Optimizimg energy-efficiency of late 19th century („Gründerzeit“) buildings

Practical suggestions for the construction of details of interior insulation with special regard to the requirements of the energy saving directive of April 2009

Summary Account

Research project	Z 6 – 10.08.18.7-08.27 Supported by Bundesamt für Bauwesen und Raumordnung Bonn
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1. Aims of the research study

By subsequent thermal insulation of exterior walls of older buildings it is generally possible to achieve substantial savings on heating energy. If, however, the appearance of a building should be preserved, e.g. if it is a protected monument, applying interior insulation is often the only practical solution.
In contrast to exterior insulation of a building, interior insulation may involve physical problems which concern the sequence of layers as well as constructional details in places where the insulation layers are interrupted.

In building practice there is a wide-spread opinion that interior insulation involves too many technical risks, especially if the requirements of enhanced thermal insulation are complied with. So, if the application of exterior insulation is impossible, it is often considered the best solution to do without any insulation at all.

By examining installed insulation systems, this research study aims to find out which conditions are necessary for interior insulation complying with the energy saving directive of 2009 to function reliably in practice. The study focusses on late 19th-century residential buildings („Gründerzeit“ houses) because, in thermally upgrading the large stock of these buildings, the most typical problems have to be dealt with and solved adequately.

2. Establishing data

In a survey carried out among 1,135 architects and building experts, 36 houses were pointed out for inspection. Detailed information was provided on 28 buildings; twelve of those comply with the requirements of EnEV 2009 (U-value ≤ 0.35 W/(m²/k)).
Five buildings had been modernized already before the regulation EnEV 2002 was implemented, which means that the techniques applied there have proved to be satisfactorily functioning in practice (see Fig. 1).

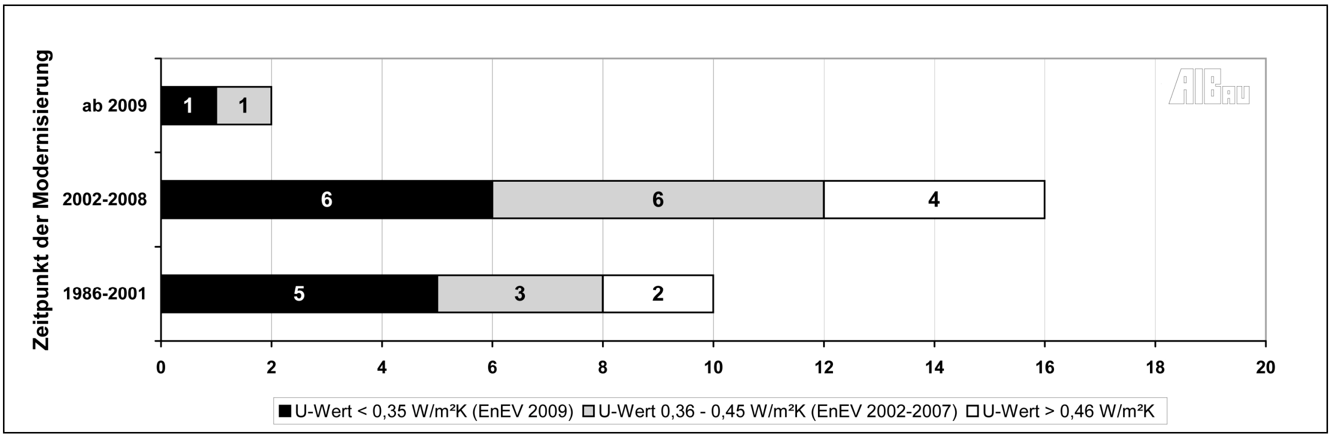

Fig. 1: Number of buildings specified, date of modernization and U-value of the exterior wall constructions realized

3. Findings

The investigation has shown that none of the specified buildings was affected by damage due to the application of interior thermal insulation. Based on the findings, the full-length study provides details and gives recommendations for practical construction.

3.1 Typical cross-section

3.1.1 Moisture conditions and resistance to diffusion

The application of interior insulation to external walls affects the temperature and moisture conditions within the typical cross section.
At the joint between the reverse side of the interior insulation and the interior surfaces of external walls, temperatures will be reduced and air humidity will increase. It is important to prevent risky amounts of condensation and the formation of mould in these places.

If one only considers damp diffusion (as the checking methods in DIN 4108 appear to suggest), it may seem reasonable to make the interior layers as impervious to damp as possible, in order to prevent any moisture from penetrating to the wall. But it is frequently overlooked that, in this way, drying out on the inside will be prevented, too, though this process may be essential when a facade is exposed to driving rain.

Before choosing and dimensioning a suitable insulation system, one should not only examine the interior climate. The exposure of the exterior wall to driving rain should also be assessed, and it must be clear if protection measures against driving rain involve the temporary storage of moisture in the cross section.

In the case of brick walls rendered on both sides – the most frequent technique in late 19th century construction – the exterior plastering will provide enough protection against driving rain.

Driving rain can penetrate into single-leaf brick and rubble masonry walls, but in dry weather it must be able to dry out on the exterior and preferably also on the interior sides.

Especially if such walls are very thick (<37.5 cm) and if they are intensely exposed to driving rain, it will be necessary to assess their capacity for storing damp and for drying out, before a suitable insulation system can be chosen.

Basically, the main distinguishing feature of interior insulation systems is whether they are diffusion-tight, resistant to, or permeable to diffusion. For the reasons explained above, in the case of single-leaf fair-faced brick masonry, all the relevant factors must be assessed and taken into account when choosing and dimensioning an adequate insulation system. On the other hand, brick walls that are protected from driving rain by external plastering do not require an interior vapour-proof sheet, even if permeable insulation materials such as mineral wool are used, provided that the layer adjoining the wall has enough capillary storage potential. With this type of construction, interior damp-proof layers will rather serve to achieve a satifactory degree of air-tightness, because air from the interior room must absolutely be prevented from circulating behind the insulation system. If insulation systems with an interior air-tight sheet are not fully bonded to the base surface, their long-term performance can be considerably improved by providing an in-between space for installations beneath the inner cladding, so that the risk of damage (for instance by installing sockets) is greatly reduced.

3.1.2 Dimensioning insulation

The maximum thickness of insulation systems depends, among other things, on the above-mentioned conditions. Of course the minimum thermal protection specified by DIN 4100 is indispensable, but one should rather aim to comply with the requirements of EnEV 2009. The effect of interior insulation will be diminished by inevitable gaps at the insulation level (s. below). The higher the insulation value of the system, the greater the effect of linear heat loss through thermal bridges along the gaps in the insulation layer (Ψ -value).

Consequently, the maximum economically efficient thickness of the insulation layer is around 10 cm (Λ = 0.035 W/(mK)). Studies have proved that a considerably thicker insulation can only slightly reduce the annual amount of heating energy required.
By a more efficient (and more costly) construction of areas affected by thermal bridges, heat loss can largely be diminished so that insulation systems up to a thickness of 15 cm can be adequate. On the other hand, when you consider the minimum expenditure for installing new interior layers (regardless of their thickness) in relation to the likely savings on heating costs, it does not seem reasonable to choose insulations that are less than 4 or 5 cm thick.

3.1.3 Other requirements

When installing interior insulation, for example in multiple dwellings, care must be taken not to diminish the sound reduction factor by using insulation materials of great dynamic stiffness, which will increase the flanking transmission of sound between rooms. If there are units of different users the requirements of fire protection have to be fulfilled.

3.2 Gaps in the insulation layer

Around windows and flush components (inner walls/ceilings) the interior insulation layer is interrupted. The resulting thermal bridges must be analysed in detail at the design stage to avoid greater heat losses and possible damage.

3.2.1 Window connections

3.2.1.1 Connections without changes in the position and geometrical shape of windows

When buildings are classified as historical monuments, usually their outward appearance, including the position of the windows, must not be changed. If the window frames themselves are protected, too, or if new windows may only be installed without altering the geometrical shape and thus the width of the window frame, there is frequently no space in the window reveals to make the insulation as thick as in the typical cross section. But insulation has at least to be so dimensioned that it will prevent damage caused by lower temperatures in the window reveals. If there is only little space one should choose insulation materials with a low thermal conductivity. If necessary, the plastering of the window reveal should be removed, but without diminishing air-tightness and protection against driving rain. In the case of brick masonry walls, sufficient surface temperatures can be achieved by applying an insulation of 2 cm to the window reveals, made of a material with a thermal conductivity of 0.030 W/(mK). From the point of view of building physics, it is effective to place insulation layers behind the window frames, which will result in considerably higher surface temperatures at the joints of the window reveals (see figures 2 and 3).

Fig. 2: Example of interior insulation installed in the area of the window reveal, continuing behind the frame

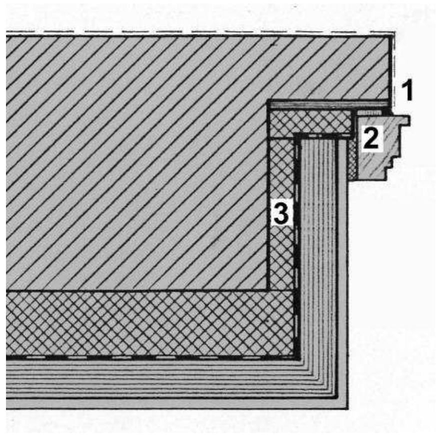

Fig. 3: Exterior joint impermeable to driving rain (1), air-tight joint between air-tight layer and window (2), insulation of window reveal and of the cavity between reveal and frame (3)

The insulation of the window reveal may be thinner if, in addition to the existing window, a second one is installed at the level of the interior insulation. Such a „winter window“ is also practicable when, for instance, the old protected (mullioned) window is to keep its single glazing. But then the joints of the exterior window level must be more permeable to air than those of the interior window area, in order to prevent damage caused by moisture (see fig. 4).

Fig. 4: Example of installing a second window at the level of the interior insulation

3.2.1.2 Connections of new windows

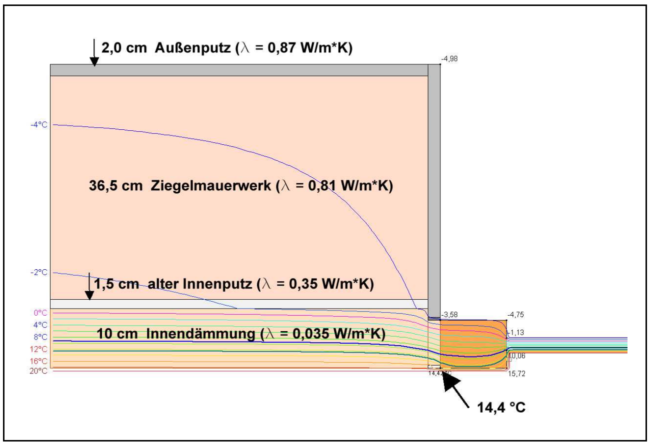

Fig. 5: Temperature curve for windows flush with the interior insulation level

If, as part of thermal upgrading measures, new windows are installed in non-protected houses, the course of isotherms (lines of equal temperature) can be favourably influenced by changing the position of a window within the cross section. The smaller the interior width of the window reveal to be insulated, the smaller the heat loss resulting from this thermal bridge (see figures 5 – 7).

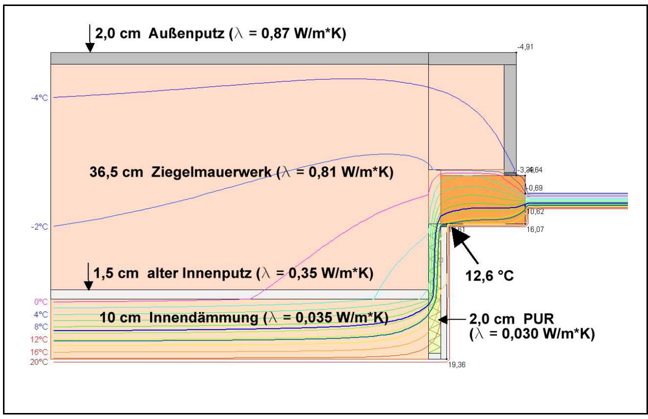

Fig. 6: Temperature curve for windows installed flush with the inner level

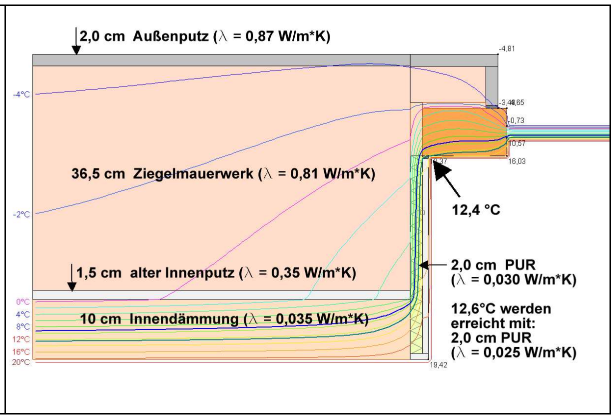

Fig. 7: Temperature curve for windows with external rebates

When installing an insulation system with a vapour-proof barrier on the inside of the room, this barrier should also function as an air-tight layer. So its joint to the window construction has to be made sufficiently vapour-proof, e.g. by using bonding-tapes or special connection profiles. The external joint should be impervious to driving rain.

3.2.2 Flushed structural components

Within structural components flushed with the load-carrying exterior walls (inner walls and ceilings), temperatures also decrease at the edges of the insulation level. To reduce heat loss and mould formation, it may be necessary – at least partly - to insulate also the flush component in the connection area. The degree of temperature decrease depends on the conductivity of the material used for the flush components.

Temperature decrease along the flush joints will be insignificantly slight, if additional insulation is applied to the cavity of double-leaf exterior walls.

3.2.2.1 Load-bearing and non load-bearing walls

In late 19th-century building, non load-bearing inner walls were often made of half-timbered framework. Because of the low thermal conductivity of the materials used for inner walls, usually additional insulation measures are not necessary.

The materials used for stiffening/load-bearing inner walls generally have a higher specific gravity and thus a higher thermal conductivity. In this case it is important to check if surface temperatures may decrease to such an extent that flush components will require additional insulation. Some examples show that even then additional insulation is dispensable if only the prevention of damage is concerned (see figures 8 – 11).

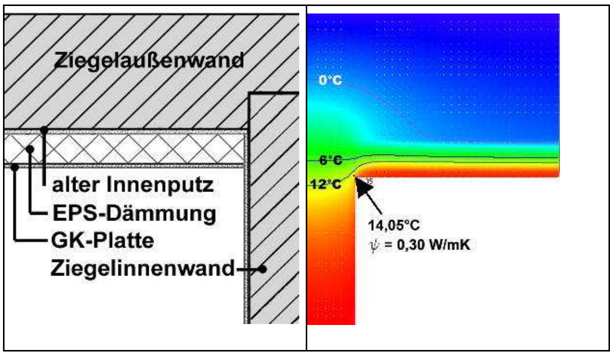

Fig. 8: At the flush joint the calculated surface temperature is 14.05 °C, the Ψ -value is 0.30 (W/mK).

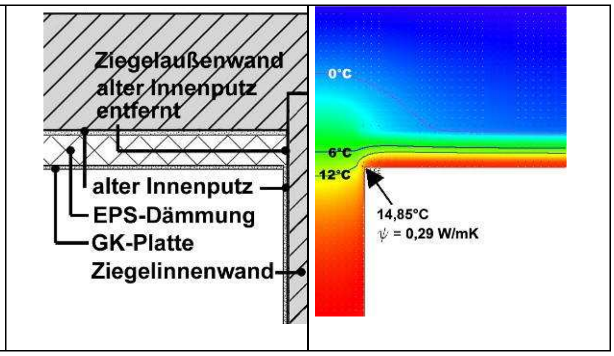

Fig. 9: If the plaster of the inner wall is removed over the width of the interior insulation of the external wall, the temperature at the edge of the room will slightly increase to 14.85°C. In this case the Ψ-value to be expected is slightly reduced to 0.29 (W/mK)..

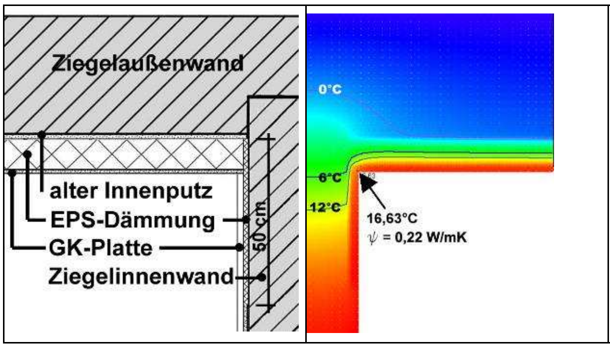

Fig. 10: The temperature of interior surfaces will be considerably increased by installing additional insulation of 2 cm width to the inner wall along a 50 cm wide strip. In this case the calculated temperature is 16.63°C The Ψ -value is reduced to .0.22 (W(mK).

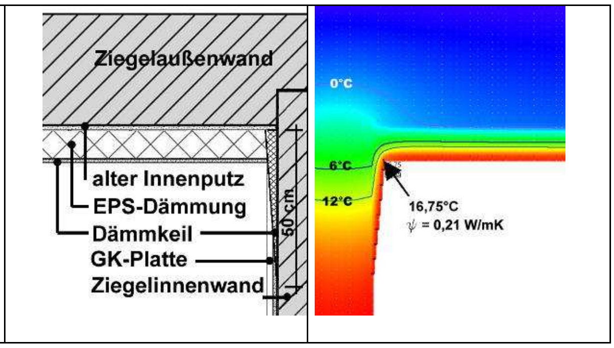

Fig. 11: Surface temperatures can further be increased to 16.75°C by installing an insulation wedge. The Ψ -value is slightly reduced to 0.21 (W/mK).

3.2.2.2 Ceilings of reinforced concrete

Flush building components of reinforced concrete, which may be found in houses rebuilt or modernized in the post-war years, usually require more extensive measures. To avoid damage, insulation must include the bottom side of the ceiling; or one can apply insulation wedges along the ceiling/wall connection. If temperatures are only slightly below the critical point, it is advisable to apply coverings (metal foils) that will conduct heat diagonally or, in eceptional situations, to install additional heating at the flush joint. This heating will not require a lot of energy since temperatures have to be raised only to such a degree that the formation of mould will be prevented.

3.2.2.3 Timber joist ceilings

In the majority of late 19th century houses, floors and ceilings are constructed of timber beams. If the timber joints rest on the exterior wall a careful check of the supports will be necessary before installing insulation.

Examples show that in the usual type of building, characterized by exterior plastering which offers protection against driving rain, there will be no problems provided that interior connections are adequately executed. But in fair-faced masonry constructions the beam ends, due to the smaller dimension of the wall cross section, often lie in an area of the masonry that is greatly affected by moisture. As explained above, additional interior insulation will diminish the drying out of the external wall cross section, therefore the degree of moisture in the cavity around the beam ends can be expected to rise, which will influence the sorption moisture of the wooden material. If a diffusion-tight insulation system is applied, the entry of additional moisture into the structure must be prevented by securing the protection against driving rain and by carefully planning and executing the air-tight layer.

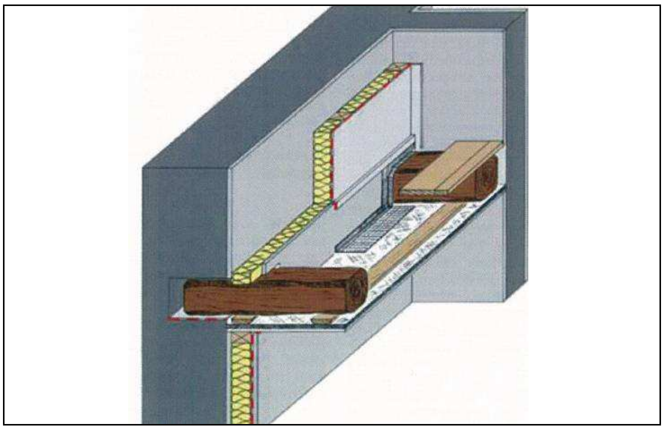

Fig. 12: Position of beam ends in a part of the masonry which is greatly affected by moisture [Energieagentur NRW 2004]

To minimize heat loss, interior insulation should, if possible, be applied to the inner surface of the exterior wall without any gaps, even in the places where the timber joist ceiling rests on supports. For this purpose the wooden floorboards, which run at a right angle to the timber joists, must be removed to insulate the spaces between the beams (see Fig. 12). Depending on accessibility, the ceiling structure can also be opened at the underside to enable the insulation to be installed from the bottom.

3.3 Summary of findings

In the frequent case of insulating rendered 19th century buildings it is not always necessary to choose an interior insulation system with a vapour-proof barrier. Investigations carried out in the context of the research project have shown that insulation systems which are permeable to diffusion are hardly ever applied. When dealing with fair-faced masonry houses which are exposed to driving rain, it is advisable to closely examine the drying-out process, too.The maximum economically efficient thermal insulation is around a thickness of 10 cm (Λ = 0.035 W/(mK), given the usual heat loss through thermal bridges.

Modernization measures of nearly all the inspected buildings included the installation of new windows. The window reveals were mostly furnished with insulation material of a lower thermal conductivity. It is physically effective to install new windows at the level of the interior insulation, because then there will be hardly any decrease in surface temperatures.

When dealing with flush masonry walls, merely to prevent the formation of mould it is not necessary to apply additional insulation to the flush connections. At a high level of thermal protection it will be more energetically efficient to insulate the flanks, too. Flush components of the inspected buildings were mostly furnished with flanking insulation. Similarly, reinforced concrete ceilings often require the insulation of flush connections.

If timber joist ceilings rest on the exterior wall, the wall structure has to be sufficiently protected from driving rain (e.g. by intact exterior rendering) in order to protect the beam ends from damage. Apart from that, convective entry of moisture from the air in the room must be prevented by air-tight interior connections. If there are indications of possible failure (e.g. in the case of single-leaf fair-faced masonry construction exposed to driving rain, or if the building has stood empty for a long time), the load-bearing capacity of the beam ends has to be checked before applying interior insulation. To reduce heat loss, the level of the insulation should be continued in the composition of the ceiling.

If adequately planned and executed, with due consideration to the above-mentioned aspects, interior thermal insulation according to EnEV 2009 can be installed and function damage-free.