Insulation and Façade Systems –  
Timber-based External Façade Systems

# Preamble

Europe sees a great deal of potential for saving energy in the building sector. This is to be tapped by implementing the Directive on the Energy Performance of Buildings (EPBD), since this directive lays down not only thermal standards for major reconstructions of older buildings, but also the “Nearly Zero-Energy Building” standard for new buildings. These goals are to be reached by a combination of increased energy efficiency and utilizing renewable sources of energy. Even though not all member states have finally defined their implementation programs yet, the issue of optimal thermal insulation will play a vital part in terms of high energy-saving potential and economic efficiency.

# Abstract

In this learning unit we show you the possibilities of timber-based external wall structures. Various types of structure and areas of application are shown and practical tips for selecting appropriate insulation materials, for installation and the physics of buildings are given. Planning criteria and feasible insulation standards are described. An important section deals with quality assurance regarding airtightness and minimizing thermal bridging.

# Objectives

**On completing this learning unit students are able to …**

* list components of different systems for timber-based external wall insulation
* compare different insulation systems for timber-based external walls
* present solutions for difficult parts of insulation systems
* describe how various external wall structures are made up
* evaluate wall insulation systems with respect to their advantages and disadvantages
* apply quality criteria to insulation systems

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# Types of external wall structure

## Timber-based external walls

There are several ways of building with timber.

The classic option is a **timber stud/timber frame structure**. **Skeleton structures** or, increasingly, **non-frame timber structures** are also possible. For external walls, we shall look at timber stud/timber frame and non-frame timber structures here.

## Timber stud/timber frame structures

Timber stud/timber frame structures are based on a load-bearing system of timber studs and connecting crosspieces or frames, which are mainly installed at the level of the respective ceilings.



Figure 1: Example of timber frame structure (source: Holzbau Henz GmbH)

### Load-bearing structures in timber stud/timber frame buildings

The load-bearing structural elements in timber stud/timber frame buildings consist of non-frame timber or wood-based materials.

**Solid timber profiles can be used**; they usually have a width of 6 to 12 cm, with stud bays measuring 14 to more than 20 cm. If **glued laminated timber** is used, profiles as slim as 4 cm (say) can be achieved.



Figure 2: Timber frame structure (source: Holka Genossenschaft)

If **I-joists made from wood-based materials** are used, even slimmer profiles are feasible. With these slim structural elements wood-based materials have the advantage that the load-bearing structure involves less thermal bridging. However, the thermal conductivity of wood-based materials can exceed that of solid timber.

In general the structure should be laid out with a grid module that makes installing the cladding and, if used, insulation panels with standard dimensions as easy as possible.



Figure 3: Timber I-joists (source: [www.dataholz.com](http://www.dataholz.com), ein Service der Holzforschung Austria)

**What is thermal conductivity?**

Thermal conductivity is a material property, namely the ability of a material to transport heat through thermal conduction.

The lower the thermal conductivity, the better the insulation effect.

The unit of thermal conductivity (λ) is W/mK.

### Insulation materials in timber stud/timber frame structures

Any insulation material that can be fitted into a prefabricated timber structure can be used. Battens, which adapt to the grid geometry during installing with minor deviations, are particularly suitable. Blow-in insulation, to be injected between the profiles, may be even easier.



Figure 4: injecting cellulose into a timber stud wall (source: Isocell GmbH)

### Fastening/securing in timber stud/timber frame structures

The insulation must be installed so as to achieve permanent dimensional stability and avoid compressing the materials further over time in some areas, leaving air spaces elsewhere.

### Services layer in timber stud/timber frame structures

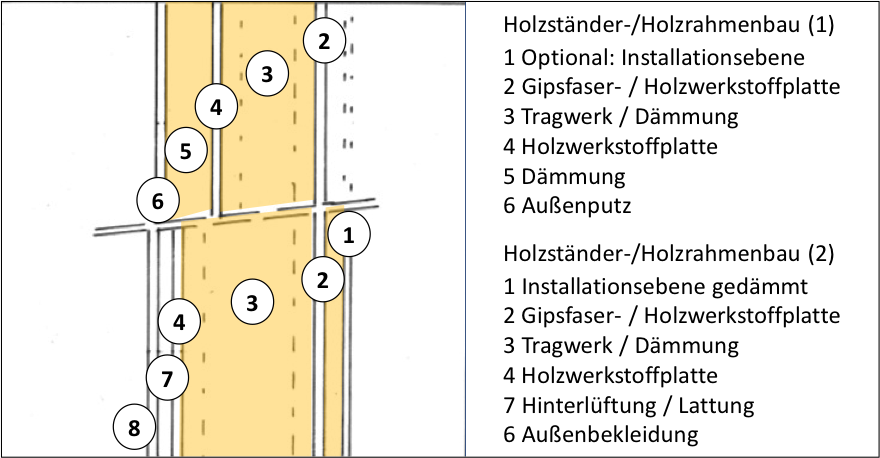
It may be a good idea to provide a services layer about 3 to 5 cm thick on the inside. The advantage of this is that lines for building services can be installed in this layer with no need to penetrate the airtight layer, which usually rests on the interior cladding of the main load-bearing structure; it can be installed and checked before work starts on installing the building services. The insulation of the services layer is on the inside of the airtight layer.

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| **What is an airtight layer?**  The airtight layer is a continuous layer in a building which is located at the inside of the external building components. The airtight layer surrounds the building without interruption. It can be drawn without interruption into a cross-section with a pen (“pen rule”). It surrounds the heated building volume.    Figure 5: Continuous airtight layer of a building (source: Schulze Darup)  In brick buildings the airtight layer is formed by the interior plaster, in timber buildings it is implemented by foils, vapour barriers or vapour seals. |

### Weatherproofing in timber stud/timber frame structures

The classic version of weatherproofing in timber stud/timber frame structures is a curtain wall. The choice of material depends entirely on the promoters’ and architects’ preferences.

An alternative option is to apply an additional exterior thermal insulation system to the cladding on the load-bearing structure (see the following figure).



Timber stud / timber frame structure (1)

1 Optional: services layer

2 Gypsum fiber / wood-based panel

3 Load-bearing structure / insulation

4 Wood-based panel

5 Insulation

6 Exterior plaster

Timber stud / timber frame structure (2)

1 Insulated services layer

2 Gypsum fiber / wood-based panel

3 Load-bearing structure / insulation

4 Wood-based panel

7 Air space / battens

8 Exterior cladding

Figure 6: diagram of a timber stud/timber frame external wall; above, the stud structure with interior and external cladding plus an insulation shell with a plaster surface on the outside; below, a variant with an interior services layer and exterior cladding (source: Schulze Darup, adapted)

Figure 7: prefabricating and installing façade elements (source: Augsburger Holzhaus GmbH)

### U values in timber stud/timber frame structures

**Excellent U values can be achieved with timber stud structures.** This is possible with comparatively modest wall thicknesses, since the insulation can be effective throughout almost the entire wall.If vacuum insulation is used, the result can be walls that reach passive-house standard with a structure 20 cm thick.

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| **Sample calculation**  The following U value calculation for a timber stud/timber frame wall is based on a typical passive-house structure. 8 % of the structure cross-section is taken up by the load-bearing timber structure, and a U value of 0.126 W/m2K results. If the timber element were ignored, the U value would be 0.108 W/m2K; if the timber made up 15 %, this would result in a U value of 0.143 W/m2K.  Layers (from inside to outside) d   1 Plasterboard 1.50 0.210  2 Battens in between: insulation installation 3.00 0.130 / 0.035  3 Gypsum fiber panel 1.50 0.350  4 Battens in between: insulation 28.00 0.130 / 0.035  5 Wood-based material 2.00 0.130  6 Airspace / battens \* 3.00 0.000  7 Cladding \* 2.00 0.000  Corr. 1.00 thickness [cm] 36.00 U value 0.126  Figure 8: U value calculation for a timber stud/timber frame wall; the load-bearing timber structure takes up 8 % of the structure’s thickness, which has a marked effect on the result – if the timber element were ignored, the U value would be 0.108 W/m2K; if the timber made up 15 %, this would result in a U value of 0.143 W/m2K. \* Air circulation and cladding have not been taken into account in the calculation. |

## Non-frame timber structure with external insulation

**Non-frame timber construction involves solid timber elements for walls, roof and ceilings.** The great **advantages** of non-frame timber construction are: **good structural properties in conjunction with comparatively slim structures**; **satisfactory** properties as regards **soundproofing, fire protection and overheating in summer**; and the fact that this type of structure stores considerable amounts of CO2 and thus has a positive impact on the **climate balance** throughout the useful life of the building.

As regards thermal insulation, conditions are similar to those applying to non-frame structures with curtain walls or composite thermal insulation systems.



Figure 9: Vacuum insulation on a non-frame timber wall; cladding is provided by a curtain wall (source: Variotec, Neumarkt)

### Load-bearing structures in non-frame timber structures

The **load-bearing structure** is made up of **solid timber**, actually glued or cross-laminated timber elements. The layers are either glued together or connected mechanically using wooden dowels or metal connectors. **Arranging the layers crosswise counteracts swelling and shrinking across the width of the timber**, so that dimensionally very stable elements result. Wide spans can be bridged with comparatively modest built heights, making this way of construction suitable not only for new buildings, but also for reinforcing weak ceiling structures during renovation.



Figure 10: Dowelled board stack elements (source: Bruno Spagolla)

### Services layer in non-frame timber structures

A services layer on the inside would considerably reduce the advantage of protection against overheating in summer, which is achieved by the mass of the non-frame wall. So it is advisable to choose solutions for the building services that do not require a separate layer, such as **laying cables in the floor** or **in the skirting board**, and vertical slits inside interior plasterboard cladding.

### Insulation in non-frame timber structures

Because of the physics of buildings, the **insulation** should be located **on the outside** of the timber structure. Both a composite thermal insulation system and a curtain wall are options for this. Figure 10 compares possible configurations for these two systems. The U value calculation below (Figure 11) compares the structures and resulting wall thicknesses for a target U value of 0.125 W/m2K.

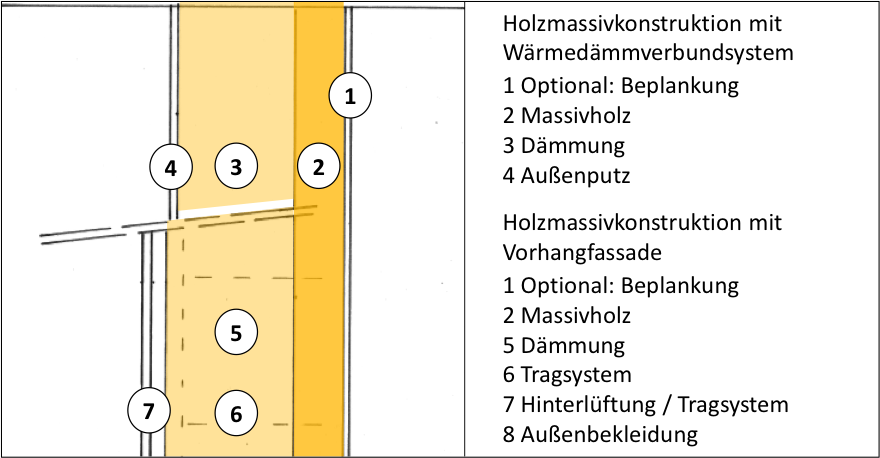
### Fastening/securing in non-frame timber structures

A composite thermal insulation system is installed using either **mechanical fastening**, adhesive or a combination of both, depending on the system in question; **in any case the manufacturer’s instructions for installing must be kept to**.

A curtain wall is secured by methods appropriate to the system in question. Thermal decoupling should be as good as possible. The load-bearing structure has to be taken into account in calculating the U value. The sample calculation below shows this for a timber structure with a curtain wall.

### Weatherproofing in non-frame timber construction

The same systems are possible as with timber frame structures: either plaster over the insulation, or a curtain wall with a wide choice of surface materials, depending on the promoters’ and architects’ preferences.



Non-frame timber structure with composite thermal insulation system

1 Optional: cladding

2 Solid timber

3 Insulation

4 Exterior plaster

Non-frame timber structure with curtain wall

1 Optional: cladding

2 Solid timber

5 Insulation

6 Load-bearing system

7 Air space / load-bearing system

Figure 11: diagram of the external wall of a non-frame timber structure; above, a plaster surface with a composite thermal insulation system; below, a version with a curtain wall (source: Schulze Darup, adapted)

### U values in non-frame timber structures

Non-frame timber structures can achieve good U values with comparatively modest wall thicknesses.

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| **Examples of U value calculations**   1. 1. Here we have a non-frame timber wall with a curtain wall. With this configuration (including air space and cladding) a wall approx. 45 cm thick with a U value of 0.125 W/m2K results. Let’s assume a timber structure for the curtain wall. The share of the load-bearing timber structure within the curtain wall should be as small as possible, and fastening should be done using measures to minimize thermal bridging.   Layers (from inside to outside) d   1 Plasterboard 1.50 0.210  2 Non-frame timber wall 12.00 0.130  3 Timber structure, in between: insulation 25.00 0.035 / 0.130  4 Softwood fiber 2.00 0.045  5 Air space \* 3.00 0.000  6 Cladding \* 2.00 0.000  Corr. 1.00 Thickness [cm] 40.50 U value 0.125  Figure 12: U value calculation for a non-frame timber wall with a timber-based curtain wall; the share of the load-bearing timber structure within the curtain wall should be as small as possible, and securing should be done so as to minimize thermal bridging. Assuming a 5 % timber share, a U value of 0.125 W/m2K results. \* Air circulation and cladding have not been taken into account in the calculation.   1. 2. For comparison, here is a calculation for a version of a non-frame timber structure with a composite thermal insulation system – often the more cost-effective choice. For a comparable U value the wall is about 6 cm less thick, which has a considerable effect on economic efficiency, especially in inner-city locations, because living space in a typical apartment building can be increased by almost 2 %.   Layers (from inside to outside) d   1 Plasterboard 1.50 0.210  2 Non-frame timber wall 12.00 0.130  3 Insulation 24.00 0.035  4 Exterior plaster 1.50 0.520  Corr. 1.00 Thickness [cm] 39.00 U value 0.124  Figure 13: U value calculation for a non-frame timber wall with a composite thermal insulation system (in comparison with the previous calculation). For almost the same U value the wall is a few centimetres less thick in this case. |

### Excursus

The following overview contrasts planning aspects of timber-based construction with those of non-frame construction and compares their advantages and disadvantages:

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| **Timber-based construction** | | |
| **Advantages**: - Temporary carbon storage with favorable impact on the climate balance  - Primary energy input to the building is lower than that of most non-frame constructions  - Wider choice of insulation materials for most designs  - Considerable architectural freedom in façade design | **Disadvantages**: - Soundproofing and fire protection - Timber protection - Emission behaviour of timber surfaces, particularly wood-based materials - In general more elaborate planning required - Construction costs are higher for high-quality implementation | |
| **Non-frame construction** | |
| **Advantages:**  - Cost - Soundproofing (heavy building materials) - Fire protection - Practically no emissions from mineral construction elements with mineral plaster and coating  - Heat storage capacity for protection against overheating in summer - Aura of value stability | **Disadvantages:**  - Primary energy balance sheet - Choosing insulation materials is harder: polystyrene and mineral fibres are common, renewable or purely mineral insulation materials are possible, but more expensive |

Regarding this comparison matrix, it should be noted that accurate assessment is possible only if the entire system of a building is taken into account.

# Quality criteria for producing an insulation system

## Quality assurance at the planning stage

Energy-optimized buildings should be planned by a planning team in which all relevant trades are represented.

In selecting the insulation system, for example, this involves taking users’ wishes into account together with structural requirements, and implementing them in terms of high-quality architecture. Along with this, numerous technical and legal aspects, such as soundproofing and fire protection, and of course energy-related requirements, play a part.

Nowadays a building is fit for the future only if high-grade heat protection is provided. This involves not only a U value of at most 0.15 W/m2K, but also requirements concerning airtightness and minimizing thermal bridging, which have to be taken into account as early as the planning phase. The simpler the design of the building and the less complicated the interfaces, the more cost-effective erecting the building can be.

**The target should be simple systems which are easy for skilled workers to implement and which need only a minimum of maintenance during use.**

## Quality assurance during construction

If planning and scheduling have been done with the above-mentioned aspects in mind and have been described clearly in the tender documents, the contractors’ job is to carry out the work with as few defects as possible.

**For this it is important to clarify and reach agreement on the details, and particularly the interfaces between the various trades, within the construction team at an early stage.** If the contractors’ tasks are clarified in detail in advance, this will avoid some misunderstandings during the construction phase.

However, all contractors are obliged to inform every single tradesperson about their tasks on site and to train them in innovative techniques as appropriate. Advantage should be taken of training courses offered by energy agencies, trade associations or producers, too.

Finally, site management by the architect must ensure not only that the tasks are coordinated continuously, but also that they are performed without defects. Regular visits to the site are essential here, as are the interim and final acceptance procedures.

## Airtightness

**The passive-house standard for buildings requires an ACH50 value of at most 0.6 1/h, to be demonstrated in a blower-door test.**

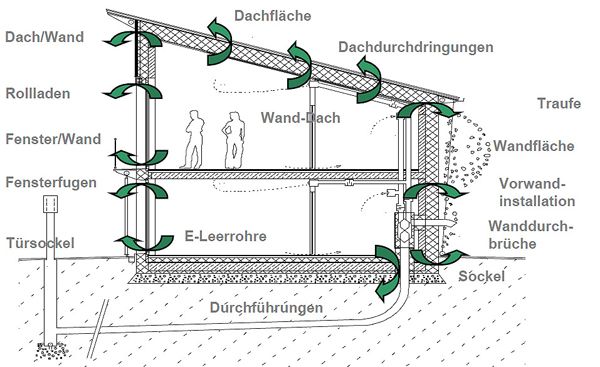
The **airtight layer** must be taken into account r**ight from the start of planning**, and must be implemented with precision in detailed planning.

**In timber stud and timber frame structures the airtight layer is generally located at the cladding or the vapour barrier on the inside of the load-bearing system.**

In **non-frame timber structures** it is **on the inside of the non-frame timber layer**.

In **non-frame external walls** the airtight layer is formed **by the interior plaster** in all the configurations described. In non-frame construction an air seal is usually achieved by means of the interior plaster or by levelling on the inside of the external masonry.

The following diagram presents an overview of the potential weak spots in the airtight layer (junctions between and penetrations through building elements).



Roof surface

Penetrations through roof

Eave

Wall surface

Pre-wall installation

Penetrations through wall

Wall/roof

Roller shutters

Window/wall

Window joints

Empty electrical conduits

Wall/roof

Dado

Door base

Leadthroughs

Figure 14: Section through a passive house, showing the problem areas within the airtight layer (source: Schulze Darup, PHS 2.1 slide p. 20, adapted)

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| Figure 15: Measuring for leaks where a beam penetrates the roof (source: Schulze Darup) | Figure 16: Airtight connection between timber wall and ceiling above ground floor (source: Schulze Darup)    Figure 17: Airtight layer in timber construction (source: Schulze Darup) |

**A video on airtight building:**

<https://www.youtube.com/watch?v=S9-lsaMmqDQ>

## Minimizing thermal bridging

Thermal weak spots, as compared to the average heat transfer coefficient of an external construction element, are called thermal bridges. These spots must be analysed in terms of heat losses. The differential value is the coefficient of thermal bridging loss (Ψ) in W/mK.

Structure geometry involves a risk of thermal bridging at projections or corners, for example. However, if the insulation is drawn around the corner at almost the mean insulation thickness, this results in a “negative” thermal bridge.

This means a small plus when the heat losses through the external construction elements are calculated.

Interior corners always involve additional thermal bridging due to geometry.

To minimize the thermal bridging at windows/surrounds in all types of configuration, the insulation must be drawn over the window frame as far as possible.

## Additional quality criteria

**Depending on the type of structure, the following additional considerations apply:**

**Timber stud/timber frame structures:**

In U value calculation, the first thing is to compare the timber and insulation shares of the structure; both enter into the U value of the area overall. In addition, thermal bridging at the dado, at the intersecting ceilings, at the roof transition and, if applicable, at intersecting inner walls must be taken into account.

**Non-frame timber structures with external insulation:**

If the thermal insulation is on the outside, intersecting construction elements do not generally form thermal bridges. Dado and roof intersection usually enter the calculations of heat flow as negative thermal bridges, due to the geometry of outside corners. Penetrations of the insulation layer to the outside, such as spot thermal bridges for anchors, are disadvantageous.

**External wall structures with composite thermal insulation systems (ETICS):**

As far as thermal bridging is concerned, these are similar to non-frame timber structures: no problems with intersections of inner walls and ceilings; advantages at outside corners such as dado and roof connection, if the insulation is drawn around the corner at full thickness. In recent years systems to minimize thermal bridging have been developed for mounting construction elements on the outside of the wall; these should be included in the thermal bridging balance sheet.

**External wall structures with curtain wall:**

Basically the same applies as for external walls with ETICS. But since there is a load-bearing scaffold for the facing on the outside, this has to be taken into account in the U value calculation. On the other hand attaching lightweight construction elements to the façade is not a problem, because they can be fixed to the load-bearing scaffold. Spot thermal bridges due to structurally relevant penetrations must be assessed individually.

**Single-shell external wall structures:**

All construction elements with deviating coefficients of thermal conductivity must enter the balance sheet as thermal bridges if they intersect the external wall. This is the case for ceilings, due to the necessary load transfer, and possibly for walls because of soundproofing requirements. On the other hand, dado and roof connections can usually be implemented with negative heat transfer coefficients, which means they yield a small bonus in the energy balance sheet.

**Double-shell external wall structures:**

Basically the same applies to these as to external wall structures with a curtain wall.

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