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Thermal bridge comparison

Thermal benefits of CLT

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Thermal bridge comparison
Thermal benefits of CLT

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ABSTRACT

The aim of the thesis was to investigate the thermal properties of different frame materials and structures. The aim was to prove that wooden buildings have better thermal properties than other frame materials. There was five different frame materials, which were compaired by using eight different structures. The client for the thesis is Stora Enso.

One of the main purposes of the thesis was to study trough the comparisons, wheather CLT (cross laminated timber) and generally wooden buildings have better thermal properties compaired to concrete or brick buildings. The comparison is calculated and analyzed by using software called Flixo. Flixo is especially made for calculating thermal bridges.

In the theory part the focus was on introducing CLT and the other frame materials. It also explains what thermal bridges are, how to prevent them and what consequences of they have. The theory part also explains the calculation formulas and ther symbols which are used in calculations.

The results of the thesis were clear. CLT and wooden buildings have lower heat losses through plane surfaces and trough the junctions, even though the wall is not as thick as with compaired frame materials.

Key words: thermal bridge, CLT, thermal analysis, Psi-value, U-value

Lahden ammattikorkeakoulu
Puutekniikan koulutusohjelma

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TIIVISTELMÄ

Opinnäytetyön tavoitteena oli tutkia eri runkomateriaalien ja erilaisten rakenteiden lämpöominaisuuksia. Tavoitteena oli todistaa miten paljon paremmat lämpöominaisuudet puisilla rakennuksilla on käyttämällä viittä eri runkomateriaalia, joita verrattiin kahdeksassa erilaisessa rakenteessa. Opinnäytetyön toimeksiantaja on Stora Enso.

Runkomateriaalien vertaus suoritettiin laskemalla ja analysoimalla Flixo-ohjelmalla. Flixo on tehty erityisesti kylmäsiltojen laskemista varten. Yksi tärkeimmistä asioista opinnäytetyössä oli tutkia vertausten avulla onko CLT:llä(cross laminated timber) tai yleisesti puurakennuksella paremmat lämpöominaisuudet kuin verrattavilla runkomateriaaleilla.

Teoriaosuudessa keskitytään esittelemään CLT ja muut runkomateriaalit. Teoriaosuus kertoo myös mikä on kylmäsilta, kuinka kylmäsiltojen muodostuminen voidaan estää ja mitkä ovat mahdolliset seuraukset, joita ne aiheuttavat. Teoriaosuudessa kerrotaan myös laskuissa käytetyt kaavat ja symbolit.

Opinnäytetytyön tulokset olivat selvät. CLT:llä sekä puurunko rakenteisilla taloilla oli matalammat lämpöhukat liitosten sekä tasaisen pinnan läpi, vaikka runkomateriaali ei ollut läheskään yhtä paksu kuin verrattavissa materiaaleissa.

Avainsanat: kylmäsilta, CLT, lämpöanalyysi, Psi-avo, U-arvo

CONTENTS

1 INTRODUCTION

The purpose of the thesis is to investigate thermal properties of different kinds of frame materials in different kinds of structures and prove how much better thermal properties wood have. The results are showed in thermal analysis and calculations. One of the main targets is also to examine the benefits of building with cross laminated timber (CLT), but also going through the other options by calculating and analyzing thermal bridges in different structures and lay-ups.

This thesis is only focusing on thermal properties of different lay ups. Condensation risk is not taken into consideration.

My own goal for this thesis was to learn about different structures and lay-ups and also investigating causes and consequnces of thermal bridges in more detail. One of the most important aims was to learn to understand how to prevent heat loss and how to design and build houses with as minimal heat losses as possible. I also investigated different junctions, and with different methods to build them.

I wanted to make this thesis as comprehensive and diverse as possible, by using different frame materials and structures. Through a lot of research I also managed to make the thesis as informative as possible.

This thesis has been made in cooperation with Stora Enso and during my intership in Stora Enso, Austria. Only Stora Enso´s CLT material properties are used in the calculations.

2 CLT - CROSS LAMINATED TIMBER

Wood is a building material for the future. People have built with wood through generations, because of its good formability and durability. After decades of domination of concrete constructions, people have again become aware of the good properties of wooden houses. Wood constructions are more common every year and CLT has already gained its place in the construction industry for being a significantly faster building material than others in the market.

2.1 General information

CLT is a solid wood panel, which is made of at least three bonded single-layer panels arranged at a right angle to each other. Bonded single-layer panels are cross laminated to create a panel which has good strength properties and durability. CLT is suitable for load-bearing structures, but it is also used for partition walls, roofs and floor structures. The raw material used in CLT is usually spruce or pine.

FIGURE 1. Cross laminated timber (Puuinfo, 2014)

Technical specifications

Use	wall, ceiling and roof panels
Maximum width	2.95 m (on request up to 4.00 m)
Maximum length	16.00 m
Maximum thickness	400 mm
Panel design	3, 5, 7 or 8 layers
Machining	any cut required
Wood species	spruce, pine
Wood moisture	12% ± 2%
Visual quality	non-visible, industrial visible and visible quality
Surface	sanded on both faces

Weight approx.	470 kg/m³ CLT
Water vapour transmission resistance	20–50 μ
Thermal conductivity	0.11 W/(mK)
Specific heat capacity C_p	1,600 J/(kgK)
Usage	class 1 and 2

(Stora Enso, 2015)

2.1.1 Manufacturing CLT

The CLT manufacturing line is highly automated and it starts from sorting the wood planks according to the quality and dimensions. The planks are finger-jointed to reach the desired length. After finger-jointing, planks go through four-edge -plane and gluing machine. Glue is spread to the edges of the planks and the planks are placed in a press, where the one layer of panel is created.

When the panels are pressed, they are sawed to the right dimensions. After this, panels are cross laminated, using a four-edge press. The four-edge press ensures that the panels do not move during the pressing. In CLT there is always an uneven number of layers, so that the panel will not warp in any directions after the press. Ready made CLT panel has a moisture content about 12 %. Surface finishing for the panel is just sanding and puttying.

Depending on the use, the panels are formed with a CNC machine to fit for the customer’s demands. Window-and door places are made with CNC-machine.

It is also possible to manufacture CLT by nailing layers together. The manufacturing process is the same, but instead of gluing the panels together they are stacked crosswise by nails. Also in this case the number of layers must be uneven.

2.2 Use

CLT panels are mostly used in constructions. They can be used in wall, floor and roof structures. With CLT it is possible to build multi-storey houses and because CLT comes to the construction site as a ready formed element the building time of a house is significantly shorter than when building a house with e.g. a brick or wooden frame. CLT elements are also light, so with the help of a crane, they don’t need many men to assemble them.

FIGURE 2. CLT construction site in Graz

When building with CLT, one must take into consideration that, CLT must be protected against moist surfaces e.g. concrete and masonry.

CLT has many good properties escpecially for constructions. Besides being ecologic and a material with good strength properties, it is also energy efficient, airtight and fire-safe. It has good acoustic properties and flexible possibilities for building design and healthy inner air.

2.3 Quality

There are three different surface qualities for CLT. The choise of quality depends on where in a construction the CLT panel is used. Visible structures must have high surface quality, but panels which are invisible do not need as high quality recuirements.

From attachment files you can find exampls of quality recommendations from Stora Enso.

2.4 Environment

Wood is a renewable material, which is not going to run out and this is one of the reasons why building with wood is growing more and more popular in multi-storey buildings and single family house houses. Building with CLT is environmentally friendly and the buildings have long lifespans, up to 80 years.

CLT production uses a lot of electricity, but it also creates wood chips and saw dust, which are used in power plants to create more energy. CLT panels are also bonded by using environmentally friendly adhesive, and it can be recycled after use.

In the University of British Columbia, they have investigated the environmental performance of CLT and concrete in a five-storey building; by redesigning an already existing building with CLT. This building is located in Canada and it was built using a reinforced concrete structure.

Initial embodied energy represent the non-renewable energy consumed in the acquisition of raw materials, their processing, manufacturing, transportation to site and construction.

> *Compared to reinforced concrete, laminated timber system could save about 18% of non-renewable energy (Chen 2012, 22).*

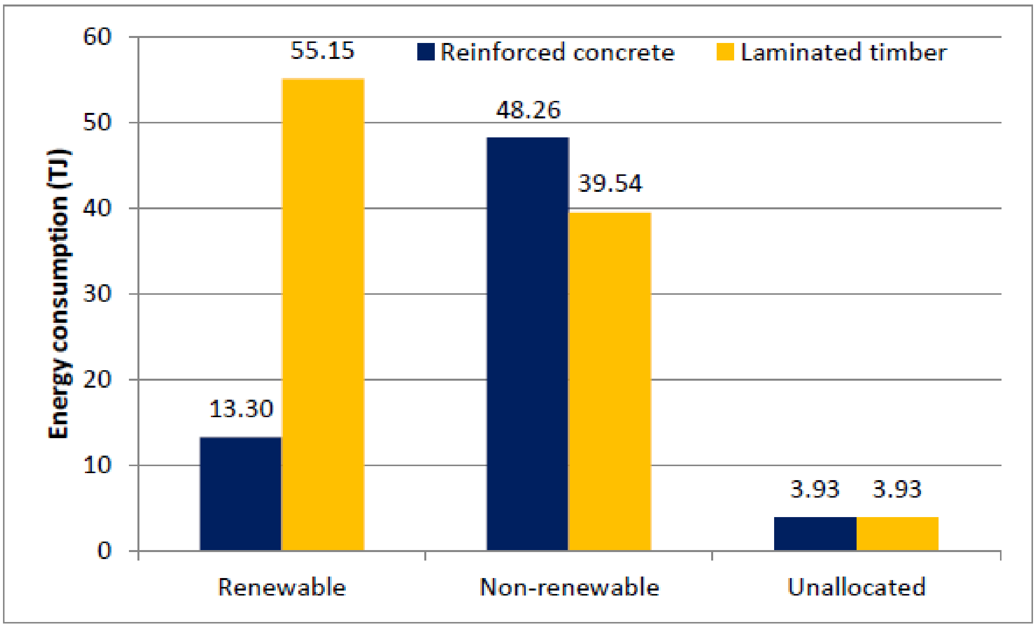


FIGURE 3. The total initial energy consumption to construct the building using reinforced concrete or laminated timber systems (Chen 2012, 23)

Notice that in Figure 3 the advantages of CLT, like wood chips, which are created when CLT is manufactured, are not taken into consideration as a renewable energy even though it is used for creating energy. If it were taken into consideration, it would increase the renewable energy advatanges of CLT.

2.5 Thermal conductivity

In general, thermal conductivity means heat transfer along the material when the material itself is not moving. The thermal conductivity of materials is that amount of heat which during the unit time transfers along the material in the unit length and one degree of temperature difference between two known surfaces. W/(m·K). (Kärkkäinen 1985, 242-243. Translated by writer)

Thermal conductivity of wood is low because of its porosity and also because of the properties of its constituent. According to Tuomola and Ruso (1957) the thermal conductivity of pine and spruce is perpendicular to wood grain, and it is about three times more compaired to generally used glass wool insulation. Anyway compaired to the mechanical strenght of wood the thermal conductivity is low. (Kärkkäinen 1985, 242-243. Translated by writer)

According to many studies, thermal conductivity of each wood type is directly proportional to the density of the wood piece, so that when the density grows, also thermal conductivity grows. Increased huminity, also increases thermal conductivity significantly. (Kärkkäinen 1985, 243. Translated by writer)

Thermal conductivity of CLT is a bit lower than normal wood. This is because of the cross laminating and the glue between the layers.

3 OTHER LAY-UPS

I chose five different kinds of lay ups for this theses, and for the CLT and timber frame I used a plaster façade and a wooden façade as well, to see the difference in both cases. In this chapter, I introduce briefly the other lay-ups I have used for the following calculations, to understand why these lay-ups have been chosen to be the comparison for CLT.

3.1 Timber frame

Timber frame constructions are chosen for the thesis mainly because it is good comparison for CLT and it is also a common way to build a house in Finland and in the rest of Europe as well.

FIGURE 4. Timber frame construction (Buildinganddiy 2014)

I took timber frame lay-ups directly from the German website dataholz and the same lay ups are used in every timber frame calculation. Drawings in the calculations are either plan view or vertical section view and in the vertical section the timber frame is invisible, but it has been taken into consideration in the calculations. Timber frame constructions do not use expanded polystyrene (EPS) as an insulation material, and this is why it can not been found from timber frame calculations.

Like CLT, timber frames also have low thermal conductivity, which gives it the best thermal properties that constructions can have. Thermal conductivity which is used for the calculations is the general thermal conductivity of wood.

A timber frame building is faster to build than a brick or concrete building, because drying time is not needed. Like CLT buildings, the wooden frame buildings also have healthier inner air than the reference lay-ups have.

3.2 Brick masonry

FIGURE 5. Brick masonry construction. (Wienerberger 2014)

I wanted to calculate brick masonry structures as well, because it is a common building type all around Europe. Brick masonry has good strenght properties and it can withstand different kind of natural phenomenons.

It is possible to make brick masonry with steel reinforcement by adding bars and wires inside the bricks. This makes it stronger and more durable, but in the following calculations, I have only used normal brick masonry without reinforcement. It can also been made with insulation inside the brick, but I haven’t take this into consideration either.

One big benefit that brick has is its small size. It can be used for nearly any construct configurations, but it also makes the designing harder, because each brick will have unique section properties. Figure 5 shows a typical brick masonry frame at an early stage, without interior plaster or insulation. (The Brick industry association 1993)

A brick house does not have so good thermal properties as a wooden house, because of higher thermal conductivity of bricks. Also, the building time is longer because the masonry needs time to dry. All the material properties of brick masonry have been taken from a book called Gemaurte Wände, made by Pech and Kolbitsch.

3.3 Concrete

Figure 6. Concrete constuction site. (Aaro Kohonen FMC Group, 2014)

Concrete constructions have ruled the construction industry for decades. This is why it was interesting for me to investigate the thermal properties of the biggest competitor of wood.

If big, stable and safe structures, which are often linked to the water are needed, concrete is the good a option. As a load bearing material concrete has gained popularity because of its low price, resistance of moisture, its strength and its stiffness. Concrete is also ductile and safe. (Betoni 2013)

Concrete constructions are strong and they can withstand hurricases and eathquaekes. With concrete it is possible to build really high skycrapers, but it is also used in smaller multi-storey houses and bridges. As in brick concstructions, concrete constructions also need drying time.

Thermal conductivity of concrete is high compaired to wood and also because of heat and temperature variations there may be cracking problems.

In the calculations I have used reinforced concrete with 1 % steel. Also some brick masonry lay-ups include concrete if there is a balcony or an intermediate floor.

3.4 Concrete sandwich

A concrete sandwich is the most common concrete element type. It contains insulation layer between an interior and exterior concrete shell. This is shown in Figure 7. (Sisäilmayhdistys 2013)

Thermal insulation used in concrete sandwich elements are usually EPS or PUR. This is why in the calculations, wood fibre insulation has not been taken into consideration. The anchoring material used in concrete sandwich calculations is stainless steel.

FIGURE 7. Concrete sandwich element (Weckenmann 2014)

Concrete sandwich lay-ups have similar thermal properties as normal reinforced concrete, but because of anchoring penetrating the insulation layer the thermal conductivity and heat losses are a bit higher. In the calculations anchoring has been taken into consideration even though it can not be seen in every drawing. I wanted to see the thermal differences between the sandwich element and the reinforced concrete element. The difference is not that big, as you can see from the results.

As the thermal properties are similar, so are the risks. Concrete sandwich structure may also crack because of heat and temperature variations. Also, if the moisture somehow finds its way into the insulation layer, it cannot get out and this way causes condensation.

4 THERMAL BRIDGES

4.1 General information

A thermal bridge is a localised area of the building envelope where the thermal conductivity is bigger than in the surrounding structures. The heat energy moves from molecules to other molecules allowing heat to flow through the path created. The larger the difference is between exterior and interior temperature in the building, the faster the building gains or losses heat. From Figure 8, is possible to see the building envelopes heat losses and where they are located. (Thermal bridge catalog unpublished.)

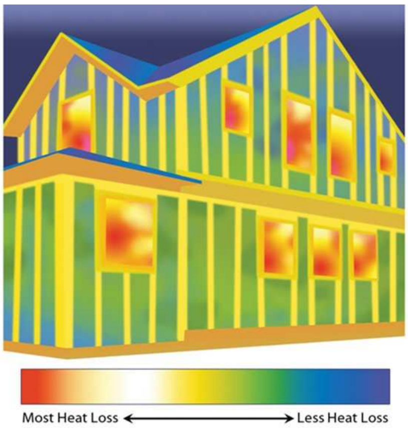


FIGURE 8, Heat losses in building envelope (Suistanabilityworkshop 2014)

The most obvious locations for thermal bridges are where different kinds of building material join. These locations are parts in the building envelope where there are geometrical changes, deliberate penetrations, or places with structural changes. (Thermal bridge catalog unpublished)

Heat losses through the building envelopes occur in two different ways. One way is the heat losses through the plane areas (e.g. the walls, roof, floor and windows) and an other is through the junction between the plane areas (thermal bridge). (Thermal bridge catalog unpublished.)

The material properties are affecting the heat transfer as well. Thermal bridges can not be sufficiently evaluated by the one-dimensional models of calculation which are normally used in standards and norms for the thermal performance of building, because thermal bridges are charactized by multidimensional heat transfer. (Thermal bridge catalog unpublished.)

There are two basic kinds of thermal bridges:

Geometrical thermal bridge

Geometrical thermal bridges are formed because of geometrical changes in the building envelope. This kind of changes are components which differ from the flat form, direction changes of the surfaces forming in the building envelope, locally reduced thickness of the surfaces forming or corners and edges in the building envelope. The situation like this is presented in Figure 9. (Thermal bridge catalog, Stora Enso, 2014.)

> *They can be 2-dimensional (where 2 planes intersect) or 3-dimensional (where 3 or more plane intersect). The occurrence of geometric thermal bridging is likely to increase the more complex the building geometry is. (Leeds Becket University 2014.)*

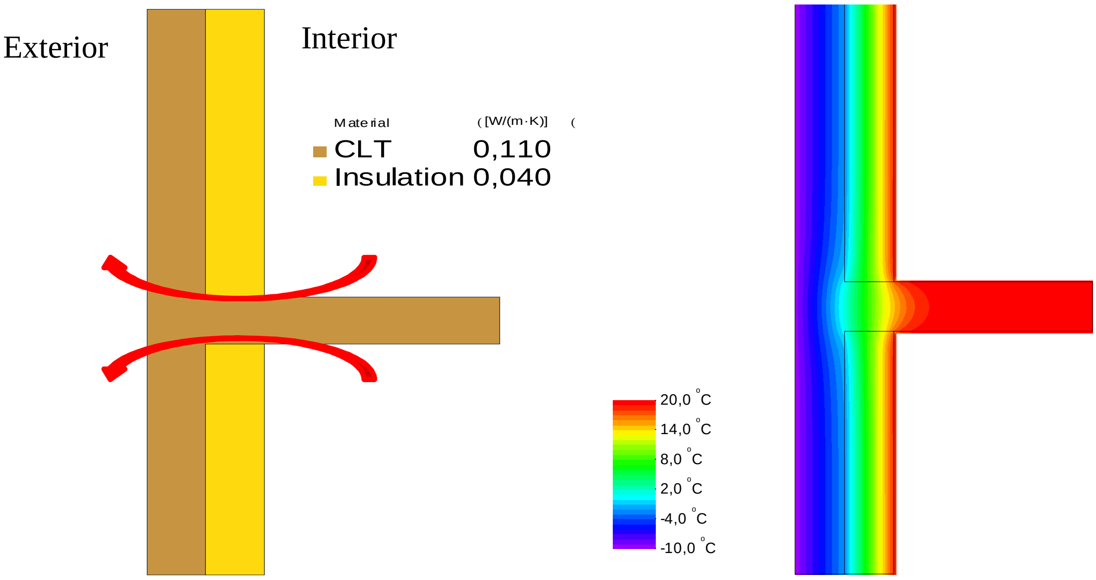


FIGURE 9. Geometrical thermal bridge in a wall structure with inner insulation (plan view) (Thermal bridge catalog unpublished.)

Material related thermal bridges

A materials high thermal conductivity is also one of the main factors causing thermal bridges to the building envelope. Wood does not have so high thermal conductivity and therefore is does not transfer the heat as well as e.g. steel. (Thermal bridge catalog unpublished.)

Thermal bridges related to material properties are located in areas where the thermal properties of one or several layers of a structural element are changed e.g. a concrete column in a brick wall or mounting equipment penetrating the element. This kind of situation is presented in Figure 10 below. (Siegen University 2014.)

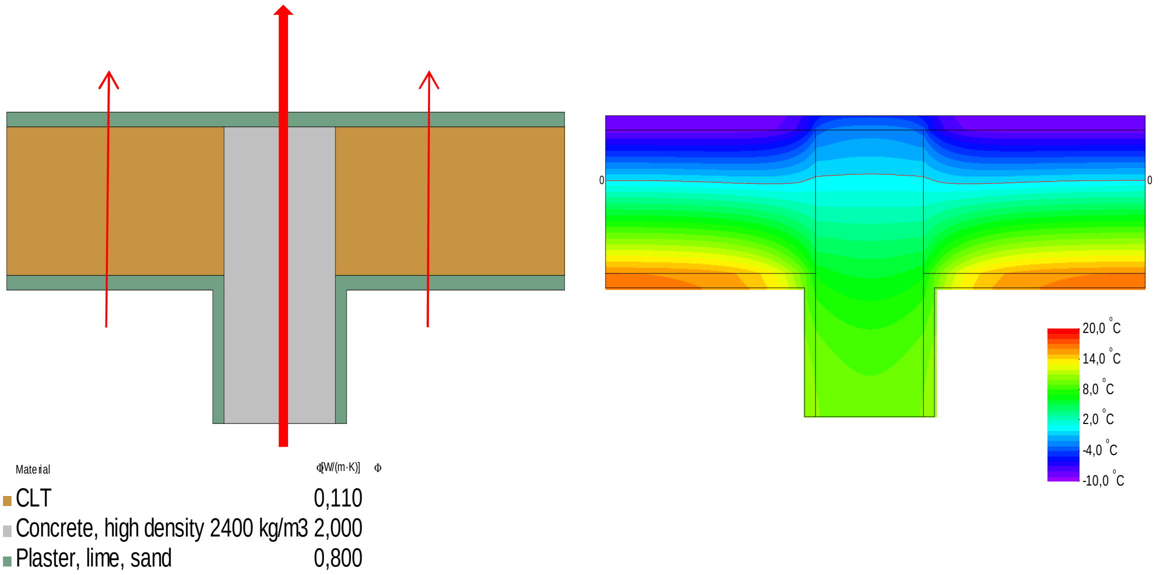
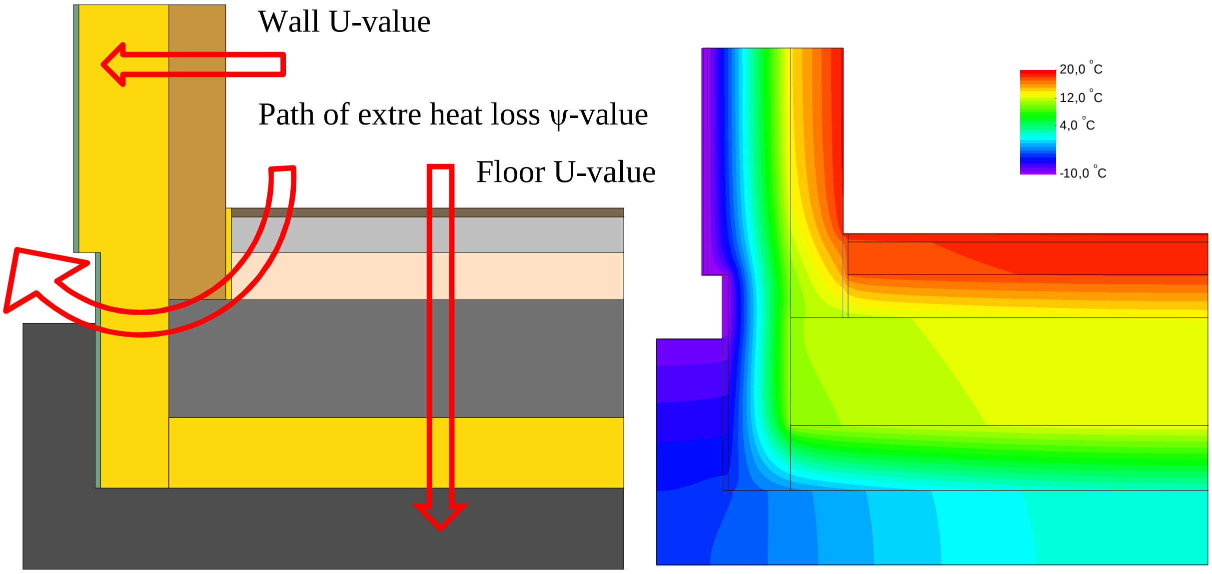


FIGURE 10. Material related thermal bridge in a wall structure (plan view) (Thermal bridge catalog unpublished.)

Furthermore, there are two ways thermal bridges appear in buildings, either in linear or in punctual form.

Linear thermal bridges

Linear thermal bridges emerge at joints over the length of the building component e.g. at window sill details, balconies or eaves joints. Figure 11 is presenting the linear thermal bridges. The heat loss from a linear thermal bridge is called the linear thermal transmittance coefficient, the ψ-value. The magnitude of ψ-value depends on different dimensions of the components and the quality of structure junctions and it is connected to the U-value. With ψ-value you can calculate the total heat loss through thermal bridge connections between building components. (Thermal bridge catalog unpublished.)



Material	φ[W/(m·K)]	φ
■ CLT	0,110	
■ Clay aggrigate	0,101	
■ Concrete, high density 2400 kg/m3	2,000	
■ Concrete, reinforced (with 1% of steel)	2,300	
■ Insulation	0,040	
■ Plaster, gypsum, sand	0,800	
■ Plywood 500 kg/m3	0,130	
■ Sand and gravel	2,000	

FIGURE 11. Linear thermal bridge through wall anchorage at the foundation slab and its thermal analysis (Thermal bridge catalog unpublished.)

Point thermal bridges

Point thermal bridges emerge if e.g. a building envelope is penetrated by metal parts like screws or dowels. Figure 12 is showing exterior wall, which is penetrated by steel component and causing this way point thermal bridge. Also, columns or overhanging beams (which penetrate the exterior wall) can cause point thermal bridges. (Thermal bridge catalog unpublished.)

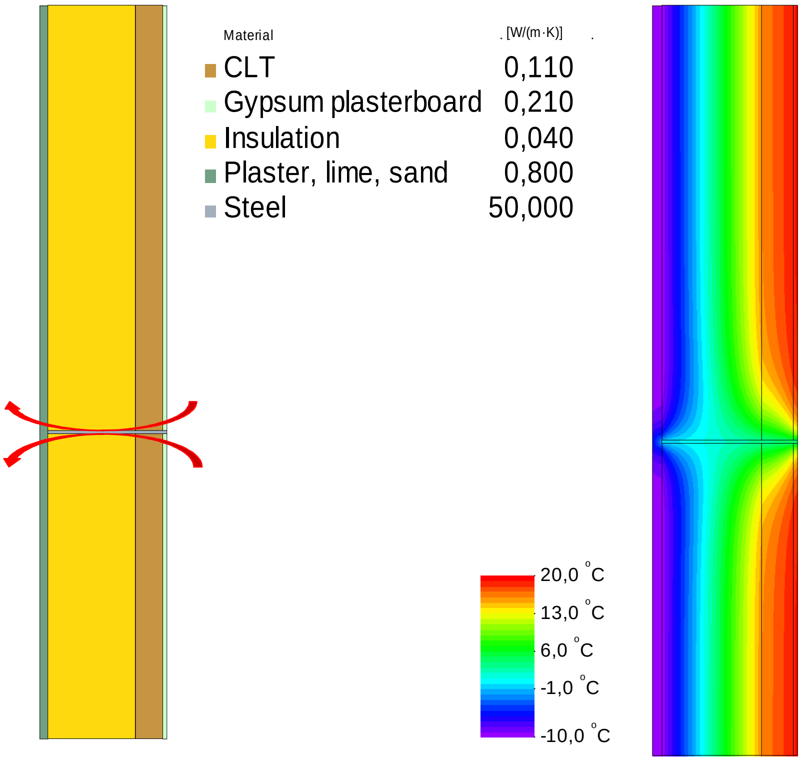


FIGURE 12. Steel component penetrating insulation and CLT structure creating a point thermal bridge (Thermal bridge catalog unpublished.)

4.1.1 Thermal bridge calculations

Thermal bridge calculations need different values, which are presented in this chapter.

U-value

U-value is a measurement for heat loss in a building component e.g. wall, floor or roof. It can also be used to measure how well parts of the building transfer heat, which is why it is also referred to as an overall heat transfer co-efficient. High U-value means low thermal performance of the building envelope. A low U-value usually means high levels of insulation. (Thermal bridge catalog unpublished.)

> *The unit for the U-value is* $W/m^2 \cdot K$ *and it means the rate of transfer of heat, in watts trough one square meter of a surface divided by the difference in temperature across the structure. (Antherm 2014)*

U-value calculations are recommended to be performed in the early stage of the desinging process to avoid expensive re-work later in a project. (Thermal bridge catalog unpublished.)

ψ-value

> *ψ-value is a measurement for linear thermal transmittance and it means the extra heat loss through a junction. ψ-value is pronounced Psi-value and its unit is W/mK, which means the heat flow rate in the steady state divided by length and by the temperature difference between the environments on either side of a thermal bridge. (Antherm 2014)*

ψ-value depends on several values such as the U-value of the adjacent building components, the quality of the components and their connection, heat flow term and which type ψ-value is determined. (Thermal bridge catalog unpublished.)

ψ-value can be negative or positive, depending on wheather interior or exterior dimensions of building components are considered. If for the calculation of heat loss through exterior dimension of plane building components are considered, the heat loss at e.g. wall corners is overestimated (or rather considered twice) and therefore the linear thermal bridge, or rather Psi-value, may become negative. The picture below, Figure 13 is showing a plan view of an exterior wall corner, shall give better understanding abouot negative and positive Psi-values. (Thermal bridge catalog unpublished.)

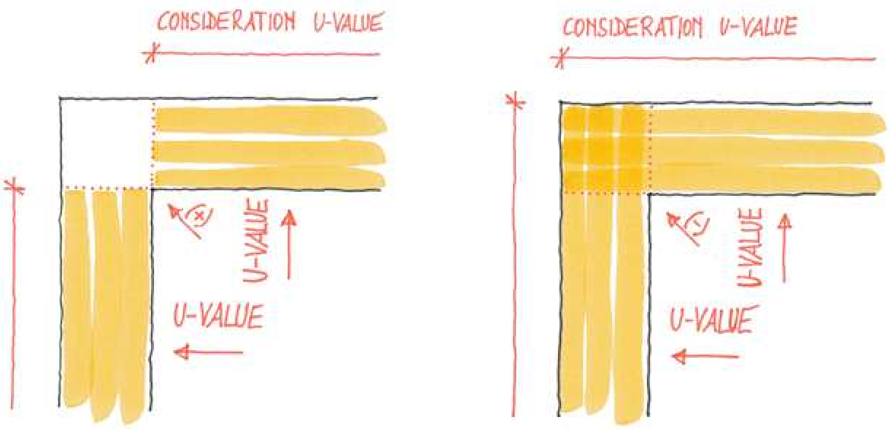


FIGURE 13. Negative and positive Psi-values. (Thermal bridge catalog unpublished.)

> *ψ-value is different for point thermal bridges. It is called Chi and it means point thermal transmittance. The unit for point thermal tranmittance is W/K, which means heat flow rate in the steady state, divided by the temperature difference between the environments on either side of a thermal bridge. (Antherm 2014)*

φ-value

Also known as Fii-value. φ-value means heat flow rate that flows trough a particular surface line. The heat flow value is positive if it flows into the observed system and negative if it flows out of the system. Unit for φ-value is W/m and it means watts per linear meter (constructional element perpendicular to the section). (Thermal bridge catalog unpublished.)

λ-value

λ-value is known as lambda value and it means thermal conductivity of the material. The unit is W/(m·K). Thermal conductivity is explained in chapter 2.5.

4.1.2 Consequences

In thermal bridge areas the increased heat losses lead to decrease of the interior surface temperature, which seriously interferes with the physical performance of the building. When the surface temperature decreases too low, it can lead to moisture formation in building components and mould growth. In Figure 14, is presented some places with mold growth.

FIGURE 14. Mold growth in thermal bridge areas (Beodom 2014)

Because of the mould there are also possible health consequences like allergy. Formation of the moisture can also effect the color of the interior plaster, paint, wood or paper and slowly deteriorate the structural elements. (Thermal bridge catalog unpublished.)

Thermal bridges can cause up to 20 % of the total heat losses in a building, if the building is not properly insulated (Isover 2014).

Due to thermal bridges, possible increasing heat losses can also cause an increase in heat costs. Due to the ever strickter U-value requirements, the importance of thermal bridges in relation to the total energy loss of a building envelope grows increasingly significant and needs to be addressed to satisfy the demands of Building Regulations and Standards. (Thermal bridge catalog unpublished.)

4.1.3 Prevention

Thermal bridges should be avoided as well as possible through adequate structural measures. The goal is to bring the negative effects to a point that is tolerable and will not cause any damage for the building elements. The prevention of thermal bridges needs to start from designing the building. With multidimensional evaluation during planning and detail designing, thermal bridges and its possible consequences can be effectively prevented. (Thermal bridge catalog unpublished.)

Also by avoiding unnecessary corners and angles in external walls, it is possible to minimize the heat losses. An efficient and safe solution for preventing thermal bridges is to cover the whole external wall with a continius layer of insulation, which is presented in Figure 15. Interior thermal insulation is well known to create many thermal bridges that could be completely avoided by doing exterior thermal insulation instead. (Thermal bridge catalog unpublished.)

The insulation layer must not be penetrated by a component which is thermally conductive e.g. steel wire. Also avoiding penetrations of the building envelope by e.g. screws or seals will prevent the formation of point thermal bridges. (Thermal bridge catalog unpublished.)

It is also possible to install materials that have better insulation properties between e.g. metal components to decrease the passage of heat trough fixings, etc. This option is called thermal break. (Thermal bridge catalog unpublished.)

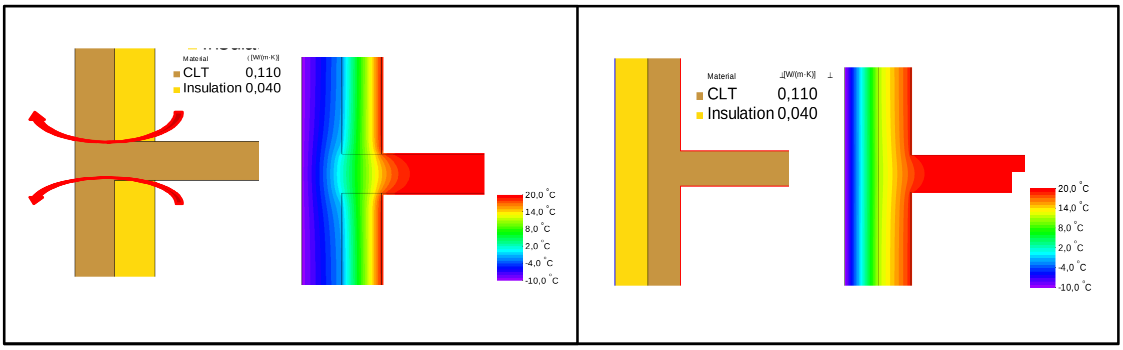


Figure 15. Interior (left) and exterior (right) insulation in a floor-wall junction. Using external insulation, thermal bridges can be prevented as it is presented in the picture above. (Thermal bridge catalog unpublished.)

5 FLIXO-SOFTWARE

The calculations of this thesis has been made using Flixo software. Flixo is thermal bridge software and it follows standards EN ISO 10211:2007 and EN ISO 1007-2:2003. With Flixo you can calculate 2-dimensional components in steady state boundary conditions. By using Flixo while designing a building, it is possible to deteckt thermal bridges at an early stage so that they can be eliminated through design changes. It is also possible to import CAD files to Flixo and calculate thermal and condensation values for CAD files.

With Flixo you can create thermal-hygro analyses of different kind of components, where you can define the minimal internal surface temperature, which helps to avoid formation of condensation. An example of Flixo file is presented in Figure 16.

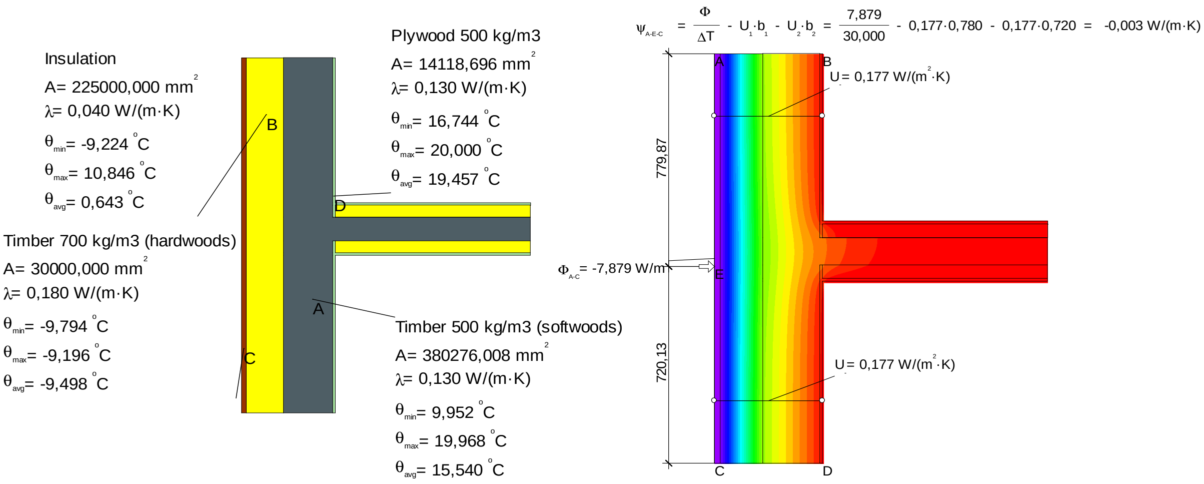


FIGURE 16. Example Flixo file (Thermal bridge catalog unpublished.)

5.1 Evaluation

Flixo software is easy to use and fast to learn. It is made for the kind of calculations which are used in this thesis and the developing of the software is going on all the time. Even though there are still some features which are not possible to use in specific cases or structures, there is always the possibility to do the features in an other way, but it will take a longer time and more effort. Flixo is really useful for anyone who is thinking about building a house of their own, or if someone wants to calculate the heat losses of existing building.

Calculations in this thesis are not taking into consideration the condensation risks. Figures on the result chapter do not show the realistic picture of the mold risk, because for calculating condensation risk with Flixo, different kinds of boundary conditions are needed. From Stora Ensos Thermal bridge catalog (which is going to be published during year 2015) it is possible to find minimal temperatures of inner surfaces and the place where the condensation might form, in same kind of structures as used in this thesis.

6 CALCULATION VALUES

6.1 Boundary conditions

Boundary conditions which are used in these calculations are directly from Flixo. Boundary conditions mean room/outside temperatures and thermal transfer coefficients. Ventilated exterior boundary condition is used with wooden facades.

TABLE 1. Boundary conditions used on thermal balance calculations

Boundary conditions		
	Temperature [°C]	Surface resistance [m2·K/W]
Interior, normal	+20	0.13
Interior, upwards	+20	0.10
Interior, downwards	+20	0.17
Exterior, normal	-10	0.04
Exterior, ventilated	-10	0.13

6.2 Materials and calculation

The components used in these calculations only contain thermally relevant materials. This is why e.g. wind shield cannot be found in the drawing. The different insulations used in the calculations are mineral wool, EPS and wood fibre. In some lay ups there are only two different insulations. This is because the insulation which has been dropped off is not normally used in this kind of lay-up. To see the comparison, I decided to change the thickness of the insulation layer same way in every lay up.

TABLE 2. Material values, which used in calculations (* these insulation materials are used almost every calculation. By changing the thicknes it is possible to see the comparison between different lay ups.)

Material values			
	Material	ρ [kg/m^3]	λ [W/(m·K)]
🟥	Brick masonry	1700,0	0,760
⬛	Cement screed	2000.0	1.33
🟫	Stora Enso CLT	470.0	0.11
🟨 *	EPS (insulation material)	18.0	0.031
🟩	Exterior plaster	1700.0	1.0
🟩	Fire-protection plasterboard	800.0	0.25
🟪	Gravel fill	1200.0	0.70
🟫	Import sound insulation (mineral wool)	68.0	0.035
🟦	Interior plaster	1600.0	0.7
🟨 *	Mineral wool (insulation material)	18.0	0.035
⬜	OSB	600.0	0.13
🟩	Plaster	2000.0	1.00
⬛	Reinforced concrete (2% steel)	2400.0	2.5
⬛	Reinforced concrete (1 % steel)	2300.0	2.3
🟦	Stainlessteel	7900.0	17.0
🟩	WLG040 (insulation material)	45.0	0.004
🟫	Wooden battens	500.0	0.130
🟧	Wooden façade	500.0	0.130
🟧 *	Wood fibre (Insulation material)	130.0	0.038

Psi-value

From this thesis you can find calculated Psi-values for different junctions, with different layups. These results help to see which kind of structure works with a certain layup, without high heat losses. The smaller the Psi-value, the lower the heat losses through the junction.

Formula for calculating Psi-value

$$\psi = \frac{\Phi}{\Delta T} - U_1 \cdot b_1 - U_2 \cdot b_2 - U_3 \cdot b_3 \ldots$$

Φ= Heat flow that flows through a particular surface line
ΔT= Temperature difference between exterior and interior boundary conditions
U_1= U-value of building component 1
U_2= U-value of building component 2
U_3= U-value of building component 3
b_1=1, surface area
b_2= 2, surface area
b_3= 3, surface area

Marks and symbols in the calculations

ρ = Weight of the material

Psi$_i$-value = Psi-value, if interior dimensions are considered

Psi$_{i,I}$-value = Psi-value, if interior dimensions are considered (and more than one Psi value is needed)

Psi$_{i,II}$-value = Psi-value, if interior dimensions are considered (and more than one Psi value is needed)

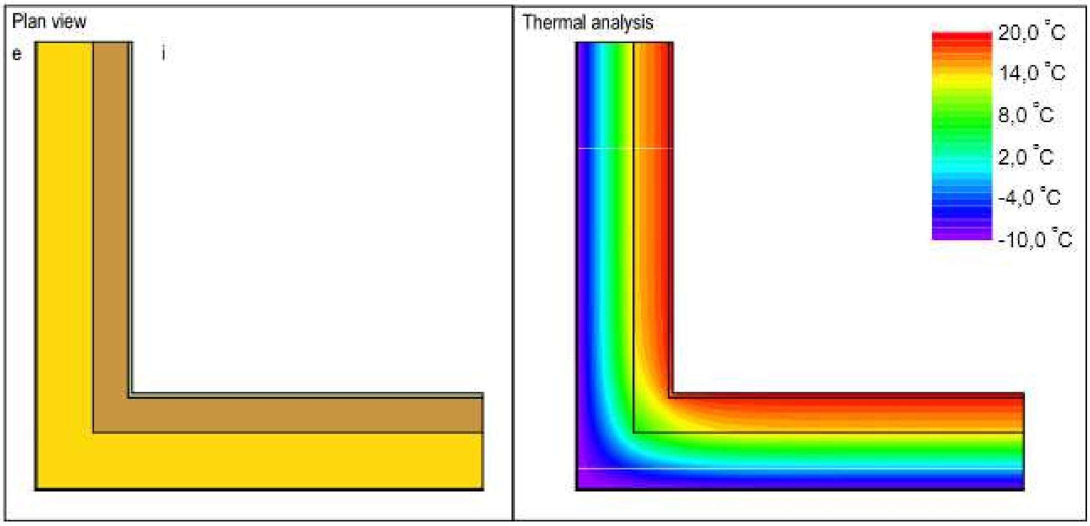
Psi$_e$-value = Psi-value, if exterior dimensions are considered

7 THERMAL ANALYSES AND CALCULATIONS

This chapter includes calculations of all the different structures and lay-ups which have been studied in this thesis. The results can be seen in the tables under the drawing and thermal analysis. Thermal analysis shows what the temperature differences are in the structure with the boundary conditions which have been previously definied.

7.1 External wall – external corner

It is important to make the junction between external wall and the external corner as airtight as possible. In every building there is at least four external corners and to ensure low heat losses, they must be properly built.

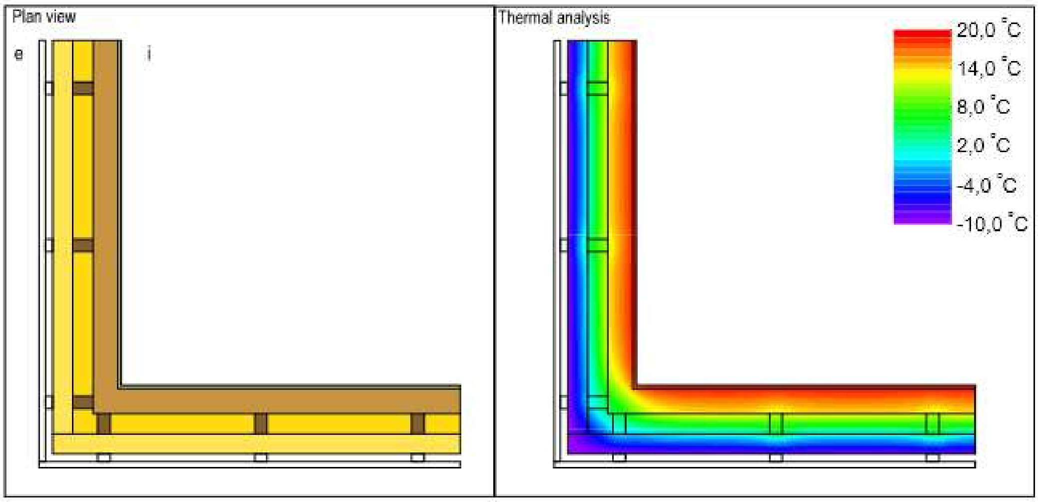


Component design		
Material		Thickness [mm]
External wall e→i		
🟩	Plaster	5,0
🟨	Thermal insulation	160,0/200,0/260,0
🟫	CLT	100,0
🟩	Fire-protection plasterboard	12,5

Results				
Thermal insulation		Thermal balance		
Type	Thickness [mm]	U-value (External wall) [W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,175	+0,038	-0,060
	200,0	0,146	+0,035	-0,057
	260,0	0,117	+0,033	-0,056
EPS	160,0	0,159	+0,035	-0,053
	200,0	0,132	+0,033	-0,050
	260,0	0,105	+0,030	-0,049
Wood fibre	160,0	0,187	+0,039	-0,065
	200,0	0,156	+0,037	-0,062
	260,0	0,125	+0,034	-0,060

Source: Stora Enso, Thermal Bridge catalog, 2014

FIGURE 17. CLT lay-up, with plaster façade. Source: Thermal bridge catalog unpublished



Component design		
Material		Thickness [mm]
External wall e→i		
▨ *	Wooden façade	25,0
▨ *	Wooden battens	30,0
▨	Thermal insulation, wooden battens (e=625,0 mm)	160,0 /200,0 /260,0
▨	CLT	100,0
▨	Fire-protection plasterboard	12,5

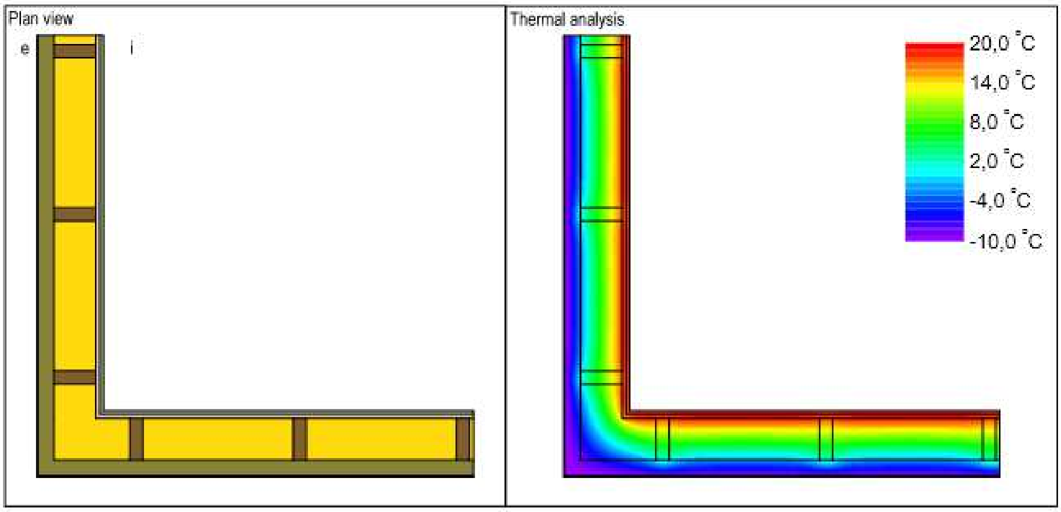
Results				
Thermal insulation		Thermal balance		
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,197	+0,044	-0,063
	200,0	0,166	+0,042	-0,062
	260,0	0,134	+0,041	-0,059
Wood fibre**	160,0	0,184	+0,039	-0,061
	200,0	0,154	+0,037	-0,060
	260,0	0,124	+0,034	-0,058

* In the component picture the color of wooden facade and wooden battens (in the ventilation layer) is white because these layers are not relevant for the calculation

** Wood fibre insulation does not contain wooden battens

Source: Stora Enso, Thermal Bridge catalog, 2014

FIGURE 18. CLT lay-up, with wooden façade. Source: Thermal bridge catalog unpublished

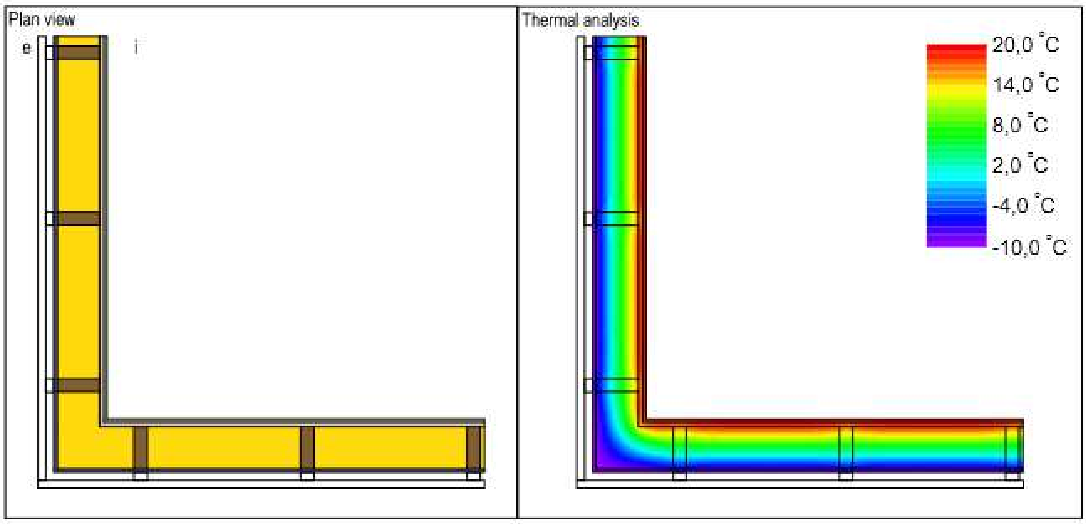


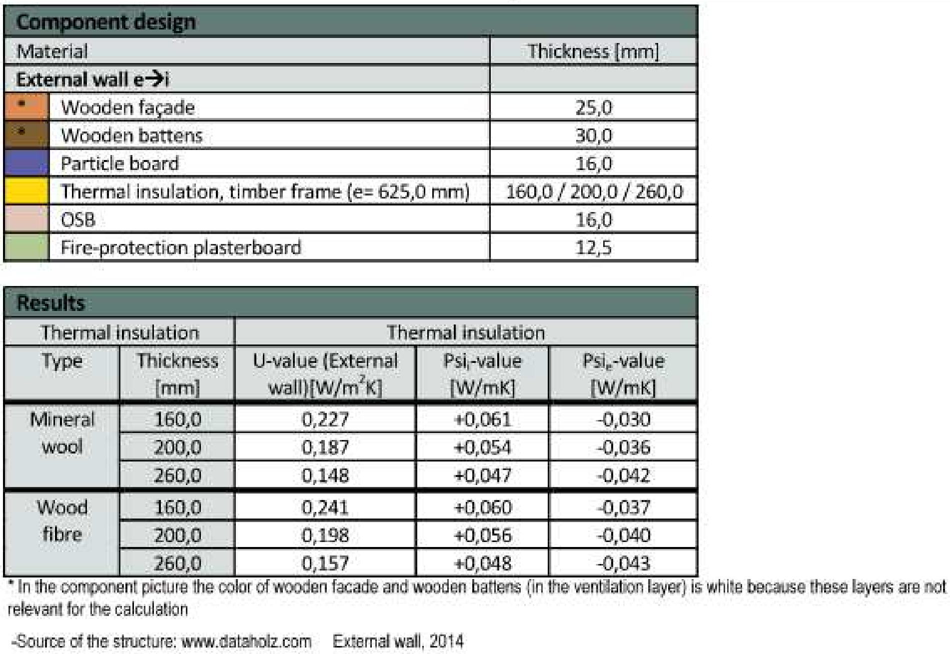
Component design		
Material		Thickness [mm]
External wall e→i		
🟩	Plaster	5,0
🟫	High density Wood fibre board	60,0
🟨	Thermal insulation, timber frame (e= 625,0 mm)	160,0 / 200,0 / 260,0
🟥	OSB	16,0
🟩	Fire-protection plasterboard	12,5

Results				
Thermal insulation		Thermal insulation		
Type	Thickness [mm]	U-value (External wall)[W/m^2K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,173	+0,039	-0,048
	200,0	0,148	+0,039	-0,047
	260,0	0,123	+0,036	-0,051
Wood fibre	160,0	0,181	+0,040	-0,052
	200,0	0,156	+0,039	-0,052
	260,0	0,129	+0,038	-0,053

Source of the structure: www.dataholz.com External wall, 2014

FIGURE 19. Timber frame lay-up with plaster façade. Structure source: Dataholz, 2014





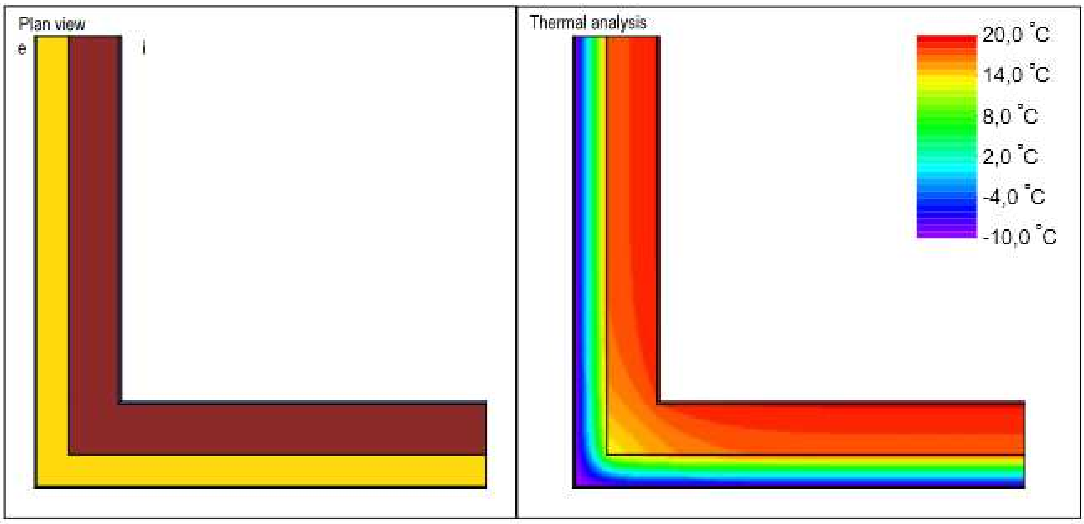
Component design		
Material		Thickness [mm]
External wall e→i		
🟧 *	Wooden façade	25,0
🟫 *	Wooden battens	30,0
🟦	Particle board	16,0
🟨	Thermal insulation, timber frame (e= 625,0 mm)	160,0 / 200,0 / 260,0
⬜	OSB	16,0
🟩	Fire-protection plasterboard	12,5

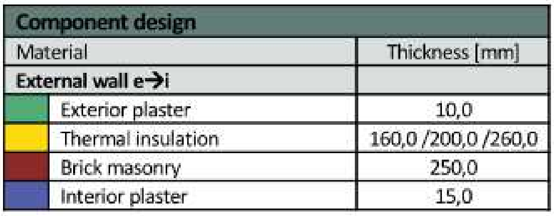
Results				
Thermal insulation		Thermal insulation		
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,227	+0,061	-0,030
	200,0	0,187	+0,054	-0,036
	260,0	0,148	+0,047	-0,042
Wood fibre	160,0	0,241	+0,060	-0,037
	200,0	0,198	+0,056	-0,040
	260,0	0,157	+0,048	-0,043

* In the component picture the color of wooden facade and wooden battens (in the ventilation layer) is white because these layers are not relevant for the calculation

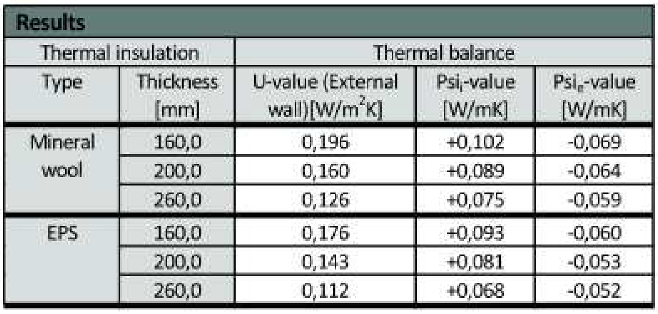
-Source of the structure: www.dataholz.com External wall, 2014

FIGURE 20. Timber frame lay-up with wooden façade. Structure source: Dataholz, 2014



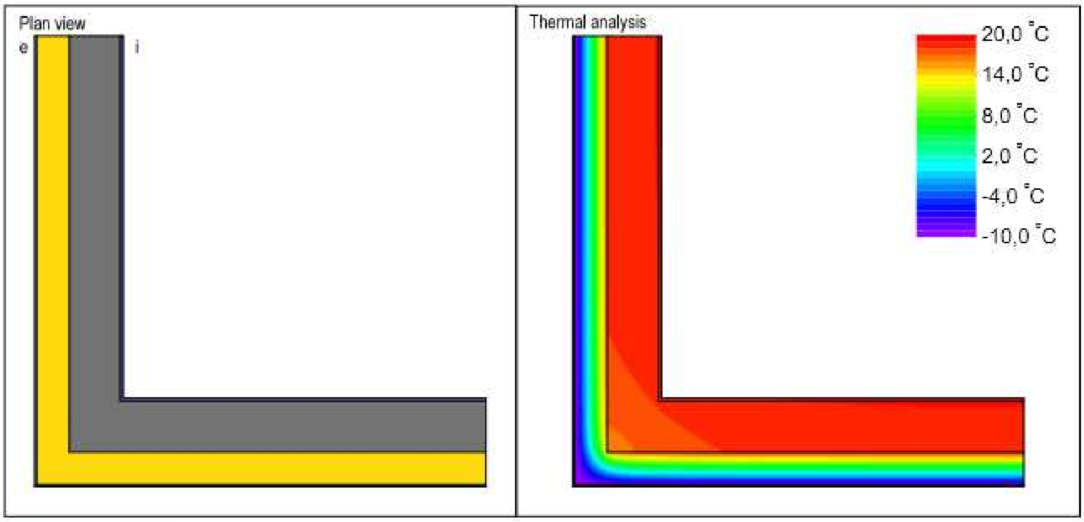


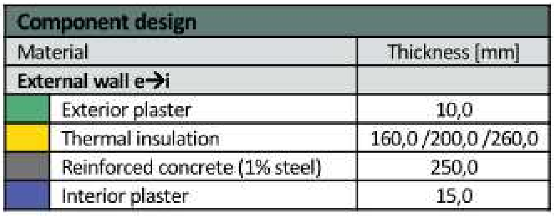
Component design		
Material		Thickness [mm]
External wall e→i		
🟩	Exterior plaster	10,0
🟨	Thermal insulation	160,0 /200,0 /260,0
🟫	Brick masonry	250,0
🟦	Interior plaster	15,0



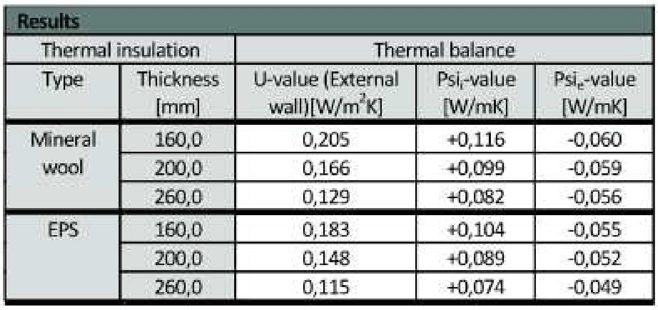
Results				
Thermal insulation		Thermal balance		
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,196	+0,102	-0,069
	200,0	0,160	+0,089	-0,064
	260,0	0,126	+0,075	-0,059
EPS	160,0	0,176	+0,093	-0,060
	200,0	0,143	+0,081	-0,053
	260,0	0,112	+0,068	-0,052

FIGURE 21. Brick masonry lay-up. Structure source: Pech and Kolbitsch, 23



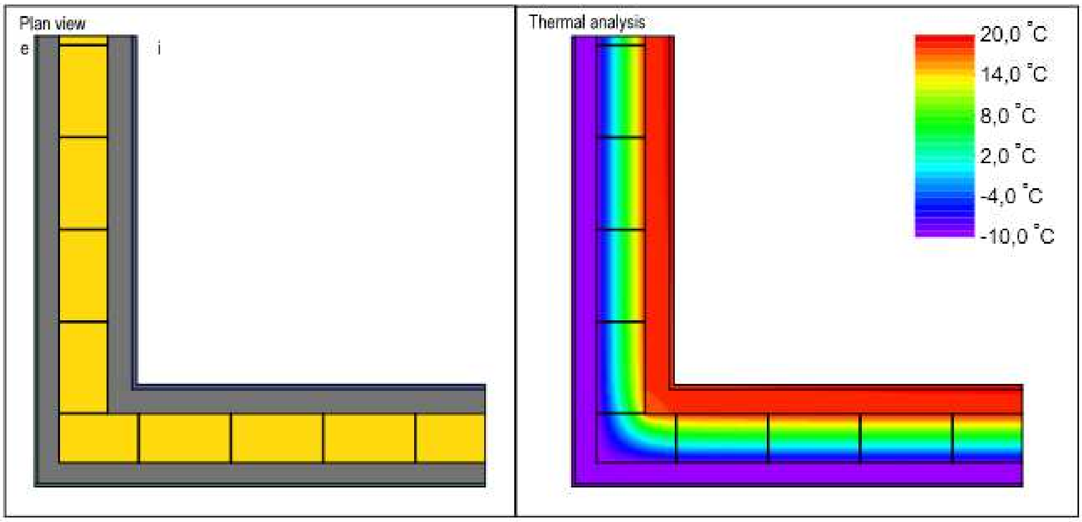


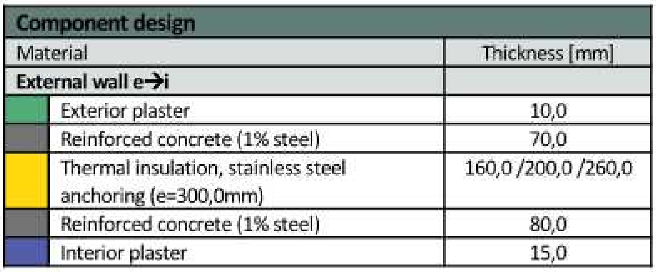
Component design		
Material		Thickness [mm]
External wall e→i		
🟩	Exterior plaster	10,0
🟨	Thermal insulation	160,0 /200,0 /260,0
▨	Reinforced concrete (1% steel)	250,0
🟦	Interior plaster	15,0



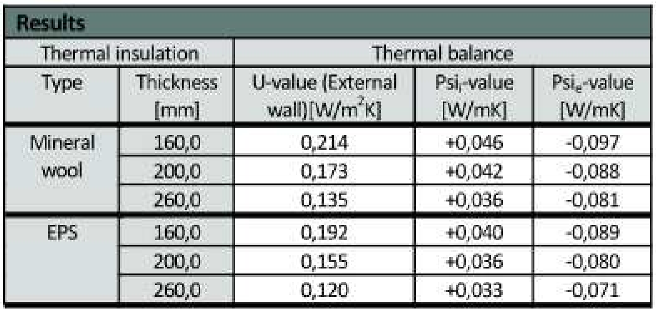
Results				
Thermal insulation		Thermal balance		
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,205	+0,116	-0,060
	200,0	0,166	+0,099	-0,059
	260,0	0,129	+0,082	-0,056
EPS	160,0	0,183	+0,104	-0,055
	200,0	0,148	+0,089	-0,052
	260,0	0,115	+0,074	-0,049

FIGURE 22. Concrete lay-up. Structure source: Pech and Kolbitsch, 28





Component design		
Material		Thickness [mm]
External wall e→i		
🟩	Exterior plaster	10,0
▨	Reinforced concrete (1% steel)	70,0
🟨	Thermal insulation, stainless steel anchoring (e=300,0mm)	160,0 /200,0 /260,0
▨	Reinforced concrete (1% steel)	80,0
🟦	Interior plaster	15,0



Results				
Thermal insulation		Thermal balance		
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,214	+0,046	-0,097
	200,0	0,173	+0,042	-0,088
	260,0	0,135	+0,036	-0,081
EPS	160,0	0,192	+0,040	-0,089
	200,0	0,155	+0,036	-0,080
	260,0	0,120	+0,033	-0,071

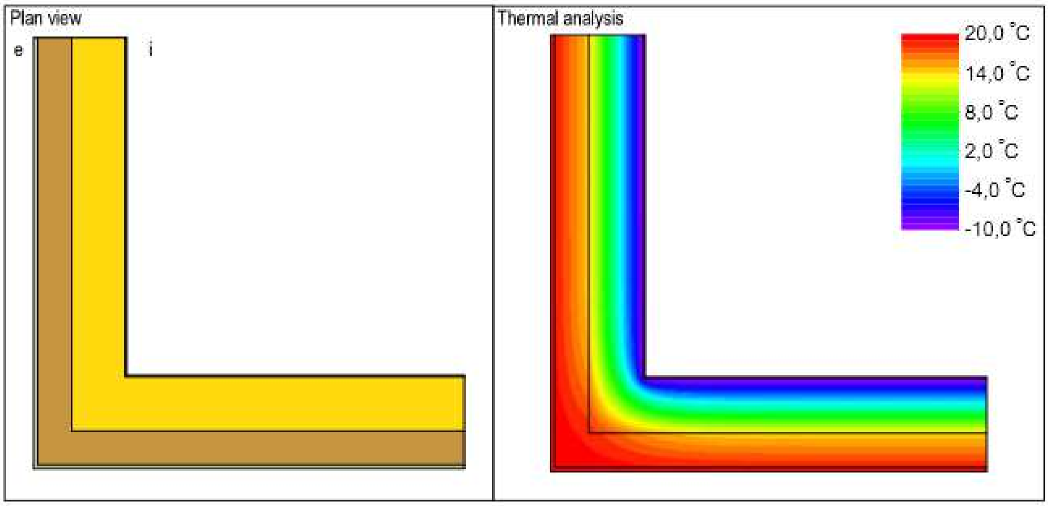
FIGURE 23. Concrete sandwich lay-up. Structure source: Lämpö- ja kosteustekniikka, 2013

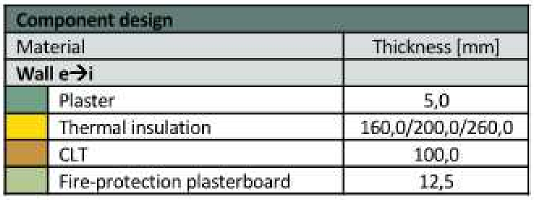
7.1.1 Evaluation of the results

This structure is found in every building and because of that it is important that there is no high heat losses through the corner. From the results you can see that CLT gives the lowest heat loss values for the junction (Psi-value) and for the plane surface as well (U-value).

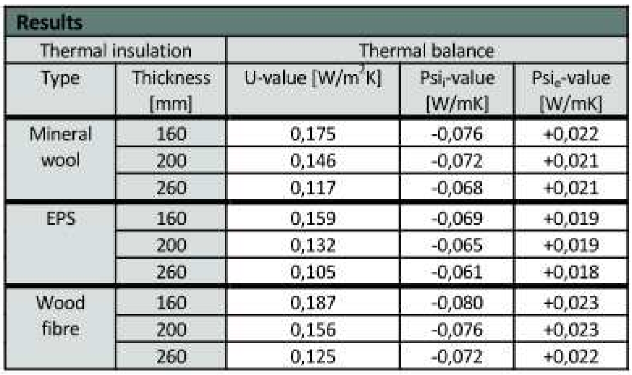
7.2 External wall – internal corner

This is a simple structure where the airtightness in the corner is important. The structure, thermal analysis and the results are similar to an external corner.





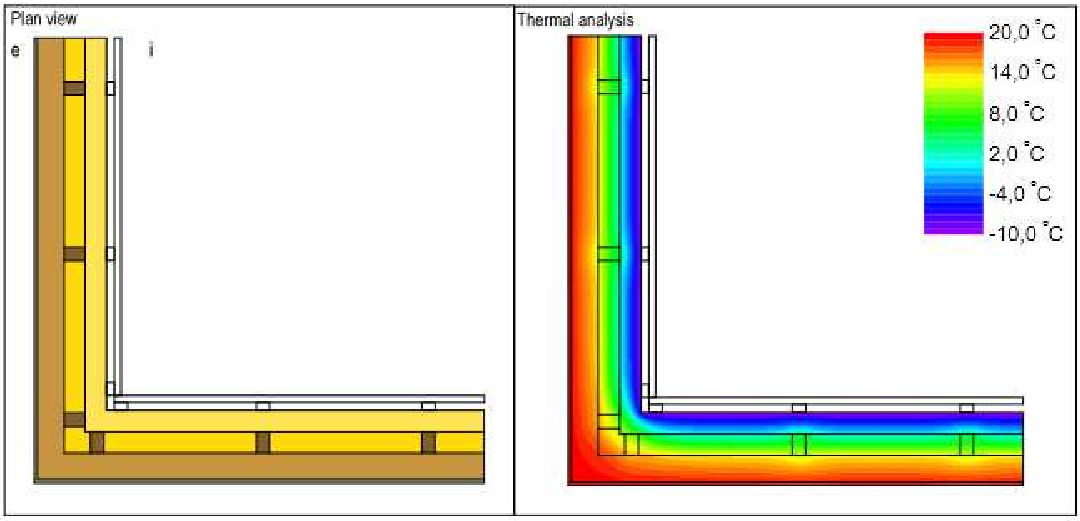
Component design		
Material		Thickness [mm]
Wall e→i		
🟩	Plaster	5,0
🟨	Thermal insulation	160,0/200,0/260,0
🟫	CLT	100,0
🟩	Fire-protection plasterboard	12,5



Results				
Thermal insulation		Thermal balance		
Type	Thickness [mm]	U-value [W/m²K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160	0,175	-0,076	+0,022
	200	0,146	-0,072	+0,021
	260	0,117	-0,068	+0,021
EPS	160	0,159	-0,069	+0,019
	200	0,132	-0,065	+0,019
	260	0,105	-0,061	+0,018
Wood fibre	160	0,187	-0,080	+0,023
	200	0,156	-0,076	+0,023
	260	0,125	-0,072	+0,022

Source: Stora Enso, Thermal Bridge catalog, 2014

FIGURE 24. CLT lay-up with plaster façade. Source: Thermal bridge catalog unpublished



Component design		
Material		Thickness [mm]
External wall e→i		
🟧 *	Wooden façade	25,0
🟫 *	Wooden battens	30,0
🟨	Thermal insulation, wooden battens (e=625,0 mm)	160,0 /200,0 /260,0
🟫	CLT	100,0
🟩	Fire-protection plasterboard	12,5

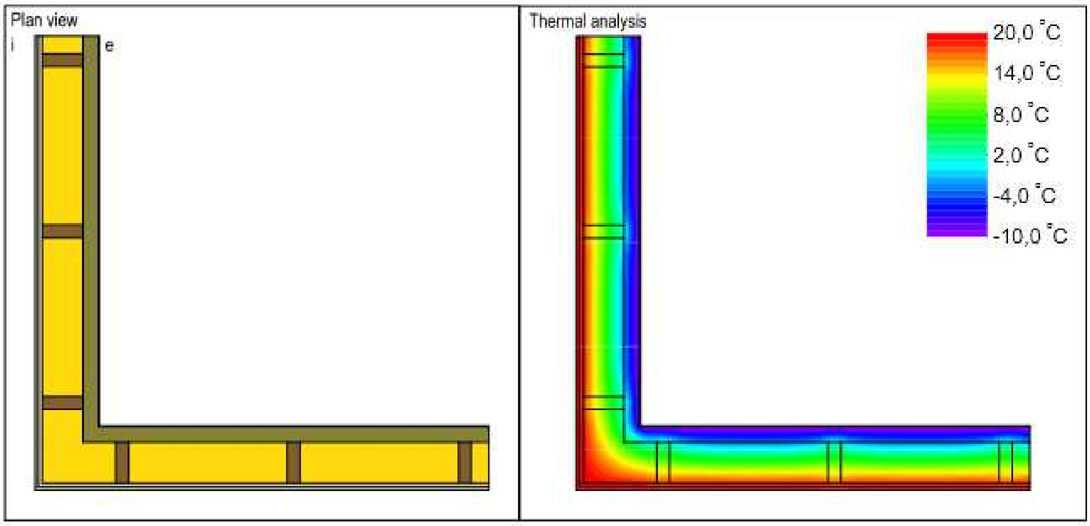
Results				
Thermal insulation		Thermal balance		
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,197	-0,082	+0,025
	200,0	0,166	-0,079	+0,025
	260,0	0,134	-0,074	+0,025
Wood fibre**	160,0	0,185	-0,081	+0,021
	200,0	0,155	-0,076	+0,021
	260,0	0,125	-0,072	+0,021

* In the component picture the color of wooden facade and wooden battens (in the ventilation layer) is white because these layers are not relevant for the calculation

** Wood fibre insulation does not contain wooden battens

Source: Stora Enso, Thermal Bridge catalog, 2014

FIGURE 25. CLT lay-up with wooden façade. Source: Thermal bridge catalog unpublished

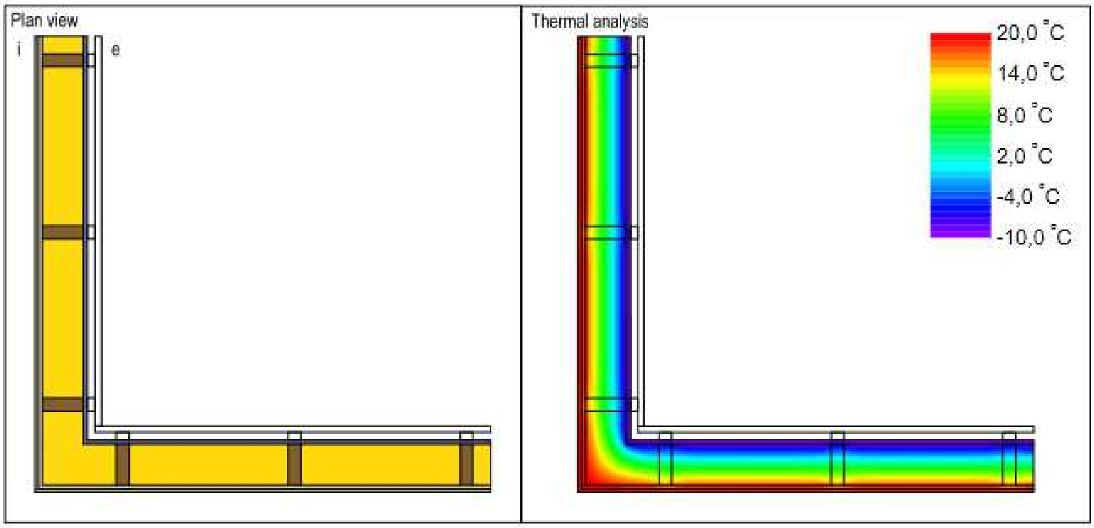


Component design		
Material		Thickness [mm]
External wall e→i		
🟩	Plaster	5,0
🟫	High density wood fibre board	60,0
🟨	Thermal insulation, timber frame (e= 625,0 mm)	160,0 / 200,0 / 260,0
▨	OSB	16,0
🟩	Fire-protection plasterboard	12,5

Results				
Thermal insulation		Thermal balance		
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_{i,i}$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,173	-0,056	+0,031
	200,0	0,148	-0,056	+0,031
	260,0	0,123	-0,058	+0,029
Wood fibre	160,0	0,181	-0,060	+0,032
	200,0	0,156	-0,060	+0,031
	260,0	0,129	-0,060	+0,031

Source: www.dataholz.com External wall, 2014

FIGURE 26. Timber frame lay-up with plaster façade. Structure source: Dataholz, 2014



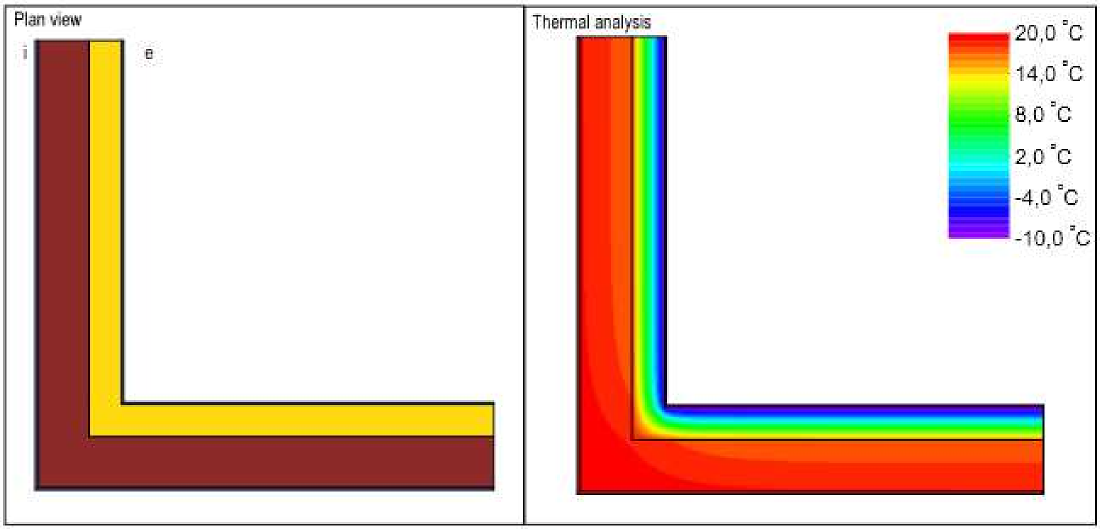
Component design		
Material		Thickness [mm]
External wall e→i		
🟧 *	Wooden façade	25,0
🟫 *	Wooden battens	30,0
🟦	Particle board	16,0
🟨	Thermal insulation, timber frame (e= 625,0 mm)	160,0 / 200,0 / 260,0
▨	OSB	16,0
🟩	Fire-protection plasterboard	12,5

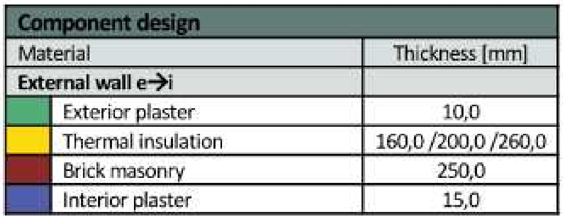
Results				
Thermal insulation		Thermal balance		
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_{i,l}$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,227	-0,050	+0,042
	200,0	0,187	-0,052	+0,039
	260,0	0,148	-0,055	+0,035
Wood fibre	160,0	0,241	-0,057	+0,041
	200,0	0,198	-0,054	+0,041
	260,0	0,157	-0,059	+0,037

* In the component picture the color of wooden facade and wooden battens (in the ventilation layer) is white because these layers are not relevant for the calculation

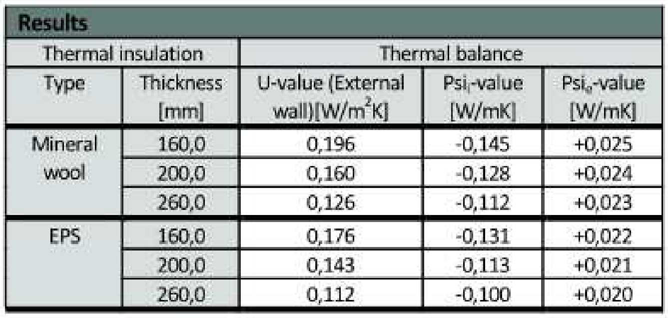
Source: www.dataholz.com External wall, 2014

FIGURE 27. Timber frame lay-up with wooden façade. Structure source: Dataholz, 2014



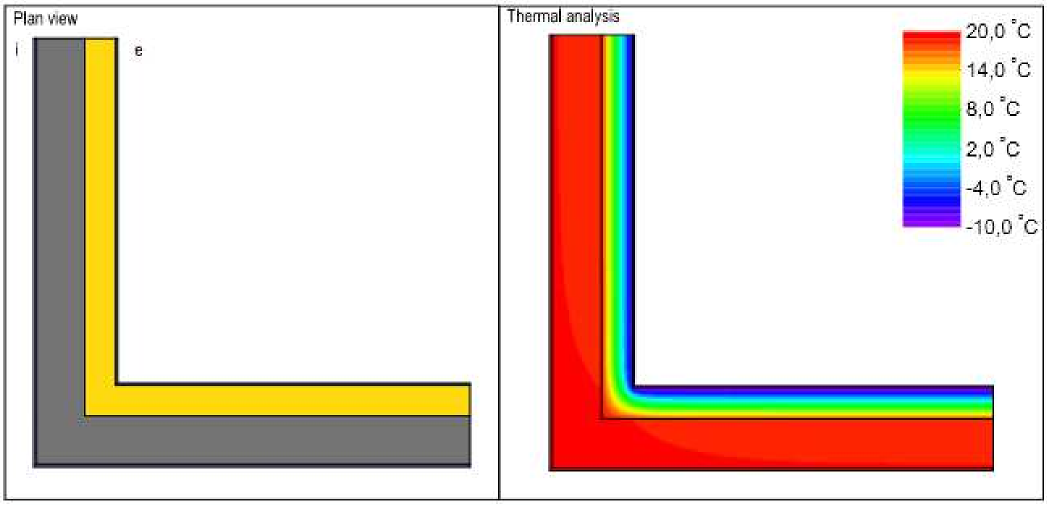


Component design		
Material		Thickness [mm]
External wall e→i		
🟩	Exterior plaster	10,0
🟨	Thermal insulation	160,0 /200,0 /260,0
🟫	Brick masonry	250,0
🟦	Interior plaster	15,0



Results				
Thermal insulation		Thermal balance		
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,196	-0,145	+0,025
	200,0	0,160	-0,128	+0,024
	260,0	0,126	-0,112	+0,023
EPS	160,0	0,176	-0,131	+0,022
	200,0	0,143	-0,113	+0,021
	260,0	0,112	-0,100	+0,020

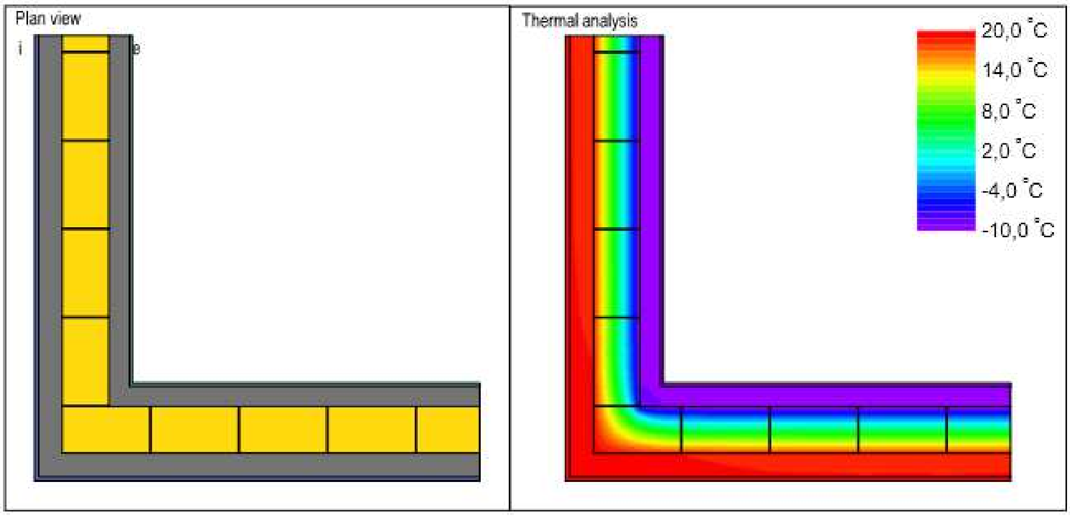
FIGURE 28. Brick masonry lay-up. Structure source: Pech and Kolbitsch, 23

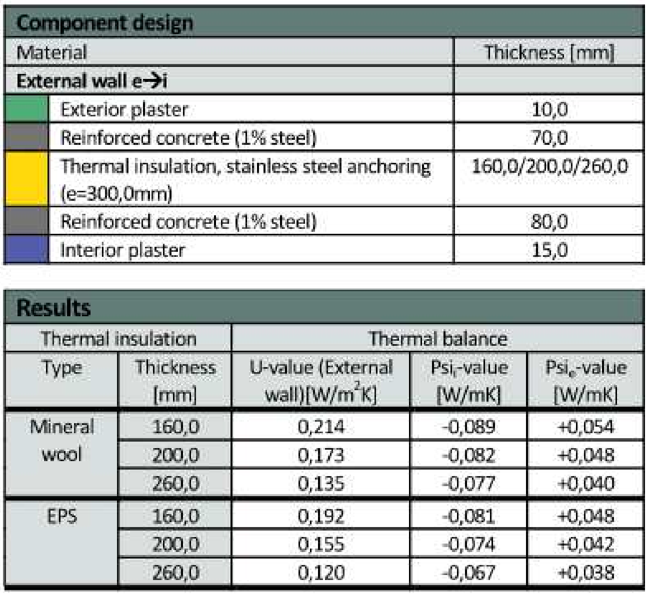


Component design		
Material		Thickness [mm]
External wall e→i		
🟩	Exterior plaster	10,0
🟨	Thermal insulation	160,0 /200,0 /260,0
⬛	Reinforced concrete (1% steel)	250,0
🟦	Interior plaster	15,0

Results				
Thermal insulation		Thermal balance		
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_o$-value [W/mK]
Mineral wool	160,0	0,205	-0,149	+0,025
	200,0	0,166	-0,134	+0,024
	260,0	0,129	-0,116	+0,023
EPS	160,0	0,183	-0,137	+0,022
	200,0	0,148	-0,119	+0,021
	260,0	0,115	-0,103	+0,020

FIGURE 29. Concrete lay-up. Structure source: Pech and Kolbitsch, 28





Component design		
Material		Thickness [mm]
External wall e→i		
🟩	Exterior plaster	10,0
⬛	Reinforced concrete (1% steel)	70,0
🟨	Thermal insulation, stainless steel anchoring (e=300,0mm)	160,0/200,0/260,0
⬛	Reinforced concrete (1% steel)	80,0
🟦	Interior plaster	15,0

Results				
Thermal insulation		Thermal balance		
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,214	-0,089	+0,054
	200,0	0,173	-0,082	+0,048
	260,0	0,135	-0,077	+0,040
EPS	160,0	0,192	-0,081	+0,048
	200,0	0,155	-0,074	+0,042
	260,0	0,120	-0,067	+0,038

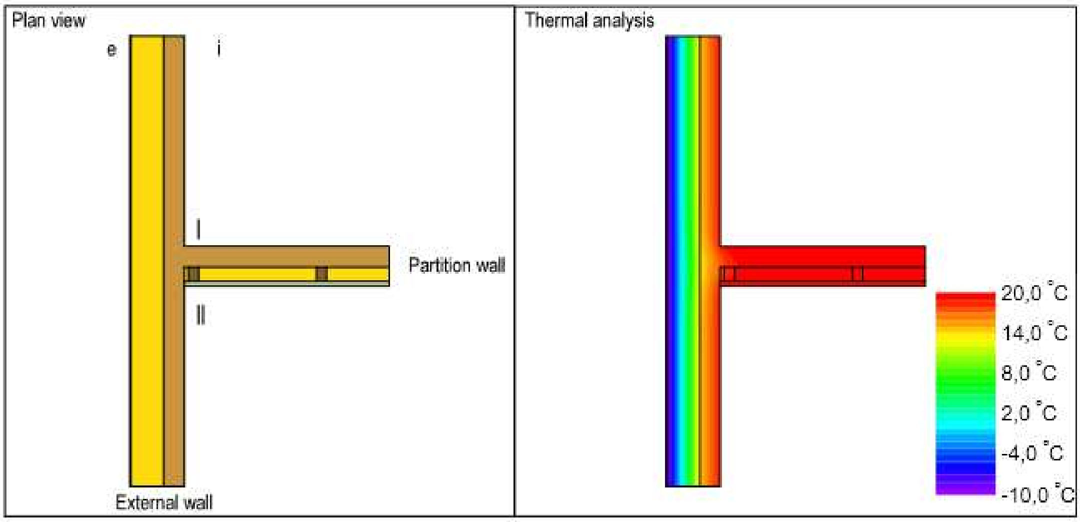
FIGURE 30. Concrete sandwich lay-up. Structure source: Lämpö- ja kosteustekniikka, 2013

7.2.1 Evaluation of the results

Internal corner is not found in every building and the heat losses through internal corner are higher than in external corner. As in external corner the CLT results give the lowest heat losses through the junction and the plane area. It is also important to take into consideration that CLT has the thickness of 100.0 mm, when brick masonry and concrete have the thickenss of 250.0 mm, so even that CLT is less than half of the thickness of concrete, it still has better thermal properties.

7.3 External wall – partition wall

The calculations have been made by using a single frame in the partition wall. If better acoustic properties are needed, partition walls can also be built with a double frame and by adding acoustic insulation in the wall.



Component design

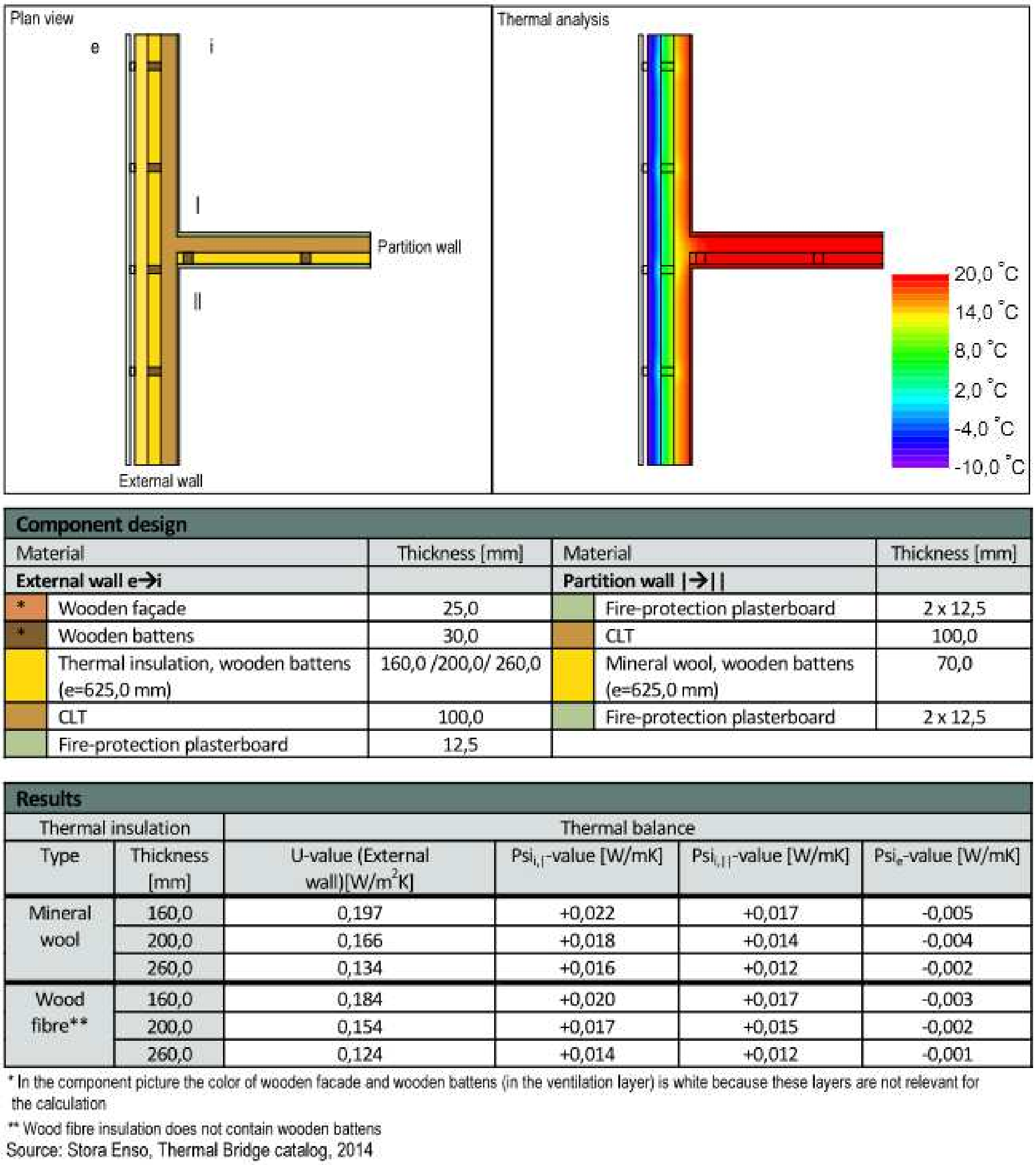
	Material	Thickness [mm]		Material	Thickness [mm]
	External wall e→i			**Partition wall |→||**	
🟩	Plaster	5,0	🟫	CLT	100,0
🟨	Thermal insulation	160,0/200,0/260,0	🟨	Mineral wool, Wooden battens (e=625,0 mm)	70,0
🟫	CLT	100,0	🟩	Fire-protection plasterboard	2 x 12,5

Results

Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall) [W/m^{2}K]	$\text{Psi}_{i,\vert}$-value [W/mK]	$\text{Psi}_{i,\vert\vert}$-value [W/mK]	Psi_{e}-value [W/mK]
Mineral wool	160,0	0,177	+0,016	+0,016	-0,002
	200,0	0,147	+0,014	+0,014	-0,001
	260,0	0,117	+0,011	+0,011	-0,001
EPS	160,0	0,160	+0,015	+0,015	-0,002
	200,0	0,133	+0,012	+0,012	-0,001
	260,0	0,106	+0,010	+0,010	-0,001
Wood fibre	160,0	0,189	+0,017	+0,017	-0,002
	200,0	0,158	+0,015	+0,015	-0,002
	260,0	0,126	+0,012	+0,012	-0,001

Source: Stora Enso, Thermal Bridge catalog, 2014

FIGURE 31. CLT lay-up with plaster façade. Source: Thermal bridge catalog unpublished



Component design

	Material	Thickness [mm]		Material	Thickness [mm]
	External wall e→i			**Partition wall |→||**	
*	Wooden façade	25,0	🟩	Fire-protection plasterboard	2 x 12,5
*	Wooden battens	30,0	🟧	CLT	100,0
🟨	Thermal insulation, wooden battens (e=625,0 mm)	160,0 /200,0/ 260,0	🟨	Mineral wool, wooden battens (e=625,0 mm)	70,0
🟧	CLT	100,0	🟩	Fire-protection plasterboard	2 x 12,5
🟩	Fire-protection plasterboard	12,5			

Results

Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_{i,\|}$-value [W/mK]	Psi$_{i,\|\|}$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,197	+0,022	+0,017	-0,005
	200,0	0,166	+0,018	+0,014	-0,004
	260,0	0,134	+0,016	+0,012	-0,002
Wood fibre**	160,0	0,184	+0,020	+0,017	-0,003
	200,0	0,154	+0,017	+0,015	-0,002
	260,0	0,124	+0,014	+0,012	-0,001

* In the component picture the color of wooden facade and wooden battens (in the ventilation layer) is white because these layers are not relevant for the calculation

** Wood fibre insulation does not contain wooden battens

Source: Stora Enso, Thermal Bridge catalog, 2014

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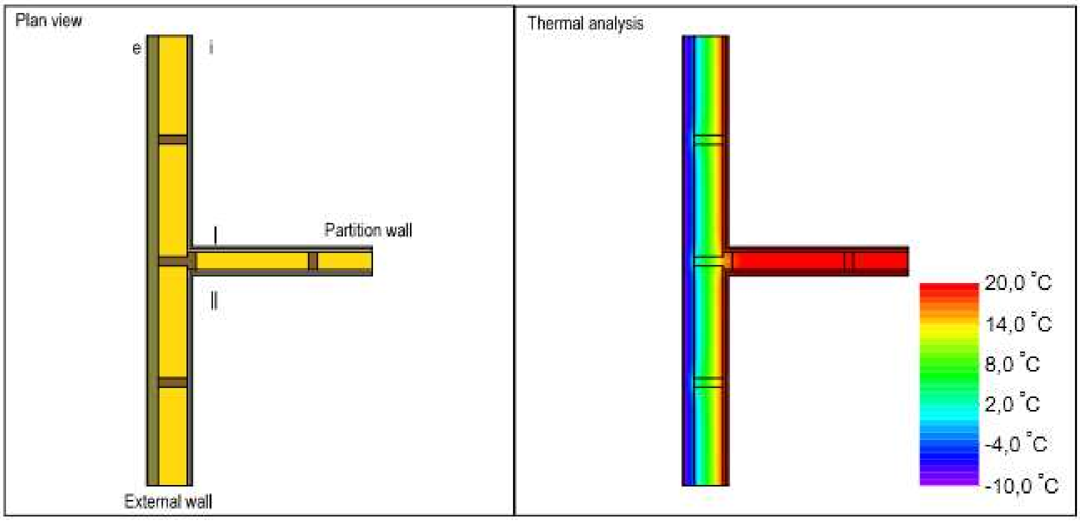
FIGURE 32. Clt lay-up with wooden façade. Source: Thermal bridge catalog unpublished

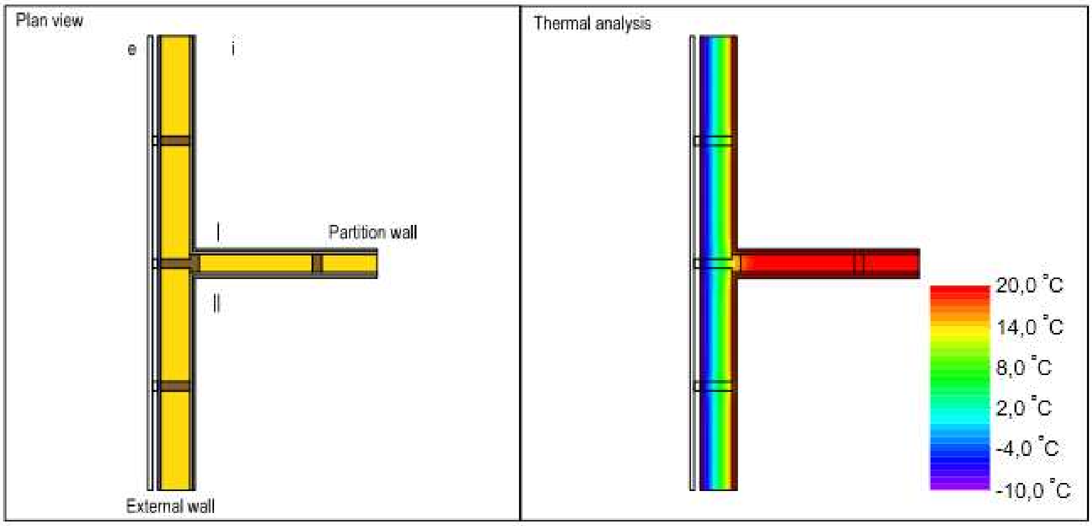


Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Partition wall I→II**		
🟩	Plaster	5,0	🟩	Fire-protection plaster board	15,0
🟫	High density wood fibre board	60,0	▨	OSB	16,0
🟨	Thermal insulation, timber frame (e=625,0 mm)	160,0 /200,0/260,0	🟨	Mineral wool, timber frame (e=625,0 mm)	100,0
▨	OSB	16,0	▨	OSB	16,0
🟩	Fire-protection plasterboard	12,5	🟩	Fire-protection plaster board	15,0

Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^2K]	$Psi_{i,I}$-value [W/mK]	$Psi_{i,II}$-value [W/mK]	Psi_e-value [W/mK]
Mineral wool	160,0	0,173	+0,006	+0,006	-0,014
	200,0	0,148	+0,006	+0,006	-0,011
	260,0	0,123	+0,004	+0,004	-0,011
Wood fibre	160,0	0,181	+0,007	+0,007	-0,013
	200,0	0,156	+0,006	+0,006	-0,012
	260,0	0,129	+0,005	+0,005	-0,010

Source: www.dataholz.com External wall and partition wall, 2014

FIGURE 33.Timber frame lay-up with plaster façade. Structure source: Dataholz, 2014



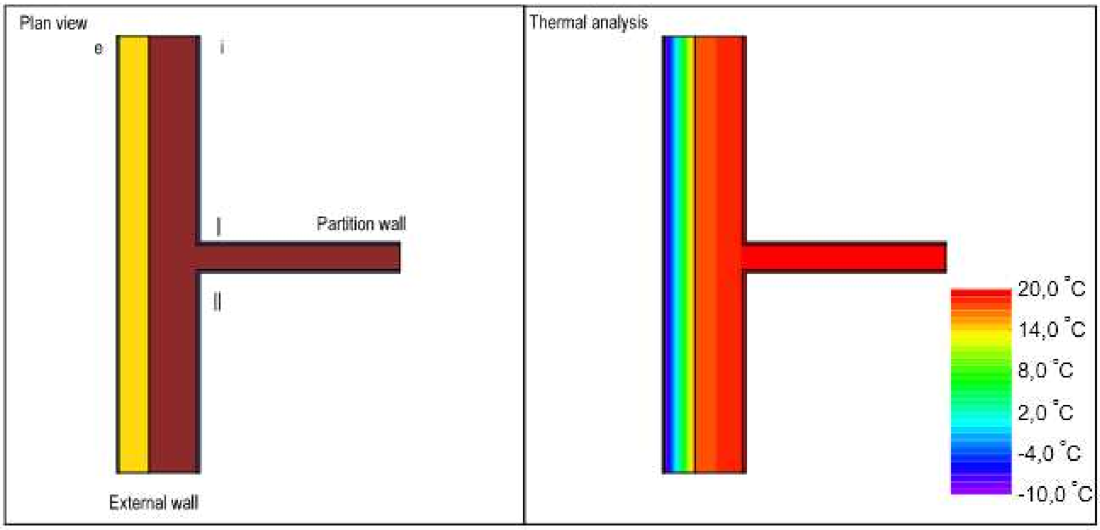
Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Partition wall |→||**		
🟧 *	Wooden façade	25,0	🟩	Fire-protection plaster board	15,0
🟫 *	Wooden battens	30,0	🟥	OSB	16,0
🟦	Particle board	16,0	🟨	Mineral wool, timber frame (e=625,0 mm)	100,0
🟨	Thermal insulation, timber frame (e=625,0 mm)	160,0 /200,0 /260,0	🟥	OSB	16,0
🟥	OSB	16,0	🟩	Fire-protection plaster board	15,0
🟩	Fire-protection plasterboard	12,5			

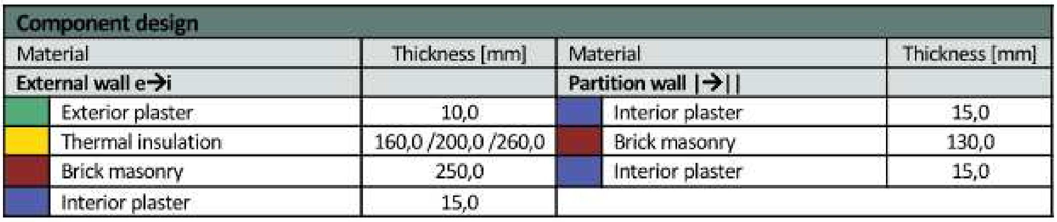
Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	$\text{Psi}_{i,\|}$-value [W/mK]	$\text{Psi}_{i,\|\|}$-value [W/mK]	Psi_{e}-value [W/mK]
Mineral wool	160,0	0,227	+0,006	+0,006	-0,022
	200,0	0,187	+0,005	+0,005	-0,019
	260,0	0,148	+0,004	+0,004	-0,015
Wood fibre	160,0	0,241	+0,007	+0,007	-0,023
	200,0	0,198	+0,006	+0,006	-0,018
	260,0	0,157	+0,005	+0,005	-0,015

* In the component picture the color of wooden facade and wooden battens (in the ventilation layer) is white because these layers are not relevant for the calculation

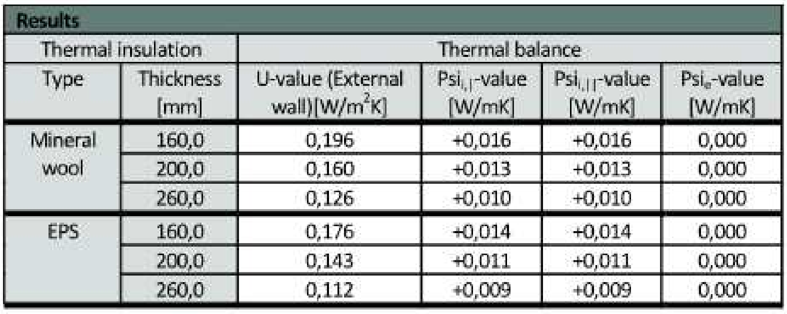
Source: www.dataholz.com External wall and partition wall, 2014

FIGURE 34. Timber frame lay-up with wooden façade. Structure source: Dataholz, 2014



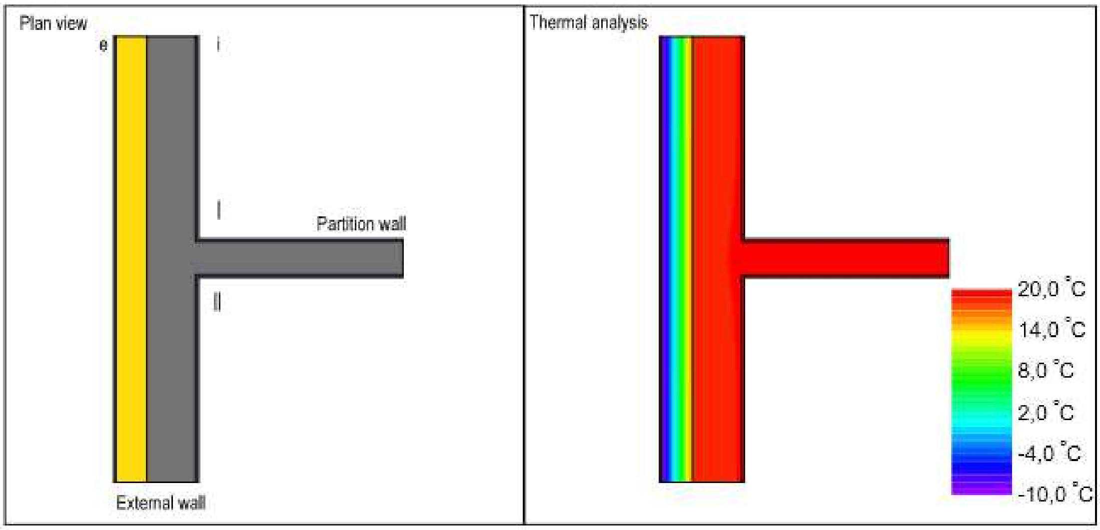


Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Partition wall I→II**		
🟩	Exterior plaster	10,0	🟦	Interior plaster	15,0
🟨	Thermal insulation	160,0 /200,0 /260,0	🟫	Brick masonry	130,0
🟫	Brick masonry	250,0	🟦	Interior plaster	15,0
🟦	Interior plaster	15,0			



Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_{i,I}$-value [W/mK]	Psi$_{i,II}$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,196	+0,016	+0,016	0,000
	200,0	0,160	+0,013	+0,013	0,000
	260,0	0,126	+0,010	+0,010	0,000
EPS	160,0	0,176	+0,014	+0,014	0,000
	200,0	0,143	+0,011	+0,011	0,000
	260,0	0,112	+0,009	+0,009	0,000

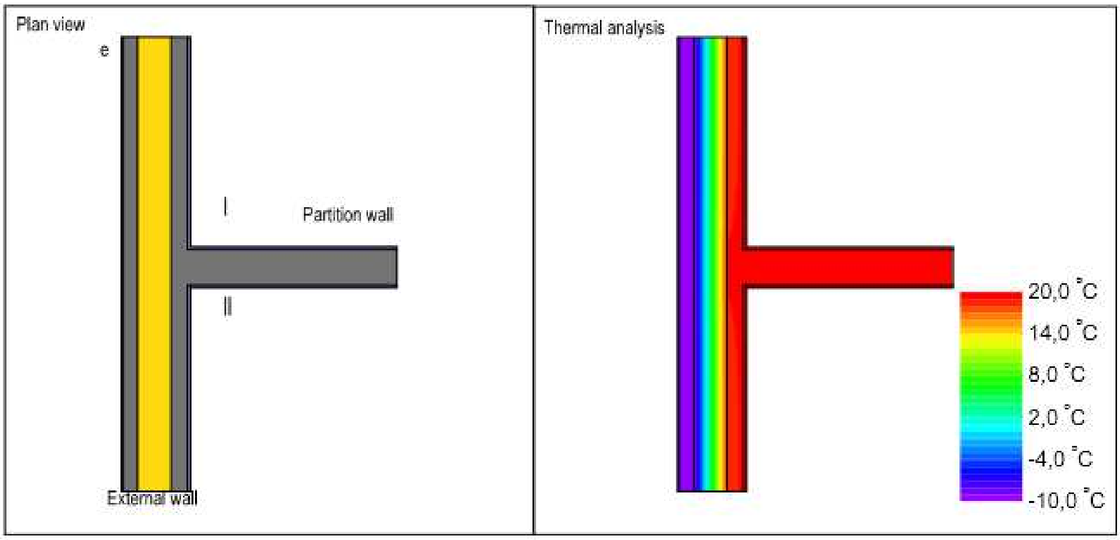
FIGURE 35. Brick masonry lay-up. Structure source: Pech and Kolbitsch, 23

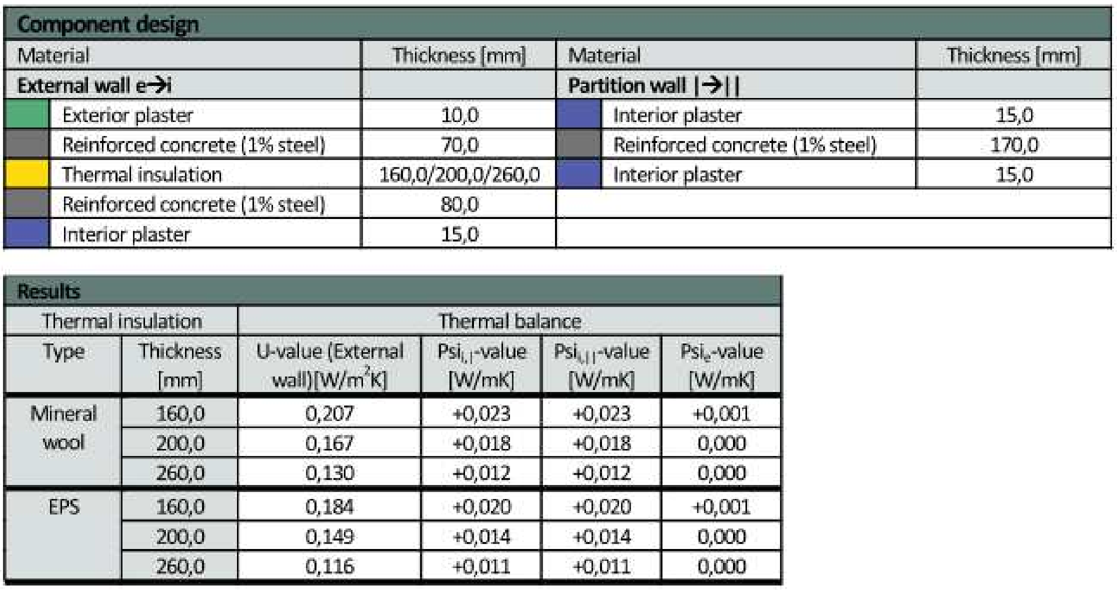


Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Partition wall I→II**		
🟩	Exterior plaster	10,0	🟦	Interior plaster	15,0
🟨	Thermal insulation	160,0 /200,0 /260,0	⬛	Reinforced concrete (1% steel)	170,0
⬛	Reinforced concrete (1% steel)	250,0	🟦	Interior plaster	15,0
🟦	Interior plaster	15,0			

Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	$\text{Psi}_{i,I}$-value [W/mK]	$\text{Psi}_{i,II}$-value [W/mK]	Psi_e-value [W/mK]
Mineral wool	160,0	0,205	+0,021	+0,021	+0,001
	200,0	0,166	+0,017	+0,017	0,000
	260,0	0,129	+0,013	+0,013	0,000
EPS	160,0	0,183	+0,019	+0,019	0,000
	200,0	0,148	+0,015	+0,015	0,000
	260,0	0,115	+0,012	+0,012	0,000

FIGURE 36. Concrete lay-up. Structure source: Pech and Kolbitsch, 28





Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Partition wall I→II**		
🟩	Exterior plaster	10,0	🟦	Interior plaster	15,0
⬛	Reinforced concrete (1% steel)	70,0	⬛	Reinforced concrete (1% steel)	170,0
🟨	Thermal insulation	160,0/200,0/260,0	🟦	Interior plaster	15,0
⬛	Reinforced concrete (1% steel)	80,0			
🟦	Interior plaster	15,0			

Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	$\text{Psi}_{i,I}$-value [W/mK]	$\text{Psi}_{i,II}$-value [W/mK]	Psi_e-value [W/mK]
Mineral wool	160,0	0,207	+0,023	+0,023	+0,001
	200,0	0,167	+0,018	+0,018	0,000
	260,0	0,130	+0,012	+0,012	0,000
EPS	160,0	0,184	+0,020	+0,020	+0,001
	200,0	0,149	+0,014	+0,014	0,000
	260,0	0,116	+0,011	+0,011	0,000

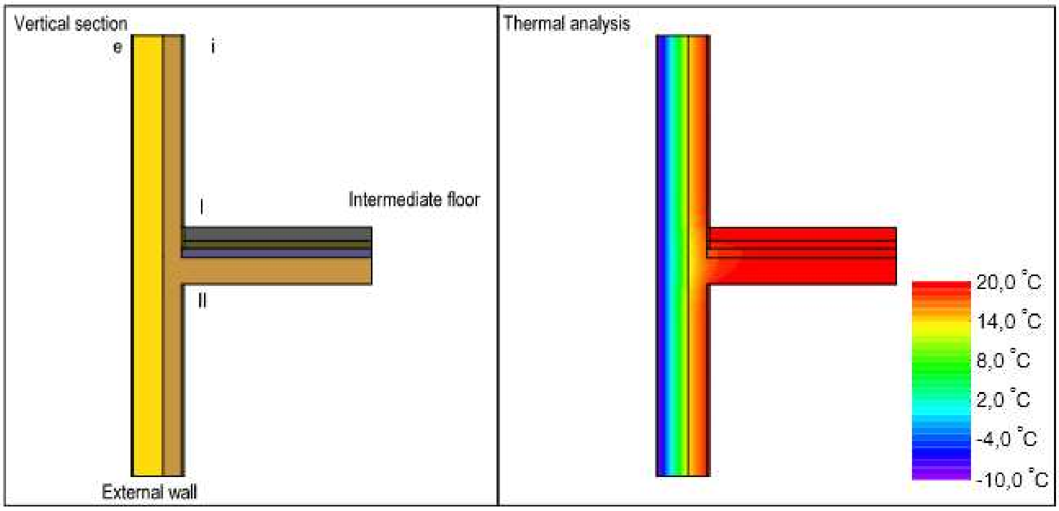
FIGURE 37. Concrete sandwich lay-up. Structure source: Lämpö- ja kosteustekniikka, 2013

7.3.1 Evaluation of the results

The junction between external wall and partition wall is not a critical structure, because the partition wall is connected to the interior surface of the exterior wall without any penetration in the exterior wall. In these cases the concrete and brick lay-ups give lower exterior Psi-values.

7.4 Intermediate floor

This is one of the most critical junctions in a building envelope, because the intermediate floor is penetrating the external wall structure. By using exterior insulation, the heat losses are minimized and can be almost prevented entirely.

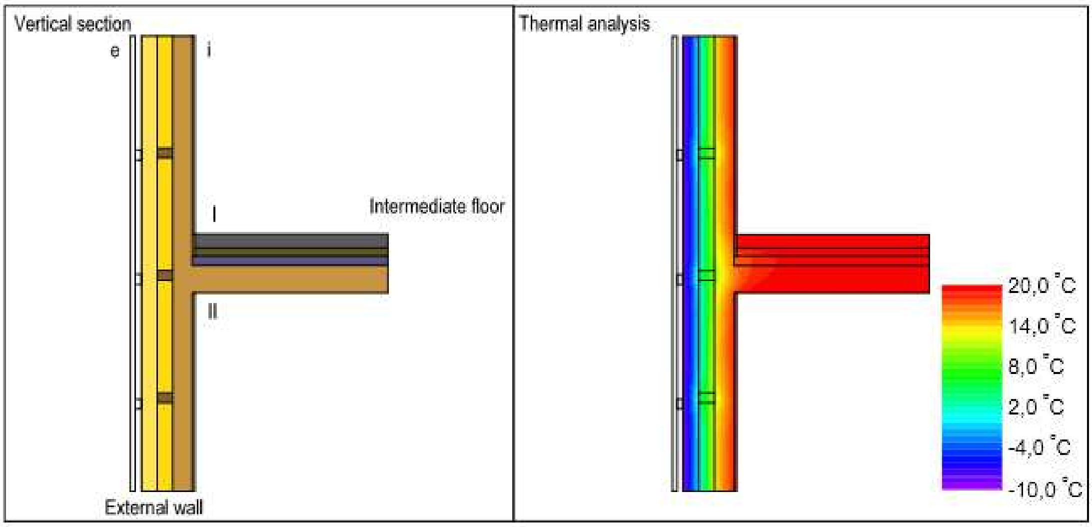


Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Intermediate floor I→II**		
🟩	Plaster	5,0	⬛	Cement screed	70,0
🟨	Thermal insulation	160,0/200,0/260,0	🟫	Sound insulation (mineral wool)	40,0
🟫	CLT	100,0	🟪	Gravel fill	50,0
🟩	Fire-protection plasterboard	12,5	🟫	CLT	140,0

Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall) [W/m^{2}K]	Psi$_{i,I}$-value [W/mK]	Psi$_{i,II}$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,175	+0,026	+0,023	-0,003
	200,0	0,146	+0,022	+0,020	-0,002
	260,0	0,117	+0,018	+0,016	-0,001
EPS	160,0	0,159	+0,024	+0,021	-0,003
	200,0	0,132	+0,020	+0,018	-0,002
	260,0	0,105	+0,016	+0,014	-0,001
Wood fibre	160,0	0,187	+0,028	+0,025	-0,004
	200,0	0,156	+0,023	+0,021	-0,002
	260,0	0,125	+0,019	+0,017	-0,002

Source: Stora Enso, Thermal Bridge catalog, 2014

FIGURE 38. CLT lay-up with plaster façade. Source: Thermal bridge catalog unpublished



Component design

	Material	Thickness [mm]		Material	Thickness [mm]
	External wall e→i			**Intermediate floor I→II**	
🟧 *	Wooden façade	25,0	⬛	Cement screed	70,0
🟫 *	Wooden battens	30,0	🟫	Sound insulation (mineral wool)	40,0
🟨	Thermal insulation, wooden battens (e=625,0 mm)	160,0/200,0 /260,0	🟪	Gravel fill	50,0
🟧	CLT	100,0	🟧	CLT	140,0
🟩	Fire-protection plasterboard	12,5			

Results

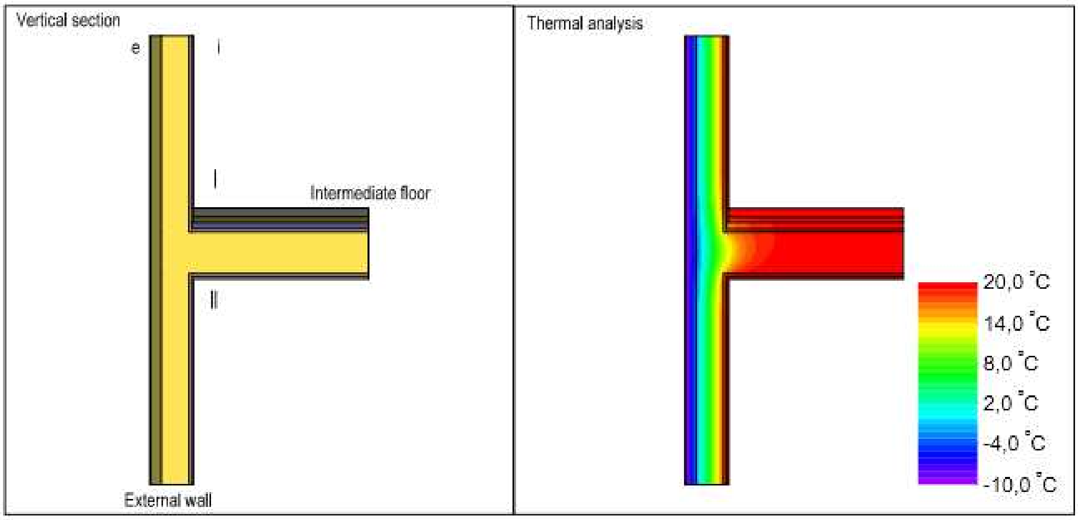
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall) [W/m²K]	Psi$_{i,I}$-value [W/mK]	Psi$_{i,II}$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,197	+0,026	+0,025	-0,009
	200,0	0,166	+0,022	+0,021	-0,007
	260,0	0,134	+0,018	+0,018	-0,005
Wood fibre **	160,0	0,184	+0,027	+0,025	-0,003
	200,0	0,154	+0,023	+0,021	-0,002
	260,0	0,124	+0,019	+0,017	-0,002

* In the component picture the color of wooden facade and wooden battens (in the ventilation layer) is white because these layers are not relevant for the calculation

** Wood fibre insulation does not contain wooden battens

Source: Stora Enso, Thermal Bridge catalog, 2014

FIGURE 39. CLT lay-up with wooden façade. Source: Thermal bridge catalog unpublished

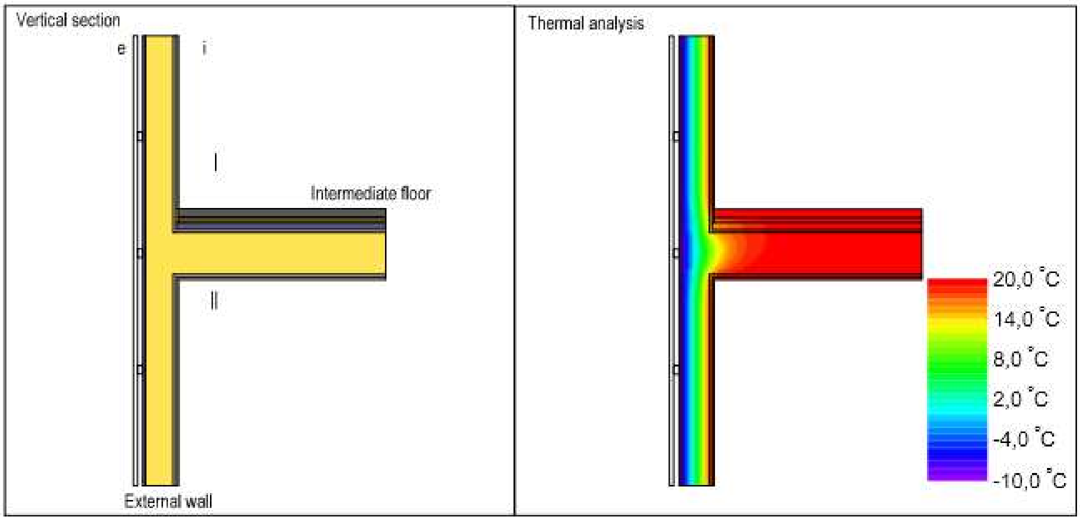


Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Intermediate floor I→II**		
🟩	Plaster	5,0	⬛	Cement screed	50,0
🟫	High density wood fibre board	60,0	🟫	Impact sound insulation	30,0
🟨	Thermal insulation, timber frame (e=625,0 mm)	160,0 /200,0/260,0	🟪	Gravel fill	40,0
⬜	OSB	16,0	⬜	OSB	18,0
🟩	Fire-protection plasterboard	12,5	🟨	Mineral wool, timber frame (e=625,0 mm)	240,0
			⬜	OSB	16,0
			🟩	Fire-protection plasterboard	15,0

Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	$Psi_{i,I}$-value [W/mK]	$Psi_{i,II}$-value [W/mK]	Psi_e-value [W/mK]
Mineral wool	160,0	0,173	+0,034	+0,024	-0,011
	200,0	0,148	+0,030	+0,021	-0,008
	260,0	0,123	+0,025	+0,018	-0,005
Wood fibre	160,0	0,181	+0,035	+0,024	-0,012
	200,0	0,156	+0,030	+0,021	-0,010
	260,0	0,129	+0,026	+0,018	-0,007

Source: www.dataholz.com External wall and intermediate floor, 2014

FIGURE 40. Timber frame lay-up with plaster façade. Structure source: Dataholz 2014



Component design

	Material	Thickness [mm]		Material	Thickness [mm]
	External wall e→i			**Intermediate floor I→II**	
🟧 *	Wooden façade	25,0	⬛	Cement screed	50,0
🟫 *	Wooden battens	30,0	🟫	Impact sound insulation	30,0
🟦	Particle board	16,0	🟪	Gravel fill	40,0
🟨	Thermal insulation, timber frame (e=625,0 mm)	160,0 /200,0/260,0	▨	OSB	18,0
▨	OSB	16,0	🟨	Mineral wool, timber frame (e=625,0 mm)	240,0
🟩	Fire-protection plasterboard	12,5	🟩	Fire-protection plasterboard	15,0

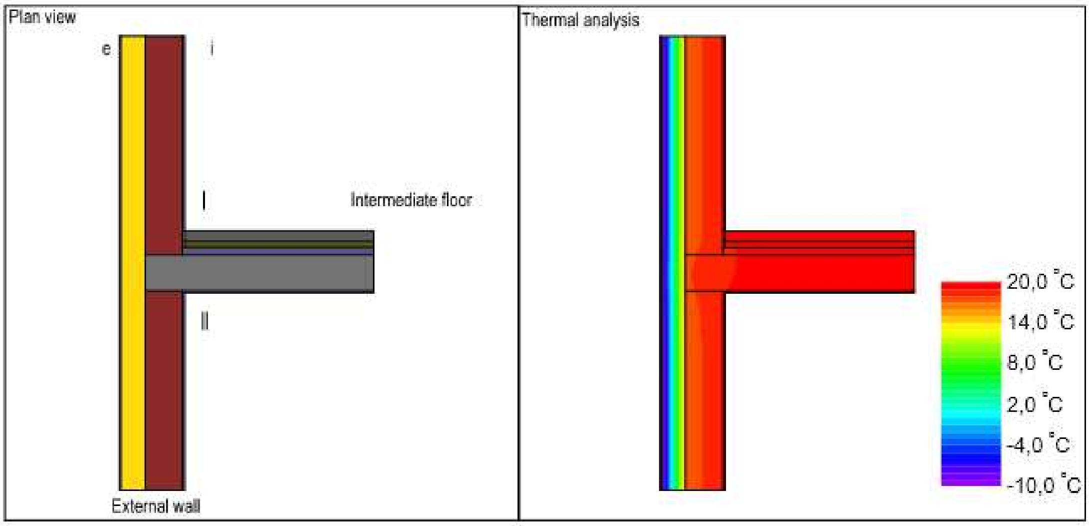
Results

Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	$\text{Psi}_{i,I}$-value [W/mK]	$\text{Psi}_{i,II}$-value [W/mK]	Psi_{e}-value [W/mK]
Mineral wool	160,0	0,227	+0,040	+0,026	-0,024
	200,0	0,187	+0,033	+0,021	-0,020
	260,0	0,148	+0,026	+0,017	-0,015
Wood fibre	160,0	0,241	+0,040	+0,025	-0,030
	200,0	0,198	+0,034	+0,021	-0,022
	260,0	0,157	+0,027	+0,017	-0,018

* In the component picture the color of wooden facade and wooden battens (in the ventilation layer) is white because these layers are not relevant for the calculation

Source: www.dataholz.com External wall and intermediate floor, 2014

FIGURE 41. Timber frame lay-up with wooden façade. Structure source: Dataholz 2014



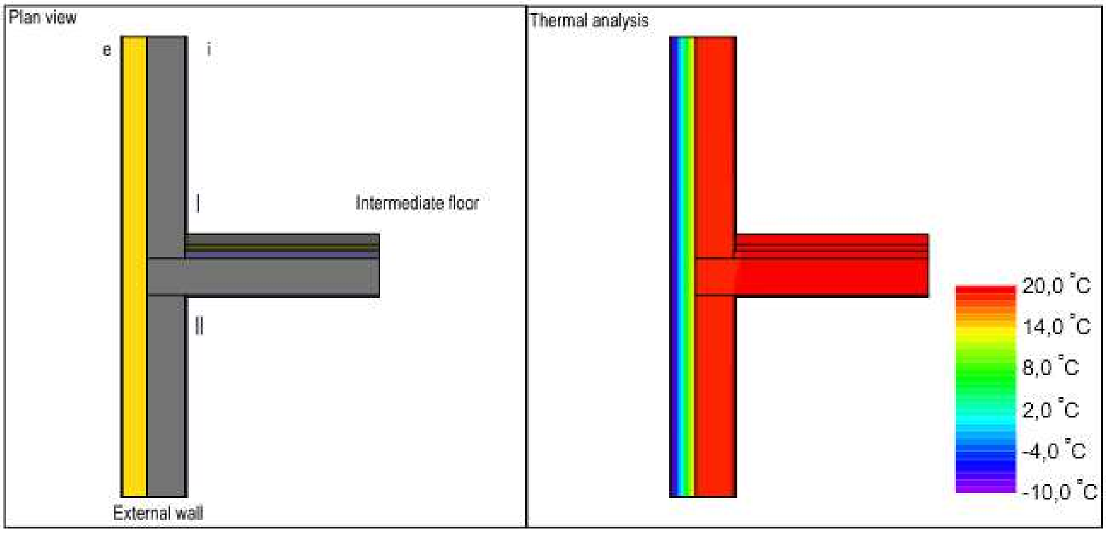
Component design

Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Intermediate floor I→II**		
🟩	Exterior plaster	10,0	⬛	Cement screed	70,0
🟨	Thermal insulation	160,0 /200,0 /260,0	🟫	Sound insulation (mineral wool)	40,0
🟥	Brick masonry	250,0	🟪	Gravel fill	50,0
🟦	Interior plaster	15,0	▨	Reinforced concrete (1% steel)	240,0
			🟦	Interior plaster	15,0

Results

Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_{i,I}$-value [W/mK]	Psi$_{i,II}$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,196	+0,020	+0,064	+0,002
	200,0	0,160	+0,016	+0,052	+0,001
	260,0	0,126	+0,012	+0,041	+0,001
EPS	160,0	0,176	+0,017	+0,057	+0,002
	200,0	0,143	+0,014	+0,046	+0,001
	260,0	0,112	+0,011	+0,036	+0,001

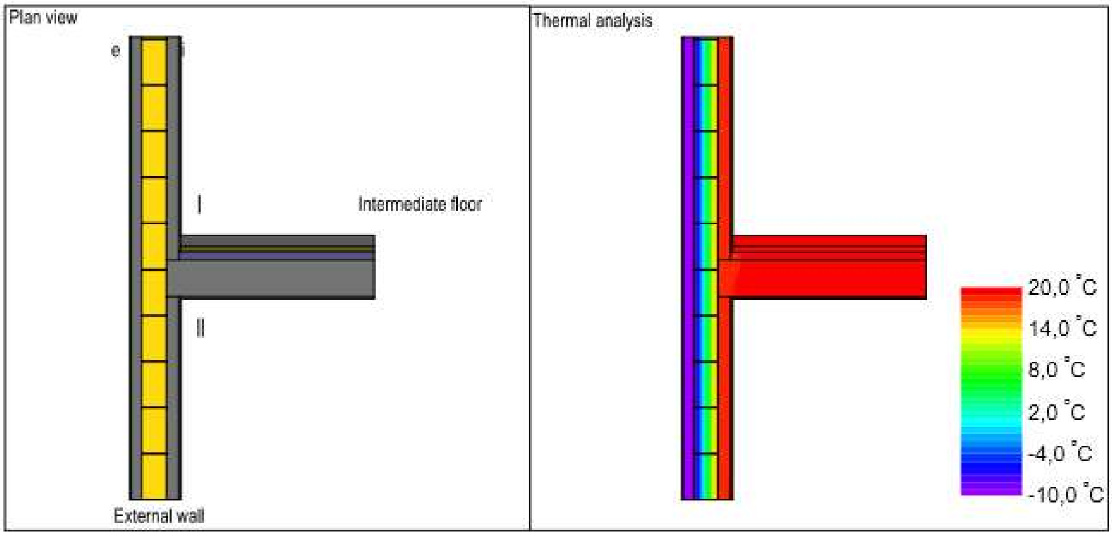
FIGURE 42. Brick masonry lay-up with reinforced concrete intermediate floor. Structure source: Pech and Kolbitsch, 23



Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Intermediate floor I→II**		
🟩	Exterior plaster	10,0	⬛	Cement screed	70,0
🟨	Thermal insulation	160,0 /200,0 /260,0	🟫	Sound insulation (mineral wool)	40,0
⬛	Reinforced concrete (1% steel)	250,0	🟪	Gravel fill	50,0
🟦	Interior plaster	15,0	⬛	Reinforced concrete (1% steel)	240,0
			🟦	Interior plaster	15,0

Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_{i,I}$-value [W/mK]	Psi$_{i,II}$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,205	+0,025	+0,059	-0,001
	200,0	0,166	+0,020	+0,048	0,000
	260,0	0,129	+0,016	+0,038	0,000
EPS	160,0	0,183	+0,022	+0,053	-0,001
	200,0	0,148	+0,018	+0,043	0,000
	260,0	0,115	+0,014	+0,033	0,000

FIGURE 43. Concrete lay-up. Structure source: Pech and Kolbitsch, 28



Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Intermediate floor I→II**		
🟩	Exterior plaster	10,0	⬛	Cement screed	70,0
⬛	Reinforced concrete (1% steel)	70,0	🟫	Sound insulation (mineral wool)	40,0
🟨	Thermal insulation, stainless steel anchoring (e=300,0mm)	160,0 /200,0 /260,0	🟪	Gravel fill	50,0
⬛	Reinforced concrete (1% steel)	80,0	⬛	Reinforced concrete (1% steel)	240,0
🟦	Interior plaster	15,0	🟦	Interior plaster	15,0

Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	$\text{Psi}_{i,I}$-value [W/mK]	$\text{Psi}_{i,II}$-value [W/mK]	Psi_{e}-value [W/mK]
Mineral wool	160,0	0,214	+0,027	+0,061	-0,001
	200,0	0,173	+0,022	+0,049	-0,001
	260,0	0,135	+0,016	+0,038	-0,002
EPS	160,0	0,192	+0,024	+0,054	-0,001
	200,0	0,155	+0,020	+0,044	-0,001
	260,0	0,120	+0,016	+0,035	+0,001

FIGURE 44. Concrete sandwich lay-up. Structure source: Lämpö – ja kosteustekniikka 2013

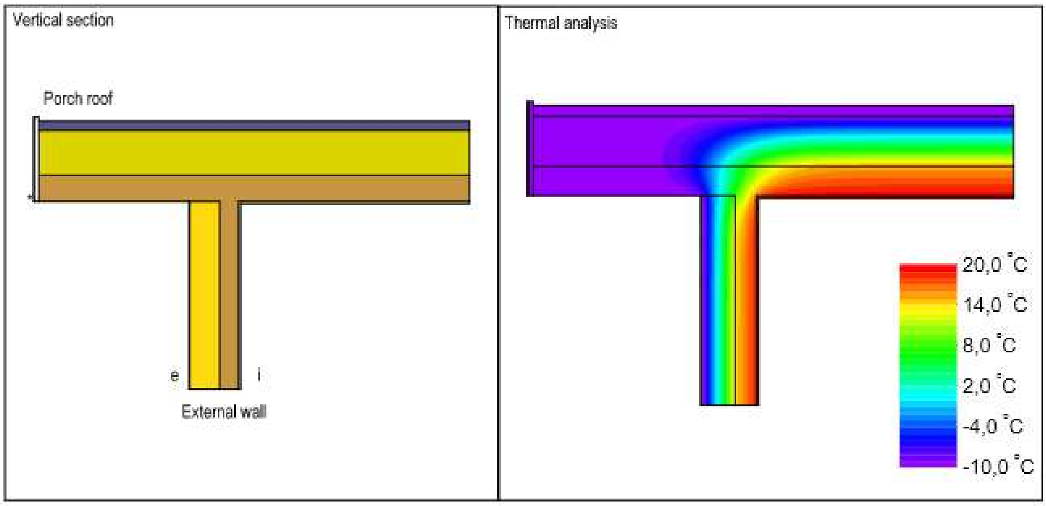
7.4.1 Evaluation of the results

From the results it is possible to see that all the lay-ups give good results, so when building a house with an intermediate floor it is just important to build it with exterior insulation and as airtight as possible.

Also, looking at the thermal analysis you can see clearly the difference between timber/CLT lay-ups and the concrete/brick lay-ups. The effect of thermal conductivity is easy to see by compairing the concrete/brick lay-ups to the wooden lay ups. In the concrete and brick lay-ups (Figure 42 and 43), the warm air inside is transfering all the way to the insulation layer, warming up the whole wall. As you can see from the Figure 38-41, in the wooden lay-up the warm air is staying on the interior surface.

7.5 Flat roof

Different insulation materials were used, depending on which lay-up was calculated. The timber frame lay-up uses a different insulation material in the roof part than the other lay-ups. This is because timber frame lay-ups do not generally use EPS as an insulating material. When making flat roof structures, the effect of insulating the overhanging part was studied. The results were interesting and they are presented in Figures below.



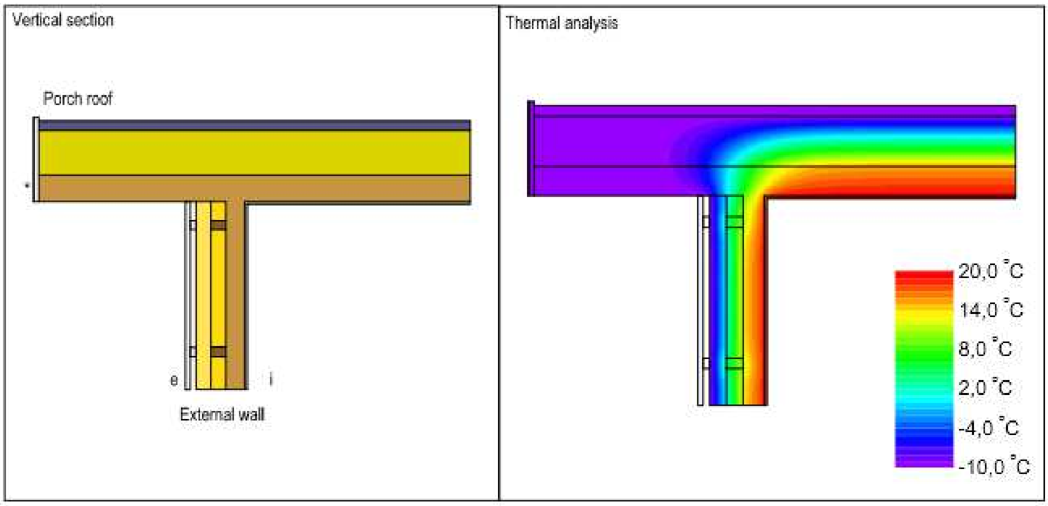
Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Porch roof e→i**		
🟩	Plaster	5,0	🟪	Gravel fill	50,0
🟨	Thermal insulation	160,0 /200,0 /260,0	🟨	EPS	240,0
🟧	CLT	100,0	🟧	CLT	140,0
🟩	Fire-protection plasterboard	12,5	🟩	Fire-protection plasterboard	12,5

Results					
Thermal insulation (External wall)		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (Porch roof) [W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,175	0,108	+0,051	-0,057
	200,0	0,146	0,108	+0,049	-0,049
	260,0	0,117	0,108	+0,047	-0,045
EPS	160,0	0,159	0,108	+0,052	-0,048
	200,0	0,132	0,108	+0,049	-0,043
	260,0	0,105	0,108	+0,047	-0,040
Wood fibre	160,0	0,187	0,108	+0,051	-0,061
	200,0	0,156	0,108	+0,049	-0,055
	260,0	0,125	0,108	+0,046	-0,050

* Edge of the roof is protected with OSB board and metal cover

Source: Stora Enso, Thermal Bridge catalog,2014

FIGURE 45. CLT lay-up with plaster façade. Source: Thermal bridge catalog unpublished



Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Porch roof e→i**		
🟧 **	Wooden Façade	25,0	🟪	Gravel fill	50,0
🟫 **	Wooden battens	30,0	🟨	EPS	240,0
🟨	Thermal insulation, wooden battens (e=625,0 mm)	160,0 /200,0 /260,0	🟫	CLT	140,0
🟫	CLT	100,0	🟩	Fire-protection plasterboard	12,5
🟩	Fire-protection plasterboard	12,5			

Results					
Thermal insulation (External wall)		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (porch roof) [W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,197	0,108	+0,054	-0,063
	200,0	0,166	0,108	+0,051	-0,056
	260,0	0,134	0,108	+0,049	-0,051
Wood fibre***	160,0	0,184	0,108	+0,051	-0,060
	200,0	0,154	0,108	+0,049	-0,053
	260,0	0,124	0,108	+0,046	-0,048

* Edge of the roof is protected with OSB board and metal cover

** In the component picture the color of wooden facade and wooden battens (in the ventilation layer) is white because these layers are not relevant for the calculation

*** Wood fibre insulation does not contain wooden battens

Source: Stora Enso, Thermal Bridge catalog, 2014

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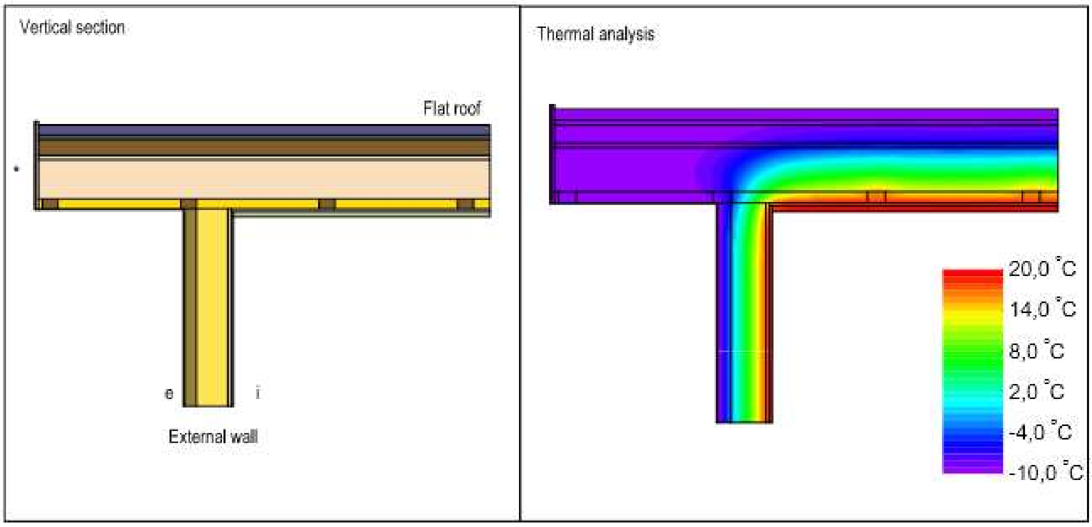
FIGURE 46. CLT lay-up with wooden facade. Source: Thermal bridge catalog unpublished

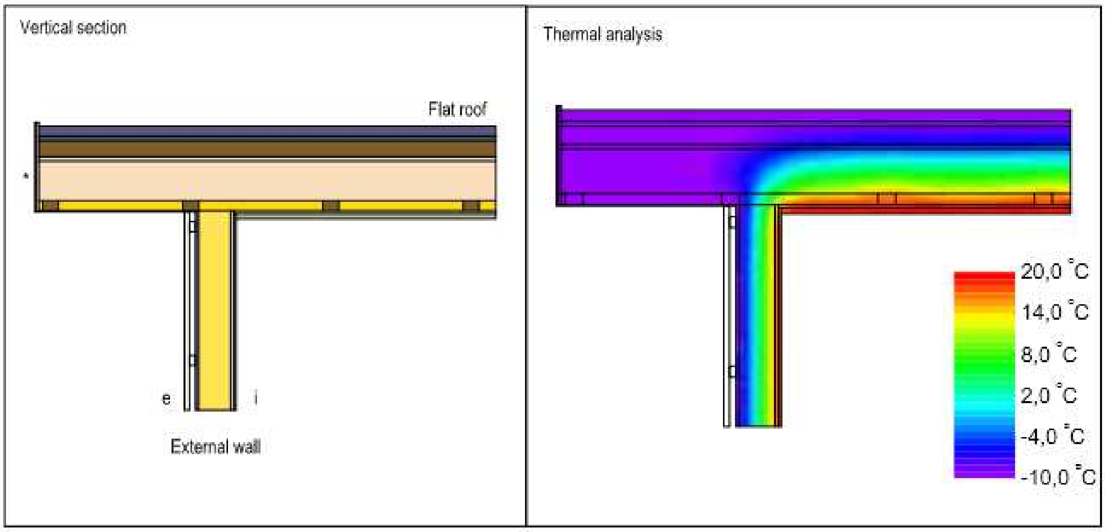


Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Flat roof e→i**		
▨	Plaster	5,0	▨	Gravel fill	
▨	High density wood fibre board	60,0	▨	Softwood closed cladding	24,0
▨	Thermal insulation, timber frame (e=625,0 mm)	160,0 /200,0 / 260,0	▨	Wooden battens (e=625,0 mm)	80,0
▨	OSB	16,0	▨	Soft board	22,0
▨	Fire-protection plasterboard	12,5	▨	Wood fibre, timber frame (e=800,0 mm)	200,0
			▨	Mineral wool, wooden battens (e= 625,0 mm)	50,0
			▨	OSB	16,0
			▨	Fire-protection plaster board	2X12,5

Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (Flat roof)[W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,173	0,141	+0,033	-0,079
	200,0	0,148	0,141	+0,032	-0,076
	260,0	0,123	0,141	+0,030	-0,075
Wood fibre	160,0	0,181	0,141	+0,033	-0,085
	200,0	0,156	0,141	+0,032	-0,079
	260,0	0,129	0,141	+0,031	-0,079

* Edge of the roof is protected with OSB board and metal cover
Source: www.dataholz.com, 2014

FIGURE 47. Timber frame lay-up with plaster façade. Structure source: Dataholz 2014



Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Flat roof e→i**		
🟧 **	Wooden façade	25,0	🟪	Gravel fill	
🟫 **	Wooden battens	30,0	⬛	Softwood closed cladding	24,0
🟦	Particle board	16,0	🟫	Wooden battens (e=625,0 mm)	80,0
🟨	Thermal insulation, timber frame (e=625,0 mm)	160,0/200,0/ 260,0	⬜	Soft board	22,0
⬜	OSB	16,0	🟧	Wood fibre, timber frame (e=800,0 mm)	200,0
🟩	Fire-protection plaster board	12,5	🟨	Mineral wool, wooden battens (e= 625,0 mm)	50,0
			🟩	Fire-protection plaster board	2X12,5

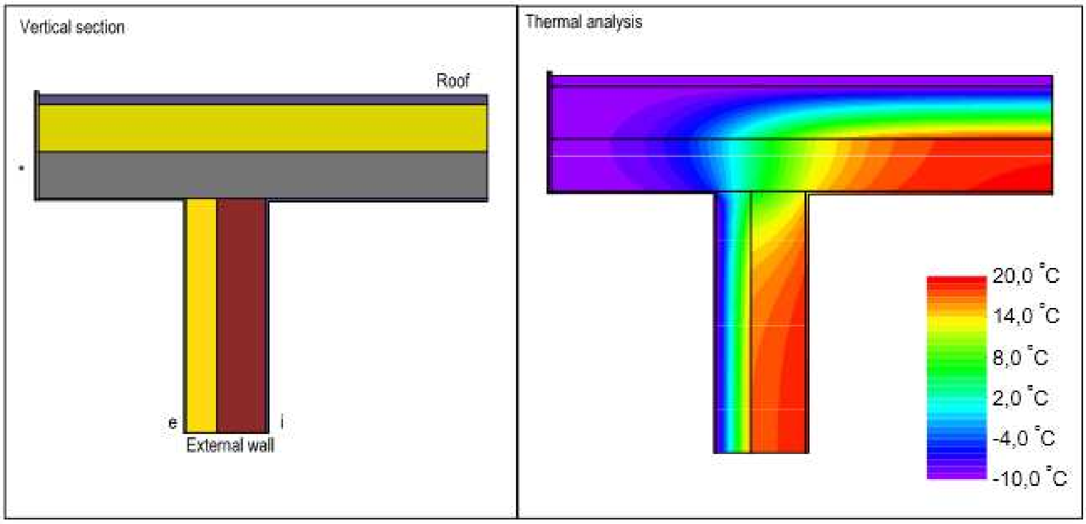
Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m²K]	U-value (Flat roof)[W/m²K]	Psi_i-value [W/mK]	Psi_e-value [W/mK]
Mineral wool	160,0	0,227	0,141	+0,034	-0,094
	200,0	0,187	0,141	+0,032	-0,087
	260,0	0,148	0,141	+0,030	-0,079
Wood fibre	160,0	0,241	0,141	+0,033	-0,102
	200,0	0,198	0,141	+0,033	-0,090
	260,0	0,157	0,141	+0,031	-0,086

* Edge of the roof is protected with OSB board and metal cover

** In the component picture the color of wooden facade and wooden battens (in the ventilation layer) is white because these layers are not relevant for the calculation

Source: www.dataholz.com, 2014

FIGURE 48. Timber frame lay-up with wooden façade. Structure source: Dataholz 2014



Component design

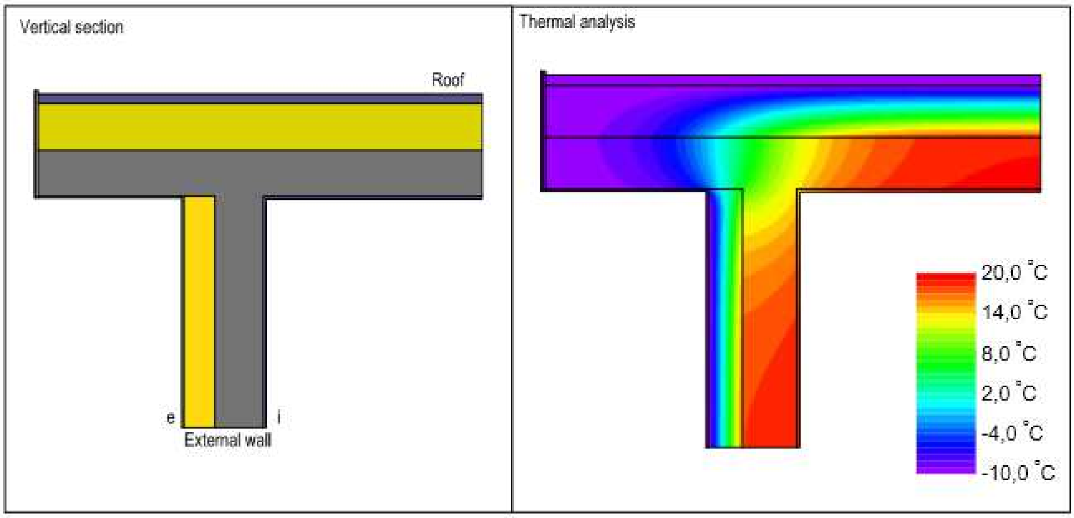
Material	Thickness [mm]	Material	Thickness [mm]
External wall e→i		**Roof e→i**	
🟩 Exterior plaster	10,0	🟪 Gravel	50,0
🟨 Thermal insulation	160,0 /200,0 /260,0	🟨 EPS	240,0
🟥 Brick masonry	250,0	⬛ Reinforced concrete (1% steel)	240,0
🟦 Interior plaster	15,0	🟦 Interior plaster	15,0

Results

Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)$[W/m^2K]$	U-value (Roof) $[W/m^2K]$	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,196	0,124	+0,714	+0,552
	200,0	0,160	0,124	+0,685	+0,540
	260,0	0,126	0,124	+0,644	+0,512
EPS	160,0	0,176	0,124	+0,717	+0,565
	200,0	0,143	0,124	+0,687	+0,553
	260,0	0,112	0,124	+0,646	+0,517

* Edge of the roof is protected with OSB board and metal cover

FIGURE 49. Brick masonry lay-up. Structure source: Pech and Kolbitsch, 23



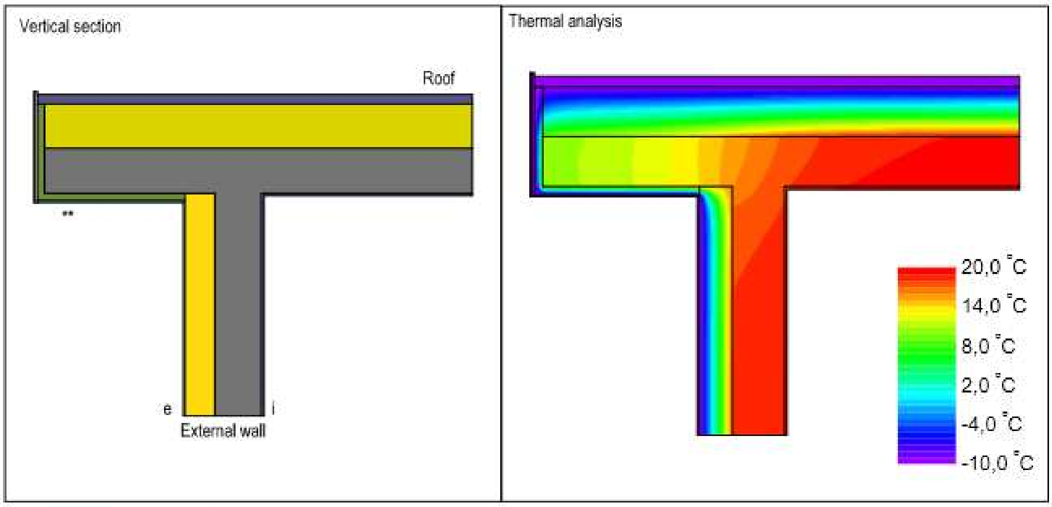
Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Roof e→i**		
🟩	Exterior plaster	10,0	🟪	Gravel	50,0
🟨	Thermal insulation	160,0 /200,0 /260,0	🟨	EPS	240,0
⬛	Reinforced concrete (1% steel)	250,0	⬛	Reinforced concrete (1% steel)	240,0
🟦	Interior plaster	15,0	🟦	Interior plaster	15,0

Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (Roof) [W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,205	0,124	+0,811	+0,645
	200,0	0,166	0,124	+0,773	+0,625
	260,0	0,129	0,124	+0,722	+0,588
EPS	160,0	0,183	0,124	+0,815	+0,660
	200,0	0,148	0,124	+0,776	+0,640
	260,0	0,115	0,124	+0,724	+0,596

* Edge of the roof is protected with OSB board and metal cover

FIGURE 50. Concrete lay-up without insulation under the overhanging part.

Structure source: Pech and Kolbitsch, 28



Component design

Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Roof e→i**		
🟩	Exterior plaster	10,0	🟪	Gravel	50,0
🟨	Thermal insulation	160,0 /200,0 /260,0	🟨	EPS	240,0
▨	Reinforced concrete (1% steel)	250,0	▨	Reinforced concrete (1% steel)	240,0
🟦	Interior plaster	15,0	🟦	Interior plaster	15,0

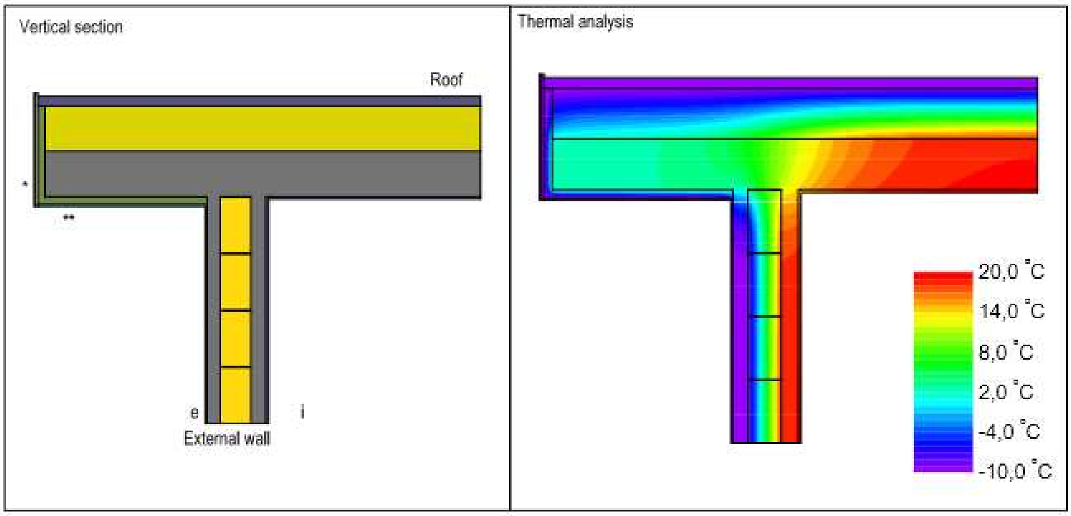
Results

Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (Roof) [W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,205	0,124	+0,205	+0,044
	200,0	0,166	0,124	+0,213	+0,062
	260,0	0,129	0,124	+0,219	+0,082
EPS	160,0	0,183	0,124	+0,207	+0,051
	200,0	0,148	0,124	+0,212	+0,070
	260,0	0,115	0,124	+0,218	+0,092

* Edge of the roof is protected with OSB board and metal cover
** 40,0mm WLG040 and 10,0mm exterior plaster

FIGURE 51. Concrete lay-up with insulation around the overhanging part.

Structure source: Pech and Kolbitsch, 28



Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Roof e→i**		
🟩	Exterior plaster	10,0	🟪	Gravel	50,0
⬛	Reinforced concrete	70,0	🟨	EPS	240,0
🟨	Thermal insulation, stainless steel anchoring (e=300,0mm)	160,0/200,0/260,0	⬛	Reinforced concrete (1% steel)	240,0
⬛	Reinforced concrete	80,0	🟦	Interior plaster	15,0
🟦	Interior plaster	15,0			

Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^2K]	U-value (Roof) [W/m^2K]	Psi_i-value [W/mK]	Psi_e-value [W/mK]
Mineral wool	160,0	0,214	0,124	+0,576	+0,420
	200,0	0,173	0,124	+0,558	+0,417
	260,0	0,135	0,124	+0,535	+0,402
EPS	160,0	0,192	0,124	+0,578	+0,446
	200,0	0,155	0,124	+0,560	+0,427
	260,0	0,120	0,124	+0,535	+0,414

* Edge of the roof is protected with OSB board and metal cover
** 40,0mm WLG040 and 10,0mm exterior plaster

FIGURE 52. Concrete sandwich lay-up with insulation around the overhanging part. Structure source: Lämpö- ja kosteustekniikka 2013

7.5.1 Evaluation of the results

I investigated the results of insulating the overhanging roof part in concrete lay-up. The results can been seen clearly from the table and from the thermal analysis picture as well. I did the investigation after I noticed how big the heat losses were without insulation under the overhanging part.

From Figures 50 and 51 it is possible to see the effect of the insulated overhanging part. Even though the overhanging part is not relevant for the calculation, it has a significant effect on the results.

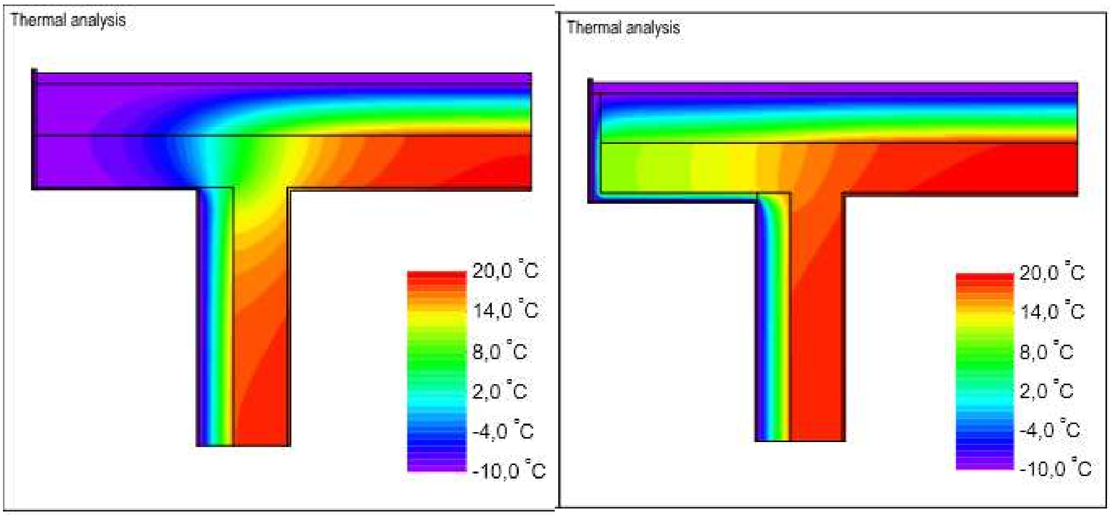
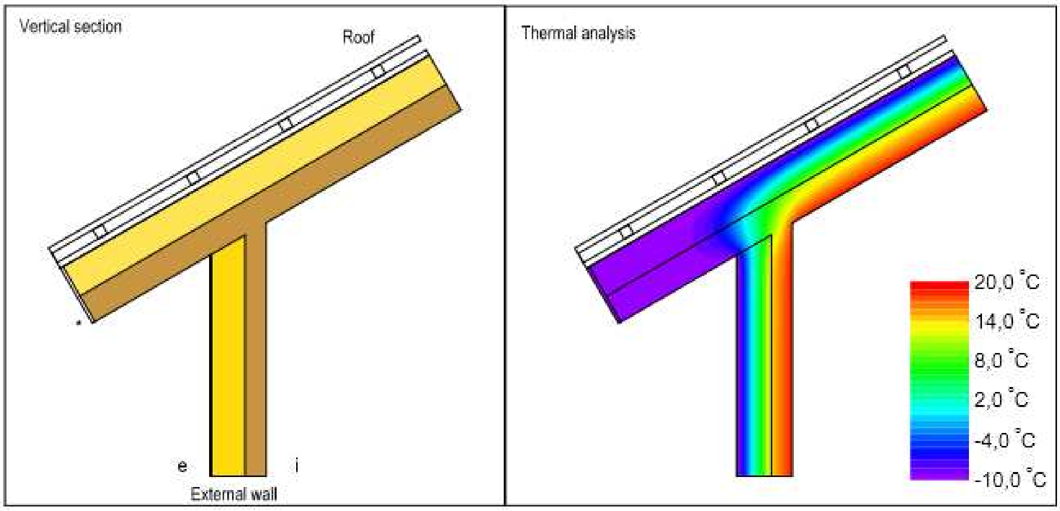


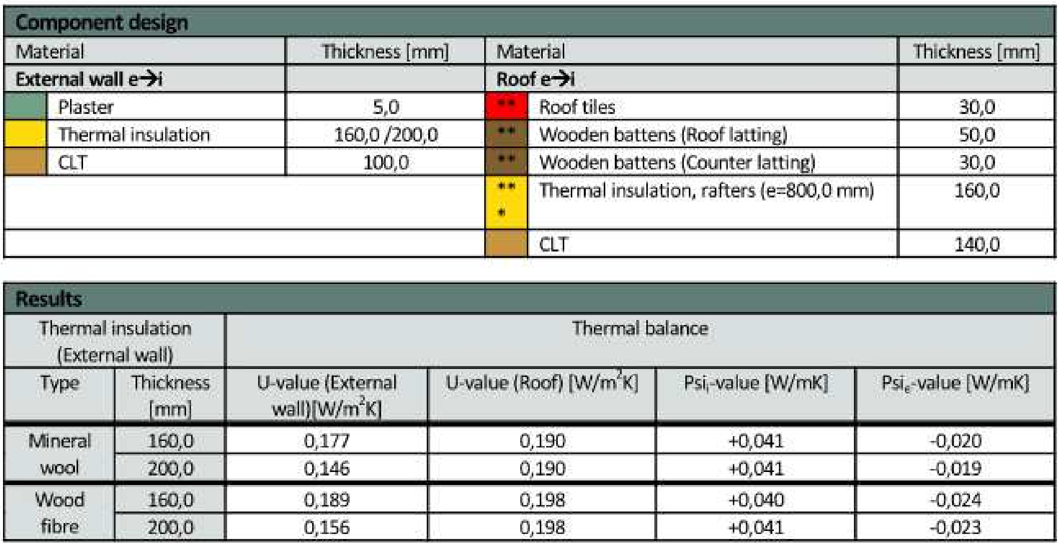
FIGURE 53. Concrete lay up with noninsulated overhanging roof (left, figure 50) and insulated (right, figure 51).

CLT has good material properties especially for structures which have overhanging parts. With CLT, the overhanging parts are easily made and the cold air does not transfer through the structure. Also, the insulation layer under the overhanging part is not necessary in CLT buildings. If a structure like this is built with concrete it is necessary to install an insulation layer around the overhanging structure, as seen in the results.

7.6 Steep roof

In this chapter two different CLT roof structures were investigated: roof with CLT eaves and rafter roof, Figure 54 and Figure 55. Rafter roof has also been used to calculate values for timber frame and brick masonry lay-ups.





Component design

	Material	Thickness [mm]		Material	Thickness [mm]
	External wall e→i			**Roof e→i**	
🟩	Plaster	5,0	🟥 **	Roof tiles	30,0
🟨	Thermal insulation	160,0 /200,0	🟫 **	Wooden battens (Roof latting)	50,0
🟫	CLT	100,0	🟫 **	Wooden battens (Counter latting)	30,0
			🟨 ***	Thermal insulation, rafters (e=800,0 mm)	160,0
			🟫	CLT	140,0

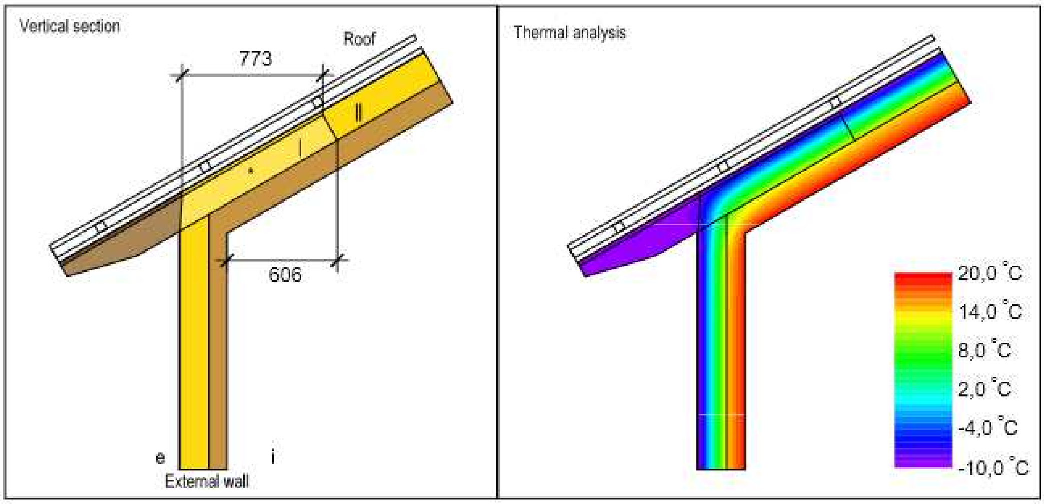
Results

Thermal insulation (External wall)		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m²K]	U-value (Roof) [W/m²K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,177	0,190	+0,041	-0,020
	200,0	0,146	0,190	+0,041	-0,019
Wood fibre	160,0	0,189	0,198	+0,040	-0,024
	200,0	0,156	0,198	+0,041	-0,023

* Edge of the roof is protected with OSB board and metal cover
** In the component picture the color of roof tiles and wooden battens is white because these layers are not relevant for the calculation
*** If thermal insulation in external wall is wood fibre, the roof insulation is considered as the same material

Source: Stora Enso, Thermal Bridge catalog, 2014

FIGURE 54. CLT lay-up with CLT eave and plaster façade. Source: Thermal bridge catalog unpublished



Component design

	Material	Thickness [mm]		Material	Thickness [mm]
External wall e→i			**Roof e→i**		
🟩	Plaster	5,0	🟥 **	Roof tiles	30,0
🟨	Thermal insulation	160,0 /200,0	🟫 **	Wooden battens(Roof latting)	50,0
🟫	CLT	100,0	🟫 **	Wooden battens (Counter latting)	30,0
			🟨 ***	Soft board (same as thermal insulation)	22,0
			🟨 ***	Thermal insulation	160,0
			🟫	CLT	140,0

Results

Thermal insulation (External wall)		Thermal balance				
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (Roof) [W/m^{2}K]		Psi$_i$-value [W/mK] *	Psi$_e$-value [W/mK] *
			I	II		
Mineral wool	160,0	0,177	0,181	0,149	+0,007	-0,052
	200,0	0,147	0,181	0,149	+0,006	-0,052
Wood fibre	160,0	0,189	0,178	0,159	+0,016	-0,046
	200,0	0,157	0,178	0,159	+0,014	-0,043

* Containing thermal insulation and rafter (e=800,0mm), U-value of this part is used on Psi-calculations

** In the component picture the color of roof tiles and wooden battens is white because these layers are not relevant for the calculation

*** If thermal insulation in external wall is wood fibre, the roof insulation is considered as the same material

Source: Stora Enso, Thermal Bridge catalog, 2014

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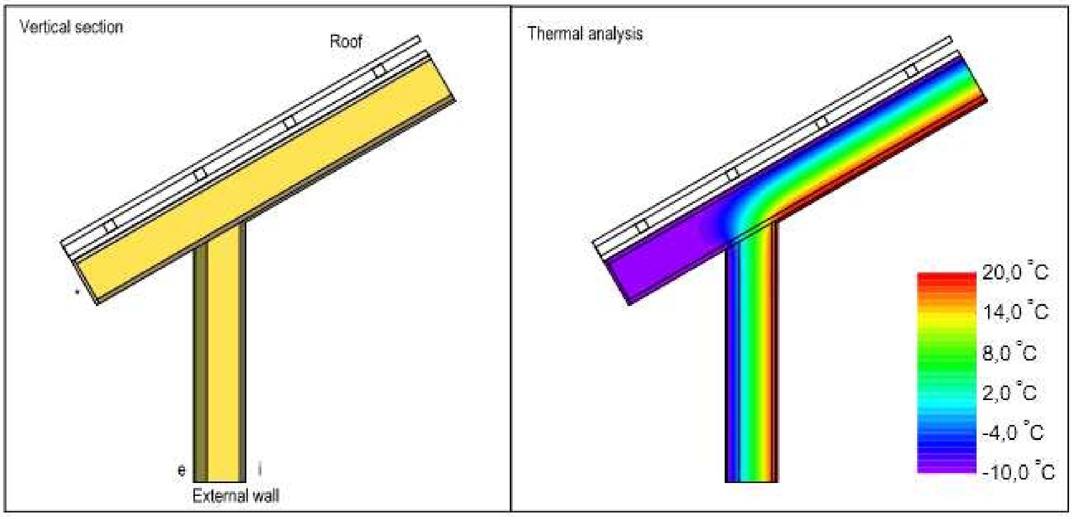
FIGURE 55. CLT lay-up with rafter roof and plaster façade. Source: Thermal bridge catalog unpublished



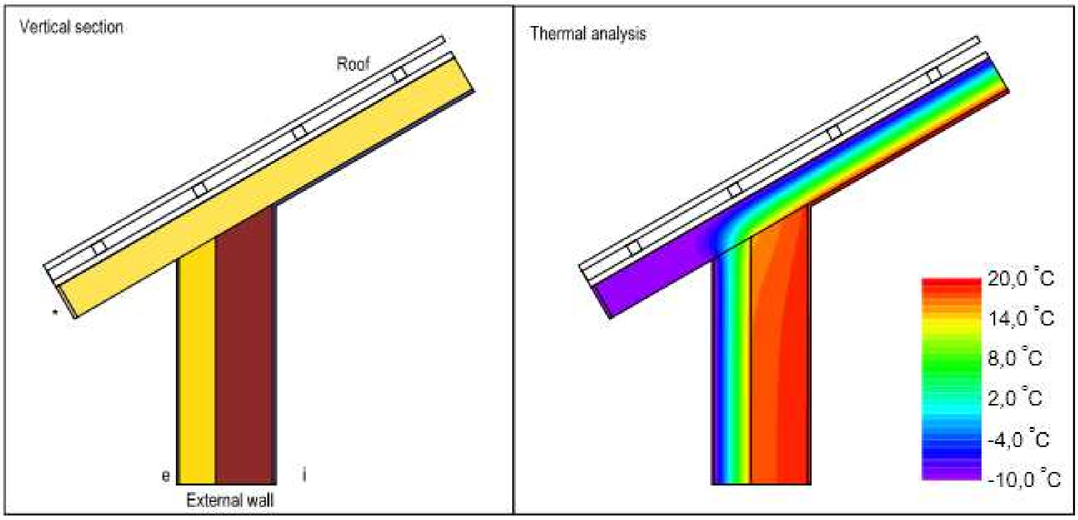
Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Roof e→i**		
🟩	Plaster	5,0	🟥 **	Roof tiles	30,0
🟫	High density wood fibre board	60,0	🟫 **	Wooden battens (roof latting)	50,0
🟨	Thermal insulation, timber frame (e=625,0mm)	160,0/200,0/260,0	🟫 **	Wooden battens (counter latting)	30,0
🟫	OSB	16,0	⬜	Soft board	22,0
🟩	Fire-protection plasterboard	12,5	🟨	Thermal insulation, timber frame (e=800,0 mm)	200,0
			🟫	Wooden battens (e= 625,0 mm)	24,0
			🟩	Fire-protection plasterboard	12,5

Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value(Roof) [W/m^{2}K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,173	0,177	+0,023	-0,032
	200,0	0,148	0,177	+0,024	-0,032
Wood fibre	160,0	0,181	0,186	+0,024	-0,031
	200,0	0,156	0,186	+0,025	-0,031

* Edge of the roof is protected with OSB board and metal cover
** In the component picture the color of roof tiles and wooden battens is white because these layers are not relevant for the calculation
*** If thermal insulation in external wall is wood fibre, the roof insulation is considered as the same material
Source: www.dataholz.com, 2014

FIGURE 56. Timber frame lay-up with rafter roof and plaster façade.

Structure source: Dataholz 2014



Component design

Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Roof e→i**		
🟩	Exterior plaster	10,0	🟥 **	Roof tiles	30,0
🟨	Thermal insulation	160,0 /200,0 /260,0	🟫 **	Wooden battens (roof latting)	50,0
🟥	Brick masonry	250,0	🟫 **	Wooden battens (counter latting)	30,0
🟦	Interior plaster	15,0	🟨	Mineral wool, rafters (e=800,0 mm)	160,0
			🟦	Interior plaster	15,0

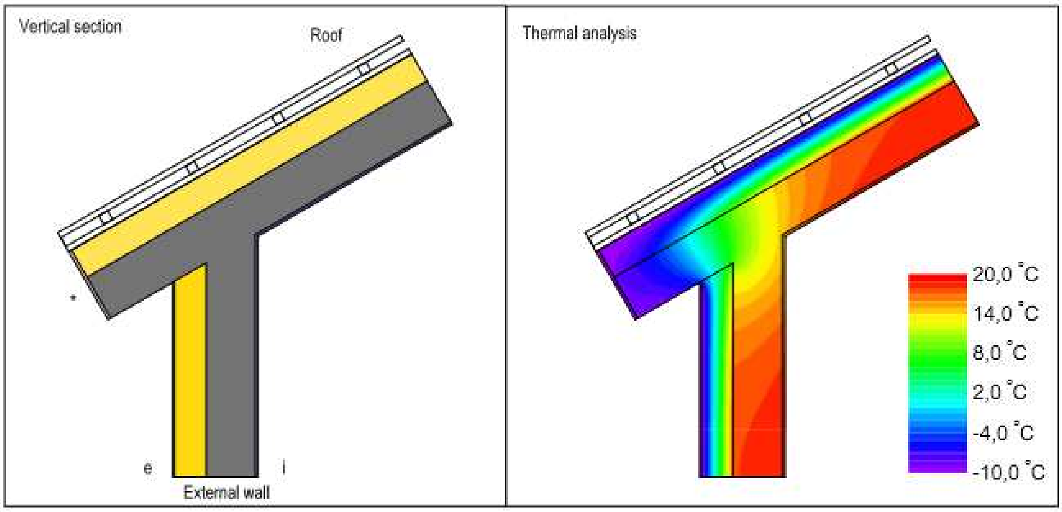
Results

Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (roof) [W/m2K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,196	0,249	+0,053	+0,311
	200,0	0,160	0,249	+0,060	+0,322
EPS	160,0	0,176	0,249	+0,057	+0,314
	200,0	0,143	0,249	+0,063	+0,323

* Edge of the roof is protected with OSB board and metal cover

** In the component picture the color of roof tiles and wooden battens is white because these layers are not relevant for the calculation

FIGURE 57. Brick masonsry lay-up with rafter roof. Structure source: Pech and Kolbitsch, 23



Component design

	Material	Thickness [mm]		Material	Thickness [mm]
External wall e→i			**Roof e→i**		
🟩	Exterior plaster	10,0	**	Roof tiles	30,0
🟨	Thermal insulation	160,0 /200,0 /260,0	**	Wooden battens (roof latting)	50,0
⬛	Reinforced concrete (1% steel)	250,0	**	Wooden battens (counter latting)	30,0
🟦	Interior plaster	15,0	🟨	Mineral wool, rafters (e=800,0 mm)	160,0
			🟦	Interior plaster	15,0

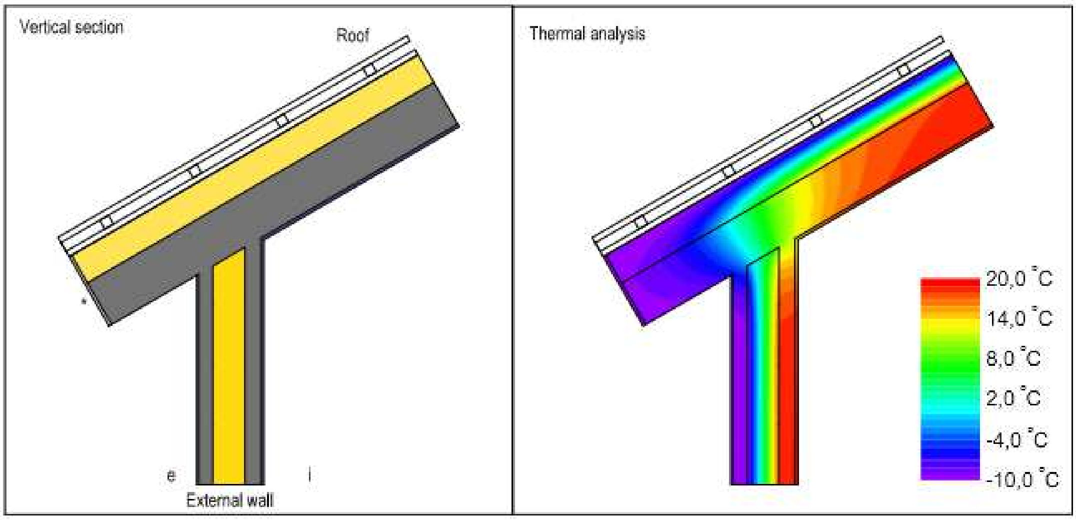
Results

Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (roof) [W/m2K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,205	0,243	+0,811	+1,043
	200,0	0,166	0,243	+0,765	+1,010
EPS	160,0	0,183	0,243	+0,812	+1,043
	200,0	0,148	0,243	+0,771	+1,017

* Edge of the roof is protected with OSB board and metal cover

** In the component picture the color of roof tiles and wooden battens is white because these layers are not relevant for the calculation

FIGURE 58. Concrete lay-up with concrete roof. Structure source: Pech and Kolbitsch, 28



Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Roof e→i**		
🟩	Exterior plaster	10,0	**	Roof tiles	30,0
⬛	Reinforced concrete (1% steel)	70,0	**	Wooden battens (roof latting)	50,0
🟨	Thermal insulation, stainless steel anchoring (e=300,0mm)	160,0/200,0	**	Wooden battens (counter latting)	30,0
⬛	Reinforced concrete (1% steel)	80,0	🟨	Mineral wool, rafters (e=800,0 mm)	160,0
🟦	Interior plaster	15,0	🟦	Interior plaster	15,0

Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (roof) [W/m2K]	Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,214	0,243	+0,785	+0,987
	200,0	0,173	0,243	+0,743	+0,959
EPS	160,0	0,192	0,243	+0,789	+1,006
	200,0	0,155	0,243	+0,746	+0,979

* Edge of the roof is protected with OSB board and metal cover

** In the component picture the color of roof tiles and wooden battens is white because these layers are not relevant for the calculation

FIGURE 59. Concrete sandwich lay-up with concrete roof. Structure source: Pech and Kolbitsch, 28 and Lämpö- ja kosteustekniikka 2013

7.6.1 Evaluation of the results

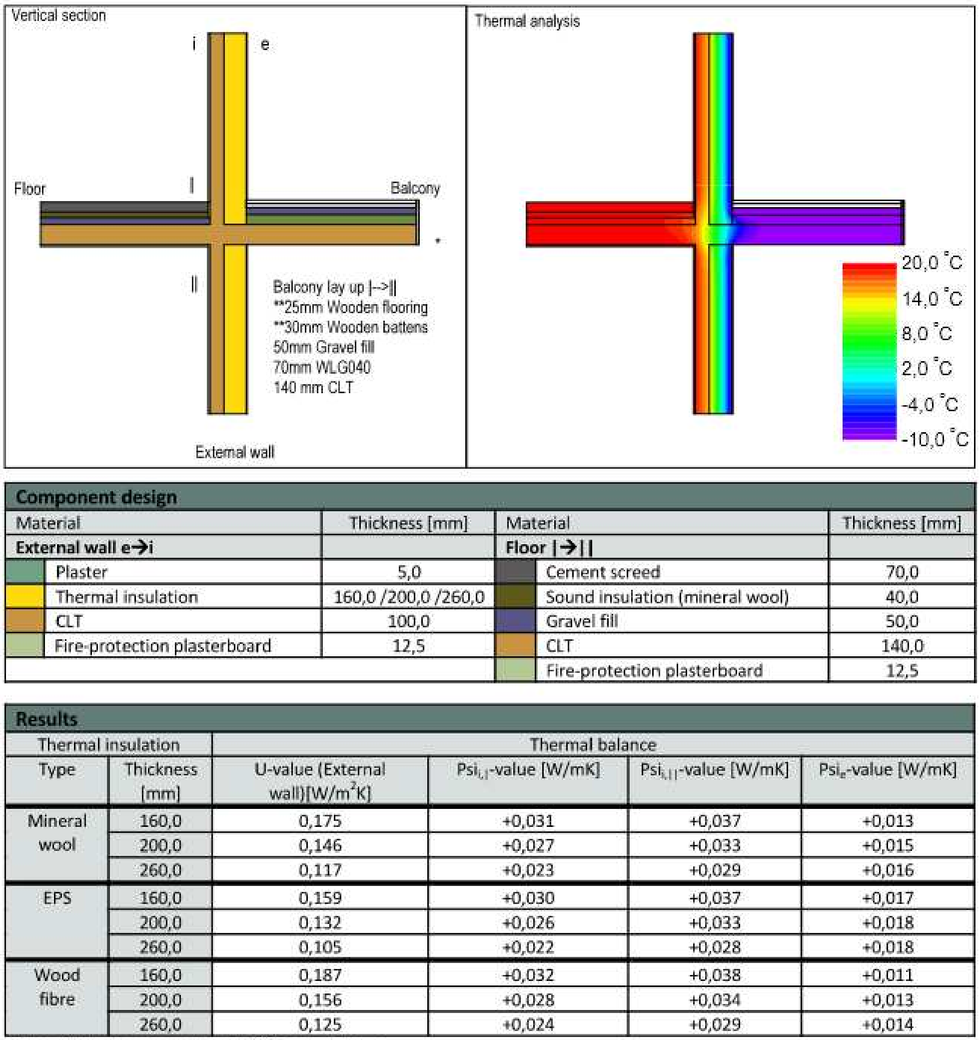
The steep roof structures were studied, to see the difference between a concrete roof and a wooden roof. It is not a critical structure, but as you can see from the results, the wooden roof gives clearly lower heat losses through the junction. I also made comparisons between two different ways to make a CLT roof, and both results give low heat losses.

Even though the thermal properties do not give critical results, the condensation risk is highest on the roof structures. This is because the warm air rises to the ceiling of the building and if the vapor barrier is broken it might cause formation of condensation inside the structure. Furthermore, there is always mold risk under the eaves if there is no underlayer which will direct the moisture out of the wall. Also, if there is no underlayer under the roof tiles or roofing sheet the moisture will get to the structure.

7.7 Balcony

Balconies are built in many different ways and this chapter only deals with overhanging balconies. Timber frame structures do not usually have overhanging balconies and this is why there are no calculations for this kind of construction. It is possible to make, by using continued timber beams from the intermediate floor, but it is not currently used anymore.

The chapter on balconies also introducs different ways to make the balcony, a separated one and a continued one. The difference between insulated balcony and an unisulated balcony were investigated and the result are presented here in Figure 64 and 65.



Component design

	Material	Thickness [mm]		Material	Thickness [mm]
	External wall e→i			**Floor I→II**	
🟩	Plaster	5,0	⬛	Cement screed	70,0
🟨	Thermal insulation	160,0 /200,0 /260,0	🟫	Sound insulation (mineral wool)	40,0
🟧	CLT	100,0	🟪	Gravel fill	50,0
🟩	Fire-protection plasterboard	12,5	🟧	CLT	140,0
			🟩	Fire-protection plasterboard	12,5

Results

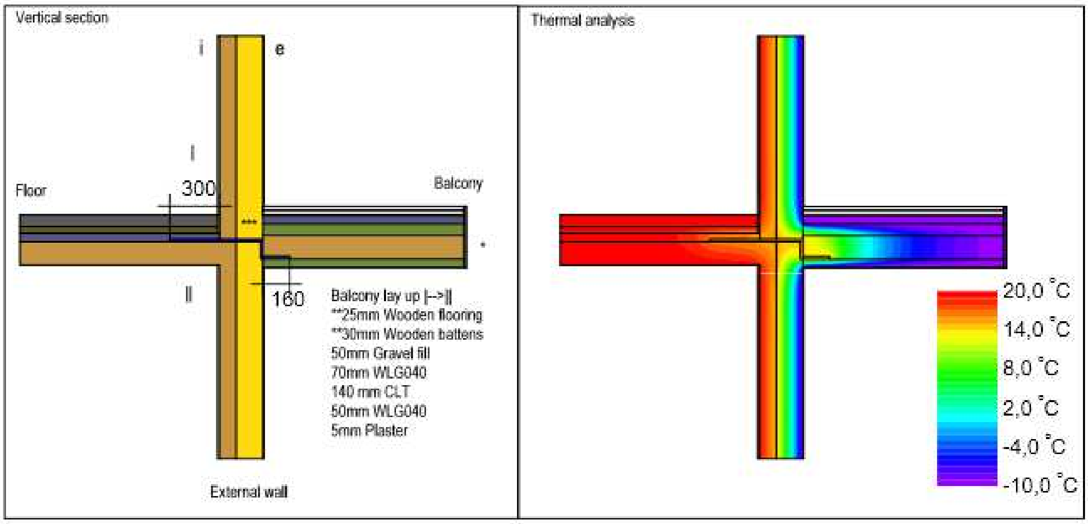
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	Psi$_{i,I}$-value [W/mK]	Psi$_{i,II}$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,175	+0,031	+0,037	+0,013
	200,0	0,146	+0,027	+0,033	+0,015
	260,0	0,117	+0,023	+0,029	+0,016
EPS	160,0	0,159	+0,030	+0,037	+0,017
	200,0	0,132	+0,026	+0,033	+0,018
	260,0	0,105	+0,022	+0,028	+0,018
Wood fibre	160,0	0,187	+0,032	+0,038	+0,011
	200,0	0,156	+0,028	+0,034	+0,013
	260,0	0,125	+0,024	+0,029	+0,014

* Edge of the balcony is protected with OSB and metal cover

** In the component picture the color of wooden flooring and wooden battens is white because these layers are not relevant for the calculation

Source: Stora Enso, Thermal Bridge catalog

FIGURE 60. CLT lay-up, continued balcony with plaster façade. Source: Thermal bridge catalog unpublished



Component design

Material	Thickness [mm]	Material	Thickness [mm]
External wall e→i		**Floor I→II**	
■ Plaster	5,0	■ Cement screed	70,0
■ Thermal insulation	160,0 /200,0 /260,0	■ Sound insulation (mineral wool)	40,0
■ CLT	100,0	■ Gravel fill	50,0
■ Fire-protection plasterboard	12,5	■ CLT	140,0

Results

Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	$\mathrm{Psi}_{i,I}$-value [W/mK]	$\mathrm{Psi}_{i,II}$-value [W/mK]	Psi_{e}-value [W/mK]
Mineral wool	160,0	0,175	+0,049	+0,041	+0,038
	200,0	0,146	+0,049	+0,042	+0,047
	260,0	0,117	+0,049	+0,043	+0,057
EPS	160,0	0,159	+0,047	+0,040	+0,039
	200,0	0,132	+0,047	+0,041	+0,048
	260,0	0,105	+0,047	+0,041	+0,057
Wood fibre	160,0	0,187	+0,050	+0,043	+0,037
	200,0	0,156	+0,050	+0,043	+0,047
	260,0	0,125	+0,050	+0,044	+0,057

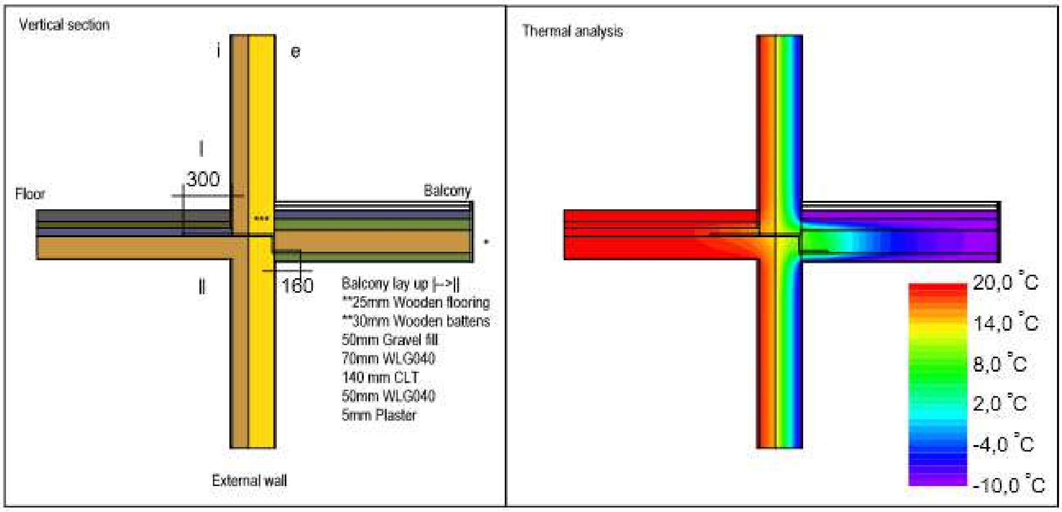
* Edge of the balcony is protected with OSB and metal cover

** In the component picture the color of wooden flooring and wooden battens is white because these layers are not relevant for the calculation

*** Continuous stainless steel part

Source: Stora Enso, Thermal Bridge catalog

FIGURE 61. CLT lay-up with plaster facade and seperated (with continuous stainlesssteel part) overhanging balcony. Overhanging balcony is also insulated in this calculation. Source: Thermal bridge catalog unpublished



Component design

Material	Thickness [mm]	Material	Thickness [mm]
External wall e→i		**Floor I→II**	
🟩 Plaster	5,0	⬛ Cement screed	70,0
🟨 Thermal insulation	160,0 /200,0 /260,0	🟫 Sound insulation (mineral wool)	40,0
🟫 CLT	100,0	🟪 Gravel fill	50,0
🟩 Fire-protection plasterboard	12,5	🟫 CLT	140,0

Results

Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	$\mathrm{Psi}_{i,I}$-value [W/mK]	$\mathrm{Psi}_{i,II}$-value [W/mK]	Psi_{e}-value [W/mK]
Mineral wool	160,0	0,175	+0,039	+0,033	+0,019
	200,0	0,146	+0,037	+0,032	+0,026
	260,0	0,117	+0,037	+0,031	+0,032
EPS	160,0	0,159	+0,037	+0,031	+0,021
	200,0	0,132	+0,036	+0,031	+0,027
	260,0	0,105	+0,034	+0,030	+0,033
Wood fibre	160,0	0,187	+0,040	+0,034	+0,017
	200,0	0,156	+0,038	+0,033	+0,025
	260,0	0,125	+0,037	+0,032	+0,031

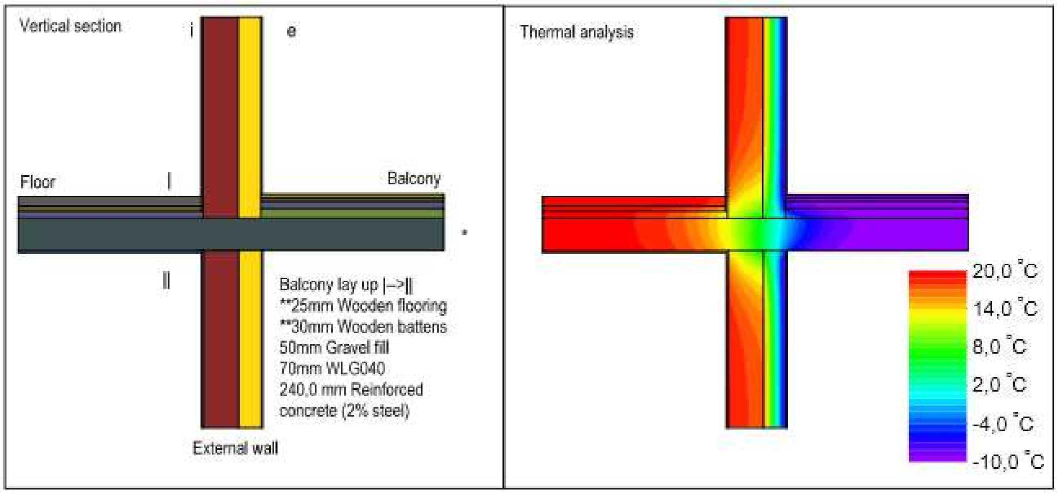
* Edge of the balcony is protected with OSB and metal cover

** In the component picture the color of wooden flooring and wooden battens is white because these layers are not relevant for the calculation

*** Noncontinuous stainless steel part,width 150mm, e=1000,0mm

Source: Stora Enso, Thermal Bridge catalog

FIGURE 62. CLT lay-up with plaster facade and seperated (with noncontinuous stainlessteel part) overhanging balcony. Overhanging balcony is also insulated in this calculation. Source: Thermal bridge catalog unpublished



Component design

	Material	Thickness [mm]		Material	Thickness [mm]
External wall e→i			**Floor |→||**		
🟩	Exterior plaster	10,0	⬛	Cement screed	70,0
🟨	Thermal insulation	160,0 /200,0 /260,0	🟫	Sound insulation (mineral wool)	40,0
🟥	Brick masonry	250,0	🟪	Gravel fill	50,0
🟦	Interior plaster	15,0	⬛	Reinforced concrete (2 % steel)	240,0
			🟦	Interior plaster	15,0

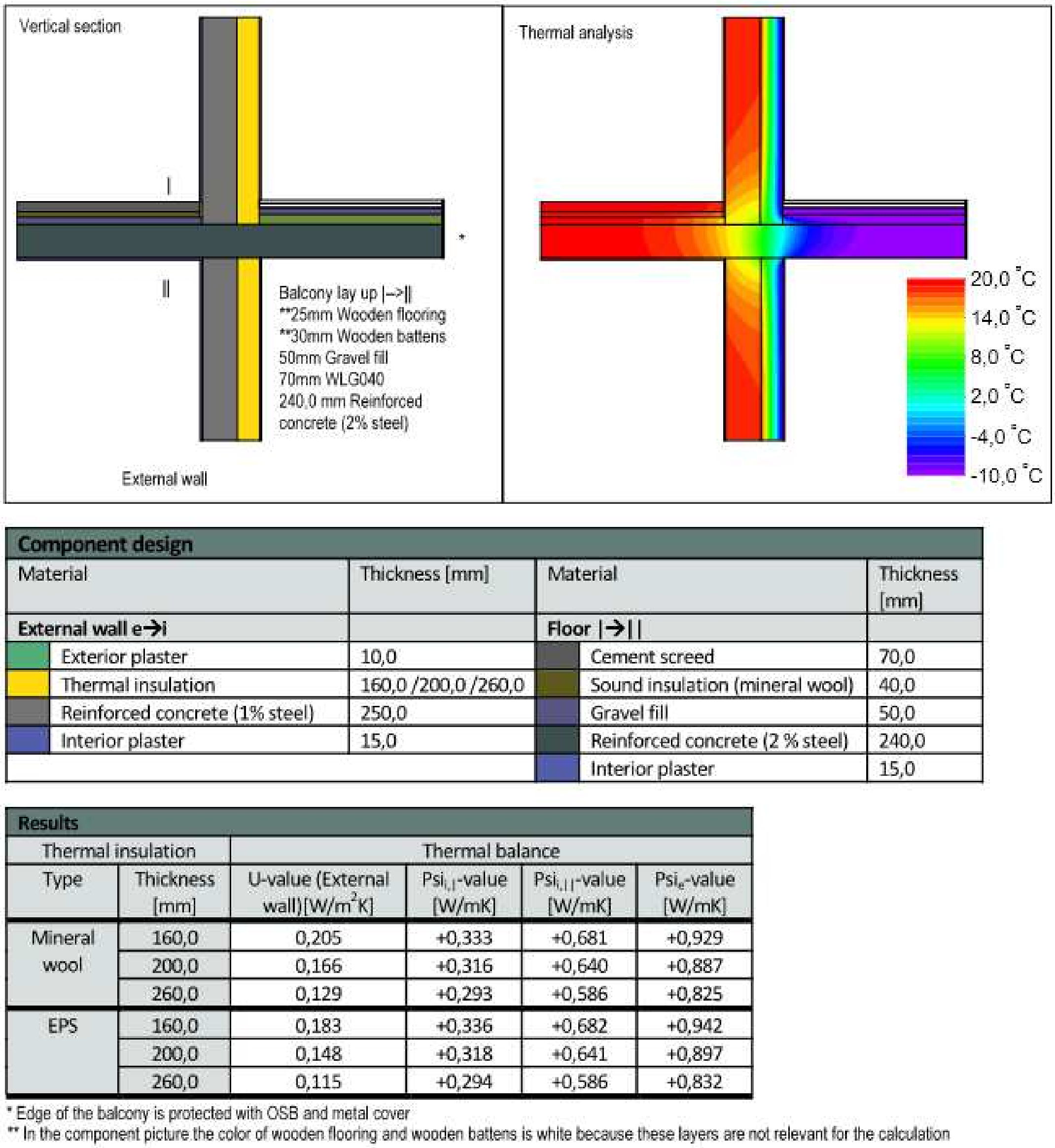
Results

Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m²K]	$\text{Psi}_{i,|}$-value [W/mK]	$\text{Psi}_{i,||}$-value [W/mK]	Psi_{e}-value [W/mK]
Mineral wool	160,0	0,196	+0,221	+0,641	+0,780
	200,0	0,160	+0,212	+0,608	+0,754
	260,0	0,126	+0,199	+0,564	+0,711
EPS	160,0	0,176	+0,223	+0,642	+0,792
	200,0	0,143	+0,213	+0,609	+0,763
	260,0	0,112	+0,200	+0,565	+0,718

* Edge of the balcony is protected with OSB and metal cover

** In the component picture the color of wooden flooring and wooden battens is white because these layers are not relevant for the calculation

FIGURE 63. Brick masonry lay-up with continued concrete balcony. Structure source: Pech and Kolbitsch, 23 and 28



Component design

	Material	Thickness [mm]		Material	Thickness [mm]
	External wall e→i			**Floor |→||**	
🟩	Exterior plaster	10,0	⬛	Cement screed	70,0
🟨	Thermal insulation	160,0 /200,0 /260,0	🟫	Sound insulation (mineral wool)	40,0
⬛	Reinforced concrete (1% steel)	250,0	🟪	Gravel fill	50,0
🟦	Interior plaster	15,0	⬛	Reinforced concrete (2 % steel)	240,0
			🟦	Interior plaster	15,0

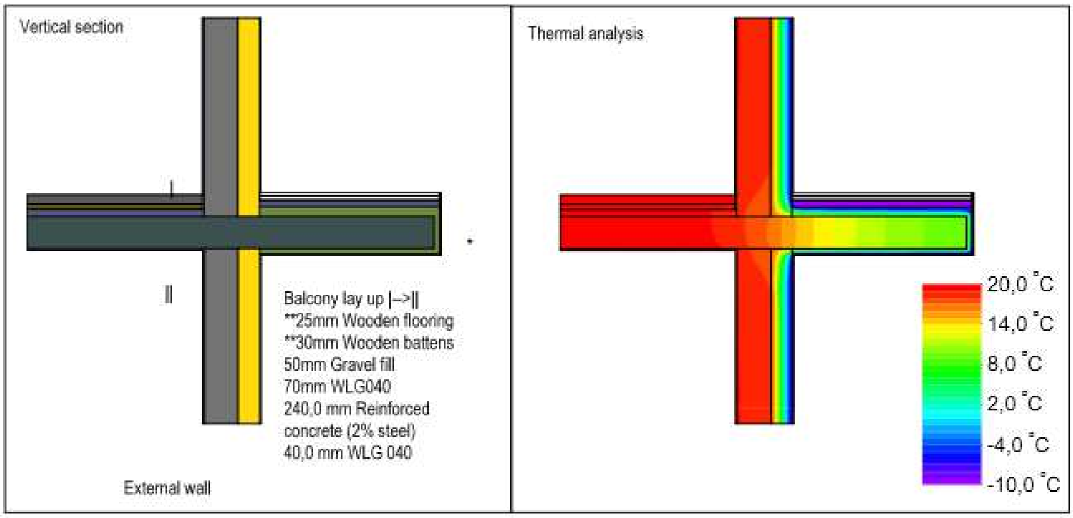
Results

Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m²K]	Psi$_{i,I}$-value [W/mK]	Psi$_{i,II}$-value [W/mK]	Psi$_e$-value [W/mK]
Mineral wool	160,0	0,205	+0,333	+0,681	+0,929
	200,0	0,166	+0,316	+0,640	+0,887
	260,0	0,129	+0,293	+0,586	+0,825
EPS	160,0	0,183	+0,336	+0,682	+0,942
	200,0	0,148	+0,318	+0,641	+0,897
	260,0	0,115	+0,294	+0,586	+0,832

* Edge of the balcony is protected with OSB and metal cover

** In the component picture the color of wooden flooring and wooden battens is white because these layers are not relevant for the calculation

FIGURE 64. Concrete lay-up with continued concrete balcony and without insulation on the balcony. Structure source: Pech and Kolbitsch, 28



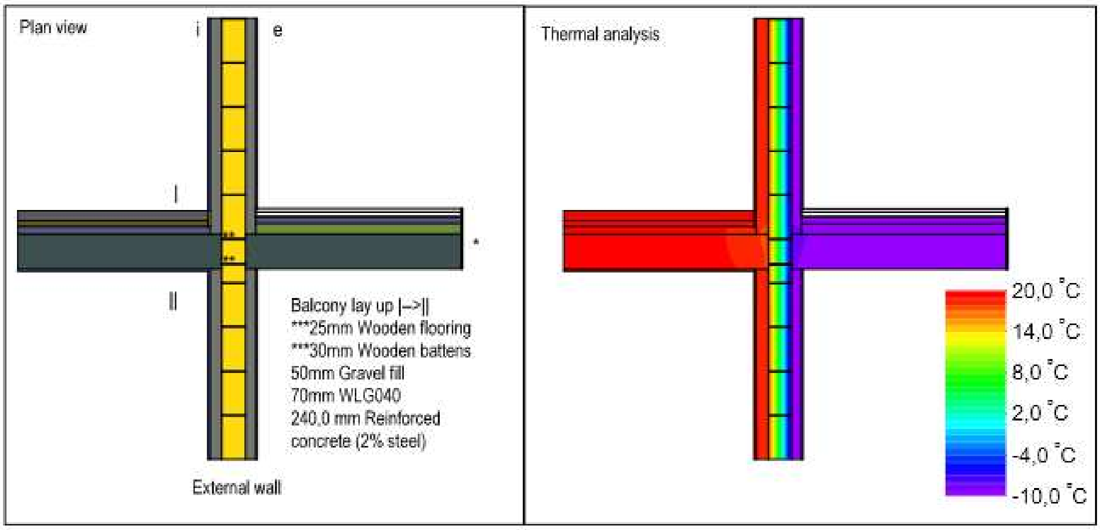
Component design					
Material		Thickness [mm]	Material		Thickness [mm]
External wall e→i			**Floor |→||**		
🟩	Exterior plaster	10,0	⬛	Cement screed	70,0
🟨	Thermal insulation	160,0 /200,0 /260,0	🟫	Sound insulation (mineral wool)	40,0
▨	Reinforced concrete (1% steel)	250,0	🟪	Gravel fill	50,0
🟦	Interior plaster	15,0	⬛	Reinforced concrete (2 % steel)	240,0
			🟦	Interior plaster	15,0

Results					
Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m²K]	$\text{Psi}_{i,\|}$-value [W/mK]	$\text{Psi}_{i,\|\|}$-value [W/mK]	Psi_{e}-value [W/mK]
Mineral wool	160,0	0,205	+0,067	+0,150	+0,133
	200,0	0,166	+0,069	+0,149	+0,149
	260,0	0,129	+0,069	+0,148	+0,164
EPS	160,0	0,183	+0,066	+0,147	+0,137
	200,0	0,148	+0,068	+0,146	+0,152
	260,0	0,115	+0,068	+0,144	+0,165

* Edge of the balcony is protected with OSB and metal cover

** In the component picture the color of wooden flooring and wooden battens is white because these layers are not relevant for the calculation

FIGURE 65. Concrete lay-up with continued concrete balcony which is also insulated. Structure sourse: Pech and Kolbitsch, 28



Component design

	Material	Thickness [mm]		Material	Thickness [mm]
	External wall e→i			**Floor I→II**	
🟩	Exterior plaster	10,0	⬛	Cement screed	70,0
⬛	Reinforced concrete	70,0	🟫	Sound insulation (mineral wool)	40,0
🟨	Thermal insulation, stainless steel anchoring (e=300,0mm)	160,0/200,0/260,0	🟪	Gravel fill	50,0
⬛	Reinforced concrete	80,0	⬛	Reinforced concrete (2 % steel)	240,0
🟦	Interior plaster	15,0	🟦	Interior plaster	15,0

Results

Thermal insulation		Thermal balance			
Type	Thickness [mm]	U-value (External wall)[W/m²K]	$Psi_{i,I}$-value [W/mK]	$Psi_{i,II}$-value [W/mK]	Psi_e-value [W/mK]
Mineral wool	160,0	0,214	+0,047	+0,124	+0,083
	200,0	0,173	+0,039	+0,102	+0,070
	260,0	0,135	+0,030	+0,079	+0,055
EPS	160,0	0,192	+0,045	+0,119	+0,084
	200,0	0,155	+0,037	+0,098	+0,071
	260,0	0,120	+0,030	+0,078	+0,058

* Edge of the balcony is protected with OSB and metal cover
**Representing thermal breaking, Isokorb, Source: Schöck, 2014
*** In the component picture the color of wooden flooring and wooden battens is white because these layers are not relevant for the calculation

FIGURE 66. Concrete sandwich lay-up with seperated and noninsulated balcony. Structure source: Lämpö – ja kosteustekniikka 2013

7.7.1 Evaluation of the results

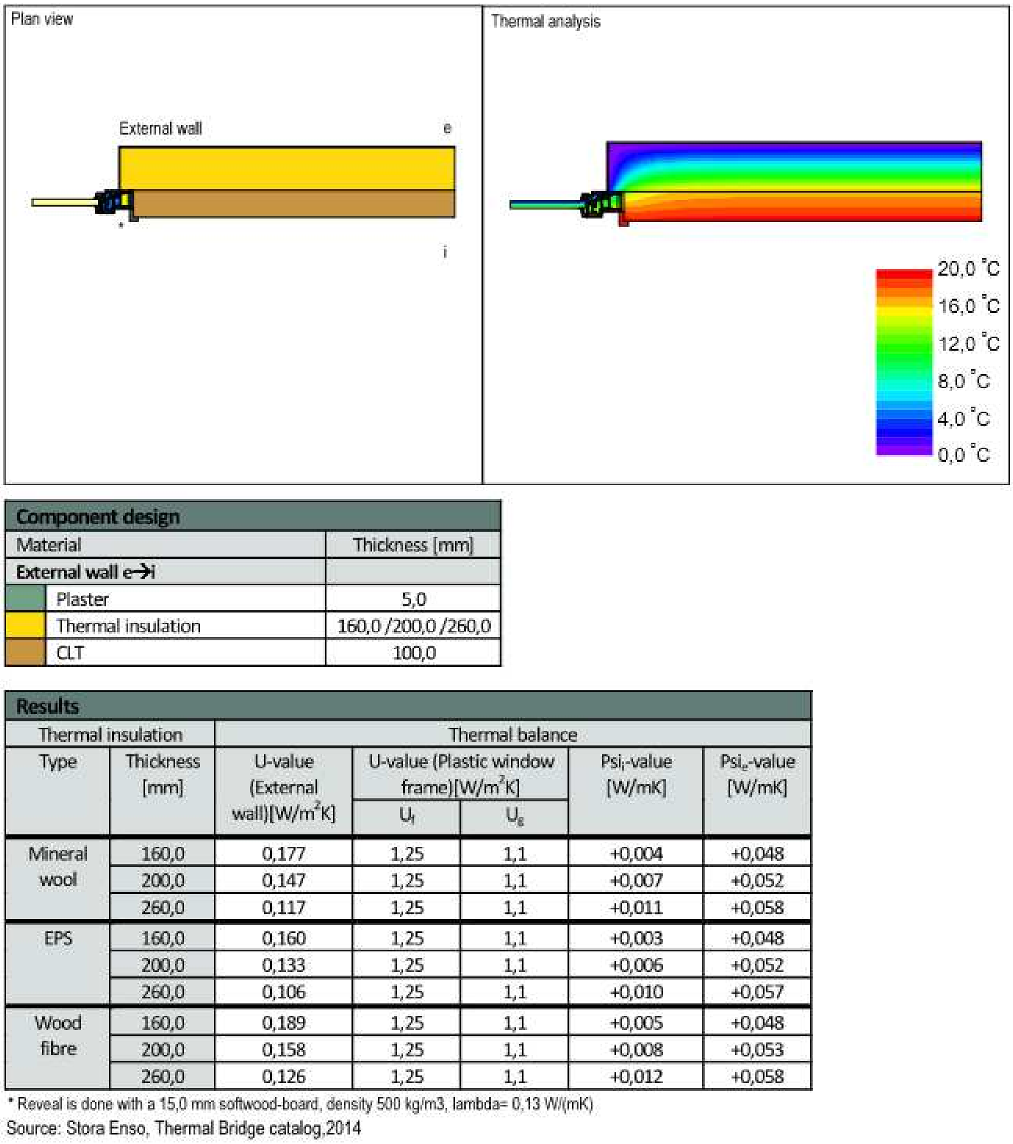
From the results it is possible to see the difference between reinforced concrete balconies which are not insulated and the balconies which are. The results show how important it is to insulate the overhanging part of the balcony when reinforced concrete is penetrating the external wall´s insulation layer.

In the case of a separated intermediate floor and a balcony the results for the junction are different. As in the case of Figure 61, it is also important to use the insulation around the overhanging balcony to prevent too high heat losses.

When building with CLT, it is not necessary to insulate the overhanging balcony structure, but when building with concrete the balcony must eather be insulated or the intermediate floor must be separated from the overhanging balcony by assembling the balcony on the exterior wall surface without any penetration.

7.8 Window installations

These window installation calculations are made by using the same frame in every lay-up. The calculations use the ready made frame which is directly from the software. It is important for the calculations to use this specific frame. To ensure that the results are correct, the window glass needs to be changed to a panel as it is already made in Flixo´s own frames. If the properties of the ready made frame are changed, the results are wrong and it might give two thermal bridges in the same window frame construction. The structures are made with the frame installed into the load bearing material so that the insulation covers a bit of the exterior surface of the frame. This gives the best thermal results.



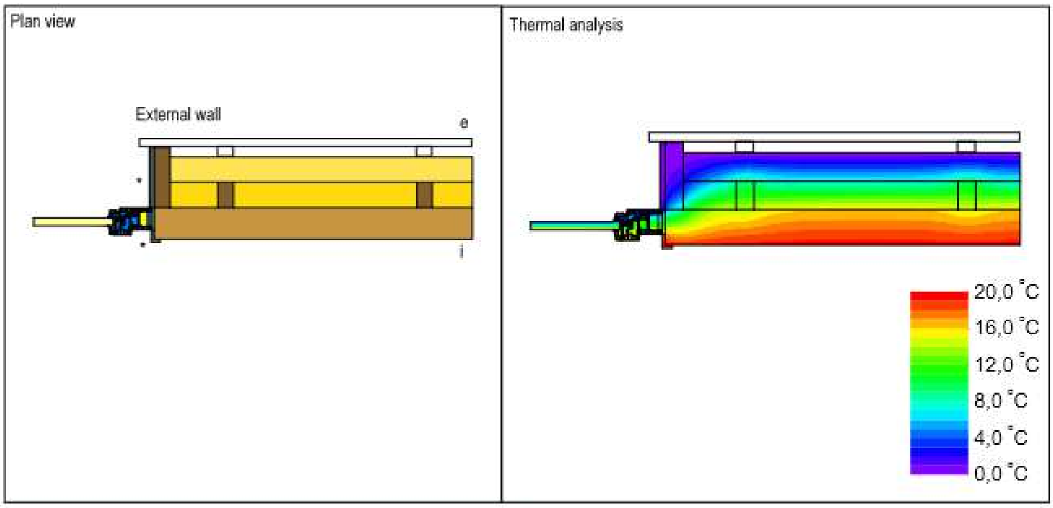
Component design		
Material		Thickness [mm]
External wall e→i		
🟩	Plaster	5,0
🟨	Thermal insulation	160,0 /200,0 /260,0
🟫	CLT	100,0

Results						
Thermal insulation		Thermal balance				
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (Plastic window frame)[W/m^{2}K]		Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
			U$_f$	U$_g$		
Mineral wool	160,0	0,177	1,25	1,1	+0,004	+0,048
	200,0	0,147	1,25	1,1	+0,007	+0,052
	260,0	0,117	1,25	1,1	+0,011	+0,058
EPS	160,0	0,160	1,25	1,1	+0,003	+0,048
	200,0	0,133	1,25	1,1	+0,006	+0,052
	260,0	0,106	1,25	1,1	+0,010	+0,057
Wood fibre	160,0	0,189	1,25	1,1	+0,005	+0,048
	200,0	0,158	1,25	1,1	+0,008	+0,053
	260,0	0,126	1,25	1,1	+0,012	+0,058

* Reveal is done with a 15,0 mm softwood-board, density 500 kg/m3, lambda= 0,13 W/(mK)

Source: Stora Enso, Thermal Bridge catalog,2014

FIGURE 67. CLT lay-up with plaster façade. Source: Thermal bridge catalog unpublished



Component design

	Material	Thickness [mm]
External wall e→i		
🟧 **	Wooden façade	25,0
🟫 **	Wooden battens	30,0
🟨	Thermal insulation, wooden battens (e=625,0 mm)	160,0 /200,0 / 260,0
🟫	CLT	100,0

Results

Thermal insulation		Thermal balance				
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (Plastic window frame)[W/m^{2}K]		Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
			U$_f$	U$_g$		
Mineral wool	160,0	0,203	1,250	1,169	+0,047	+0,052
	200,0	0,170	1,250	1,169	+0,053	+0,058
	260,0	0,137	1,250	1,169	+0,059	+0,065
Wood fibre**	160,0	0,189	1,250	1,169	+0,044	+0,058
	200,0	0,158	1,250	1,169	+0,049	+0,063
	260,0	0,126	1,250	1,169	+0,056	+0,070

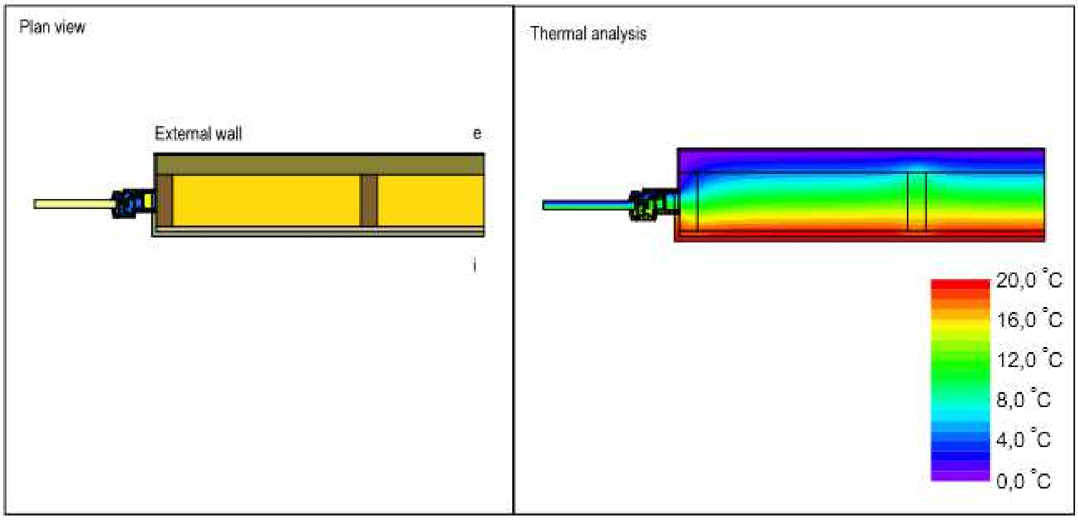
* Reveal is done with a 15,0 mm softwood-board, density= 500kg/m3, lambda= 13,00 W/(mK)

** In the component picture the color of wooden facade and wooden battens (in the ventilation layer) is white because these layers are not relevant for the calculation

*** Wood fibre insulation does not contain wooden battens

Source: Stora Enso, Thermal Bridge catalog, 2014

FIGURE 68. CLT lay-up with wooden façade. Source: Thermal bridge catalog unpublished

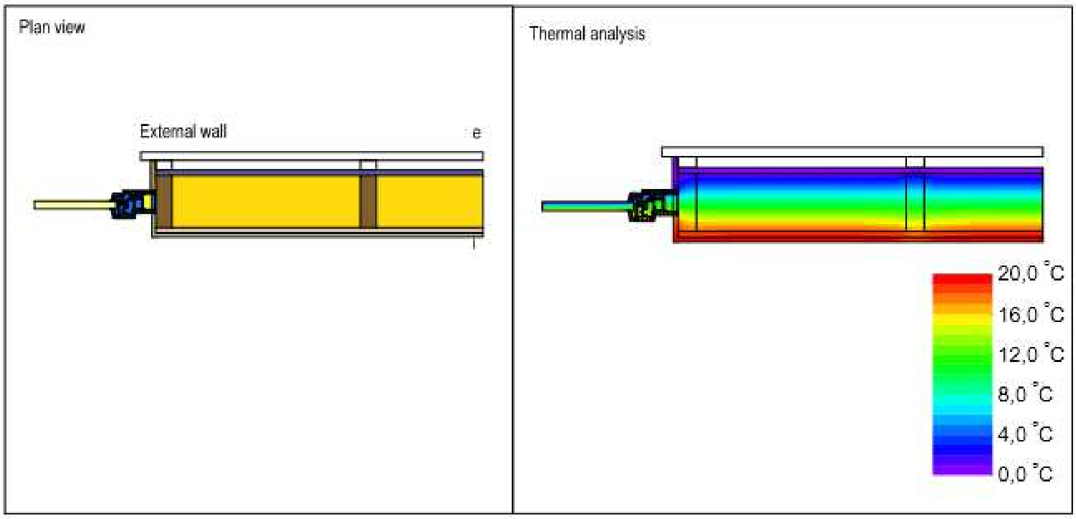


Component design		
Material		Thickness [mm]
External wall e→i		
■	Plaster	5,0
■	High density wood fibre board	60,0
■	Thermal insulation, timber frame (e=625,0mm)	160,0 /200,0/260,0
■	OSB	16,0
■	Fire-protection plasterboard	12,5

Results						
Thermal insulation		Thermal balance				
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (Plastic window frame)[W/m^{2}K]		Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
			U$_f$	U$_g$		
Mineral wool	160,0	0,173	1,25	1,1	+0,044	+0,036
	200,0	0,148	1,25	1,1	+0,049	+0,041
	260,0	0,123	1,25	1,1	+0,054	+0,046
Wood fibre	160,0	0,181	1,25	1,1	+0,044	+0,036
	200,0	0,156	1,25	1,1	+0,049	+0,041
	260,0	0,129	1,25	1,1	+0,055	+0,047

Source: www.dataholz.com, 2014

FIGURE 69. Timber frame lay-up with plaster façade. Structure source: Dataholz 2014



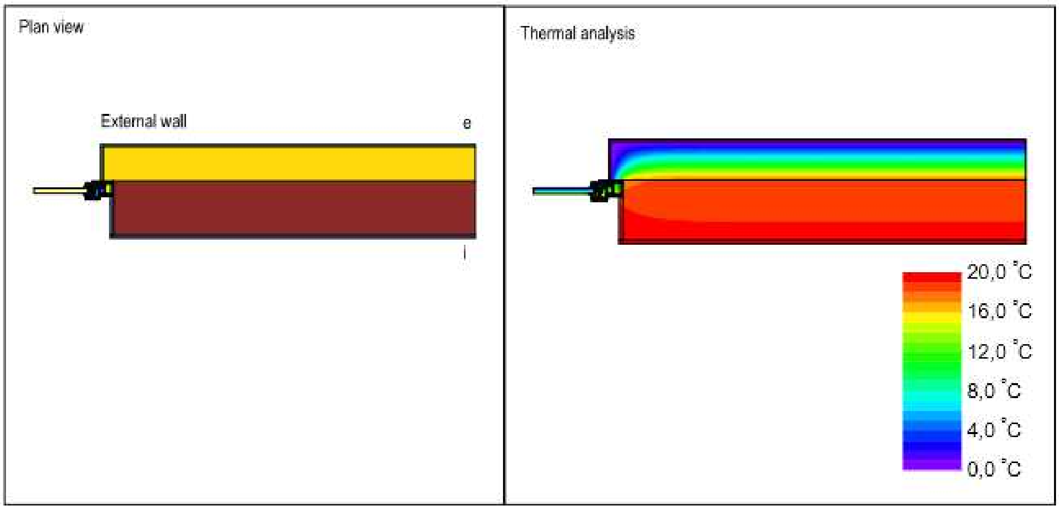
Component design		
Material		Thickness [mm]
External wall e→i		
🟧 *	Wooden façade	25,0
🟫 *	Wooden battens	30,0
🟦	Particle board	16,0
🟨	Thermal insulation, timber frame (e=625,0 mm)	160,0/200,0/260,0
⬜	OSB	16,0
🟩	Fire-protection plasterboard	12,5

Results						
Thermal insulation		Thermal balance				
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (Plastic window frame)[W/m^{2}K]		Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
			U$_f$	U$_g$		
Mineral wool	160,0	0,227	1,25	1,1	+0,036	+0,039
	200,0	0,187	1,25	1,1	+0,038	+0,041
	260,0	0,148	1,25	1,1	+0,043	+0,046
Wood fibre	160,0	0,241	1,25	1,1	+0,035	+0,038
	200,0	0,198	1,25	1,1	+0,038	+0,041
	260,0	0,157	1,25	1,1	+0,043	+0,046

* In the component picture the color of wooden facade and wooden battens (in the ventilation layer) is white because these layers are not relevant for the calculation

Source: www.dataholz.com, 2014

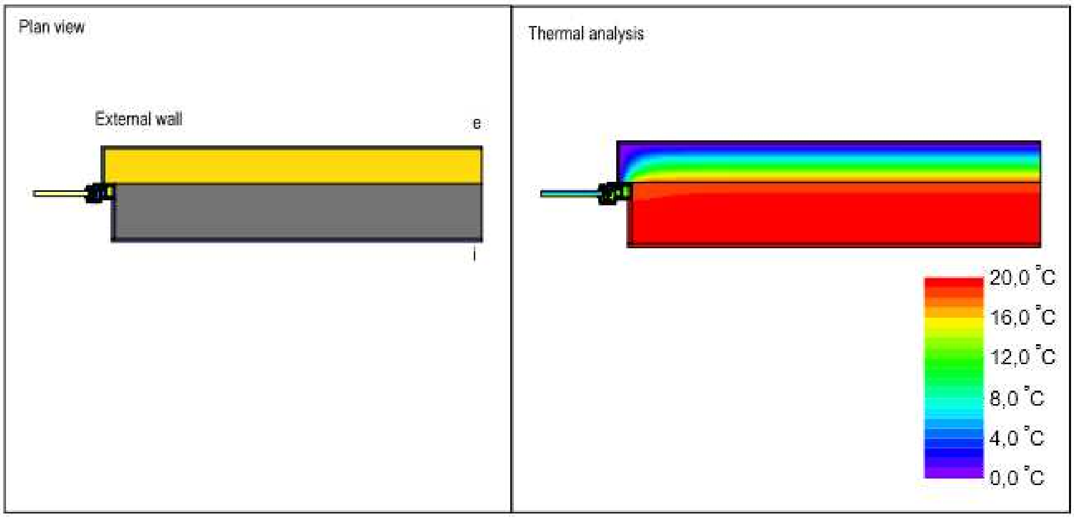
FIGURE 70. Timber frame lay-up with wooden façade. Structure source: Dataholz 2014



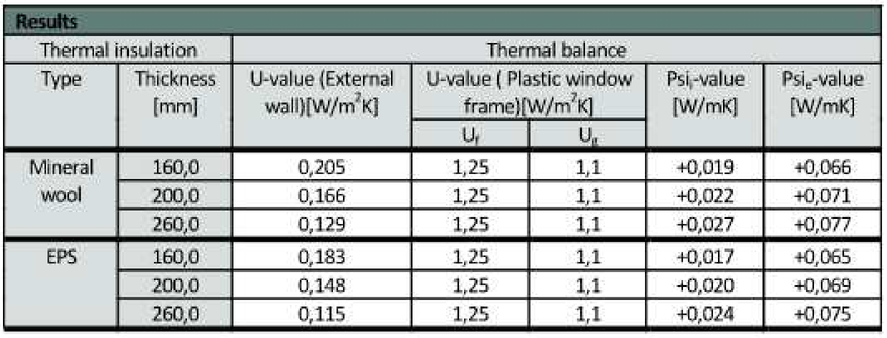
Component design		
Material		Thickness [mm]
External wall e→i		
🟩	Exterior plaster	10,0
🟨	Thermal insulation	160,0 /200,0/260,0
🟥	Brick masonry	250,0
🟦	Interior plaster	15,0

Results						
Thermal insulation		Thermal balance				
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (Plastic window frame)[W/m^{2}K]		Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
			U$_f$	U$_g$		
Mineral wool	160,0	0,196	1,25	1,1	+0,017	+0,064
	200,0	0,160	1,25	1,1	+0,020	+0,069
	260,0	0,126	1,25	1,1	+0,024	+0,075
EPS	160,0	0,176	1,25	1,1	+0,015	+0,063
	200,0	0,143	1,25	1,1	+0,018	+0,068
	260,0	0,112	1,25	1,1	+0,022	+0,073

FIGURE 71. Brick masonry lay-up. Structure source: Pech and Kolbitsch, 23

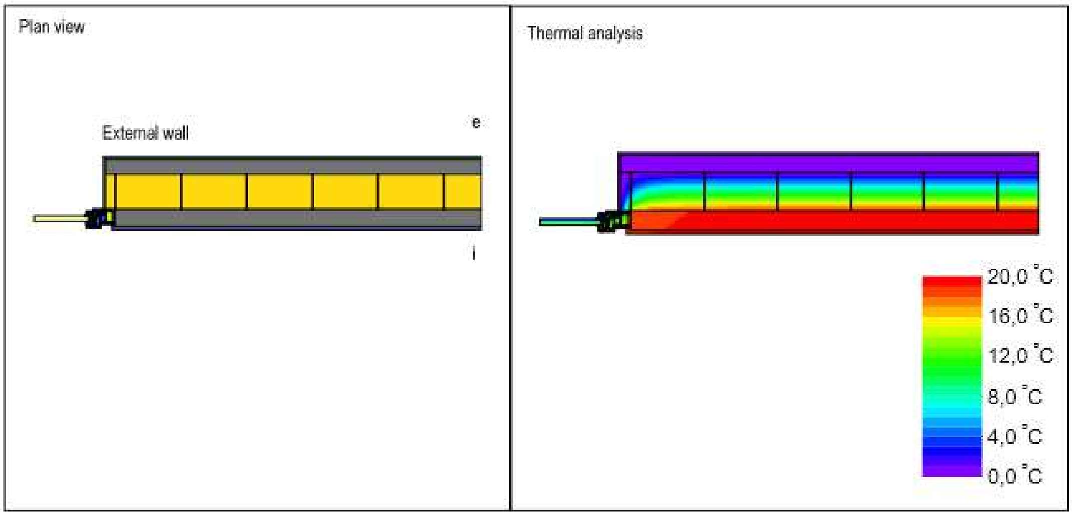


Component design		
Material		Thickness [mm]
External wall e→i		
🟩	Exterior plaster	10,0
🟨	Thermal insulation	160,0 /200,0/260,0
⬛	Reinforced concrete (1% steel)	250,0
🟦	Interior plaster	15,0



Results						
Thermal insulation		Thermal balance				
Type	Thickness [mm]	U-value (External wall)[W/m²K]	U-value (Plastic window frame)[W/m²K]		Psi_i-value [W/mK]	Psi_e-value [W/mK]
			U_f	U_g		
Mineral wool	160,0	0,205	1,25	1,1	+0,019	+0,066
	200,0	0,166	1,25	1,1	+0,022	+0,071
	260,0	0,129	1,25	1,1	+0,027	+0,077
EPS	160,0	0,183	1,25	1,1	+0,017	+0,065
	200,0	0,148	1,25	1,1	+0,020	+0,069
	260,0	0,115	1,25	1,1	+0,024	+0,075

FIGURE 72. Concrete lay-up. Structure source: Pech and Kolbitsch, 28



Component design		
Material		Thickness [mm]
External wall e→i		
🟩	Exterior plaster	10,0
■	Reinforced concrete (1% steel)	70,0
🟨	Thermal insulation, stainless steel anchoring (e=300,0mm)	160,0/ 200,0/ 260,0
■	Reinforced concrete (1% steel)	80,0
🟦	Interior plaster	15,0

Results						
Thermal insulation		Thermal balance				
Type	Thickness [mm]	U-value (External wall)[W/m^{2}K]	U-value (Plastic window frame)[W/m^{2}K]		Psi$_i$-value [W/mK]	Psi$_e$-value [W/mK]
			U$_f$	U$_g$		
Mineral wool	160,0	0,214	1,25	1,1	+0,033	+0,072
	200,0	0,173	1,25	1,1	+0,038	+0,078
	260,0	0,135	1,25	1,1	+0,041	+0,083
EPS	160,0	0,192	1,25	1,1	+0,031	+0,070
	200,0	0,155	1,25	1,1	+0,035	+0,076
	260,0	0,120	1,25	1,1	+0,040	+0,082

FIGURE 73. Concrete sandwich lay-up. Structure source: Lämpö – ja kosteustekniikka 2013

7.8.1 Evaluation of the results

With this kind of constructions it is possible to get a structure that is almost free from thermal bridges. An other option would be to install the window into the insulation layer, but after evaluaiting the results, I decided only to use the lay-up where the frame is connected to the load-bearing structure.

In window frame calculations the results are different than other calculations, because when you increase the thickness of insulation the Psi-value gets higher.

This is because the junction area where the heat is going through gets thicker, when the insulation is thicker. This effect can be best seen from the thermal analysis picture, where the cold air is going past the insulation layer to the frame.

Window frame calculations use different boundary conditions, which take into consideration the corners and properties of the frame.

8 SUMMARY

By evaluating the thermal properties of these five different kinds of lay-up, it can not be denied how much better thermal properties wood has. However, in some cases brick masonry or concrete are better choices, for example in skyscrapers, which cannot be built of wood, at least not yet.

In this thesis, I used structures from Finnish and German sources to get results that are usable in other countries as well as in Finland. Also by choosing five different lay-ups I ensured that the thesis is as comprehensive as possible. The outcome in the end is clear and gives a lot of information about different kinds of structures, lay-ups and the cause, prevention and consequenses of thermal bridges.

By investigating and studying all the structures, with the help of my collagues in Stora Enso, I learned a lot. I reached my target and exceeded my expectations, to concerning how much I learned during the time I have been doing this thesis.

SOURCES

Antherm. 2014. Basics and some theory of anTherm [referenced to 23.10.2014] Available at http://help.antherm.at/PrimaryConcepts/16_Transmittance.htm

Beodom. 2014. Fighting thermal bridges or how to make better buildings [referenced to 23.10.2014] Available at http://beodom.com/en/education/entries/fighting-thermal-bridges-or-how-to-make-better-buildings

Betoni. 2014. Betonin ominaisuudet ja käyttö [referenced to 23.10.2014] Available at http://www.betoni.com/tietoa-betonista/perustietopaketti/betonin-ominaisuudet-ja-kaytto

Building and DIY. 2014. Timber frame [referenced to 23.10.2014] Available at http://www.buildinganddiy.com/self_build-property-renovation-diy/timber-frame-%7C-sips/timber-frame-%7C-timber-frame-kits-%7C-manufacturers-340/local

Chen.Y. 2012. Comparison of environmental performance of a five-storey building built with cross-laminated timber and concrete. Report. Sustainable building science program [referenced to 23.10.2014]

Dataholz. 2014. Components. [referenced to 28.8.2014] Available at http://dataholz.com/

Isover. 2014, What is a thermal bridge [referenced to 20.11.2014] Available at http://www.isover.com/Q-A/Implementation/What-is-a-thermal-bridge

Kohonen.A. 2014. Precast concrete [referenced to 23.10.2014] Available at http://www.aarokohonen.com/english/page_ref_concrete.html

Kärkkäinen. M. 1985.Puutiede. 242-243

Leeds Beckett University. 2014. Types of thermal bridges [referenced to 23.10.2014] Available at http://www.leedsmet.ac.uk/teaching/vsite/low_carbon_housing/thermal_bridging/types/index.htm

Pech & Kolbitsch. Gemaurte Wände. 23-28

Puuinfo.2014. Cross laminated timber [referenced to 23.10.2014] Available at http://www.puuinfo.fi/rakentaminen/suunnitteluohjeet/clt-ristiinliimattu-massiivipuu-cross-laminated-timber

Sisäsilmayhdistys. 2014. Kivirakenteiset ulkoseinät [referenced to 23.10.2014] Available at http://www.sisailmayhdistys.fi/terveelliset-tilat-tietojarjestelma/kunnossapito-ja-korjaaminen/ulkoseinat/kivirakenteiset-ulkoseinat/

Suistanabilityworkshop. 2014. Total R-values and thermal bridging [referenced to 23.10.2014] Available at http://sustainabilityworkshop.autodesk.com/buildings/total-r-values-and-thermal-bridging

Suvanto. E. 2013. Rakennusosien liitosten muodostamat kylmäsillat ja niiden lisäkonduktanssien laskenta. Bachelor thesis Metropolia. Construction engineering [referenced to 23.10.2014] Available at http://www.theseus.fi/bitstream/handle/10024/57740/Rakennusosien%20liitosten%20muodostamat%20kylmasillat%20ja%20niiden%20lisakonduktanssien%20laskenta.pdf?sequence=1

Stora Enso. Thermal bridge catalog. (Will be published on the beginning of 2015) [referenced to 28.8.2014]

The brick industry association. 2014. Technical notes on brick constructions. [referenced to 23.10.2014] Available at http://www.gobrick.com/portals/25/docs/technical%20notes/tn3b.pdf

University Siegel.2014. Thermal insulation [referenced to 23.10.2014] Available at http://nesa1.uni-siegen.de/wwwextern/idea/keytopic/6.htm

Wienerberger. 2014.Terca tiilitalo [referenced to 23.10.2014] Available at http://www.wienerberger.fi/tiilet-/-julkisivut/ratkaisut/terca-tiilitalo/terca-tiilitalo

ATTACHMENTS

Attachment 1 Stora Enso quality descriptions

QUALITYDESCRIPTIONS

Stora Enso offers three different CLT single-layer panel qualities:

NVI Non-visible quality
IVI Industrial visible quality
VI Visible quality

The three different single-layer panel qualities are available with the following CLT surface qualities:

NVI quality description

NVI (Non-visible quality)

NVI (Non-visible quality)

NVI (Non-visible quality)

INV quality description

IVI (Industrial visible quality)

NVI (Non-visible quality)

NVI (Non-visible quality)

VI quality description

VI (Visible quality)
NVI (Non-visible quality)
NVI (Non-visible quality)

BVI quality description

VI (Visible quality)
NVI (Non-visible quality)
VI (Visible quality)

IBI quality description

IVI (Industrial visible quality)
NVI (Non-visible quality)
IVI (Industrial visible quality)

IVI quality description

VI (Visible quality)
NVI (Non-visible quality)
IVI (Industrial visible quality)

Overview

Cover layer	NVI	VI	VI	IVI	IVI	VI
Quality description	**NVI**	**VI**	**BVI**	**INV**	**IBI**	**IVI**
Cover layer	NVI	NVI	VI	NVI	IVI	IVI