the loft was installed, but without insulation. Afterwards, the house had a much higher airtightness. Regular window opening is required to ensure sufficient ventilation. In the multi-family house, the south-facing windows on ground and 1st floor were enlarged and the loft was converted into children's bedrooms. In this way, the area of flats, roofs and windows was slightly increased whereas the area of outer walls and upper ceiling was decreased. The areas of the single-family house were not modified. After renovation, the heating demand of the now 1100 m^2 large 24-family house is 123 kWh/m^{2}a. Compared to the original 1950 level, 56 % heat is saved in single family house and 61 % in the multi-family house. The heating demand of the single-family house is 165 kWh/m^{2}a. According to the current regulations in some European countries, energy consumptions of only 100 kWh/m^{2}a for single-family houses and 70 kWh/m^{2}a for multistorey buildings should be achieved when undertaking renovation work.

Renovation on low-energy house level: In this case, the aim was to exceed the quality of a new building. For this purpose, the conrete cellar ceiling was insulated on its bottom side with a 10 cm layer, the outer walls with a 12 cm layer from outside. The new PVC window frames have 5 divisions, quality double glazing and double sealing. In the single-family house, the small south-facing widows were enlarged by 4 m^2. The new front doors are made of PVC with insulation and two seals all-round. Roof and upper ceiling received a 24 cm insulatation. The new hatch insulation is 5 cm thick and well sealed. A central exhaust system (without heat exchanger) takes care of ventilation: it draws used air from kitchen, bathroom and toilet and sucks in fresh air by self-adjusting valves in the outer walls. In the multi-family house, the calculations are based on the same area size as assumed for the minimum renovation variant.
The heating demand of the renovated single-family house is now **86 kWh/m^{2}a**
whereas the heating demand of the 1100 m^2 24-family house was cut to **66 kWh/m^{2}a**
Compared to the original 1950 level, 77 % heating energy is saved in the single-family house and 79 % in the multi-family house.

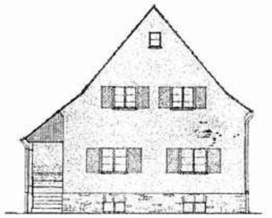
Renovation on Multi-Comfort house level: Components in passive house quality were used whenever possible to achieve the highest possible comfort level and minimize the heating demand. The insulation of the cellar ceiling is 28 cm thick, that of the outer walls 30 cm. The new windows and front door have insulated frames, triple glazing and three surrounding seals each. Roof and upper ceiling received 40 cm insulation. A 20 cm insulation layer was installed over the hatch. Ventilation is done mechanically via a heat exchanger (thermal efficiency: 80 %). The controlled, permanent supply of fresh air improves the living comfort, eliminates cold drafts and provides warm inner surfaces of all walls, floors and the roof. The area size is the same as for the low-energy renovation variant.
The heating demand of the single-family house is now only **28 kWh/m^{2}a** 1)
The heating demand of the 1100 m^2 24-family house was reduced to **15 kWh/m^{2}a** 2)
Compared to the original 1950 level, 93 % heating energy is saved in the single-family house and 95 % in the multi-family house. The following two chapters will explain how much the building components contributed to the original energy flows and how important the investments were for realizing energy savings.

1) In some countries, the definition of passive house level is 10 kWh/m^{2}a. One should therefore try to reach a heating energy demand of 15 kWh/m^{2}a. This is already a challenging target due to the structural thermal bridges which are difficult to compensate in renovation.

2) In some countries, the defintion for passive house level is 10 kWh/m^{2}a.

Saving effects in an old single-family house

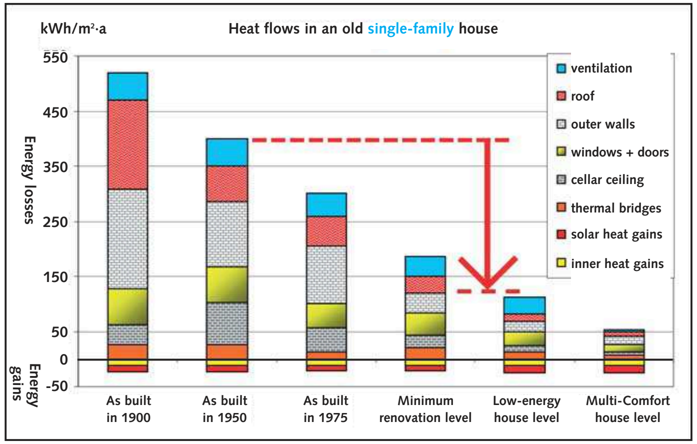
The first house is a typical single-family house built in 1955. Its cellar and loft were not heated. Houses of such form and size were built from around 1900 until 1975 (with little difference concerning window form and roof pitch). It has a living area of 100 m² and a thermal envelope of 417 m². Its original construction corresponds to that of a house built in 1950 (see description in the technical data table). After its thermal renovation in 2004, the insulation quality was only slightly lower than that of a low-energy house. Brick walls of 30 cm thickness received 14 cm of external insulation. The pitched roof, starting on 1st floor level, was opened from outside and insulated with a 20 cm layer. The upper ceiling was opened from the top and received 24 cm insulation. The single-glazed windows with wooden frames were replaced by new wooden windows with heat-saving double glazing. In this process, the two south-facing windows were slightly enlarged. The concrete floor on ground level was insulated from the bottom with a layer of 8 cm thickness. Front and cellar doors were replaced. Two separate exhausters were installed in the kitchen and bathroom to control the moisture (only used if required). A new, highly efficient gas heating was installed. The building's heat demand was reduced from about 350 kWh/m²a down to 125 kWh/m²a.



Drawing of 1950

Photo of 2004

The following bar chart shows the heat flows of the most important building components of this house when built according to the 1900, 1950 (real) and 1975 level of thermal insulation. In addition, the chart shows the values achieved with three other variants of thermal renovation. The heating demands range from 490 to 29 kWh/m²a; possible heating savings range from 50 to 90 %. The bars in the chart show the heat losses (above zero) as well as the heat gains (below zero). The losses have to be compensated by the gains.



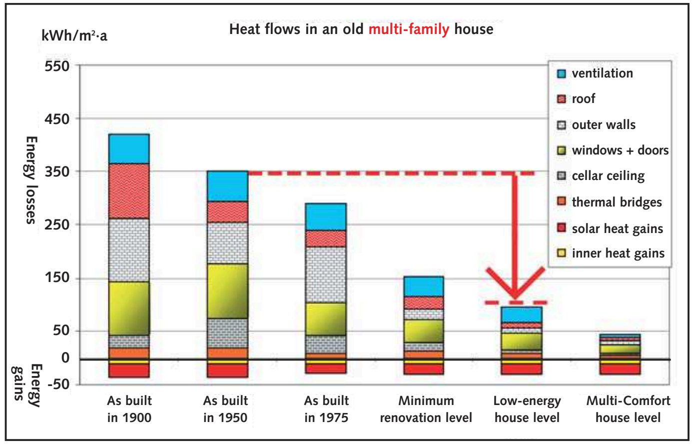
Saving effects in an old multi-family house

This house from the early 1950s is a typical example that you find in many housing estates of German towns. It has a living area of 1000 m², subdivided into 24 flats accessible via 6 staircases, and is located in a colony with about 30 identical ones. Its cellar and loft were not heated. Its original construction corresponds to the one described in the technical data table (as built in 1950). In 2006, it was completely renovated to a level superior even to new buildings.

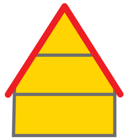
The 30 cm thick brick walls received 14 cm of external insulation. The pitched roof on the 3rd floor level was opened from outside and insulated with a layer of 24 cm. The upper ceiling was opened from the top and also received an insulation layer of 24 cm thickness. The single-glazed windows with wooden frames were replaced by new wooden windows with heat-saving double glazing. In this process, in every flat two south-facing windows were enlarged. The concrete floor on the ground level was insulated from the top with a layer of 8 cm thickness. At the same time, the old wooden floor was removed that was laid with 6 cm air space between the boards and the concrete. The front and cellar doors were replaced. Mechanical ventilation was not installed. A new, highly efficient gas heating system was installed in each of those 6 flats under the roof that are located above staircases. The heating demand could be reduced from about 310 kWh/m²a down to 90 kWh/m²a.

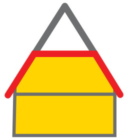
Thermal envelope	**2252 (2362) m²**	**100 %**
Outer walls	**732 (820) m²**	**31 (40) %**
Roof + upper ceiling	**563 (722) m²**	**25 (31) %**
Cellar ceiling	**515 m²**	**23 %**
Windows	**237 (270) m²**	**10 (12) %**
Outer doors	**12 m²**	**1 %**
Other areas	**110 m²**	**5 %**
Living area	**1000 (1100) m²**	

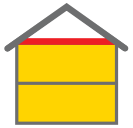
The following bar chart shows the heat flows of the most important building components of this house when built according to the 1900, 1950 (real) and 1975 level of thermal insulation. In addition, the chart shows the values achieved for three other variants of thermal renovation. The heating demands range from 382 to 14 kWh/m²a whereas the possible heating savings range from 50 to 90 %. The bars in the chart show the heat losses (above zero) as well as the heat gains (below zero). The losses have to be compensated by the gains.



V. How to reduce heat losses by using better roof components


Pitched roof


Pitched roof and upper ceiling


Only upper ceiling


Flat roof

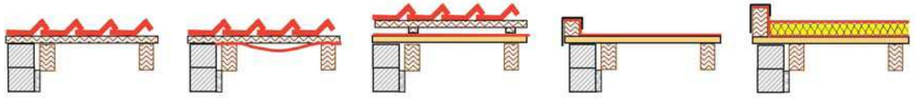
Pitched roofs, flat roofs and top floors in contact with unheated lofts form part of the heat-transmitting envelope of a house if they adjoin heated rooms. Depending on the geometry of the house, they account for 8 to 30 % of the whole heat-transmitting envelope. They cause between 20 and 45 % of the total transmission loss in the cold season. As a result of poorly insulated roof components, the snow in winter melts off fast and irregularly as the photos below show. People living in rooms under such roofs often suffer from cold radiation effects and air drafts. In the hot season, the rooms under not or only slightly insulated roofs can become very hot. Excellent roof insulation helps ensure comfortable living all year round.

If you want to realize high energy savings and thermal comfort through thermal renovation of the roof, you should install an insulation layer of 30 to 40 cm thickness. National regulations only require minimum insulation: when renovating the roof, the layer thickness must correspond to the height of the wooden rafter. But rafter height is often only 10-16 cm. An insulation layer of this thickness is insufficient: it does not protect against summer heat and does not reduce heating costs as much as possible. Today, 20 cm roof insulation is the minimum requirement for new buildings in Germay. But this as well cannot completely block off the summer heat under such roofs. 30 cm roof insulation meets the low-energy house requirement, ensuring low heating costs in winter and acceptable summer conditions. 40 cm roof insulation corresponds to the Multi-Comfort or passive house level. This guarantees maximum thermal comfort in winter and summer while minimizing the heating costs.

Adding insulation to poorly insulated roof components is usually the first and best energy-saving measure in an old house as it offers a favourable cost/benefit ratio. It therefore often takes priority in thermal renovation. The good thing is that high energy efficiency can be achieved at relatively low costs for the roof components. Wooden roof and ceiling constructions already contain cavities where insulation materials can be fitted in. Additional space can be provided at little expense. And there is usually enough space on top for installing thicker insulation layers.

When renovating roof components, also other functional layers of the roof need to be considered. These include the layers of external water protection, wind protection, airtightness and moisture control. Their structure can vary depending on the type and age of the roof.

Weather protection is the most important function of a roof. Pitched roofs are primarily covered with roof tiles while flat roofs are covered with a waterproofing membrane. Many pitched roofs have a second roof under their tiles which is made of sheeting or roofing felt. In windy regions, this second roof is often fixed on boards. The following drawings show the five most frequent coverings used on old roofs.


Tiles without second roof (not fully rainproof)

Tiles with second roof made of roofing felt

Tiles with second roof made of roofing felt on board

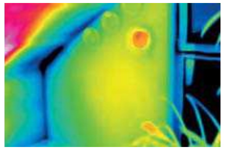
Cold flat roof with a waterproofing membrane on boards

Warm flat roof with a waterproofing membrane on top of the upper insulation

Types of coverings used on old wooden roofs

Some important aspects of this outer protection need to be highlighted:

- Pitched roofs without a second waterproofing layer allow the penetration of rain and snow, especially in the presence of strong wind. The result: unwanted humidity in the roof and its insulation. This can be avoided by installing a second waterproofing layer when doing roof renovation.
- Optimum **windtightness** and moisture protection is offered by a diffusion-capable membrane that is used outside on wooden frame, wall and roof constructions for providing wind and water protection. It can be directly installed on the rough formwork under the roof (wooden boarding). It protects your roof against water and provides windtightness.


Cold airflows in a leaky room corner

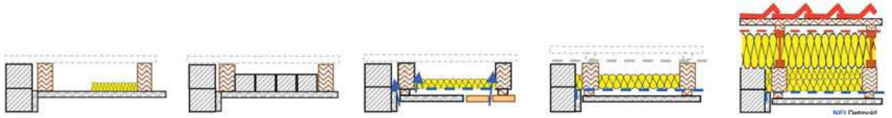
The airtightness and moisture control of a roof is necessary as it prevents the air from circulating through the whole roof or flowing from inside the rooms into the insulation layer. Every leak in the highly insulated areas leads to avoidable heat losses and considerable ingress of moisture. With very costly consequences. But all this can be avoided quite easily, with only little manual effort – and the climatic membrane system ISOVER VARIO. ISOVER VARIO KM Duplex ensures airtightness and moisture control in keeping with the highest passive house standard. The flexible climatic membrane system adjusts itself to the seasons. In winter, humidity penetrating from inside is blocked. In summer, ISOVER VARIO KM Duplex allows the released water vapour to escape in all directions. This means: Ideal vapour barrier function against the ingress of moisture in lightweight constructed roofs and walls. In the case of concrete roofs or upper ceilings, the concrete itself is airtight.

In cold climates, ISOVER VARIO always needs to be installed on the warm side of the construction.


Fixing


Taping


Sealing


Only plaster as airflow barrier and vapour retarder (1750 - 1970)

Stones and plaster as airflow barrier and vapour retarder (1920 - 1970)

Aluminium foil as airflow and vapour barrier (often defective) (1970 - 1990)

PE sheeting or kraft paper as airflow barrier and vapour retarder (1985 - today)

ISOVER VARIO KM: unique climatic membrane with variable resistance to diffusion

Internal insulation materials used for old wooden roofs

Plaster baseboard from outside with a recently opened roof

The following pages show some variations of airtight layers and water vapour retarders or barriers used on old roofs. Their positive qualities but also their problems are explained below. Wooden roofs built between 1750 and 1970 usually have an inner plaster surface and no or only very little insulation between the rafters. The space between the rafters is strongly ventilated with fresh air. The plaster coat is fixed on plaster bases such as straw mats, wire lathing, wooden reinforcements, or cement-bound woodwool boards. This plastering coat has a double function: to provide a trim inner surface as well as an air- and vapour-tight layer for the moisture control of the roof. The airtightness of the plastering coat can be high and durable. Very durable if it was fixed on woodwool cement boards that were mostly installed under roofs between 1950 and 1970. But all natural materials like plaster, loam or straw become brittle with age and dry out.

Defective aluminium-coated roof insulation and airtight layer

Concerning its moisture protection, a plastering coat is not vapourproof but allows a lot of vapour to diffuse from heated rooms into the roof. This is usually not a problem in not or poorly insulated roofs because of the strong ventilation between the rafters. But it may become different when the space between the rafters is completely filled with insulation material and a second roof membrane or kraft paper is additionally installed outside this insulation package. Both layers reduce the drying capacity of the roof. To avoid such problems, roofs with inside layers made exclusively of plaster are usually equipped with an additional vapour-retarding layer or vapour barrier before more insulation or other outer layers are installed.

Since about 1970, wooden roofs in Germany do no longer have inner plastering coats but are equipped with dry lining elements such as wooden boards or gypsum wallboards. This inner boarding is usually fixed on battens with ventilation spaces in-between so that it can neither function as airtight nor vapour barrier. These functions are mostly fulfilled by separate layers, installed directly below the rafters on the warm side of the thermal insulation. Between 1965 and 1985, aluminium foils were much in use: they were glued directly onto mineral wool mats. They had foil-flanges on each side that were fixed to the rafters, connected to each other and to walls or ceilings to form a continuous air and vapour barrier.

In principle, this product idea was ingenious as it combined insulation, airtightness, vapour-tightness and easy installation. But most product users did neither understand the triple function of the aluminium foil nor did they succeed in making these functions work durably. The majority of these aluminium-coated insulation mats was therefore improperly installed and did never or does no longer fulfil all of its functions. Often, the longitudinal and transverse joints are not carefully taped and joints between the aluminium foils and other adjoining building components are not closed. Many mats are not secured by crossbars; they are only fixed with nails along the foil edges. Due to their weight and additional wind pressure, they can be stripped off (see photo). The reason why these constructions do not cause permanent moisture problems is that the roofs are often so wind-leaky that all unwanted humidity can dry out. This may be helpful to keep the roof structure dry but weakens the effect of its insulation.

Since about 1985, wooden roof structures make neither use of plastering coats nor aluminium-coated mineral wool mats for air- and vapour-tightness any more. Instead, separate PE foils, vapour-retarding kraft paper or plywood boards are installed under the rafters over the full roof area. The connections to the plastering of adjacent walls, concrete floors or to window frames are sealed. These insulation layers are usually very tight as long as they form a homogeneous area.

Smoke pressed out by a Blower Door fan to show the roof leaks

The tightness of the interface areas, however, depends on the craftsmen's workmanship. Air leaks often occur around crossing components such as pipes, cables or rafters.

It is principally helpful to test the airtightness of an old roof at the start of renovation. In this way, existing leaks can be found early enough and repaired when accessible during the renovation process. Airtightness is tested using the so-called Blower Door Test. On request, additional fog generators can be used that make any air flowing out through leaks easily visible (see photo).

The following chapters illustrate the possibilities of thermal renovation of different roof components and roof types, including pitched roofs, top floors below unheated lofts and flat roofs, each either opened from outside or inside.

V 1. Additional insulation of pitched roofs

We can distinguish 4 different cases for the additional thermal insulation of pitched roofs:

1. The outer part of the roof (roof covering) needs to be replaced. The inner layers and surfaces are in good condition and therefore need not be opened. The installation of additional insulation and of the new roof covering is done from outside. It is necessary to add a layer that ensures an air- and vapour-tight barrier over the inner covering. This case is described in chapter V.1.1.

2. The roof covering is OK and the roof only needs to be opened from inside. Therefore, thermal insulation, a new airtight vapour barrier and a final inner surface are installed from inside. If the outer roof is not capable of diffusion because it is made of tar paper or tin, a vapour barrier with variable diffusion resistance must be installed (e.g. ISOVER VARIO KM). This case is described in chapter V.1.2.

3. Both sides of a roof are opened, because they need to be modified. In this case, additional thermal insulation and all other necessary layers can be installed like in new buildings – with optimum quality and without compromises in insulation thicknesses. This case is described in chapter V.1.3.

4. Roof covering and inner layers /surfaces are intact and need not be opened or destroyed. Additional thermal insulation can only be installed by blow-in insulation. In this case, it is not possible to ensure the good performance of the inner air and vapour barrier and of the outer waterproofing layers. The possible insulation thickness is limited by the existing space in the roof construction. This case is described in chapter V.1.4.

The following drawings illustrate the most common constructions of pitched roofs. The three vertical columns show side by side the variants of outer roof construction whereas the horizontal lines show six variants of inner covering.

Roof made of tiles only (not reliably rainproof)

Roof with old second roof made of foil or tar paper (dampproof)

Roof with dampproof second roof on hardboards

Without inner covering when first completed or when old one was removed

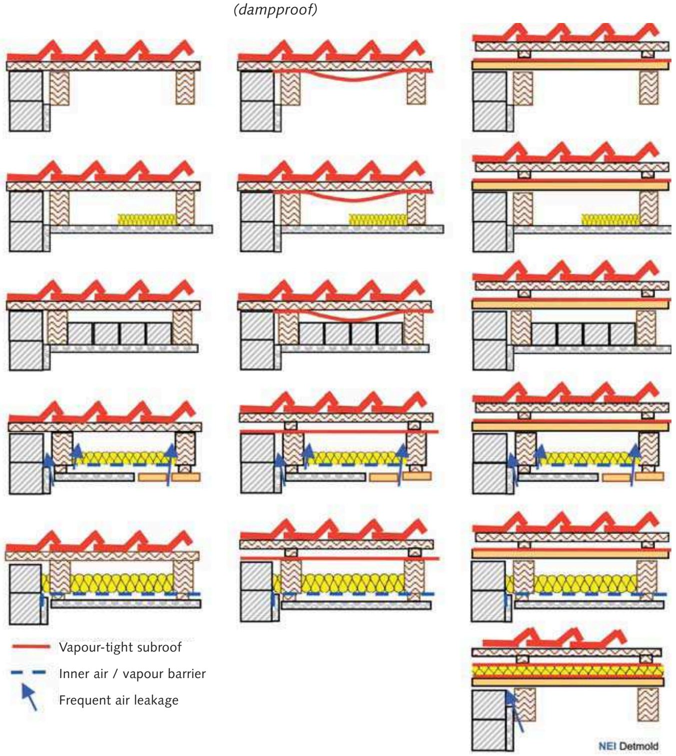
Inner covering made of plaster with no or little insulation only (1950 - 1970)

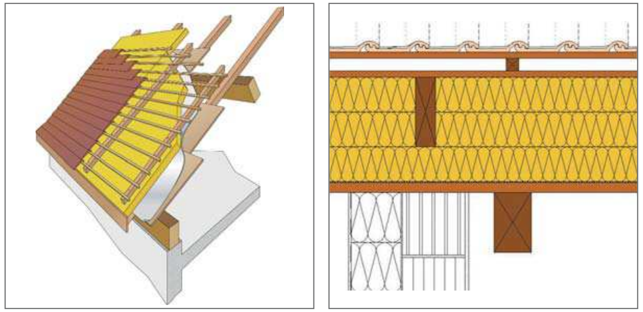
Inner covering made of plaster with solid filling instead of insulation (1900 - 1970)

Ventilated inner covering made of wood or gypsum boards with aluminium-coated insulation (1970 - 1985)

Ventilated inner covering made of wood or gypsum boards with separate air and vapour barriers made of PE foil or kraft paper (1985 - today)

Visible rafters and boards with outer foil to provide air- and vapour-tightness (1960 - today)





If for aesthetic reasons the timber construction shall be made visible inside the inhabited attic space, the insulation can also be installed above the wooden rafters. Additional advantage: continuous insulation layer free of thermal bridges, with optimum thickness of about 30 cm.

The following table show the U-values, heat losses and heating costs of the six variants of old and renovated pitched roofs described above. Losses and costs are calculated based on a total roof area of 100 m², a useful life of 40 years after renovation, and heating costs of 0.07 euros or 7 eurocents/kWh.

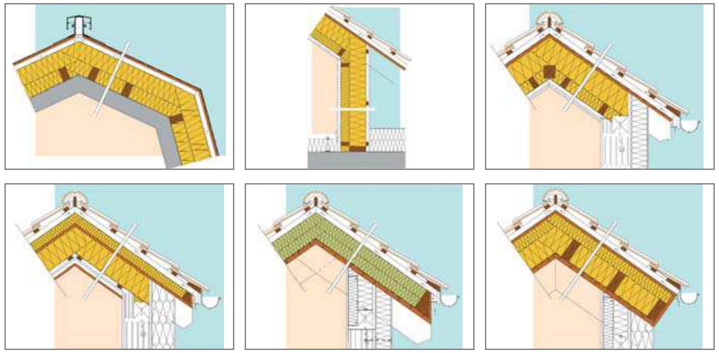
The possible savings that can be realized for a newly renovated roof over the next 40 years of its useful life amount to 145,000 to 928,032 kWh heating energy and to 10,000 to 47,500 euros heating costs. Only minimal savings can be realized if a roof, that was already poorly insulated, receives only little additional insulation. Example: Our 1975 roof construction with 10 cm insulation receives only 6 cm additional insulation which is the minimal thickness required, e.g. by the German law.

Maximal savings can be realized when an uninsulated roof from 1900 is upgraded to Multi-Comfort level by installing a roof insulation of 40 cm. In this second case, savings of 95 % can be generated. Based on today's heating costs of about 7 eurocents/kWh, about 64,891 euros can be saved within the next 40 years of its useful life.

U-values, heat losses and heating costs of a 100 m² pitched wooden roof with different insulation thicknesses

					New house level	Low-energy house level	Multi-Comfort house level
Insulation thickness	0 cm	3 cm	5 cm	10 cm	20 cm	30 cm	40 cm
U-value	2.87 W/m²K	1.04 W/m²K	0.74 W/m²K	0.65 W/m²K	0.22 W/m²K	0.15 W/m²K	0.11 W/m²K
Annual heat losses	24,125 kWh	8,736 kWh	6,216 kWh	5,460 kWh	1,848 kWh	1,260 kWh	924 kWh
Heat losses over 40 years	964,992 kWh	349,440 kWh	248,640 kWh	218,400 kWh	73,920 kWh	50,400 kWh	36,960 kWh
Annual heating costs	1,689 EUR	612 EUR	435 EUR	382 EUR	129 EUR	88 EUR	64 EUR
Heating costs over 40 years	67,549 EUR	24,461 EUR	17,405 EUR	15,288 EUR	5,174 EUR	3,528 EUR	2,587 EUR

Ceiling area: 100 m²   Calculated useful life: 40 years   Heating costs: 7 eurocents/kWh (average price in 2006)
The financial benefit of insulation will automatically increase with higher energy prices.



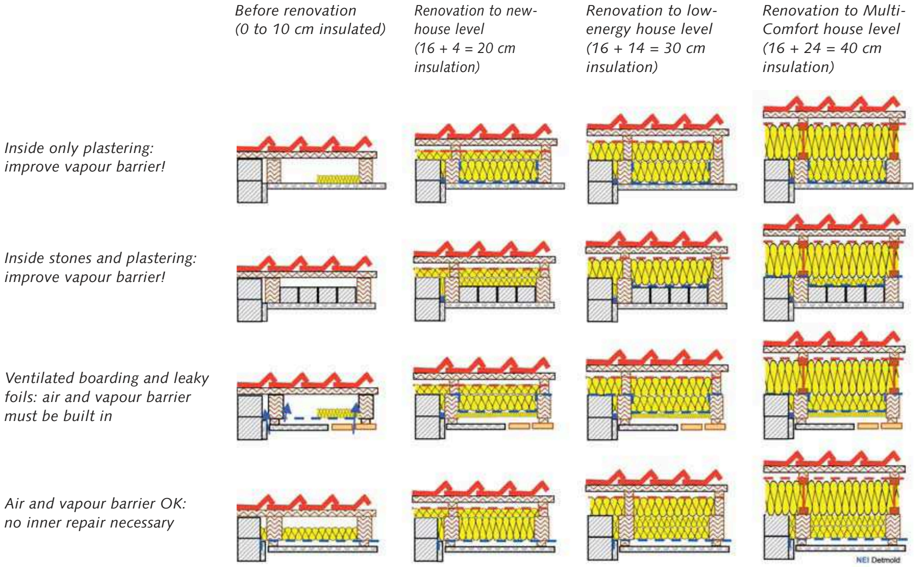
The insulation of a pitched roof allows all combinations – from above-rafter insulation, between-rafter insulation to insulation on a concrete construction. When insulating a pitched roof, one should also try to close the gap to the outside wall insulation in order to avoid thermal bridges.

V.1.1. Thermal insulation of pitched roofs opened from outside

If a roof is refurbished from outside, also additional insulation can be installed from outside. It is advisable to use an insulation thickness of at least 20 cm as for new buildings. Even better is a thickness of 30 cm as built into low-energy houses. But the best insulation performance is achieved with 40 cm as for Multi-Comfort houses.

When roofs are open from outside, the insulation materials can first be installed between the rafters. Usually, their heights vary between 10 and 16 cm. But this thickness does not produce durable saving effects and provides poor heat protection for the attic rooms in the hot season. For reasons of economy and living comfort, it is therefore advisable to install additional insulation layers outside the rafters.

The necessary space for additional insulation can be provided by joists or rafters that are attached length- or crosswise from outside. If additional insulation space of more than 20 cm thickness is required, it is recommended to use TJI joists with heights up to 30 cm instead of solid timber joists in order to reduce the effect of structural thermal bridges. The following drawings show four old roof constructions commonly used: first in their original state and then on three quality levels of thermal renovation.



Variants of pitched roof renovation from outside

The left column shows pitched roofs before renovation as described in the previous chapter. They differ in the amount of existing insulation and the quality of inner air-sealing and vapour-retarding layers. Their outer covering is of no importance here as it will be completely removed when renovating the roof from outside. Columns 2, 3 and 4 show how these different old roofs can be improved to the level of new houses, low-energy houses and Multi-Comfort houses. To reach the roof insulation level of a new house, a 4 cm lath is fixed onto the existing 16 cm rafters and an insulation layer of 20 cm is installed. To reach low-energy house level, joists of 14 cm height are fixed on the existing rafters and a total insulation layer of 30 cm is installed. To reach Multi-Comfort or passive house level, 24 cm TJI joists are screwed on top of the rafters and a total insulation layer of 40 cm is built in.

- *Continuous thermal insulation without thermal bridges*
- *High insulation thicknesses are possible without losing interior space*
- *Excellent airborne sound insulation against street noise*
- *Additional impact sound insulation against rain*
- *The existing room-facing roof construction is maintained*

As soon as the thermal insulation has been installed and the roof energetically refurbished, it can be covered again with the old roof tiles in keeping with its style.

Depending on the airtightness and vapour-retarding quality of the existing inner layers, these layers also need to be replaced.

Normally, roofs built from 1750 to 1950 with an inner plastering coat (see 1st line of the table) do not need additional airtight layers as long as the plastering is neither broken nor perforated. But because of its high vapour permeability, a vapour-retarding flexible climatic membrane such as ISOVER VARIO KM Duplex should be placed into the open space between rafters before installing the new insulation.

If, however, the inner plastering coat is no longer airtight, a new airtight layer needs to be installed from outside over the whole roof area before installing the insulation and also covering the upper surface of the rafters. ISOVER VARIO KM Duplex climatic membrane perfectly fulfils the double function of a vapour-retarding and airtight layer.

For roofs built from 1880 to 1940 (2nd line of the table) with inner plastering and an additional lightweight stone lining between the rafters, the same applies as in the previous paragraph. Depending on the insulation effect of the stones and the thickness of the additional outer insulation, it may be necessary but also disadvantageous to install a vapour barrier between the outer side of the stone filling and the inner side of the new insulation. Here, a building physicist should be consulted before renovation. If old fillings provide little insulation, it may be useful to remove them and fill the whole space with new insulation material. Removal is easy if the filling was installed on separate wooden boards between the rafters. But when the filling is directly connected with the inner plastering, this may be destroyed in the process of removal.

The next roof type (shown in line 3 of the table) has a ventilated inner covering and mineral wool mats with glued-on aluminium foil that serves as an air and vapour barrier. In this case, new air and vapour barriers usually need to be installed over the complete roof area, because the old alumium foils are usually no longer tight along the connections. This can be done from outside if specially designed vapour-retarding foils with variable diffusion properties such as ISOVER VARIO KM Duplex are used. The proper and tight installation of these foils requires careful planning and work. The installation is not so difficult in the directly accessible areas between the rafters.


Pitched roof with lightweight stone filling, just opened from outside


Pitched roof with plastering inside. A mineral wool layer of 3 cm has already been installed as foil protection. Additional insulation is being prepared. Additional upper laths are also visible.

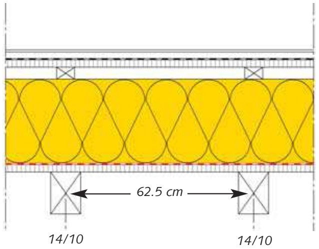
However, it is often difficult to connect the air- and vapourproof layers all around the roof in a durable and tight way with the walls, ceilings and other adjoining components of the house. In addition, all penetrations of the new foil must be sealed to ensure durable tightness. These include, for example, chimneys, pipes, cables or wooden joists that cross the foil layer. If the sharp tips of nails or screws protrude from the inner decorative covering into the space between the rafters, they can damage the new foil. To prevent this, some centimeters of insulation material can be installed before to protect the inner foil surface from damage.

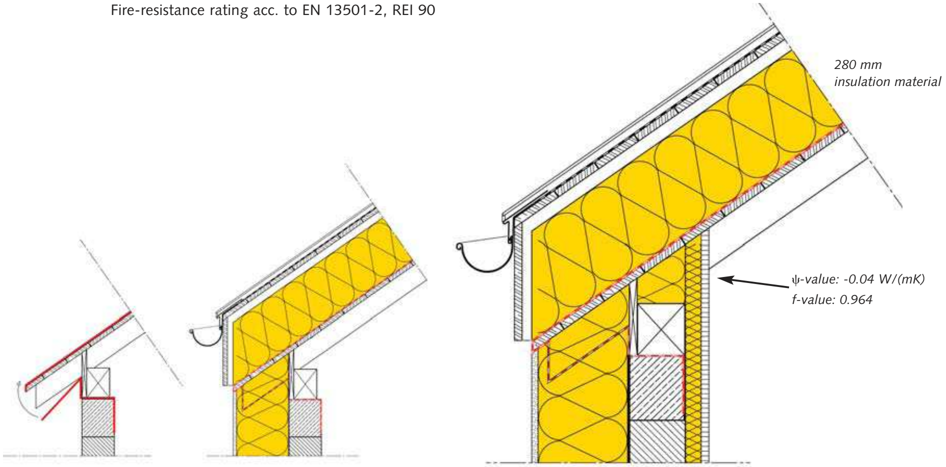
The roofs shown in line 4 of the table are unproblematic if effective new thermal insulation is to be installed between and above the rafters. Since there are well-functioning inner air and vapour-retarding layers, no moisture problem can arise. In all these cases, the new outer layers of the renovated roof should be capable of vapour diffusion and equipped with ventilated tiles so that any humidity in the roof can dry out. Only when vapour-retarding outer layers need to be installed on pitched roofs (e.g. on small inclined grass roofs), special solutions may be necessary.

Slim construction offering good acoustic and thermal insulation

The above-rafter insulation consists of a slim, continuous thermal insulation board with an integrated water-draining layer. It offers excellent heat and sound protection. The boards are laid thermal bridge free above the rafters and ensure high comfort in summer.

Roof:	Sound reduction index Rw = 44 dB Fire-resistance rating acc. to EN 13501-2, REI 30
Outer wall:	Sound reduction index Rw = 56 dB Fire-resistance rating acc. to EN 13501-2, REI 90



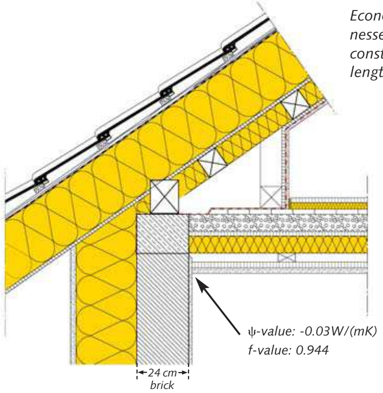


V.1.2. Thermal insulation of pitched roofs opened from inside

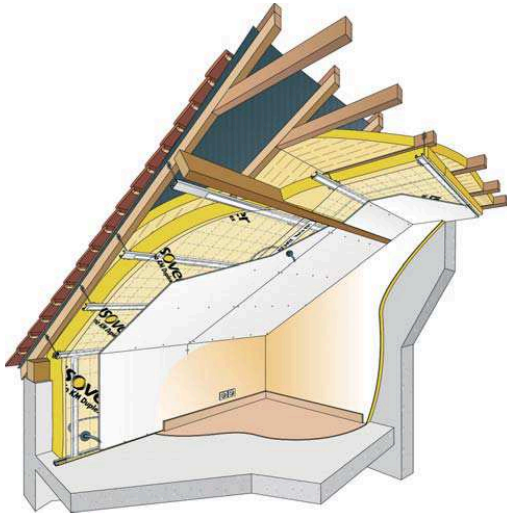
Thermal insulation is built into a pitched roof from inside on two conditions: if the outer covering of the roof is in very good condition and should therefore not be opened or when its inner layers or surfaces must be completely replaced or newly installed in a previously unheated loft. Advisable is a roof insulation thickness of at least 30 cm as in new buildings. Optimal is a thickness of 40 cm to achieve Multi-Comfort house level.

To start with, insulation can be installed in the space between the existing rafters which in old roofs usually have heights of 12 to 16 cm. But insulation of this dimension will not realize the full cost saving potential for heating in winter and cooling in summer.

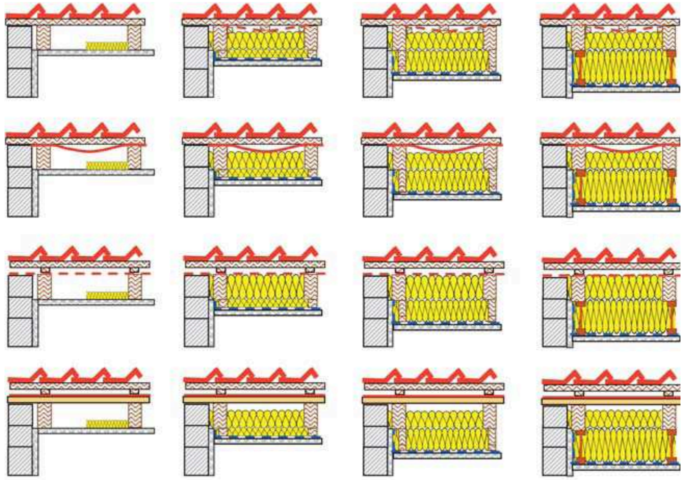
The necessary space for additional insulation can be constructed inside with length- or crosswise mounted joists, laths or metal suspension systems. The first insulation layer is placed between the wooden rafters; the second is fixed with the help of a metal suspension system that at the same time allows the fixation of ISOVER VARIO KM Duplex as a vapour barrier and air-tight layer on the warm side of the roof construction. Finally, gypsum fire protection boards are mounted.



Economical system for producing optimal insulation thicknesses of 30-40 cm. Installation of two layers in a timber construction. Reduced thermal bridge effects due to the length- and crosswise mounting of the wooden joists.



Economical system for producing optimal insulation thicknesses of 30-40 cm. Strongly reduced thermal bridge effects due to the pointwise suspension of the metal rail system.

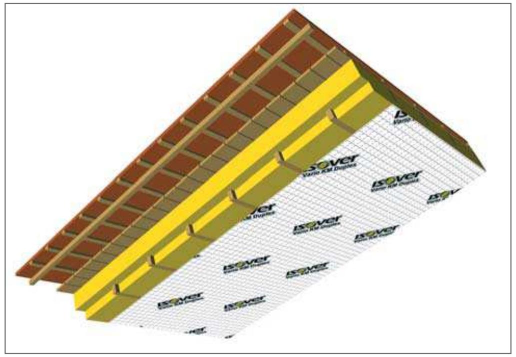


Variants of pitched roof renovation from inside

In all these variants, completely new air- and vapour-tight layers are installed with a quality comparable to that of new buildings. Moisture problems caused by excessive vapour diffusing from the room into the roof construction need not be expected.

If the old roof has no subroof (see 1st column of the table), moisture can penetrate the roof insulation from outside through leaky tiles. This should be prevented by installing a roofing underlay (e.g. a foil or boards) from inside under the tile laths at a small distance to the laths. In this way, the water can flow down the outer side. This new second layer should be highly vapour diffusion permeable to allow the moisture in the roof to escape and thus dry out.

Good thermal insulation of the roof is economically viable. As most roofs are lightweight structures that leave a lot of space for insulation layers, high energy savings can be generated at low cost and effort. A highly efficient solution is the fully insulated, non-ventilated roof structure. A model example of this is the combination of between- and under-rafter insulation. This construction does not require ventilation, thus saving time and costs. And last but not least energy. Contrary to ventilated roofs, there is no uncontrolled air exchange via joints and gaps – and consequently no heat loss.



A shelf fixed laterally to the rafters provides additional space for 24 cm insulation.

Two layers of laths inside the rafters to provide more space for insulation.

Roof insulation from inside with two additional insulation layers and a diffusion-variable membrane

Proper installation ensures airtightness and full moisture protection of the roof construction.

To hamper the inward diffusion of moisture into the construction and speed up the drying process, the moisture-adaptive membrane ISOVER VARIO is used. It is installed on the room-facing side of the insulation layer. Make sure that the single strips overlap by approx. 10 cm and that the seams are reliably and durably sealed with VARIO adhesive tape. Joints between the membrane and solid building components must be filled with VARIO sealant. Penetrations must be sealed airtight with adhesive tape VARIO KB3 or Powerflex. Before installing the interior cladding, the construction must be checked for tightness and any weak spots be eliminated. The result should be leakproof, airtight and free of thermal bridges.

In any case, all joints and connections of insulation foils or boards to adjoining or crossing components must be permanently airtight. It is always beneficial here to achieve a much higher level of airtightness than minimally required by the law.

The heat loss reductions and heating cost savings that can be generated by the thermal renovation of a pitched roof from inside are identical with those of a roof renovated from outside (see previous chapter). Depending on the thickness of the total insulation, it is possible to reach the quality and comfort level of new buildings, low-energy houses or Multi-Comfort houses. Heat losses and heating costs caused by this part of the building can be reduced by as much as 50 % to 95 %.

This roof structure sets a good example for every building.

- Roof cladding
- Roof battening
- Counterlathing
- Roof underlay
- Rafter system with mineral wool full rafter insulation
- Moisture-adaptive membrane, e.g. Difunorm VARIO
- Levelling battens / Installation layer insulated with mineral wool
- Interior cladding

Good to know: protection against condensation water.

The insulation material must be installed free of joints and thermal bridges. On the inner side, an airtight layer produced with Difunorm VARIO prevents the intrusion of moisture and protects from air infiltration.

Proper bonding is essential.

All overlaps in the surface area must be durably sealed with suitable adhesive tapes. Connections to penetrations must be sealed with collars and/or elastic adhesive tapes to ensure that they are air- and vapour-tight.

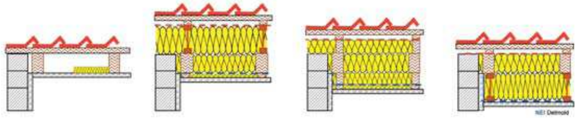
V.1.3. Thermal insulation of pitched roofs opened from both sides

High living comfort under the roof as well as high energy and cost savings without later complications have best chances of being realized when pitched roofs are opened from both sides in the renovation process. This is necessary when both tiles and inner surfaces must be replaced. In this case, highly effective thermal insulation can be installed between, under and on the rafters or on both sides of the rafters. The most suitable combination of inner and outer insulation in the individual case depends on a variety of factors. Inside, additional insulation reduces the room height but can be installed more easily by the investors themselves in dry conditions.

It is often easier to have the complete outer insulation or only the additional space-providing construction done by carpenters or tilers with prefabricated products. The best time is when the roof is open anyway as shown in the first photo. But additionally installed outer insulation can change the outer proportions of a roof. As a result, more complicated adjustments around dormers, gutters, eaves or gables may become necessary. This means that the functional outer and inner layers of the roof can all be produced in the same quality as for new buildings. Only the connections to roof-adjoining old components may require special planning.

The photo right shows a pitched roof with 16 cm rafters, opened on both sides, in the process of renovation. Here, the rafters are still reinforced from outside with two laths of 4 cm thickness. Later, a transversal 6 cm lath was installed from inside, too. Instead of originally 16 cm between the rafters, the space was extended to now 30 cm and filled with insulation materials, thus reaching the roof quality of low-energy houses. Before renovation, the roof was merely equipped with inner plastering fixed on straw mats. Heat losses through the roof and the resulting heating costs could thus be reduced by about 90 %. Some 30,000 euros will be saved in the next 40 years for this 64 m^2 pitched roof, based on heating costs of 7 eurocents/kWh.

The following drawings illustrate three insulation variants for a pitched roof opened from both sides. The left drawing illustrates the old status. The second shows insulation that was mainly added from outside. Additional space was created by a TJI-joists screwed on top of the rafters. The third drawing shows insulation layers added on both sides, each made of common joists (as in the photos above). The fourth drawing shows insulation added from inside, constructed in reverse order to the outside insulation shown in drawing 2. In each variant, a new airtight and vapour-retarding foil was installed inside (broken blue line). A small amount of insulation is also positioned between the laths of the inner gypsum wallboards. In each case, a new vapour-permeable second roof was installed outside (broken red line). And in each case, insulation materials of about 40 cm thickness were installed. As a result, the heat losses could be reduced by about 95 % compared to the old uninsulated roof.



Variants of pitched roof insulation when opened from both sides

V.1.4. Thermal insulation of pitched roofs without opening a side

If both outer tiles and inner surfaces of the roof are in good condition and shall not be opened or damaged to reinforce the thermal insulation, only limited results can be achieved and possibly not all roof-related problems be solved. Thermal insulation can, however, be poured, blown or crimped into the limited free space between rafters – usually 12 to 16 cm in old roofs. Gaps in layers designed to retard airflows, vapour or rain are often beyond repair, but there are possibilities of handling these risks.

Loose granule fill between rafters made of expanded shale

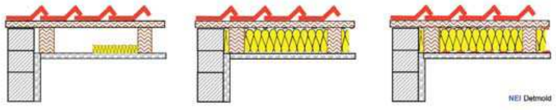
If the inner covering of the roof is airtight and vapour-retarding and if the roof's outer layers are waterproof, it is often possible to fill or blow insulation materials into the empty space between the rafters. Suitable materials are granules of expanded shale (as shown in the first photo) or loose mineral wool. If the spaces are not sufficiently tight on all sides to prevent small particles from flowing out again through gaps or if the outer roof is not reliably waterproof, it is possible to place waterproof but vapour-permeable bags made of plastic or kraft paper into the spaces before blowing in the insulation (see second photo). If the spaces between the rafters can be filled completely and the insulation material stays dry, this can have a durable effect – only limited by the small thickness of the built-in insulation.

Vapour-permeable bags placed between rafters to cover later blown-in insulation

If, however, access to these spaces is hindered and the filling is incomplete, thus allowing airflows around the insulated parts, this has next to no effect. In most cases, it doesn't make much sense to push mineral wool mats from the loft side into the pitched roof spaces. These mats often get wedged or jammed on their way down and cannot be slid into a continuous layer between the rafters. The installation of insulation bags can be made difficult by the tips of nails and screws protruding from inner laths or boards into the space between the rafters.

If you want to reduce the heat loss through a pitched roof in the cold season, it is advisable to install at least insulation of 12 cm thickness than none at all. Of course, 30 cm insulation thickness would be much better.

The following simplified drawings show two variants of pitched roof thermal insulation where only the inner empty spaces are filled. The left drawing shows the unrenovated status. The middle drawing shows roof space that has been filled without air-, vapour- or water-protecting bags. In the right drawing, bags have been inserted, symbolized by the broken red line around spaces. If this works well, the heat losses of a roof with 16 cm insulation can be reduced by about 75 % in the cold season compared to the former uninsulated roof. If this works only partially, the positive effect can be much lower. It is therefore advisable to enhance such makeshift insulation. This can be done later when opening the roof from outside, e.g. for replacing tiles.



Variants of pitched roof insulation without roof opening

V.2. Additional insulation of loft ceilings

We distinguish six different cases for the additional thermal insulation of pitched roofs:

Concrete ceiling insulated on its upper side

1. The ceiling is made of concrete. The insulation can be installed on its upper side. As concrete is airtight and very impermeable to vapour, there are no moisture control problems. Only around places where the ceiling is penetrated by pipes, cables or chutes, tightness may have to be reinforced. This case is described in chapter V.2.1.

Ceiling opened and insulated from the top

2. The ceiling is made of wood and its bottom layers and surfaces shall not be opened. Any additional insulation must only be installed from the top. Depending on whether the bottom layers of the ceiling are air- and vapour-tight or not, it may be necessary to reinforce these functions from the top. This case is described in chapter V.2.2.

Ceiling opened and insulated from the bottom

3. The ceiling is a wooden construction whose bottom layers are to be renewed. For this purpose, the ceiling is opened from the bottom. The upper boarding is OK and does not need to be opened. Any insulation must only be installed from the bottom. Depending on the vapour-retarding quality of the upper layers and old fillings that may have been built inside the ceiling, different moisture control measures may be necessary. This case is described in chapter V.2.3.

Ceiling opened from both sides

4. The ceiling is a wooden construction and both upper and lower layers are to be replaced. In the first step, they are removed so that temporarily the beams are completely exposed. This often happens when single beams need replacement because they are rotten by humidity or woodworm attack. In this case, the insulation can later be installed from both sides. Both upper and lower layers can be newly produced with the desired level of tightness. This case is described in chapter V.2.4.

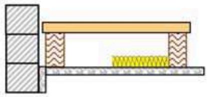
Wooden loft ceiling that must not be opened

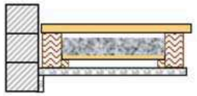
5. The ceiling is a wooden construction. Neither the bottom layers shall be modified nor the top boards be opened completely. In this case, additional insulation can only be blown into the empty spaces of the ceiling or laid across the hollow ceiling. Possible problems caused by untightness of the bottom layers and airflows through the hollow ceiling must be considered. This case is described in chapter V.2.5.

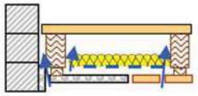
Wooden loft ceiling with beams visible from below

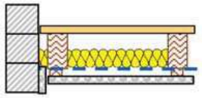
6. The ceiling has beams visible from below on which boards have been placed but no space enclosed inside. On its upper side, only small or no insulation layers exist. This is often found in old farmhouses where the straw or hay filling in the ceiling served as upper insulation in the cold season and was replaced every year. Today, additional insulation can be applied from the top, but it may be necessary to install air- and vapour-tight layers in advance. This case is described in chapter V.2.6.

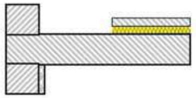
The following drawings show six variants of loft ceiling construction. They differ with respect to their airtightness and vapour-retarding quality, their usable inner space that can be filled with insulation and the level of already existing insulation. The bottom layers in the first four examples are identical with the pitched roof constructions described in the previous chapters. The fifth (a concrete construction) and the sixth (a boards-only construction with beams visible from below) are additional construction variants.

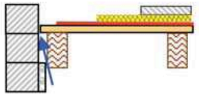

Bottom plastering as airflow
barrier and vapour retarder,
no or little insulation
(1750-1970)


Bottom plastering as
airflow barrier and
vapour retarder,
cinder filling inside
(1920-1960)


Aluminium foil as
airflow and vapour barrier
(often defective),
only little insulation
(1970-1990)


PE foil or kraft paper
as airflow barrier and
vapour retarder,
only little insulation
(1985-today)


Concrete ceiling without
or with top side insulation
(1930-today)


Boards over visible beams
with different upper layers
(1850-today)

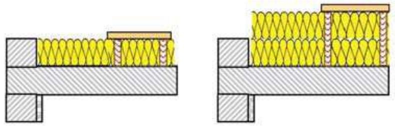
Variants of old loft ceilings

V.2.1. Thermal insulation of concrete loft ceilings from the top


Top side mineral wool insulation and chipboard on wooden spacers

If the loft ceiling is made of concrete, additional insulation can simply be laid on top in all desired sizes and without moisture problems. Advisable is a total insulation thickness of 30 cm as built into low-energy houses; optimal is the 40 cm insulation of Multi-Comfort houses. This upgrading incurs only the material and very low installation costs. For this reason, very thick levels of insulation ensure the best cost/benefit ratio.

If the loft is not used for storage, the easiest method is to place soft mineral wool mats (at least two crosswise layers) over the total ceiling area as shown in the third photo. Soft mineral wool mats stick closely without thermal bridges to the slightly rough substrate and can prevent unwanted airflows from the warm lower to the cold upper side. If the loft is used for storage, boards can be installed on top of the insulation layer supported by either very solid mineral wool mats or a slim wooden spacer construction as shown in the first photo. This can be done in one or two crosswise layers to minimize thermal bridge effects caused by wooden beams.


Mineral wool insulation on top of a concrete ceiling with partial wood construction to provide a walkway to roof windows and chimneys.


For fire protection it is important to use non-combustible mineral wool insulation.

Top side mineral wool insulation without covering – the most cost-efficient way to insulate the top floor ceiling.

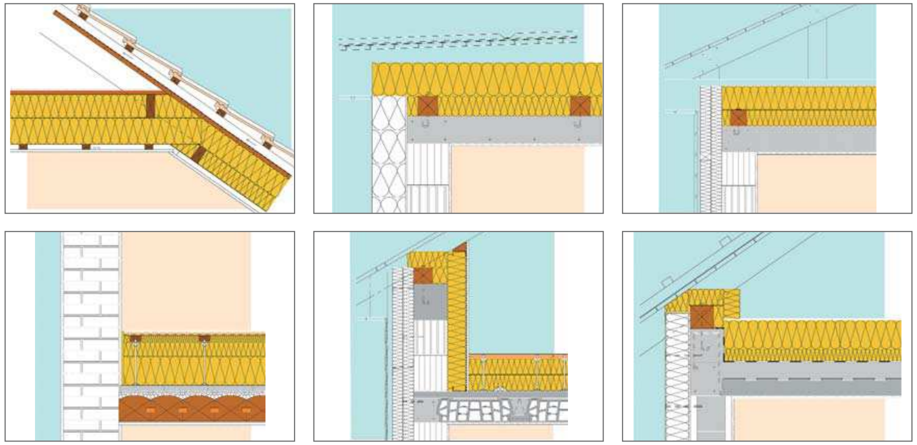
The following table show the reduction of U-values, heat losses and heating costs of a concrete loft ceiling. The calculation is based on 100 m² total ceiling area and heating costs of 7 eurocents/kWh for one year or 40 years of total useful life.

Within this useful life, savings of more than 90 % – or in absolute terms 80,000 euros – can be generated if the previously uninsulated loft ceiling is upgraded to Multi-Comfort house level with 40 cm insulation thickness. Apart from the savings, the residents also benefit from maximum thermal comfort.

U-values, heat losses and heating costs of a 100 m² concrete loft ceiling with different insulation thicknesses

					New house level	Low-energy house level	Multi-Comfort house level
Insulation thickness	**0 cm**	**3 cm**	**5 cm**	**10 cm**	**20 cm**	**30 cm**	**40 cm**
U-value	3.50 W/m²K	0.96 W/m²K	0.65 W/m²K	0.36 W/m²K	0.17 W/m²K	0.11 W/m²K	0.09 W/m²K
Annual heat losses	24,400 kWh	8,064 kWh	5,460 kWh	3,024 kWh	1,428 kWh	0,924 kWh	0,714 kWh
Heat losses over 40 years	1,176,000 kWh	322,560 kWh	218,400 kWh	120,960 kWh	57,120 kWh	36,960 kWh	28,560 kWh
Annual heating costs	2,058 EUR	564 EUR	382 EUR	212 EUR	100 EUR	65 EUR	50 EUR
Heating costs over 40 years	82,320 EUR	22,579 EUR	15,288 EUR	8,467 EUR	3,998 EUR	2,587 EUR	1,999 EUR

Ceiling area: 100 m²   Calculated useful life: 40 years   Heating costs: 7 eurocents/kWh (average price in 2006)
The financial benefit of insulation will automatically increase with higher energy prices.



When insulating the top floor ceiling, one should also try to close the gap to the outer wall insulation in order to avoid thermal bridges.

V.2.2. Thermal insulation of wooden loft ceilings when opened from the top

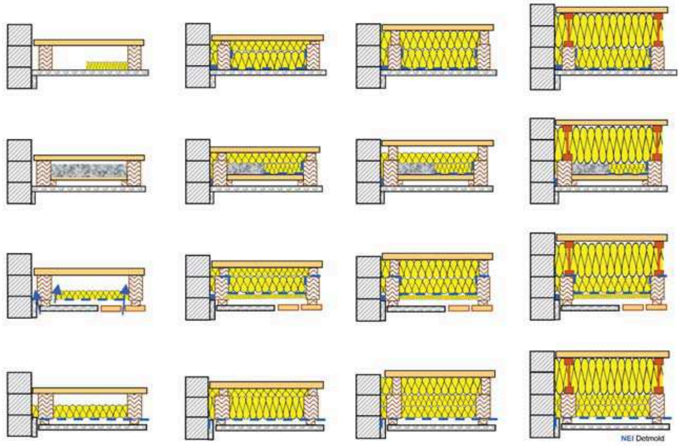
If the loft ceiling is made of wood and there is no upper flooring or boarding that must be removed during renovation, the insulation can first be inserted into the space between the beams and then additionally on top. If the loft is used for storage, new upper flooring should be installed. Alternatively, the insulation can be put in place with just a gangway installed on top.

Loft ceiling opened from the top and insulated first between rafters

Advisable for such wooden loft ceilings is a total insulation thickness of at least 30 cm as in new buildings on low-energy level. Optimal are 40 cm to achieve Multi-Comfort house level. If cinder fillings were applied inside the ceiling space for thermal, acoustic or fire protection reasons, these can either be kept or replaced by new insulation materials.

… and then between additional battens installed on top

The drawings below show four typical loft ceiling constructions: the old condition (on the left) and three different quality levels of thermal renovation. The left column shows loft ceiling constructions before renovation. They differ in the mass of existing insulation and the quality of inner air- and vapour-retarding layers.



Before renovation (0 to 10 cm insulation)

Renovation to new house level (16 + 4 = 20 cm insulation)

Renovation to low-energy house level (16 + 14 = 30 cm insulation)

Renovation to Multi-Comfort house level (16 + 24 = 40 cm insulation)

Only plastering on the bottom side: *improve the vapour retarder*

Only plastering on the bottom side, inside cinder filling: *improve the vapour retarder*

Ventilated boarding and leaky foils: *build in an air and vapour barrier*

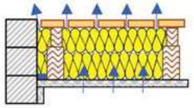
Air and vapour barrier OK: *no bottom repair necessary*

Variants of wooden loft ceilings – Renovation from the top

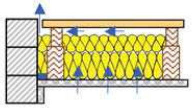
Here, the upper flooring is of no importance, because it will be completely removed when the ceiling is renovated. The second, third and fourth columns show how the different old roofs can be improved to the level commonly found in new houses, low-energy houses and Multi-Comfort houses.

In order to achieve Multi-Comfort or passive house level, 24 cm high TJI-joists are screwed on top of the beams and an insulation layer of 40 cm total thickness is built in. When insulating the top floor ceiling, make sure not to forget the installation of an airtight area and vapour barrier on the warm side of the construction. ISOVER VARIO is an innovative membrane system for all timber frame constructions that adapts quite flexibly to different climatic conditions, allows the moisture to escape and keeps the construction dry.

When renovating a loft ceiling from the top, it is important not to cover the complete ceiling area with a vapour impermeable layer like chipboard, carpet with a homogeneous synthetic backing or an impermeable foil. This would block the necessary drying process of the inner ceiling space and prevent the release of humidity into the loft airspace.



Top side not airtight



or ventilated floor boards

Insulation between rafters

The following table show the reduction of U-values, heat losses and heating costs of a wooden loft ceiling. The calculation is based on 100 m² total ceiling area and heating costs of 7 eurocents/kWh for one year or 40 years total useful life. Within this useful life, savings of more than 90 % – or in absolute terms 73,000 euros – can be generated if the previously uninsulated loft ceiling is upgraded to Multi-Comfort house level with 40 cm insulation thickness. Apart from the savings, the residents also benefit from maximum thermal comfort.

U-values, heat losses and heating costs of a 100 m² wooden loft ceiling with different insulation thicknesses

					New house level	Low-energy house level	Multi-Comfort house level
Insulation thickness	**0 cm**	**3 cm**	**5 cm**	**10 cm**	**20 cm**	**30 cm**	**40 cm**
U-value	3.20 W/m²K	1.09 W/m²K	0.76 W/m²K	0.44 W/m²K	0.21 W/m²K	0.13 W/m²K	0.09 W/m²K
Annual heat losses	26,880 kWh	9,148 kWh	6,409 kWh	3,671 kWh	1,730 kWh	1,084 kWh	0,790 kWh
Heat losses over 40 years	1,075,200 kWh	365,904 kWh	256,368 kWh	146,832 kWh	69,216 kWh	43,344 kWh	31,584 kWh
Annual heating costs	1882 EUR	640 EUR	449 EUR	257 EUR	121 EUR	76 EUR	55 EUR
Heating costs over 40 years	75,264 EUR	25,613 EUR	17,946 EUR	10,278 EUR	4,845 EUR	3,034 EUR	2,211 EUR

Ceiling area: 100 m²   Calculated useful life: 40 years   Heating costs: 7 eurocents/kWh (average price in 2006)
The financial benefit of insulation will automatically increase with higher energy prices.

V.2.3. Thermal insulation of wooden loft ceilings when opened from the bottom

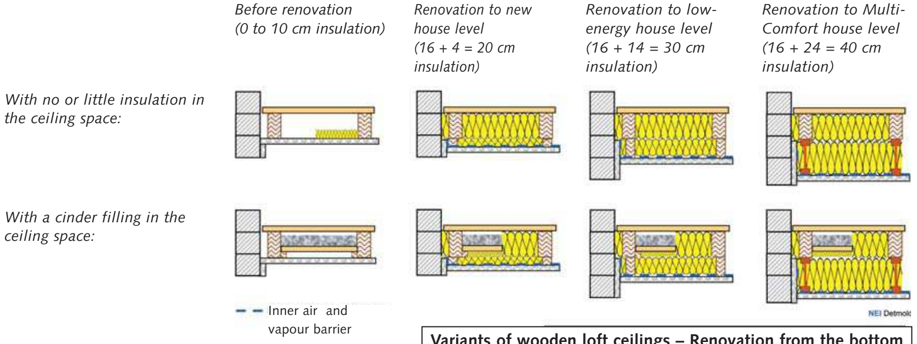
If a loft ceiling is made of wood and its lower layers or surfaces have been broken away because they need to be completely replaced, additional insulation should be installed from the bottom. If the space between the beams is empty, the first insulation layer can be inserted in full beam height between the beams. Additional layers can be applied under the beams between new laths or beams fixed with spacers. At least from the bottom, new air- and vapour-tight layers can be installed. The final surfaces will then have a quality comparable to that of new buildings.

Loft ceiling insulated from the bottom: between and below the beams

Advisable for such loft ceilings is a total insulation thickness of at least 30 cm as in new buildings on low-energy level. If the room height of the upper floor allows, an optimum insulation thickness of 40 cm should be installed to achieve Multi-Comfort house level. If cinder fillings were applied inside the ceiling space for thermal, acoustic or fire protection reason, these can either be kept or replaced by new insulation materials.

With an additional insulated metal subconstruction

The following drawings show two typical loft ceiling constructions in their old condition (left). The first example shows a ceiling with empty space between the beams; the second a ceiling with false floor and cinder filling, here screwed with the bottom plastering. Variants of the bottom layers are not shown in the drawings as these layers will be removed anyway when opening the ceiling from the bottom. The second, third and fourth columns show how the different old roofs can be improved to new house, low-energy house and Multi-Comfort house level. To reach the quality of a new house, a 4 cm thick lath is fixed under the existing 16 cm high beams and an insulation layer of 20 cm total thickness built in. To reach low-energy house level, 14 cm high joists are fixed below the existing beams, followed by 30 cm insulation. To reach Multi-Comfort or passive house level, 24 cm high TJI joists are screwed under the beams, followed by a total insulation layer of 40 cm. Instead of single high spacers, smaller ones can be installed on distance blocks. Alternatively, crosswise smaller layers or wire hangers with metal profiles can be installed.



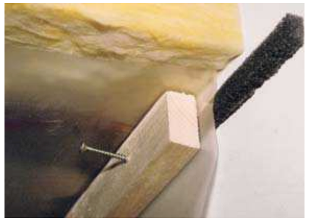
Variants of wooden loft ceilings – Renovation from the bottom

Normally, an airtight or vapour-retarding foil is installed from below. Apart from foils, also kraft paper or vapour-retarding boards can be used. These layers must have durably tight connections between all sides of the ceiling and the adjoining walls or other building components as shown in the second photo.

When insulating the top floor ceiling, it is crucial not to forget the installation of an airtight layer and vapour barrier on the warm side of the construction. ISOVER VARIO is an innovative membrane system for all timber frame constructions that adapts quite flexibly to different climatic conditions, allows the moisture to escape from the structure and keeps the construction dry.

The following table show the reduction of U-values, heat losses and heating costs of a wooden loft ceiling. The calculation is based on 100 m² total ceiling area and heating costs of 7 eurocents/kWh for one year or 40 years of total useful life. Savings can amount to more than 90 % – or in absolute terms 73,000 euros – within this useful life if the previously uninsulated loft ceiling is revamped to Multi-Comfort house level with 40 cm insulation thickness. And, on top, the residents will benefit from maximum thermal comfort.


New air- and vapour-tight foil installed from below with foil connections to the walls


Durably airtight connection between foil and wall plastering with a compressible sealing and fixing lath

U-values, heat losses and heating costs of a 100 m² wooden loft ceiling with different insulation thicknesses installed from below

					New house level	Low-energy house level	Multi-Comfort house level
Insulation thickness	**0 cm**	**3 cm**	**5 cm**	**10 cm**	**20 cm**	**30 cm**	**40 cm**
U-value	3.20 W/m²K	1.09 W/m²K	0.76 W/m²K	0.44 W/m²K	0.21 W/m²K	0.13 W/m²K	0.09 W/m²K
Annual heat losses	26,880 kWh	9,148 kWh	6,409 kWh	3,671 kWh	1,730 kWh	1,084 kWh	0,790 kWh
Heat losses over 40 years	1,075,200 kWh	365,904 kWh	256,368 kWh	146,832 kWh	69,216 kWh	43,344 kWh	31,584 kWh
Annual heating costs	1,882 EUR	640 EUR	449 EUR	257 EUR	121 EUR	76 EUR	55 EUR
Heating costs over 40 years	75,264 EUR	25,613 EUR	17,946 EUR	10,278 EUR	4,845 EUR	3,034 EUR	2,211 EUR

Ceiling area: 100 m²   Calculated useful life: 40 years   Heating costs: 7 eurocents/kWh (average price in 2006)
The financial benefit of insulation will automatically increase with higher energy prices.

V.2.4. Thermal insulation of wooden loft ceilings when opened on both sides

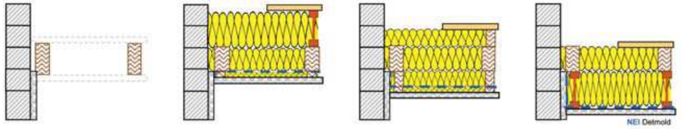
If during renovation the loft ceiling is opened from both sides, you are most likely to generate high energy and costs savings while at the same time ensuring high living comfort for the rooms below. This is the case when the ceiling beams must be replaced, the ceiling construction be modified or both inner surfaces and upper boards be exchanged. The first photo on the right shows a ceiling after opening. Here, it was originally planned to insulate the pitched roof above. But after consulting an expert, the ceiling was insulated between and on top of the collar beams (thickness about 30 cm). In this way, costs were reduced and savings increased. It was possible in this case to install highly efficient thermal insulation between, below and above the ceiling beams. Additional insulation that is installed from the bottom of the ceiling naturally reduces the room height. As a rule, it is easier to install insulation on top of the ceiling although it slightly reduces the loft height. The quality of the functional layers (airtightness and moisture control) will be identical to that of new buildings. Only the connections to old materials around the ceiling area need to be planned in detail.

The first photo shows a loft ceiling opened on both sides during renovation. The spaces between the 18 cm thick beams were later filled completely with mineral wool. From below, additional 6 cm thick wooden boards were installed, with insulation in-between and covered with foil and gypsum boards. On top of the ceiling, a second layer of 18 cm mineral wool was laid at right angles to the beams to minimize thermal bridge effects of wooden construction. All in all, the insulation layer of 40 cm thickness now guarantees Multi-Comfort house level and was installed at low costs. The second photo shows a completely renewed ceiling construction. This was done to heighten the room and build in a large window. Here, the spaces between the new 18 cm beams were filled with 18 cm mineral wool. In addition, a 3 cm lath layer was installed from the bottom and filled with insulation panels. Directly on top of the new beams a chipboard floor was installed, but without any additional insulation. Although this house was built in 1890, it was possible to renovate the ceiling so well that the insulation quality corresponds to that of a new house.


Loft ceiling opened on both sides for renovation


Completely renovated loft ceiling open on both sides

The following drawings show three insulation variants of a loft ceiling opened from both sides. The left drawing illustrates the original status. The second drawing shows insulation that was mainly added from the top. The additional space was created by TJI joists screwed on top of the rafters. The third drawing shows insulation layers added on both sides, each made of common joists (as in the photos above). The fourth drawing shows insulation that was added from inside (in reverse order to drawing 2). In each variant, a new airtight and vapour-retarding foil is installed inside (broken blue line). In addition, a small amount of insulation is positioned between the laths of the inner gypsum wallboards. In the renovated variants, the loft floor top is alternatively drawn with or without wooden boards. In each case, about 40 cm insulation was built in, thus reducing heat losses by about 95 % compared to the old uninsulated ceiling with plaster inside and wooden boards on top. In this renovation case, the U-values, heat losses and heating costs were nearly the same as when opening the ceiling only from the bottom or only from the top. If space is available in both directions, this provides the best chance of generating maximum savings and optimum comfort.



Variants of wooden loft ceilings – Renovation from both sides

V.2.5. Thermal insulation of wooden loft ceilings when not opened

In some cases, the loft ceiling must neither be opened from the bottom nor from the top side. This is the case when the lower surface is still intact and no investment will be made in opening the ceiling from the top. It is, however, possible to blow additional insulation either into the empty space or on top of the ceiling. Blow-in insulation often consists of loose mineral wool fibres. If a wooden loft ceiling is not airtight from below or if the vapour-retarding ability of the bottom layers is only limited, filling the ceiling space with blow-in insulation may produce humidity risks, especially when the top flooring is not very open to diffusion. This question must be checked in advance. If there are still doubts about the air-tightness and vapour-retarding qualities of the bottom layers, it is better to open the ceiling top completely and to install adequate sealing layers before filling in the insulation.

Loft ceiling opened for blowing in insulation

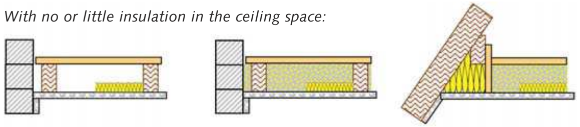
If the ceiling space is open to the pitched roof on both sides, the insulation material must be prevented from being blown out. For this purpose, vertical boards can be installed between the ceiling beams on both sides as shown in the second photo. Behind them and around the middle purlin, a non-flowable insulation material such as mineral wool mats should be installed to bridge the space to the pitched roof insulation as shown in the third photo.

Space-closing facing boards

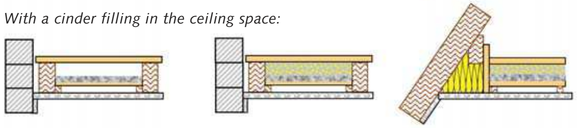
The following drawings show blow-in insulation with space-closing facing boards. The first line of drawings shows a ceiling plastered from below with no or little insulation filling inside. The second line shows a ceiling with an old cinder filling and less blow-fillable space. The third line shows a ceiling with leaky bottom layers. In this case, no blow-in insulation must be used.

Vertical boards between the collar beams and a mineral wool filling prevent outside wind from crossing the ceiling space.

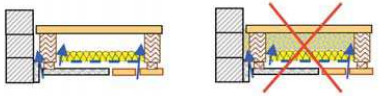
With no or little insulation in the ceiling space:



With a cinder filling in the ceiling space:



If the bottom layers of the ceiling are leaky, don't use blow-in insulation!



V.2.6. Thermal insulation of wooden loft ceilings with beams visible from below

If a loft ceiling is made of beams visible from below and is covered on top only with wooden boards, additional insulation can only be installed from above. Such ceilings are often found in older farmhouses. In the past, the space was used for storing straw or hay in the cold season – materials that also served as insulation. If these materials are no longer stored up there, the ceilings have nearly no insulation effect and also lack airtightness.

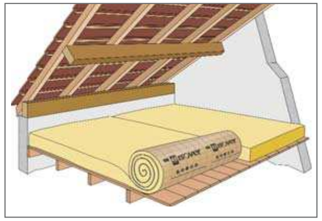
Loft ceiling only made of wooden boards – typical of old farm-houses, but now without the annually renewed straw insulation.

In this case, additional insulation of large thickness can be easily installed on top since there is enough space. The worst type of loft ceiling can thus be converted into an "energy saver" – with low construction costs, maximum heat savings and high comfort gains. If the loft is not used for storage, the easiest method is to lay soft mineral wool mats as shown in the second photo. If the loft is used for storage, boards can be installed on top of the insulation layer, supported by a very solid mineral wool mat or a slim wooden spacer construction.

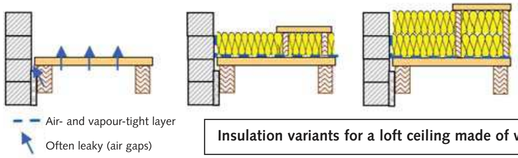
New insulation on top with an air- and vapour-tight foil underneath

Loft ceilings that are only made of wooden boards over visible beams lack air-tightness and permit vapour diffusion if no additional sealing layers exist. It is therefore necessary to apply an air- and vapour-tight layer before installing the insulation on top. A suitable membrane for this purpose is ISOVER VARIO. The seams and any connections to the adjoining plaster walls or penetrating elements are taped over to provide a durable and tight seal.

The following drawings show a wooden loft ceiling with different variants of top side insulation of mineral wool. The air- and vapour-tight layer is presented by a broken blue line. The reduction of U-values, heat losses and heating costs that can be achieved with this type of construction is extremely high. If such an uninsulated loft ceiling exists above heated rooms, its thermal insulation has higher priority than that of walls, windows or floors.



Thermal insulation of a wooden loft ceiling with beams visible from below



Insulation variants for a loft ceiling made of wooden boards (insulation from the top)

V.3. Additional insulation of flat roofs

Concerning the additional thermal insulation of flat roofs, we distinguish four different cases:

1. The flat roof is a wooden "cold roof" construction with only little insulation between the beams. On top, it is equipped with a ventilation layer and wooden boarding covered with a waterproof membrane or tar paper. The wooden boarding must be opened as it is damaged or rotten. Additional thermal insulation must be installed from the top. This case is described in chapter V.3.1.

2. The flat roof is a wooden "cold roof" construction but must be renovated from inside, because the bottom surface needs to be replaced or renovated while the top layers are still in good condition. This case is described in chapter V.3.2.

3. The flat roof is a wooden "cold roof" construction with intact inner and outer layers that both must not be opened. Additional insulation can only be installed from the top, thus modifying the roof design from a cold to a warm one. This case is described in chapter V.3.3.

4. The flat roof is a "warm" or "inverted roof" construction with sealing and insulation layers on top of the load-bearing roof ceiling. For this reason, all renovation needs to be done from the top. This case is described in chapter V.3.4.

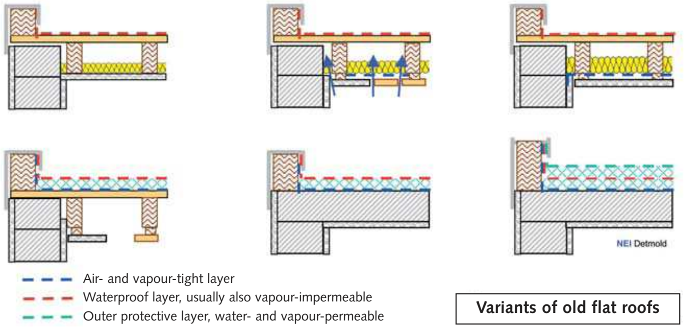
Renovation of the water-tight layer on a flat roof

The following drawings show the six possible basic conditions. The first line presents three wooden "cold roof" constructions. They differ with respect to the airtightness and vapour-retarding quality of their bottom layers. The left drawing shows a roof plastered from inside that was often built between 1950 and 1970. In the middle drawing, the bottom layer is made of ventilated decorative boards. There is a mineral wool mat between the beams with an aluminium-coated foil designed to provide airtightness and a vapour-retarding layer. This was often built between 1970 and 1990 and usually lacks airtightness. The right drawing shows a well-functioning, full-area, airtight and vapour-impermeable foil installed on the room-facing side that has been in use since 1990. All types are equipped with a ventilation layer under the cold roof.

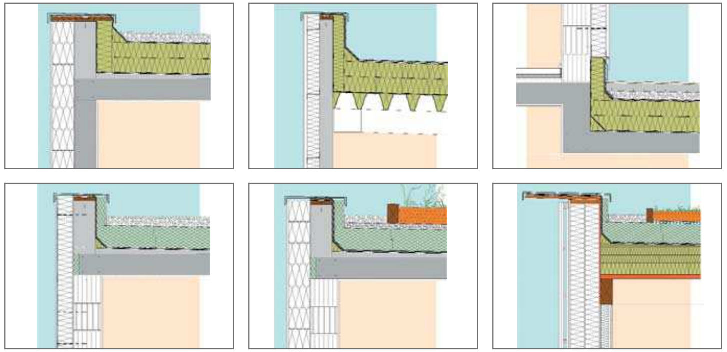
The second line shows a "warm" and so-called "inverted warm roof" construction. On the left, you can see a classical warm roof with a wooden, load-bearing roof construction. There may or may not be a decorative layer of gypsum boards or ventilated wooden boards below, but they don't have any functional importance. The middle drawing shows a "warm" concrete roof with all functional layers installed on top of the load-bearing roof ceiling construction. The right drawing shows basically the same construction, but on top of the waterproof membrane (broken red line) – on its wet side – there is a second insulation layer made of a water-resistant insulation material.

"Cold roof" constructions with inner layers of different quality:

Classical and inverted "warm roofs" with a load-bearing roof ceiling made of wood or concrete:



Variants of old flat roofs



Examples of different flat roof constructions

V.3.1. Thermal insulation of flat cold roofs renovated from the top

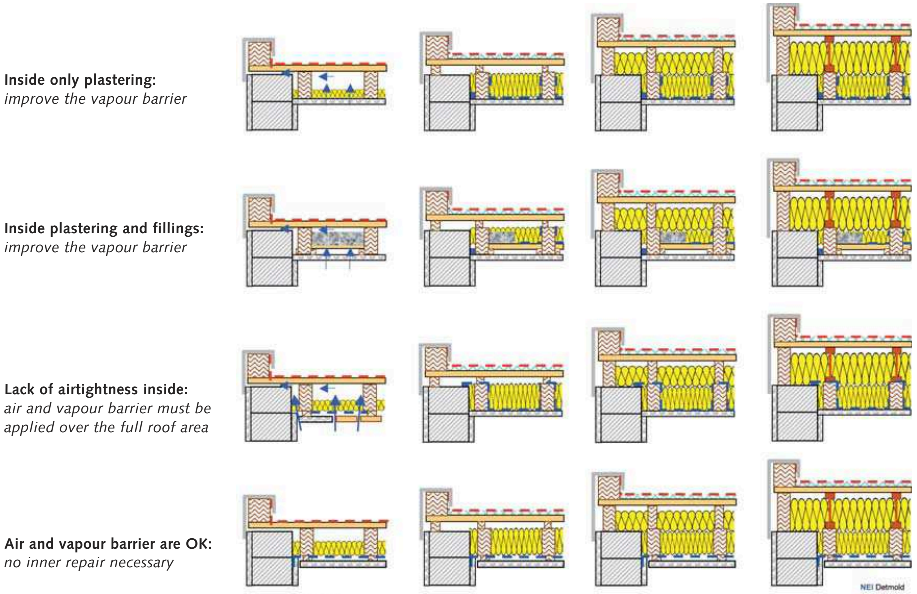
If a flat cold roof needs to be renovated from the top because it is no longer waterproof or some of the wooden boards beneath the waterproof layer are rotten, additional thermal insulation can be installed from outside.

The thickness of the existing insulation is usually 3 to 6 cm with flat cold roofs that were built from 1950 to 1970, or up to 10 cm when built from 1970 to 1990. When the roof is opened from outside, the insulation material can first be filled into the space between the existing beams. Their height usually varies between 14 and 20 cm.

But insulation of that thickness does not result in permanent and high savings, nor does it guarantee heat protection in the hot season for the rooms below. For reasons of economy and living comfort, it is advisable to install additional insulation layers on top. The recommended minimum insulation thickness is 30 cm as required for newly built roofs today. Optimum results are achieved with an insulation thickness of 40 cm – Multi-Comfort house level all year round.

The necessary space for additional insulation can be created through joists or laths attached length- or crosswise from outside. If additional insulation space of more than 20 cm height is needed, it is better to use industrially made timber joists (e.g. TJI joists) of up to 30 cm height instead of solid timber joists. This simplifies the work process and minimizes thermal bridges.

The following drawings show four construction variants of flat cold roofs that were used in the past. The left row illustrates the old roof condition. Next to it, you will see three quality levels of thermal renovation done from the roof top. The four old roof constructions differ regarding their airtightness, quality of the vapour barrier and insulation of their inner layers.



- - - Watertight roof covering
- - - Inner air and vapour barrier

**Variants of wooden flat cold roofs –
Renovation from the top**

If the interior sealing layers of old roofs are not tight enough, they must be revamped. However, the handling of flat cold roofs differs depending on their year of construction: 1930, 1950, 1970 or later than 1990 as shown here.

The drawings in the first row show a flat cold roof with inner plastering that was built between 1850 and about 1970. Its inner plaster coat may be airtight but not very vapour-retarding. In this case, it is usually necessary to install a vapour-retarding foil under the new insulation to reduce or stop the ingress of moisture from below into the insulation. The same may apply to a flat cold roof covered with lightweight stones or a cinder filling between the beams. This type of roof was built between 1910 and 1960 and is shown in the second row.

Tightness problems in flat cold roofs arise because the interior insulation only consists of ventilated decorative boards and aluminium-coated mineral wool mats. The aluminium foil itself is very tight, but usually the connections of the different layers were not properly sealed in the past. To achieve good airtightness, the aluminium foil must be replaced by an airtight foil over the full roof area (shown in row 3). The fourth row of drawings shows modern insulation layers that are air- and vapour-tight over the entire surface area. If they function properly, no improvement of inner tightness is necessary. How can the inner layers in flat cold roofs be improved if required? In the same way as described for pitched roofs opened from outside. Please refer to chapter V.1.1 for more information.

All flat cold roofs have a special moisture problem in common: thermal insulation of the upper, ventilated boarding that carries the waterproof layer does often not exist. The wooden boards – or chipboards since 1965 – are covered with tar paper or foil and often have an additional gravel fill on top.

Condensed water forming on the bottom surface of an upper boarding installed on a flat cold roof when exposed to cold night temperatures

Flat cold roof opened from the top with additional joists to provide space for a total insulation layer of 24 cm thickness

This boarding is always ventilated with outside air from below – this is where the name "cold roof" comes from – to allow humidity from the inner roof space to dry out.

Due to radiation losses in cold, starlit winter nights, the upper layer can cool down to a lower temperature than that of the ambient air. Vapour in the air of the ventilation layer can then condense on the inner side of the boarding when being in contact with its undercooled lower surface.

In the past, the upper boarding of many flat cold roofs rotted as a result of wetness from below. In order to prevent the excessive cooling of the boarding from below, a thin thermal insulation layer of 3 to 4 cm thickness should be installed onto the boarding, directly below the waterproof foil. This is symbolized by light-blue zigzag lines in the above drawings of renovated flat cold roofs.

The following table show the reduction of U-values, heat losses and heating costs for a wooden flat cold roof. The calculation was based on a total ceiling area of 100 m² and heating costs of 7 eurocents/kWh for one year or 40 years of total useful life. Within this period, heating cost savings of more than 90 % – or in absolute terms 59,000 euros – can be realized if the flat roof is upgraded to Multi-Comfort house level with an insulation layer of 40 cm thickness.

U-values, heat losses and heating costs for a wooden flat cold roof of 100 m² with different insulation thicknesses

					New house level	Low-energy house level	Multi-Comfort house level
Insulation thickness	0 cm	3 cm	5 cm	10 cm	20 cm	30 cm	40 cm
U-value	2.64 W/m²K	1.01 W/m²K	0.72 W/m²K	0.63 W/m²K	0.21 W/m²K	0.15 W/m²K	0.11 W/m²K
Annual heat losses	22,210 kWh	8,484 kWh	6,082 kWh	5,326 kWh	1,798 kWh	1,235 kWh	941 kWh
Heat losses over 40 years	888,384 kWh	339,360 kWh	243,264 kWh	213,024 kWh	71,904 kWh	49,392 kWh	37,632 kWh
Annual heating costs	1,555 EUR	594 EUR	426 EUR	373 EUR	126 EUR	86 EUR	66 EUR
Heating costs over 40 years	62,167 EUR	23,755 EUR	17,026 EUR	14,912 EUR	5,033 EUR	3,457 EUR	2,634 EUR

Ceiling area: 100 m²   Calculated useful life: 40 years   Heating costs: 7 eurocents/kWh (average price in 2006)
The financial benefit of insulation will automatically increase with higher energy prices.

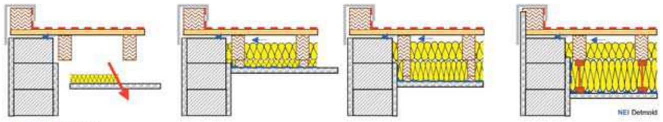
V.3.2. Thermal insulation of flat cold roofs renovated from below and inside

If a flat cold roof is to be opened or is already open from inside, additional thermal insulation can be installed from underneath. This happens in three cases: first, when the roof's inner layers or surfaces have to be replaced; second, when no side needs to be opened, but the roof must be insulated and the costs of opening from below are lower than those of opening from the top; third, when it is planned to convert the loft below the flat roof into a heated room and there is still no inner surface.

It is advisable in such cases to install a new insulation of at least 30 cm thickness. This is generally required for newly built roofs today. All-year round Multi-Comfort level can be achieved if extending the insulation to 40 cm thickness. In practice, the possible insulation thickness is only limited by the decrease in room height below the roof. The first layer can be built inside the space between the existing beams. Here, it is only necessary to leave a sufficient ventilation layer below the roof's upper boarding and the upper surface of the insulation.

In view of the beam height of 14 to 20 cm usually found in flat roofs, it is possible to install 8 to 14 cm insulation in the space between the beams. This does, however, neither provide durable savings nor heat protection in the hot season. For reasons of economy and living comfort, it is advisable to install additional insulation layers under the rafters. The necessary space for additional insulation can be created with joists or laths that are length- or crosswise attached inside. If even larger insulation space of more than 20 cm is required, use industrially made timber joists (up to 30 cm height) instead of solid timber joists or a metal suspension system.

The following drawings show three renovation variants for old roofs: the left drawing illustrates the old condition of the roof, the other three the different quality levels of thermal renovation.



Variants of wooden flat cold roofs – Renovation from the top

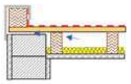
In all three variants, the inner airtight and vapour-retarding layers are newly installed in a quality corresponding to that of new buildings (see photo above). For this reason, not all variants of formerly used inner layers are shown here, but only one with inner plastering (left drawing). When completely renewing the inner sealing layers, future humidity problems – caused by high amounts of vapour flowing from the roomside into the insulation layer – need not be expected. If special foils with variable vapour-retarding abilities such as ISOVER VARIO KM Duplex are used, the upper ventilation layer may no longer be necessary after renovation of the roof. The complete beam space can then be used for insulation and the former "cold roof" is converted into a "warm roof". The feasibility of this should, however, be checked in each individual case by an expert consultant.

The possible savings in energy and heating costs are the same as when opening a flat cold roof from the top and installing equivalent insulation. Refer to the last chapter for more details.

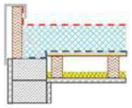
V.3.3. Thermal insulation of flat cold roofs from the top – Conversion into warm roofs

Let's consider the following case: A flat cold roof is to be equipped with additional insulation but without opening it from below or from the top. In this case, additional insulation can only be installed on top of the upper boarding – under special conditions. The former ventilated cold roof will then be modified to a non-ventilated warm roof. The waterproof layer – formerly outside – will later be located on the warm side of the new insulation and functions as a vapour barrier. The old ventilation layer must be completely sealed to the outside as it will later be located on the warm side. This change in roof design may be advantageous if both inner layers and upper boarding are in good condition and must not be damaged. The recommended minimum thickness of the new insulation is 30 cm. This is generally required for newly built roofs today. Even better is a thickness of 40 cm as this guarantees Multi-Comfort house level in all seasons. The required space is no problem in most cases. But the need to raise the parapet walls accordingly may change the proportions of the building (higher facade). Two special aspects need to be considered when planning the conversion from a flat cold roof to a warm roof.

The most important detail is to completely close all lateral and top openings of the former ventilation layer around the roof in order to produce a new, uninterrupted airtight layer on the warm side of the new insulation. The following drawings illustrate such a case.



Flat cold roof with a well-working ventilation layer

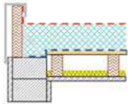


Conversion into a warm roof with closed ventilation layer and airtight connection to wall

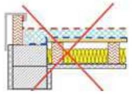
Conversion into a warm roof without closing the airtight layer: how NOT to do it!

The left drawing shows the old cold roof with the required and well-functioning ventilation layer under the upper boarding. Here, the vapour can flow out via the top end of the walls. The second drawing shows a renovated variant. Here, the upper boarding was cut off over the inner side of the walls. The airtight foil of the upper boarding was extended downwards to the wall crown and tightly connected there. The new parapet wall is made of a vertical square plank fixed with a metal bracket. The third drawing shows a variant where the upper boarding is left in place and the new insulation applied over the full surface area. Under the boarding, the former ventilation openings are still open which is not acceptable. It would be too risky to close these openings only from outside as the air sealing layer would be located on the cold outer side of the wall. The warm air in the space between the roof beams could then flow to this cold sealing layer, condense and cause moisture problems. The less tight the layers below the roof, the higher these risks.

The second important aspect is the thickness of the old insulation that still exists between the beams. This layer will later be located inside the vapour-retarding layer. The acceptable thickness of this inner insulation is limited; otherwise, vapour may also condense below the vapour-retarding layer in the old existing insulation. The thicker the new upper insulation and the smaller the old one, the lower this risk.



Usually unproblematic ratio of outer to inner insulation: > 4:1

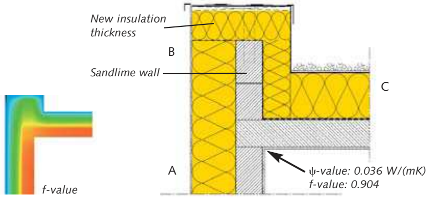


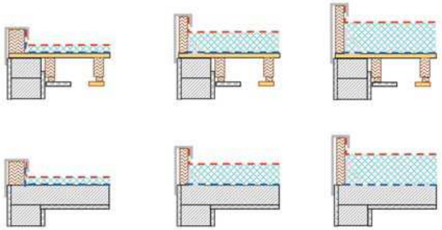
Problematic ratio of outer to inner insulation

If this old inner insulation accounts for more than 25 % of total roof insulation after renovation, an expert should be consulted in advance. If these two special problems can be solved, it can be cheaper and more effective to convert a former cold roof into a warm one than to open the entire roof area from the bottom or top.

V.3.4. Thermal insulation of flat warm roofs renovated from above

Let's finally consider the following case. A flat warm roof with insulation above the load-bearing concrete or wooden layer needs to receive additional insulation. Normally, this can be done from the top without problem. Depending on the condition of the old insulation material or the vapour-retarding layer, these can be left in place underneath or should be removed before. In such a case, it is advisable to install a new insulation layer of at least 30 cm thickness, comparable to that required for newly built roofs today. Optimum results are achieved with an insulation thickness of 40 cm for Multi-Comfort house level throughout the year. The required space is usually not a problem. But since the parapet walls need to be raised, this may change the proportions of the facade.





The above drawings show flat warm roofs made of wood resp. conrete with upper insulation of different thickness. The table show the reduction of U-values, heat losses and heating costs for a flat warm roof made of wood. The calculation was based on 100 m² total roof area and heating costs of 7 eurocents/kWh for one year or 40 years of total useful life. Within this period, heating cost savings of more than 90 % – or in absolute terms 73,000 euros – can be generated if the former uninsulated roof is later upgraded to Multi-Comfort house level. The insulation layer of 40 cm thickness also guarantees maximum thermal comfort.

U-values, heat losses and heating costs for a wooden upper loft ceiling of 100 m² with different insulation thicknesses below

					New house level	Low-energy house level	Multi-Comfort house level
Insulation thickness	**0 cm**	**3 cm**	**5 cm**	**10 cm**	**20 cm**	**30 cm**	**40 cm**
U-value	3.20 W/m²K	1.09 W/m²K	0.76 W/m²K	0.44 W/m²K	0.21 W/m²K	0.13 W/m²K	0.09 W/m²K
Annual heat losses	26,880 kWh	9,148 kWh	6,409 kWh	3,671 kWh	1,730 kWh	1,084 kWh	0,790 kWh
Heat losses over 40 years	1,075,200 kWh	365,904kWh	256,368 kWh	146,832 kWh	69,216 kWh	43,344 kWh	31,584 kWh
Annual heating costs	1,882 EUR	640 EUR	449 EUR	257 EUR	121 EUR	76 EUR	55 EUR
Heating costs over 40 years	75,264 EUR	25,613 EUR	17,946 EUR	10,278 EUR	4,845 EUR	3,034 EUR	2,211 EUR

Ceiling area: 100 m² Calculated useful life: 40 years Heating costs: 7 eurocents/kWh (average price in 2006)
The financial benefit of insulation will automatically increase with higher energy prices.

VI. How to reduce heat losses through outer walls

Outer walls are important parts of the heat-transmitting envelope of a house. They account for 8 to 30 % of the total envelope area, with 1 to 4 floors depending on the geometry of the house. As much as 20 to 45 % of all heat loss is caused by transmission heat lost through outer walls in the cold season. This can be demonstrated by thermography where warm colours correspond to warm areas. Poorly insulated walls are consequently shown in yellow and red (see example). In winter, one can often feel a cold airflow and an unpleasant indoor climate in rooms with only little insulation. If the inner surface temperature of outer walls is very low, vapour can condense on these surfaces, causing water damage and mould. This happens especially when, in addition to insufficient wall insulation, geometrical thermal bridges exist or when the heat distribution inside a room is impeded by furniture.

In order to reduce the high energy losses through outer walls and the resulting lack of comfort, the walls should be thermally renovated to U-values of max. 0.35 W/m^{2}K. This corresponds to 10 cm pure insulation and is the minimum quality level required for new houses in some European countries. If possible, even more effective insulation should be installed to produce even higher savings and comfort than minimally required by law. The low-energy house level can usually be achieved with about 20 cm wall insulation. And the Multi-Comfort or passive house level with about 30 cm wall insulation, thus ensuring most comfortable conditions in all seasons. First, however, the thermal quality of the existing walls needs to be checked.

The wall constructions found in old houses vary with respect to their thermal quality which depends on wall material and thickness. The table below shows the U-values of commonly built solid walls, made of different stones, with a thickness ranging from 24 to 40 cm. After adding insulation, the thickness was increased by 5 to 30 cm. The different colours symbolize the six quality levels of insulation. Red stands for "very high energy losses", orange for "high energy losses", yellow for "insufficient insulation", light green for "new house level", green for "low-energy house level" and dark green for "Multi-Comfort level". It is obvious that the heat conductivity of heavier stones such as natural stones, lime-sand bricks and full bricks is much higher than that of lighter perforated bricks or porous stones. And it is also well-known that a higher wall thickness will never produce the same positive effect on energy savings that even a thin additional insulation layer can provide. The possibilities of adding thermal insulation to outer walls depend on wall construction and design. The first photo shows a solid wall with a smooth plaster surface. This type usually allows easy and cost-effective external insulation without problematic side-effects. Instead of using plaster, the facade can also be covered with other materials such as clinker, wooden boards or natural stones on top of the insulation layer.

U-values of walls in W/m^{2}K	λ =	d =	Wall insulation						
	W/mK	cm	0 cm	5 cm	10 cm	15 cm	20 cm	25 cm	30 cm
Natural stones	2.20	40	2.589	0.551	0.308	0.214	0.164	0.133	0.112
Lime-sand-bricks	0.56	24	1.580	0.482	0.286	0.203	0.157	0.128	0.109
		30	1.351	0.459	0.277	0.199	0.155	0.127	0.107
		36	1.168	0.435	0.268	0.194	0.152	0.125	0.106
Full bricks (1900)	0.50	24	1.461	0.471	0.281	0.201	0.156	0.128	0.108
		30	1.243	0.446	0.272	0.196	0.153	0.126	0.107
		36	1.082	0.423	0.264	0.192	0.150	0.124	0.105
Perforated bricks or light cement stones (1950)	0.39	24	1.220	0,442	0.271	0.195	0.153	0.125	0.106
		30	1.027	0.414	0.260	0.190	0.149	0.123	0.105
		36	0.957	0.389	0.250	0.184	0.146	0.121	0.103
Pumice or light perforated bricks (1970)	0.27	24	0.915	0.395	0.252	0.186	0.147	0.121	0.103
		30	0.760	0.363	0.239	0.178	0.142	0.118	0.101
		36	0.643	0.334	0.226	0.171	0.137	0.115	0.099
Gas concrete (1970)	0.24	24	0.830	0.378	0.246	0.182	0.144	0.120	0.102
		30	0.688	0.345	0.231	0.174	0.139	0.116	0.100
		36	0.580	0.316	0.218	0.166	0.134	0.113	0.097

U-values of homogeneous solid outer walls with different wall and insulation thicknesses. The colours represent the different levels of insulation quality. Colour explanation: refer to the table on the next page.

If houses have nice, decorative facades made of stucco, natural stones or high-quality clinker (see photos 2 and 3), it is often not desirable to modify the facade. In these cases, there are two options for installing additional insulation: either from inside if the walls have a homogeneous structure. Alternatively, in the case of cavity walls, the empty ventilation space in-between can be filled with insulation materials. But often not all sides of a house were built in the same way. Take, for example, the house shown in the third photo from the front and in the fourth photo from the back. It has a decorated front facade whereas its side and rear walls are covered with plaster. In this particular case, three quarters of the wall area can be easily insulated from outside while only the front wall requires another handling.

If the outer walls of a house are not homogeneous but have ventilation layers between the load-bearing inner wall and the outer clinker or other facade layer, any insulation that is installed from outside cannot be effective if outer air can circulate between the layers. It needs to be checked if either the air gap can be filled with insulation and be sealed from all sides to stop such airflows or if the front facade can be pulled down completely to install the new insulation directly on the load-bearing, warm inner wall. The following chapters describe how the outer insulation of walls, the insulation of wall cavities and the internal insulation of walls can be done. The table below shows the heat losses and heating costs of outer walls for different quality levels. The calculations are based on average real U-values of these levels, a total wall area of 100 m^2 and heating costs of 7 eurocents/kWh over a period of one year resp. 40 years of useful life. It is clearly visible that these losses and costs can be reduced by 50 to 90 % when installing additional insulation. In view of the high share that outer walls have in the total heat-transmitting envelope of an old building, it is logical that the additional insulation of outer walls takes high priority. In any case, outer walls with U-values in the red or orange range should be given high priority when planning thermal insulation. U-values in the yellow range should also be insulated although they possibly have a lower priority compared to other parts of the house. Old walls with U-values in the light green range have already been insulated to a small extent. If this insulation works well, there is no urgent need to modify it.

Heat losses and heating costs of outer walls	Very high energy losses	High energy losses	Insufficient insulation	New house level	Low-energy house level	Multi-Comfort house level
U-values	1.00 - 2.50	0.50 - 1.00	0.35 - 0.50	0.25 - 0.35	0.15-0.25	< 0.15
Calculated U-value	1.25 W/m^{2}K	0.75 W/m^{2}K	0.43 W/m^{2}K	0.30 W/m^{2}K	0.20 W/m^{2}K	0.13 W/m^{2}K
Annual heat losses	10,500 kWh	6,300 kWh	3,570 kWh	2,520 kWh	1,680 kWh	1,050 kWh
Heat losses over 40 years	420,000 kWh	252.000 kWh	142,800 kWh	100,800 kWh	67,200 kWh	42,000 kWh
Annual heating costs	735 EUR	441 EUR	250 EUR	176 EUR	118 EUR	74 EUR
Heating costs over 40 years	29,400 EUR	17.640 EUR	9,996 EUR	7,056 EUR	4,704 EUR	2,940 EUR

Wall area: 100 m^2. Calculated useful life: 40 years. Heating costs 7 eurocents/kWh (average price in 2006). The financial benefit of insulation will automatically increase with higher energy prices.
Heat losses and heating costs of outer walls with different insulation levels.

VI.1. Thermal insulation of solid outer walls from outside

If solid outer walls were built in one layer with external plastering or visible brickwork, thermal insulation can be easily installed from outside. Later, the surface can be covered with a new plaster coat, clinker or a ventilated wooden, metal or natural stone facade. The thickness of the new thermal insulation should be at least 12 cm, thus meeting the legal requirements for new houses today. The more comfortable low-energy house level can be reached with 14 to 20 cm, even better with 25 to 30 cm insulation to ensure Multi-Comfort house level. The adequate thickness also depends on the existing wall quality as shown in the table on page 48.

16 cm polystyrene (EPS) insulation installed from outside before the new plastering

If a rendered facade is required again, there is a choice of different insulation materials that can be directly installed on the old wall. The most common are polystyrene (EPS) and rigid mineral wool. In houses up to 4 storeys height, polystyrene boards are most often used due to their low price. If also sound- and fireproofing are required, rigid mineral wool is preferred as it is non-combustible and softer for noise control.

Correct application of the sealing compound

To generate high energy savings, the outer insulation must be fixed tight to the wall without any ventilation in-between. For this purpose, the sealing compound is applied on the back of the insulation boards – not only spot-wise in lumps but like a continuous strip around the board edges. This produces an enclosed airspace behind each board and prevents any air circulation behind the boards.

Another important aspect is the avoidance of thermal bridges. These occur where walls meet windows, doors, balconies or the continuing cold walls or ceilings of unheated parts of the building. The new insulation of outer walls should therefore be directly connected to the frames of doors and windows. In addition, it should overlap the adjoining cold parts of the building by about 50 cm.

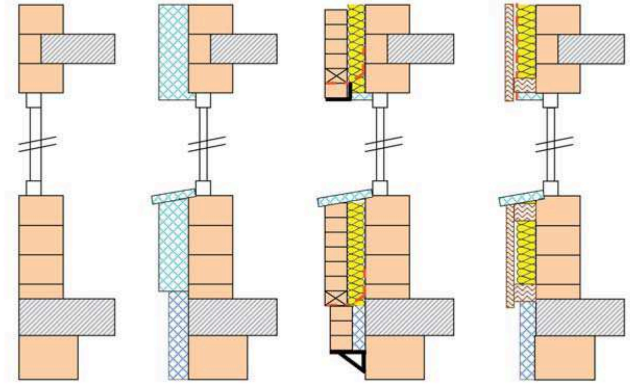
Make sure to avoid thermal bridges on basement walls.

The following drawings show insulation installed on window connections and on the wall crown of the basement. More detailed information about thermal bridges can be found in chapter IV.

Polystyrene (5 to 35 cm)

Rigid mineral wool board

Solid outer walls from outside



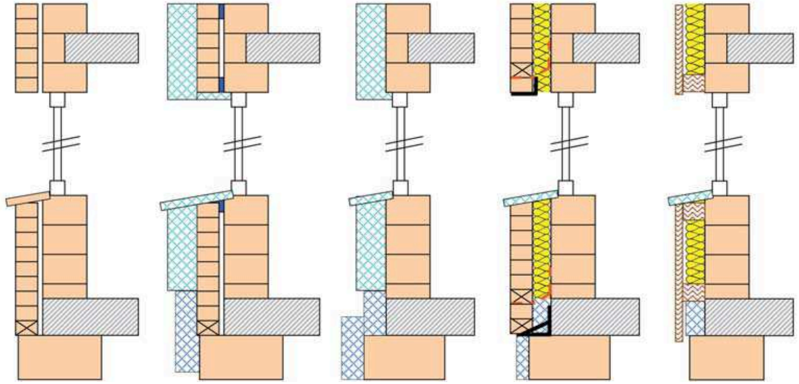
Homogeneous solid wall before insulation

With outer polystyrene insulation and new plastering

With outer insulation and new clinker

With outer insulation and new, ventilated facade

Clinker walls from outside with or without removal of the old clinker



Before the renovation: clinkered but not insulated

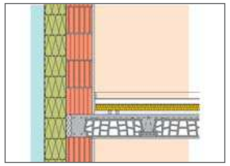
With outer polystyrene insulation and new plastering (very thick)

Identical, but installed after removing the old clinker, thus reducing the wall thickness by 15 cm

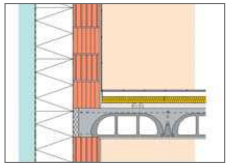
... or clinkered again after insulation

... or decorated with a ventilated facade after removing the old clinker

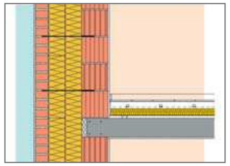
Some examples of typical outer wall constructions.



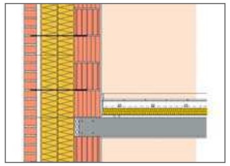
External thermal insulation compound system with ISOVER stone wool lamella facade boards



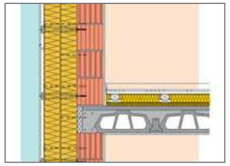
External thermal insulation compound system with EPS foam



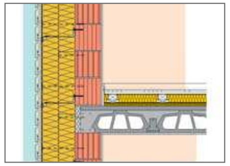
Double-leaf cavity wall with full-cavity insulation



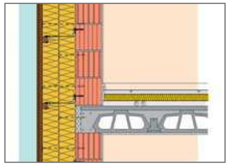
Double-leaf cavity wall with ventilation area



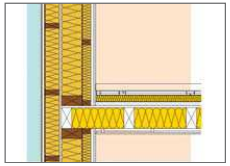
Ventilated outer wall with reinforced cement facade-cladding



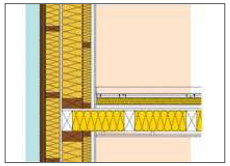
Ventilated outer wall with precast concrete blocks



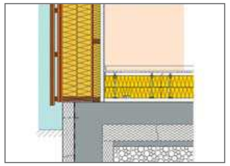
Outer wall with framework boarding



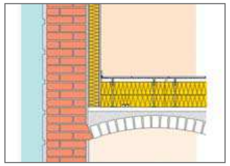
Ventilated outer wall with exterior facade cladding (board)



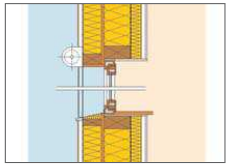
Timber framework wall with timber boarding



Timber framework wall with timber I-section beams



Interior insulation of an outer wall



Timber framework wall with timber boarding

Energetic, visual and financial benefits: with mineral-based thermal insulation systems.

These benefits can be expected of mineral-based thermal insulation composite systems from Saint-Gobain Weber:

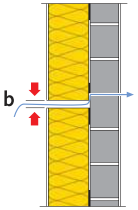
- Perfect external and internal insulation
- Moisture control and capability of diffusion
- Maximum fire protection
- Optimum sound insulation
- Excellent resistance against the growth of fungi and algae
- Long service life
- Multitude of possible designs – even for old buildings
- Rapid and cost-saving workability

Cavities, insulation gaps and joints.

A closed, not too big cavity has only little energetic impact. By contrast, gaps and joints in the thermal insulation of a house cause considerable heat loss.

No need to worry about closed cavities.

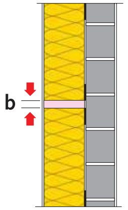
Cavities located in the insulation layer are always airtight although they are not insulated. With cavities below 5 mm width, this lack of insulation does not cause any problems. As long as the cavities are non-communicating, no remedial measures need to be taken. Not so with cavities of more than 5 mm width. Their thermal bridge effect is so strong that they should best be filled with mineral wool. But don't use mortar as this would even reinforce the thermal bridge effect. Also watch out for communicating cavities: they can render an insulating layer nearly ineffective.



A joint is open on both sides and makes the house leaky.

Insulation gaps ruin the energy balance.

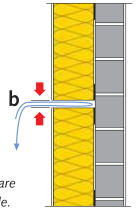
As gaps in the insulation are closed on only one side, they allow airflows on the other. This results in considerable heat loss. Thus a gap of 10 mm can reduce the insulating effect of a 300 mm thick composite thermal insulation system down to that of an insulation layer of just 90 mm thickness.



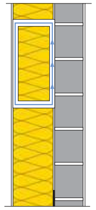
Cavities are airtight, but insulation is missing.

Joints are fatal.

Joints which are open on both sides have only little flow resistance. In a system that is otherwise completely closed, the heat loss multiplies many times over. It is therefore absolutely necessary to locate and completely eliminate them. Otherwise the building will be drafty and prone to structural damage.



Insulation gaps are open on one side.



Communicating cavities considerably increase convection, thus being able to render the insulation nearly ineffective.

If the new facade is to be made of clinker, mineral wool is usually installed in two layers behind to minimize heat losses caused by air flowing through the mat joints. The clinker itself must be based on new foundations or on a steel bracket fixed to the basement wall. Both the mineral wool mats and the clinker are fixed horizontally with wall anchors which are available today for even more than 40 cm insulation thickness.

To reduce the effects of thermal bridges, the windows should ideally be positioned in the middle of the insulated area.

If the facade is to be made of wood, the outer insulation is usually installed between two crosswise installed lath layers as shown in the third and fourth photo. The insulation should be covered with a waterproof but vapour-open (diffusible) membrane such as TYVEK®, followed by distance laths to provide a ventilation layer and wooden facade boards. This can be done over the total wall area or combined with other facade variations as shown in the third photo. In the same way, slim cementitious fibre boards or metal facades can be fixed on wooden subconstructions.

If the facade area is very large or if it is made of heavy materials such as stone, very sturdy and precisely adjustable subconstructions are required. Advantageous are subconstructions made of aluminium sections. When using metal subconstructions, however, make sure to minimize as much as possible the thermal bridge effects caused by the metal elements crossing the entire insulation layer.

Let's consider the following special case: Old clinker walls without existing insulation are to be insulated from outside. If the ventilation space between the inner wall and the clinker is not wide enough to blow in granular or fibrous insulation as desribed in chapter VI.2, additional insulation can be installed outside on top of the clinker (see second photo on this page). Alternatively, the clinker can be removed and new insulation applied directly on the bearing inner walls. The owners of old clinker houses are often reluctant to pull down the old clinker facade as it was long regarded as a quality symbol. But for energetic and cost-benefit reasons this step is often recommendable.

The photo on the left shows the broken-down clinker facade of a house built in 1970. Behind, there was only a cold wall made of lime-sand bricks. After installing an external polystyrene (EPS) insulation of 30 cm thickness, the heat losses through the wall could be reduced by about 90 %, thus reaching Multi-Comfort house level.

2 x 6 = 12 cm outer insulation of a solid wall with a clinker facade

2 x 6 = 12 cm outer insulation of a solid wall with a ventilated wooden facade on the 1st floor

Outer insulation of a solid wall with a ventilated wooden facade over the entire area

VI.2. Thermal insulation of cavity walls

If solid outer walls consist of two stone rows built with 5 cm minimum distance from each other, the ventilation space in-between can be filled with insulation material over the full wall area. Specially prepared loose mineral wool can be blown into this cavity. In low-budget houses built between 1930 and 1960, both stone rows often consisted of 11 cm solid bricks and provide a ventilation layer of 6 to 10 cm width. With other house types, the cavity is between 3 and 8 cm wide when erecting bearing walls of 17.5 to 24 cm width with an outer clinker or plaster facade.

Blowing granular perlite insulation into a cavity wall

Before blowing insulation into the cavity, some conditions need to be fulfilled:

The most important precondition is that the cavity is closed on all sides so that the insulation material cannot flow out. Normally, the loose mineral wool will be so strongly compressed after being blown in that it will stay in the cavity due to its own weight. Any existing openings should be checked and closed before filling in the insulation. These include wall boardings on all sides of windows, doors and roller shutter boxes. In addition, also the interfaces between walls and wooden ceilings should be checked.

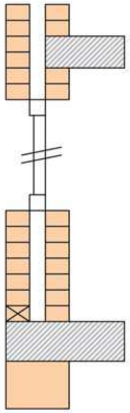
Cavity wall that has been opened around a window opening

Large usable ventilation layer around a window opening

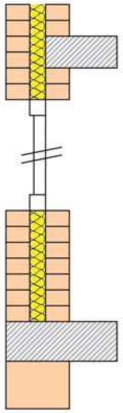
Finally, it must be checked if the cavity needs to remain empty so that it can dry up any humidity that may penetrate the wall. This can be the case for walls with clinker facades made of very water-absorbing stones or with very untight mortar joints. Here, the incoming water flows down into the cavity and out again through special drainage gaps in the lowest clinker row. Any insulation material installed in the ventilation layer would not only prevent the drying process but also get wet. But if the outer wall is plastered or the mortar joints covered with paint, there will be no ingress of water into the ventilation layer.

When filling a cavity of 6 to 10 cm, heat losses can be significantly reduced. The resulting heating cost savings will amount to something between 45 and 65 %. They can amount to even 95 % when installing additional insulation from outside.

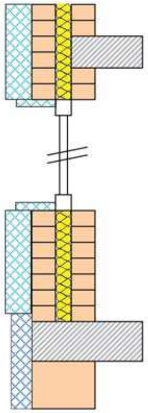
Cavity walls



Cavity wall without insulation



... filled with insulation



... with additional external insulation

VI.3. Thermal insulation of solid outer walls from inside

If solid outer walls with a high heat transmission can neither be insulated from outside nor inside the cavity, it is advisable to install insulation from inside. In order to limit the loss of available room space, internal insulation is usually installed at a thickness of 4 to 8 cm, but also higher thicknesses of 12 to 15 cm are possible.

The material of choice for internal insulation is again mineral wool, available in rolls or slabs. The recommended material, shape and thickness in the individual case depend on the intended level of comfort and use of the wall and the need for surface stability.

In any case, it is important to have an expert check the moisture control of the walls after their reconstruction. Fact is that the stones of outer walls will be much colder after installing insulation from inside. This is because the dew point of the old wall is now located in the new insulation layer and no longer in the middle of the stone layer.

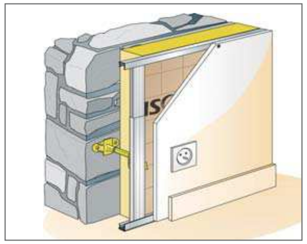
A candidate for insulation from inside: 5 cm will generate a 60 % heat loss reduction of the 36 cm brick walls.

To avoid damage caused by condensation in the insulation layer or in the adjoining wooden components, it is necessary to install an airtight and vapour-retarding layer on the room facing side of the internal insulation to prevent vapour flowing from the room into the insulation.

If the new internal insulation layer is crossed by concrete or wooden ceilings between the floors or by internal wall connections, it may also be necessary to take thermal bridge effects into account. This aspect should be checked by an expert before installing insulation from inside. In many cases, the flanking insulation of the connections between outer walls and ceilings has proved to be useful. Crossing wooden components like ceiling beams may require special vapour retarders when penetrating the internal insulation layer as they cause thermal bridges and large temperature differences compared to the insulation material.

The heat loss reductions which can possibly be realized through internal insulation of outer walls will be high if the old outer walls had very high U-values (see the dark red values in the table on page 50). Let's, for example, take the house shown in the photo on the previous page. By installing an internal insulation layer of only 5 cm on the existing 36 cm full brick walls, the heat losses through walls would be reduced by about 60 %. If the walls were made of 40 cm natural stone, a 5 cm insulation from inside would decrease the heat losses through walls by even 80 %.

In general, internal insulation will always be the second best solution in cases where external insulation is possible. But in cases where old facades do not allow insulation from outside, internal insulation is the alternative of choice.



OPTIMA dry wall lining system for thermal and acoustic insulation of outer walls from inside.

The OPTIMA system can be easily installed and adjusted. The system components include metal studs, intermediate support pieces and glass wool. The plasterboards are screwed onto C-channel sections.

Internal insulation of an outer wall with ISOVER composite panels CALIBEL made of glass wool and gypsum board

Internal insulation with an additional thin brick wall

Internal insulation with gypsum boards

Internal insulation of an outer wall with resilient bars and gypsum boards

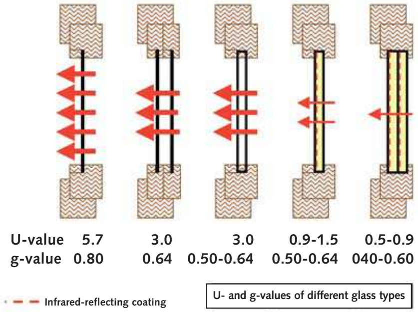
VII. How to reduce heat losses through windows and outer doors

Windows and outer doors account for 5 to 17 % of the whole heat-transmitting envelope of a house (depending on its height). Between 22 and 50 % of all transmission losses in the cold season are caused by windows and outer doors. Old and new window glazing, window frames and outer doors differ very much with respect to their thermal quality, including the factors heat transmission (U-values), solar energy transmittance (g-values), airtightness and thermal bridge effects.


Thermal quality of new windows

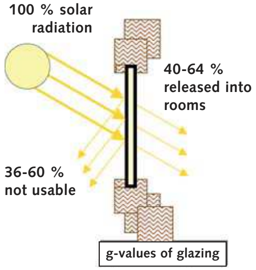
The highest heat losses are caused by doors and windows with only single glazing, metal frames and without all-round rubber lip sealing. Minimal heat losses occur through triple-glazed windows or doors with insulated frames and double or triple rubber lip sealing all around. The following drawings and tables show the different quality levels of glazing and frames.

The first drawing shows the U- and g-values of old single-glazed windows compared to today's double- and triple-glazed windows. The heat loss range is 10:1 between old single-glazed windows (U-value approx. 5.7 W/m²K) and modern double-coated, triple-glazed windows (U-value approx. 0.5 W/m²K). Double frame windows with two single panes (1950-1970) and thermopane glazing of the first generation (1970-1990) with air filling but without coating have U-values of approx. 3.0 W/m²K. Today's most commonly used double-glazed windows with inert gas filling (argon, krypton or xenon) and infrared-reflecting coating reach U-values between 0.9 and 1.5 W/m²K. U-values should be as low as possible since they play an important role for the heat transmission of the windowpane in the cold and hot season.



U-value	5.7	3.0	3.0	0.9-1.5	0.5-0.9
g-value	0.80	0.64	0.50-0.64	0.50-0.64	040-0.60

U- and g-values of different glass types



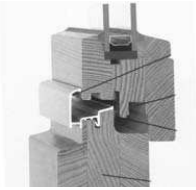
g-values of glazing

Besides the U-value, also the g-value of the glazing is important. It indicates how much of the incoming solar radiation in the energetically important wavelength range penetrates the window without being reflected or absorbed. High g-values help produce solar gains in winter, especially through south-, south-west and south-east facing windows that are not shaded by mountains, neighbouring houses or trees. If solar gains are wanted, g-values should be high. New double-glazed windows feature g-values of up to 64 %, triple-glazed ones of up to 60 %.

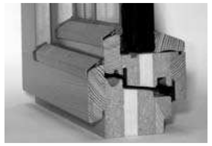
Houses with large windows tend to overheat in summer due to solar radiation through windows. Glazing with low g-values can help reduce this effect. But low g-values on the other hand reduce solar gains in winter. It is therefore preferable in most cases to use movable outer shading systems in summer instead of sun protection glazing all year round. The third aspect of thermal glass quality is the spacer material between the two (or three) single glass panes. These spacers form a direct thermal bridge between the cold outer and the warm inner glazing. Available are spacers made of aluminium, stainless steel and plastic. Aluminium spacers have the highest heat transmission value, stainless steel spacers a medium and plastic spacers the lowest value. Naturally, aluminium spacers are no longer state of the art.

Apart from the thermal glass quality, also security and sound insulation are important factors. Window producers can provide more detailed information.

Usually, window and door frames are made of wood, plastic, aluminium or steel. They differ with respect to material thickness and are offered with or without insulation layer inside. U-values for frames (U_f-values) can vary strongly in the thermal insulating qualities.


Wooden frame without insulation

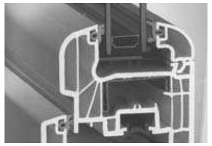
Wooden frames consist of hard- or softwood. Their thickness varies between 45 and 72 mm (up to 120 mm when including the insulation layers). Lighter and softer types of wood are less heat-conducting, harder or tropical wood species are more resistant to water and UV radiation. To improve the heat insulation of wood frames, they can be made of thicker solid wood or with inner insulation layers of polyurethane, cork, lightwood or closed air spaces. Possible U_f-values of wood frames are between 2.0 and 0.50 W/m²K (see table on page 63).


Wooden frame with PU insulation

Plastic frames of windows and doors are usually made of PVC profiles with an inner metal profile for stabilization. Their heat conductivity depends on the number of separate air chambers and the filling (air or an insulation material). Window frames with only two or three chambers should no longer be used for permanently heated rooms. PVC frames with five chambers are common in new buildings; frames with 6 or 7 chambers have 20-35 % lower heat losses. Minimal heat losses are achieved by PVC frames with blown-in PU insulation.


PVC frame with 3 chambers

Metal frames of windows or outer doors are usually made of aluminium profiles and are often found in multi-family houses or public buildings. Aluminium has much higher heat conductivity (200 W/mK) than wood (0.13-0.18 W/mK) or insulation materials (0.03-0.05 W/mK). The thermal quality of such frames mainly depends on the separation of the warm inner and the cold outer frame layers by insulating spacers. Frames without thermal separation by plastic spacers are very cold inside in winter and should therefore be replaced. A well-insulated metal frame requires at least 2-4 cm insulated separation between its outer and inner aluminium parts.

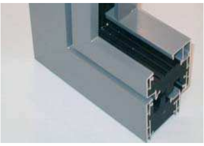

PVC frame with 5 chambers

Various combinations of frame and glass can be found in old houses. Since about 2000, new spacers with low thermal conductivity are available in the market. They also reduce the thermal bridge effect between the different glass layers.


PVC frame with 7 chambers

PVC frame filled
with PU insulation

Aluminium front door
of 1970 with not
insulated frames



Well insulated
aluminium frame

The first table on page 63 shows the U_w-values of different window constructions based on a window of 1.78 m height and 1.10 m width.

In the first table, the lines show the values of different glazing qualities, the columns those of different frame qualities. The colours indicate the different thermal quality levels of the components. The bright coloured fields contain the resulting U_w-value of a window with the selected combination of frame and glass. The six rightmost columns contain black values (use of aluminium glass spacers) and blue values (use of less heat-conducting stainless steel spacers). Plastic spacers can even better reduce thermal bridge effects.

The table shows how much the U_w-value for the whole window can be reduced if windows are completely replaced by those with new frames and new glazing. Secondly, it is visible how different the result will be if the old frames stay and only new panes are built in. This often happens when the frames are in good condition. Thirdly, it is evident how much impact less heat-conducting spacers can have. But all results only apply for the window size mentioned above. If the frame's share of the window area is much smaller or bigger, the impact of frame and glass quality will be different.

The second table shows the heat losses and heating costs of windows with different thermal qualities in a single-familiy house. The calculations are based on a total window area of 25 m² and heating costs of 7 eurocents/kWh over a period of one year and 40 years of useful life. When building new windows into heated rooms, heat losses and costs can be reduced by 50-84 %. Windows with U-values indicated in red should definitely be replaced by new ones. Windows with yellow values should also be replaced, but other parts of the house may have a higher priority. Windows with light green values usually need not be replaced unless they are defective.

Windows and outer doors should at least be airtight to prevent heat loss and lack of comfort caused by unwanted cold airflows.

U_w-values of windows		Thermal quality of glass – U_g-values										
		Single glazing	Double glazing 1970-90		Double glazing 1990-…		Double glazing 2000-…		Triple glazing 2000- …			
		5.2	3.2	2.8	1.5	1.3	1.2	1.0	0.8	0.7	0.6	0.5
Thermal quality of frames – U_f-values	4.0	5.2	4.0 (alu)	3.7 (alu)	2.9 (alu)	2.7 (alu)	2.6 (alu) 2.3 (ss)	2.4 (alu) 2.2 (ss)	2.3 (alu) 2.0 (ss)	2.2 (alu) 2.0 (ss)	2.2 (alu) 1.9 (ss)	2.1 (alu) 1.8 (ss)
	3.5	5.1	3.8 (alu)	3.5 (alu)	2.7 (alu)	2.6 (alu)	2.4 (alu) 2.2 (ss)	2.3 (alu) 2.1 (ss)	2.2 (alu) 1.9 (ss)	2.1 (alu) 1.8 (ss)	2.0 (alu) 1.8 (ss)	1.9 (alu) 1.7 (ss)
	3.0	5.0	3.6 (alu)	3.4 (alu)	2.5 (alu)	2.4 (alu)	2.3 (alu) 2.0 (ss)	2.1 (alu) 1.9 (ss)	2.0 (alu) 1.7 (ss)	1.9 (alu) 1.7 (ss)	1.9 (alu) 1.6 (ss)	1.8 (alu) 1.5 (ss)
	2.5	4.9	3.5 (alu)	3.2 (alu)	2.3 (alu)	2.2 (alu)	2.1 (alu) 1.9 (ss)	2.0 (alu) 1.8 (ss)	1.9 (alu) 1.6 (ss)	1.8 (alu) 1.6 (ss)	1.8 (alu) 1.5 (ss)	1.7 (alu) 1.4 (ss)
	2.0	4.8	3.3 (alu)	3.0 (alu)	2.2 (alu)	2.0 (alu)	2.0 (alu) 1.8 (ss)	1.8 (alu) 1.6 (ss)	1.7 (alu) 1.5 (ss)	1.7 (alu) 1.5 (ss)	1.6 (alu) 1.3 (ss)	1.5 (alu) 1.3 (ss)
	1.8	4.7	3.2 (alu)	3.0 (alu)	2.1 (alu)	2.0 (alu)	1.9 (alu) 1.7 (ss)	1.8 (alu) 1.6 (ss)	1.7 (alu) 1.4 (ss)	1.6 (alu) 1.3 (ss)	1.5 (alu) 1.3 (ss)	1.5 (alu) 1.2 (ss)
	1.6	4.6	3.2 (alu)	2.9 (alu)	2.0 (alu)	1.9 (alu)	1.8 (alu) 1.6 (ss)	1.7 (alu) 1.5 (ss)	1.6 (alu) 1.3 (ss)	1.5 (alu) 1.3 (ss)	1.5 (alu) 1.2 (ss)	1.4 (alu) 1.1 (ss)
	1.4	4.5	3.1 (alu)	2.8 (alu)	2.0 (alu)	1.8 (alu)	1.8 (alu) 1.5 (ss)	1.6 (alu) 1.4 (ss)	1.5 (alu) 1.3 (ss)	1.5 (alu) 1.2 (ss)	1.4 (alu) 1.1 (ss)	1.3 (alu) 1.1 (ss)
	1.2	–	2.9 (alu)	2.7 (alu)	1.9 (alu)	1.8 (alu)	1.7 (alu) 1.5 (ss)	1.6 (alu) 1.3 (ss)	1.5 (alu) 1.2 (ss)	1.4 (alu) 1.1 (ss)	1.3 (alu) 1.1 (ss)	1.3 (alu) 1.0 (ss)
	1.0	–	2.9 (alu)	2.4 (alu)	1.8 (alu)	1.7 (alu)	1.6 (alu) 1.4 (ss)	1.5 (alu) 1.3 (ss)	1.4 (alu) 1.1 (ss)	1.3 (alu) 1.1 (ss)	1.3 (alu) 1.0 (ss)	1.2 (alu) 0.9 (ss)
	0.8	–	–	–	–	–	1.5 (alu) 1.3 (ss)	1.4 (alu) 1.2 (ss)	1.3 (alu) 1.0 (ss)	1.2 (alu) 1.0 (ss)	1.2 (alu) 0.9 (ss)	1.1 (alu) 0.9 (ss)
	0.6	–	–	–	–	–	1.4 (alu) 1.2 (ss)	1.3 (alu) 1.1 (ss)	1.2 (alu) 1.0 (ss)	1.1 (alu) 0.9 (ss)	1.1 (alu) 0.8 (ss)	1.0 (alu) 0.8 (ss)

(alu) / (ss) = aluminium or stainless steel spacers between the two or three glass panes
U-values of windows with different frames, glazing and spacers (window dimension in this example: height 1.78 m and width 1.10 m)

	Very high energy losses		Insufficient insulation		New house level	Low-energy house level		Multi-Comfort house level
U-values	5.00	4.00	3.00	2.50	1.80	1.40	1.00	0.80
Annual heat losses	8,400 kWh	6,720 kWh	5,040 kWh	4,200 kWh	3,024 kWh	2,357 kWh	1,680 kWh	1,344 kWh
Heat losses over 40 years	338,000 kWh	268.800 kWh	201,600 kWh	168,000 kWh	120,960 kWh	94,080 kWh	67,200 kWh	53,760 kWh
Annual heating costs	588 EUR	470 EUR	353 EUR	294 EUR	212 EUR	165 EUR	118 EUR	94 EUR
Heating costs over 40 years	23,520 EUR	18.816 EUR	14,112 EUR	11,760 EUR	8,467 EUR	6,586 EUR	4,704 EUR	3,763 EUR

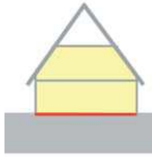
Total window area: 25 m² Calculated useful life: 40 years Heating costs: 7 eurocents/kWh (average price in 2006).
The financial benefit of insulation will automatically increase with higher energy prices.

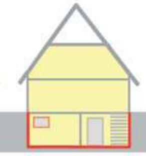
Heat losses and heating costs of windows (25 m²) with different thermal qualities

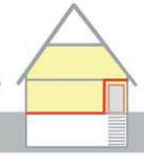
VIII. How to reduce heat losses through cellar components

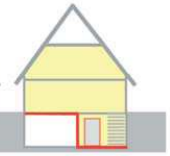
Cellar components are often underestimated parts of a building's thermal envelope. But they account for 20 to 30 % of its entire heat-transmitting envelope. As the temperature difference between heated rooms and cellar is about half as much as between heated rooms and outside air temperature, their share of transmission heat losses is usually between 10 and 15 %.

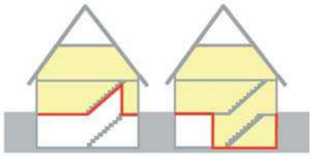
To find out where the additional insulation of cellar components can generate high heating cost savings, the interfaces between heated and unheated rooms in a house must first be analyzed. The drawings below show the different heat-transmitting areas of a cellar.


No cellar

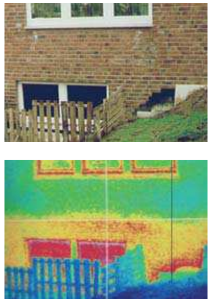

Warm cellar


Cold cellar door upstairs


Cold cellar door downstairs


Thermal interfaces when cellar door upstairs or downstairs

The first drawing shows a house without a cellar. Here, the ground floor is the bottommost part of the building envelope. The second drawing shows a house with a completely heated cellar. Its thermal envelope encompasses the whole sole plate, all outer walls and windows of the cellar, but no components between cellar and ground floor. The third and fourth drawings show a house with an unheated cold cellar and a stairway door – either in the cellar or upstairs on ground floor level. Apart from the cellar ceiling, also components around the cellar stairs are part of the thermal envelope. These include the walls of the cellar stairs up to ground floor level (if the stairway is cold) or to the outside (if the stairway is warm), the cellar door, the ceiling above the stairway and the sole plate below the stairway. These areas may not be large, but if made of concrete, heavy stones or wooden boards, a lot of heating energy can escape.


The thermographic picture of the facade shows that the cellar wall is not insulated, thus producing heat losses that are higher than those of the ground floor.

These heat-transmitting areas can be individually configured. We differ between seven different cellar components:

- floor slab under heated rooms
- cold cellars ceilings to heated ground floors
- inner walls between heated and unheated cellar rooms
- outer walls of heated cellars to ground or to outer air
- cellar stair ceiling if the door is upstairs
- door of cellar stairs
- warm cellar windows

In old houses, there is often no clear dividing line between heated and unheated cellar rooms. Boiler rooms with old heating systems are warm although the temperature is not needed. Laundry rooms have open doors and windows for drying the laundry. Other rooms are used for storing textiles, shoes, furniture, papers etc., so little heating is necessary to keep these things dry and prevent mould. The smaller the cellar, the more often the cellar door is left open, the more it is difficult to control heat and air flows as well as vapour distribution. The biggest problem arises when cellar rooms – originally constructed for storage – are used for living or working and are permanently heated. If their thermal envelope does not fulfil minimum demands for thermal insulation, substantial heat losses and an unhealthy climate must be expected. This is shown by the thermographic picture on the left page.

In brief: The thermal insulation of cellar components does not only help reduce heat losses from ground floor to cellar. It also helps reduce the cellar's own heat losses, the risk of mould growth and its consequences for residents and stored objects.

VIII.1. Thermal insulation of floor elements

If floor elements under heated rooms have no or poor insulation, additional insulation should be installed on top whenever the floor is renovated. To reduce high energy losses and to raise the floor surface temperature, the U-values of renovated floors should be lower than 0.35 W/m²K. Very low losses and higher comfort can be achieved when reaching U-values between 0.30 and 0.15 W/m²K (low-energy or Multi-Comfort house level).


Concrete sole plate with 10 cm XPS insulation on top

Which materials are suitable and which other layers need to be checked or installed apart from insulation? All this depends on the old floor construction. The most important criteria are waterproofness and vapour-retarding function, the inner room height, the expected floor load and if a floor heating system is wanted or not.

In very old houses, the bottom layer of the sole plate is usually made of sand, slag or stones. This was done to prevent the capillary rise of moisture, stop rodents and vermin entering the house and produce a level, dry and durable upper surface. Since about 1900, cement screed and later concrete floor elements have come into use to provide a load-bearing surface. Until 1955, thermal insulation merely consisted of a layer of beams. The air space in-between was covered by wooden boards. This wooden floor construction raised the inner surface temperature and, where necessary, allowed ground moisture to dry out. However, when later covered with vapour-retarding layers such as PVC flooring, this construction was prone to damage as these layers prevent the required drying of humidity.

After 1950, sole plates were usually made of concrete with waterproof tar paper or a bituminous coating on top or with a polystyrene, cork or rubber insulation layer and cement screed on top. Until the 1960s, the insulation height was 1-2 cm, since the 1970s 5-6 cm; since about 1990 it was increased to 6-8 cm. Below the polystyrene flooring a waterproof layer was installed, usually resulting in a dry construction.

Today, a much greater choice of insulation materials is available. These include polystyrene and polyurethane foam boards, cork, perlite granular filings, foamed glass, hard wooden fibre boards, mineral wool mats and since about 2002 vacuum insulation panels (see second photo on page 66).

These materials differ with respect to their heat conductivity (see table below), their load-bearing capacity and their sensitivity to humidity.

	λ-value W/mK	U-value 0.35 needs
Foam glass, cork, wood fibres	0.050	14 cm
Mineral wool	0.035	9 cm
Uncoated PU	0.030	8 cm
Aluminium-coated PU	0.025	7 cm
Vacuum panels	0.0042	1.5 cm

Heat conductivity of common insulation materials used on concrete sole plates

When thermally insulating floor elements or improving the existing insulation, it first needs to be checked whether the subconstruction is waterproof and dry. Otherwise, this must be remedied. A great variety of floor insulating materials is available today so that no compromise is needed any longer.

In the case of a low room height, the old layers can either be removed to gain more height or very effective insulation materials can be used. The recommended insulation thickness for new floors of good quality is usually 8-12 cm. Best quality is achieved with 22 cm insulation material and heat conductivities between 0.040 and 0.025 W/m²K. Only vacuum panels provide the same effect but at a much smaller thickness.

The following table shows the heat losses and heating costs caused by a 100 m² sole plate of different thermal quality. The calculations are based on heating costs of 7 eurocents/kWh over a period of one year and over 40 years of useful life. High savings can be realized when upgrading old floors that were not or only poorly insulated. The values calculated for the three old variants are based on a polystyrene insulation of 0.04 W/mK. The new quality levels are based on a better insulation material of 0.035 W/mK conductivity (commonly used today).


Lowered sole plate, newly waterproofed with 6 cm PU insulation on top (0.025 W/mK)


Additional sole plate insulation with vacuum panels in a sports hall (photo: Va-Q-Tec)


Additional sole plate insulation with ISOVER raised floor system Distansol. Special moisture and condensation protection is needed!

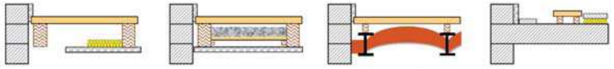
ISOVER Multi-Comfort House

Heat losses and heating costs caused by concrete sole plates	Very high energy losses	High energy losses	Insufficient insulation	New house level	Low-energy house level	Multi-Comfort house level
U-values	4.87 W/m²K	1.31 W/m²K	0.79 W/m²K	0.39 W/m²K	0.27 W/m²K	0.15 W/m²K
Construction / Insulation	concrete only	+2 cm 040	+4 cm 040	+8 cm 035	+12 cm 035	+22 cm 035
Annual heat losses	20,454 kWh	5,489 kWh	3,318 kWh	1,646 kWh	1,138 kWh	0,643 kWh
Heat losses over 40 years	818,160 kWh	219,576 kWh	132,720 kWh	65,856 kWh	45,528 kWh	25,704 kWh
Annual heating costs	1,432 EUR	384 EUR	232 EUR	115 EUR	80 EUR	45 EUR
Heating costs over 40 years	57,271 EUR	15,370 EUR	9,290 EUR	4,610 EUR	3,187 EUR	1,799 EUR

Sole plate area: 100 m². Calculated useful life: 40 years. Heating costs: 7 eurocents/kWh (average price in 2006)
The financial benefit of insulation will automatically increase with higher energy prices.

VIII.2. Thermal insulation of cellar ceilings

If a cellar ceiling is not or only poorly insulated, this results in high heat losses from the heated ground floor to the unheated cellar and in a cold ground floor temperature. This can be remedied by installing additional insulation. The thickness of the new insulation should not be less than 8 cm, corresponding to new house level. More comfortable low-energy house level can be achieved with 12 cm, Multi-Comfort house level with 22-24 cm insulation.


Variants of old cellar ceilings

Old cellar ceilings are usually constructed in one of the four ways sketched. On the left you can see a wooden ceiling with or without downside covering (closing), with an empty air space in-between or a poor mineral wool insulation layer. The second drawing shows a wooden ceiling with a cinder filling on the middle boards and a plaster coat underneath. Number three is a ceiling made of steel T-beams with an arch brick filling, topped by an air layer and a wooden floor. The fourth variant shows a concrete cellar ceiling, covered either by a wooden floor on ventilated spacers or a cement screed with/without polystyrene foam insulation below. Unlike cellar floors, cellar ceilings are not exposed to the capillary rise of ground moisture. And the temperature difference between the upper and underside of a cellar ceiling is only half as much as that of top floor ceilings. If the cellar is unheated and the thermal insulation is placed on the ceiling between ground floor and cellar, a vapour barrier needs to be installed on the warm side of the insulation.

We differ between three situations for the additional thermal insulation of a cellar ceiling:


Wooden cellar ceiling opened from below

1. The ceiling is a wooden construction. Either its top or its bottom surface or none of them must be opened (see photo on the left). This case is described in chapter VII.2.1.


Insulation is blown into a T-beam ceiling

2. The ceiling is a steel T-beam construction with unfilled space above the arch bricks and the wooden floor. Insulation material can be blown into this space from below (see photo on the left) or installed from above or below. This case is described in chapter VII.2.2.


Concrete ceiling insulated from below

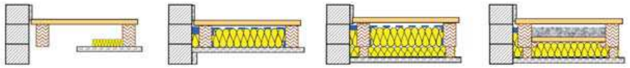
3. The cellar ceiling is made of concrete. Insulation is usually installed from below as shown in the third photo. Installation from above is also possible. This case is described in chapter VII.2.3.

VIII.2.1. Thermal insulation of wooden cellar ceilings

Wooden cellar ceilings are usually easy to insulate: they are located in the dry inner area of houses and contain cavities that are often empty or can be emptied and filled with insulation material. The beams of cellar ceilings are 12-18 cm high. This allows an insulation quality equal to that of low-energy houses, without need for additional layers. If the maximum comfort of Multi-Comfort houses is desired, additional insulation layers can easily be installed from above or below.

Wooden cellar ceiling, opened for insulation from below

Insulation is installed from below if there is no bottom lining or if the ceiling can be more easily or cheaply opened from below than from the top (see photo 1).



Wooden cellar ceilings, opened from above or below

Insulation from above is only advisable if the upper wooden floor needs to be completely replaced (see photo 2). Reasons for opening the top or both sides of a ceiling: the ceiling beams or floors need to be replaced, because they are rotten or attacked by worms (see photo 3).

If the cellar ceiling needs not be opened because both surfaces are in good condition, insulation can be blown into the available space from above or below if the cavities are empty. For this purpose, you either open one floorboard in every room (see photo on page 69) or drill holes into the bottom so that insulation material can be blown in with a pipe (see first photo on page 70).

Wooden cellar ceiling with new insulation installed from the top

When insulating cellar ceilings, also the criteria air and vapour tightness need to be considered. The temperature difference between the heated ground floor and the unheated cellar is only half as much as the difference to the outer air. Nevertheless, a vapour barrier must be installed on the warm side of the insulation to ensure a dry construction.

Wooden cellar ceiling, completely opened for rafter repair

The airtightness of a wooden cellar ceiling is an important aspect. An old wooden floor is not airtight. For this reason, additional airtight layers can be installed on top over the full surface, made of linoleum, PVC, glued chipboards or cement screed. Alternatively, full-surface plastering or gypsum boards can be installed from below. If the cellar is dry, the airtight layer should be applied on top of the insulation (warm side). Below is also possible if the insulation is vapour-permeable. Not useful are vapour-impermeable layers like aluminium or PE foils or glued chipboards installed from below.

Wooden cellar ceiling, only partly opened for blow-in insulation

If water and gas pipes or cables are installed at a ceiling height where insulation is to be applied, it is necessary to consider security and service aspects. The run of pipes and cables should be documented and later access should be possible. Gas pipes need all-round ventilation and a sufficiently sized cladding tube that is open on both sides to cellar air.

The table below shows the reductions in heat losses and heating costs that can be achieved for wooden cellar ceilings. The calculations are based on a 16 cm beam layer where the space is filled only with air, 8 cm cinders or 3-24 cm mineral wool (24 cm with added lath layer). The bottom surface consists of 2 cm plastering. U-values range between 1.14 and 0.18 W/m^2K. When filling a 16 cm high ceiling space completely with mineral wool of 0.035 W/mK heat conductivity, a U-value of 0.26 W/m^2K can be reached. This corresponds to low-energy house quality.

It is true that the smaller temperature difference between ground floor and cellar generates smaller insulation benefits compared to building components in contact with outside air. Nevertheless, the cost-benefit ratio of additional cellar ceiling insulation is attractive since the installation costs are quite low.

Heat losses and heating costs caused by wooden cellar ceilings	**Very high energy losses**	**High energy losses**	**Insufficient insulation**	**New house level**	**Low-energy house level**	**Multi-Comfort house level**
U-values	**1.14 W/m^2K**	**0.78 W/m^2K**	**0.59 W/m^2K**	**0.39 W/m^2K**	**0.30 W/m^2K**	**0.18 W/m^2K**
16 cm beams with …	16 cm airspace	8 cm cinder	3 cm 040	8 cm 035	12 cm 035	24 cm 035
Annual heat losses	4,784 kWh	3,276 kWh	2,474 kWh	1,617 kWh	1,264 kWh	0,773 kWh
Heat losses over 40 years	191,352 kWh	131,040 kWh	98,952 kWh	64,680 kWh	50,568 kWh	30,912 kWh
Annual heating costs	335 EUR	229 EUR	173 EUR	113 EUR	88 EUR	54 EUR
Heating costs over 40 years	13,395 EUR	9,173 EUR	6,927 EUR	4,528 EUR	3,540 EUR	2,164 EUR

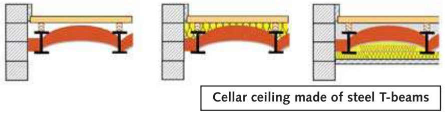
Cellar ceiling area: 100 m^2. Calculated useful life: 40 years. Heating costs: 7 eurocents/kWh (average price in 2006)
The financial benefit of insulation will automatically increase with higher energy prices.

VIII.2.2. Thermal insulation of cellar ceiling cavities without complete opening

From 1850 to 1950, cellar ceilings were often made of steel T-beams between which arch bricks were placed, visible from below by their plastered bown surface. Wooden spacer beams were laid on top of the steel T-beams with empty air space in-between and covered by wooden floorboards. The space above the arches was seldom filled (see the drawings on the right).


Wooden cellar ceiling: insulation is blown in from below

The space between the arch bricks and the wooden flooring is 6-20 cm high and very well suited for insulation. When completely filled with insulation material, the heat losses through the cellar ceiling can usually be reduced by 60-70 %. Insulation can be blown in from below as shown in the first photo. With one drill hole a space of about 2 m^2 can be filled. If single floorboards can be opened from the top (see 2nd photo), the blowing pipe can be inserted by up to 4 meters and slowly pulled out while blowing. In this way, larger areas can be filled in one shot.



T-beam ceiling with arch bricks: without, with inner and with bottom insulation

If the spaces in a T-beam ceiling are not empty but filled with old lightweight fillings like cinders, these may still have a good insulation effect. But if the spaces are filled with cement, sand or other heavy stuff, no significant insulation effect exists. In this case, the ceiling should be additionally insulated from above or below.


T-beam ceiling opened from the top

The third photo shows a case where the space was filled with cement. The owner then welded hangers beneath the T-beams for fixing wooden laths. These served as a holding construction for new gypsum boards installed 10 cm below the old ceiling. The new space between old ceiling and gypsum boards was filled with 10-18 cm insulation made of mineral wool rolls or slabs. The heat transmission through the ceiling could be reduced by more than 80 %.

If neither insulation from inside nor from below is possible because the space is not empty and the cellar room height too low, the solution is top insulation. This was described in the previous chapter on floor elements.


T-beam ceiling with freshly welded hangers for installing insulation from below

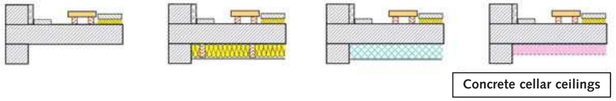
VIII.2.3. Thermal insulation of concrete cellar ceilings

Concrete cellar ceilings have been built since the beginning of the 19th century. Until the 1960s, they were mostly built without insulation layer, resulting in U-values above 2 W/m^2K, cold ground floor temperatures and high heat losses to the cellar. The heat losses and heating costs caused by a 100 m^2 concrete cellar ceiling are comparable to those of sole plates under heated rooms as described and calculated in chapter VIII.1.


Concrete cellar ceiling without insulation. High U-value = 2.2 W/m^2. 10 cm insulation from below can reduce heat losses by 85 %

Advisable is a total insulation thickness of more than 10 cm to achieve low-energy house level.

Whenever the cellar height allows, additional insulation should be installed from below. Typically used are mineral wool mats fixed between laths, covered with gypsum boards from below.



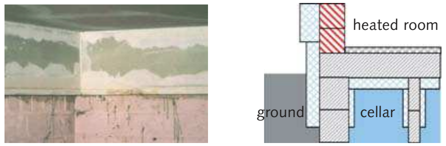
Problems with air or vapour tightness do not usually exist with such cellar ceilings: the concrete functions as a perfect vapour barrier. Gaps around crossing pipes or cables should be checked and closed. When installing bottom insulation in boiler rooms, oil storerooms, cellar corridors or other rooms with open air connection to staircases, the use of non-flammable materials is recommended. Alternatively, the insulation can be covered with fireproof layers to minimize fire and smoke risks in emergency exits. The detailed requirements are defined by national laws.


Insulation from below with 2 x 6 cm mineral wool mats

In addition, thermal bridge effects should be considered when insulating concrete cellar ceilings from below. Cold cellar walls made of concrete or heavy stones in direct contact with the warm (because bottom-insulated) cellar ceiling are significant thermal bridges and can cause high heat losses.


Insulation from below with 12 cm glass wool boards

These can be considerably reduced by installing a flanking insulation layer of at least 4 cm thickness on the upper cellar walls (over a length of 40-50 cm) below the ceiling as shown in the small photo below.

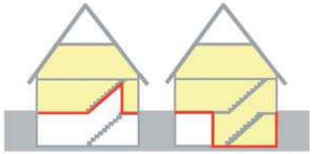


Flanking insulation of upper cellar walls to minimize thermal bridges

Insulation from below with 12 cm polystyrene boards

VIII.2.4. Thermal insulation of inner cellar walls

If unheated cellar rooms are located beside heated rooms or beside staircases open to the heated ground floor, the walls between them are part of the building's thermal envelope. Consequently, heat is lost from the warm to the cold side. The amount depends on wall area, temperatures on both sides of the walls and wall construction. Very often such walls only consist of 12 or 18 cm heavy stones with a plaster coat; their U-values range between 1.7 and 2.1 W/m^{2}K.



Thermal interfaces when the cellar door is located upstairs or downstairs

To minimize these heat losses, the insulation should be improved to U-values of maximum 0.40 W/m^{2}K. This corresponds to new building quality and requires 6-8 cm insulation on a heavy stone wall. The U-value for low-energy houses is 0.30 W/m^{2}K, requiring about 10 cm insulation; for Multi-Comfort houses the U-value is 0.18 W/m^{2}K and requires 16-20 cm inner cellar wall insulation.

The installation of additional insulation on inner cellar walls can be very simple. It takes place in dry surroundings with a temperature not below 5°C on the cold side. Easy to install are polystyrene boards and mineral wool mats glued or screwed on the cold side of inner walls or installed between laths screwed to the walls and covered with gypsum boards. If there is the risk of water flowing into the cellar, the bottom part of the wall insulation (20-30 cm) should be made of water-resistant materials or left uncovered to allow rapid drying of the wet cellar after water attack. When applying additional insulation on the cold side of walls, moisture control will usually be no problem if the insulation surface on the cold side is vapour permeable.

If cellar rooms are heated only irregularly or seldom, it is advisable to apply additional insulation on the warm side of walls. This has a positive effect on the thermal comfort. After turning on the heating, the wall surface temperature rises faster compared to walls insulated on the cold side where the stones must first be heated. Insulation on the warm side needs to consider moisture control aspects and requires installation of a vapour barrier.

In most cases, inner cellar walls are sufficiently airtight – provided they are solidly built and completely plastered (at least on one side). If not plastered on both sides, the airtightness should be checked and improved if necessary. Air gaps are most often found around pipes and cables crossing the inner cellar walls and around chimney access doors.

Thermal bridges often exist where the inner cellar walls meet the cellar floor and the outer walls of heated cellar rooms. The best solution is when the insulation layers of different parts of the building envelope connect directly, without interruption by highly heat-conducting materials such as concrete or heavy stones. The proper insulation of cellar floors, walls and ceilings should therefore be planned in one go.

The calculation of heat losses and heating costs caused by inner cellar walls of different thermal quality is more difficult than for other parts of the thermal envelope. The real temperatures in heated and unheated cellar rooms can be very different, depending on their use and other heat sources in a cold cellar. The values in the following table are valid for a normal heated living room in a cellar, adjoining a really cold cellar with about +12.5°C mean temperature during the heating period.

Heat losses and heating costs of inner cellar walls	Very high energy losses	High energy losses	Insufficient insulation	New house level	Low-energy house level	Multi-Comfort house level
U-values	**2.10 W/m^{2}K**	**1.40 W/m^{2}K**	**0.60 W/m^{2}K**	**0.35 W/m^{2}K**	**0.30 W/m^{2}K**	**0.16 W/m^{2}K**
18 cm walls with ...	heavy stones	brick stones	3 cm 040	8 cm 035	10 cm 035	18 cm 035
Annual heat losses	2,646 kWh	1,764 kWh	0,756 kWh	0,441 kWh	0,379 kWh	0,202 kWh
Heat losses over 40 years	105,840 kWh	70,560 kWh	30,240 kWh	17,640 kWh	15,170 kWh	8,064 kWh
Annual heating costs	185 EUR	123 EUR	53 EUR	31 EUR	27 EUR	14 EUR
Heating costs over 40 years	7,409 EUR	4,939 EUR	2,117 EUR	1,235 EUR	1,062 EUR	0,564 EUR

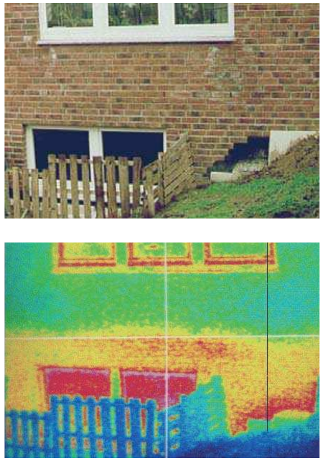
Inner cellar wall area: 30 m^2. Calculated useful life: 40 years. Heating costs: 7 eurocents/kWh (average price in 2006)
The financial benefit of insulation will automatically increase with higher energy prices.

VIII.2.5. Thermal insulation of outer cellar walls

The outer walls of heated cellar rooms are in contact with the ground and outside air. They are part of the building's thermal envelope and transmit heat from the warm to the cold side. The amount of these heat losses depends on wall area, temperatures on both wall sides and wall construction. Very often the outer walls of cellars are made of 36-50 cm thick heavy stones or 25-30 cm concrete. Without insulation layers they have U-values between 2.0 and 3.5 W/m^{2}K – three to five times higher than those of normal outer walls.

The temperature difference between the two sides of these walls depends on the depth of the ground covering the wall from outside. Additional insulation of the upper part of outer cellar walls is therefore essential because they are either in direct contact with the outside air or 40 cm below ground level (see photos).

To minimize heat losses through the outer walls of heated cellars, their insulation should be improved to U-values of maximum 0.40 W/m^{2}K. This corresponds to new building quality and requires 6-8 cm insulation on heavy



Heat losses caused by the uninsulated outer walls of a heated cellar

Additional insulation of outer cellar walls: only above ground (first step)

Additional insulation of outer cellar walls when replacing the waterproofing layer

stone walls. The U-value for low-energy houses should not exceed 0.30 W/m^{2}K, requiring about 10 cm insulation. Multi-Comfort houses with about 0.18 W/m^{2}K require 16-20 cm insulation when using materials of 0.035 W/mK heat conductivity.

Additional insulation of outer cellar walls can best be installed from outside and should be made of water- and pressure-resistant polystyrene (XPS). Precondition: the walls are freely accessible.

A good opportunity is when the waterproofing layer of outer cellar walls needs to be reinforced. The photo on the left shows the exposed walls after excavating the ground. If this is not necessary, insulation from inside may be advisable. Since walls in contact with the ground are subject to a higher water risk than walls in contact with the air, water-resistant insulation materials should always be used. In addition, measures should be taken to allow moisture to dry out.

The airtightness of outer cellar walls is usually good and needs no reinforcement since also the externally applied waterproofing layers are usually airtight. Only old cellar windows and outer doors are often untight.

The calculation of heat losses and heating costs caused by outer cellar walls highly depends on the real temperatures inside heated cellar rooms and on the outer environment. The data in the following table apply for a normal heated living room in a cellar. 80 % of its walls are located below ground; the upper 20 % are in contact with outside air.

Outer cellar walls 80 % contact to ground, 20 % to outside air	Very high energy losses	High energy losses	Insufficient insulation	New house level	Low-energy house level	Multi-Comfort house level
U-values	**2.80 W/m^{2}K**	**1.80 W/m^{2}K**	**0.44 W/m^{2}K**	**0.35 W/m^{2}K**	**0.30 W/m^{2}K**	**0.18 W/m^{2}K**
36 cm walls made of	concrete	heavy stones	+6 cm 035	+8 cm 035	+10 cm 035	+18 cm 035
Annual heat losses	9,100 kWh	5.850 kWh	1.430 kWh	1.138 kWh	0.975 kWh	0.585 kWh
Heat losses over 40 years	364,000 kWh	234,000 kWh	57,200 kWh	45,500 kWh	39,000 kWh	23,400 kWh
Annual heating costs	637 EUR	410 EUR	100 EUR	80 EUR	68 EUR	41 EUR
Heating costs over 40 years	25,480 EUR	16,380 EUR	4,004 EUR	3,185 EUR	2,730 EUR	1,638 EUR

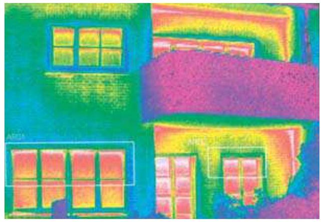
Outer cellar wall area: 30 m^2. Calculated useful life: 40 years. Heating costs: 7 eurocents/kWh (average price in 2006)
The financial benefit of insulation will automatically increase with higher energy prices.

IX. How to reduce heat losses through thermal bridges

A lot of additional heat can be lost through so-called "thermal bridges". These are parts of the thermal envelope where materials of very high heat conductivity pass from the in- to the outside. Also the special geometry of parts can cause more heat to flow. The photo on the right shows a typical house of the early 1970s with a lot of concrete elements, passing from the warm to the cold side like cooling ribs. The thermographic picture shows the different surface temperatures of a house built in the 1960s. The lack of thermal insulation around balconies, window frames and on the thin outer walls behind radiators is clearly visible. The diagram below sketches the thermal envelope of a house and the places where thermal bridges are frequently found. Any interruption of the insulation may cause a thermal bridge.

House of the early 1970s with many thermal bridges caused by concrete elements

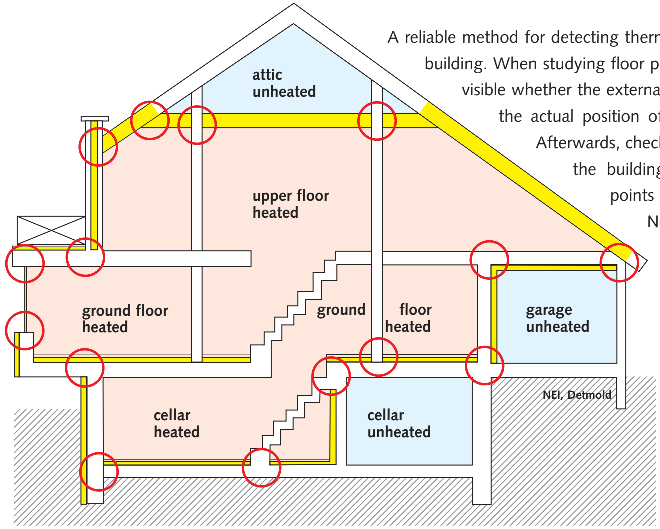
Materials of high heat conductivity are metals, concrete and heavy stones. Thermal bridges in older houses typically include concrete walls passing from the warm room to cold balconies, cold garage roofs, cold terraces or cold concrete platforms in front of doors. Other thermal bridges occur along wall edges, stone windowsills below window frames and very thin walls behind radiators or around roller shutter boxes. Thermal bridges are not only found in solidly built houses, but also in timber frame houses despite the fact that fewer heat-conducting materials are used.



Thermography shows the higher surface temperatures near thermal bridges

Critical points: interruptions of the insulating shell.

A reliable method for detecting thermal bridges is to graphically capture the building. When studying floor plans and sectional drawings, it becomes visible whether the external insulation shows any gaps. First, mark the actual position of the installed insulation layers yellow. Afterwards, check in which places the yellow line around the building is interrupted. These are the weak points where potential thermal bridges occur. Next, it must be carefully considered if they are structurally avoidable. If not, solutions must be found so that they can be minimized. Every insulation gap is a thermal bridge that negatively affects the energy balance and can lead to structural damage.

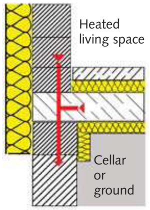


Check for thermal bridges where the yellow insulation layer is interrupted.

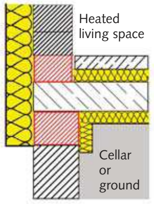
The comparison shows: There is always a good or even excellent solution to avoid thermal bridges.

Thermal bridges between cellar floors resp. base slabs with strip footing and external walls

With a single-leaf outer wall and a cellar floor or sole plate insulated from above or below

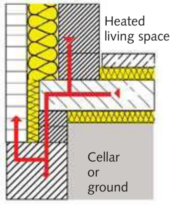


Insufficient if support of ceiling on cellar outer wall resp. strip footing and the support of warm internal wall ground floor has been installed without thermal separation using a material with λ > approx. 0.12 W/mK.

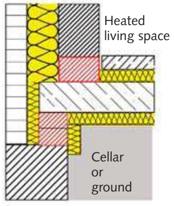


Good if both supports have been produced from a material with λ < approx. 0.12 W/mK.

With an external cavity wall and a cellar floor or slab to the ground insulated both from above and below

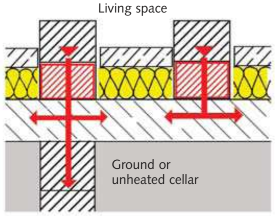


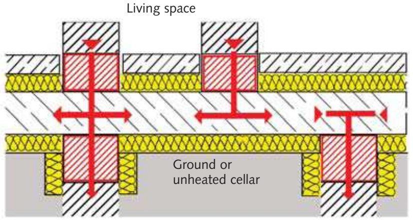
Insufficient if support of ceiling on cellar outer wall resp. strip footing and the support of warm internal wall ground floor has been installed without thermal separation using a material with λ > approx. 0.12 W/mK.



Good if both supports have been produced from a material with λ < approx. 0.12 W/mK.

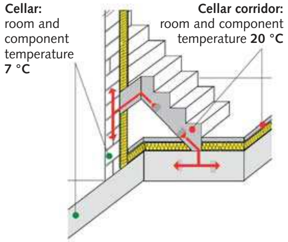
Thermal bridges between cellar floors or base slab and inner walls



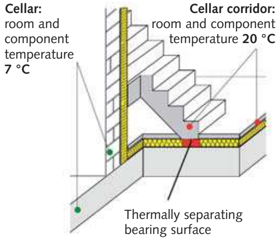


Here, the same applies as shown above for the outer walls.

Thermal bridges between stair flights and thermally separating walls or base slab



Insufficient:
Thermal bridges between the bearing surface of the warm stair flight and the cold base slab (cold because of its upper side insulation) and between the warm lateral flank of the stairs and the cold cellar wall (cold because of its room-facing insulation).

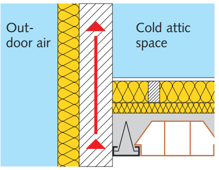


Good: Thermal separation between the bearing surface of the warm stair flight and the cold base slab by using a foundation stone of low thermal conductivity and by installing continuous insulation to ensure complete separation of the stair flight from the cellar wall.

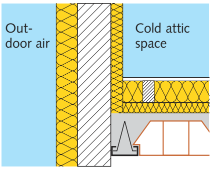
Source: Niedrig-Energie-Institut (Low Energy Institute), Detmold, Germany

Thermal bridges on vertical cold-warm wall breakthroughs

External walls

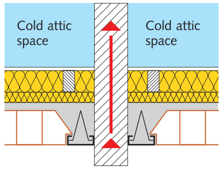


Insufficient: Thermal bridge caused by the external wall passing from a warm to a cold area with brickwork of λ > 0.12 W/mK.

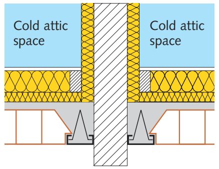


Good: Either interruption of a vertical wall with high thermal conductivity at the same height as the insulation of the penetrating ceiling by installing a thermal separation layer using a material with λ < 0.12 W/mK (gas concrete, foam glass, PUR etc.) or flank insulation to approx. 60 cm height inside the external wall in the cock loft.

Internal walls

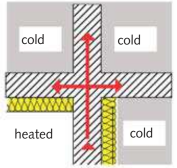


Insufficient: Thermal bridge caused by the external wall passing from a warm to a cold area for brickwork with λ > 0.12 W/mK.

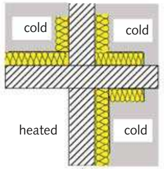


Good: Either interruption of a well heat-conducting vertical wall at the same height as the insulation of the penetrating ceiling by installing a thermal separation layer using a material with λ < 0.12 W/mK (gas concrete, foam glass, PUR etc.) or flank insulation to approx. 60 cm height inside the external wall in the cock loft.

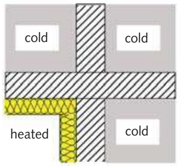
Thermal bridges on horizontal cold-warm wall breakthroughs



Unsatisfactory: The walls have been insulated partly on the warm and partly on the cold side. However, individual wall junctions pass right through.

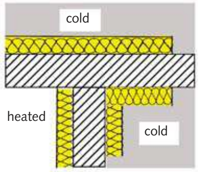


Satisfactory: All walls have been insulated on the cold side. Additionally, sufficient flank insulation has been installed on all wall junctions facing the cold side.

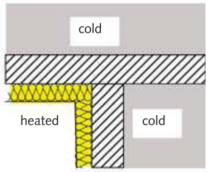


Excellent: The insulation layers interconnect without any interruption..

Thermal bridges on horizontal cold-warm wall junctions

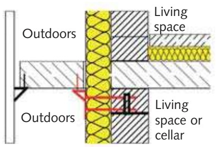


Satisfactory: Both walls have been insulated on different sides. In addition, sufficient flank insulation has been installed on the wall junction.

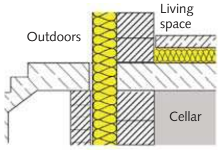


Excellent: Both walls have been insulated from inside and the insulated areas directly adjoin each other.

Possible solutions to thermal bridging on balconies, landings and overhanging ceilings



Good: Only point support of balcony or landing slabs on small steel brackets and additional support by free-standing columns in front of the house. If the cross sections of the metal penetrating the thermal envelope are small, there will only be few thermal bridges.



Excellent: Completely separated construction with a separate support of the landing (see picture) or of the balcony. This is a truly thermal bridge free solution.

Thermal bridge caused by wooden rafters without insulation above or below

The stripes formed by melting snow on the roof illustrate a thermal bridge effect. It is caused by the different heat conductivity of the wooden rafters and the insulation material used for the space in-between. This can happen if roofs are only insulated between but not above or below the rafters. When installing an additional overall insulation layer of just 6 cm on one roof side, the snow would stay longer and melt more regularly. Apart from unwanted heat losses, thermal bridges also cause lower surface temperatures inside. This may lead to higher vapour condensation and trigger mould growth as shown in the second photo.

Mould in the corners of a bathroom caused by a geometrical thermal bridge to the cold outside

The photo shows a bathroom with a typical geometrical thermal bridge. Here, the inner wall corner is smaller than its outer surface. The warm air inside the room does not heat the corner; instead, the corner is cooled down by the outside air. To prevent the condensation of vapour and formation of mould, corners either need special heating or better outer insulation. It goes without saying that these measures are important for the indoor climate.

Reduced thermal bridges on a cellar ceiling by extending the insulation (6 cm thick) to the upper part of the walls (50 cm)

The photo on the left shows how the additional thermal insulation of cold walls flanking a cellar ceiling can reduce thermal bridges. If the new insulation were merely installed under the ceiling, all adjoining cold cellar walls would have thermal bridges to the now "warm" ceiling. The flanking insulation of the upper 50 cm of cold inner and outer cellar walls can reduce this effect by about one half.

Reduced thermal bridges around a cellar window by insulated soffits (4 cm)

When insulating the outer walls of the ground floor from outside (above an unheated cellar), the insulation should extend by 50 cm below the level of the cellar ceiling. In addition, the inner and outer soffits of the cellar windows should be insulated (minimum 4 cm) as shown in the fourth photo. In this way, the former thermal bridge between cold cellar walls, warm ceiling and ground floor walls can be reduced by more than 80 %. It is advisable to always install flanking insulation on connecting cold elements if concrete slabs or beams protrude like cooling ribs into the cold outer air or into a cold cellar.

Reducing the thermal bridge of a concrete balcony by applying 6-8 cm insulation on both sides

Reducing the thermal bridge of a concrete beam in a cold loft by 10 cm flanking insulation

Reducing thermal bridges around a window when insulating the outer wall

The photo on the left shows the flanking insulation of a concrete balcony. The photo below shows the flanking insulating of a concrete jamb wall that directly connects to a new "warm" one: the concrete floor of the loft was insulated from the top. The last photo shows the connection between a newly insulated outer wall and an old window. To reduce thermal bridges, the former "nose" of the wall outside the window was cut off to provide space for 4 cm soffit insulation. Later, the window frame will be directly connected with the outer wall insulation. Only the stone windowsill will remain a thermal bridge between the warm wall and the wooden window frame.

Old houses are abundant in structural details that cause thermal bridges. What they need is an uninterrupted insulation layer. The best way to reduce thermal bridges is full-surface insulation, usually on the cold side. If this is not feasible, partial insulation and flanking insulation of cold components helps reduce the losses. Only if high heat losses cannot be eliminated by other means can inner surfaces be warmed directly to avoid humidity, mould and damage to moisture-sensitive materials.

To the point:

Geometrical and structural thermal bridges.

- *Geometrical thermal bridges are negligible as long as the exterior insulation is sufficiently dimensioned and continuous.*
- *Structural thermal bridges must be avoided or at least be minimized.*

This applies in particular to:

- *Thermal bridges on floor slabs and cellar floors*
- *Thermal bridges on stairs*
- *Thermal bridges on the upper edges of walls in the roof area*
- *Thermal bridges on cold-warm wall breakthroughs*
- *Thermal bridges on balconies, landings, projecting building components*
- *Thermal bridges on windows and roller shutter boxes*
- *Thermal bridges that repeatedly occur within a building component (rafters, lathwork, anchoring elements etc.) must be considered with respect to the U-value of the building component concerned. These structural details are referred to as inhomogeneous building components. Apart from causing high thermal loss, they can also result in structural damage. However: inhomogeneities in a brick wall behind a continuous insulation layer (e.g. a ceiling support) can be neglected if the insulation has been sufficiently dimensioned.*

X. How to reduce heat losses caused by airflows

Heat losses caused by airflows can account for a big share of a building's total heating demand as already partially described in chapter III.3. Airflows can be divided into three groups:

1. Airflows caused by manual or mechanical ventilation
2. Airflows caused by leaks in the building shell,
   moved by wind and thermal effects
3. Airflows caused by the fresh air supply of chimneys, fireplaces and other
   heating systems that are installed inside the heated part of the building
   and draw air from heated rooms.

This chapter describes the possibilities of reducing excessive heat losses caused by airflows.

Mechanical temperature and humidity meters

X.1. Heat losses caused by opening windows and doors

Small electronic temperature and humidity data logger with USB connection to computer

Visualized recording of temperature and moisture measurements

To start with, heat losses caused by manual ventilation can be reduced by more efficient handling of windows and doors. It is a well-known fact that human beings have only poorly developed sensors for the indoor air concentrations of oxygen, carbon dioxide, vapour and other air ingredients. However, one should not only respect people's subjective need for ventilation, but also use more reliable sensors. Small temperature and moisture meters provide information on the effects of shorter or longer ventilation and can be easily placed in living, sleeping and bathrooms. They are most useful in rooms that require moisture control and are inexpensively available in drugstores and photoshops. Watching the measured values over some time will give you a good feeling for the proper handling of manual ventilation.

If this type of control is found to be unsatisfactory or if manual recording is too laborious, small sensors with integrated data loggers can be used as shown in the second photo. They run on microbatteries for more than 100 days. They record the values every minute or every five minutes and can export the data via USB cable to computers into preformatted tables (see third photo). This data can be further processed with MS Excel™. Such small combined temperature and moisture loggers are available for about 50 euros in electronic shops.

Apart from stopping unnecessary ventilation, ventilation heat loss can be reduced to just 10 % of proper manual ventilation by mechanical ventilation systems. This is possible, because these systems offer two additional energy-saving features that windows don't offer: controlled, directed airflows and heat recovery.

Multi-family house of the 1970s with added mechanical ventilation

Fresh air inlet valve beside a window

Exhaust valve for used air in a bathroom

Central exhaust ventilator in the cellar, adapted to the air chimney

Directed airflow means that the distribution of fresh air in the house is no longer influenced primarily by open windows, doors, wind pressure and thermal effects. Instead, it is controlled by ventilators and precisely dimensioned outer and inner openings and air channels. Fresh air will only flow into so-called "fresh air rooms". These include the living, sleeping and children's rooms as well as the offices in commercial buildings. From there, the same air continues to flow through transit rooms which have a slightly lower demand for good air quality. Such transit rooms are for example corridors and staircases.

The same air volumes finally flow into the exhaust rooms which have the lowest demand for fresh air. Here, the highest concentrations of odour and humidity need to be removed. These typically include kitchens, bathrooms, toilets or other utility rooms where for example laundry is washed and dried. This mechanically enforced, well-directed airflow through the different air quality zones ensures that one unit of fresh air successively does three jobs: supply fresh air, ventilate middle rooms and draw off odours and moisture.

If the ventilation of these rooms were done by opening the windows, triple air volumes would be required for producing the same ventilation effect. The result: higher heat losses in the cold season. It is obvious that mechanically controlled airflows in a house can already save a lot of energy, because they reduce the air exchange rate. In old houses with moisture control problems, simple exhaust systems combined with well-controlled fresh air inlets both save energy and provide the necessary drying effect. In addition, they enhance comfort since manual ventilation discipline is no longer required. Energy savings of 20-40 % can be realized if good system components with sufficient volume control and efficient ventilators with DC motors are used.

The photos on the left show a house built in 1965 with typical energy costs and increased mould problems after installing new, tight windows two years ago. Here, fresh air is sucked in through valves located in outer walls beside the windows in all fresh air rooms. Used air is exhausted from kitchen and bathroom. An empty chimney between kitchen and bathroom is used for collecting this air. In the cellar, one central ventilator exhausts all air to the outside. Mould problems were solved and the air quality was raised. In addition, the amount of fresh air needed for a hygienic climate is lower than before when all windows had to be opened separately.

City house with bad conditions for ventilation via front windows

Fresh air supply is now from the garden side

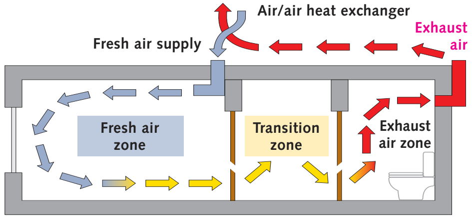
Fresh air pipes under textile-covered corridor ceilings

Ventilation system with 90 % heat recovery accommodated in the toilet

Advanced possibilities for reducing heat loss through ventilation exist when heat recovery systems are used in addition to mechanically directed airflows. These systems cool the outgoing used air down to near outer air temperature and use the gained energy to preheat the fresh air by heat exchangers. In Central Europe, the mean outdoor air temperature in winter is about +5°C whereas the mean indoor air temperature is about +20°C. Possible gains by heat exchangers are between 50 and 85 % of this temperature difference. The photos show a house built in 1930, located at a street corner with a lot of traffic during the day. Opening the windows was no longer possible due to traffic noise and exhaust gases. In 2005, the owner invested in a mechanical ventilation system with highly efficient heat recovery. It takes in fresh air from the garden side and distributes it to all living rooms via pipes installed under the ceiling of corridors. The ventilation system is installed in a small toilet room. Now, the air quality is much better, air supply is silent and energy savings are considerable. The flats can be let again and achieve a good rent.

The Comfort Ventilation System controls heating and ventilation in one breath.

The ISOVER Multi-Comfort House doesn't need a boiler room. A compact ventilation unit the size of a fridge is totally sufficient to supply all rooms with fresh air and cool or heat while at the same time removing the consumed air. How does it work? The central unit comprises a heat exchanger, fans, filters, air cooler, air pre-heater and air humidifier or dryer. Stale air from kitchen, bathroom and WC is removed via the exhaust air system. Before being routed outdoors, the heat exchanger adapts the incoming fresh air to near room temperature. Today, heat recovery rates of up to 90 % are possible.



Simplified ventilation system

Features of a passive house conforming ventilation system

As it requires only little space, the ventilation unit can be accommodated in a storeroom or even in a cabinet.

- Performance: At a maximum air change rate of about 0.4 per hour required for hygienic reasons, the ventilation system can contribute max. 1.5 kW energy to a residential building of 140 m^2 via the fresh air (when maintaining the max. supply air temperature of 51°C).
- Short duct lengths
- Duct dimensions: larger than 20 x 20 cm for main ducts, larger than 15 x 15 cm for branch ducts
- Acoustic insulation of the central unit. Install sound-absorbing ducts such as CLIMAVER. A noise level of 20-25 dB(A) should not be exceeded for living space.
- Easy maintenance, e.g. when changing filters and cleaning the unit
- The system can be easily adapted to your needs, e.g. switch off the incoming air fan when opening the windows, bypass for summer use.

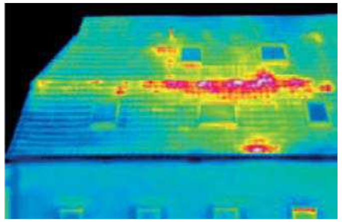
X.2. Heat losses caused by leaks in the building shell

Uncontrolled airflows through wind gaps in the building shell are the second most frequent cause of ventilation-related heat loss. The first photo on the right shows the thermal effect of a leaky connection between lower and upper roof, the second photo of an untight connection between front wall and roof. The outcoming heat is clearly visible by the yellow and red colour.

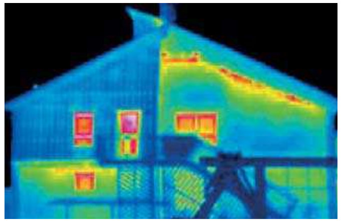
People often believe that the cracks and gaps typically found in the building shell support the wanted air exchange. This is generally true, but the negative effects are often underestimated. These are the three most important problems caused by this kind of air exchange:

a) The airflow volumes are uncontrollable. They are influenced by irregular wind pressure and thermal buoyancy that depend on variations between indoor and outdoor temperature. As a result, there can either be too little or too much air exchange. Neither the minimum supply of fresh air can be guaranteed nor too high losses be prevented.
b) The outgoing warm air transports vapour into all cracks and gaps. This can cause moisture damage in sensitive components of the building shell.
c) The incoming cold air can cause uncomfortable cold drafts in the rooms, especially on ground floor level.

In order to avoid these problems and ensure controlled air exchange, old houses should be sealed as airtight as possible. The required ventilation should be actively controlled (window opening) or preferably provided by mechanical systems. When planning thermal renovation, the tightness of the building shell should be analyzed and improved if necessary. The following chapters explain where the most frequent leaks are found.



Heat losses through an air-leaky connection between lower and upper roof



Heat losses through an air-leaky connection between front wall and roof

Airtight foil not connected with the wall.
A 5 cm wide strip around the roof is untight.

X.2.1. Leaks in roofs and ceilings

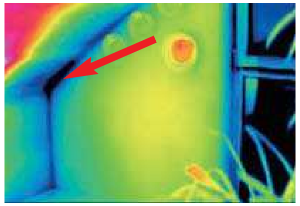
Leaky components in roofs and ceilings can cause high heat losses. In the cold season, the warm air in the upper rooms of a house is under a slight overpressure due to thermal buoyancy. This causes the warm air to flow out through small gaps in the roof. Gaps in roofs and ceilings are usually caused by untight sealing foils or gypsum boards in heated rooms. The photo on the left shows an airtight aluminium foil under a pitched roof ending 5 cm before the wall surface. This untight area can cause high air leakage and is typically found in roofs built between 1970 and 1995.

Insulated and airtight hatch leading to an unheated loft

In the case of ceilings under unheated lofts, two additional air leaks often exist: the hatch and installations inside the ceiling. Old hatches were often installed without a sealing lip and can therefore become warped. Their frame was never properly connected with the plastering on the bottom of the ceiling or another airtight layer. Usually, their lid is not insulated. Because of the space needed for the folding ladder on the lid, it is often not possible to sufficiently insulate the lid.

For this reason, it is often better to leave the bottom of the old lid as it is and to add insulation on top (see photo). Here, the lid is made of chipboard with a thick insulation layer glued on top. Airtightness is ensured by a wide soft foam stripe (black) around the opening. In addition, an airtight connection to the plastering on the ceiling bottom can be provided by using foils or chipboard. Constructions like this need a folding ladder that does not project into the airspace of the loft when the hatch is closed.

Cold airflows through this leaky slot can significantly cool down room corners. This is visible in the thermographic picture below.



Cold room corner caused by untight connections between walls and roof

In old houses, the sealing layers in insulated but not fully converted lofts can be damaged by later installations. This results in very high heat losses.

Damaged and not repaired airtight foil in a roof causes high heat losses

When snow melts irregularly on a roof, this is a sign of leaks in the roof's airtight layer or insulation with thermal-bridge and should therefore be checked and remedied.

Irregularly melting snow on a roof is an indicator of air leakage or thermal bridge

Holes in a loft ceiling not closed after installing a recessed luminaire

It often happens that the airtight layers of old ceilings are damaged when electrical or other installations are repaired or newly installed. The photo on the left shows a recessed luminaire that was later installed. The plastered wood-wool boards of this ceiling had been equipped with a well-functioning airtight layer for 50 years. Later, decorative panels with six integrated lights were installed under the old ceiling. To provide access for the cable installation from the loft side, holes were broken into the airtight wood-wool boards but not closed. These holes now form a permanent air connection between the heated rooms below and the unheated loft.

Missing connection between roof window frame and airtight foil

A frequent air leak in roofs exists around improperly installed windows as shown in the second photo. The roof window was newly installed when the roof was additionally insulated from the room side. When taking the photo, it was noticed that there was no continuous airtight layer: the blue foil was on no side connected with the window frame. This would have resulted in an enormous air leak.

It is sometimes argued that gypsum boards later installed from inside guarantee sufficient airtightness. But this argument does not hold since there are many places where the room air can flow behind the gypsum boards. If the planned airtight layer of the roof is a foil like here, it must be connected to all adjoining airtight layers (walls, concrete ceiling, window frames etc.). Two incomplete layers laid on top of each other will never provide sufficient tightness. The third photo shows an untight roof window frame: the lack of tightness is made visible with artificial smoke and overpressure inside the house.

Untight roof window frame – made visible with artifical smoke

Inner plastering of the outer wall is missing on wooden ceiling level (here opened)

X.2.2. Leaks in walls

Air-leaky walls are less frequently found with solidly built houses whose brick walls are plastered on one or both sides. Usually, the plaster (not the stone) layer is sufficiently tight. Only unplastered areas can cause air leaks. These often exist on ceiling level (see photo), in the wall areas behind bathtubs and in wall installation channels. Outer walls with old framework construction are seldom airtight. The size of joints between the frame and the compartment filling changes with the seasons due to different thermal expansion and swelling caused by moisture. Such walls will only become airtight when the inner sealing layers are applied over the full wall surface and also on ceiling height.

Cracks and gaps are often not visible

Cooling effect of an untight front door frame

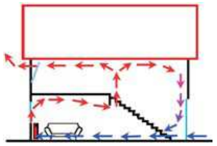
Candles make cold airflows visible

Also the additional outer insulation of such walls does usually not provide the required effects: often these insulation systems are themselves not airtight enough. Since cracks and gaps in walls are often long, thin and not easily visible, a visual check of wall tightness is mostly insufficient. Chapter X.3. later describes how to find such gaps.

X.2.3. Leaks in windows and doors

It is a well-known fact that there are air leaks around old windows and outer doors. Their replacement is often triggered by the residents' discomfort when being exposed to cold airflows in winter. The two photos on the left show the effects of an untight front door. If the sealing between frame and leaf is untight, this causes a large area of the corridor floor and half of the door leaf to cool down. The same effect can occur with a cellar door, separating an unheated cellar from the heated ground floor. Caused by thermal buoyancy, there is a slight underpressure in the lower area of a house in winter. Cold air from outside or the cellar is permanently sucked in. If there is no radiator or convector located directly beside such gaps, cold airflows can move along the floor (up to 10 meters), thus cooling down large floor areas. Cold floors on ground floor level result not only from poor insulation, but also from continuous cold airflows that are only stopped by a heat source. If the finger test is not sufficient, a row of tealights distributed on the floor can help find cold airflows and their sources.

Untight windows and doors should be equipped with seals or completely replaced when they are past repair. A single seal can already guarantee sufficient airtightness if installed all around. It must be soft and large enough to fill gaps of different width depending on the season (cold, hot, wet or dry). Two or three seals installed all-round provide additional thermal insulation in the joint between frame and casement. The next four photos show door sealing variants. On the left a primitive wooden door without sealing: it is neither airtight nor thermally insulating. Such outer doors of heated rooms should be replaced. The second a newer front door with one all-round seal and a very large door strip seal.



Cold airflow from the front door crossing the entire ground floor

Without seals

Door strip sealing

Triple sealing

Simple brush seal

The third photo shows a well-insulated front door with triple seals, the fourth an old iron back door. The largest gap of 1.5 cm height at the doorsill has been reduced by a simple, low-cost brush seal. But without all-round sealing this door still lacks tightness.

The next photo shows the freshly renovated covering and door of a cellar stairway. It looks nice but is not at all airtight: neither the gaps between door frame and leaf nor the wooden steps to the first floor. Such a nicely designed covering can be well insulated from the front or from the upper stair side. There are two options to ensure airtightness to the cellar: either insulate the inner (lower) surface and fully cover it with a sealing foil, or install an additional tight door at the bottom of the stairway so that the upper door is only decorative. This option is often cheaper and works better. In houses with several heated flats and an unheated shared staircase, the hall door of each flat should be airtight in order to ensure heat, odour and noise protection. Too light construction of these doors often causes tightness problems (see the ghost marking in the photo). Usually, the gaps between frames and ceilings or walls can be well sealed with special strips. However, the possibility of sealing gaps between frames and leafs should be checked by a building joiner. These wooden parts are often so warped that only complete replacement can ensure sufficient tightness. When replacing them, pay attention to good sound-insulating qualities of construction, sealing and glass.

Looks nice but is untight

Untight hall door to staircase

After installing new windows into an old house, there should be no more air leaks between glass, leaf and frame. But often window installers do not properly seal the gap between frame and surrounding wall. Professional installers, calculating their prices under high competitive pressure, know exactly how much extra work the proper sealing of a newly installed window in an old wall can involve. For example when a lot of old plastering was broken out. If the text for tender only says "furnish and install", possibly "decorate with cover strip" but does not specify "outside waterproofing and inside air- and dampproof", you should not expect complete work. In this case, ask for more details and for an all-inclusive price before placing the order.

Foam-filling of the new window installation gap is not sufficient. The connection between window frame and wall must be airtight and vapour-retarding all around.

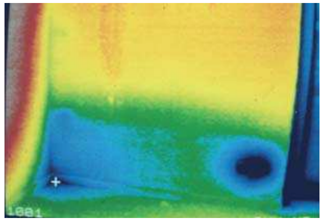
The installation gap between window frame and wall should be completely filled with a water-resistant thermal insulation material. This reduces thermal losses by heat transmission through the gap. PU foam is often used for this purpose; impregnated mineral wool and cork are also suitable. In general, materials that remain slightly elastic over time are preferable over hardening materials such as PU foams. The reason is that this gap is a small contraction joint: it tends to open in winter and close in summer because of the different thermal expansion of windows and walls.

Airtight plastering in good condition under a T-beam arch brick cellar ceiling

X.2.4. Leaks in parts of the cellar

Air leaks between an unheated cellar and a heated ground floor are also often caused by an untight cellar ceiling. While concrete cellar ceilings are generally tight, wood and T-beam ceilings with arch bricks tend to be untight if no airtight layer was installed from the bottom over the complete ceiling area and connected with the adjoining walls over its full length. Such ceiling constructions are described in more detail in chapters VIII.2.1 and VIII.2.2. If originally an airtight wooden or T-beam cellar ceiling with wooden flooring on top had been planned, it was usually realized by applying a full-surface plaster coat from below. This functions well over a long time. But its air-sealing function was not explained to later residents of the house. They often saw it merely as a decorative layer and perforated it when working on the cellar ceiling. Repair of the damaged plastering by closing the holes can easily and effectively improve the airtightness of the house.

If wooden cellar ceilings do not have a plastering layer on the underside and must first be air-sealed as part of thermal renovation, it is important to also consider moisture control aspects. If the wooden cellar ceiling contains or will be filled with insulation material to reduce heat loss to the cellar, the required air- and vapourtight foils cannot be installed on the cold (lower) side of the ceiling. This would prevent the downward drying of vapour. It is possible to use either a very diffusion-open material (gypsum boards or building paper) or to install this layer on the warm upper side of the insulation. The vapour-retarding quality is important but depends on the humidity of the cellar in the warm and cold season.



Cold area around the untight cable penetration of an outer wall

X.2.5. Leaks caused by installation channels and penetrating pipes & cables

In all parts of a building's airtight envelope, leaks can be caused by installation channels and leaky holes around pipes and cables that cross the tight layers without adequate sealing. Major leaks are often due to installation channels running from the unheated cellar through the ground and upper floors up to the unheated loft and out through the roof. Most installers of heat, gas or water pipes or of electrical and telecommunication cables neglect the need for airtightness: they leave as soon as their installed system runs. The need for an uninterrupted airtight layer around the heated parts of a house and for individual sealing of all penetrations is even underrated in newly built houses – and the more so in the renovation of old houses. Therefore these leaks continue to exist and contribute highly to ventilation heat losses.

Well-sealed pipes crossing a cellar ceiling

The photo on the left shows the well-sealed penetration of an old cellar ceiling. Fresh and waste water pipes were newly installed with an elastic covering that protects against sound transmission. If a satisfactory level of airtightness is to be achieved, a plan should first be made showing where the airtight layers are. After identifying the leaks, suitable sealing measures should be taken that ensure real tightness and not simply redirect unwanted airflows through neighbouring holes.

Open fireplace drawing fresh air from the room. It causes high ventilation heat losses regardless whether a fire is burning or not.

X.2.6. Heat losses caused by the fresh air need of fireplaces and chimneys inside heated rooms

A big airtightness problem is caused in old houses when fireplaces or chimneys have the required air opening inside a heated room. The required combustion air comes from outside, is very cold in winter and flows from any open window or gap in the building envelope through the heated room, thus causing uncomfortable cold airflows on the floor. Men sitting cosily in front of a fireplace will often get cold feet while having hot knees. Not only the comfort but also the heating effect is reduced. If fireplaces do have not airtight bodies to the room when no fire is burning, heat is permanently lost by the unwanted natural ventilation through the chimney buoyancy. When new houses in Germany are equipped with fireplaces in the heated part of the house, they are no longer allowed to take their fresh air from the room. This minimizes unwanted heat losses as well as fire and exhaust gas related risks. In old houses, open fireplaces should always be closed with fireproof metal or glass bodies and equipped with separate airchannels, if possible.

Air leak test with artificial smoke and overpressure

X.3 How to measure untightness and detect hidden leaks

If a house is to be renovated and the position and importance of assumed air leaks is not sure or undetectable by visual inspection, only two methods can be employed. With a Blower Door fan installed in an outer door or window, a negative pressure of 50 Pascals can be produced. As a result, the outer air flows at high speed through all gaps of the building envelope. Also at small gaps these airflows can easily be felt with a finger. If gaps are not accessible, airflows through untight gaps can be visualized by blowing artificial smoke into a house and producing overpressure with the help of a fan. In calm weather, the outcoming smoke is well visible on facades or roofs and helps detect leakage. If the level of airtightness is to be determined, the Blower Door Test can measure the airflow needed to keep a constant pressure difference of 50 Pascals. This value in relation to the inner volume of the house is today's indicator of airtightness.

The outcoming smoke shows air leakage on a roof

The outcoming smoke shows air leaks on a historical facade

Good planning for all building types

Whether solid, lightweight or timber construction – the selected building style requires different concepts for the planning and execution of the airtight barrier. It is therefore imperative at the planning stage to work out a detailed overall concept of airtightness, including all connections between structural components, wall junctions and penetrations. For timber constructions it is recommended to provide a separate installation layer on the room-facing side of the vapour barrier to reduce the number of penetrations through the airtight layer.

ISOVER VARIO KM Duplex ensures airtightness in keeping with the highest passive house standard.

The flexible climatic membrane adjusts itself to the seasons. In winter, humidity penetrating from inside is blocked. In summer, ISOVER VARIO KM Duplex allows the released water vapour to escape in all directions. This means:

- Ideal vapour barrier function against the ingress of moisture in roof and walls
- Maximum security for the building
- Excellent comfort of living.

To the point.

These are the requirements to be met by the materials:

- *Airtight materials for the surface area, e.g. membranes, roofing felts, panels, plasters*
- *Carefully matched and compatible materials, especially sealing membranes and adhesives*
- *Moisture-, UV- and tear-resistant materials*
- *Vapour diffusion resistant materials (act as vapour barriers): in regions with cold winters, the airtight barrier is always installed on the warm side of the structure, i.e. facing the interior.*

When penetrating the airtight layer, make sure to provide a leak-tight seal of the connections.

Good to know before starting work.

Nothing is more important for renovation than the careful execution of the building envelope. For this reason, the chosen materials must always be employed under optimal conditions. This means in particular:

- Joints must only be sealed in dry weather.
- Substrate and joint flanks must be dry and free of dust.
- All junctions between adhesive tapes and porous materials must be pre-treated with a primer.
- For structural reasons, joint sealing tapes must also be able to prevent the penetration of water and moisture.
- Larger expansion joints can be sealed with VARIO KM FS (mineral wool joint tape).

The earlier the better: checking the airtightness.

The airtightness check is essential for ensuring a building's airtightness. It must always be carried out before completion of the inner surface of the building envelope so that any faulty workmanship can be detected in good time and remedied at relatively low cost.

The Blower Door Test is used to detect any leak in the building envelope. The lower the measured value, the higher the airtightness. Passive houses require a value of 0.6. This means: during the measurement, at most 60 % of the indoor air volume is allowed to escape through leaky spots within one hour. Experience has shown that values between 0.3 and 0.4 are attainable.

XI. Ways to maximize renovation efficiency

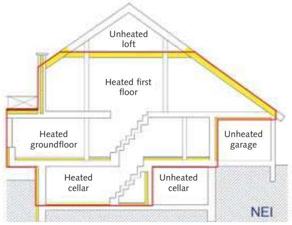
In order to achieve the highest possible reduction of heating energy and costs with a one-time investment, thermal renovation of an old house should be carefully planned. These are the **five planning steps** described in this chapter:

- Analyze energetically weak spots
- Define quality standards for the components to be renovated
- Find technical interdependencies of possible measures
- Clarify what needs to be done immediately and what can be done later
- Set up a time and work plan

To analyze a building's heat losses, it must first be clarified where the thermal envelope runs. This means: Which rooms are usually heated, which are unheated? Heated does not mean that heating equipment is installed, but that it is used and that the room temperature is normally above 18°C. The thermal (heat-transmitting) envelope can be defined around these rooms as shown in the first diagram.

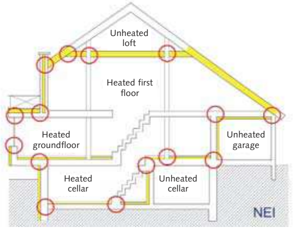
XI.1. Analyze energetically weak spots

This house, for example, has heated and unheated cellar rooms, an integrated unheated garage on ground floor level, an unheated loft and a projecting oriel where ceiling and floor are exposed to outdoor air. The red line shows the external outline of its thermal envelope. The exact locations of existing or planned insulation layers are shown in yellow. Such a diagram helps detect weak spots and develop an overall renovation plan.



Parts of the heat-transmitting envelope

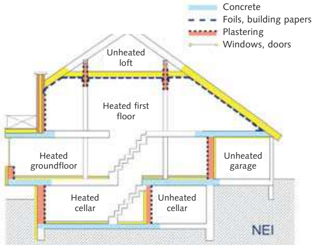
When planning new insulation layers, any existing and newly produced thermal bridges should be considered. The red circles in the second diagram show where the planned insulation layers are interrupted – sometimes unavoidably, sometimes unnecessarily. After the exact positions of insulation layers have been entered, it is possible to analyze and reduce thermal bridges.



Check of thermal bridges

The next step in taking stock of deficiencies is to find out where the airtight layers around the old house run and what they are made of. The third diagram shows the example of a modern building. An early check of these layers helps ensure a really airtight house. If the quality of these layers cannot easily be analyzed, carry out an air pressure or artificial smoke test (see chapter X.3). It is important in such a test to look at connections and interruptions of the different airtight layers.

After having done this preliminary work, the weak points should be visible. Old houses differ with respect to the places where the heat flows out in the cold season. The contribution of a building component to total transmission loss depends on its area and insulation.



Check of airtight layers

For a first orientation the following checklist may help:

Very high heat losses that need urgent remedy are caused by:

- Roof components with no or not more than 3 cm old insulation between inner lining and roof cladding or upper finish of the walked-on loft ceiling (see chapter V)
- Outer walls made of concrete or heavy solid walling blocks with no external or internal insulation (see chapter VI)
- Windows or outer doors with only single glazing or with thermally unseparated aluminium/steel frames or frames without functioning all-round sealings (see chapter VII)
- Components of cellars if the parting planes between the building's heated and unheated parts are only made of heavy or thin materials (see chapter VIII)
- Thermal bridges where materials of high heat conductivity cross the insulated thermal envelope (see chapter IX)
- Ventilation through undisciplined window opening if there are no well-directed airflows and if no heat recovery exists (see chapter X.1.)
- Air leaks caused by outer doors, cellar doors, old windows, wooden cellar stairway coverings, trap doors, wooden cellar and loft ceilings, around installation channels and indoor fireplaces (see chapter X.2.)

If such "very cold" building components exist, their thermal renovation should be given highest priority.

High heat losses caused by poorly insulated parts of the envelope:

- Roof components with only 4-8 cm old insulation between inner lining and roof cladding or upper finish of the walked-on loft ceiling (see chapter V)
- Outer walls of 24-30 cm made of light stones or perforated blocks without insulation, or walls with only 5 cm insulation on heavy solid walling blocks (see chapter VI)
- Windows or outer doors with old double glazing without infrared-reflecting coating or with metal frames of only 1 cm thermal separation (see chapter VII)
- Cellar components equipped with functioning insulation layers of only 2-4 cm as often found in concrete cellar ceilings of 1950-1970.

If such "cold" building components exist, they take second priority in a thermal renovation project. They should be renovated whenever possible after the "very cold" ones have been eliminated.

XI.2. Quality standards for components to be renovated

Most parts replaced or newly added within a thermal renovation project are expected to function over a period of 30 to 60 years. In this period, a lot of energy will flow and we do not know which record heights energy prices will reach. It is difficult to define economically viable levels of thermal insulation quality since we need to face a lot of imponderables when trying to calculate the long-term cost-benefit relationship. Apart from purely economical aspects, also the gain in thermal comfort and the increased independence from national energy suppliers may help in making the right decision.

Today, the Multi-Comfort house is the ultimate level to achieve wherever possible. If only single components need to be renovated, this excellent thermal quality level can often be realized. For instance when only the roof or the walls or windows need refurbishment. The following table shows achievable quality levels of single components when highest Multi-Comfort level or good low-energy house level or only minimal renovation is planned for a 1950 single-family house. For more details refer to chapter IV.

Technical data	As built in 1900	As built in 1950	As built in 1975	Minimal renovation	Low-energy house level	Multi-Comfort house level
Cellar ceiling	Beams and cinder $U = 0.73\ W/m^2K$	Concrete + subfloor $U = 2.20\ W/m^2K$	Concrete, 1.5 cm ins. $U = 1.13\ W/m^2K$	Concrete, 4 cm ins. $U = 0.63\ W/m^2K$	Concrete, 10 cm ins. $U = 0.30\ W/m^2K$	Concrete, 24 cm ins. $U = 0.14\ W/m^2K$
Outer walls	40 cm nat.stone $U = 1.72\ W/m^2K$	30 cm brick $U = 1.12\ W/m^2K$	30 cm light brick $U = 0.99\ W/m^2K$	6 cm insulated $U = 0.35\ W/m^2K$	14 cm insulated $U = 0.20\ W/m^2K$	30 cm insulated $U = 0.11\ W/m^2K$
Windows	Wood, single glazed $U = 4.90\ W/m^2K$	Wood, single glazed $U = 4.90\ W/m^2K$	PVC, double glazed $U = 2.93\ W/m^2K$	PVC, double ins. glass $U = 2.00\ W/m^2K$	PVC, double coated glass $U = 1.40\ W/m^2K$	PVC, triple coated glass $U = 0.80\ W/m^2K$
Outer doors	Wood 58 mm $U = 3.50\ W/m^2K$	Wood 58 mm $U = 3.50\ W/m^2K$	Wood 58 mm $U = 3.50\ W/m^2K$	PVC + ins. glazing $U = 3.50\ W/m^2K$	PVC + coated glass $U = 1.50\ W/m^2K$	Insulated door $U = 0.80\ W/m^2K$
Roofs	Only plastered $U = 2.13\ W/m^2K$	3 cm insulated $U = 0.86\ W/m^2K$	5 cm insulated $U = 0.70\ W/m^2K$	10 cm insulated $U = 0.40\ W/m^2K$	26 cm insulated $U = 0.17\ W/m^2K$	40 cm insulated $U = 0.11\ W/m^2K$
Ventilation and airtightness	Gaps + windows $n_{(50)} = 4.5\ 1/h$	Gaps + windows $n_{(50)} = 4.5\ 1/h$	Windows + gaps $n_{(50)} = 4.5\ 1/h$	Windows $n_{(50)} = 3.0\ 1/h$	Ventilation without heat exchangers $n_{(50)} = 1.5\ 1/h$	Ventilation with heat exchangers $n_{(50)} = 0.6\ 1/h$
Heat demand of a single-family house	$496\ kWh/m^2a$	$376\ kWh/m^2a$	$280\ kWh/m^2a$	$165\ kWh/m^2a$	$86\ kWh/m^2a$	$28\ kWh/m^2a$
Heat demand of a multi-family house	$384\ kWh/m^2a$	$314\ kWh/m^2a$	$260\ kWh/m^2a$	$123\ kWh/m^2a$	$66\ kWh/m^2a$	$15\ kWh/m^2a$

Comparison of the technical data assumed for six energetic levels

If the budget doesn't allow realization of the highest quality, it must be carefully considered if only a few single components should be renovated on a very high level or a greater number of components on a lower level. This is always difficult and no general recommendation can be given. But the following decisions should be taken: What must be done immediately and what can be done later? Is it more expensive to realize interim solutions or to follow some things through to completion?

XI.3. Technical interdependencies of possible measures

If an old house is renovated bit by bit over a longer period of time, it can be very annoying to remove parts that were installed just a couple of years ago only because they are not compatible with more recent components. Whenever replacing or improving a part, it is therefore advisable to look at all surrounding components to check if their later replacement or improvement will require special adaptations. Here some examples:

- If the roof over heated rooms is retiled and has empty spaces between the rafters, insulation (incl. airproofing and vapour-retarding layers) should be installed. When the rafters are only 10-16 cm high, an additional outer installation layer should be installed between the laths that are fixed on top. This ensures good insulation for the hot and cold season (for details see chapter V).
- If the roof is retiled and the house walls are poorly insulated, a roof overhang should be built so that the outer wall insulation will later be covered by the roof. It must be considered that high-quality outer wall insulation may have a thickness of 20-30 cm instead of merely 8 or 10 cm.
- If the windows are replaced and the house walls are poorly insulated, the new windows may not be positioned in the middle of the old wall but more outside. In this way, the outer soffits will not be so deep when later installing the outer insulation. If the walls outer insulation is planned for the near future, the windows can be installed flush with the outer wall. This also minimizes later thermal bridges (for details see chapter VI).
- If windows, doors or roller shutter boxes are refitted in houses with cavity walls, insulation material can later be blown into the air space between the walls. However, all connections to this air space should be closed so that the blown in insulation cannot flow out.
- If front door, terrace doors or french windows extending down to the floor are replaced on ground floor level and if the ceiling of this room is later insulated, it may be necessary to adapt the door or window size (e.g. shorten them from below) so that they can still be opened after renovation.
- If balcony doors are refitted in a house with an old concrete balcony (important thermal bridge), the bottom edge of the doors can be lifted by about 10 cm. This allows later the thermal insulation of the old concrete balcony while creating a slope that rain water can run off.
- When freshly painting the facade or repairing the plastering, this is an excellent chance for installing outer insulation (provided the wall is poorly insulated). Otherwise, all repair costs will be wasted when outer insulation is added a couple of years later.
- When insulating the facades from outside, the lower edge of the insulation should not be on the same height as the cellar ceiling. Instead, it should be 40-60 cm lower to reduce thermal bridge effects. If the cellar is fully or only temporarily heated, the outer insulation should extend by 1 m below the surface of the earth.
- If very air-leaky windows or doors are replaced and sealed, the changed need for ventilation should be considered to avoid moisture problems. The drying effect resulting from untight gaps and airflows does no longer exist. It is recommendable to install at the same time a mechanical ventilation system with well-controlled airflows. Always the best solution: a ventilation system with heat recovery.
- If a wooden loft ceiling is insulated from above and the boarding is opened for this purpose, all electric light cables inside should be checked. If their service life is shorter than 40 years, they should be renewed. In addition, any air leaks should be closed before insulation is installed.
- If the roller shutter boxes are replaced by new ones with a smaller diameter, the space gained in the box should be used for additional insulation.
- If the water pipe or electric cable networks are old and in bad condition, they should be renewed before finishing the surfaces because penetrations will be necessary.

XI.4. Components: immediate replacement of later installation?

If the investment budget is not sufficient to cover all of the necessary renovation work at once, a meeting should be called in of all co-investors and later residents (including children) to set up a list of all wanted measures, considering technical, economic and also emotional priorities. These three criteria may not have the same rational importance, but discussing them at an early stage can help reduce misunderstandings and later dissatisfaction.

If an old house has just been bought and the new owners want to move in soon, it is advisable to first renew the inner surfaces to ensure the residents' comfort. But if it is foreseeable that components behind these surfaces need to be replaced, this should be done first. For this reason, it is generally useful to carry out the following checks:

- Check the quality of wooden beams or rafters before investing in new, expensive flooring on top of wooden ceilings or in new roofing tiles on an old roof.
- Check the remaining life expectancy of freshwater, waste water and heating pipes as well as electric cables inside walls before investing in new bathroom tiles, sanitaryware or built-in kitchens. Repair of an old floor heating system under newly installed marble flooring can be a tedious job.
- Check the roof insulation before investing in the interior decoration of attic rooms. It may be useful to open roof spaces from inside if additional insulation is urgently needed and the outer roof will not need repair for many years.

In principle, priority must be given to investments that are likely to stop the gradual destruction of the building components. If, for instance, water from a leaky roof or gutter constantly runs into the roof structure or loft floor or along the outer walls, this should be repaired as soon as possible – even if a newly bought older house is not yet inhabited.

Another case: If the heating system is untight and water must often be refilled, the leaks must be urgently closed. This is not because fresh water is so expensive, but because fresh water transports new oxygen into the old iron pipes.

Consequently, they will corrode fast. The costs of water damage and complete pipe renewal can be very high.

It is also better to completely replace an old electric cable network before freshly painting the interior surfaces. Later, it will be much more expensive. In addition, the continued use of such a network can be quite risky.

To sum up, the investment priorities can be influenced by divergent interests: by the need to feel comfortable, to save energy, to prevent damage and to avoid higher costs if the measures are taken in the wrong order or not considered in due time.

XI.5. Time and work schedule

Scope and complexity of renovation work in old houses is never completely predictable. But it is very useful to set up and regularly check a time and work schedule for renovation. It helps you not to forget important things, makes you feel good when bit by bit nearing completion, and also helps control the budget.

Professional investors have sophisticated systems for controlling the timing and cost development at all planning stages, including enquiries, orders, quality control, payments and warranty periods. Amateur investors should try to have at least a clear document system, sorted either by trades or by building components. It should contain all important data – from the first site inspection and deficiencies found to product catalogues, offers, calculations, contracts, photos of building components (before, during and after renovation). Today, digital photography allows the inexpensive and very detailed documentation of many things at many different stages. It often happens that someone later needs information on a structural detail and will be happy to find it in a well-sorted photographic documentation.

If a house is to be renovated while being inhabited, it helps to have a clear separation between dirty working and clean living areas. When renovating upper floors, it is recommendable not to use the shared staircase for demolition waste or material transport, but to install outer routes and close the staircase with a dust cover sheet.

The renovation timing also needs to take outer influences into account. For example if the time or budget for completion are limited. Authority approvals can take longer than expected and may delay more extensive construction work. Credits may not be granted in time so that the payment plans need to be modified. The work of craftsmen can be slowed down by weather, illness, holidays, wrong time management or bankruptcy. The resulting delays will also influence the work of other craftsmen. This cannot totally be prevented, but at least it is possible to lay the possibilities down in the terms of contract to avoid penalties. The best is to plan sufficient time tolerances into the overall work schedule to minimize the stress level.

These last recommendations are not meant to heighten houseowners concerns and warn against renovating old houses to a high quality level. In most cases, the realization period will be a mix of very positive experiences and various troubles and setbacks – sometimes you simply have to go through a bit of a "barren spell".

But when later living in a comfortable house of excellent thermal quality and low heating costs, this will definitely make up for a lot of trouble. And, in addition, there is the good feeling of having done one's best to help save our environment.

Renovation examples

Dipl. Physiker Raimund Käser
SAINT-GOBAIN ISOVER G+H AG

Dipl. Ing. Architekt Bernd Seiler, Seckenheim

Conversion of a listed barn into a passive house dwelling

This project shows the scope of feasible measures to refurbish an old building according to passive house standard. The conversion turned out to be a particularly challenging task since special requirements had to be fulfilled with respect to building physics, statics and monument protection.

The project was supported by the companies SAINT-GOBAIN ISOVER G+H AG, SAINT-GOBAIN GLASS Germany and BASF in order to demonstrate that also historical buildings can be rehabilitated to state-of-the-art building technology. The barn, which was built around 1850, is part of a listed ensemble of former tobacco barns in the Hessian Brundtland City Viernheim – well-known as an energy-saving town. Some of these ancient tobacco barns had already earlier been converted into residential buildings, a library or a municipal culture barn.

The project idea was to transform the barn into a passive house with an annual heat energy demand of 15 kWh/m^2 in compliance with DIN EN 832, thus realizing a passive house standard that had been unachieved so far for such a listed building.

The objectives

- Observe the monument protection regulations
- Achieve the passive house standard
- Protect the visible timber framework and salt-infested natural stone wall against the penetration of moisture
- Fulfil special static requirements by properly securing the neighbouring buildings.

The starting situation

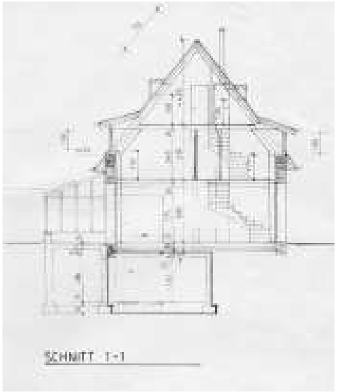
Barn seen from the yard and garden side (May 1997)

Due to intensive agricultural use, the external natural stone walls as well as the interior constructions were heavily salt-contaminated and damaged. In addition, the roof structure was in a dilapidated condition: it showed considerable traces of fire on the still existing wooden framework caused by air-raid damage in World War II. For this reason, it was planned and agreed with the Monument Preservation Authority to tear down and rebuild the roof truss as well as two severely damaged external walls. When clearing away the truss, further damage and cracks on the remaining external walls became visible. Bit by bit, the existing natural stone walls of the roughly 12 m by 8 m large building were pulled down by the owners in July 1997. The stones were cleaned and stored for re-use in the garden.

Clearing away the rubble and securing the remaining construction

Architecture and spatial allocation

Due to the existing monument protection regulations and the barn's integration into the local town-planning scheme, it turned out to be very difficult to realize spatial allocation optimally, i.e. without creating excessive heights for the individual storeys. An additional obstacle to realizing a good number of storeys and well-balanced storey height was the height of the eaves line with respect to the neighbouring barn as well as the need to observe the ridge line. It was therefore necessary to generate a cross-sectional view of the building on a scale of 1:20 which included the frame conditions. Based on this cross-section, it was possible to bring the interior heights into line both with the exterior conditions and the requirements of building physics. In agreement with the Lower Monument Preservation Authority, the location, size and divisions of the dormer windows were fixed. After these preconditions had been set, the architect was able to realize three storeys while at the same time taking the residents' wishes for living space into account. On the ground floor, space for a kitchen, storeroom, living room, dining room, utility room and guest WC was provided. On the first floor, three children's rooms, a study and a bathroom were created. And the attic now accommodates a parents' bedroom, dressing room, another bathroom and a room for domestic service facilities – total useful space 212 m^2. Based on these floor heights, the window heights on ground floor level were designed – in keeping with monument preservation requirements. This also applied to the conservatory which was attached on the garden-facing side. Compared to the original heights of the historic barn, the ground-floor floor was slightly lowered: two steps were created leading from the terrace up to the garden.



Cross-section of the barn

Foundations and carcass

The new construction was planned as a concrete skeleton with front-mounted natural stone walls placed at a fixed distance. This planning was based on the assumption that the existing remaining brickwork would no longer be able to fulfil the static requirements. In addition, it was found necessary to separate the load-bearing interior construction from the salt-contaminated rough rubble wall in order to ensure efficient moisture control.

Two-layered insulation with Styrodur 5000 floor boards within the ring footing for the natural stone walls

First of all, a small concrete cellar was built. The cellar, which is accessible via outside stairs and whose floor partly consists of sand, is now used as a wine vault. After that, the ring footings for the newly erected natural stone walls were laid. On top of a blinding layer installed above the cellar and within the ring footings, two thermal insulation layers of 80 mm thickness each were installed, consisting of extruded rigid foam boards Styrodur 5000 WLG 035.

In the next step, the insulation layer was covered with a polyethylene membrane in order to prevent the penetration of cement laitance into the joints of the insulation boards when casting the base slab. The thermal insulation laid on top of the foundation slab adjoins the rising internal insulation of the rough rubble wall. This then forms a kind of trough for the 35 cm thick concrete slab. This was achieved without any thermal bridges. The total load of the building is now carried by both foundation slab and thermal insulation and thus transferred into the ground. On top of this foundation slab, it was possible to erect the static effective concrete skeleton construction.

Erection of the concrete skeleton

Roof construction and timber framework

Next, the roof truss was newly erected which also included the gable framework. After putting up the roof boarding and building the dormers, the above-rafter insulation was installed, consisting of rock wool strips and glass wool felts of 180 mm thickness.

Between the rafters, the roof construction was additionally insulated from the inside with mineral wool felts of 200 mm thickness (Integra ZKF 1-035). Under the rafters, a separate installation layer was created and insulated with a 60 mm thick layer of mineral wool. Of special importance was the use of the moisture-controlling climatic membrane Vario KM. This special type of vapour barrier membrane has a triple effect: it prevents water vapour diffusing through the insulated area as well as air flowing through joints and connections into the layered structure of the thermal insulation. Moreover, it allows the reverse drying of wooden or other building components that are affected by moisture.

Additional benefit of the membrane: no need for chemical wood preservation. All in all, the insulation of the barn roof reached a total thickness of up to 440 mm in some places and was clad with two layers of plain tiles.

Installation of above-rafter insulation on the ridge

Roof construction in the dormer area with separate installation layer

Wall construction

After completing the roofing work, it was time to raise the natural stone walls again.

From the inside, the natural stone walls were then lined with thermal insulation. This procedure is of crucial importance in terms of building physics. The heavy salt contamination of the natural stones comes along with a moisture load that must not be allowed to affect the interior structure of the building. The use of not moisture-transporting mineral wool therefore offers great benefits for this kind of application.

Raising the natural stone walls on the separate ring footing

Next, the building owners themselves installed mineral wool felts of 140 to 180 mm thickness (WLG 035) on the inside of the external wall and on the gable walls with the help of a special mounting frame. Basically, this construction consisted of 9 mm gypsum plasterboards mounted on metal sections that were only anchored to the wall and ceiling. The resulting cavity was filled with mineral wool felt, a non-hygroscopic and therefore not moisture-transporting insulation material. The felt material was applied in strips so as to compensate for the strongly differing size of the natural stones and avoid the formation of gaps.

Metal frame construction facing the natural stone wall

This type of construction ensures both freeness from thermal bridges and reliable protection against the penetration of moisture. The gypsum plasterboards were again covered with the moisture-adaptive climatic membrane Vario KM, serving both as an airtight layer and vapour barrier. After that, double-planked plasterboards of 12.5 mm thickness were installed with the help of 75 mm metal sections. This front-mounted additional installation wall was likewise fully insulated with mineral wool felts. The result: an external wall of 220 to 250 mm total insulation thickness.

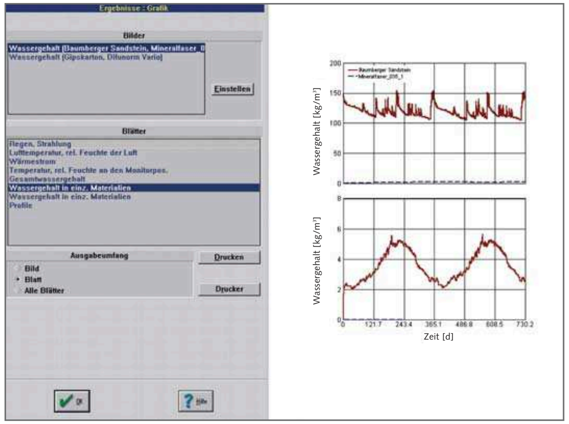
Also the visible timber framework had to be carefully dampproofed as there is always the risk of moisture deeply penetrating through the joints. After putting up the gable framework, a 100 mm thick layer of thermal insulation (Sillatherm WVK-1 stone wool lamellae) was installed in the timber compartments with the help of perimeter arris rails. These lamellae were covered with a reinforcing layer and an undercoat plaster. Finally, facing bricks were bonded on top.

Bonding the Sillatherm lamellae into the timber framework and fixing the facing bricks on top

However, neither perimeter triangular battens installed in the compartments nor additional sealing tapes can durably prevent the ingress of moisture in the case of driving rain. Further security is therefore offered by a moisture-distributing timber shuttering installed behind the compartments. This ensures that any moisture intruded is distributed over a wider surface area. It is of vital importance that this construction has a good potential for reverse drying.

On top of this timber shuttering, a thermal insulation layer of 180 mm thickness was installed from inside, consisting of rock wool strips and glass wool felts. In a second step, this layer was covered with the moisture-adaptive climatic membrane Vario KM, functioning both as an airtight and vapour control layer. Here as well, double-planked 12.5 mm gypsum plasterboards were front-mounted in 75 mm metal sections in a separate installation wall which was also fully insulated with mineral wool. The total insulation thickness in the timber framework thus amounted to 350 mm.

Especially with the visible timber framework and the natural stone facade with its constant risk of moisture absorption, the increased reverse drying potential of the moisture-adaptive climatic membrane to the inside is a physical property of high structural importance. The construction described above was necessary since the usual moisture calculation – carried out according to DIN 4108 – would have shown that the diffusion behaviour of the natural stone walls was unacceptable. The calculations made with the WUFI program of the Fraunhofer Institute for Building Physics prove that the climatic membrane is able to ensure a reliably dampproof structure.



Dynamic moisture calculation of the natural stone walls with the help of WUFI

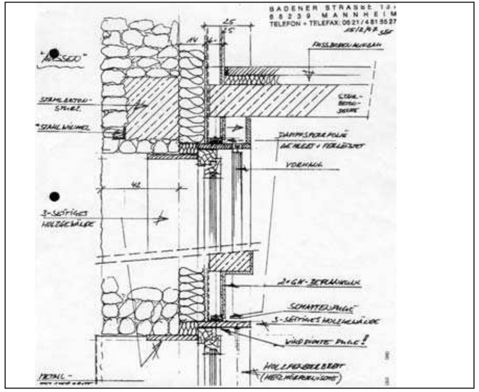
The windows

The windows were equipped with Climatop V triple thermal insulation glazing, featuring a heat transfer coefficient of $U_g = 0.6$ W/(m²K). Also the wood-aluminium window frames were specially insulated. A particular challenge was the integration of the window frames into the external walls: with as few thermal bridges as possible, but without sacrificing static security. By using special jambs made of glued laminated timber (glulam) in the insulation layer, it was possible to achieve a statically stable but nonetheless thermal-bridge-reduced construction.

Triangular dormer window

Glulam construction

Window section



Many detailed drawings and thermal bridge calculations needed to be done before it was possible to reach the passive house value for windows of $U_w = 0.8$ W/(m²K).

Solution for a structural detail (draft)

Interior finishing work

The internal walls were dry mounted, consisting of two layers of gypsum plasterboards (12.5 mm thickness) and a cavity fill of partition walls slabs type Akustik TP 1 (60 mm thickness). As a screed substitute, the raised floor system was used – newly developed by ISOVER Austria. It consists of 32 mm chipboards with an additional cavity fill of facade insulation boards Kontur FSP 1-040 (100 mm thickness). A customized solution was also the inside insulation of the dormer ceilings using the ROSATWIST system developed by ISOVER France. A special suspension construction made it possible to install up to 50 cm insulation material.

Ceiling construction of the shed dormers with ROSATWIST

After finishing the installation layers behind the external wall, the dry-mounted internal walls and the above-mentioned raised floors, ideal conditions had been created for accommodating electric and other installations.

Conservatory

Thanks to the excellent window construction, the conservatory is now thermally separated from the rest of the building. Nevertheless, the floor and also the ceiling underneath the solar collectors (mounted on top of the conservatory roof) had to be well insulated. For two reasons: in order to reduce not only the emission of heat into the cellar, but also the temperature level in summertime.

Conservatory

Heating and ventilation systems

The standard heat load was determined based on DIN 4701 and also according to the special passive house heat load calculation procedure. Due to the shading caused by the building's inner-city location, the value was approx. 3 to 5 kW. For this reason, a gas-fired condensing boiler (Buderus GB 112) equipped with water-heating solar collectors is now used as a back-up unit and for additional hot water generation.

A Jovex DC ventilation system by the company Termovex with heat recovery (> 90 %) and geothermal heat exchanger ensures a comfortable indoor climate.

Fresh air routing of the geothermal heat exchanger via the terrace

Photo source: Pressebüro Pfäffinger

Control of the HVAC systems was facilitated by installing a bus system and building in window contacts. In addition, a data network for telephone and computer lines was installed.

Geothermal heat exchanger with 200 mm sewage pipes laid around the cellar

Airtightness

When connecting the walls with the concrete members of the building, a special construction was used for sealing – offered by ISOVER Sweden. Strips of mineral wool were wrapped with the climatic membrane Vario KM and used for sealing inaccessible cavities. Thanks to the elastic recovery of the insulation material, the cavities are now filled in a permanently airtight and also dampproof way as the measurements have shown. When carrying out a preliminary check, a value of 2 1/h was measured which is insufficient for passive houses. This value was caused by two factors: the unplastered chimney installed for later use with a wood pellet oven and some leaks around the window frames. After adequate thermal insulation and sealing of both chimney and window constructions, it was possible to achieve the passive house standard value of 0.6 1/h.

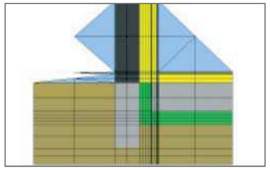
As a result of refinishing work, which had meanwhile been carried out on the data supply lines and the very tricky dormer windows, new leakages were caused. The measurements were repeated and showed a too high value of 1.4 1/h.

Tricky airtightness detail in the triangular dormer windows

This again shows the crucial importance of good cooperation and understanding among the craftsmen involved in the building project since innovative solutions are always special challenges to good workmanship. And this also proves that in most cases a one-time measurement of airtightness is not sufficient, but that the work needs to be constantly monitored.

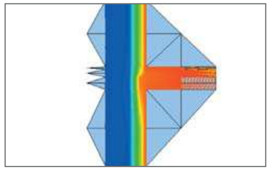
Thermal bridges

For the planning of details it was necessary to calculate different connections – from the base slab via the timber framework up to the roof:



Connection detail base slab/wall (insulation layers: green and yellow, concrete and natural stone areas: grey and black)

Thermal bridge	ψ-value in W/(mK)
Connection base slab/wall	-0.046
Incorporating floor slab	0.02
Support in the wall	0.025
Connection of eaves	0.019
Timber framework	0.01
Roof	0.008



Isothermal picture of the embedded floor slab

The construction and energy data

After completion and based on the constructions described above, the building now has an annual heat energy demand of 2834 kWh according to DIN EN 832. Related to the useful floor space of 212 m^2, the annual heat energy demand per square meter amounts to 13.4 kWh/m^2 and thus meets the passive house standard. The energy demand calculations were carried out with the program HELENA 2.0 resp. 3.0, the thermal bridge calculations with the two-dimensional software ARGOS 1.0 developed by ISOVER Consult.

U-values	in W/(m^2K)
Thermal insulation glazing incl. frame	0.8
Wall areas	0.12 - 0.15
Barn roof (incl. wooden components)	0.09
Floor	0.14

After start of construction in summer 1997, it was necessary to carry out substantial building work for redeveloping the entire front courtyard. This did not only include the new laying of all sewage, water and gas pipes as well as electricity and telephone lines, but also the installation of a rainwater cistern. This extra work – and also the stand-alone developments and structural solutions for roof, walls and windows described above – considerably delayed the progress of work. After its official completion in April 2000, the building was finally ready for moving in.

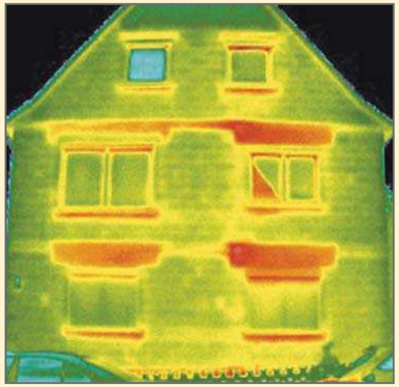
Building seen from the garden and courtyard side (August 2000)

The building project

Building owners/Building physics:	Stephanie and Raimund Käser, Viernheim
Architect:	Dipl.Ing. Bernd Seiler, Seckenheim
Framework planning:	Engineering office Dipl.Ing. Peter Bläß, Viernheim
HVAC engineering:	ebök, Ing.büro für Energieberatung, Haustechnik und ökologische Konzepte, Tübingen
Insulation technology:	SAINT GOBAIN ISOVER G+H AG, Ludwigshafen; BASF, Ludwigshafen
Glazing:	SAINT-GOBAIN GLASS, Aachen
Window technology:	Eurotec Pazen GmbH, Zeltingen
Carcass work:	Fa. Zalewski, Seckenheim
Carpenter's work:	Fa. Metz, Edingen
Roofer's/plumber's work:	Fa. Hartwig, Viernheim
Electrician's work:	Fa. Elektro-Ringhof, Viernheim
Heating, ventilation and sanitary facilities:	Fa. Willi und Thomas Beikert, Viernheim
Builders merchants:	Fa. Kühner, Viernheim

Some recent examples of successful renovation work in Europe

On the following pages, you will discover numerous renovation projects from around Europe. They represent diverse ways in which architects and owners have risen to the challenge of implementing energy efficiency. These projects have distinguished themselves in various ways: by achieving high energy savings, by overcoming a particular technical, logistical or budgetary challenge, or by demonstrating that building preservation and energy efficiency are perfectly compatible goals.



> "40 % of Europe's total energy is consumed by buildings."

Makartstrasse 30-40 Austria

Energy savings of
92 %

Precision in the choice of materials, anticipating alternative solutions …
Taking the necessary time up front often makes it possible to save time downstream.

> **"This project is a stellar example of the passive house standard perfectly executed."**

Arch + More ZT GmbH, Austria
Architect: Ingrid Domenig-Meisinger

Challenge

This 5-storey, multi-unit residential building was built in the late 1950s. In keeping with the time of construction, a lot of deficiencies could be identified. Its low energy efficiency translated into high heating costs. The challenge was to transform the building into a perfect example of passive house technology.

The full range of prefabricated elements necessary for the renovation had to be chosen and installed with the utmost respect for the building's exterior envelope to ensure its energy efficiency.

Technical strategy

The installation of a controlled ventilation system contributed to a clear improvement in interior air quality and resulted in better protection against exterior noise. The exterior architectural design, composed of solar panels in grey and red, give the building its resolutely modern appeal. Thanks to the high insulation level of all components and the watertight design of the loggias, it was possible to completely eliminate all thermal bridges.

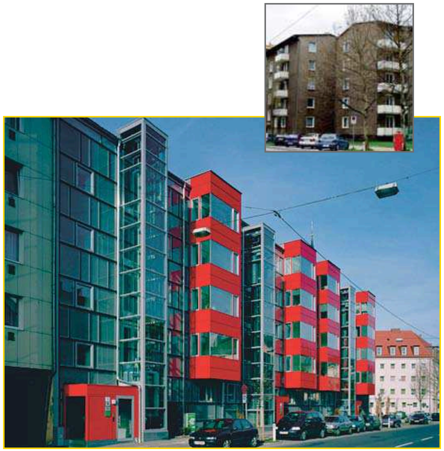
Building type	Collective residential housing
Facade – Construction	Solid construction with a wooden framework
Total surface area	3106 m^2
Number of floors	5 floors
Year of construction	Late 1950s
Renovation time	13 months

Key points

The building's initial volumes were maintained but refurbished. It was decided to implement an autonomous energy source in the form of solar panels. Together, these systems reduced energy consumption and made it possible to divide monthly heating costs by a factor of 10 while at the same time enlarging the floor space by 351 m^2.

Performance analysis

Total consumption heating only	14.4 kWh/m^2a
U-value for the windows	0.86 W/m^2K
U-value for the roof	0.094 W/m^2K
U-value to ground	0.24 W/m^2K
U-value for the walls	0.082 W/m^2K
Air tightness	1.3



Low-energy house in Chemnitz Germany

Energy savings of
95%

Renewable energies are diverse and now available to all. Each has its particular advantages but how you make them work together can be a key factor of project success.

> **"The result is a building complex that's user-friendly, adapted to children and has a practical and modern floor plan."**

Planungs- und Konstruktionsbüro Taube, Germany
Architect: Matthias Taube

Challenge

This renovation project, located in an urban context, consisted of stand-alone apartment houses built in 1911. The age of the structure itself represented a sizeable challenge. The services of an independent energy expert, consulted prior to and during the renovation, proved particularly useful. From the start, the goal was to combine four sources of renewable energy (solar heating, heat pump, rainwater recovery and heat exchanger).

Technical strategy

The first step in the renovation process was to significantly upgrade the building's thermal envelope. The integration of shutters and the redesign of each unit's balcony required additional insulation. The insulation of walls and ceilings was accomplished with mineral wool. Low-temperature heated floors were installed in each of the units. Airtightness was improved thanks to a central ventilation system with heat recycling. Recycled rainwater is fed into the sanitary units and washing machines of each apartment.

Building type	Collective residential housing
Total surface area	430 m^2
Number of floors	3.5 floors
Number of units	4 apartments
Year of construction	1911
Renovation time	16 months

Key points

The renovation improved the thermal comfort of all residents of the building and enabled a 90 % drop in the consumption of primary energy. This project, once completed, inspired the enthusiasm of not just the building's residents but also experts and representatives of local and international media. Indeed, the project received the "House of the Future" award from the German Energy Agency (DENA) in the category "optimised renovation".

Performance analysis

Total consumption of the building	14 kWh/m^{2}a
Total consumption heating only	9.84 kWh/m^{2}a
U-value for the windows	0.8 W/m^{2}K
U-value for the roof	0.136 W/m^{2}K
U-value to ground	0.216 W/m^{2}K
U-value for the walls	0.157 W/m^{2}K
Airtightness	0.49

Single-family house Schroiff Germany

Energy savings of
83.3%

Renovating in accordance with today's energy standards sometimes entails significant costs. It's the cost of a new "status quo" regarding the environment that from now on has to be taken into account.

> **"Solar panels fixed on the roof provide a source of autonomous energy."**

Planning Office, Germany
Architect: Petra L. Mueller

Challenge

This urban, single-family house, entirely without insulation, with single-glazed windows and purely natural (non-controlled) ventilation, required complete renovation. In the course of the necessary structural modifications, a second unit (the owner's parents' house) was annexed. When undertaking these modifications, the main challenge was to use only ecologically friendly construction materials.

Technical strategy

The project necessitated the reorganization of floor plans according to a new conception of living spaces, making them more functional and flexible, including the possibility of adapting the separate units to the needs of elderly or younger residents. Insulation work encompassed all aspects of the old building (floors, walls, roofing, windows, outbuildings). The renovation objectives were determined after an on-site expert analysis. The thermal insulation turned out to be significantly more effective than projected by the analysis.

Building type	Individual residential housing
Total surface area	251 m^2
Number of floors	1.5 floors
Renovation time	10 months

Key points

The new extension increases the available floor space to at least 200 m^2. Divided into two separate living units, the modified space is well adapted to the family's growing space requirements. Apart from enlarging the living space, the objective was to create a highly energy-efficient house despite a very tight budget with relation to the high degree of insulation and functional innovation required. The result was a completely modified structure executed according to the highest quality standards at a reasonable cost. The house was particularly adapted to the owner's needs in terms of functionality.

Performance analysis

Total consumption of the building	79.4 kWh/m^{2}a
Total consumption heating only	50.8 kWh/m^{2}a
U-value for the windows	1.4 W/m^{2}K
U-value for the roof	0.18 W/m^{2}K
U-value to ground	0.33 W/m^{2}K
U-value for the walls	0.22 W/m^{2}K

Public Library G. Petkevicaite-Bite Lithuania

Energy savings of
79%

Confronting technical difficulties of all sorts puts know-how to the test and expands our competencies.

> **“A truly harmonious blend of historical heritage, modern architecture and interior comfort.”**

Miestprojektas AB, Lithuania
Architect: Saulius Juskys

Challenge

The building is situated in the historical town centre, a zone declared part of the Panevezys patrimony. The design possibilities within this zone were thus extremely limited. The conditions imposed on the facade renovation were perhaps the defining challenge of the whole project. For this reason, and in order to preserve scrupulously the building’s historical integrity, the insulation of the old facade had to be undertaken entirely from inside the building.

Technical strategy

The walls were insulated on the interior face with panels of glass wool and gypsum board contained by a metal frame. The acoustic insulation of air ducts was achieved with a glass wool layer that was covered with an aluminium laminate. The original windows were replaced by new, modern ones that ensure both thermal and acoustic insulation. Finally, new wood and aluminium doors completed the renovation.

Building type	Public Library
Facade – Construction	Thin layer plaster facade
Total surface area	5991 m^2
Number of floors	3 floors
Year of construction	1920
Renovation time	36 months

Key points

The renovated building can be accessed via a new annex to the neighbouring library, thus greatly optimizing visitor access to the building. The space dedicated to various locales was expanded while the ambient temperature and other aspects of the building’s interior comfort were improved. The building is now fully integrated into the historic core thanks to the highly adapted renovation options.

Performance analysis

Total consumption of the building	137 kWh/m^2a
Total consumption heating only	44 kWh/m^2a
U-value for the windows	1.7 W/m^2K
U-value for the roof	0.20 W/m^2K
U-value to ground	0.37 W/m^2K
U-value for the walls	0.32 W/m^2K
Airtightness	5.82

Lausanne GuestHouse Switzerland

Energy savings of
70%

To offer a comfortable living space that respects the environment is probably the best way to make someone feel welcome in your home.

> **“Whether it’s for renovation work or the construction of new buildings, a holistic approach is essential. There’s an ethical dimension to the architect’s work, consisting of ensuring the comfort and well being of future inhabitants approach is essential.”**

Patrick Chiché Architecture
Architect: Patrick Chiché

Challenge

The object of this renovation project was the conversion of a house dating from 1894 into a hotel and apartment complex. The hotel accepts 15 guests in winter and 70 in summer. 16 residents occupy 6 apartments all year round. It was the owners' desire to preserve the building's aesthetics while at the same time significantly reducing energy consumption. Optimizing the work environment for the hotel staff was another priority.

Technical strategy

A gas-based condensing water heater was installed for hot water while water for the shower is heated with solar energy. To meet MINERGIE standards, controlled ventilation is essential. Such an installation is often poblematic in the case of existing buildings. In the original configuration of the house, each room was equipped with a separate stove heater. From this the team deduced the existence of conduits previously used to draw off fumes from the heaters. By tapping on the walls they determined their location and these spaces were then used to install the new ventilation system.

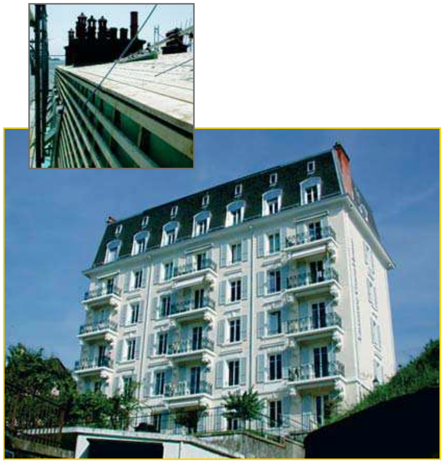
Building type	Collective residential housing
Facade – Construction	Stonewalls
Total surface area	1879 m^2
Number of floors	6 floors
Number of units	6 apartments with 3-4 rooms
Year of construction	1894
Renovation time	12 months

Key points

The approach to the project was holistic. The goal was to unite comfort, aesthetic appeal, architectural quality and a healthy environment – in harmony with with today’s energy challenges. The result has fully met the expectations of the owners, particularly with respect to the outstanding thermal and acoustic protection.

Performance analysis

Total consumption of the building	97 kWh/m^2a
Total consumption heating only	49 kWh/m^2a
U-value for the windows	1.1 W/m^2K
U-value for the roof	0.18 W/m^2K
U-value for the walls	0.9 W/m^2K



Chemin des Libellules Switzerland

Energy savings of

60%

The diverse constraints of a project constitute obstacles, to be sure. But when creativity and performance come together in ways that allow us to go beyond them – these are reasons to be proud of.

> **"To overcome technical obstacles of all kinds, that's the pleasure of this business. Obtaining MINERGIE certification in the context of all the challenges was far from being guaranteed."**

Patrick Chiché Architecture
Architect: Patrick Chiché

Challenge

For the complete renovation of these four buildings dating from the 1970s, each successively set back from the street, the goal was relatively classic: meet the level of comfort desired by the owners but also create a harmonious blend of architectural qualities and technical and energy-related performance. The original construction represented had numerous shortcomings related to age and the construction techniques employed at the time: water infiltration, thermal bridges, irregularities and deformations in windows, corrosion of frames and joints.

Technical strategy

A new external envelope was built with reinforced insulation based on glass wool. A system of controlled ventilation was installed in the rooms of each apartment. The conduits required by this system were embedded in the first layer of insulation. Balconies and verandas were also insulated, allowing them to act as non-heated buffer spaces.

Building type	Collective residential housing
Facade – Construction	Typical construction of the 1960s-1970s: external masonry walls and internal partitions with 3 cm insulation. Reinforced concrete floors extending beyond the facade. Flat, non-accessible roof.
Total surface area	1300 m²
Number of floors	8 floors
Number of units	137 apartments
Year of construction	1973
Renovation time	12 months

Key points

The particularly low thermal insulation coefficient and clearly unsatisfactory technical installations contributed to a picture that was little encouraging. In spite of these problems, the renovated building was one of the first of its kind in Switzerland to receive the MINERGIE quality certificate. Finally, a survey of residents showed one of the highest satisfaction scores for this type of housing.

Performance analysis	
Total consumption of the building	68 kWh/m²a
Total consumption heating only	47 kWh/m²a
U-value for the windows	1.1 W/m²K
U-value for the roof	0.29 W/m²K
U-value for the walls	0.26 W/m²K

Soic Family House Croatia

Energy savings of

85%

When tradition and technology are the starting points, the result can resolve what might seem paradoxical: surprise and tradition, innovation in conjunction with preservation.

> **"This project has allowed us to pay homage to traditional heritage and know-how. Our creed: associate modern thinking with traditional craftsmanship."**

Ured ovlastene arhitektive Vesna Soic
Architects: Vesna Soic, Marina Lincir, Bruno Krunich

Challenge

A big challenge was finding the traditional craftsmen to assist in the renovation of the house. This ancient profession is disappearing fast with no young people to carry on the tradition. It combines a number of skills – carpenter and builder but also that of an artist as each craftsman leaves his personal imprint on the house he builds. According to the Croatian Chamber of Architects, this is the sole case where "posavina" house has been entirely taken apart and rebuilt on a new site. Architecturally speaking, the challenge of this renovation project was to find a balance between modern lifestyles and the conservation of the home's traditional construction.

Technical strategy

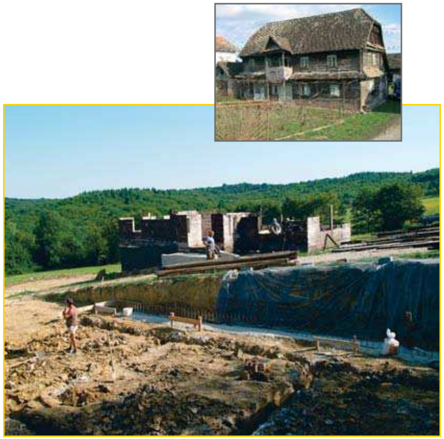
The existing traditional wooden house was transformed to meet modern requirements while paying special attention not to diminish the original energy-efficient design. This was achieved by installing a layer of ISOVER mineral wool in the walls, floors and roof surfaces in calculated thicknesses. The indoor finishing layer consists of cast-cardboard panels and /or old oak boards. The existing double windows were replaced by exact replicas of the original windows, but equipped with ISO glass of appropriate insulation properties.

Building type	Individual residential housing
Facade – Construction	Timber construction
Total surface area	240 m²
Number of floors	3 floors
Year of construction	1898
Renovation time	18 months

Key points

The home was adapted to a modern family lifestyle while preserving the values of Croatia's traditional architectural heritage. All traditional wooden features present in the house in its initial state were restored – very delicate work to say the least.

Performance analysis	
Total consumption of the building	61 kWh/m²a
Total consumption heating only	46 kWh/m²a
U-value for the windows	1.15 W/m²K
U-value for the roof	0.28 W/m²K
U-value to ground	0.52 W/m²K
U-value for the walls	0.33 W/m²K
Airtightness	0.8



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