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REVIEW OF LINEAR THERMAL BRIDGES IN HIGH-RISE BUILDING

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ABSTRACT

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Due to the lack of energy resources, European governments have started to establish new legislation a few years ago. In its turn, Ministry of Environment of Finland published a new guide for the calculation of linear thermal transmittance in April 2012, which is the main feature of thermal bridges in buildings that lead to significant heat losses.

The aim of this thesis work is to make an analysis of thermal bridging in a high-rise building, determine the importance of linear thermal bridges on the total heat loss of the building and compare particular values of linear thermal transmittances with tabulated values given in National Building Code D5, in order to answer the question of their reliability and quality of design of joints. As well, the current work should help students and engineers, who do not speak Finnish, to use the guide mentioned above.

Determination of linear thermal transmittance is possible by applying different methods described in ISO 14683. Nevertheless, in the current work the results were achieved by numerical calculation, which typically gives an accuracy from 0 to 5 % instead of the accuracy of reference tables from 0 to 50%. The survey was carried out in accordance with the international and Finnish standards. For computer simulation, COMSOL Multiphysics software was chosen.

Finally, the evaluated linear thermal transmittance had an absolute difference from 17 up to 200% with the tabulated values. The heat losses due to linear thermal bridges took 13% of the value of total heat losses of the building. These results show the importance of the current study and obligation of obtaining of linear thermal transmittances and heat losses of thermal bridges, as their sizes are comparable with heat losses of doors and even bigger than heat losses of basements and upper floors, which generally have the highest risk.

Keywords: thermal bridge analysis, linear thermal transmittance, heat analysis in COMSOL Multiphysics, Building Code values

TIIVISTELMÄ

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Euroopan hallitukset ovat huolissaan tulevaisuuden energialähteistä. Tämän vuoksi ne ovat aloittaneet neuvottelut uudesta energialaista. Osana uutta lakia Suomen Ympäristöministeriö julkaisi uuden laskentakaavan viivamaisen lisäkonduktanssin tarkastelemiseksi kylmäsilloissa. Tämä on merkittävä uudistus, sillä kylmäsillat saattavat aiheuttaa merkittävän suuria lämpöhäviöitä rakennuksen ulkokuoren lävitse.

Tämän opinnaytetyön tavoitteena on tehdä kylmäsiltöjen analyysi korkeassa kerrostalossa, määrittää viivamaisten kylmäsiltojen painoarvo kokonaislämpöhäviöstä ja verrata viivamaisen lisäkondukssin arvoja annettuihin Suomen Rakentamismääräyskokoelman osan D5-arvojen kanssa, jotta voidaan varmistua niiden luotettavuudesta ja niiden vaikutuksesta liitosten suunnittelun. Lisäksi tämä opinnäytetyö auttaa suomen kieltä osaamattomia opiskelijoita ja insinöörejä käyttäämään edellä mainittua ohjetta.

Viivamaisen lisäkondukssin määrittely on mahdollista soveltamalla ISO 14683-standardissa kuvattuja menetelmiä. Tässä työssä käytettiin numeerisia laskentamenetelmiä, jotka tyypillisesti antavat tarkkuuden 0-5 % vertailuna viitetaulukon tarkkuus 0-50 %. Tutkimus suoritettiin kansainavälisienja Suomen standardien mukaisesti. Tietokonesimulaatiot tehtiin COMSOL Multiphysics ohjelmistolla..

Lasketut viivamaiset lisäkondukssit eroavat 17-200% taulukoidusta arvosta. Yhteensä viivamaisen kylmäsiltöjen lämpöhäviöt voivat ollat 13 % kokonaislämpöhäviöstä. Tulokset vahvistavat viivamaisten kylmäsiltojen merkitystä osana kerrostalojen lämpöhäviöiden laskentaa, sillä lämpöhäviöt kylmäsilloista voivat olla jopa suurempia kuin ala- ja yläpohjan lämpöhäviöt, joita on yleensä pidetty merkittävimpinä lämpöhäviön aiheuttajina.

Avainsanat: kylmäsiltöjen analyysi, Viivamaisen lisäkondukssi, lämpöanalyysi ohjelmassa COMSOL Multiphysics, Rakentamismääräyskokoelman arvot

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CONTENTS

1 INTRODUCTION

Natural resources are limited on earth and now the era of sustainable technologies is coming. The price of energy rises and it encourages implementation of energy efficiency measures, particularly, in buildings. In 2012, the Finnish Ministry of Environment published new energy regulations: Building Code D5 related to energy consumption and heat losses of buildings and a Calculation Guide regarding thermal bridges. Those documents highlight that linear thermal bridges represent an essential and indefeasible part of calculation of heat losses. The new legislation also stimulates to reduce energy consumption in a building stock.

A building consists of variable components such as walls, roofs, foundations, in which several physical changes such as heat, moisture and air transfer apply. These physical processes determine the performance of the building. That is why temperatures and the heat flow rate through the building envelope should be predicted while carrying out a project. Nowadays, computer simulation allows anticipating the consequences of these physical changes on the building envelope and making appropriate technical decisions (Hagentoft 2003). The design of the building should involve rational materials/insulation and avoid unnecessary edges and corners as they form thermal bridges, which increase the heat losses.

The basics of thermal bridges are in heat transfer theory. Heat transfer in building structures is a common outcome, which results from differences in temperatures and is met in every building. Basics of heat transfer establish that heat flows from hot bodies to the cold ones, and this should be noticed. Thus, is it important to know the values of heat losses due to thermal bridges?

The aim of this thesis work is to make an analysis of thermal bridging in a particular high-rise building, to determine the linear thermal transmittances values and to answer the question of their importance on the total heat loss. At the same time, the thesis work is supposed to highlight some theoretical and practical issues concerning such calculations.

Thermal bridges in building structures give changes in heat flow rates and surface temperatures compared with those of an unbridged structure. These heat flow rates and temperatures can be precisely determined by numerical calculation in accordance with ISO 10211. However, for linear thermal bridges, it is possible and often convenient to use tabulated values to obtain their linear thermal transmittance (ISO 14683 2005, V). The current survey will check out the trustworthiness and reliability of the values given in D5 tabulated for linear thermal transmittance by comparing them with numerically calculated for the examined building.

This report is also meant to help students and engineers, who do not speak Finnish, in implementing analyses of thermal bridges according to the calculation guide, provided by the Ministry of Environment, since it only exists in Finnish.

In the first section of this thesis work, a summary of the theory of heat transfer phenomenon is introduced, drilling into details of thermal bridges and methods for determining the linear thermal bridges. Various thermal characteristics, which contribute to the calculations of linear thermal bridges, and ways of their acquisition, are also described. An analysis of the international and Finnish standards concerning this field can be found. This study has been developed in order to meet the official requirements and to be a useful tool for its readers. Moreover, a tutorial aiming at introducing the work in COMSOL Multiphysics, the software selected for the computing part of the calculation, especially for Heat Transfer Study, has been developed in this section. The last part of the first section highlights specific details for calculating the linear thermal bridges in different types of joints, and examples of those particular cases for the test building are narrowly and circumstantially shown in the second section, where all those calculations were made by following the above-mentioned calculation guide, provided by the Ministry of Environment. Also, the second section includes a description of the examined building and evaluations of all needed thermal characteristics. Finally, the third section summarizes the results and counts the significance of thermal bridges in the total building heat loss. This last section concludes all the work that was done, and emphasis the achieved goals.

2 THEORETICAL FOUNDATION

2.1 Heat transfer

Heat transfer in a building is a process by which energy is transported within and between building components of different temperature. The science of heat transfer seeks to predict rate at which the energy exchange will take place (Hagentoft 2003, 4).

In other words, theory of heat transfer is the study of the processes of dissemination of heat into the areas with a non-uniform temperature field. (Lobasova et. al. 2009, 6) There are three modes of heat transfer: conduction, convection and radiation.

Thermal conductance is a molecular heat transfer, directly between the contacting bodies or particles of one body with different temperatures, at which the exchange of movement energy of the structural particles (molecules, atoms, free electrons) happens. Convection is implemented by moving in the area of non-uniformly heated volumes of the substance. In this case, the heat transfer is inextricably linked with the transfer of the substance itself. Thermal radiation is characterized by the transfer of energy from one body to the other by electromagnetic waves. Often, processes of heat transfer are carried out together, for example, convection is always accompanied by heat conduction. Many of the processes of heat transfer are accompanied by the transfer of material - mass exchange (Lobasova et. al. 2009, 7-8).

According to the hypothesis of Fourier expressed in formula 1 (Lobasova et. al. 2009, 13), heat quantity passing through the isothermal surface element during the time interval is proportional to the temperature gradient:

$$d^2Q_\tau = -\lambda \cdot \frac{\partial t}{\partial n} \cdot dF \cdot d\tau \qquad 1.$$

where

d^2Q_τ	is the heat quantity
dF	is the surface area of isothermal element
$d\tau$,	is the time interval
$\frac{\partial t}{\partial n}$	is the temperature gradient
λ	is the thermal conductivity coefficient

The minus sign in formula 1 indicates that the heat is transferred in the direction of decreasing temperature. The amount of heat passed in a unit of time through a unit of isothermal surface is called the heat flux.

The thermal conductivity coefficient is a physical parameter of a material that characterizes its ability to conduct heat. Numerically, the thermal conductivity is equal to the amount of heat that passes in a unit of time through a unit of isothermal surface with 1-unit temperature differences between environments. Its dimension is W/(mK). Values of thermal conductivity of various materials are determined by reference tables based on experimental data. (Lobasova et. al. 2009, 13)

The worst heat conductors are gases. Thermal conductivity increases with increasing gas temperature, and it is from 0,006 to 0,6 W/(mK). It should be noted that the upper value refers to helium and hydrogen, the thermal conductivity coefficient of which is 5-10 times higher than of other gases. The coefficient of thermal conductivity of air at 0˚C is 0,0244 W/(mK). For liquid thermal conductivity coefficient is from 0,07 to 0,7 W/(mK) and generally decreases with increasing temperature. The best heat conductors are metals, which thermal conductivity is from 20 to 418 W/(mK). The most thermally conductive metal is silver. For most metals, thermal conductivity decreases with increasing temperature and also with the presence of various impurities. Materials with thermal conductivity coefficient less than 0,25 W/(mK) are usually used for thermal insulation. (Lobasova et. al. 2009, 13-14)

A study of such phenomena is possible in stationary conditions and transient. A steady-state situation is considered when the surrounding temperatures are stable for a long period of time. Steady-state problems are important, because they give average temperature and heat flows (Hagentoft 2003, 12). Transient analysis takes place when temperature changes within a time. In the real world, heat transfer starts out as transient and then approaches a steady-state with time.

2.2 Thermal Bridges

Thermal bridges usually happen at connections between building components and where a building structure changes its composition. For instance, a two-dimensional thermal bridge can occur at the junction between two walls or the connection of a wall and floor. Such phenomena have serious consequences: an increased heat flow rate and moisture problems. (Hagentoft 2003, 34)

According to the main standard in actual field ISO 10211 (2008, 2), “Thermal bridge is part of the building envelope, where the otherwise uniform thermal resistance is significantly changed by full or partial penetration of the building envelope by materials with a different thermal conductivity, and/or a change in thickness of the fabric, and/or a difference between internal and external areas, such as occur at wall/floor/ceiling junctions”.

Building envelope transmission heat losses can, in principle, be calculated in a three-dimensional numerical calculation model, wherein thermal bridges need not be taken into account as presented in figure1.

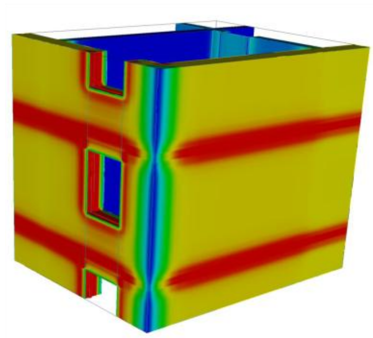


FIGURE 1. Example of building envelope in three-dimensional temperature field calculation. (Heikkinen et. al. 2012, 7)

In practice, a building cannot be calculated as a unit, but it is considered as separate structural elements, such as walls, floors, windows and roofs. The thermal transmittance *U* is calculated or measured separately for each of the construction, without taking into account how they relate to other components. Formula 2 shows the equation for determining thermal transmittance *U* according to the Finnish Building Code C4 (2003, 6):

$$U = \frac{1}{R_T} \qquad 2.$$

where

U is the thermal transmittance of a building component, $W/(m^2K)$

R_T is the total thermal resistance of a building component from one environment to another, $(m^2K)/W$, which will be explained in the next section 2.4

Edges of the building parts are assumed to be adiabatic boundary conditions or perfect thermal insulation. Under this assumption, the inaccuracy will be corrected when calculating total building heat losses according to formula 3 (ISO 14683 2005, 3):

$$H_{total} = \sum U_{ext.wall}A_{ext.wall} + \sum U_{roof}A_{roof} + \sum U_{basement}A_{basement} + \sum U_{window}A_{window} + \sum U_{door}A_{door} + \sum \psi_k l_k + \sum X_j \quad (3.)$$

where

H_{total} is the total transmission heat losses of the building, *W/K*

U is the thermal transmittance of a building component, *W/(m^{2}K)*

A is the surface area of a structural component, *m^2*

ψ_k is the linear thermal transmittance of the joint k, *W/(mK)*

l_k is the length of the joint k, *m*

X_j is the point thermal transmittance, *W/K*

In formula 3, the last term *X* takes into account the individual thermal bridges such as the balcony mortgages, which are not considered in the current thesis. This thesis contains instructions on the calculation method for determining the linear thermal transmittance ψ of junctions between building parts.

The international standard ISO 10211 (2008, 4) defines the linear thermal bridge as "… thermal bridge with uniform cross-section along one of the three orthogonal axes" and the linear thermal transmittance as "… heat flow rate in the steady state divided by length and by the temperature difference between thee environments on either side of a thermal bridge. The linear thermal transmittance is a quantity describing the influence of a linear thermal bridge on the total heat flow."

The calculation guide provided by Finnish Ministry of Environment demonstrates an example of linear thermal transmittance and illustrates how it can be determined. Figure 2 is an example of a connection of two walls and floor, which includes a thermal bridge.

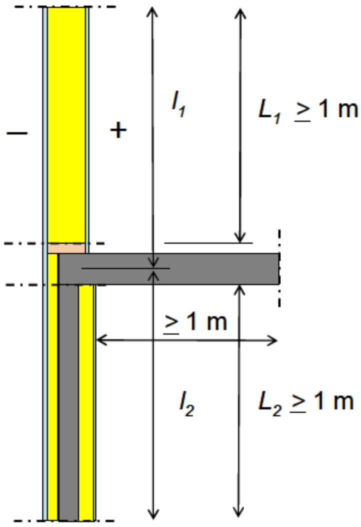


FIGURE 2. Example of walls and floor joint with thermal bridge. (Heikkinen et. al. 2012, 8)

Formula 4 expresses the total transmission heat losses taken from formula 3 for situation shown in the figure 2:

$$H_{total} = U_1 A_1 + U_2 A_2 + \psi l \qquad 4.$$

where

H_{total} is the total transmission heat losses of building components 1 and 2 and their joint, *W/K*
Ψ is the linear thermal transmittance of the joint, *W/(mK)*
l is the length of the joint between walls 1 and 2 (perpendicular to the plane of the figure), *m*
U_1 is the thermal transmittance of the wall 1, *W/(m²K)*
A_1 is the surface area of the wall 1, m^2
U_2 is the thermal transmittance of the wall 2, $W/(m^2K)$
A_2 is the surface area of the wall 2, m^2

The linear thermal transmittance ψ, used in formula 4, is obtained by applying formula 5:

$$\psi = \frac{H_{joht}}{l} - U_1 l_1 - U_2 l_2 \qquad 5.$$

Therefore, thermal transmittance must evaluate the difference between the actual heat flow and heat conductivity coefficients. This phenomenon is illustrated in figure 3:

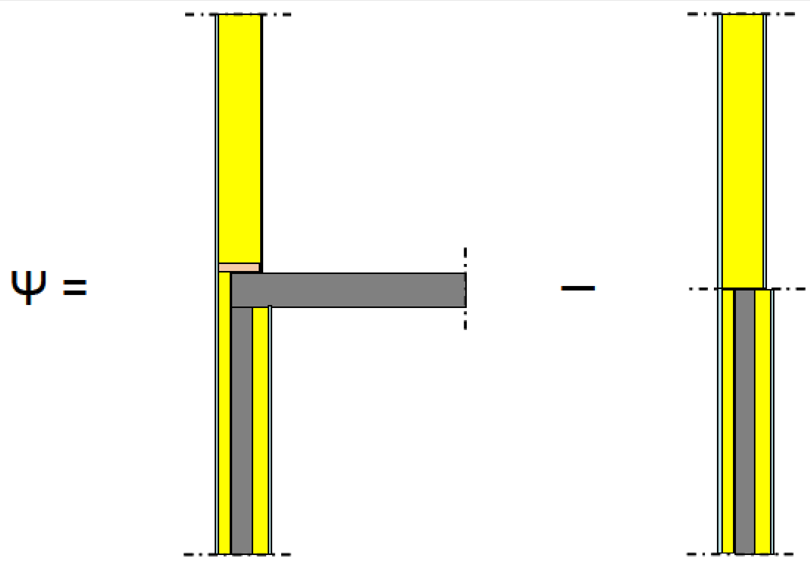


FIGURE 3. Linear thermal transmittance ψ of a junction is the heat flow difference of the heat flow of the real structure (left) and the comparative structure (right). (Heikkinen et. al. 2012, 9)

In other cases also, for obtaining the linear thermal transmittance of a junction, subtract the actual heat flux of the structure with the heat fluxes of the main structures. This procedure is considered in the following section.

2.3 Choice of method

The following study was carried out using the calculation guide provided by the Ministry of Environment of Finland for evaluating the thermal bridges in buildings. In order to implement the regulated guidelines into the thesis, the entire guide has been translated into English.

The determination of the linear thermal transmittance ψ can be implemented by using different methods. The choice of the method should take into account either the thermal bridges of the whole building or the room transmission heat losses. Four alternative methods are highlighted in the international standard ISO 14683 (2008). The best accuracy is obtained by numerical calculation (with a typical accuracy of ± 5%) and the least accuracy by using reference tables (with a typical accuracy 0% to 50%). Table 1 illustrates the use of the reference table technique of the Finnish National Building Code D5 (2012), where linear thermal transmittance is tabulated according to the frame material. The values of linear thermal transmittances ψ take into account the connections between the building parts and the irregular thermal bridges caused by the additional heat loss.

TABLE 1. Guideline values for thermal bridges (originally in Finnish) (D5, 2012)

Joint	Linear thermal transmittance ψ_k, *W/(mK)*					
	External wall base material					
	Concrete	Lightweight concrete	Expanded clay aggregate	Brick	Wood	Timber
Connection between the external walls, outer corner	0,06	0,05	0,05	0,05	0,04	0,05
Connection between the external walls, inner corner	-0,06	-0,05	-0,05	-0,05	-0,04	0,05
Windows and doors, the heat insulation case	0,04	0,04	0,04	0,04	0,04	0,04
Windows and doors, other cases	0,15	0,07	0,10	0,10	0,07	0,07

External wall / base material	Linear thermal transmittance ψ_k, *W/(mK)*									
	Roof material			Floor material			Basement material			
	concr.	lightcon cr.	wood	concr.	Light concr.	wood	concr.	concr.	Light concr.	Wood
Concrete	0,08	-	0,04	0,00	-	-	0,24	0,28	-	-
Lightweight concrete	0,18	0,06	0,04	0,10	0,00	-	0,09	0,08	0,03	-
Exp. clay	0,13	-	0,04	0,07	-	-	0,15	0,11	-	-
Brick	0,08	-	0,04	0,00	-	-	0,17	0,06	-	-
Wood	-	-	0,05	-	-	0,05	0,10	-	-	0,06
Timber	-	-	0,04	-	-	0,00	0,11	-	-	0,09

The guide applies to the linear thermal transmittance determined with a numerical method. Linear thermal transmittance values are taken into account in table 1 according to the Finnish and International standards, such as ISO 14683:2008 *"Thermal bridges in building construction - transmittance - Simplified methods and default values"*, ISO 10211:2008 "*Thermal bridges in* *building construction. Surface temperatures. Detailed calculations"*; ISO 13370:2008 "*Thermal performance of buildings. Heat transfer calculation methods*", ISO 6946:2008"*Building components and building elements and thermal transmittance - Calculation method*"; SFS-EN ISO 10456:2007"*Building materials and products – Hydrothermal Tabulated design values and procedures for determining declared and design*", ISO 10077-2:2007"*Thermal performance of windows, doors Calculation of thermal transmittance. Part 2: Numerical method for frames*", Finnish Building Code D3 on Energy efficiency in buildings "*Regulations and guidelines 2012*", Finnish Building Code C4 on Thermal insulation "*Help 2012*", and the Finnish Building Code D5 on building's energy consumption and heat output required for the calculation "*Help 2012*".

According to the standard ISO 10211 (2008, 23), linear thermal transmittance can be determined by using formula 6:

$$\psi = L_{2D} - \sum_{J=1}^{N_j} U_j l_j \qquad 6.$$

where

L_{2D}	is a numerically defined two-dimensional (2D) technical thermal coupling factor considered for the joints of the building, *W/(mK)*
U_j	is related to the structure j thermal transmittance, *W/(m²K)*
l_j	is the length (in meters) of the part of the structural model j, where U_j transmission coefficient can be applied.

Building Code C4 defines the values of thermal transmittance U_j and the length l_j in formula 6. This formula gives the linear thermal transmittance value, which leads to the right heat losses of the building in formula 3. Heat flux in thermal bridges through the structure from the inside to the outside is calculated numerically with one-degree temperature difference per meter (unit W/mK).

Modelling the heat flux can be carried out by using various software. The minimum requirement for evaluating thermal bridges comprises a two-dimensional temperature field calculation option in steady state. General-purposed computing program has the advantage of suitability for a variety of options and thoroughly tested functionality. Narrower conduction heat transfer applications are generally easier to use and allow to obtain the linear thermal transmittance directly. Some of the programs are free. Most of the programs are inline with the international standard ISO 10211. It gives an idea of the quality of software but does not guarantee the functioning of other types of tasks. (Heikkinen et. al. 2012, 13)

The technical thermal coupling coefficient is defined in ISO 10211 (2008, 3) as a "…heat flow rate per temperature difference between two environments which are thermally connected by the construction under consideration". In the present thesis, the coupling coefficients L_{2D} have been evaluated using the software COMSOL Multiphysics 4.3. This software is a commercial general-purposed program, which applies the recommendations and guidelines from the international standard ISO 10211.

The principle of computational calculation is to create a geometrical model of heat conduction in the counted area, which is divided into a sufficient number of elements. Partition is needed because the solution of differential equation, which will be processed by the software, is based on the finite element method.

The next step is to tag the required materials. A material library already exists within the software, but personal materials can also be created. Material tagging enables assigning the value of the thermal conductivity *k* as an input to the general heat diffusion represented in formula 7 (Lienhard IV, Lienhard V 2008, 55). A two-dimensional model will be made in stationary conditions, consequently as it can be noticed from formula 7, values of density and specific heat capacity of the materials are not necessary to set.

$$\rho C_p \frac{\partial T}{\partial t} + \nabla(-\mathrm{k}\nabla\mathrm{T}) = Q \qquad 7.$$

where

ρ is density, kg/m^3
Cp is specific heat capacity at constant pressure, J/(kgK)
T is absolute temperature, K
k is thermal conductivity, W/(mK)
Q is volume heat source, W/m^3

The calculation process of the program does not really matter for the user. The most important thing is to ensure that the computing network is sufficiently dense in each case.

Boundary conditions are important to the calculation. The most common types of boundary conditions are the ambient temperature and the surface resistance as well as the thermal insulation edge, which is under adiabatic conditions.

In practical cases, heat flow takes into account the surface resistances of structural parts according to the Finnish Building code C4 and the international standard ISO 6946 (2007), which values are given in table 2.

TABLE 2. Surface elements resistances (ISO 6946 2007, 3)

Surface resistance, $(m^2K)/W$	Heat flow direction		
	Upward	Horizontally	Downward
The inner surface, R_{si}	0,10	0,13	0,17
The outer surface, R_{se}	0,04	0,04	0,04

The thermal resistances R_{si} and R_{se} should be applied for plane surfaces on boundary conditions.

2.3.1 Calculation of thermal bridges in COMSOL Multiphysics

This chapter demonstrates the computation of thermal bridges in COMSOL Multiphysics, that has been chosen as the appropriate program. COMSOL Multiphysics is a flexible platform for simulation, which environment includes a possibility to add any physical effect on the model. It is known to be a complete problem-solving tool. (Introduction to COMSOL Multiphysics)

The step-by-step methodology of the work in COMSOL Multiphysics used in the current study follows the eight steps below:

1. Start the software using the *Model Wizard*. Next, choose *2-D* in *Space Dimension* and *Heat Transfer in Solids (ht)* module for study type. Then select *Stationary* as we deal with steady-state analysis. Click *Finish*.
2. Ensuing step is to define the geometry of the model. For making a 2-D model, which will be discretized by Mapped Mesh (see step 6), it is important to create computational geometry from simple shapes, which are integrated to each other in joints as it is shown in figure 4. COMSOL presents comparably full suite of drawing instruments, another alternative is to import geometry from CAD-program files. Empirical investigation shows that it is better to draw directly within the software by using the Rectangle tool. Each rectangular forms a so called domain.

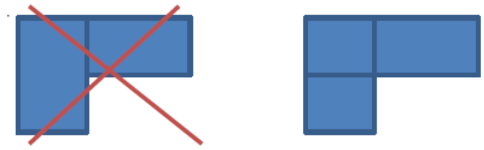


FIGURE 4. Wrong and preferred variants of geometry partition

3. Take materials from *Materials library* base, or create a personal one and set necessary properties. In the present study, the needed characteristic is thermal conductivity, which is denoted as *k* inside the program. Then, each material is inserted into certain domains. A possibility of setting different appearances, by colours for each material, streamlines the model for visual perception and helps in avoiding model-building mistakes, which could lead to wrong results.

Next, add *Parameters* in *Global Definition* as follows: T_out for external temperature, T_in for internal temperature and heat transfer coefficients of surfaces (see 3.2). Surface resistances R_{si} and R_{se} for each case are obtained from table 2.

The next step consists of setting the boundaries for *Heat flux (Model1* →right click on *Heat Transfer).* The amount of Heat fluxes depends on specific structure. For instance, a junction between walls will only have two heat fluxes - for external and internal surfaces, while floor junction will have three - for external and internal surfaces of walls and for floor surface. In particular, for wall external boundary, add *Heat Flux 1*, then select *Inward heat flux*, enter the *Heat transfer coefficient h.* Also, enter *External temperature T*ext = *T_out* and select corresponding boundaries. In the present software, inward heat flux is defined by equation expressed in Formula 8. For internal walls boundaries add another *Heat Flux 2* with specific *h* and *T*ext = T_in.

$$q_0 = h(T_{ext} - T) \qquad 8.$$

4. Since the software is processing differential equation, which is based on the finite element method, the starting point for that is to create meshing. The meshing can be described as partition of the geometry into small units of a simple shape, mesh elements. The mesh generator discretizes the domains into triangular or quadrilateral mesh elements. If the boundary is curved, these elements represent only an approximation of the original geometry. The sides of the triangles and quadrilaterals are called mesh edges. COMSOL offers several types of meshing. Free meshing is easy to create and very fast, though some mesh elements have poor

aspect ratios and in general such a way is non-rational. Another option is the above mentioned *Mapped Mesh*. This technique gives a lot more control over sizes and ratios of the mesh elements, allows to concentrate zone of interest and provides more accuracy. However, it takes much more time for its creation.

5. From this point, the model is ready for being processed. Right click on *Study →Compute.* This process can be time consuming, also note that it requires some operational memory from the computer.

COMSOL allows making a wide variety of representations of the results. Some of them, such as a graph of *Temperature* inside the structure and *Isothermal Contours* with heat flux arrows, are implemented automatically. In this study, heat flux data shall be represented. Graphics of *Conductive heat flux magnitude* in *2D Plot Group* of *Results* and *Line Integration* of heat flux magnitude in *Derived Values* are added manually, knowing that in Finland it is common and accepted to set internal lines as boundaries. For instance, Southern European countries consider the external boundaries as it is shown in figure 5, which leads to over-measuring of the heat loss of an element at certain junctions (Little/Arregi 2011, 5). From the last procedure, *Conductive Heat Flux Magnitude (W/m)* can be evaluated.

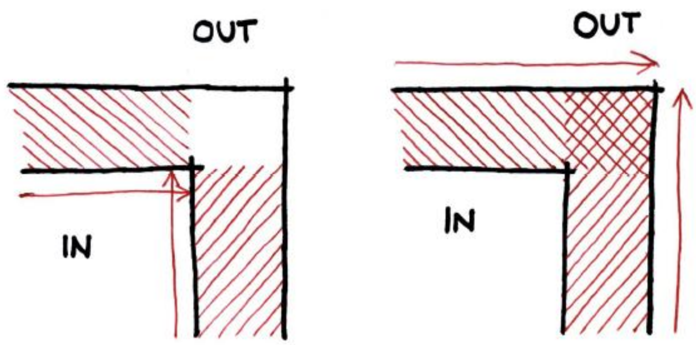


FIGURE 5. Sketches showing how the Finnish and British measure building heat flux from the inside and Germans from the outside (Little/Arregi 2011, 5)

Now the computational process of calculation has been completed by obtaining needful value. The next steps for linear thermal transmittance determination are described in section 2.4.

More itemized processes of particular cases are shown in section 3.2 and its subsections. Other program-related details are possible to find in COMSOL Multiphysics Tutorial enclosed to each software package or directly in the *Help* module provided by the software.

2.4 Calculation principles for different types of structures

In this section, the calculation processes to determinate the linear thermal transmittance for different types of structures are approached. *Conductive Heat Flux Magnitude,* that can be evaluated according to section 2.3.1, is designated with Φ_{lj}. This value is "the heat flow rate of linear bridge from the internal environment, designated by the subscript *"i"*, to the external environment, designated by the subscript "*e*" (ISO 10211 2007, 23), and it is given in formula 9:

$$\Phi_{lj} = L_{2D}(\theta_i - \theta_e) \qquad 9.$$

where

Φ_{lj} is the heat flow rate of the linear bridge, W/m

L_{2D} is the technical coupling coefficient, W/(mK)

θ_i is the external temperature, K

θ_e Is the internal temperature, K

In order to obtain the thermal coupling factor L_{2D}, formula 9 may be transformed as follow:

$$L_{2D} = \Phi_{lj} / (\theta_i - \theta_e) \qquad 10.$$

To determine the linear thermal transmittance from formula 6 in section 2.3, all values were defined previously. However, in order to determine the thermal transmittance U_j from formula 2 in section 2.2, thermal resistanceR_T was not explained.

Building structures (walls, roof, floor) consist of several material layers, where, for each of them, thermal resistance is calculated by formula 11 in accordance with the Finnish Building Code C4 (2002, 6).

$$R = \frac{d}{\lambda} \qquad 11.$$

where

d is the thickness of the structural layer, m

λ is the thermal conductivity of the material related to the layer, $W/(mK)$

The international standard ISO 10456 (2007, 2) defines design thermal resistance as "…value of thermal resistance of a building product under specific external and internal conditions, which can be considered as typical of the performance of that product when incorporated in a building component“. The total thermal resistance of a structure that consists of many material layers is evaluated as a summary of thermal resistances from formula 12 (C4 2002, 6):

$$R_T = R_{si} + R_1 + R_2 + R_3 + \cdots + R_{se} \qquad 12.$$

where

R_{si}, R_{se}	are the thermal resistances of the structures of inner and outer surfaces, $(m^2K)/W$
$R_1, R_2 \dots R_n$	are the thermal resistances of structural layers 1 ... n, $(m^2K)/W$

The effective thermal conductivity λ' of non-homogeneous layers, for instance, layers of insulation and wooden frames, should be calculated by formula 13 according to the International Standard ISO 10211 (2007, 16):

$$\lambda' = \frac{A_1\lambda_1 + \cdots + A_n\lambda_n}{A_1 + \cdots + A_n} \qquad 13.$$

where

$\lambda_1 \dots \lambda_n$	are the thermal conductivities of the constituent materials, $W/(mK)$
$A_1 \dots A_n$	are the areas of the constituent materials measured in the plane of the layer, m^2

Specific details of linear thermal transmittance determination are concerned in the following subsections.

2.4.1 Joints between external walls

The following section investigates the calculation of the linear thermal transmittance for joints between external walls. Figure 6 is an example of a joint between external walls, which includes a thermal bridge.

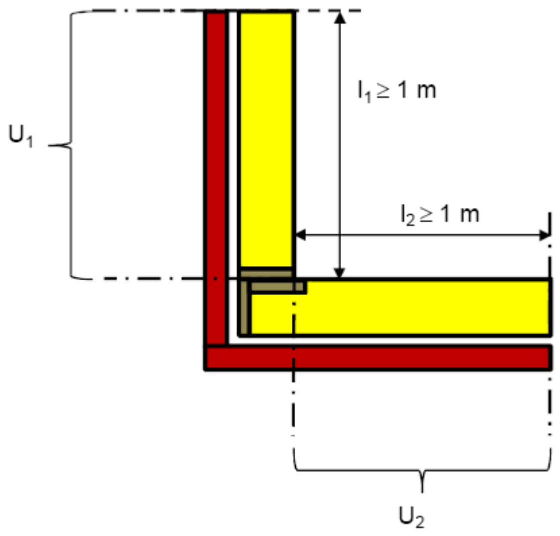


FIGURE 6. Representation of a joint between external walls with thermal bridge (Heikkinen et. al. 2012, 29)

The principle of a calculation of a linear thermal transmittance is as follows according to the calculation guide provided by the Ministry of Environment (Heikkinen et. al. 2012, 29):

1. Calculate the heat flow through the structure from the inside to the outside with one-degree temperature difference per meter (unit W/(mK)) numerically (according to 2.3 and 2.3.1). Each structure must generally include at least one-meter length of walls. In particular, the joint details close to the structure should be involved as much as possible. The thermal conductivities of the materials should be taken from the Finnish Building Code C4, Section 4.

2. Using formula 2 from section 2.2, the thermal transmittances of walls U_1 and U_2 (figure 6) shall be calculated.

3. The lengths of the walls l_1 and l_2 are taken of the internal surfaces in accordance with figure 6*FIGURE 6* above.

4. Then, by subtracting the actual heat flow of the joint structure with the heat flux of the walls, which is calculated applying formula 6, a linear thermal transmittance ψ is obtained in formula 14.

$$\psi = L_{2D} - U_{w1}l_{w1} - U_{w2}l_{w2} \qquad 14.$$

where

L_{2D} is a numerically defined two-dimensional (2D) technical thermal coupling factor for

	the joint of the building obtained by formula 10, W/(mK)
U_{w1}	is the thermal transmittance of the wall 1, W/(m^{2}K)
l_{w1}	is the length of the wall 1, used in model, m
U_{w2}	is the thermal transmittance of the wall 2, W/(m^{2}K)
l_{w2}	is the length of the wall 2, used in model, m

2.4.2 Joints between window and external wall

Calculation of the thermal bridges for window junctions is carried out in a similar manner as for joints between external walls (see 2.4.1). However, specific details apply in the case of a junction between a window and an external wall. A thermal bridge of the window junction can be calculated according to two methods: advanced or simplified. Both methods are described in the Calculation Guide provided by the Ministry of Environment (Heikkinen et. al. 2012, 26-28). The advanced method of calculation procedure is quite tedious, because the calculation of window U-value is very demanding. The procedure is highly appropriate to use while the window U-value is calculated in any case. Therefore, in the current thesis the calculations were simplified with the precision of leaving the window completely out of the calculation area and setting the window frame position in an adiabatic boundary condition (perfect thermal insulation) as shown in figure 7 (Heikkinen et. al. 2012, 27).

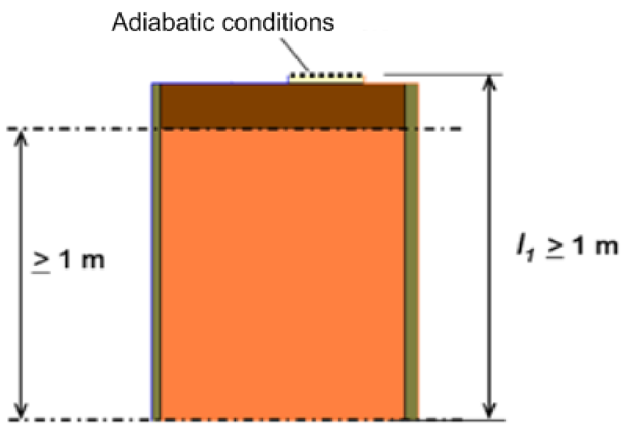


FIGURE 7. Simplified procedure for calculation of thermal bridge of a window junction. The window is replaced by the adiabatic boundary conditions (Heikkinen et. al. 2012, 28).

The supporting frame has a thickness of 50 mm and the frame gap of 10 mm. The thermal conductivity values used for the supporting frame and frame gap are 0,13 W/(mK) and 0,05 W/(mK) respectively (Heikkinen et. al. 2012, 51).

Computational depth of the frame depends on the real frame depths and window type according to table 3. Those values apply for wooden windows and wood-aluminium windows, which are attached to supporting frame or massive wall. Narrowing the frame in the calculation should be done from the outside (Heikkinen et. al. 2012, 28).

TABLE 3. Computational window frame depth for simplified method of thermal bridge calculation.

Window type	The computational depth of the frame
SEK, MS2E	0,7 x frame depth
MSE, MS3E	0,6 x frame depth
MEK, SE	Smaller of the numbers 0,95 x frame depth, as well as 100 mm

The result of subtracting the actual heat flow with the heat flux of walls will be the linear thermal transmittance ψ of the junction. For the current case shown in figure 7, the general equation for the linear thermal transmittance expressed in formula 6 can be simplified as written in formula 15.

$$\psi = L_{2D} - U_w l_w \qquad 15.$$

where

L_{2D} is a numerically defined two-dimensional (2D) technical thermal coupling factor for the joint of the building obtained by formula 10, W/(mK)

U_w is the thermal transmittance of the wall, W/(m^{2}K)

l_w is the length of the wall, used in the model, m

2.4.3 Joints between floor and external walls

Calculation of the thermal bridge of floor junctions is similar to the cases presented in sections 2.4.1 and 2.4.2. An example of a connection of two different types of external walls and concrete floor, which includes a thermal bridge, is shown in figure 8.

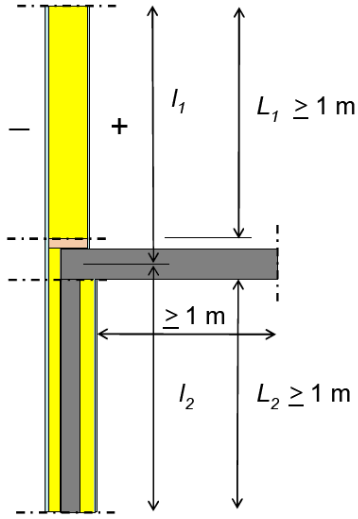


FIGURE 8. Calculation principle scheme of a floor junction (Heikkinen et. al. 2012, 24)

First of all, a computational model must in general include at least one meter of a wall and one meter of a floor slab. In particular, the model joint details should be as close to the real structure as possible (Heikkinen et. al. 2012, 25). The actual heat flux should be calculated numerically in accordance with sections 2.3 and 2.3.1.

The result of subtracting the actual heat flow with the heat flux of the wall will be the linear thermal transmittance ψ of a junction. For the current case shown in figure 8, the general equation for the linear thermal transmittance expressed in formula 6 can be simplified as written in formula 14.

2.4.4 Joints between roof and external wall

Calculation of a thermal bridge of roof junctions is similar to the cases presented in sections 2.4.1, 2.4.2 and 2.4.3. A computational model must in general include at least one meter of a wall and one meter of a roof. In particular, the joint details of a model should be as close to the structure as possible (Heikkinen et. al. 2012, 23). An example of a joint of an external wall and a roof, which includes a thermal bridge, is shown in figure 9 below.

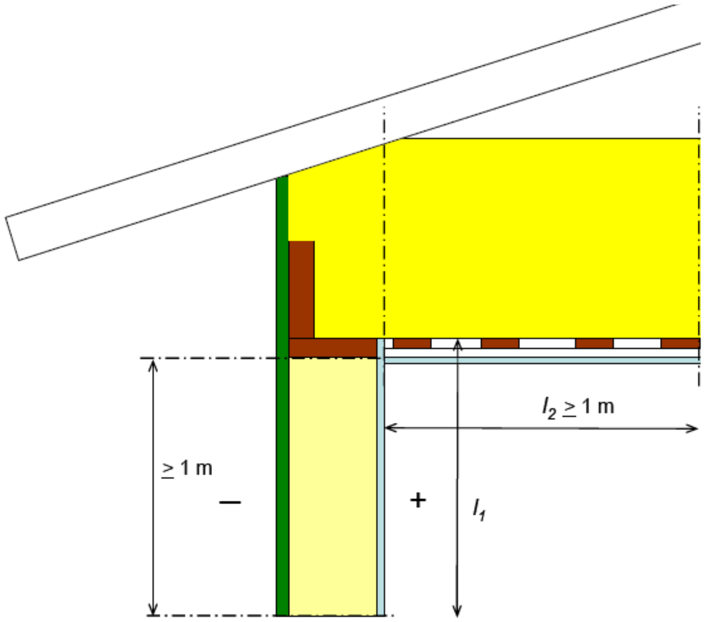


FIGURE 9. Calculation principle scheme of a roof joint (Heikkinen et. al. 2012, 23)

The actual heat flux should be calculated numerically in accordance with sections 2.3 and 2.3.1. The result of subtracting the actual heat flow with the heat fluxes of wall and roof will be the junction linear thermal transmittance ψ. For the current case shown in figure 9, the general equation for the linear thermal transmittance expressed in formula 6 can be simplified as written in formula 16.

$$\psi = L_{2D} - U_w l_w - U_r l_r \qquad 16.$$

where

L_{2D}	is a numerically defined two-dimensional (2D) technical thermal coupling factor for the joint of the building obtained from Formula (10), W/(mK)
U_w	is the thermal transmittance of wall, W/(m^{2}K)
l_w	is the length of the wall used in model (l_1 in figure 9) , m
U_r	is the thermal transmittance of roof, W/(m^{2}K)
l_r	is thelength of the roof used in model (l_2 in figure 9), m

2.4.5 Basement joints

This section highlights the determination of linear thermal transmittance in a basement junction, which differs from other cases. FIGURE 10 shows an example of a basement and an external wall connection, which includes a thermal bridge. To calculate the heat flux for those types of joints we need to create a two-dimensional model as shown below.

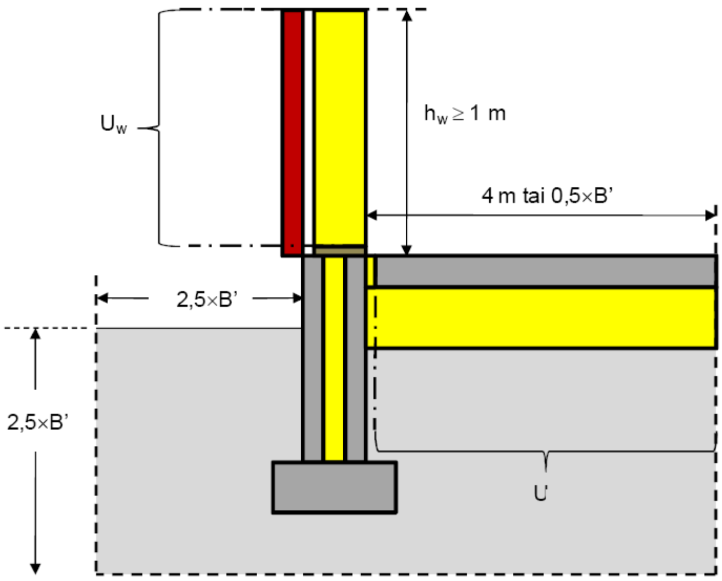


FIGURE 10. Scheme of calculation principle for basement connection (Heikkinen et. al. 2012, 16)

The computational model is at least one meter of a wall and 0,5 × B ' of a base floor, wherein B' is the basement characteristic of the building, which can be obtained from formula 17. The outside structure of the landmasses should include 2,5 times of basement characteristic of the building, as well as a part below the basement (figure 10). Dotted lines are boundaries of adiabatic conditions. In particular, the joint details of the structure must be involved as much as possible (Heikkinen et. al. 2012, 16).

$$B' = \frac{A}{0,5 \times P} \qquad 17.$$

where

B' is the basement characteristic of the building, m

A is the area of the building base, m^2

P is the perimeter of the building, district overall length formed by the outer walls, m

Linear thermal transmittance of a floor junction is the result of subtracting the actual heat flow by calculated heat fluxes of external wall and basement. According to the international standard ISO 10211 (2008, 24), the formula for determining the linear thermal transmittance for basement joints can be expressed as follows:

$$\psi = L_{2D} - h_w U_w - 0{,}5 \times B^{\prime} \; U \qquad 18.$$

where

L_{2D}	is a numerically defined two-dimensional (2D) technical thermal coupling factor for the joint of the building obtained by formula 10, *W/(mK)*
U_w	is the thermal transmittance of external wall, *W/(m²K)*
h_w	is the height of the wall structure used in the model (hw≥ 1 m), *m*
B'	is the basement characteristic of the building, *m*
U	is the thermal transmittance of the basement structure, *W/(m²K)*

Thermal transmittance of the basement structure U should be calculated by applying formula 19 (Heikkinen et. al. 2012, 17).

$$U = \frac{\lambda}{0{,}457 \times B^{\prime} \; + d_t} + \frac{\psi_{ge}}{B^{\prime}} \qquad 19.$$

where

λ	is the base thermal conductivity, *W/(mK)*
d_t	is the equivalent thickness of the base structure, *m*
ψ_{ge}	is the linear thermal transmittance of a foundation wall, vertical thermal insulation or the edge of the floor structure, *W/(mK)*

Determination of equivalent thickness d_t is expressed in formula 20 (Heikkinen et. al. 2012, 18).

$$d_t = w + \lambda\left(R_{si} + R_f + R_{se}\right) \qquad 20.$$

where

w	is the thickness of the wall structure (figure 10), *m*
R_f	is the thermal resistance of the floor structure, *(m²K)/W*
R_{si}, R_{se}	are resistances of the inner and outer surfaces of base floor, (m²K)/W

Calculation of the linear thermal transmittance of a foundation wall ψ_{ge} is shown in formula 21 (Heikkinen et. al. 2012, 18).

$$\psi_{ge} = -\frac{\lambda}{\pi}\left[ln\left(\frac{2D_v}{d_t} + 1\right) - ln\left(\frac{2D_v}{d_t + d_v^{\prime}} + 1\right)\right] \qquad 21.$$

where

D_v is the height of the foundation wall with thermal insulation below the ground level, *m*

d'_v is the equivalent thickness of a thermal insulation of the foundation wall, m

The equivalent thickness of a thermal insulation of the foundation wall d'_v should be calculated by formula 22 (Heikkinen et. al. 2012, 18).

$$d'_v = \lambda \left(R_{nv} - \frac{d_{nv}}{\lambda} \right) \qquad 22.$$

where

R_{nv} is the thermal resistance of the foundation wall, *W/(mK)*

d_{nv} is the thickness of the foundation wall, *m*

Now, after the main principles of the calculation have been described, the next section shows the process of the calculation in details, starting with initial data received from the company.

3 RESEARCH TASK

The current thesis work aims to review the thermal bridges in structural parts of a high-rise building located in Finland, city of Oulu, Rita-Aukiontie 14, “Talo A”. For further investigation, the company provided building drawings such as floor plans, sections and detailed specifications made by WSP Finland Oy, which are enclosed to the report in appendix 1.

Returning to the formula 3 regarding total heat losses of the building, and applying the definition of linear thermal transmittance provided by ISO 10211 (2008, 4), the influence of a linear thermal bridge on the total heat flow is described with values of linear thermal transmittance. Therefore, twenty-two certain distinctive structural junctions (given in appendix 2 and marked in appendix 1) were selected by the supervisor of the thesis, in which thermal transmittance values present the main interest.

3.1 Structural features of test case building

The examined building includes various types of walls, roof and floor structures, which consist of different building materials. All structural specifications were provided by the company and are enclosed to the report in appendix 1.

The design values of thermal conductivities of building materials and products should either be calculated in accordance with the international standard ISO 10456 (2007), or taken from tabulated values such as in ISO 10456 (2007, 9-14). The thermal conductivities of materials used in the present building are conducted in table 4.

TABLE 4. Thermal conductivities of materials, used in the current building

№	Name of material in Finnish (that was specified in appendix 1)	Name of material in English	Thermal conductivity, *(W/mK)*
1	Tuulensuojaminer. Villa	Wind-proof mineral wool	0,035
2	Kertopuu (pustyrunko)	Laminated veneer lumber (LVL)	0,11
3	Rankaväleissäminer.villa	Mineral wool	0,037
4	Kipsilevy EK	Plaster board	0,21
5	Betoni- tai teräsbetoniseinä BY 40	Concrete or reinforced concrete	1,7
6	Solumuovi	Foam insulation	0,036
7	Puhalluseriste, mineralivilla	Blow-in insulation, mineral wool	0,045

Wind barrier plates outside the ventilation gap and cladding boards are not taken into account in the calculations, because the ventilation gap is supposed to be well ventilated (Heikkinen et. al. 2012, 31). In this case, other surface layers such as brick, timber and panel cladding are also not included in the calculations and neither in table 4.

In accordance with the ISO 13370 (2008, 10) “the thermal properties of the ground may be specified in national regulations or other documents, and such values may be used where appropriate. In other cases, the following apply:

a) if known, use values for the actual location, averaged over a depth equal to the width of the building and allowing for the normal moisture content;

if the soil type is known or specified, use the values in table 1;

b) otherwise, use *λ = 2,0 W/(mK)* and ρ_c = *2,0×10^6^ J/(m^3^K).*”

In the current case, it is assumed that the thermal conductivity of the soil is equal to 2,0 W/(mK). According to sections 2.2 and 2.4, thermal transmittances *U* for each structure and thermal resistances *R* for each structural layer are required to be evaluated in order to complete the original calculation of linear thermal bridges. Information regarding structural layers of external walls related to the current building and calculated thermal resistances and thermal transmittances to be applied in formulas 11 and 2 respectively is given in table 5 to table 9. Surface resistances R_{si} and R_{se} were defined in table 2.

TABLE 5. Structural layers and thermal parameters of external walls US1 and US2

Structural layer	Thickness d, mm	Thermal conductivity $\lambda, W/(mK)$	Thermal resistance $R, (m^2K)/W$
Surface Resistance R_{si}			0,13
Plaster board	13	0,21	0,0619
Mineral wool + LVL-frame (v) 50x50 (600)	50	0,0413	1,2107
Mineral wool+ LVL-frame (v) 50x200 (600)	200	0,0413	4,8426
Wind-proof mineral wool	50	0,035	1,4286
Surface Resistance R_{se}			0,04
$\sum$ R			7,7137
U= 1/$\sum$ R			0,1296

For the second layer of mineral wool and LVL-frame 50x50 (600) thermal conductivity should be calculated using formula 13:

$$\lambda' = \frac{(0{,}05\ m \cdot 0{,}55\ m) \cdot 0{,}035\ W/(mK) + (0{,}05\ m \cdot 0{,}05\ m) \cdot 0{,}11\ W/(mK)}{(0{,}05\ m \cdot 0{,}55\ m) + (0{,}05\ m \cdot 0{,}05\ m)} =$$

$$= 0{,}0413\ W/(mK).$$

Similarly, the third layer of mineral wool and LVL-frame 200x50 (600) has a thermal conductivity of 0,0413 W/(mK).

TABLE 6. Structural layers and thermal parameters of wall US2.1

Structural layer	Thickness d, mm	Thermal conductivity $\lambda, W/(mK)$	Thermal resistance $R, (m^2K)/W$
Surface Resistance R_{si}			0,13
Plaster board	13	0,21	0,0619
Mineral wool + LVL-frame (v) 50x50 (600)	50	0,0413	1,2107
Mineral wool+ LVL-frame (v) 50x200 (600)	200	0,0413	4,8426
Mineral wool+ LVL-frame (v) 50x66 (600)	66	0,0413	1,5981
Wind-break plaster board	9	0,21	0,0429
Surface Resistance R_{se}			0,04
∑R			7,9261
U= 1/∑ R			0,1262

TABLE 7. Structural layers and thermal parameters of wall US3

Structural layer	Thickness d, mm	Thermal conductivity $\lambda, W/(mK)$	Thermal resistance $R, (m^2K)/W$
Surface Resistance R_{si}			0,13
Concrete	180	1,7	0,1059
Mineral wool + LVL-frame(v) 50x200 (600)	200	0,0413	4,8426
Mineral wool	50	0,037	1,3514
Wind-proof mineral wool	50	0,035	1,4286
Surface Resistance R_{se}			0,04
∑R			7,8984
U= 1/∑ R			0,1266

TABLE 8. Structural layers and thermal parameters of wall US4

Structural layer	Thickness d, mm	Thermal conductivity $\lambda, W/(mK)$	Thermal resistance $R, (m^2K)/W$
Surface Resistance R_{si}			0,13
Concrete	180	1,7	0,1059
Mineral wool + LVL-frame(v) 50x200 (600)	200	0,0413	4,8426
Mineral wool + LVL-frame(h) 50x50 (600)	50	0,0413	1,2107
Wind-proof mineral wool	50	0,035	1,4286
Surface Resistance R_{se}			0,04
$\sum$R			7,7577
U= 1/$\sum$ R			0,1289

TABLE 9. Structural layers and thermal parameters of wall US5

Structural layer	Thickness d, mm	Thermal conductivity $\lambda, W/(mK)$	Thermal resistance $R, (m^2K)/W$
Surface Resistance R_{si}			0,13
Concrete	300	1,7	0,1765
Mineral wool+ LVL-frame (v) 50x200 (600)	200	0,0413	4,8426
Mineral wool + LVL-frame (h) 50x50 (600)	50	0,0413	1,2107
Wind-proof mineral wool	50	0,035	1,4286
Surface Resistance R_{se}			0,04
$\sum$R			7,8283
U= 1/$\sum$ R			0,1277

In the Joint 13 (see appendix 2), external wall US2 is conjugated with a concrete wall with a thickness of 150 mm. The thermal transmittance for this wall is calculated separately and given in table 10.

TABLE 10. Structural layers and thermal parameters of wall US2'

Structural layer	Thickness d, mm	Thermal conductivity $\lambda, W/(mK)$	Thermal resistance $R, (m^2K)/W$
Surface Resistance R_{si}			0,13
Concrete	150	1,7	0,0882
Plaster board	13	0.21	0,0619
Mineral wool + LVL-frame (v) 50x50 (600)	50	0,0413	1,2107
Mineral wool+ LVL-frame (v) 50x200 (600)	200	0,0413	4,8426
Wind-proof mineral wool	50	0,035	1,4286
Surface Resistance R_{se}			0,04
$\sum R$			7,8020
U= $1/\sum R$			0,1282

Information regarding structural layers of roof structures related to the current building and the calculated thermal resistances and thermal transmittances to be applied in formulas 11 and 2 respectively are given in table 11 to table 13. Surface resistances R_{si} and R_{se} are defined from table 2.

TABLE 11. Structural layers and thermal parameters of roof YP 1.1

Structural layer	Thickness d, mm	Thermal conductivity $\lambda, W/(mK)$	Thermal resistance $R, (m^2K)/W$
Surface Resistance R_{si}			0,10
Concrete	265	1,7	0,1559
Mineral wool	100	0,035	2,8571
Blow-in mineral wool	400	0,045	8,8889
Wind-proof mineral wool	30	0,035	0,8571
Surface Resistance R_{se}			0,04
$\sum$			12,8991
U= $1/\sum R$			0,0775

TABLE 12. Structural layers and thermal parameters of roof YP 1

Structural layer	Thickness d, mm	Thermal conductivity $\lambda, W/(mK)$	Thermal resistance $R, (m^2K)/W$
Surface Resistance R_{si}			0,10
Concrete	265	1,7	0,1559
Mineral wool	200	0,035	5,7143
Blow-in mineral wool	400	0,045	8,8889
Surface Resistance R_{se}			0,04
$\sum$			14,8991
U= $1/\sum \mathrm{R}$			0,0671

TABLE 13. Structural layers and thermal parameters of roof YP1'

Structural layer	Thickness d, mm	Thermal conductivity $\lambda, W/(mK)$	Thermal resistance $R, (m^2K)/W$
Surface Resistance R_{si}			0,10
Concrete	365	1,7	0,2147
Mineral wool	200	0,035	5,7143
Blow-in mineral wool	400	0,045	8,8889
Surface Resistance R_{se}			0,04
$\sum$			14,9579
U= $1/\sum \mathrm{R}$			0,0669

Information regarding structural layers of the floor structures related to the current building and calculated thermal resistances and thermal transmittances to be applied in formulas 11 and 2 respectively are given in table 14. Surface resistances R_{si} and R_{se} are defined from table 2.

TABLE 14. Structural layers and thermal parameters of the floor

Structural layer	Thickness d, mm	Thermal conductivity $\lambda, W/(mK)$	Thermal resistance $R, (m^2K)/W$
Surface Resistance R_{si}			0,17
Concrete slab	80	1,7	0,0471
Foamed insulation	200	0,036	5,5556
$\sum$			5,7726
Uf= 1/$\sum$ R			0,1732

3.2 Calculation process

This section discusses the actual procedures for determining the linear thermal bridges. The building considered in the thesis work includes 22 joints. Five junction types between different structures of the building were defined: junction between external walls, junction between window and external wall, junction between floor and external walls, junction between roof and external wall and basement junction. As it occurred that several joints had a similar architecture, one joint per junction types has been detailed in this thesis work and are summarized in table 15.TABLE 15 Nevertheless, the results for the other joints are available in appendix 3.

TABLE 15. Summary of the joint type developed within subsections 3.2.1 to 3.2.5

Type of junction	Joints Considered	Similar Joints (see appendix 3)
Joints between external Walls	Joint 1	Joint 2, Joint 4, Joint 5, Joint 13, and Joint 15
	Joint 8	Joint 10
Window and external wall joints	Joint 3	Joint 9, Joint 11, Joint 12, and Joint 16
	Joint 6	Joint 7
Floor and external walls joints	Joint 17	Joint 19, and Joint 20
Roof and external wall joints	Joint 21	Joint 22, and Joint 18
Basement joints	Joint 14	None

The calculation process started with the creation of simplified models of structures of the joints on COMSOL Multiphysics. All the process was carried out in accordance with section 2.3.1. In particular, the following parameters and conditions were applied:

1. Space Dimension: *2-D*

Study type: *Heat Transfer in Solids (ht)*.
Analysis: *Stationary*.

2. Geometry of the model was done by using the *Rectangle* tool and divided into numerous elements. Personal materials were created and thermal conductivities, which are designated as *k* within the software, were set in accordance with TABLE 4table 4.

Global Definitions were set as shown in figure 11 and the following parameters were added:

T_out = 0[degC]	is external temperature, taken at 0°C
T_in = 1[degC]	is internal temperature, taken at 1°C
alpha_out = 1/0,04	is heat transfer coefficient, when $R_{se} = 0{,}04\ m^2K/W$,
alpha_in = 1/0,13	is heat transfer coefficient, when $R_{si} = 0{,}13\ m^2K/W$,
alpfa_fl = 1/0,17	is heat transfer coefficient, when $R_{si} = 0{,}17\ m^2K/W$,
alpha_r = 1/0,10	is heat transfer coefficient, when $R_{si} = 0{,}10\ m^2K/W$.

Heat transfer coefficient, designated within the software as *h,* is applied in Step 5 when setting the *Heat fluxes*. Surface resistances R_{si} and R_{se} were obtained from table 2. Other inner surfaces have resistances R_{si} = 0,25 m^2K/W (Heikkinen et. al. 2012, 15) and for them heat transfer coefficient *alpha_o = 1/0,25.*

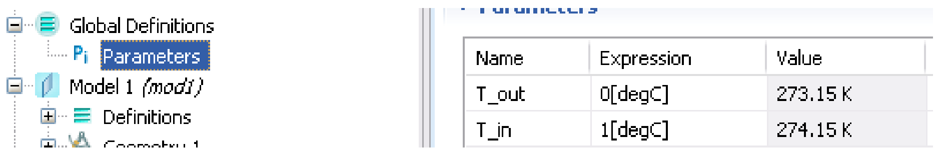


FIGURE 11. Setting the Global Definitions in COMSOL Multiphysics

Thermal bridges are evaluated per unit of temperature change between the inner and outer environments. Therefore, in this particular case, T_{out} = 0˚C and T_{in} = 1˚C.

3. The way of setting *Heat fluxes* is individual for each kind of joint and is considered in the following subsections 2.4.1 to 2.4.5.

4. In the current study, all the joints were made with *Mapped Meshing*.

5. Computing.

6. A graph of *Temperature* and *Isothermal Contours* was implemented automatically. In order to present results regarding heat flux, Graphics of *Conductive heat flux magnitude* in *2D Plot Group* of *Results* and *Line Integration* of heat flux magnitude in *Derived Values* were added manually. Setting boundaries for *Heat flux Integration* was done individually for particular cases. The *Conductive Heat Flux Magnitude (W/m)* for each joint was evaluated.

After finishing with the computational part of the calculation, thermal coupling factors for all 22 joints were calculated using the principle highlighted in the section 2.4 and values of linear thermal transmittance for all joints were evaluated. The procedures are described in subsections 3.2.1 to 3.2.5.

3.2.1 Joints between external walls

Joint 1

Joint 1 is a connection between external walls US3 and US2.1. The initial Joint 1 is enclosed in appendix 2 and can be found marked in appendix 1 in the drawing 163-003. The original structure of Joint 1 is represented in figure 12.

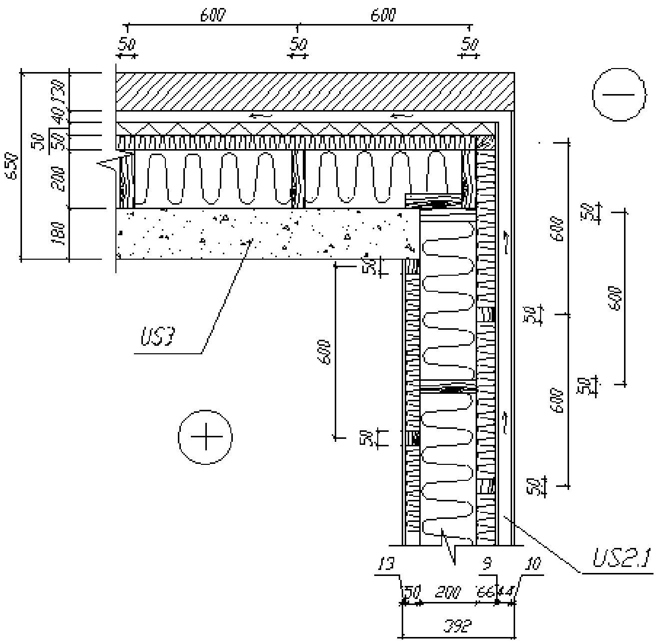


FIGURE 12. Original structure of Joint 1

The layers, situated outside a ventilated air gap, are not included in the calculation model as was mentioned in section 3.1. Figure 13 represents a simplified computational geometry and its model with the applied materials. Furthermore, while creating the model, principles of section 2.4.1 were considered.

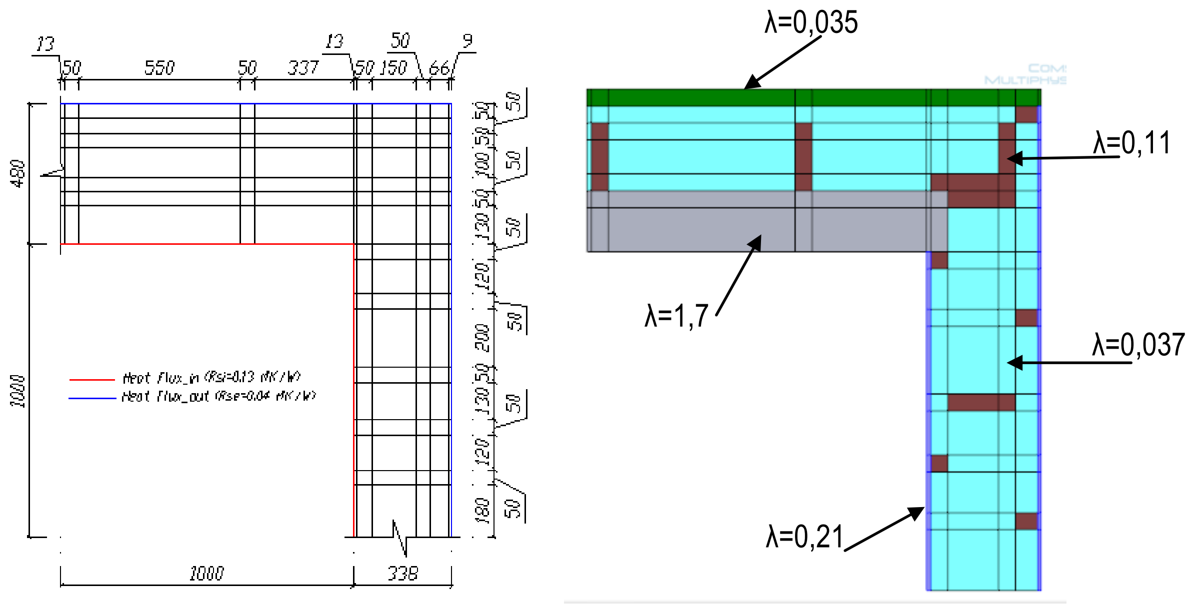


FIGURE 13. Computational geometry (including heat flux boundaries) and model materials of Joint 1 in COMSOL Multiphysics

Considering Joint 1, Heat flux 1 and Heat flux 2 were added for the outside and inside surfaces to which boundaries were set as shown in figure 13 (left). Their properties were applied as represented in figure 14.

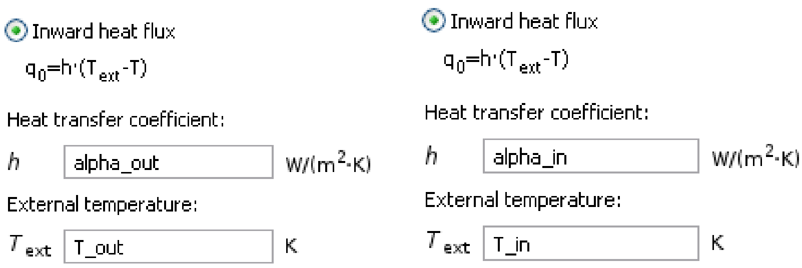


FIGURE 14. Applying the properties for Heat flux 1 and Heat flux 2 (respectively). Values for the variables are detailed in step 2 in section 3.2

The next step aimed at organizing the *Mapped Mesh*, where the central part of the model represents the main interest and, thus, should be more densely parted. Figure 15 shows the result of this procedure.

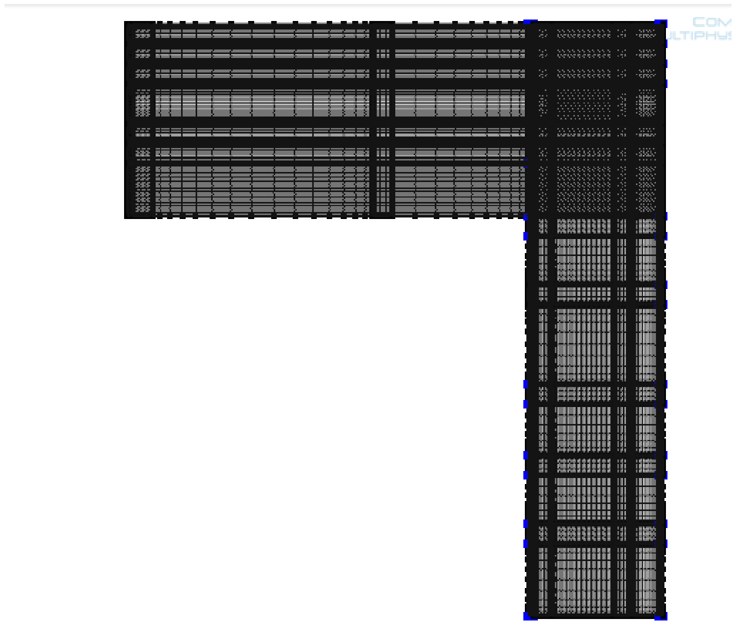


FIGURE 15. Meshing of the Joint 1in COMSOL Multiphysics

A rectangular meshing strategy was chosen in order to represent each area of the joint structure. Each zone is independently calculated. Thus, a dense meshing will require more computing memory but will result in a finer representation of the heat flux in the area studied

After that all boundaries and settings are entered in the model, and the computing step can be triggered. A graph of temperature distribution within Joint 1 is represented in figure 16. The temperature allocated smoothly with minor leaps in dispositions of LVL-frames.

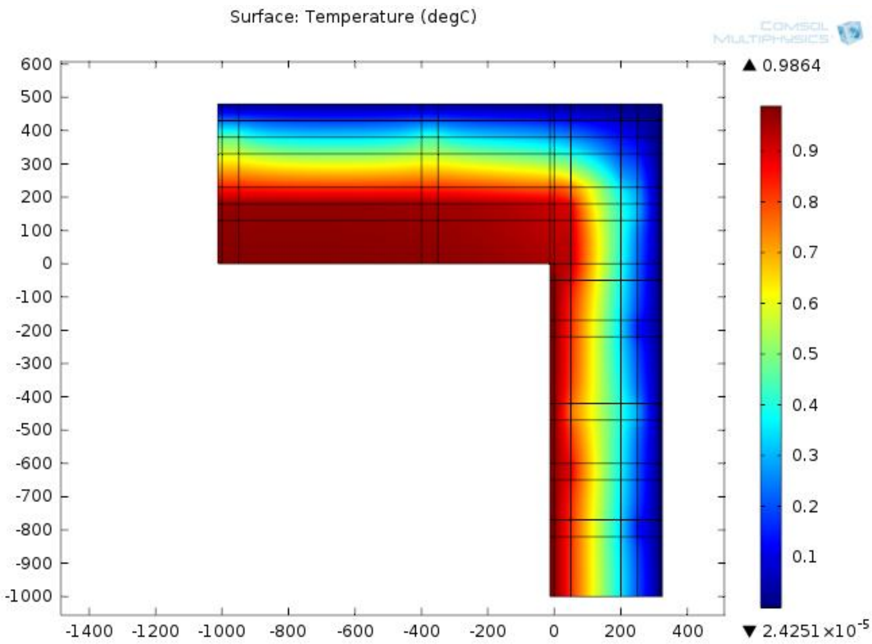


FIGURE 16. Temperature gradients within Joint 1

Also a graph of Isothermal Contours within the structure of Joint 1 that is presented in figure 17 is strong for visual perception. Arrows shown in figure 17 represents the heat flux circulation. Furthermore, the bigger the arrow is, the stronger the heat flux is at the point performed by the corresponding arrow.

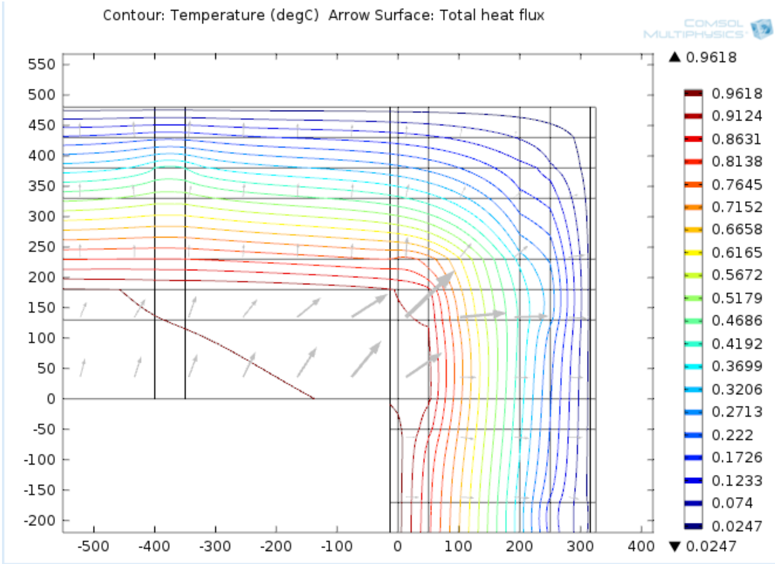


FIGURE 17. Isothermal contours within Joint 1

As the main interest is to represent the heat flux within the joint, a “heat map” of the Heat Flux magnitude within Joint 1 is included. It can be seen from the graph, which is shown in figure 18 below, that the maximum value of heat flux magnitude is 4,7162 W/m^2. However, the scale is from 0 to 0,6 due to the smallness of the area occupied with the maximum value. Heat flux rate follows a colour code, in which red colour indicates areas with the highest heat flux rate, and reciprocally the blue colour illustrates areas with the smallest heat flux rate.

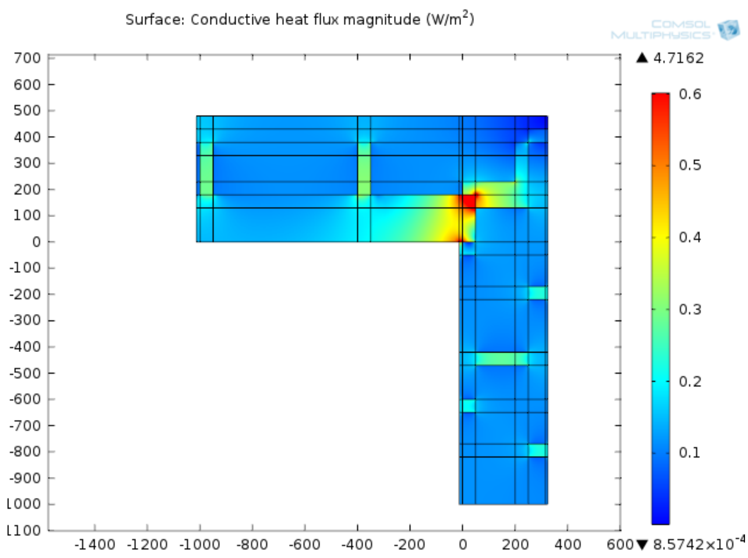


FIGURE 18. Heat flux inside Joint 1

Then, according to section 2.3.1, the value of heat flow rate was evaluated. Boundaries of heat flux integration were selected as surfaces of internal space as shown in figure 19.

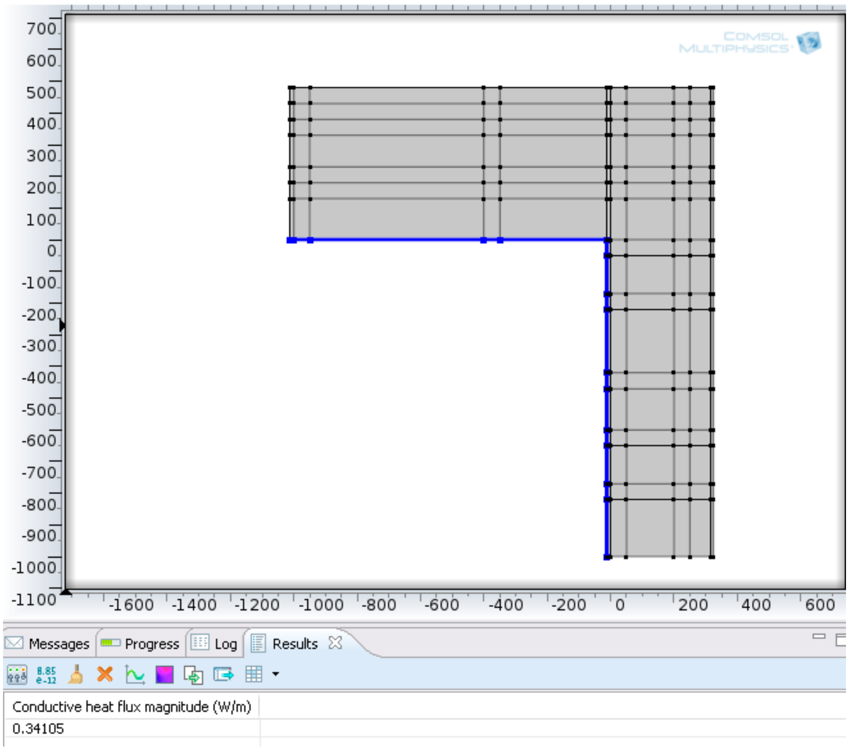


FIGURE 19. Determination of the heat flux rate in Joint 1

After setting the boundaries, COMSOL Multiphysics software automatically obtained the value of heat flux rate, which is equal to 0,34105 W/(mK) as can be noted in figure 19. Next, by using formula 10, the technical coupling coefficient L_{2D} can be calculated:

$$L_{2D} = \frac{0{,}34105\ W/m}{1\ K - 0\ K} = 0{,}34105\ W/mK$$

For this type of joint, formula 14 applies. Besides, the lengths of the walls were obtained from figure 13 and thermal transmittance values for walls $US3$ and $US2.1$, which are included in this joint, were defined from table 7 and table 6:

$$\psi = 0{,}34105\ W/(mK) - (0{,}1266\ W/(m^2K) \cdot\ 1\ m) - (0{,}1262\ W/(m^2K) \cdot\ (1 + 0{,}48)\ m) =$$
$$= 0{,}0277\ W/(mK)$$

The calculations of the linear thermal transmittance values for Joints 2, 4, 5, 13 and 15 were implemented in the same manner as for Joint 1. Results of those calculations can be found in table 16. Drawings and graphs regarding modelling in COMSOL Multiphysics are presented in appendix 3.

TABLE 16. Calculations of linear thermal transmittance for joints between external walls

Joint №	L_{2D}, W/mK	Wall 1	$U_{wall\ 1}$, $W/(m^2K)$	$l_{wall\ 1}$, m	Wall 2	$U_{wall\ 1}$, $W/(m^2K)$	$l_{wall\ 2}$, m	Ψ, $W/(mK)$
1	0,34105	US3	0,1266	1	US2.1	0,1262	1,48	0,02772
2	0,30584	US2.1	0,1262	1,385	US2	0,1296	1,054	-0,00554
4	0,51237	US3	0,1266	1	US2	0,1296	1,48	0,19390
5	0,37118	US5	0,1277	1	US5	0,1277	1,6	0,03905
13	0,29286	US2	0,1296	1	US2'	0,1282	1,313	-0,00507
15	0,34061	US3	0,1266	1	US1	0,1296	1,48	0,02214

Joint 8

Joint 8 is a connection between external walls US2, US3 and a 180 mm-thick concrete wall. The initial Joint 8 is enclosed in appendix 2 and can be found marked in appendix 1 referenced with 163-003 in the company drawings. The original structure of Joint 8 is represented in figure 20.

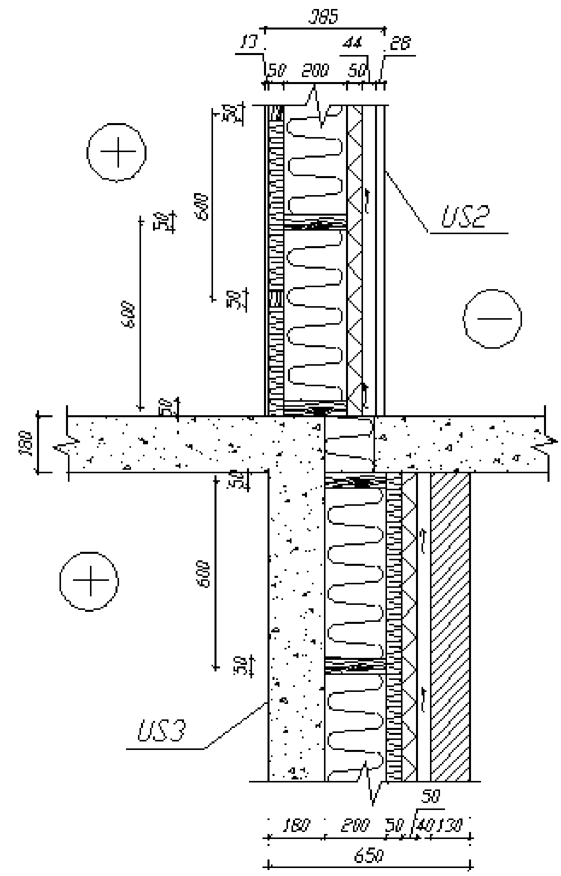


FIGURE 20. Original structure of Joint 8

Normally, as it is a joint between external walls, it should be calculated as Joint 1. However, in this case, one more concrete wall is attached to the two basic external walls. Thus, the calculation principle goes with section 2.4.3 and differs from section 2.4.1 in the last step of the determination of the heat flux rate, particularly, with the setting of boundaries. A simplified computational geometry and its model with the representation of the applied materials for Joint 8 are presented in figure 21.

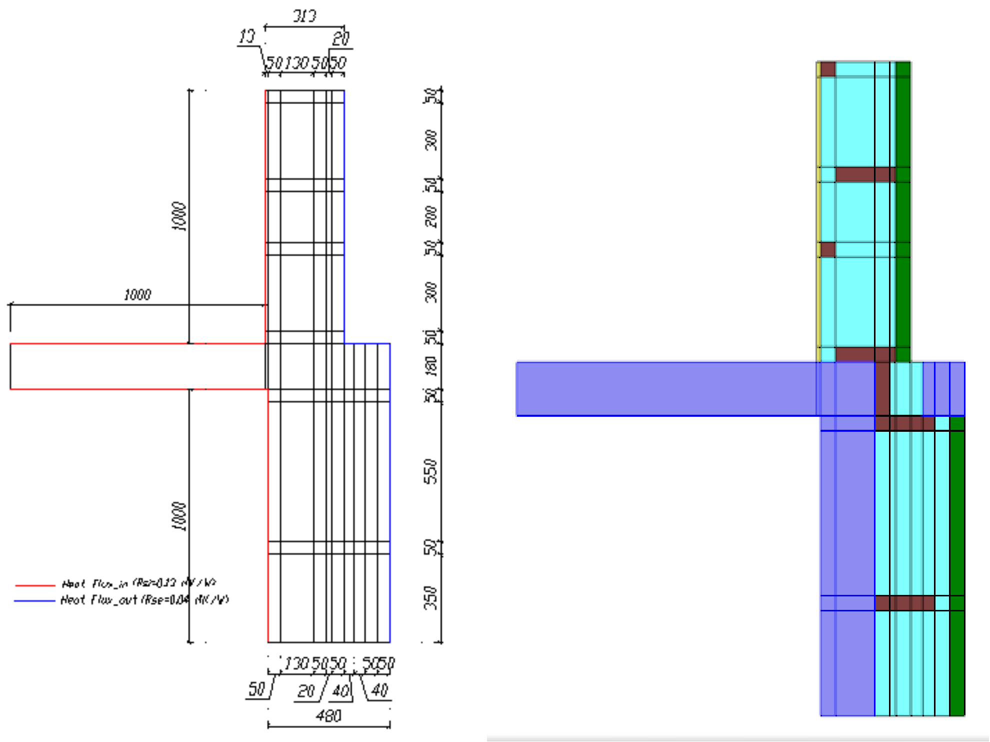
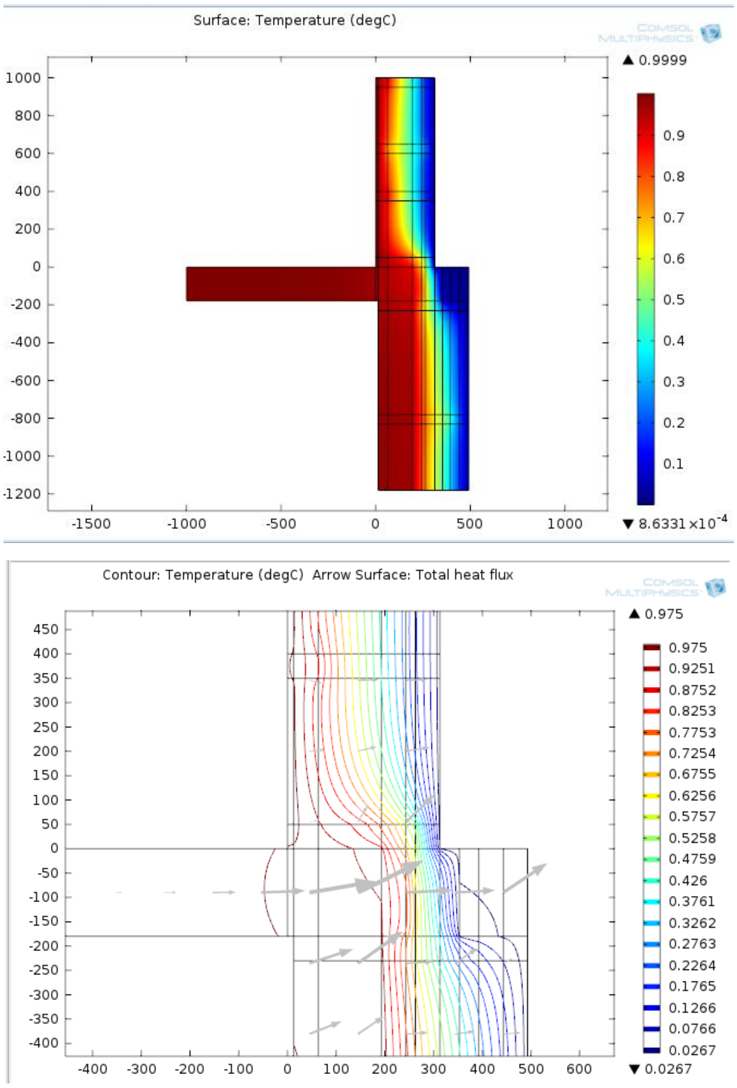


FIGURE 21. Computational geometry (including heat flux boundaries) and model materials of Joint 8 in COMSOL Multiphysics

For visual perception of the situation within Joint 8 Graphs of Temperature distribution and Isothermal contours were made, and are represented in figure 22. The arrows show the heat flux circulation inside Joint 8.



a) b)

FIGURE 22. a) *Temperature distribution within Joint 8*
b) Isothermal contours within Joint 8

A “heat map” of the Heat Flux graph is represented in figure 23. The maximum value of heat flux magnitude in Joint 8 is equal to 8,2677 W/m^2. The heat flux rate follows a colour code, in which red colour indicates areas with the highest heat flux rate, and reciprocally the blue colour illustrates areas with the smallest heat flux rate.

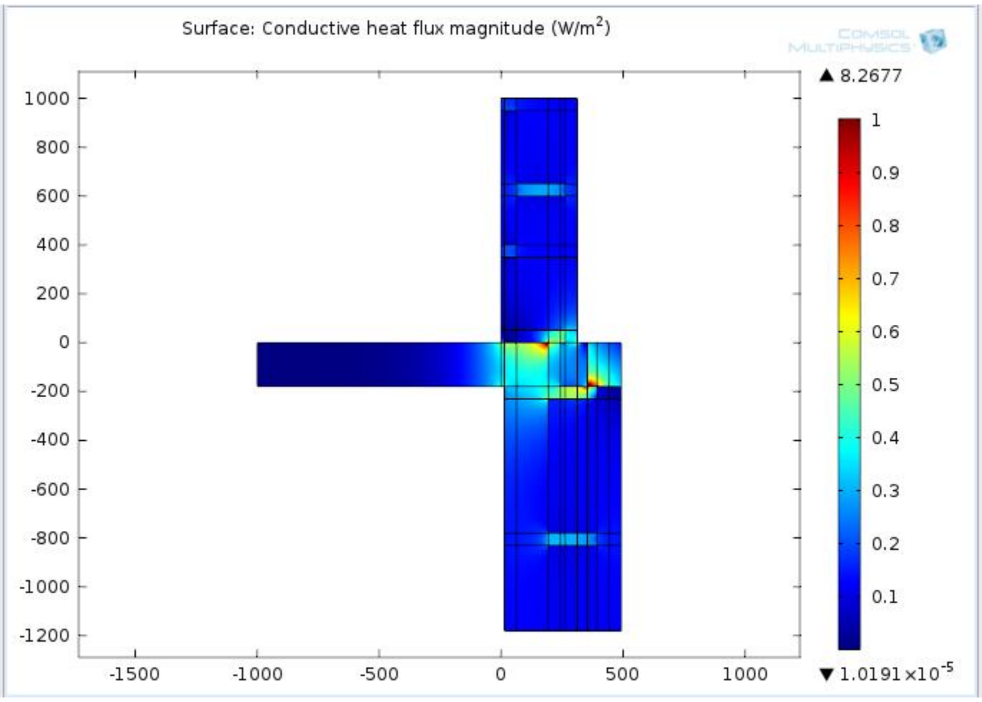


FIGURE 23. Heat flux inside Joint 8

Then, according to section 2.3.1 the value of heat flow rate was evaluated. The boundaries were selected as shown in figure 24 according to section 2.4.3.

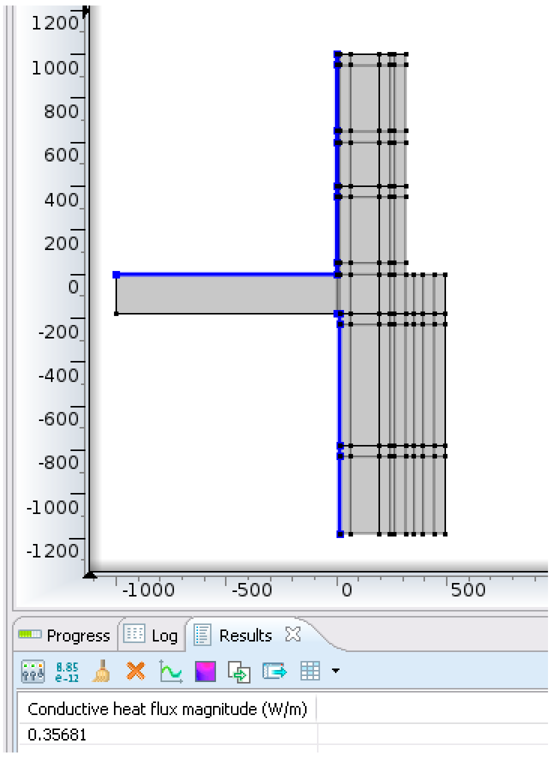


FIGURE 24. Determination of the heat flow rate of Joint 8

After setting the boundaries, COMSOL Multiphysics software automatically obtained the value of heat flux rate, which is equal to 0,35681 W/(mK) as can be noted in figure 24. Next, by using formula 10, the technical coupling coefficient L_{2D} can be calculated:

$$L_{2D} = \frac{0{,}35681\ W/m}{1\ K - 0\ K} = 0{,}35681\ W/mK$$

For this type of joint formula 14 applies. Besides, the lengths of the walls were obtained from figure 21 and the values of thermal transmittance for walls US 2 and US 2.1, which are included in this joint, were defined from table 5 and table 7:

$$\psi = 0{,}35681\ W/(mK) - (0{,}1296\ W/(m^2K) \cdot\ 1m) - (0{,}1266\ W/(m^2K) \cdot\ (1 + 0{,}18)\ m =$$
$$= 0{,}0778\ W/(mK)$$

The calculation of linear thermal transmittance value for Joint 10 was implemented in the same manner as for Joint 8. The results of the calculation can be found in table 17. The drawings and graphs regarding modelling in COMSOL Multiphysics are presented in appendix 3.

TABLE 17. Calculations of linear thermal transmittance for joints between external walls

Joint №	L_{2D}, W/mK	Wall 1	$U_{wall\ 1}$, $W/(m^2K)$	$l_{wall\ 1}$, m	Wall 2	$U_{wall\ 2}$, $W/(m^2K)$	$l_{wall\ 2}$, m	Ψ, $W/(mK)$
8	0,35681	US2	0,1296	1	US3	0,1266	1,18	0,07777
10	0,28073	US2	0,1296	1	US1	0,1296	1,2	-0,00448

3.2.2 Joints between window and external wall

The type of windows used in the building is MSK. The windows have a frame depth d_{fr} of 210 mm. According to Table 3, the computational depth d_c of the frame:

$$d_c = 0{,}7 \cdot d_{fr} = 0{,}7 \cdot\ 210\ mm = 147\ mm$$

Joint 3

Joint 3 represents a connection between a window and an external wall US4. The initial Joint 3 is enclosed in appendix 2 and can be found marked in appendix 1 in company drawing 163-003. The original structure of Joint 3 is presented in figure 25.

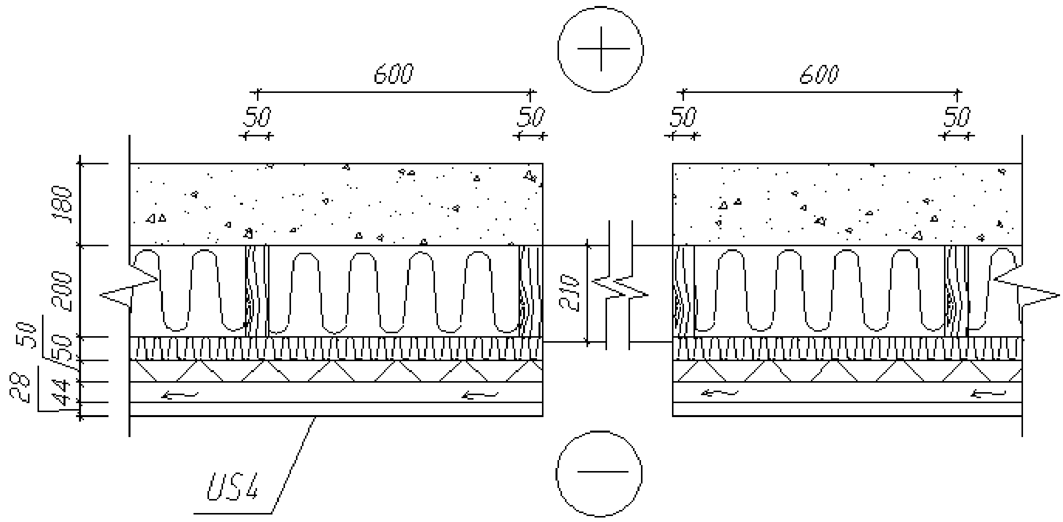


FIGURE 25. Original structure of Joint 3

As was mentioned in section 2.1, layers located outside the ventilated air gap are not included in the calculation model. Taking into account this state, simplified computational geometry and its model with applied materials are presented in figure 26. While creating the model, principles of section 2.4.2 were considered.

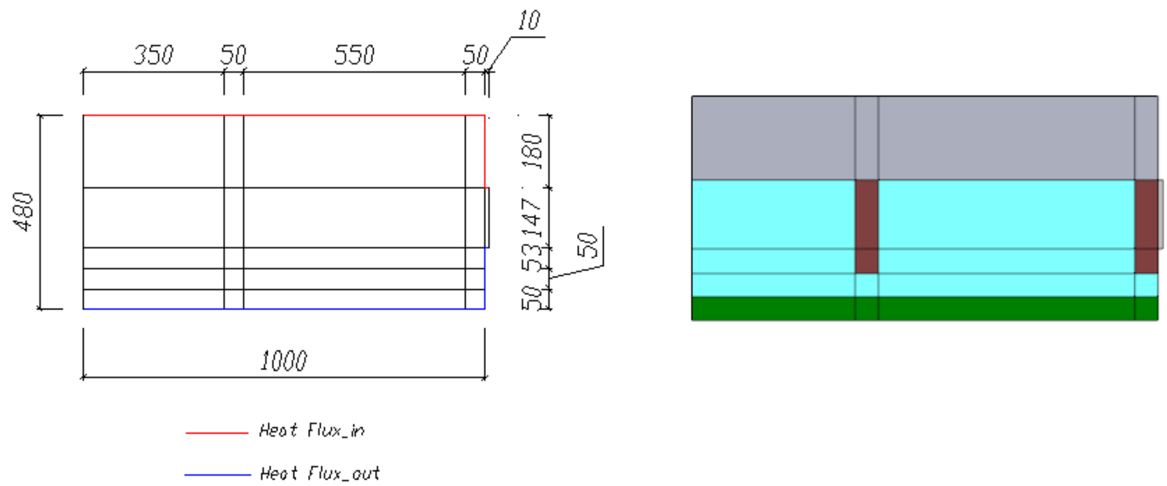


FIGURE 26. Computational geometry (including heat flux boundaries) and model materials of Joint 3 in COMSOL Multiphysics

Heat flux 1 and Heat flux 2 were added to Joint 3 on its outer and inner surfaces with boundary settings shown in figure 26 (left). Values of heat transfer coefficients for heat fluxes were set the same as for Joint 1.

For visual perception of the situation within Joint 3 Graphs of Temperature distribution and Isothermal contours were made and are presented in figure 27.

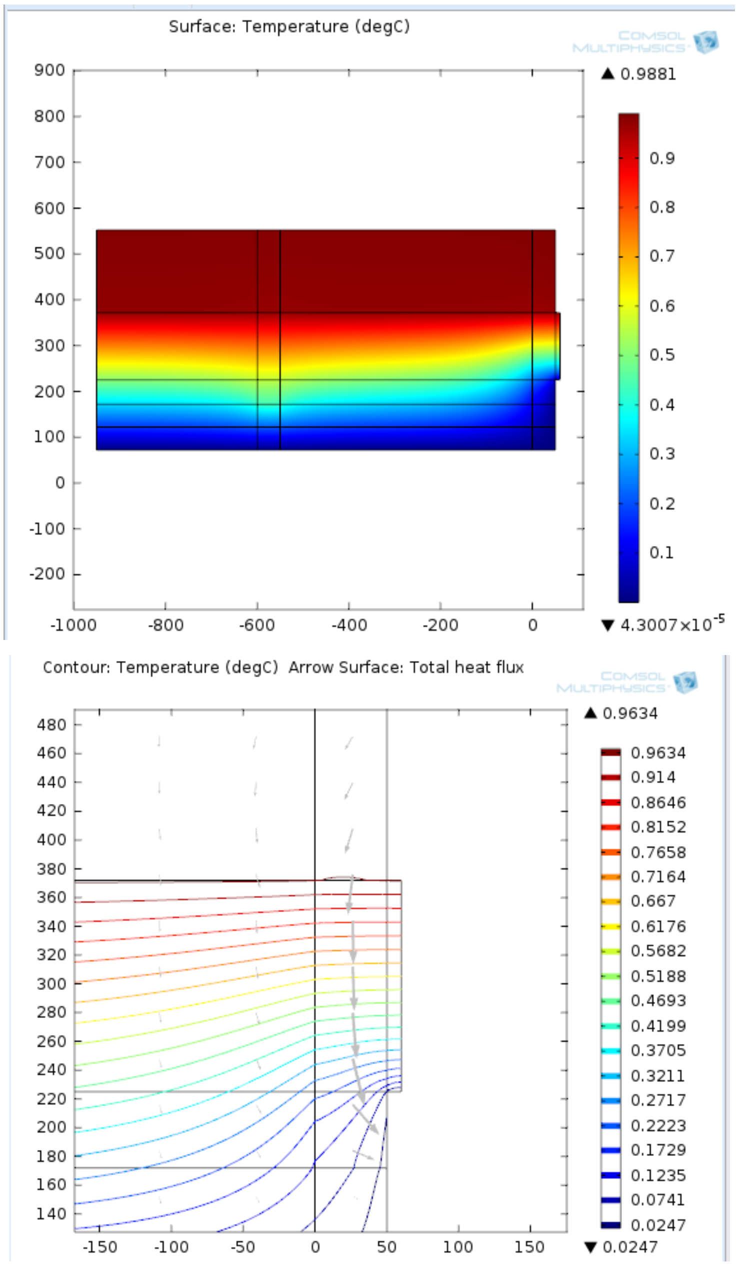


FIGURE 27. a) Temperature distribution

b) Isothermal contours within Joint 3

A "heat map" of the Heat Flux is represented in figure 28. The maximum value of heat flux magnitude in Joint 3 is equal to 2,6864 W/m^2.

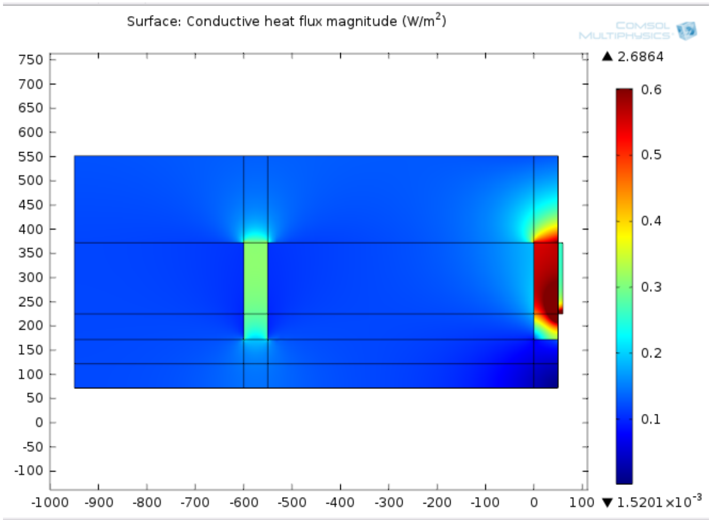


FIGURE 28. Heat flux within Joint 3

Heat flux rate follows a colour code, in which red colour indicates areas with the highest heat flux rate, and reciprocally the blue colour illustrates areas with the smallest heat flux rate.

Then, the value of heat flow rate was evaluated according to section 2.3.1. Lines of internal surface were selected for boundaries of heat flux as shown in figure 29 according to section 2.4.2.

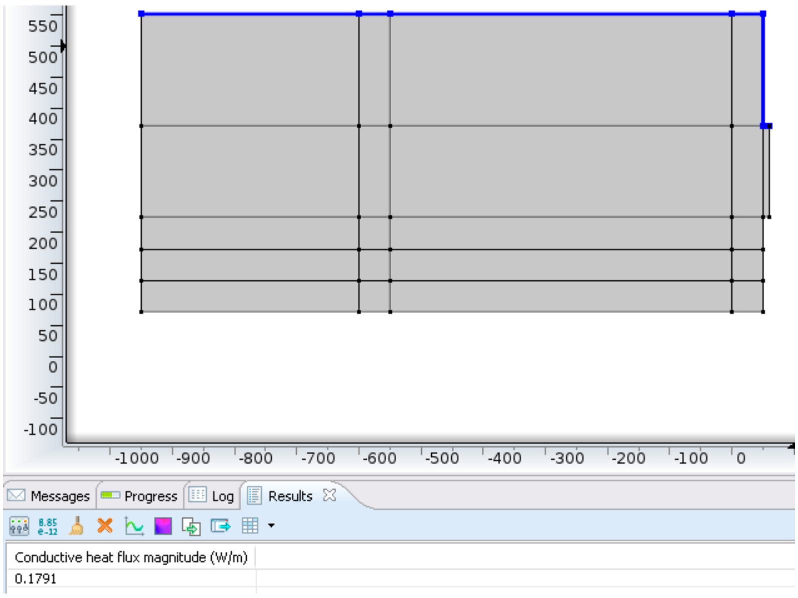


FIGURE 29. Determination of the heat flux rate within Joint 3

After all settings are done, the software automatically evaluated the value of heat flux rate that is equal to $0{,}1791\ W/m$. Next, by using formula 10 the technical thermal coupling coefficient can be calculated:

$$L_{2D} = \frac{0,1791\ W/m}{1\ K - 0\ K} = 0,1791\ W/mK$$

For this type of joint formula 15 applies. Besides, the length of the wall was obtained from figure 26 (left) and thermal transmittance value *U* of the wall $US4$, which is included in this joint, was defined from table 8:

$$\psi = 0,1791\ W/(mK) - (0,1289\ W/(m^2K) \cdot\ 1,0\ m) =\ 0,0502\ W/(mK)$$

Calculations of linear thermal transmittance values for the Joints 9, 11, 12 and 16 were implemented in the same manner as for Joint 3. The results of those calculations can be found in table 18. The drawings and graphs regarding modelling in COMSOL Multiphysics are presented in appendix 3.

TABLE 18. Calculations of linear thermal transmittance for joints between windows and external walls

Joint №	L_{2D}, W/mK	Wall 1	$U_{wall\ 1}$, $W/(m^2K)$	$l_{wall\ 1}$, m	$\Psi, W/(mK)$
3	0,1791	US4	0,1289	1	0,05020
9	0,18168	US5	0,1277	1	0,05394
11	0,17911	US3	0,1266	1	0,05250
12	0,15873	US1	0,1296	1	0,02909
16	0,15616	US21	0,1262	1	0,02999

<u>Joint 6</u>

Joint 1 is a top connection of the window and external wall US4. The initial Joint 6 is enclosed in appendix 2 and can be found marked in appendix 1 in the company drawing 163-008. The original structure of Joint 6 is presented in figure 30.

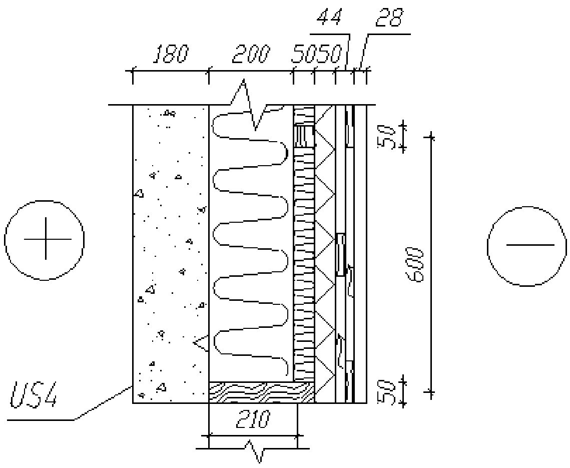


FIGURE 30. Original structure of Joint 6

Joint 6 is calculated in the same manner as Joint 3, but as it being a vertical section, it is good to show the process. Simplified computational geometry and its model with applied materials for Joint 6 are presented in figure 31.

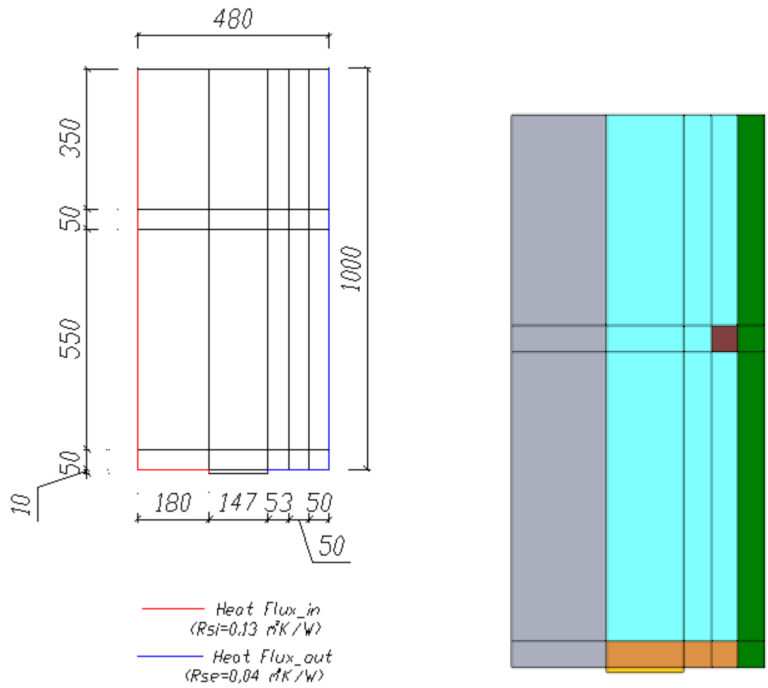


FIGURE 31. Computational geometry (including heat flux boundaries) and model materials of Joint 6 in COMSOL Multiphysics

For visual perception of the situation within Joint 6 the Graphs of Temperature distribution and Isothermal contours were made and are presented in figure 32. The arrows in figure 32b show the heat flux circulation inside Joint 6.

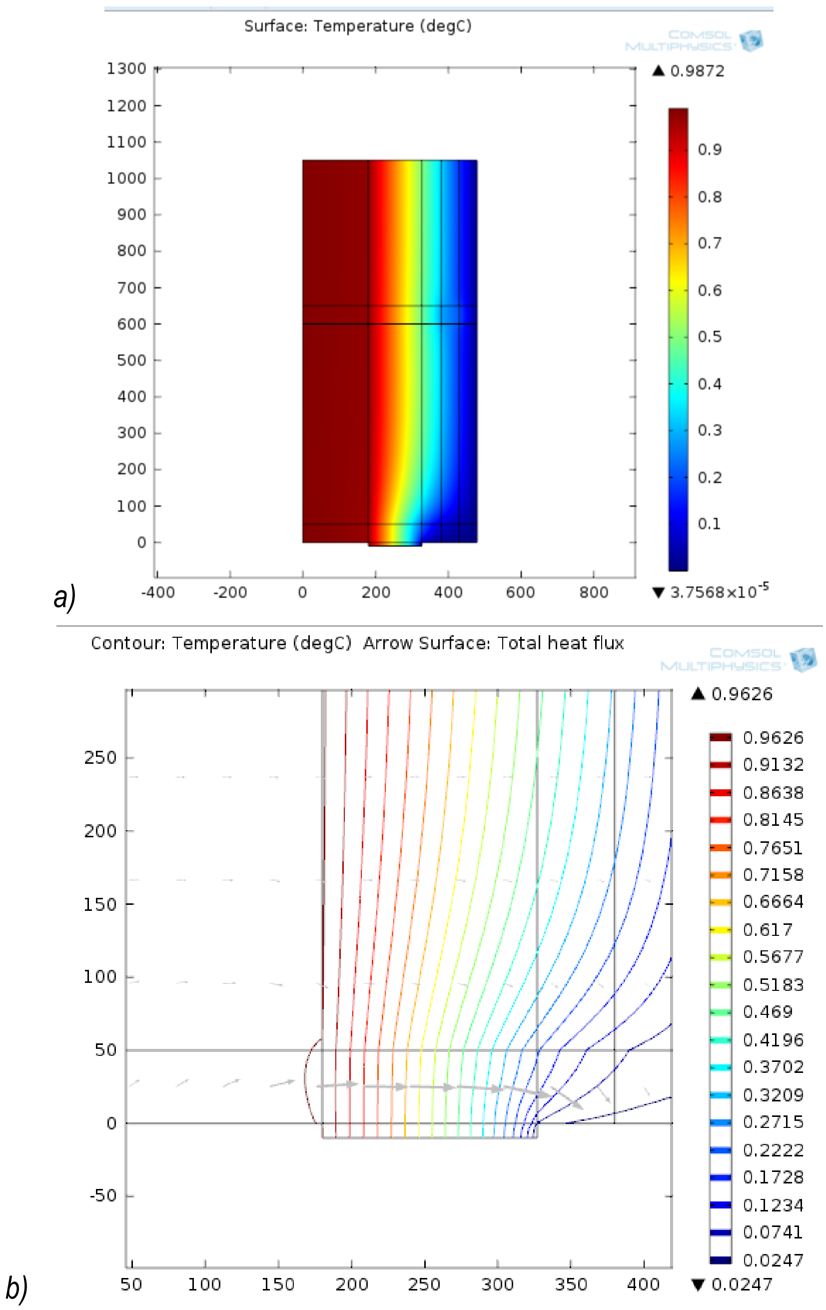


FIGURE 32. a) Temperature distribution

b) Isothermal contours within Joint 6

A “heat map” of the Heat Flux is represented in figure 33. The maximum value of heat flux magnitude in Joint 6 is equal to 2,6864 W/m^2.

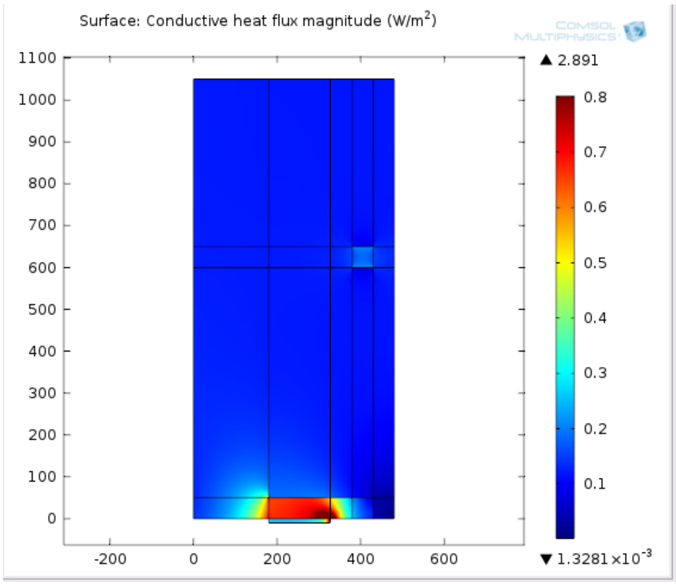


FIGURE 33. Heat flux within Joint 6

Then, the value of heat flow rate was evaluated according to section 2.3.1. The internal surfaces lines were selected for boundaries of Heat Flux as shown in figure 34 according to section 2.4.2.

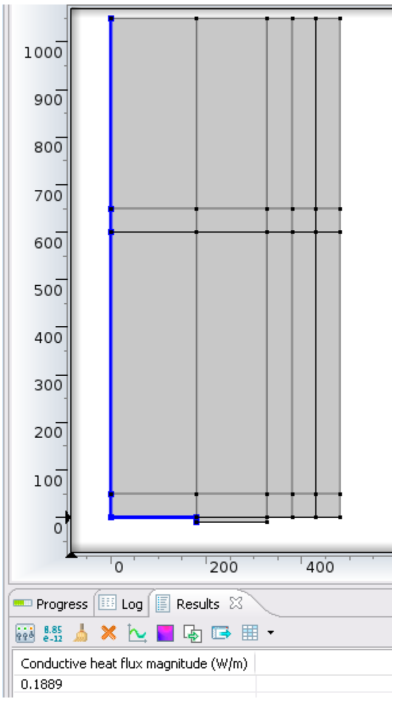


FIGURE 34. Determination of the heat flux rate in Joint 6

The software automatically evaluated the integration of heat flux rate, which is equal to $0{,}1889\ W/m$. Next, by using formula 10, the technical thermal coupling coefficient can be calculated:

$$L_{2D} = \frac{0{,}1889\ W/m}{1\ K - 0\ K} = 0{,}1889\ W/mK$$

Formula 15 applies for this type of joint. Besides, the length of the wall was obtained from figure 31 and the value of thermal transmittance U of the wall $US4$, which is included in this joint, was defined from table 8:

$\psi = 0{,}1889\ W/(mK) - (0{,}1289\ W/(m^2K) \cdot\ 1{,}05\ m) =\ 0{,}05355\ W/(mK)$

The calculation of the linear thermal transmittance of Joint 7 was implemented in the same manner as for Joint 6. The result of this calculation can be found in Table 19. The drawings and graphs regarding modelling in COMSOL Multiphysics are presented in appendix 3.

TABLE 19. Calculations of linear thermal transmittance for joints between windows and external walls

Joint №	L_{2D}, W/mK	Wall 1	U_{wall}, $W/(m^2K)$	l_{wall}, m	Ψ, $W/(mK)$
6	0,1889	US4	0,1289	1,05	0,05355
7	0,25717	US4	0,1289	1,05	0,12182

3.2.3 Joints between floor and external walls

Joint 17

Joint 17 is a connection between external walls US2 and a floor concrete slab. Initial Joint 17 is enclosed in appendix 2 and can be found marked in appendix 1 in the company drawing 163-008. The original structure of Joint 17 is presented in figure 35.

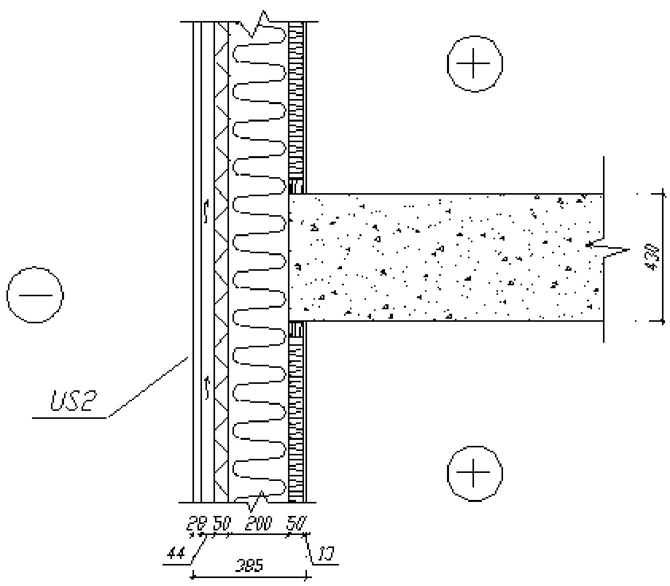


FIGURE 35. Original structure of Joint 17

Simplified computational geometry and its model with applied materials for Joint 7 are presented in figure 36.

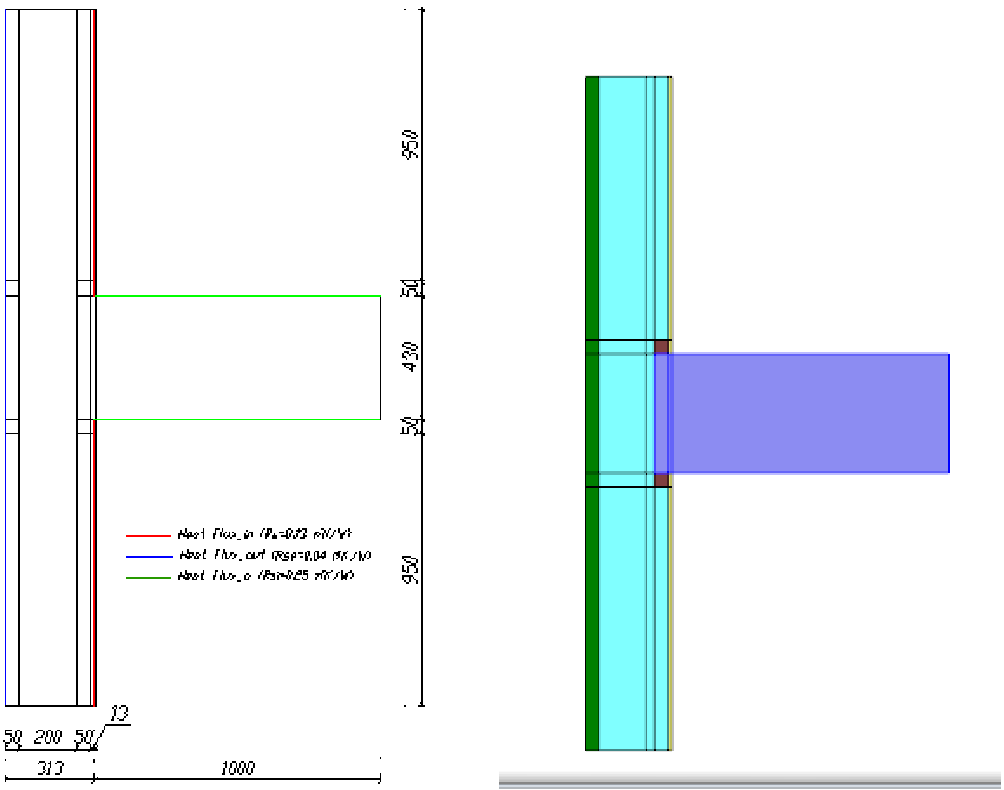


FIGURE 36. Computational geometry (including heat flux boundaries) and model materials of Joint 17 in COMSOL Multiphysics

For Joint 17 the Heat flux 1, Heat flux 2 and Heat Flux 3 were added for outer and inner wall surfaces and internal floor surfaces with setting boundaries as shown in figure 36 (left). Their properties were applied as presented in figure 37.

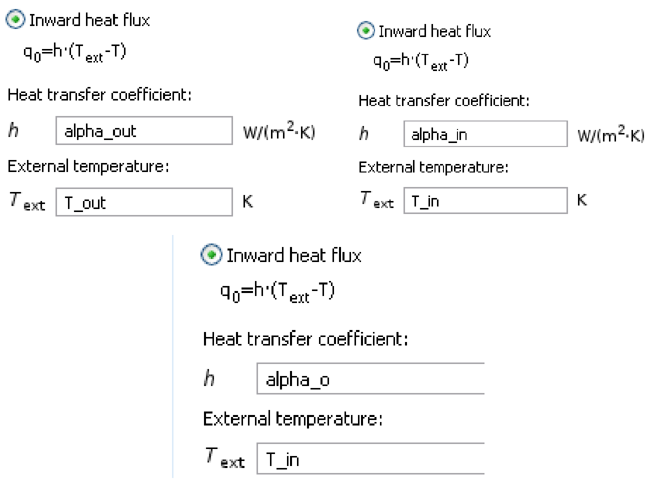


FIGURE 37. Applying the properties for Heat Flux 1, Heat Flux 2 and Heat Flux 3

Values of “alpha_out”, “alpha_in” and “alpha_fl” are detailed in the step 4 in section 2.2. For visual perception of the situation inside Joint 17 Graphs of Temperature distribution, Isothermal contours and Heat flux were made, and are presented in figure 38.

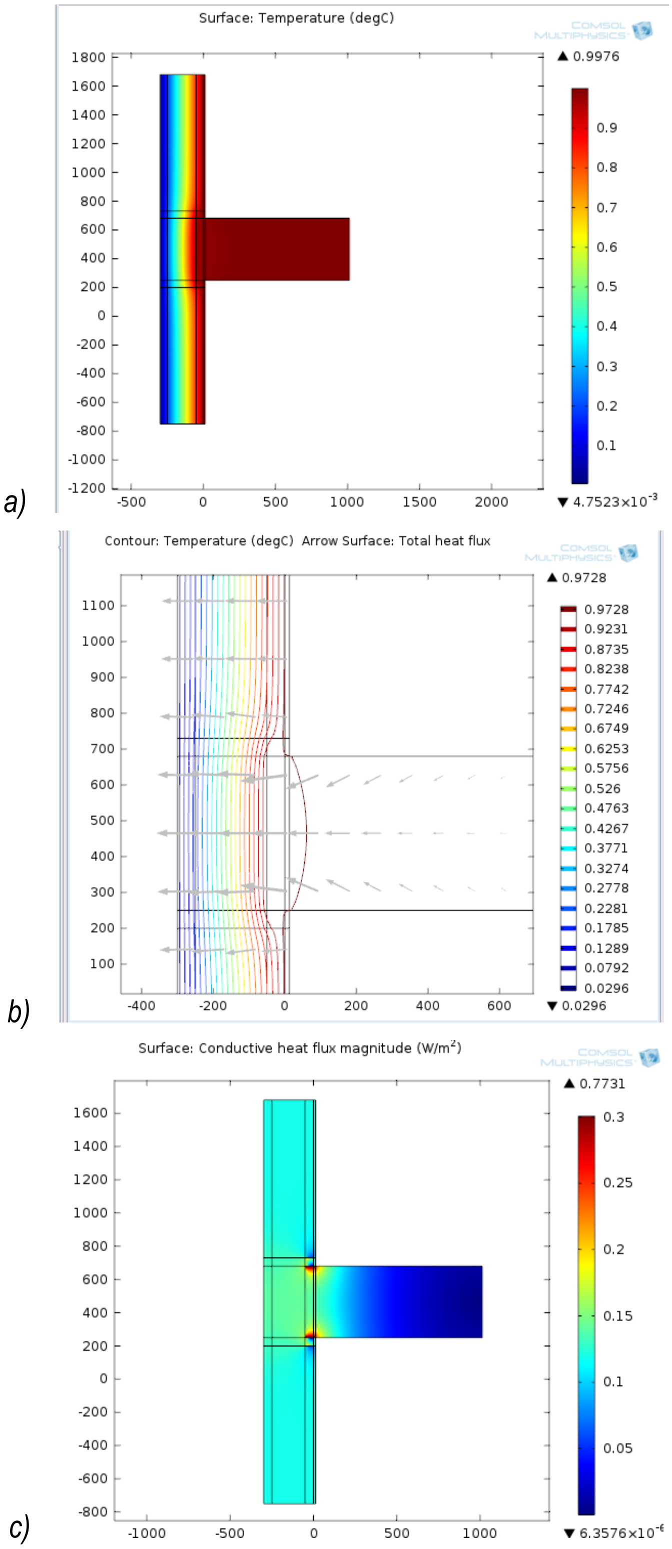


FIGURE 38. a) Temperature distribution,

b) Isothermal contours and c) Heat flux within Joint 17

The arrows in figure 38 b show the heat flux circulation inside Joint 17. Shown in the figure 38 c the maximum value of heat flux magnitude in Joint 17 is equal to 0,7731 W/m^2.

Then, according to section 2.3.1 the value of heat flow rate was evaluated. The internal surface lines were selected for boundaries of integration as shown in figure 39 according to section 2.4.3.

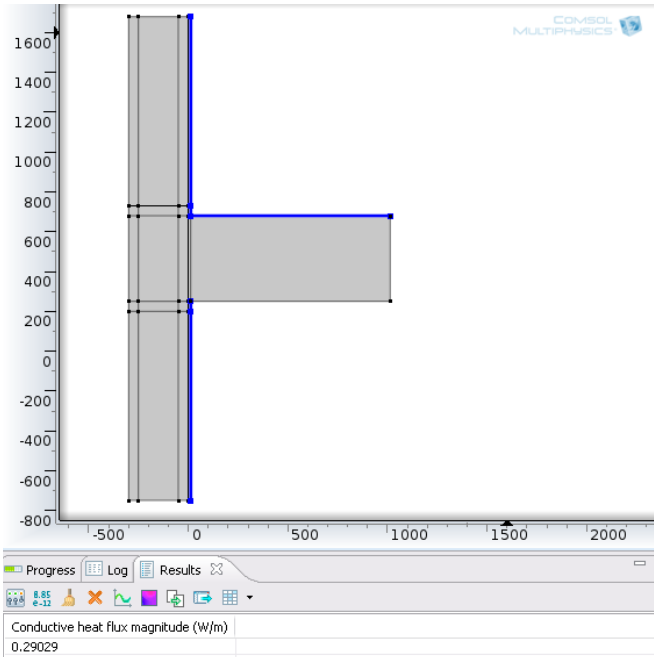


FIGURE 39. Determination of the heat flux rate in Joint 17

The software automatically obtained the value of heat flux rate, which is equal to $0{,}28494\ W/m$. Next, by using formula 10, the thermal coupling coefficient can be calculated:

$$L_{2D} = \frac{0{,}28494\ W/m}{1\ K - 0\ K} = 0{,}28494\ W/mK$$

For this type of joint formula 14 applies. Besides, the lengths of the walls were obtained from the figure 36 and the thermal transmittance value *U* of the wall US2, which is included in this joint, was defined from table 5:

$$\psi = 0{,}29029\ W/(mK) - (0{,}1296\ W/(m^2K) \cdot\ 1{,}215\ m) - (0{,}1296\ W/(m^2K) \cdot\ 1{,}215\ m) =$$
$$= -0{,}02473\ W/(mK)$$

The calculation of the linear thermal transmittance value for joints 19 and 20 were implemented in the same manner as for Joint 17. The results of those calculations can be found in table 20. The drawings and graphs regarding modelling in COMSOL Multiphysics are presented in appendix 3.

TABLE 20. Calculations of linear thermal transmittance for joints between floor structures and external walls

Joint №	L_{2D}, W/mK	Wall 1	*U wall 1* , $W/(m^2K)$	*l wall 1*, m	Wall 2	*U wall 2*, $W/(m^2K)$	*l wall 2*, m	Ψ, $W/(mK)$
17	0,28494	US2	0,1296	2,43				-0,03008
19	0,35887	US2	0,1296	1,08	US5	0,1277	1,6	0,01447
20	0,28786	US2	0,1296	2,43				-0,02716

3.2.4 Joints between roof and external wall

Joint 21

Joint 21 is a connection between external walls US4 and roof structure YP 1.1. Initially Joint 21 is enclosed in appendix 2 and can be found marked in appendix 1 in the company drawing 302925-24. The original structure of Joint 21 is presented in figure 40.

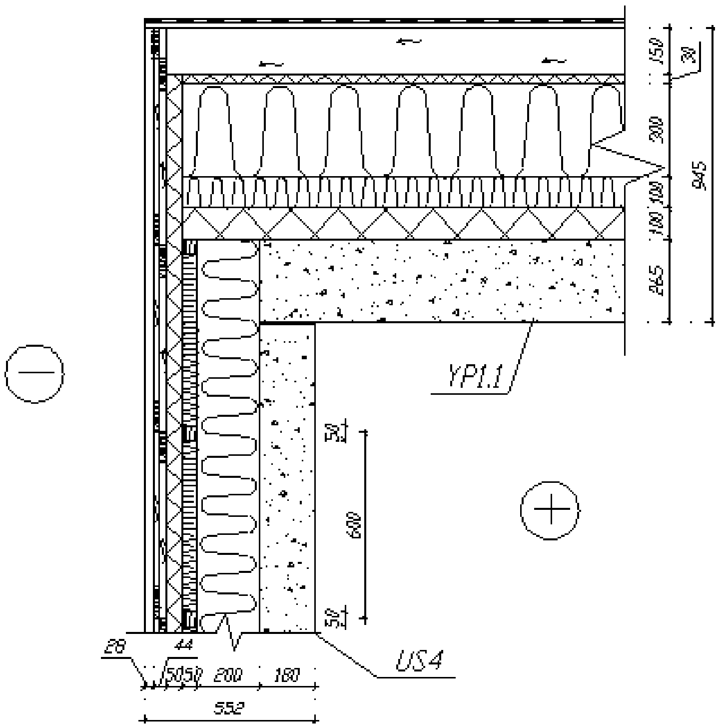


FIGURE 40. Original structure of Joint 21

A simplified computational geometry and its model with applied materials for Joint 21 are presented in figure 41. A ventilated air gap and layers behind it are not included in the model.

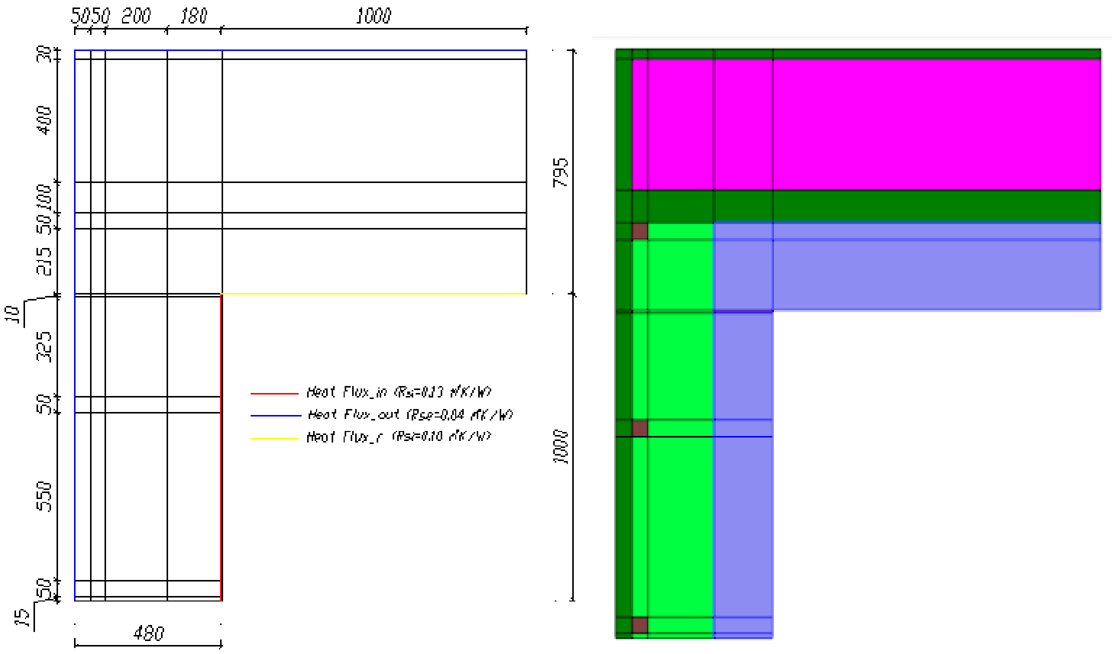


FIGURE 41. Computational geometry (including heat flux boundaries) and model materials of Joint 21 in COMSOL Multiphysics

For Joint 21 Heat flux 1, Heat flux 2 and Heat Flux 3 were added for outer and inner wall surfaces and internal floor surfaces with setting boundaries as shown in figure 41 (left). Their properties were applied as presented in figure 42.

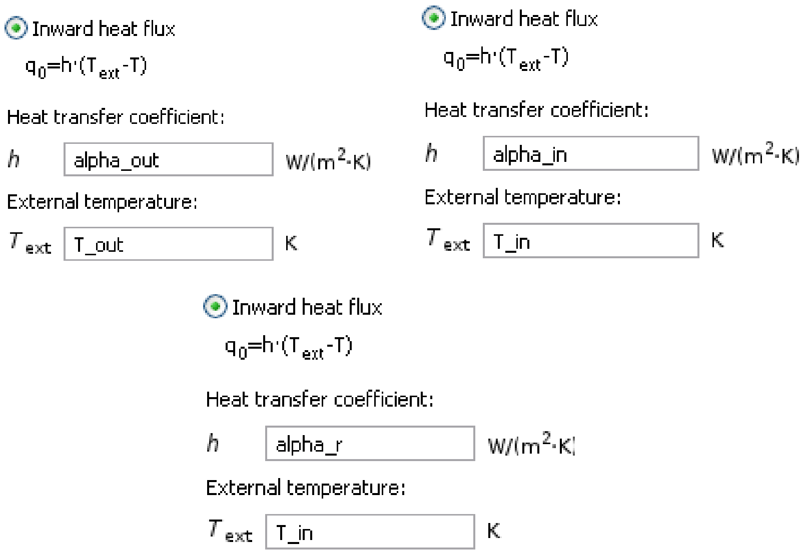
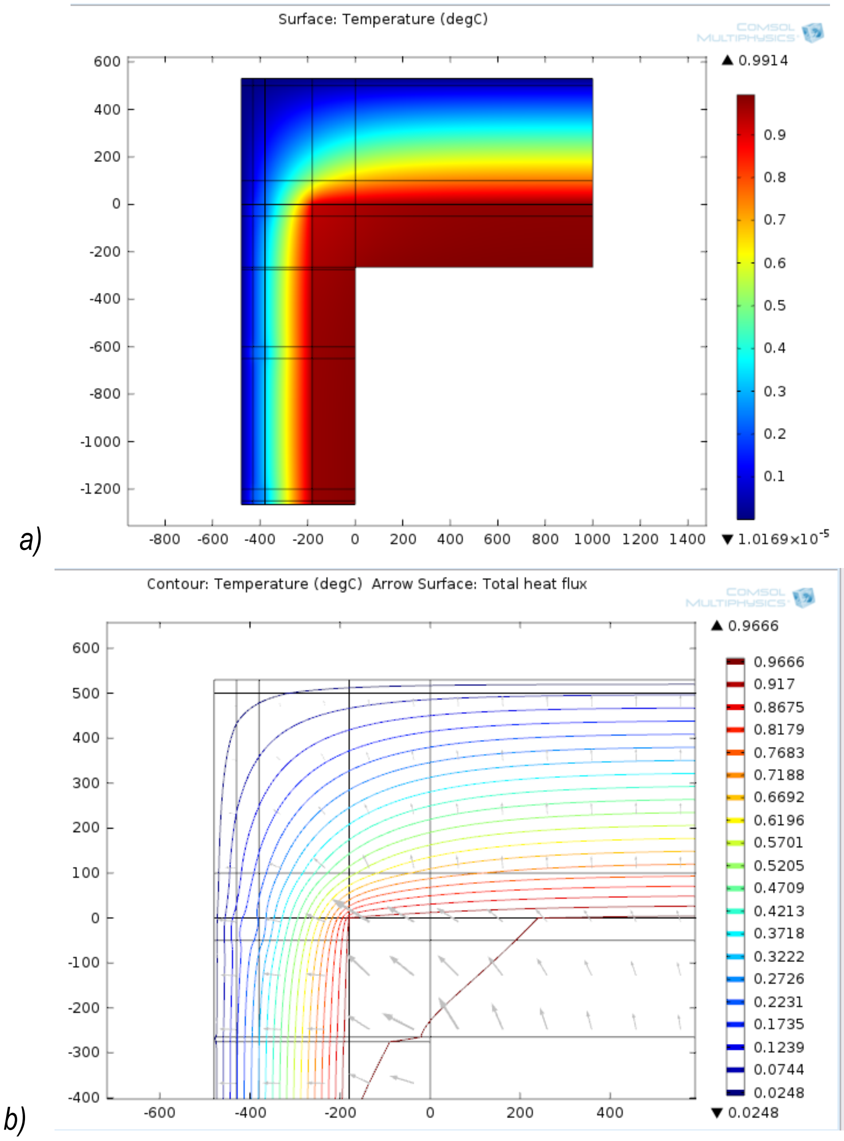


FIGURE 42. Applying the properties for Heat Flux 1, Heat Flux 2 and Heat Flux 3 (respectively)

Values of “alpha_out”, “alpha_in” and “alpha_r” were determined in the step 4 in section 3.2. For visual perception of the situation inside Joint 17 Graphs of Temperature distribution, of Isothermal contours and of Heat Flux magnitude were made and are represented in figure 43.



c)

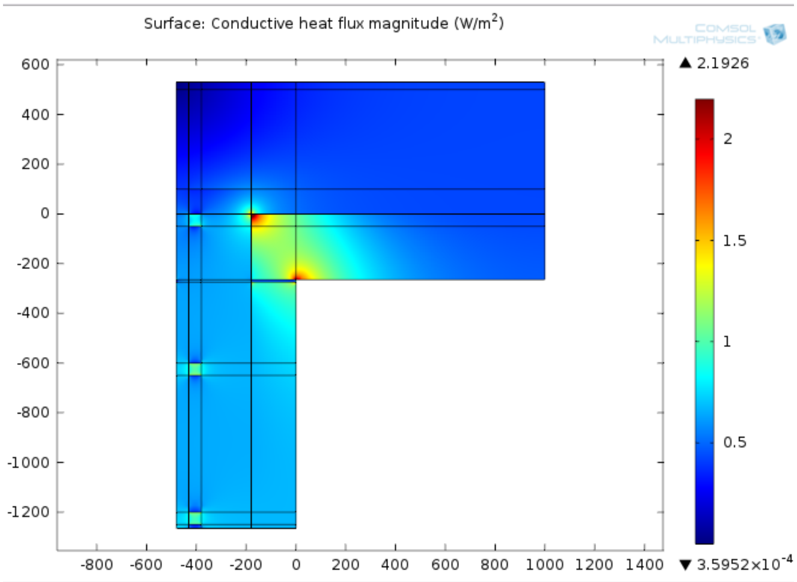


FIGURE 43. a) Themperature distribution,

b) Isothermal countours and c) Heat flux within Joint 21

The arrows in figure 43 b show the heat flux circulation within Joint 21. The maximum value of heat flux magnitude in Joint 21 is equal to 2,1926 W/m^2.

Then, the value of heat flow rate was evaluated according to section 2.3.1. The boundaries were selected according to section 2.4.4 as shown in figure 44 .

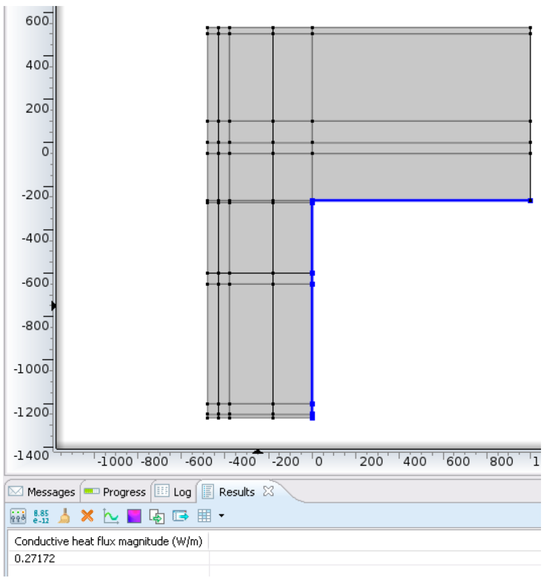


FIGURE 44. Determination of the heat flux rate in Joint 21

The value of heat flux rate is integrated within the software and is equal to $0{,}27172\ W/m$. Next, by using formula 10, the thermal coupling coefficient can be calculated:

$$L_{2D} = \frac{0,27172\, W/m}{1\, K - 0\, K} = 0,27172\, W/mK$$

For this type of joints formula 16 applies. Besides the lengths of the structures were obtained from figure 41 and the thermal transmittance values *U* of the walls US4 and roof structure YP 1.1, which are included in this joint, were defined from table 8 and table 11:

$$\psi = 0,27172\, W/(mK) - (0,1289\, W/(m^2K) \cdot\, 1m) - (0,0775\, W/(m^2K) \cdot\, (1 + 0,48)m =$$

$$= 0,14282\, W/(mK)$$

The calculations of the linear thermal transmittance of Joints 22 and 18 were implemented in the same manner as for Joint 21. The results of those calculations can be found in table 21. The drawings and graphs regarding modelling in COMSOL Multiphysics are presented in appendix 3.

TABLE 21. Calculations of linear thermal transmittance for joints between roof structures and external walls

Joint №	L_{2D}, W/mK	Wall	*U* *wall* , $W/(m^2K)$	*l* *wall* , *m*	Roof	*U* *roof,* $W/(m^2K)$	*l* *roof,* *m*	Ψ, $W/(mK)$
21	0,27172	US4	0,1289	1	YP1.1	0,0775	1,48	0,14282
22	0,26119	US2	0,1296	1	YP1	0,06712	1,313	0,13155
18	0,27984	US2	0,1296	1	YP1'	0,06685	1,313	0,15020

3.2.5 Basement joints

In section 2.4.5 it was mentioned and explained that linear transmittance for basement joints is calculated in a different way from other joints. To create a computational model we need to know the value of building basement characteristic.

Dimensions for calculating the building dimensions characteristics were taken according to the drawings provided by the company, which are enclosed in appendix 1. The current building has the following characteristics:

The base area of the building:

$A = (8,477\, m\, \times 19,7\, m) + 2,223\, m\, \times (19,7\, m - \,2\, m) + (8,47\, \times 19,7)$

$A = \,373,203\, m^2$

Building's perimeter:

$P = 2\, \times\, (19,7\, m + \,23,17\, m)$

$P = 85{,}74\ m$

Then, by applying formula 17 to the current building, the basement characteristic is equal:

$B' = 373{,}203/(0{,}5\ \times\ 85{,}74\ m)\ =\ 8{,}705\ m$

Also, for building up the model, derived values from the basement characteristics were required (Figure 10):

$0{,}5\ \times\ B' =\ 0{,}5\ \times\ 8{,}705\ =\ 4{,}353\ m$

$2{,}5\ \times\ B' = 2{,}5\ \times\ 8{,}705\ =\ 21{,}763\ m$

Joint 14

Joint 14 is a connection between external walls US4 and basement. Initial Joint 14 is enclosed in appendix 2 and can be found marked in appendix 1 in the company drawing 163-008. The original structure of Joint 14 is presented in figure 45.

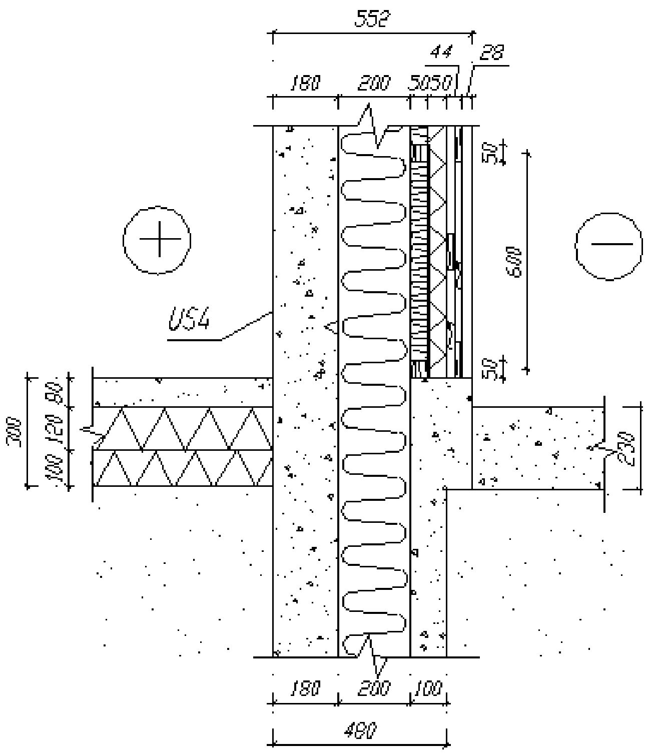


FIGURE 45. Original structure of Joint 14

Computational geometry for Joint 14 with the entire dimension calculated in the beginning of the current section is presented in figure 46.

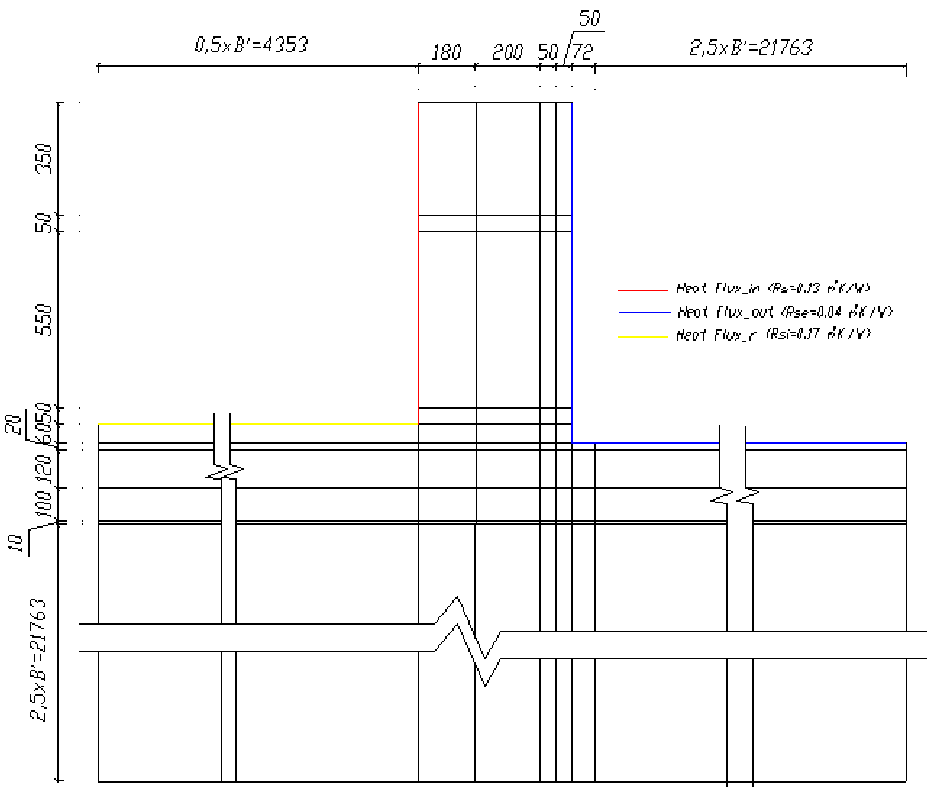


FIGURE 46. Computational geometry of Joint 14 in COMSOL Multiphysics

Model with applied materials for Joint 14 is presented in figure 47. There new material, soil, was set. The thermal conductivity of the soil is equal to 2,0 W/(mK),as it was said in section 3.1

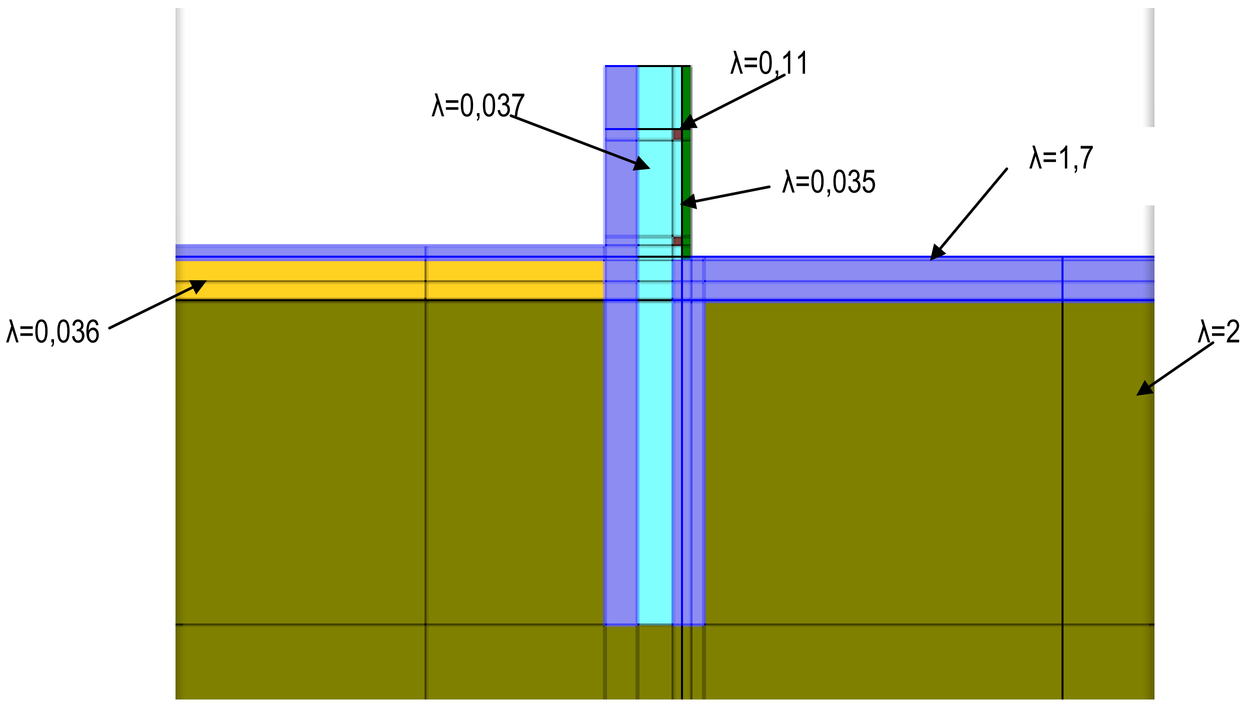


FIGURE 47. Materials in the model of Joint 14 in COMSOL Multiphysics

For Joint 14 Heat flux 1, Heat flux 2 and Heat Flux 3 were added as shown in figure 48 for outer and inner walls and internal floor surfaces with setting boundaries as shown in figure 46.

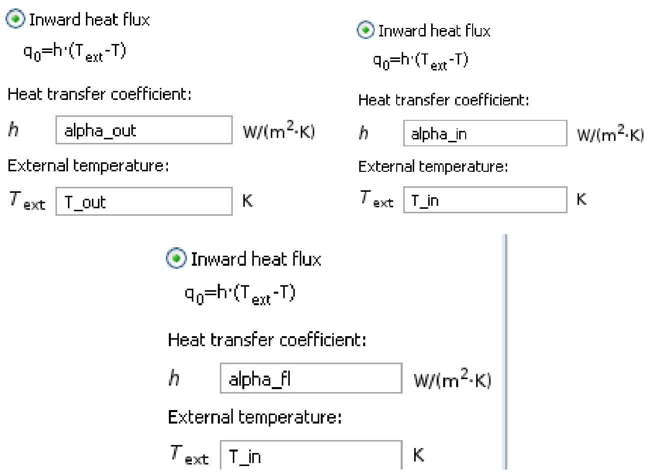
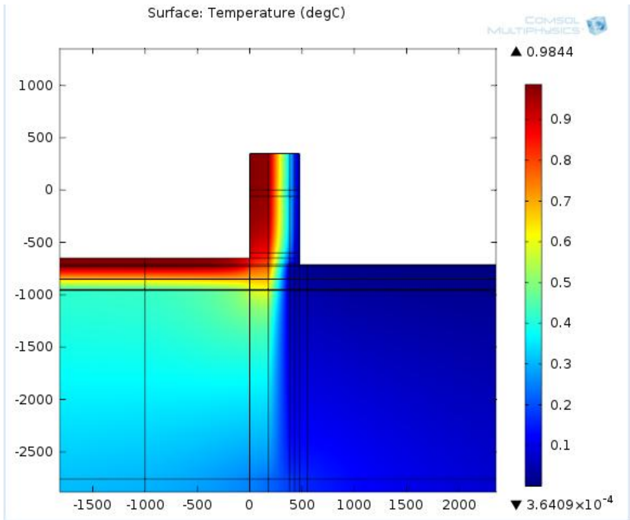


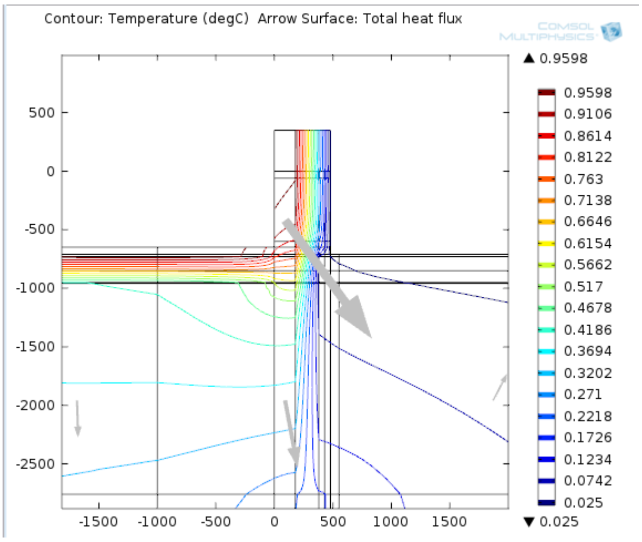
FIGURE 48. Applying the properties for Heat Flux 1, Heat Flux 2 and Heat Flux 3

For visual perception of the situation within Joint 14 the Graphs of Temperature distribution, of Isothermal contours and Heat Flux magnitude were made and are presented in figure 49.

a)



b)



c)

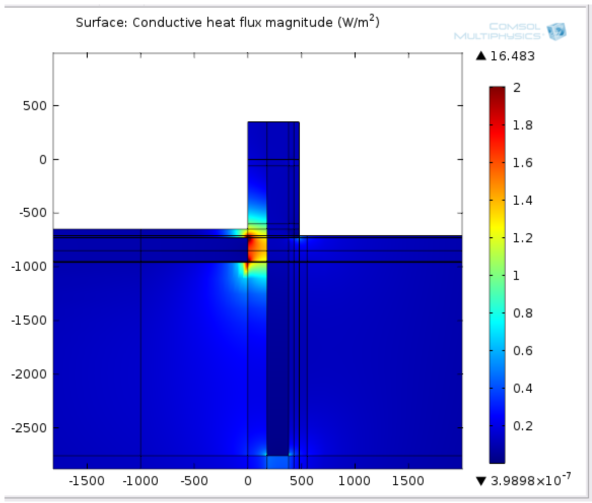


FIGURE 48. a) Temperature distribution,

b) Isothermal Countours, c) Heat flux within Joint 14

The arrows in figure 49b show the way of heat flux circulation inside Joint 14. The maximum value of heat flux magnitude in Joint 14 is equal to 9,3839 W/m^2.

Then, according to section 2.3.1 the value of heat flow rate was evaluated. The lines of internal surfaces were selected for boundaries as shown in figure 50 according to section 2.4.5.

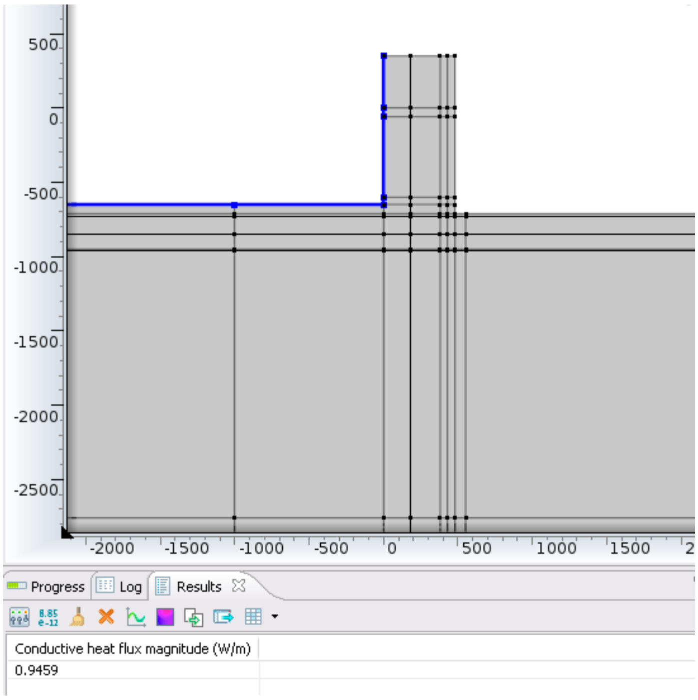


FIGURE 49. Determination of heat flux rate in Joint 14

The software integrated the value of heat flux rate, which is equal to $1{,}53983\ W/m$. Next, by using formula 10, the thermal coupling coefficient was calculated:

$$L_{2D} = \frac{0{,}9459\ W/m}{1\ K - 0\ K} = 0{,}9459\ W/mK$$

For this type of joint, formula 18 applies, which includes many undetermined values, that are calculated below. Thermal transmittance of the wall US4 was taken from table 8. Thermal transmittance of the basement structure U was calculated by applying formula 19:

$$U = \frac{\lambda}{0{,}457 \times B' + d_t} + \frac{\psi_{ge}}{B'} = \frac{2\ \mathrm{W/(mK)}}{0{,}457 \times 8{,}705\ m + 14{,}4452\ m} - \frac{0{,}05855\ W/(mK)}{8{,}705\ m} =$$

$$= 0{,}10183\ W/(m^2K),$$

where the equivalent thickness d_t of the structure is determined by formula 20:

$$d_t = w + \lambda(R_{si} + R_f + R_{se}) = 0{,}480 + 2\ \mathrm{W/(mK)}$$

$$\times (0{,}17\ (m^2K)/W + 5{,}7726\ (m^2K)/W + 0{,}04\ (m^2K)/W) = 14{,}445\ m,$$

The linear thermal transmittance of foundation wall ψ_{ge} is determined by formula 21:

$$\psi_{ge} = -\frac{\lambda}{\pi}\left[ln\left(\frac{2D_v}{d_t} + 1\right) - ln\left(\frac{2D_v}{d_t + d_v'} + 1\right)\right]$$

$$\psi_{ge} = -\frac{2\ \mathrm{W/(mK)}}{\pi}\left[ln\left(\frac{2\cdot 1{,}8\ m}{14{,}445\ m}+1\right) - ln\left(\frac{2\cdot 1{,}8\ m}{14{,}445\ m + 11{,}371\ m}+1\right)\right] =$$
$$= -0{,}05855\ W/(mK),$$

where D_v was evaluated from figure 46.

Equivalent thickness of thermal insulation of the foundation wall d_v' was calculated by formula 22:

$$d_v^{'} = \lambda\left(R_{nv} - \frac{d_{nv}}{\lambda}\right)$$
$$d_v^{'} = 2\ \mathrm{W/(mK)}\ \cdot\left(5{,}9613\ - \frac{0{,}552}{2}\right) = 11{,}371\ m.$$

Finally, by applying formula 18, the linear thermal transmittance of the basement joint ψ was found:

$$\psi = 0{,}9459\frac{W}{mK} - \left(0{,}1289\frac{W}{m^2K}\cdot 1\ m\right) - \left(4{,}353\frac{W}{m^2K}\cdot\ 0{,}10183\ m\right) =$$
$$=\ 0{,}3737\ W/(mK)$$

Finally, all the values of linear thermal transmittances have been determined.

4 RESULTS

The linear thermal transmittances Ψ_k were evaluated in the previous section 3.2. Those values have been brought together in table 22. The second column contains normative values of thermal transmittance Ψ_n, which are taken from table 1. The last column shows the percentage difference between the calculated and the normalized values. The absolute differences between the evaluated and tabulated values can reach from 17 up to 200%, as illustrated in table 22.

TABLE 22. Comparison of the evaluated values with normative

Type of joints	Normalized value of linear transmittance Ψ_n, *W/(mK)*	Joint number	Calculated linear transmittance Ψ_k, *W/(mK)*	Difference
Joints between external walls, outer corner	0,06	1	0,0277	-54%
		4	0,029	-52%
		5	0,0391	-35%
		15	0,0221	-63%
		8	0,0778	+30%
		10	-0,0045	-107%
-//-, Inner corner	-0,06	2	0,0106	-118%
		13	-0,0051	-92%
Window joints	0,04	3	0,0502	+26%
		9	0,0539	+35%
		11	0,0525	+31%
		12	0,0291	-27%
		16	0,03	-25%
		6	0,0536	+34%
		7	0,1218	+205%
Roof joints	0,18	21	0,1428	-21%
		22	0,1316	-27%
		18	0,1502	-17%
Floor joints	0,10	17	-0,03008	-130%
		19	0,01447	-86%
		20	-0,02716	-127%
Basement joint	0,24	14	0,37373	+56%

As mentioned in section 2.2, the total heat losses of the building are calculated by using formula 3. In this thesis work, the linear thermal bridges were calculated but the point thermal bridges were excluded. Appendix 1 contains the official document, called “Rakennuksen lämpöhäviöntasaus laskelma, D3-100” provided by the company. It includes the calculated heat losses, which are included in the formula below:

$$H_{build.parts} = \sum U_{ext.wall}A_{ext.wall} + \sum U_{roof}A_{roof} + \sum U_{basement}A_{basement} + $$
$$+ \sum U_{window}A_{window} + \sum U_{door}A_{door}$$
$$H_{build.parts} = 136{,}8\ W/K + 26{,}7\ W/K + 46{,}8\ W/K + 175{,}3\ W/K + 59{,}1\ W/K =$$
$$= 444{,}7\ W/K$$

In order to obtain heat losses caused by linear thermal bridges, the lengths for each linear thermal bridge were found in accordance with drawings provided by the company, in appendix 1. The lengths were measured from inside boundaries. The obtained heat losses are included in table 23 given below.

TABLE 23. Determination of heat losses caused by linear thermal bridges

Joint number	Ψ_k, *W/(mK)*	l_k, *m*	$\Psi_k l_k$, *W/K*
1	0,0277	15	0,41580
4	0,1939	51	9,88890
5	0,0391	3	0,11715
13	-0,0051	15	-0,07605
15	0,0221	21	0,46494
8	0,0778	33	2,56641
10	-0,0045	12	-0,05376
2	-0,0055	15	-0,08310
3	0,0502	30,3	1,52106
9	0,0539	3,03	0,16344
11	0,0525	93,93	4,93133
12	0,0291	99,99	2,90871
16	0,03	3,03	0,09087
6	0,0536	119,025	6,37379
7	0,0536	119,025	6,37379
21	0,1428	20,36	2,90782
22	0,1316	9	1,18395
18	0,1502	76,795	11,53461

17	-0.03008	121,002	-3,63974
19	0.01447	76,795	1,11122
20	-0.02716	109,233	-2,96677
14	0.37373	76,795	28,70060
$\sum \Psi_k l_k$			66,9

$$H_{lin.th.bridges} = \sum \psi_k l_k = 66{,}9 \text{ W/K}$$

where,

ψ_k is a linear thermal transmittance of joint k, *W/(mK)*

l_k is a length of joint k, *m*

The significance of all the values of heat losses in various building components is shown in the figure 50. It is clear that value of heat losses caused by thermal bridging covers serious part of the total heat losses of the building.

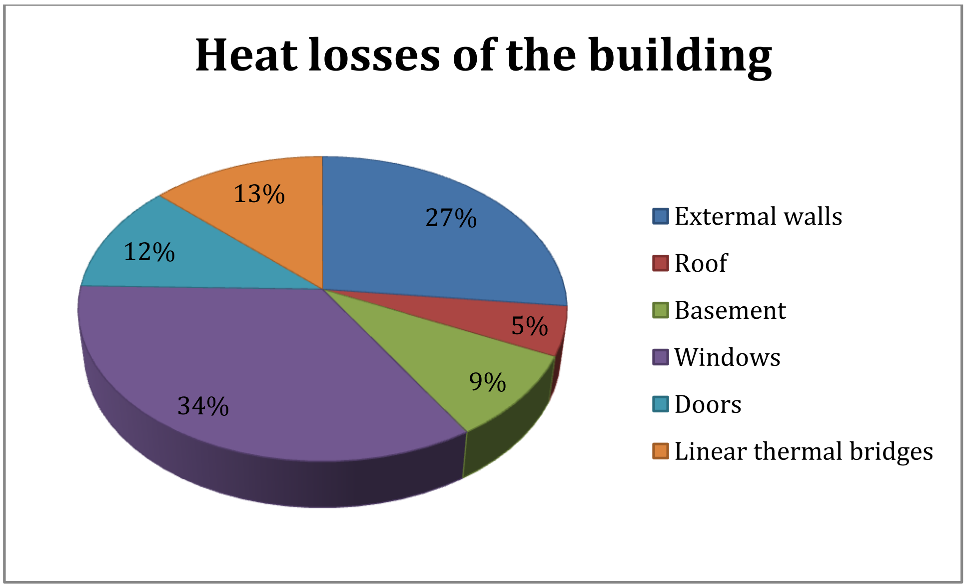


FIGURE 50. The values of heat losses in the building components

Total heat losses of a building is equal to the sum of heat losses of the building components and thermal bridges, calculated separately, and for the current building the total heat losses are equal to 511,6 W/K.

5 CONCLUSION

This study aimed at determining the linear thermal transmittance values of a particular building. An analysis of thermal bridges was done according to the instructions of a calculation guide provided by the Finnish Ministry of Environment and the results were compared with the values of linear thermal bridges issued in the Finnish Building Code D5.

The content of the work focused on accurate determination of thermal bridges and their effect for the total heat losses of the building. The calculations were carried out by applying the Finnish and International Standards. Among four alternative methods for evaluating the thermal bridges, highlighted in the standard ISO 14683, the numerical method was selected. The modelling of structures and evaluation of heat flows were done by using the software COMSOL Multiphysics.

During the study, the biggest challenge was some unconsidered details of linear thermal transmittances in the official guide. Moreover, somehow, the theory of thermal bridges has lack of information available.

After comparing the numerically obtained and tabulated values of linear thermal transmittance, it was found out that they have an absolute difference from 17 to 200%. In the majority of the cases, the numerically obtained value was smaller than the tabulated. In this situation, it gives a margin of safety. However, in several joints between external walls, windows and basement joints, numerically obtained values of linear thermal transmittances were bigger, sometimes even by two times. This fact implicates that values taken in the reference tables are not reliable and not sufficient enough to use this data for improving thermal bridges and energy efficiency of the building, or those joints were not designed well.

The determination of the total heat losses of the building showed the significance of the thermal bridging phenomena and the necessity of its calculation. In the current building, linear thermal bridges take 13% of the total heat losses.

The set objectives were successfully achieved. This thesis work can be used as a guideline for similar calculations. Improvement of thermal bridges can be implemented by reducing thermal transmittances of the materials and structures. The recommendation would be to reinforce the insulation layers in the joints, where the heat fluxes have the biggest rate. After this, the structure will resist heat transfer in a new way and will response to the requirements of energy efficiency.

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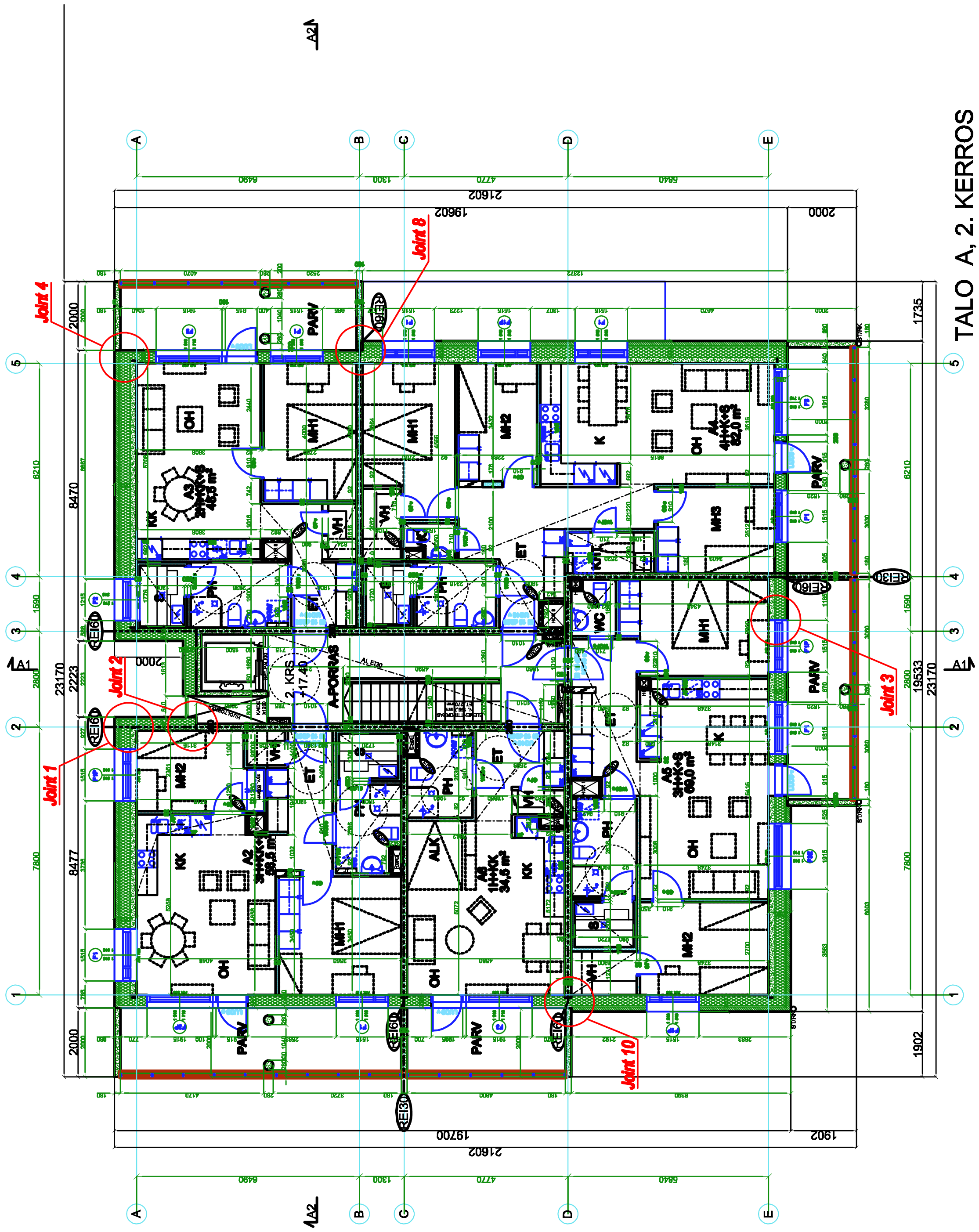
APPENDICES

APPENDIX 1	Initial drawings and documents
APPENDIX 2	Task for the thesis (marked joints)
APPENDIX 3	Figures of models and results for iterative joints

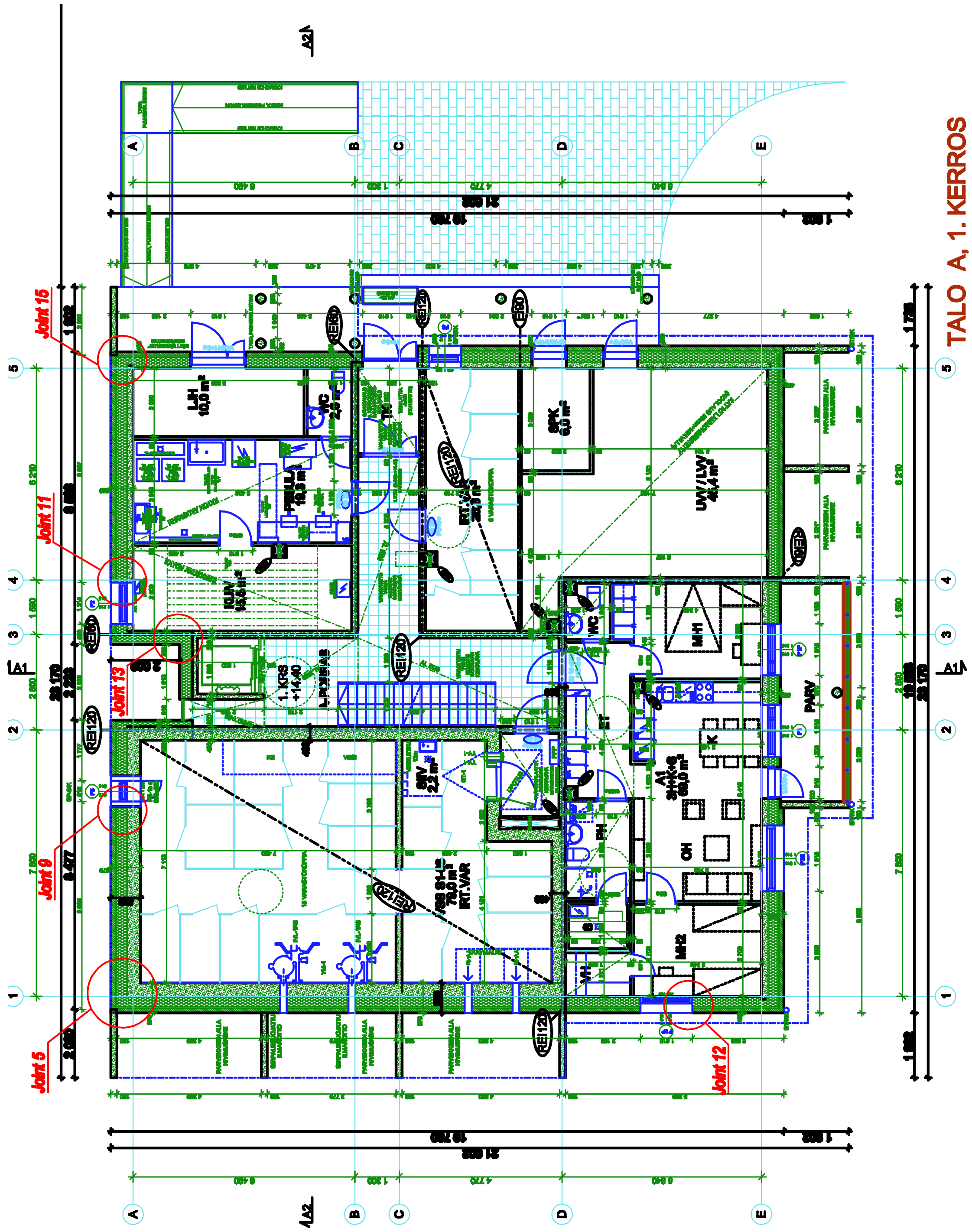
APPENDIX 1

163-003



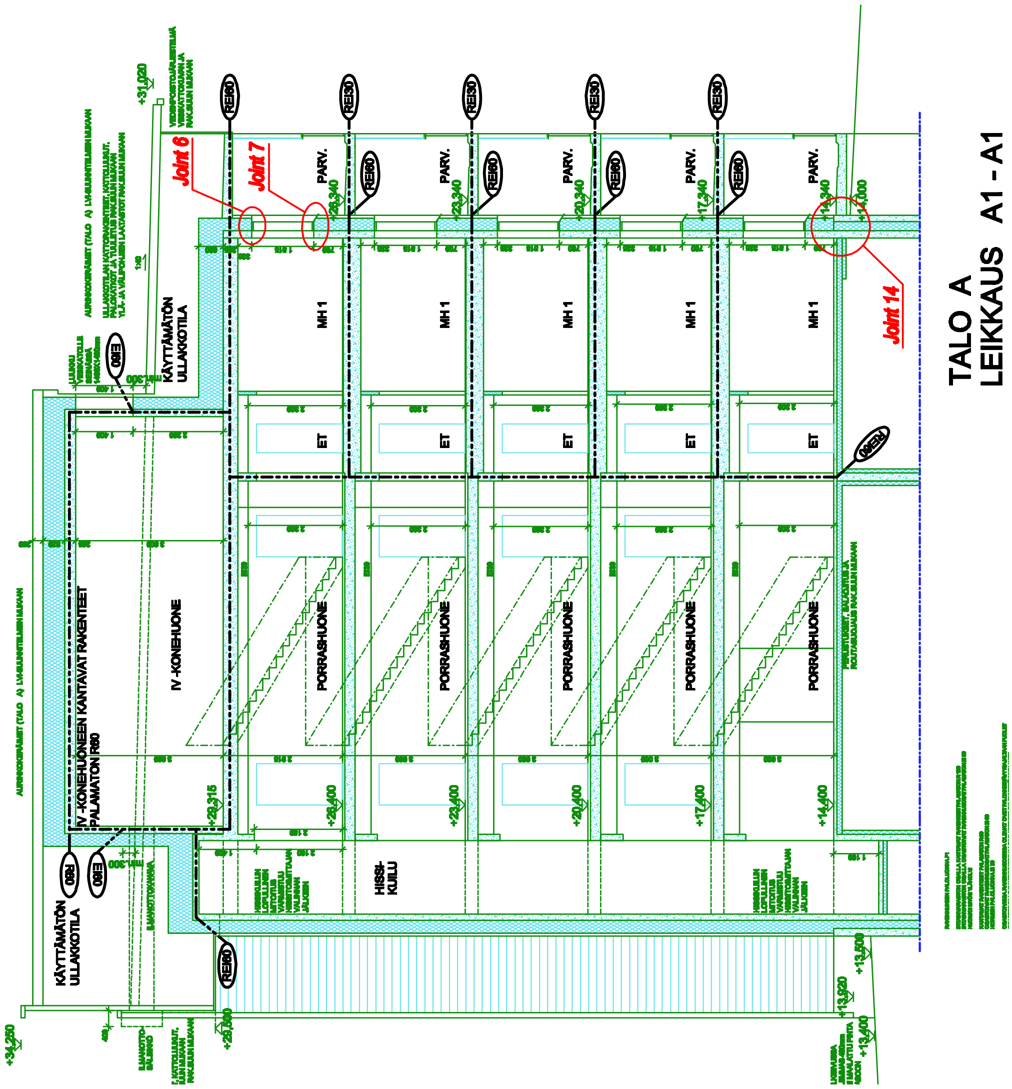
APPENDIX 1/2

163-013

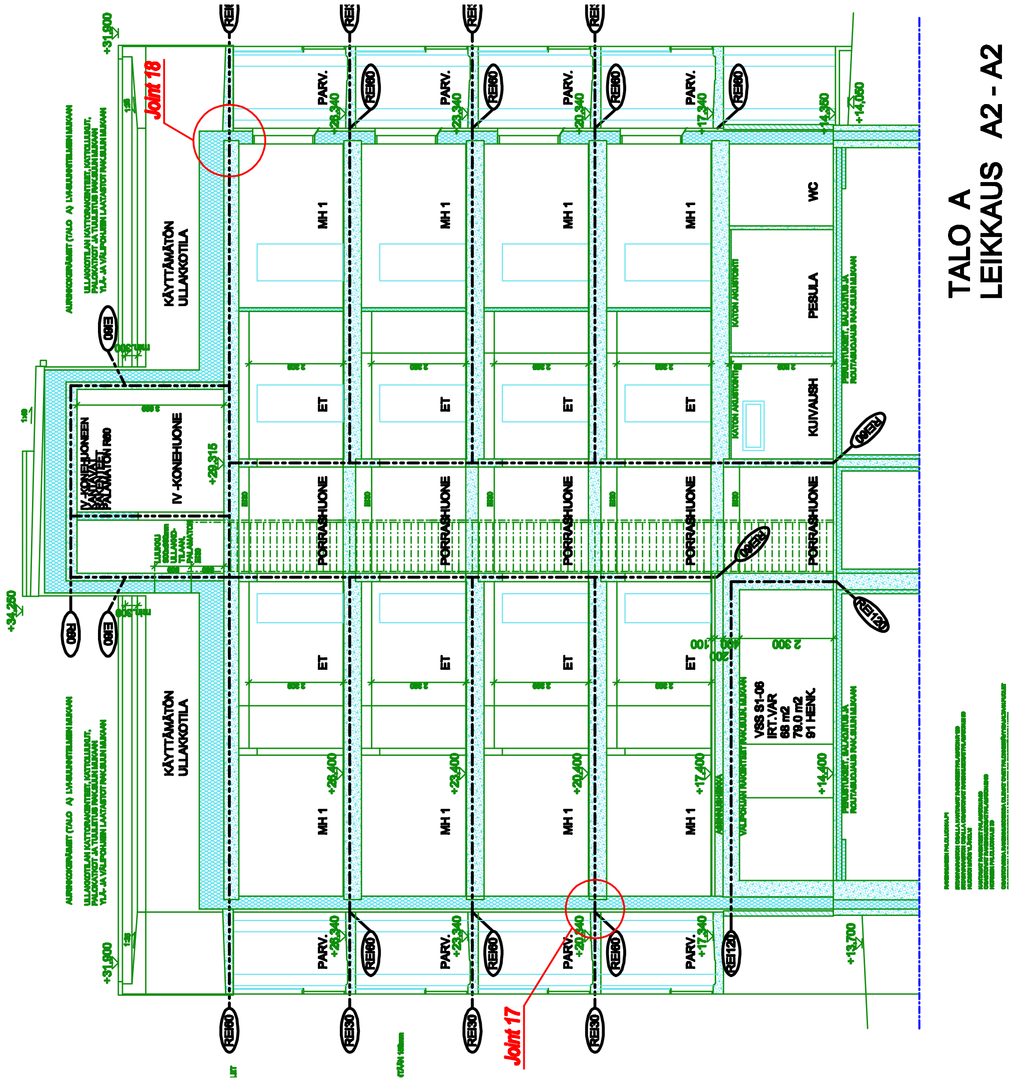


APPENDIX 1/3

163-008

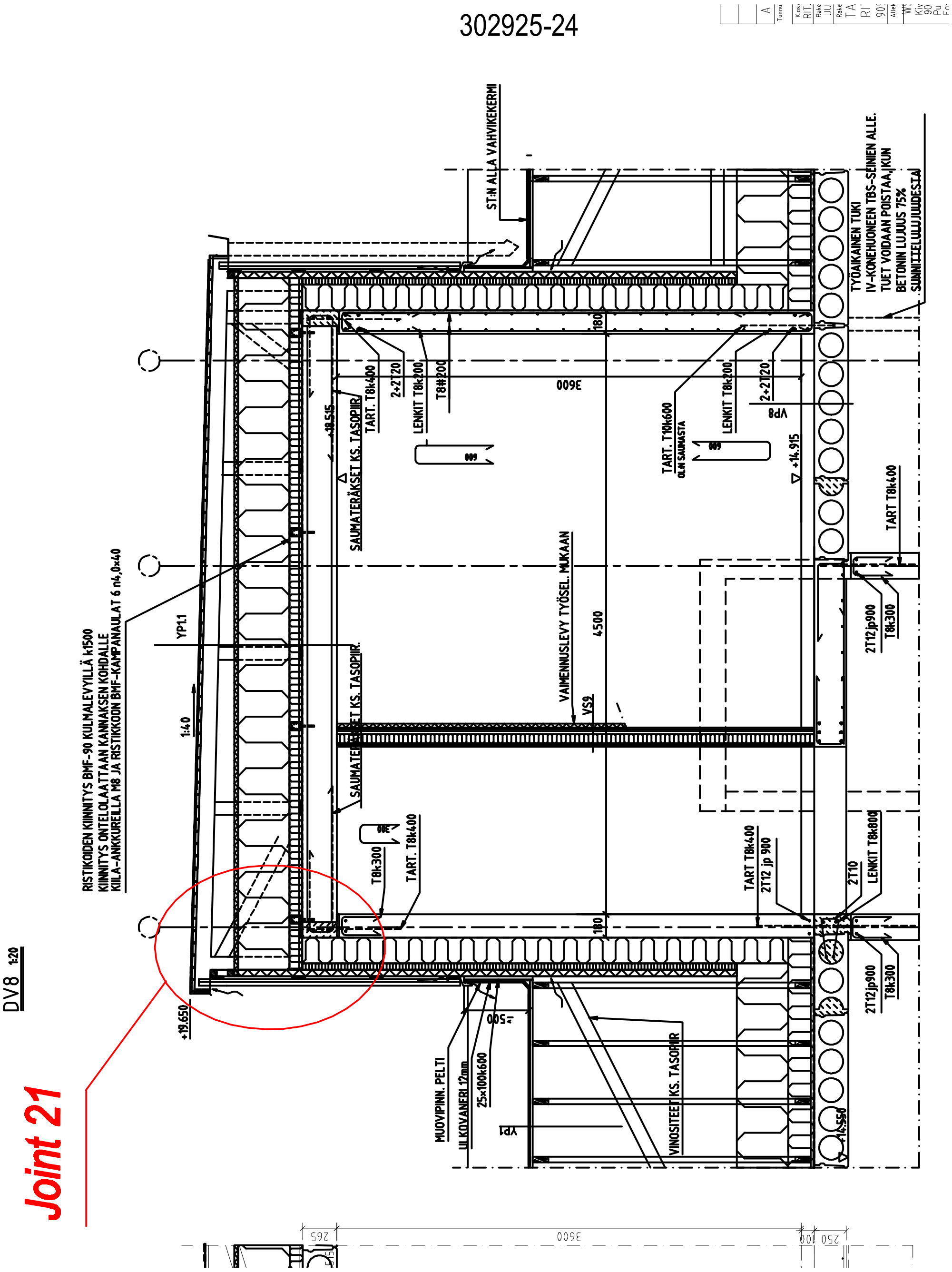


163-008

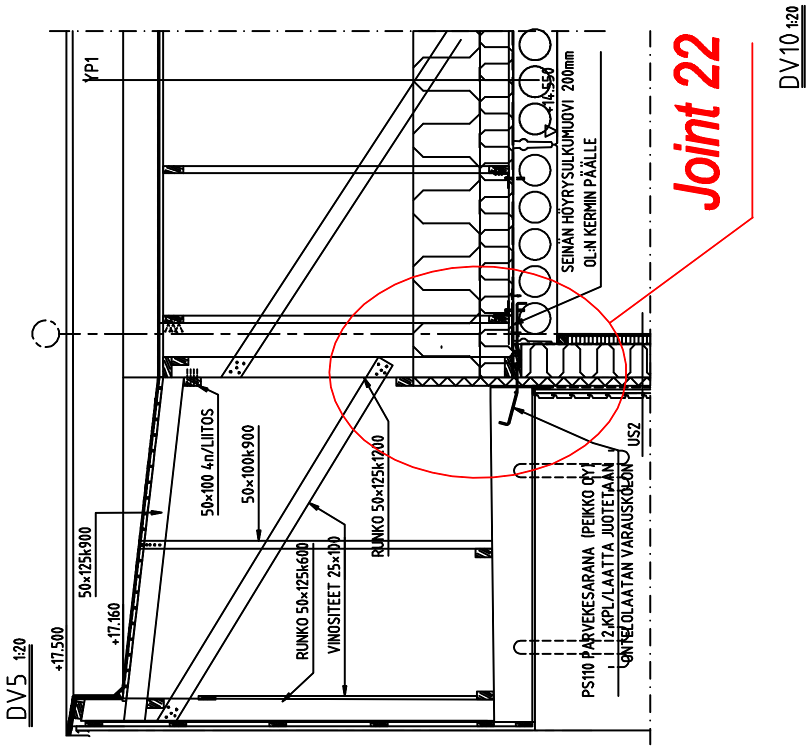

TALO A
LEIKKAUS A2 - A2
Joint 18
Joint 17
KÄYTTÄMÄTÖN ULLAKKOTILA
IV-KONEHUONE
PORRASHUONE
PARV.
MH 1
ET
WC
PESULA
KUIVAUSH

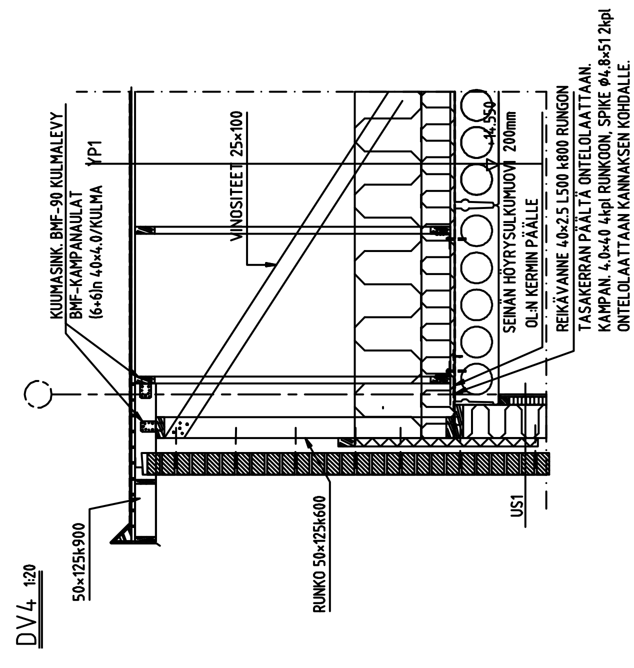
APPENDIX 1/5

302925-24

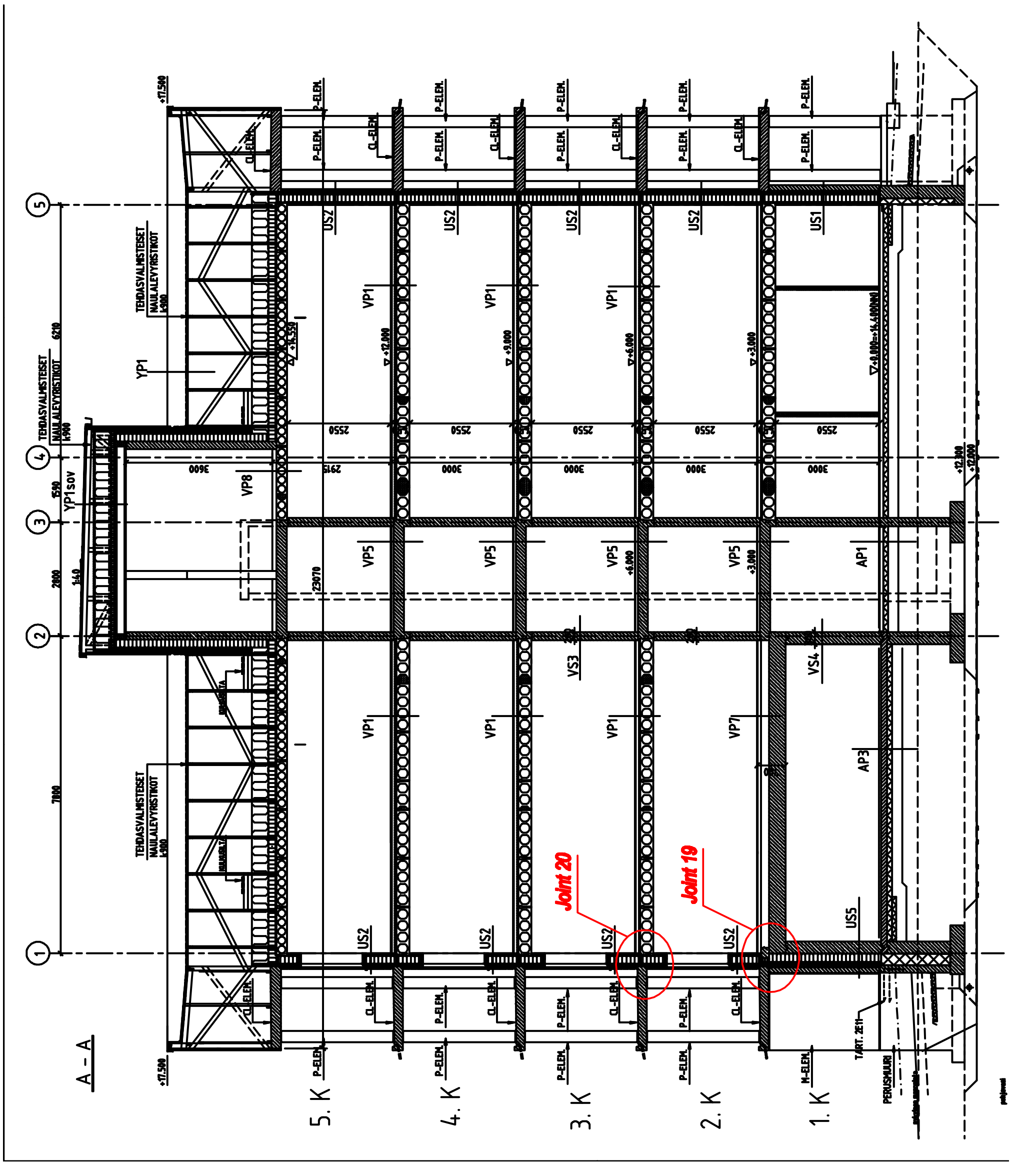


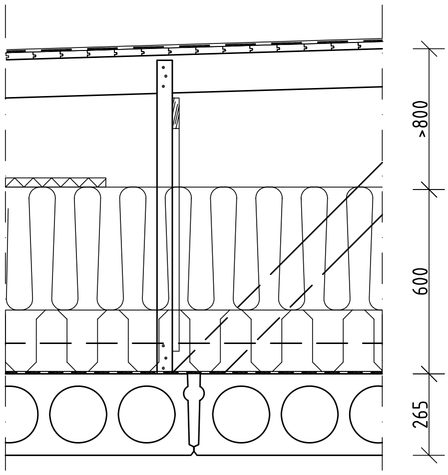
302925-24


DV5 1:20
DV10 1:20
Joint 22
+17.500
+17.160
50×125k900
50×100 4n/LIITOS
50×100k900
RUNKO 50×125k600
VINOSITEET 25×100
RUNKO 50×125k1200
YP1
US2


DV4 1:20
50×125k900
RUNKO 50×125k600
VINOSITEET 25×100
YP1
US1

302925-23


A - A
5. K
4. K
3. K
2. K
1. K
Joint 20
Joint 19
VP1
VP5
VP7
VP8
US1
US2
US5
AP1
AP3
VS3
VS4
YP1
YP1sov
P-ELEM.
CL-ELEM.
M-ELEM.
PERUSMUURI
TEHDASVALMISTEISET NAULALEVYRISTIKOT k900



YP1

YLÄPOHJA YLEENSÄ

LUMEN LIUKUESTEET, KATTOPOLLARIT JA VESIKATON KULKUSILLAT
RakMK F2:n JA ARK. SUUNNITELMIEN MUKAAN
ULLAKKOTILAAN TEHDÄÄN KULKUSILTA RAKENNUKSEN PÄÄSTÄ PÄÄHÄN

PINTA TYÖSELITYKSEN MUKAAN
KUMIBITUMIKERMIKATE, KALTEVUUS > 1:40, KÄYTTÖLUOKKA VE40, JIIREISSÄ KÄYTTÖLUOKKA VE80
KERMIEN PALOLUOKKA Broof (t2)

23 mm	RAAKAPONTTILAUDOITUS 23x95, VÄHINTÄÄN 2-AUKKOISINA JATKOKSET TUKIEN KOHDILLE RÄYSTÄIDEN ALTA NÄKYVÄ UMPILAUDOITUS TEHDÄÄN TÄYSISÄRMÄISESTÄ LAUDASTA
>800 mm	TUULETETTAVA ILMATILA ULLAKKOTILA TUULETETAAN RÄYSTÄÄN TUULETUSRAKOJEN JA ALIPAINEVENTTILEIDEN KAUTTA
	KATTOKANNATTAJAT k900 RAKENNESUUNNITELMIEN MUKAAN
400 mm	PUHALLUSERISTE, MINERAALIVILLA (λd = 0.045 W/mK) RÄYSTÄILLE NK. TUULIOHJAIMET JA HYTTYSVERKOT
200 mm	LÄMMÖNERISTE, MINERAALIVILLA (λd = 0.035 W/mK)
	KUMIBITUMIMATTO, K-EL 50/2200 KIINNITYS SAUMALIIMAAMALLA TOISIINSA JA PISTELIIMATEN ONTELOLAATTAAN KAIKKIIN LÄVISTYKSIIN TIIVISTYSLAIPPA KAUTTAALTAAN BITUMILLA LIIMATEN.
265 mm	ESIJÄNNITETTY, TYYPPIHYVÄKSYTTY ONTELOLAATTA ELEMENTTITOIMITTAJAN SUUNNITELMIEN MUKAAN. LAATTOJEN SAUMAVALUT JA -TERÄKSET RAKENNESUUNNITELMIEN MUKAAN RASITUSLUOKKA XC1

PINTA HUONESELOSTUKSEN MUKAAN

ULLAKKOTILA JAETAAN 400m2:n OSASTOIHIN EI15-SEINÄMIN
JOKAISEEN PALO-OSASTOON KATTOLUUKKU JA TUULETUSPIIPPU

PALOLUOKKA REI60

U-arvo = 0.08 W/m2K

Rakennuskohteen nimi ja osoite

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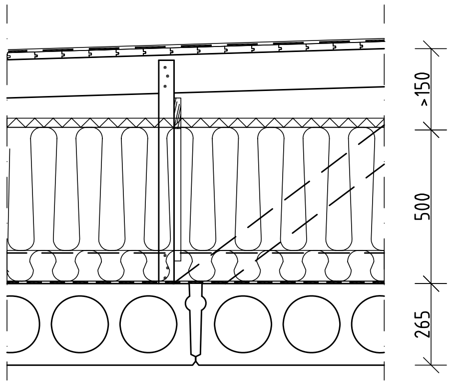
YP1.1

IV-KONEHUONEEN KATTO



LUMEN LIUKUESTEET, KATTOPOLLARIT JA VESIKATON KULKUSILLAT
RakMK F2:n JA ARK. SUUNNITELMIEN MUKAAN

PINTA TYÖSELITYKSEN MUKAAN
KUMIBITUMIKERMIKATE, KALTEVUUS > 1:40, KÄYTTÖLUOKKA VE40, JIIREISSÄ KÄYTTÖLUOKKA VE80
KERMIEN PALOLUOKKA Broof (t2)

23 mm	RAAKAPONTTILAUDOITUS 23x95, VÄHINTÄÄN 2-AUKKOISINA JATKOKSET TUKIEN KOHDILLE RÄYSTÄIDEN ALTA NÄKYVÄ UMPILAUDOITUS TEHDÄÄN TÄYSISÄRMÄISESTÄ LAUDASTA
>150 mm	TUULETETTAVA ILMATILA ULLAKKOTILA TUULETETAAN RÄYSTÄÄN TUULETUSRAKOJEN KAUTTA
	KATTOKANNATTAJAT k900 RAKENNESUUNNITELMIEN MUKAAN
30 mm	TUULENSUOJA MIN.VILLA (λd = 0.035 W/mK)
400 mm	PUHALLUSERISTE, MINERAALIVILLA (λd = 0.045 W/mK) KOTELOPUHALLETTUNA
100 mm	LÄMMÖNERISTE, MINERAALIVILLA (λd = 0.035 W/mK)
	KUMIBITUMIMATTO, K-EL 50/2200 KIINNITYS SAUMALIIMAAMALLA TOISIINSA JA PISTELIIMATEN ONTELOLAATTAAN KAIKKIIN LÄVISTYKSIIN TIIVISTYSLAIPPA KAUTTAALTAAN BITUMILLA LIIMATEN.
265 mm	ESIJÄNNITETTY, TYYPPIHYVÄKSYTTY ONTELOLAATTA ELEMENTTITOIMITTAJAN SUUNNITELMIEN MUKAAN. LAATTOJEN SAUMAVALUT JA -TERÄKSET RAKENNESUUNNITELMIEN MUKAAN RASITUSLUOKKA XC1
	PINTA HUONESELOSTUKSEN MUKAAN

PALOLUOKKA REI60

U-arvo = 0.09 W/m2K

Rakennuskohteen nimi ja osoite

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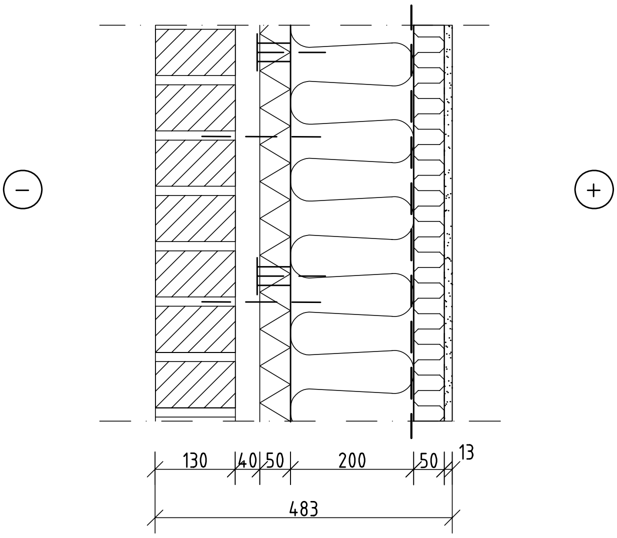
WSP

US 1

EI-KANTAVA ULKOSEINÄ
TIILIVERHOUS



	PINTA TYÖSELOSTUKSEN MUKAAN
130 mm	TIILIVERHOUS, ARK. MUKAAN, SAUMAUS MUURAUKSEN YHTEYDESSÄ. TIILIEN JA SAUMOJEN ON OLTAVA PAKKASENKESTÄVIÄ. MUURAUSSITEET Ø4, SS2333, 4kpl/m2 JA AUKKOJEN PIELISSÄ k300
40 mm	TUULETUSRAKO
50 mm	TUULENSUOJAMINERAALIVILLA (λd=0.035 W/mK) PINTALUOKKA B-s1, d0 TUULETUSRAKOON PÄIN KIINNITYS LAIPALLISELLA KIINNIKKEELLÄ ERISTELEVYN LÄPI
200 mm	PYSTYRUNKO 50x200 k600 RANKAVÄLEISSÄ MINER.VILLA (λd = 0.037 W/mK)
0.2 mm	HÖYRYNSULKUMUOVI SFS 4225, E-LUOKKA, UV-SÄTEILYSUOJATTU SAUMAT LIMITETÄÄN >200 mm. SAUMAT JA REUNAT TEIPATAAN.
50 mm	PYSTYRUNKO 50x50 k600 RANKAVÄLEISSÄ MINER.VILLA 50 mm (λd = 0.037 W/mK)
13 mm	KIPSILEVY EK
	PINTA HUONESELOSTUKSEN MUKAAN

ILMAÄÄNENERISTÄVYYS ≥ 35 dB
U-arvo = 0.15 W/m2K

Rakennuskohteen nimi ja osoite
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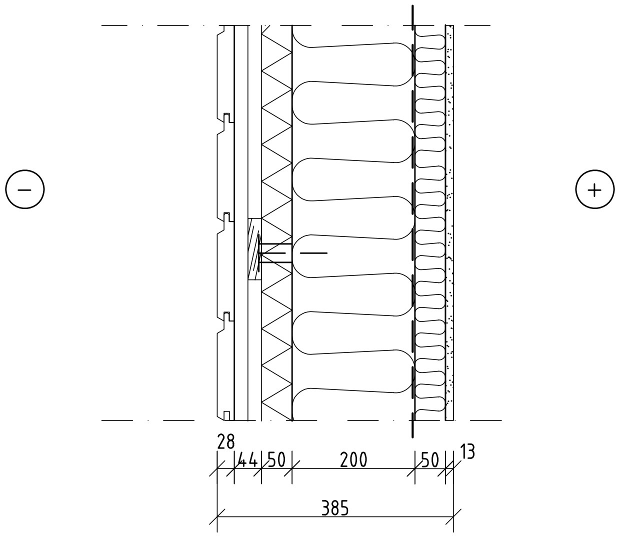
US 2

EI-KANTAVA ULKOSEINÄ
PUUVERHOUS
(PARVEKESYVENNYKSISSÄ)



PINTAKÄSITTELY TYÖSELITYKSEN MUKAAN

28 mm	PUUVERHOUS ARKK.SUUNN. MUKAAN
22+22 mm	RISTIKOOLAUS 22×100 + 22×100
50 mm	TUULENSUOJAMINERAALIVILLA (λd=0.035 W/mK) PINTALUOKKA B-s1, d0 TUULETUSRAKOON PÄIN KIINNITYS LAIPALLISELLA KIINNIKKEELLÄ ERISTELEVYN LÄPI
200 mm	PYSTYRUNKO 50x200 k600 RANKAVÄLEISSÄ MINER.VILLA (λd = 0.037 W/mK)
0.2 mm	HÖYRYNSULKUMUOVI SFS 4225, E-LUOKKA, UV-SÄTEILYSUOJATTU SAUMAT LIMITETÄÄN >200 mm. SAUMAT JA REUNAT TEIPATAAN.
50 mm	PYSTYRUNKO 50x50 k600 RANKAVÄLEISSÄ MINER.VILLA 50 mm (λd = 0.037 W/mK)
13 mm	KIPSILEVY EK

PINTA HUONESELOSTUKSEN MUKAAN

ILMAÄÄNENERISTÄVYYS ≥ 35 dB
U-arvo = 0.15 W/m2K

Rakennuskohteen nimi ja osoite
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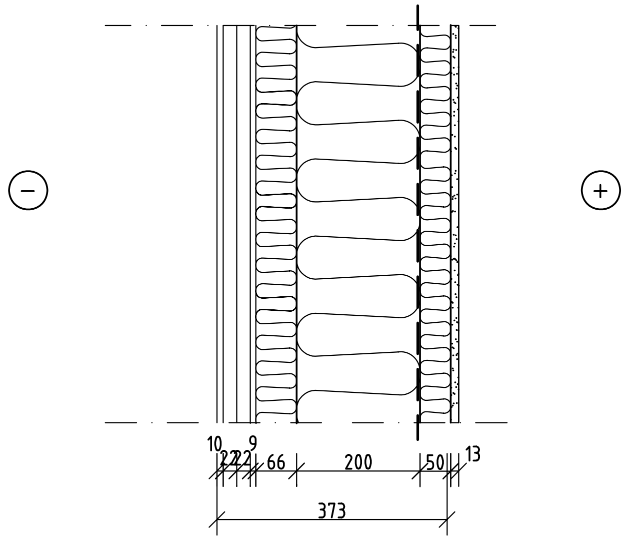
US 2.1

TALO A
EI-KANTAVA ULKOSEINÄ
PUUVERHOUS
VSS:N YLÄPUOLI 2-LINJALLA



	PINTAKÄSITTELY TYÖSELITYKSEN MUKAAN
10 mm	LEVYVERHOUS ARK. MUKAAN
22+22 mm	RISTIKOOLAUS 22x100
9 mm	TUULENSUOJAKIPSILEVY PINTALUOKKA B-s1, d0
66 mm	PYSTYRUNKO 50x66 k600 RANKAVÄLEISSÄ MINER.VILLA 66 mm (λd = 0.037 W/mK)
200 mm	PYSTYRUNKO 50x200 k600 RANKAVÄLEISSÄ MINER.VILLA (λd = 0.037 W/mK)
0.2 mm	HÖYRYNSULKUMUOVI SFS 4225, E-LUOKKA, UV-SÄTEILYSUOJATTU SAUMAT LIMITETÄÄN >200 mm. SAUMAT JA REUNAT TEIPATAAN.
50 mm	PYSTYRUNKO 50x50 k600 RANKAVÄLEISSÄ MINER.VILLA 50 mm (λd = 0.037 W/mK)
13 mm	KIPSILEVY EK
	PINTA HUONESELOSTUKSEN MUKAAN

ILMAÄÄNENERISTÄVYYS ≥ 35 dB
U-arvo = 0.15 W/m2K

Rakennuskohteen nimi ja osoite

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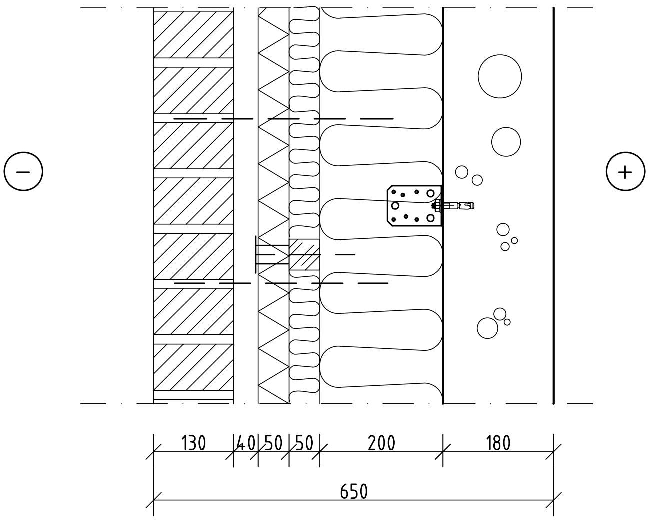
email:etunimi.sukunimi@wspgroup.fi

US 3

KANTAVA ULKOSEINÄ
YLEENSÄ



PINTA TYÖSELOSTUKSEN MUKAAN

130 mm	TIILIVERHOUS, ARK. MUKAAN, SAUMAUS MUURAUKSEN YHTEYDESSÄ. TIILIEN JA SAUMOJEN ON OLTAVA PAKKASENKESTÄVIÄ. MUURAUSSITEET Ø4, SS2333, 4kpl/m2 JA AUKKOJEN PIELISSÄ k300
40 mm	TUULETUSRAKO
50 mm	TUULENSUOJAMINERAALIVILLA (λd=0.035 W/mK) PINTALUOKKA B-s1, d0 TUULETUSRAKOON PÄIN KIINNITYS LAIPALLISELLA KIINNIKKEELLÄ ERISTELEVYN LÄPI
50 mm	VAAKAKOOLAUS 50x50 k600 RANKAVÄLEISSÄ MINER.VILLA 50 mm (λd = 0.037 W/mK)
200 mm	RUNKO 50×200 k600, KIINNITYS KUUMASINK. BMF-90 KULMALEVYILLÄ k 1800 MOL. PUOLIN KAMPANAULAT 6 n4,0×40 SOIROON JA KIILA-ANKKURI M10 (ESIM. HILTIN HSA M10×68) / LEVY RANKAVÄLEISSÄ MINERAALIVILLA (λd = 0.037 W/mK)
180 mm	KANTAVA RAKENNE, BETONI- TAI TERÄSBETONISEINÄ RAKENNESUUNNITELMIEN MUKAAN MUOTTIPINNAT: BY 40/MUO-A JA AVOPINNAT: TERÄSHIERTO / BY40 RASITUSLUOKKA XC1

PINTA HUONESELOSTUKSEN MUKAAN

ILMAÄÄNENERISTÄVYYS ≥ 35 dB
U-arvo = 0.15 W/m2K

Rakennuskohteen nimi ja osoite
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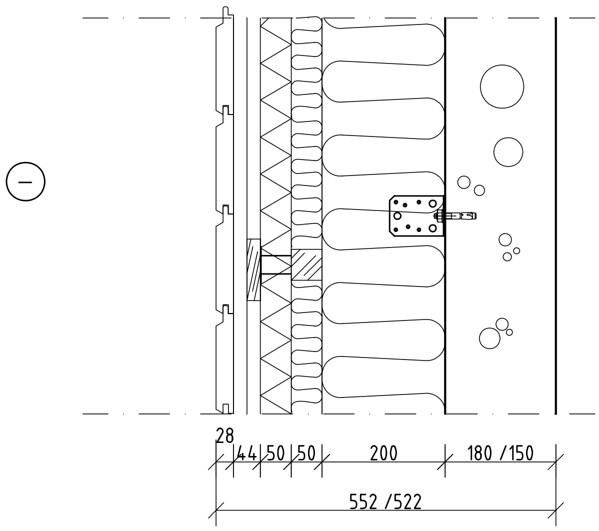
US 4

KANTAVA ULKOSEINÄ
PUUVERHOUS



PINTAKÄSITTELY TYÖSELITYKSEN MUKAAN

28 mm	PUUVERHOUS ARKK.SUUNN. MUKAAN
22+22 mm	RISTIKOOLAUS 22×100 + 22×100
50 mm	TUULENSUOJAMINERAALIVILLA (λd=0.035 W/mK) PINTALUOKKA B-s1, d0 TUULETUSRAKOON PÄIN KIINNITYS LAIPALLISELLA KIINNIKKEELLÄ ERISTELEVYN LÄPI
50 mm	VAAKAKOOLAUS 50x50 k600 RANKAVÄLEISSÄ MINER.VILLA 50 mm (λd = 0.037 W/mK)
200 mm	RUNKO 50×200 k600, KIINNITYS KUUMASINK. BMF-90 KULMALEVYILLÄ k 1800 MOL. PUOLIN KAMPANAULAT 6 n4,0×40 SOIROON JA KIILA-ANKKURI M10 (ESIM. HILTIN HSA M10×68) / LEVY RANKAVÄLEISSÄ MINERAALIVILLA (λd = 0.037 W/mK)
150/180 mm	KANTAVA RAKENNE, BETONI- TAI TERÄSBETONISEINÄ RAKENNESUUNNITELMIEN MUKAAN MUOTTIPINNAT: BY 40/MUO-A JA AVOPINNAT: TERÄSHIERTO / BY40 RASITUSLUOKKA XC1

PINTA HUONESELOSTUKSEN MUKAAN

ILMAÄÄNENERISTÄVYYS ≥ 35 dB
U-arvo = 0.15 W/m2K

Rakennuskohteen nimi ja osoite

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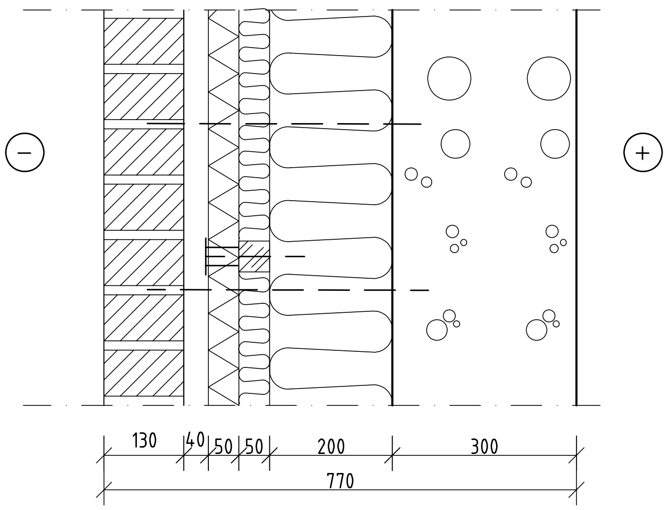
US 5

VSS:N ULKOSEINÄ
TIILIVERHOUS



PINTAKÄSITTELY TYÖSELITYKSEN MUKAAN

130 mm	TIILIVERHOUS, ARK. MUKAAN, SAUMAUS MUURAUKSEN YHTEYDESSÄ. TIILIEN JA SAUMOJEN ON OLTAVA PAKKASENKESTÄVIÄ. MUURAUSSITEET Ø4, SS2333, 4kpl/m2 (AUKKOJEN PIELISSÄ k300)
40 mm	TUULETUSRAKO
50 mm	TUULENSUOJAMINER.VILLA (λd=0.035 W/mK) PINTALUOKKA B-s1, d0 TUULETUSRAKOON PÄIN KIINNITYS LAIPALLISELLA KIINNIKKEELLÄ ERISTELEVYN LÄPI
50 mm	VAAKAKOOLAUS 50x50 k600 RANKAVÄLEISSÄ MINER.VILLA 50 mm (λd = 0.037 W/mK)
200 mm	RUNKO 50×200 k600, KIINNITYS KUUMASINK. BMF-90 KULMALEVYILLÄ k 1800 MOL. PUOLIN KAMPANAULAT 6 n4,0×40 SOIROON JA KIILA-ANKKURI M10 (ESIM. HILTIN HSA M10×68) / LEVY RANKAVÄLEISSÄ MINERAALIVILLA (λd = 0.037 W/mK)
300 mm	KANTAVA RAKENNE, TERÄSBETONISEINÄ RAKENNE- SUUNNITELMIEN MUKAAN MUOTTIPINNAT: BY 40/MUO-B JA AVOPINNAT: TERÄSHIERTO / BY40 RASITUSLUOKKA XC1

PINTA HUONESELITYKSEN MUKAAN

U-arvo=0.15 W/m2K

Rakennuskohteen nimi ja osoite

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Rakennuksen lämpöhäviön tasauslaskelma, D3-2010 (voimassa 1.1.2010 alkaen)

Rakennuskohde	**TA-Asumisoikeus Oy / Rita-aukiontie 14**
Rakennuslupatunnus	
Rakennustyyppi Lue ohjeet	5- kerroksinen asuinkerrostalo
Pääsuunnittelija	Arkkitehtitoimisto Veli Karjalainen Ky
Tasauslaskelman tekijä	Kari Kanniainen
Päiväys	25.05.2011
Tulos: Suunnitteluratkaisu	**TÄYTTÄÄ VAATIMUKSET JA LÄMPÖHÄVIÖ VASTAA MATALAENERGIATASOA**

Rakennuksen laajuustiedot

Rakennustilavuus	6 234	rak-m!
Maanpäälliset kerrostasoalat yhteensä	1 874	m"
Kerroskorkeus	3,0	m
Huonekorkeus	2,6	m
Ilmatilavuus, V, lämpimät tilat	4 618	m!
Ilmatilavuus, V, puolilämpimät tilat		m!

Laskentatuloksia

Julkisivun pinta-ala on 1172 m"
Ikkunapinta-ala on 11 % maanpäällisestä kerrostasoalasta
Ikkunapinta-ala on 18 % julkisivun pinta-alasta
Lämpöhäviö on 64 % vertailutasosta (lämpimät tilat)

Perustiedot / **Lämpöhäviöiden tasaus**

RAKENNUSOSAT	Pinta-alat, m! [A]		U-arvot, W/(m! K) [U]			Ominaislämpöhäviö, W/K [H_{joht} = A x U]	
Lämpimät tilat	Vertailu-arvo	Suunnittelu-arvo	Vertailu-arvo	*Enimmäis-arvo*	Suunnittelu-arvo	Vertailu-ratkaisu	Suunnittelu-ratkaisu
Ulkoseinä	837	912	0,17	*0,60*	0,15	142,3	136,8
Hirsiseinä			0,40	*0,60*		-	-
Yläpohja	334	334	0,09	*0,60*	0,08	30,1	26,7
Alapohja (ulkoilmaan rajoittuva)			0,09	*0,60*		-	-
Alapohja (ryömintätilaan rajoittuva) [1)]			0,17	*0,60*		-	-
Alapohja (maanvastainen)		334	0,16	*0,60*	0,14	53,4	46,8
Muu maanvastainen rakennusosa			0,16	*0,60*		-	
Ikkunat	281,1	206,2	1,00	*1,80*	0,85	281,1	175,3
Ulko-ovet		53,8	1,00	*-*	1,10	53,8	59,1
Kattoikkunat			1,00	*1,80*		-	-
Lämpimät tilat yhteensä	**1 840**	**1 840**				**560,7**	**444,7**
Puolilämpimät tilat							
Ulkoseinä			0,26	*0,60*		-	-
Hirsiseinä			0,60	*0,60*		-	-
Yläpohja			0,14	*0,60*		-	-
Alapohja (ulkoilmaan rajoittuva)			0,14	*0,60*		-	-
Alapohja (ryömintätilaan rajoittuva) [1)]			0,26	*0,60*		-	-
Alapohja (maanvastainen)			0,24	*0,60*		-	-
Muu maanvastainen rakennusosa			0,24	*0,60*		-	-
Ikkunat			1,40	*2,80*		-	-
Ulko-ovet			1,40	*-*		-	-
Kattoikkunat			1,40	*2,80*		-	-
Puolilämpimät tilat yhteensä	**-**	**-**				**-**	**-**

VAIPAN ILMAVUODOT	Ilmanvuotoluku, 1/h [n_{50}]		Vuotoilmavirta, m"/s [$q_{v,v}$ = n_{50}/25 x V/3600]		Ominaislämpöhäviö, W/K [$H_{vuotoilma}$ = 1200 x $q_{v,v}$]	
Vuotoilma	Vertailu-arvo	Suunnittelu-arvo	Vertailu-arvo	Suunnittelu-arvo	Vertailu-ratkaisu	Suunnittelu-ratkaisu
Lämpimät tilat	2,0	0,6	0,1026	0,0308	123,1	36,9
Puolilämpimät tilat	2,0				-	-

ILMANVAIHTO	Poistoilmavirta, m"/s [$q_{v,p}$]		LTO:n vuosihyötysuhde, % [! $_a$]		Ominaislämpöhäviö, W/K [H_{iv} = 1200 x $q_{v,p}$ x (1- ! $_a$)]	
Hallittu ilmanvaihto	Vertailu-arvo	Suunnittelu-arvo	Vertailu-arvo	Suunnittelu-arvo	Vertailu-ratkaisu	Suunnittelu-ratkaisu
Lämpimät tilat		1,300	45	67,6	858,0	505,4
Lämpimät tilat, ei LTO-vaatimusta			0		-	-
Puolilämpimät tilat			45		-	-
Puolilämpimät tilat, ei LTO-vaatimusta			0		-	-

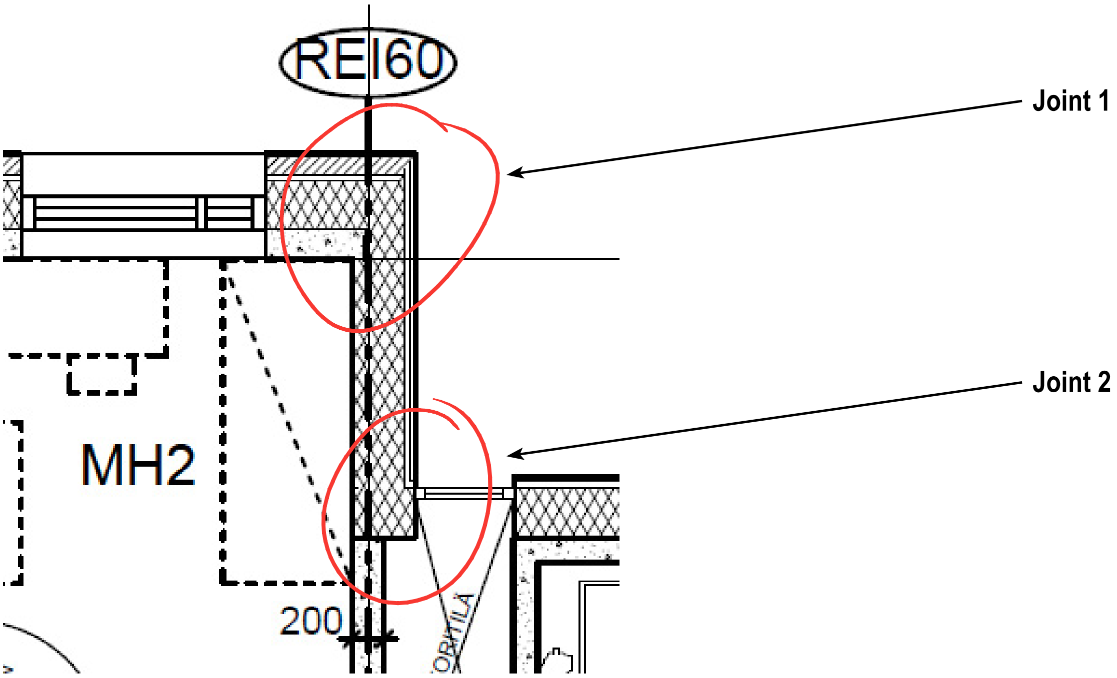
Rakennuksen lämpöhäviöiden tasaus	Ominaislämpöhäviö, W/K [H = H_{joht} + $H_{vuotoilma}$ + H_{iv}] Vertailu-ratkaisu	Suunnittelu-ratkaisu
Lämpimien tilojen ominaislämpöhäviö yhteensä	**1 542**	**987**
Puolilämpimien tilojen ominaislämpöhäviö yhteensä	**-**	**-**

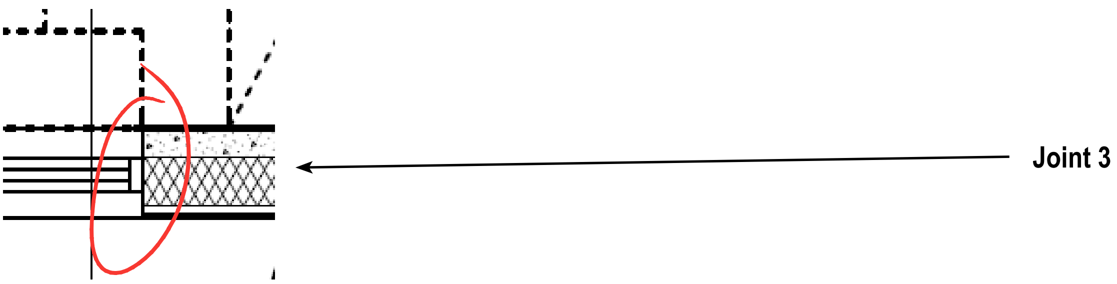
[1)] Ryömintätilaan rajoittuvan alapohjan lämpöhäviö kerrotaan luvulla 0,8 rakentamismääräykokoelman osan D3 mukaisesti.
Tällä tavalla otetaan huomioon ryömintätilan ilman ulkoilmaa korkeampi vuotuinen keskilämpötila.
Ryömintätilan tuuletusaukkojen määrä on enintään 8 promillea alapohjan pinta-alasta.

TA Harjoitustyö

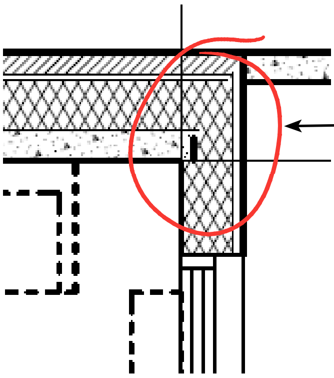
1. marraskuuta 2012
8:36

Nevanperä Jukka
Kuukasjärvi Mikko
US-US ulkonurkka
US-US sisänurkka

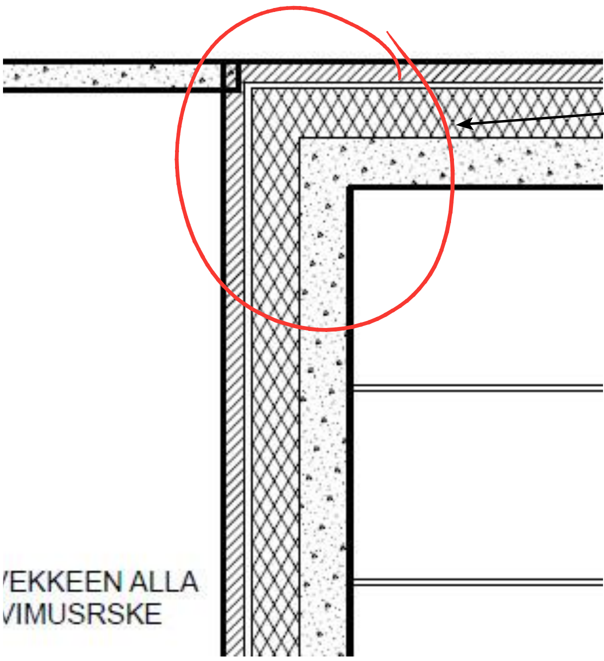




Jämsen Sami
Koivulahti Jori
Heinonen Matias
US-US ulkonurkka & VSS-ulkonurkka

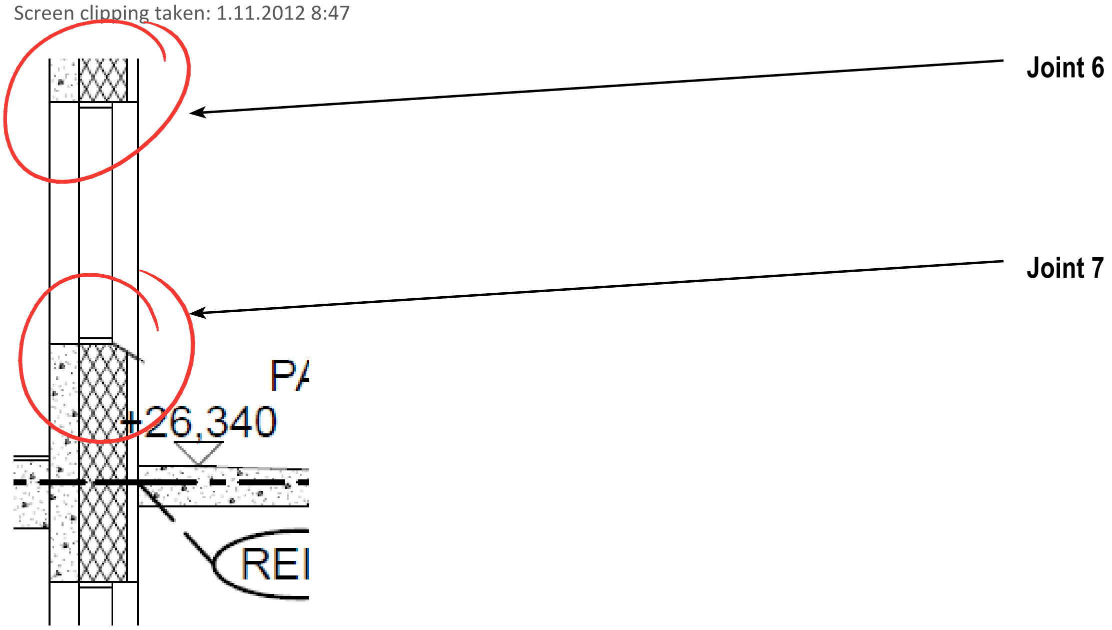


Joint 4

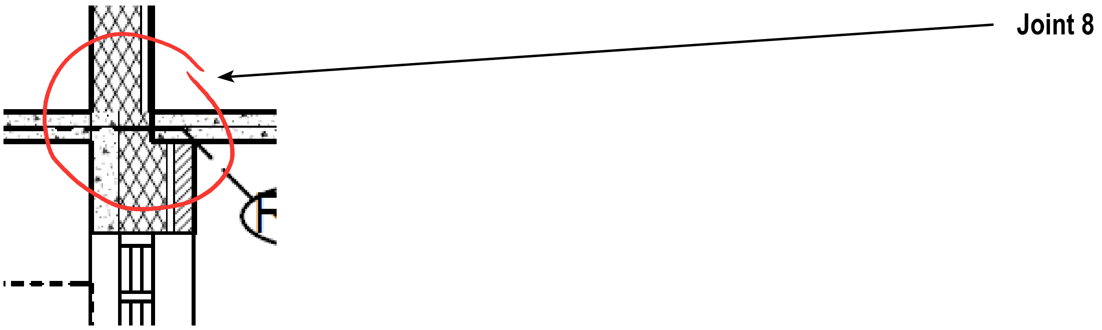


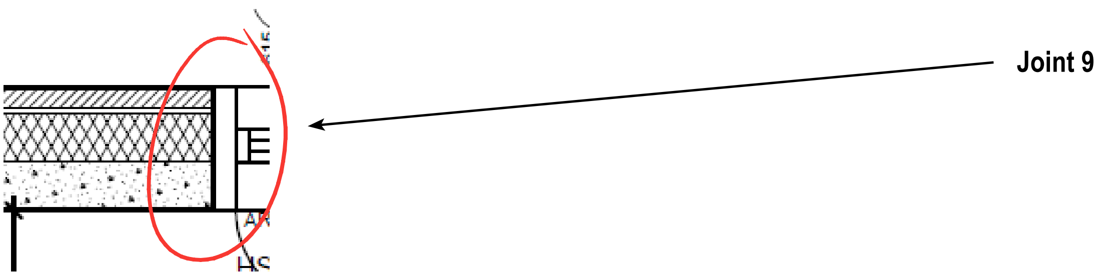
Joint 5

Screen clipping taken: 1.11.2012 8:47

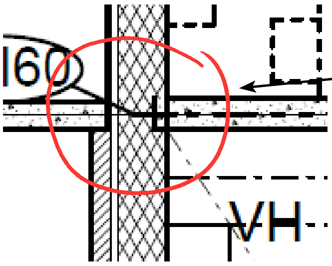


Airaksinen Olli
US-US suora liittymä

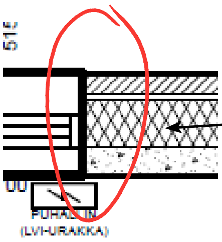




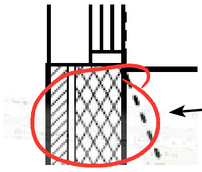
Vinkki Sami
US-VS



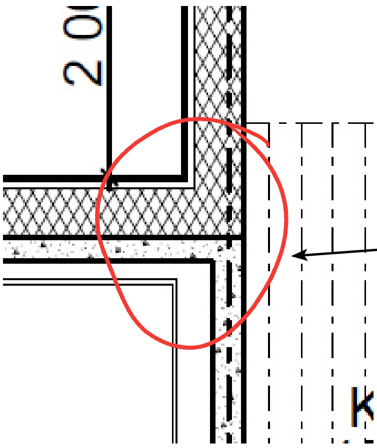
Joint 10



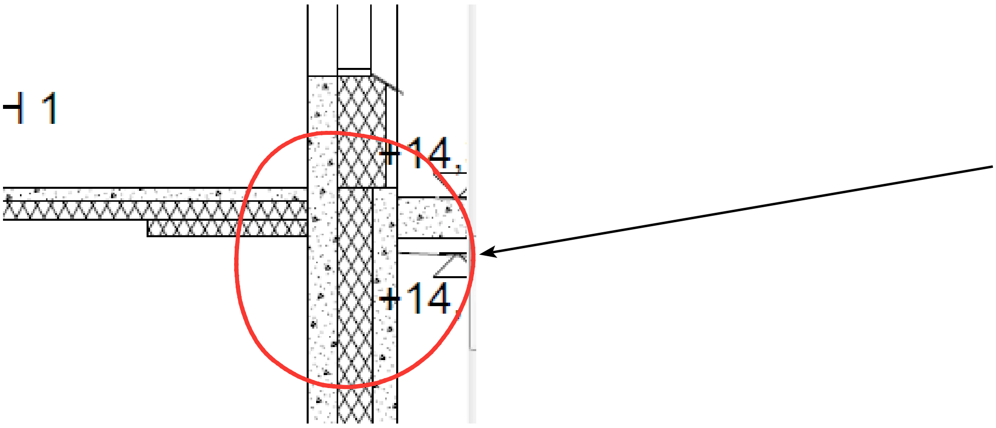
Joint 11



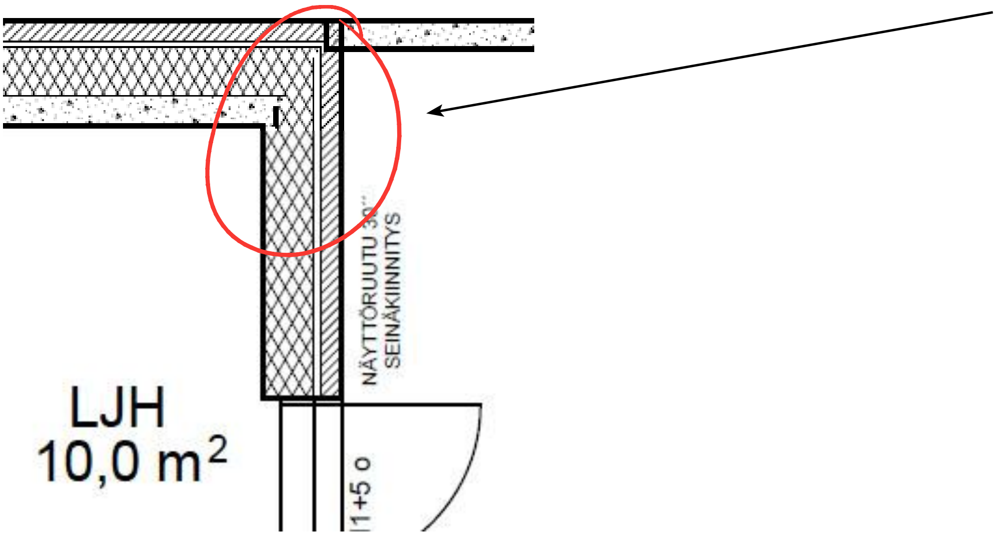
Joint 12



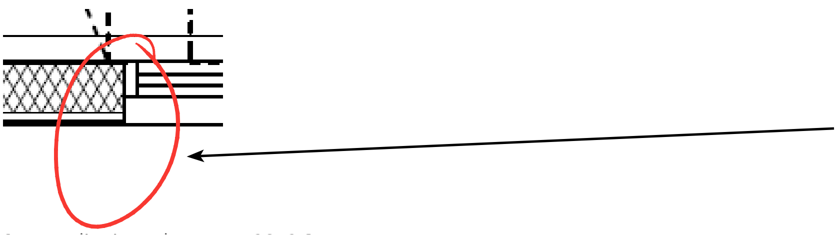
Joint 13



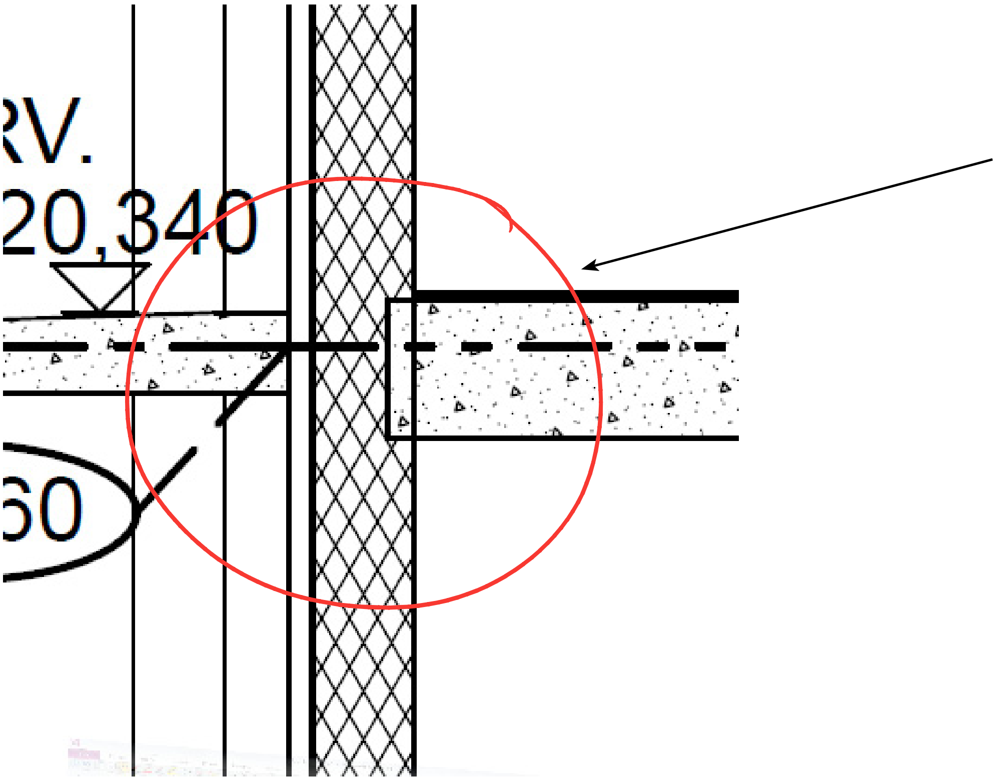
Joint 14



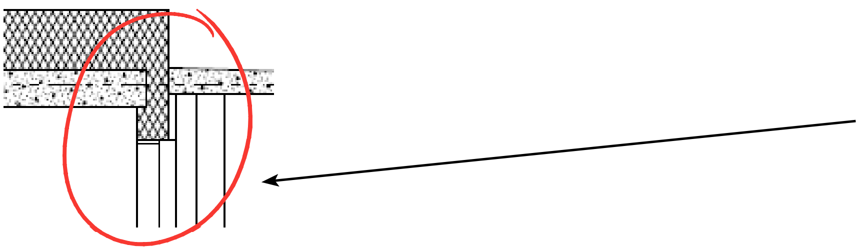
Joint 15



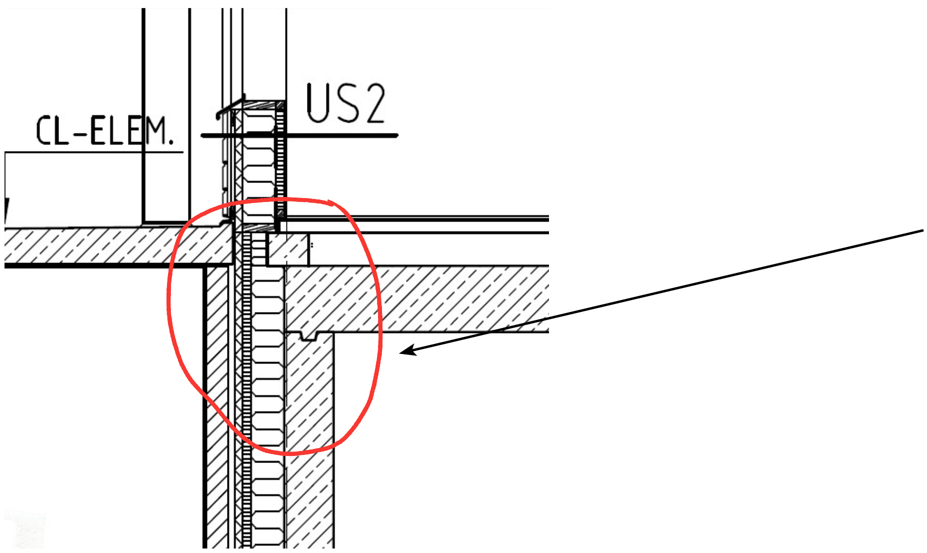
Joint 16



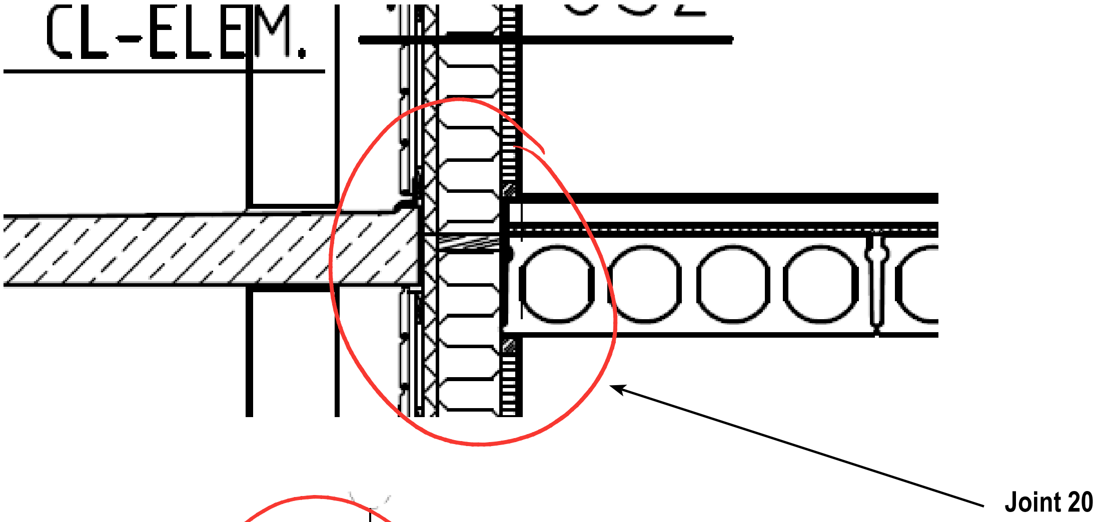
Joint 17

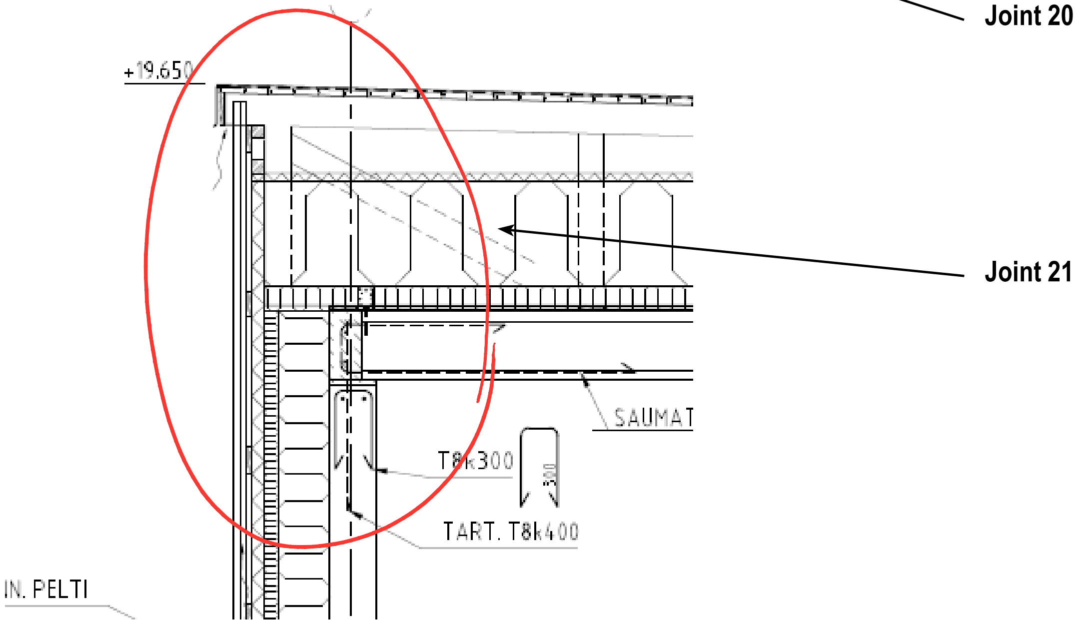


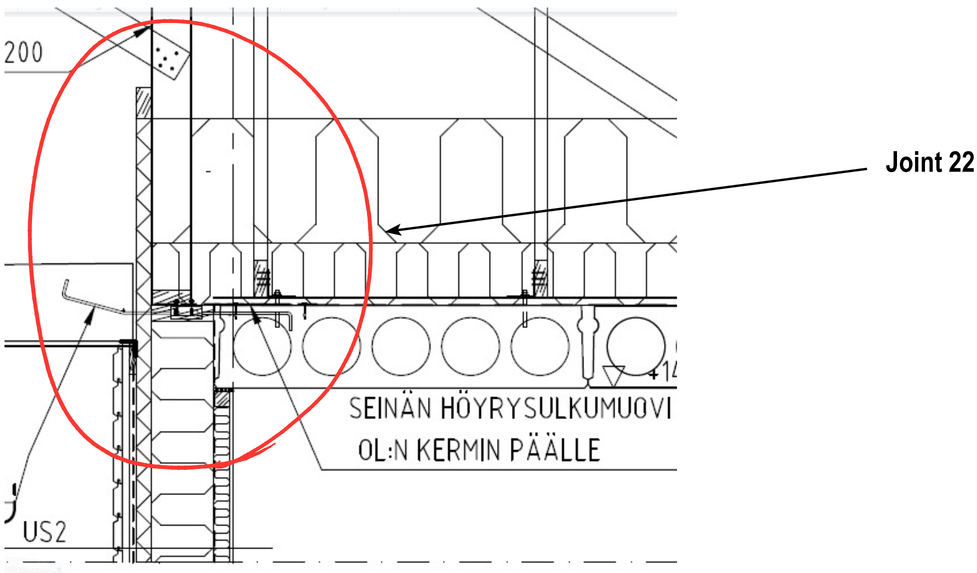
Joint 18



Joint 19


CL-ELEM.
Joint 20


+19.650
SAUMAT
T8k300
300
TART. T8k400
IN. PELTI
Joint 21


200
US2
SEINÄN HÖYRYSULKUMUOVI
OL:N KERMIN PÄÄLLE
Joint 22

APPENDIX 3

Joint 2

(Appendix 1, original drawing - 163-003). Joint 2 is a junction between external walls US2.1 and US2.

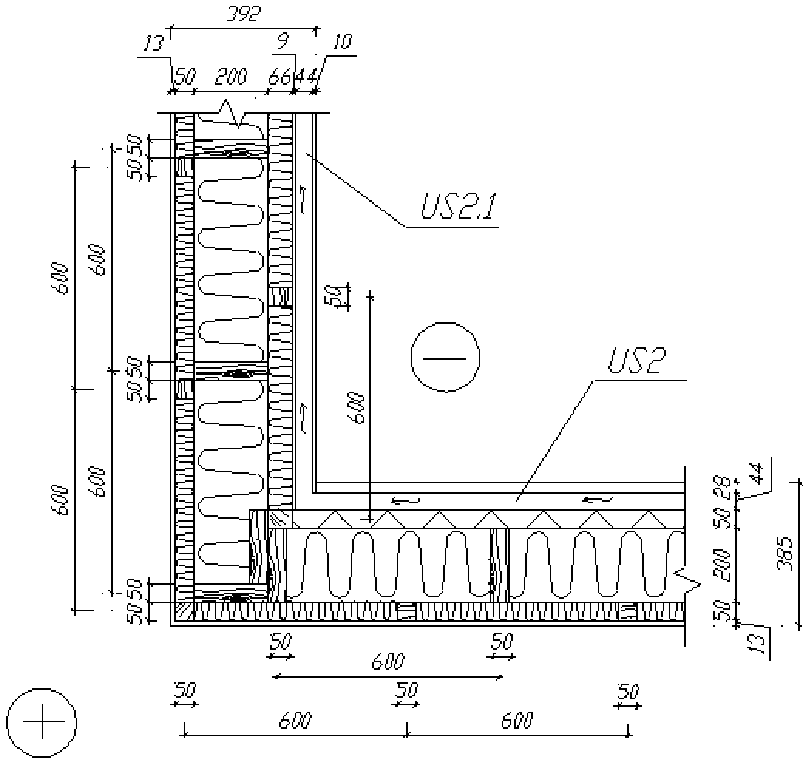


FIGURE 51. Original structure of the Joint 2

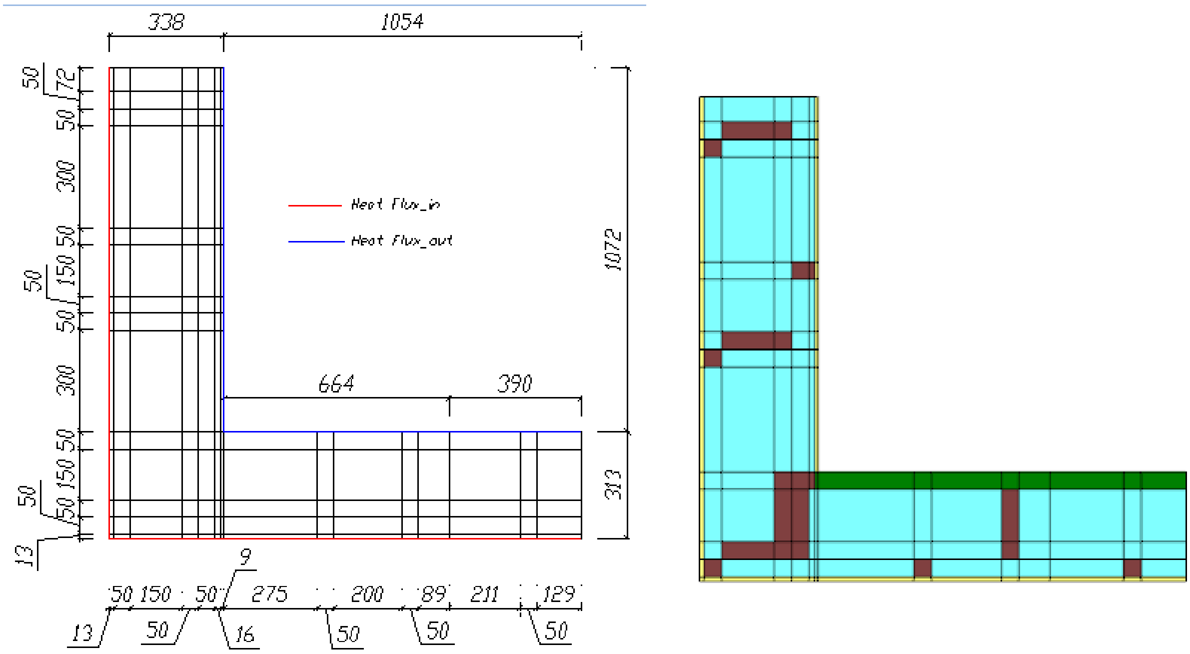


FIGURE 52. Computational geometry (with heat flux boundaries) and materials of the Joint 2 in COMSOL Multiphysics

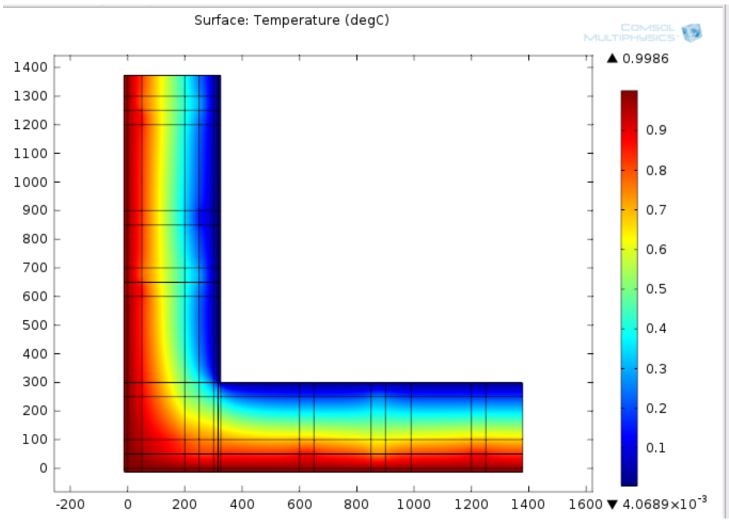


FIGURE 53. Temperature inside the Joint 2 structures

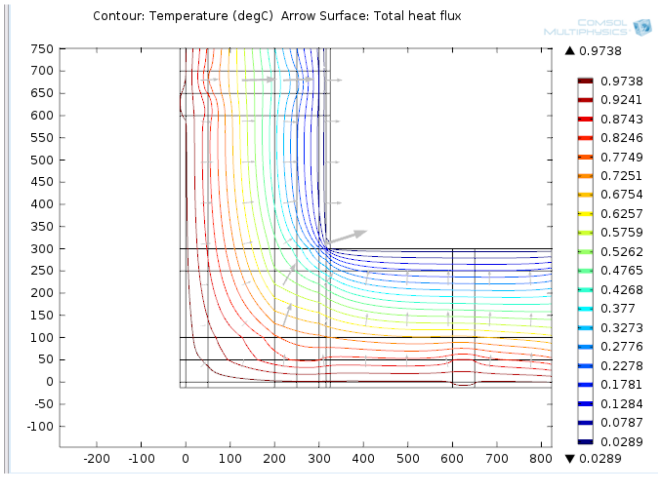


FIGURE 54. Isothermal contours inside the Joint 2 structures

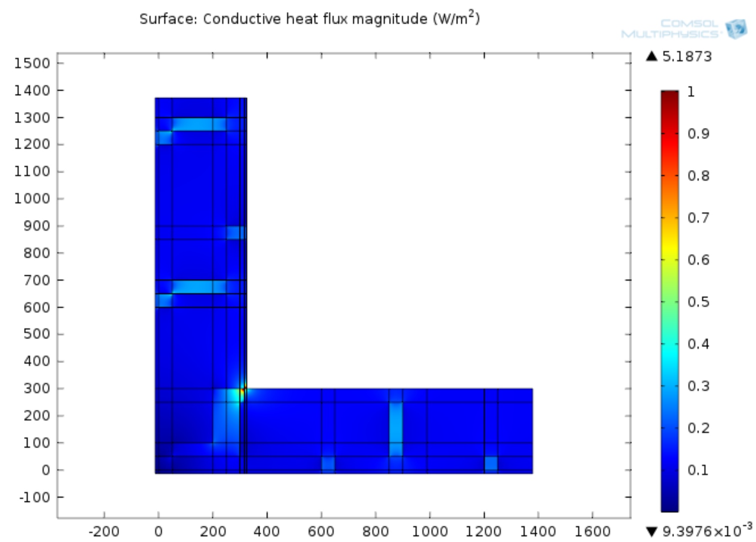


FIGURE 55. Heat flux inside the Joint 2

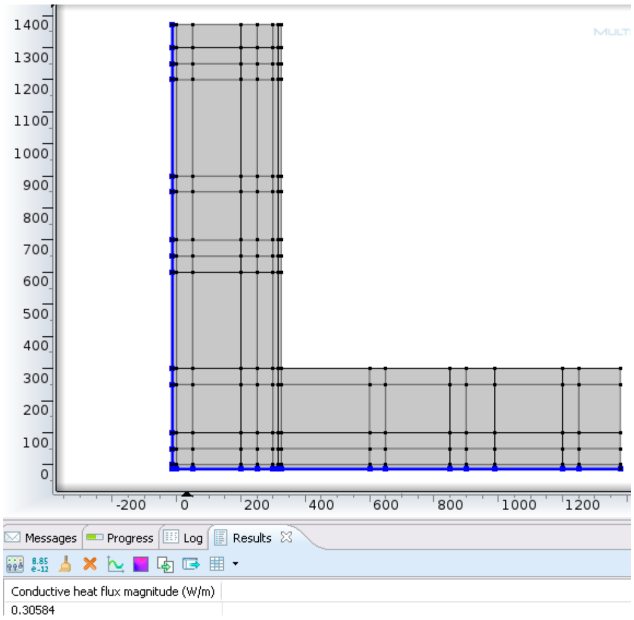


FIGURE 56. Determination of coupling coefficient for Joint 2

From figure 56 $L_{2D} = \frac{0{,}30584\ \mathrm{W/m}}{1\ K - 0\ K} = 0{,}30584\ W/mK$

$\psi = 0{,}30584\ W/(mK) - (0{,}1262\ W/(m^2K) \cdot 1{,}313\ m) - (0{,}1296\ W/(m^2K) \cdot 1m) =$

$= 0{,}01055\ W/(mK)$

<u>Joint 4</u>

(Appendix 1, original drawing - 163-003). Joint 4 is a junction between external walls US3 and US2.

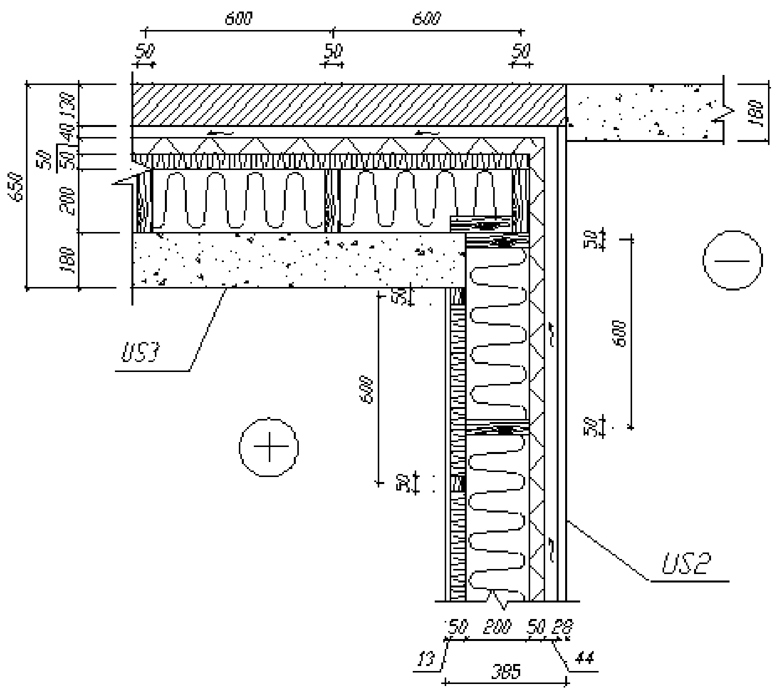


FIGURE 57. Original structure of the Joint 4

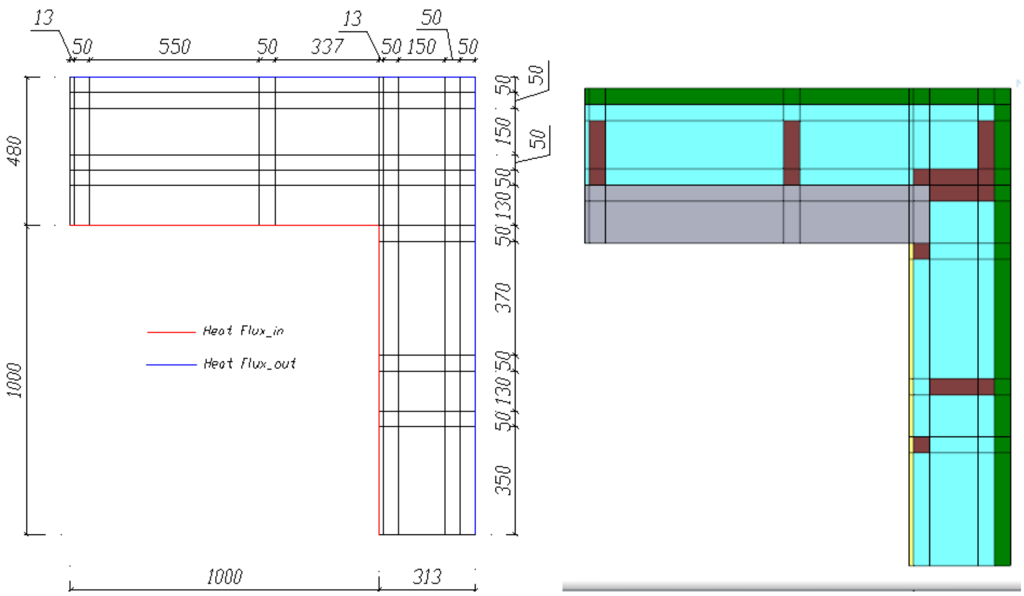


FIGURE 58. Computational geometry and materials of the Joint 4 in COMSOL Multiphysics

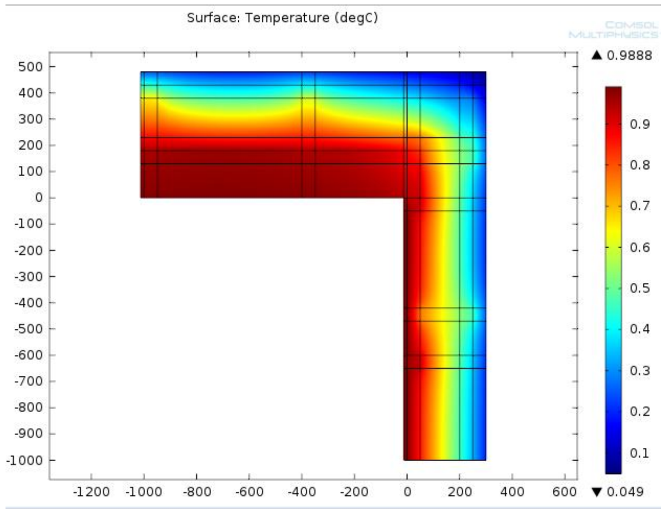


FIGURE 59. Temperature inside the Joint 4

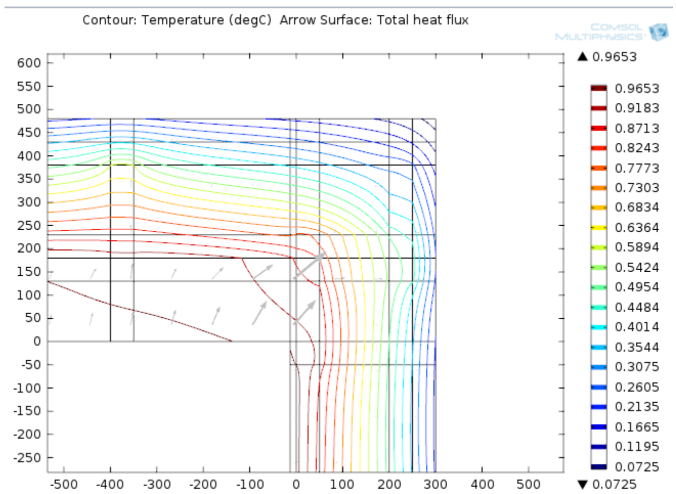


FIGURE 60. Isothermal contours inside the Joint 4

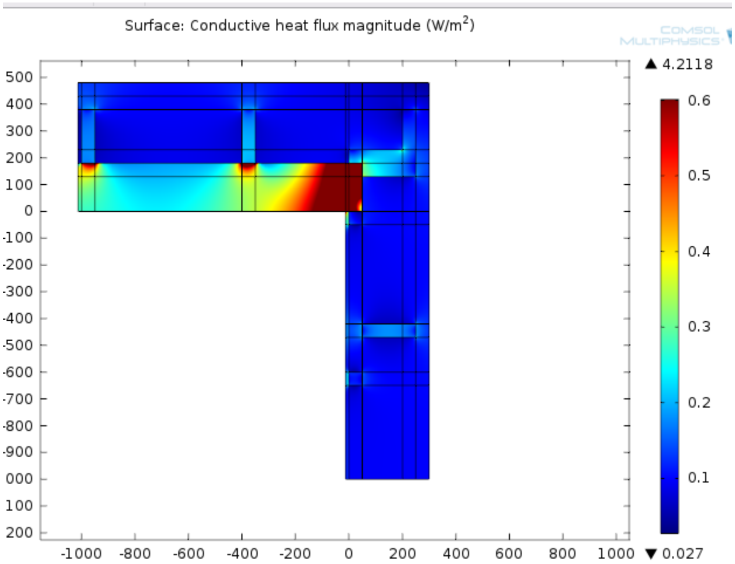


FIGURE 61. Heat flux inside the Joint 4

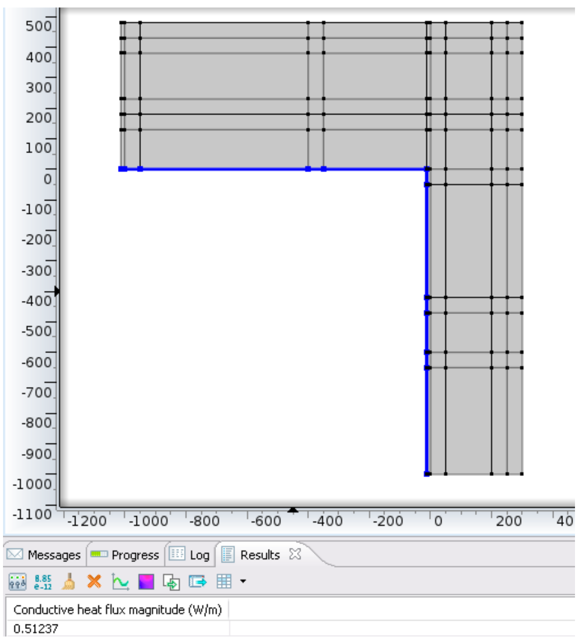


FIGURE 62. Determination of coupling factor for the Joint 4

From figure 62 we take $L_{2D} = \frac{0{,}51237\ \mathrm{W/m}}{1\ K - 0\ K} = 0{,}51237\ W/mK$

$\psi = 0{,}51237\ W/(mK) - (0{,}1266\ W/(m^2K) \cdot 1\ m) - (0{,}1296\ W/(m^2K) \cdot 1{,}48m) =$

$= 0{,}02899\ W/(mK)$

Joint 5

(Appendix 1, original drawing - 163-013). Joint between external walls US5 and US5

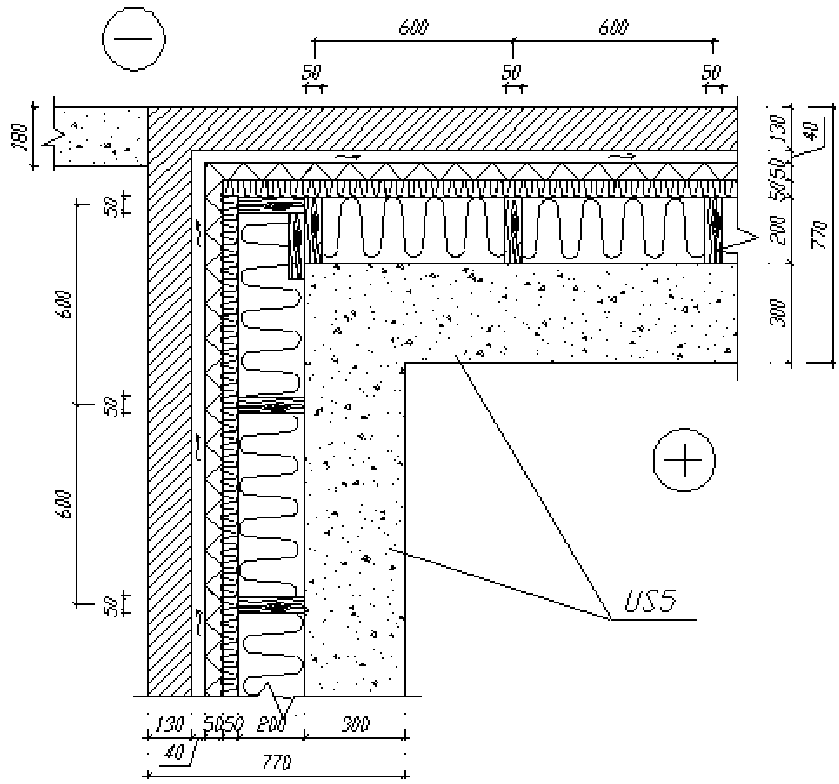


FIGURE 63. Original structure of the Joint 5

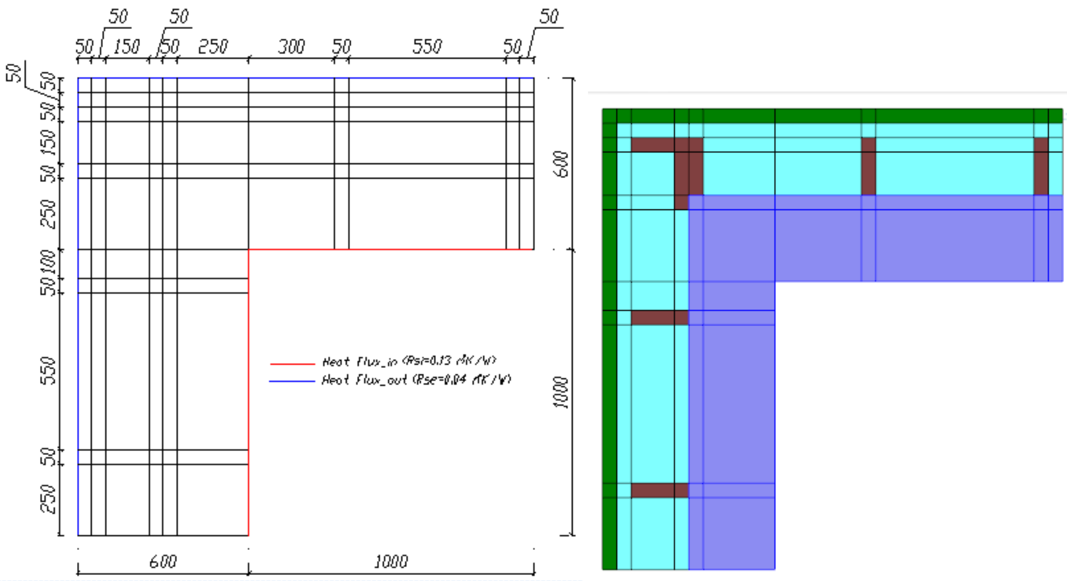


FIGURE 64. Computational geometry and materials in COMSOL Multiphysics

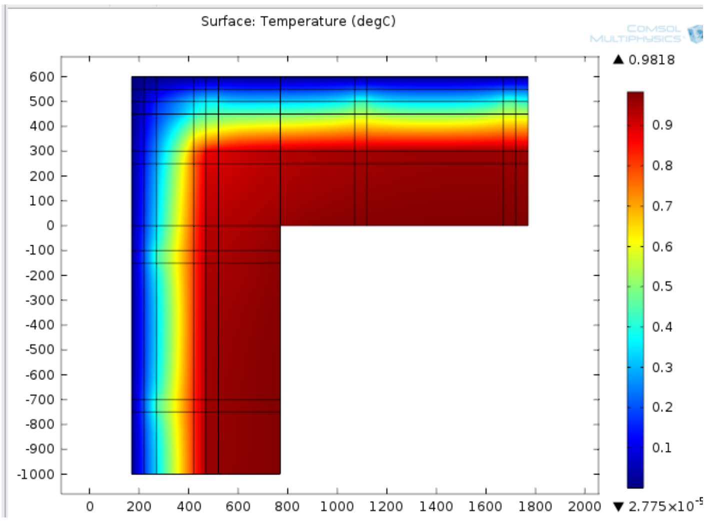


FIGURE 65. Temperature inside the Joint 5

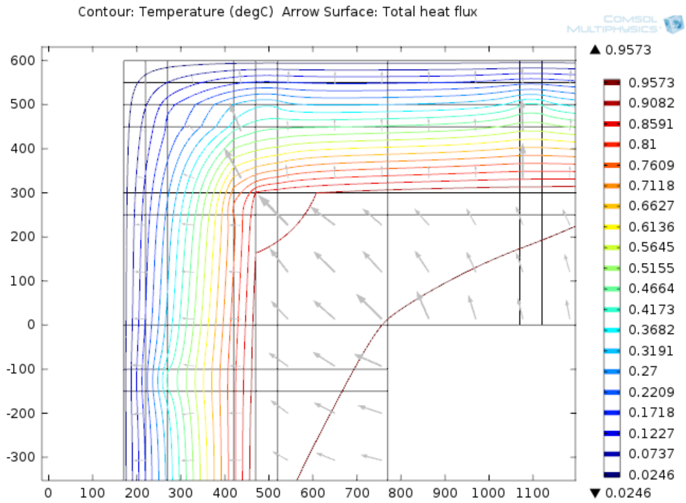


FIGURE 66. Isothermal contours inside the Joint 5

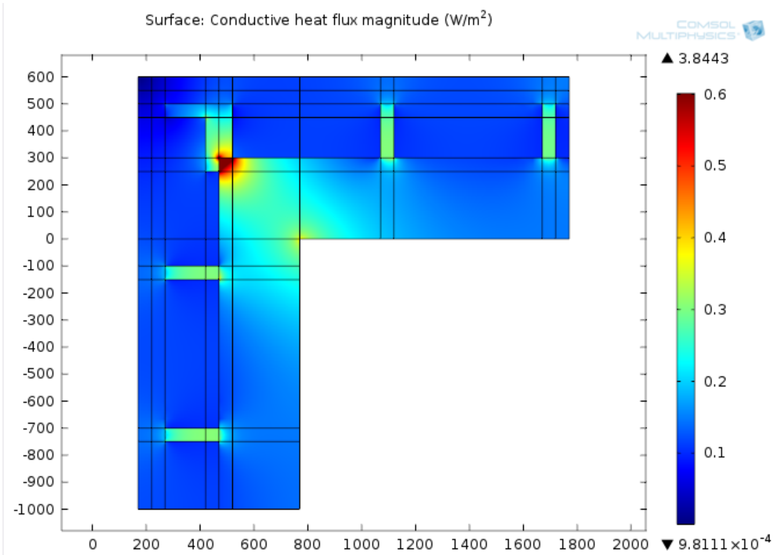


FIGURE 67. Heat flux inside the Joint 5

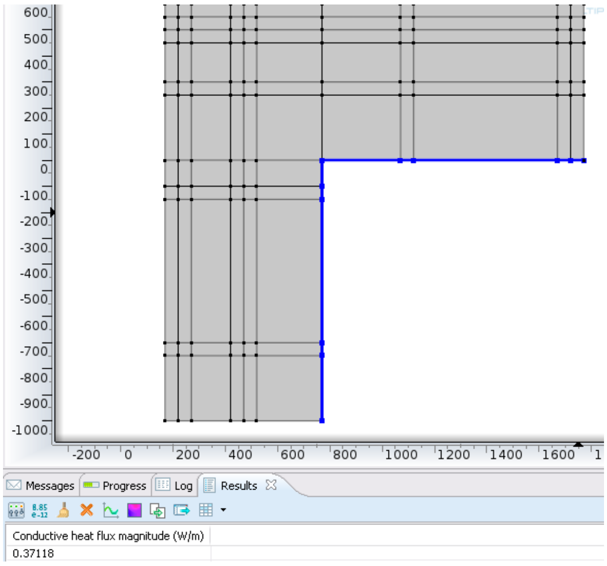


FIGURE 68. Determination of coupling factor for the Joint 5

From figure 68 we take $L_{2D} = \frac{0{,}37118\ \mathrm{W/m}}{1\ K - 0\ K} = 0{,}37118\ W/mK$

$\psi = 0{,}37118\ W/(mK) - (0{,}1277\ W/(m^2K) \cdot 1\ m) - (0{,}1277\ W/(m^2K) \cdot 1{,}6m) =$

$= 0{,}03905\ W/(mK)$

<u>Joint 13</u>

(Appendix 1, original drawing - 163-013). Joint between external walls US2 and US2 conjugated with concrete 150mm thick block=US2'

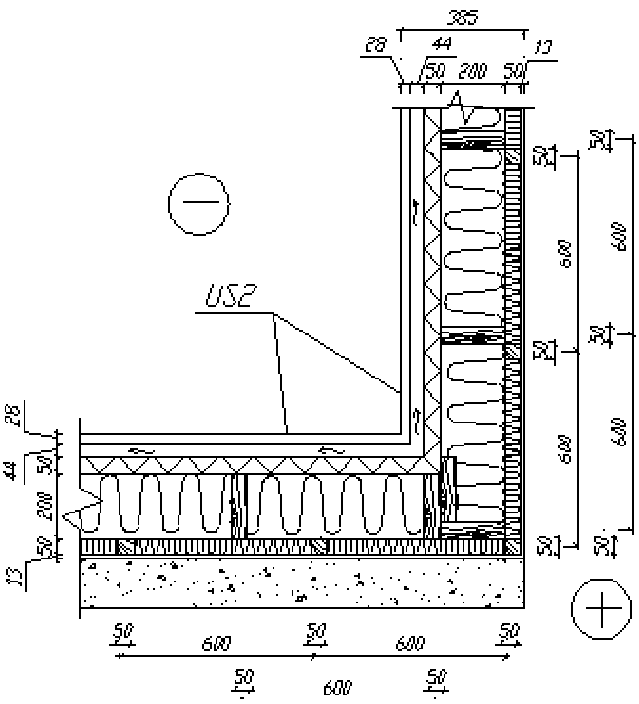


FIGURE 69. Original structure of the Joint 13

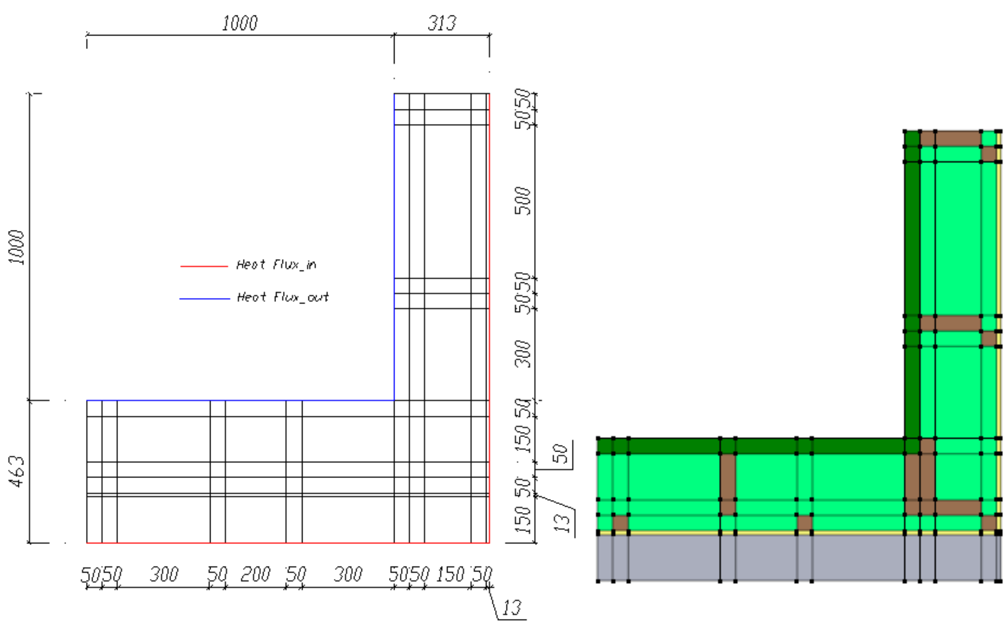


FIGURE 70. Computational geometry and materials in COMSOL Multiphysics

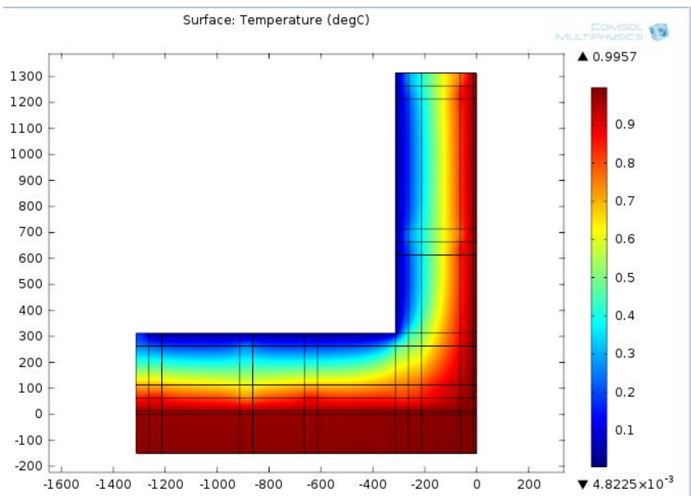


FIGURE 71. Temperature inside the Joint 13

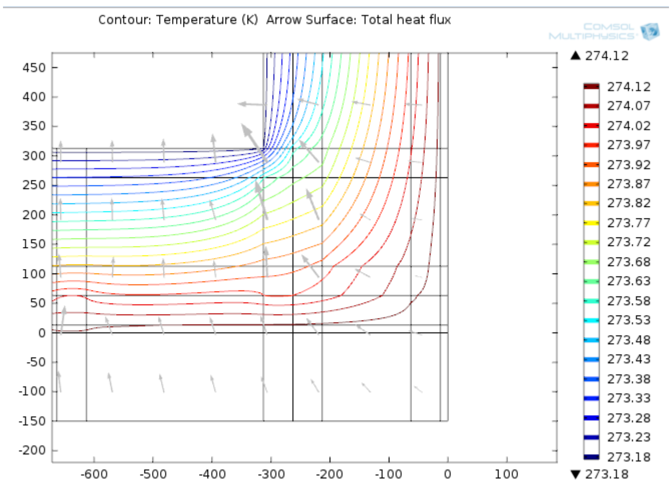


FIGURE 72. Isothermal contours inside the Joint 13

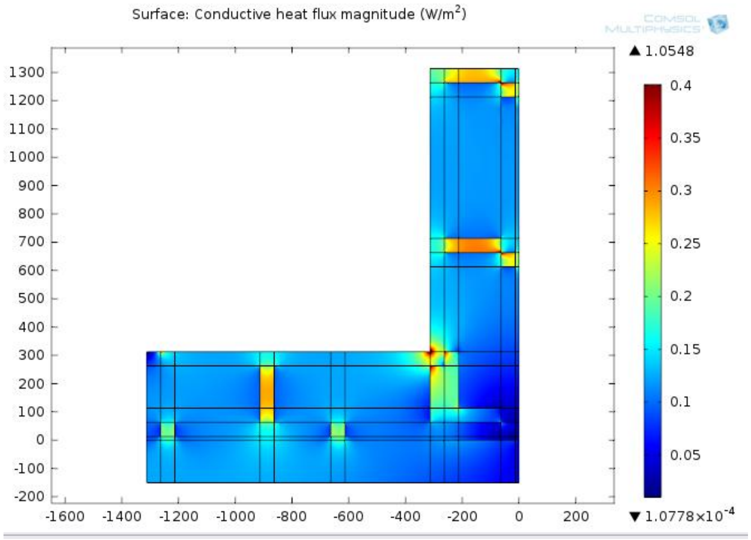


FIGURE 73. Heat flux inside the Joint 13

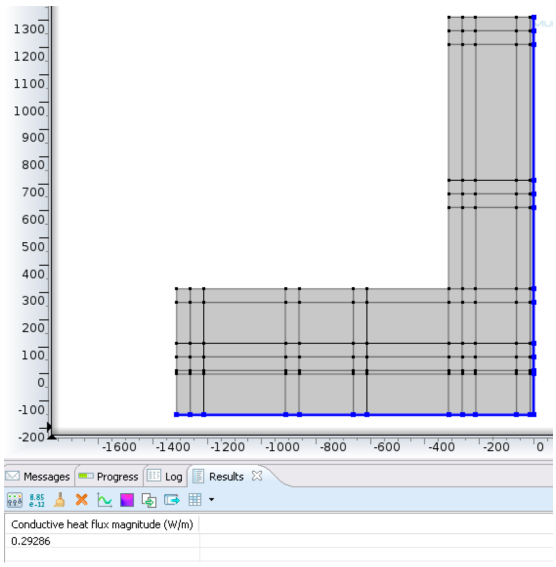


FIGURE 74. Determination of coupling coefficient for Joint 13

From figure 74 we take $L_{2D} = \frac{0{,}29286\ W/m}{1\ K - 0\ K} = 0{,}29286\ W/mK$

$\psi = 0{,}29286\ W/(mK) - (0{,}1296\ W/(m^2K) \cdot 1\ m) - (0{,}1282\ W/(m^2K) \cdot 1{,}313m) =$
$= -0{,}00507\ W/(mK)$

Joint 15

(Appendix 1, original drawing - 163-013). Joint between external walls US3 and US1

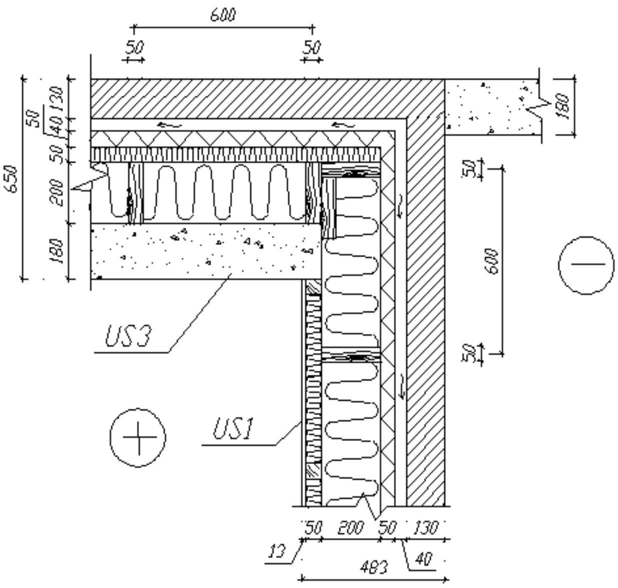


FIGURE 75. Original structure of the Joint 15

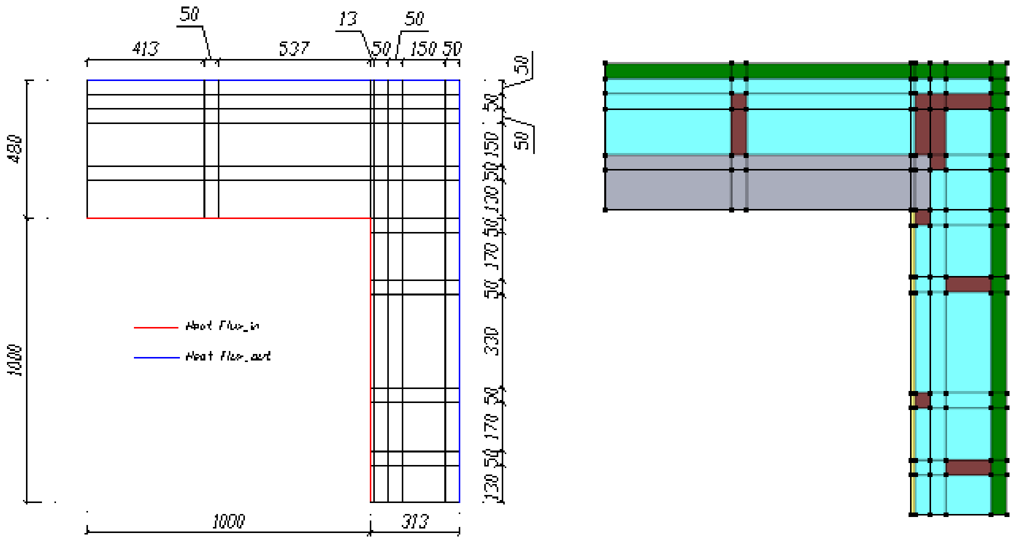


FIGURE 76. Computational geometry and materials in COMSOL Multiphysics

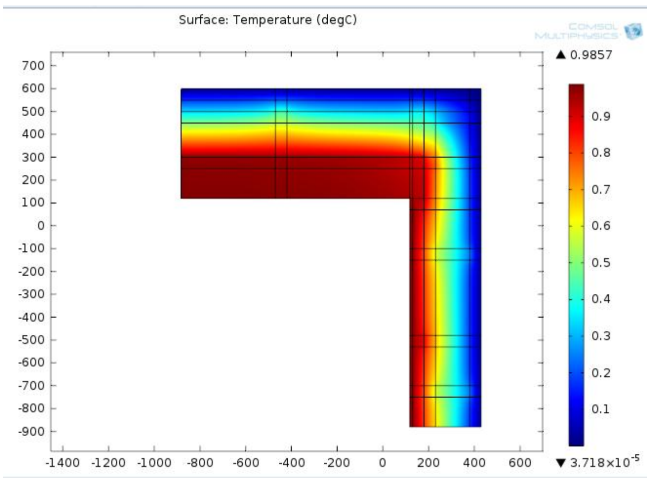


FIGURE 77. Temperature inside the Joint 15

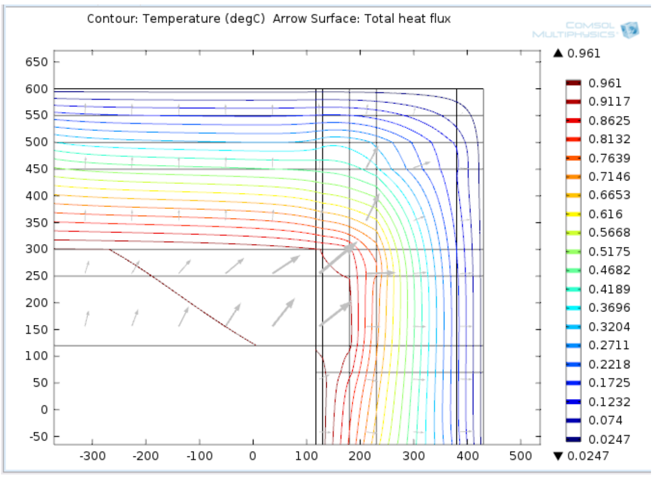


FIGURE 78. Isothermal contours inside the Joint 15

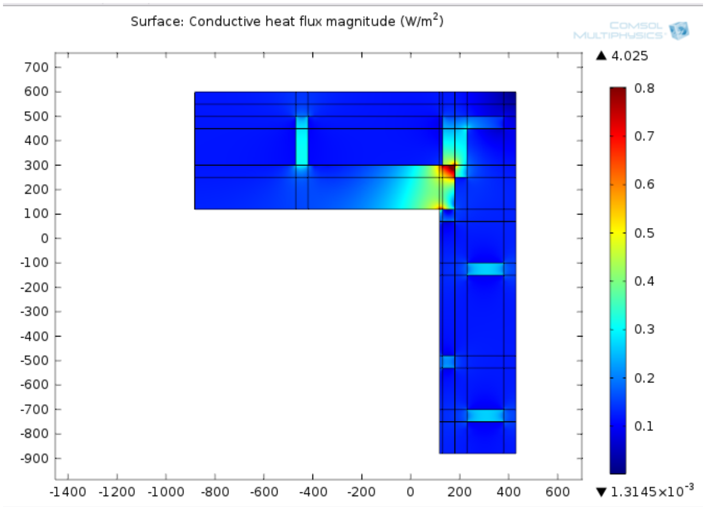


FIGURE 79. Heat flux inside the Joint 15

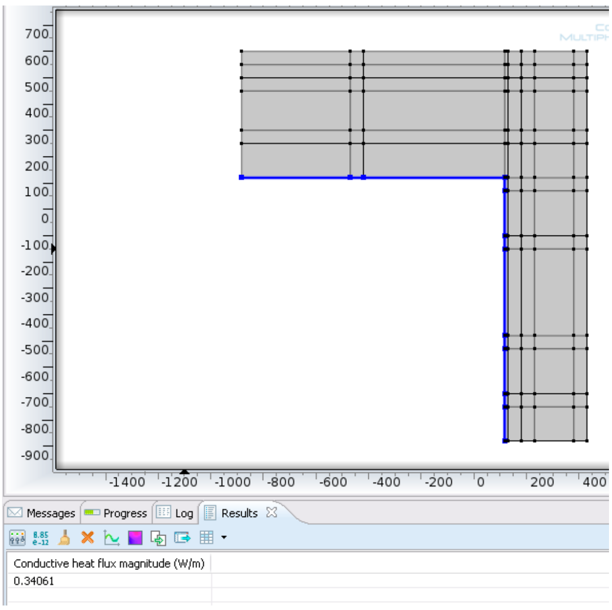


FIGURE 80. Determination of coupling coefficient for Joint 15

From figure 80 we take $L_{2D} = \frac{0,34061\ \mathrm{W/m}}{1\ K - 0\ K} = 0,34061\ W/mK$

$\psi = 0,34061\ W/(mK) - (0,1266\ W/(m^2K) \cdot\ 1\ m) - (0,1296\ W/(m^2K) \cdot\ 1,48m) =$
$= 0,02214\ W/(mK)$

Joint 10

(Appendix 1, original drawing - 163-003). Joint between external walls US2,US1 and concrete wall.

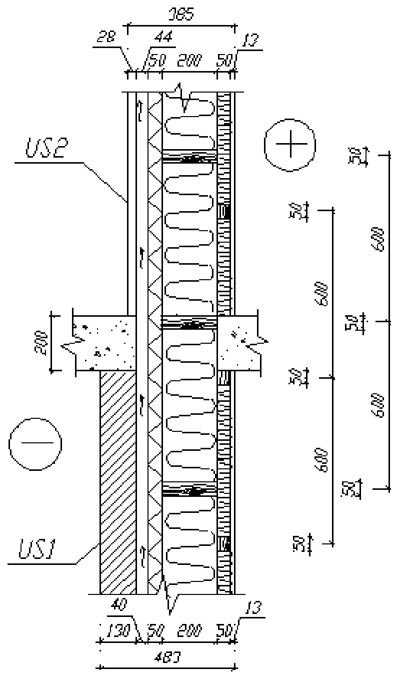


FIGURE 81. Original structure of the Joint 10

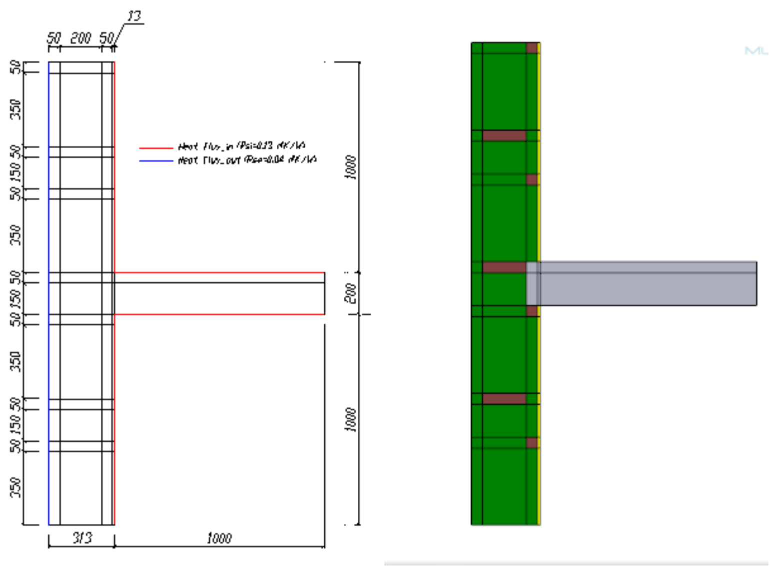


FIGURE 82. Computational geometry and materials in COMSOL Multiphysics

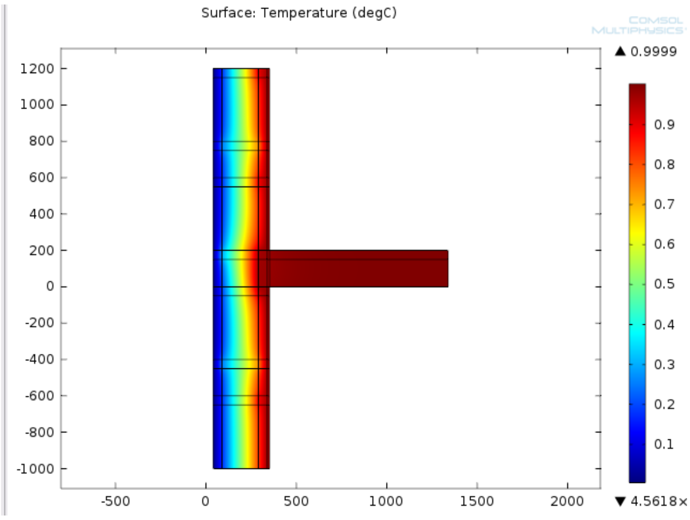


FIGURE 83. Temperature inside the joint 10 structures

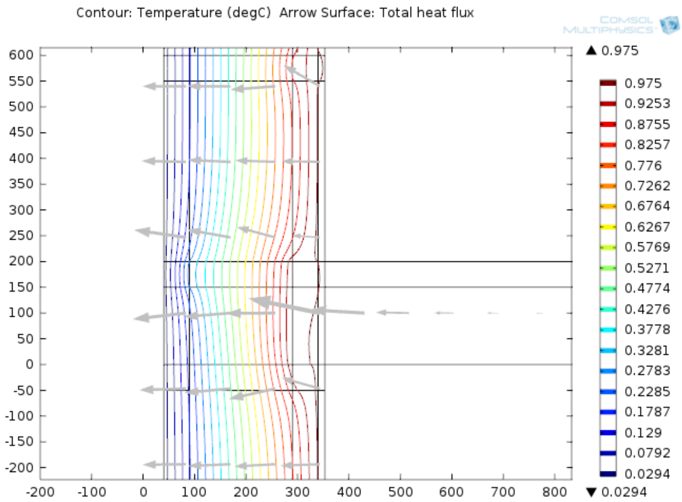


FIGURE 84. Isothermal contours inside the Joint 10 structures

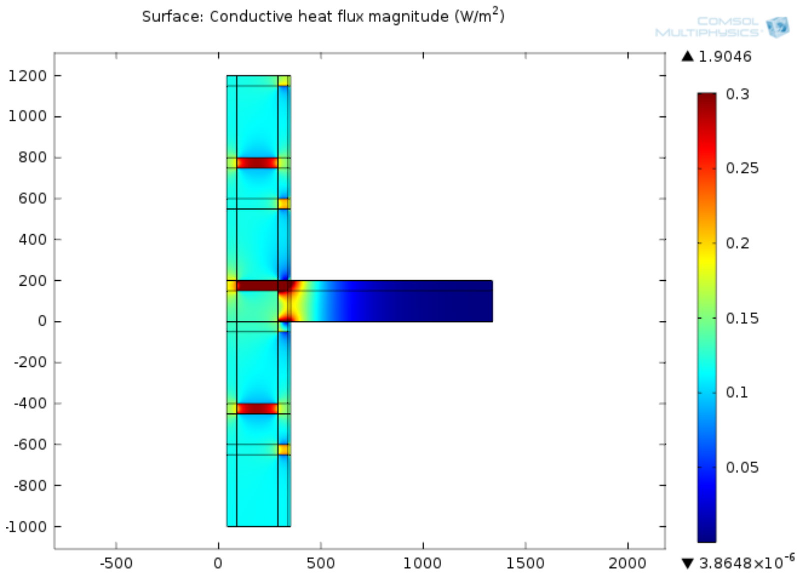


FIGURE 85 Heat flux inside the Joint 10

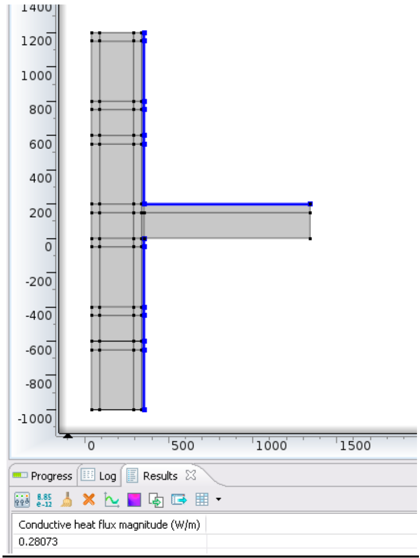


FIGURE 86. Determination of coupling factor for Joint 10

From figure 86 we take $L_{2D} = \frac{0{,}28073 \ \mathrm{W/m}}{1\,K - 0\,K} = 0{,}28073\ W/mK$

$\psi = 0{,}28073\ W/(mK) - (0{,}1296\ W/(m^2K) \cdot 1\ m) - (0{,}1296\ W/(m^2K) \cdot 1{,}2\ m) =$
$= -0{,}00448\ W/(mK)$

Joint 9

(Appendix 1, original drawing - 163-002). Junction of window and external wall US5

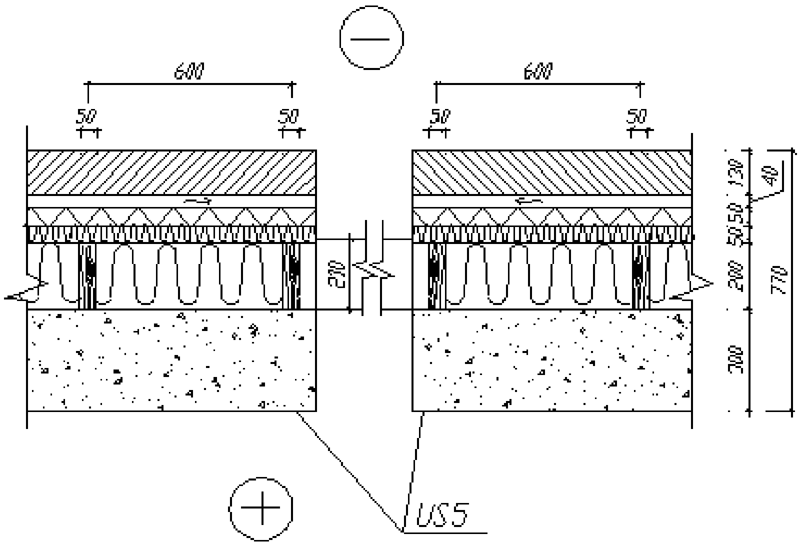


FIGURE 87. Original structure of the Joint 9

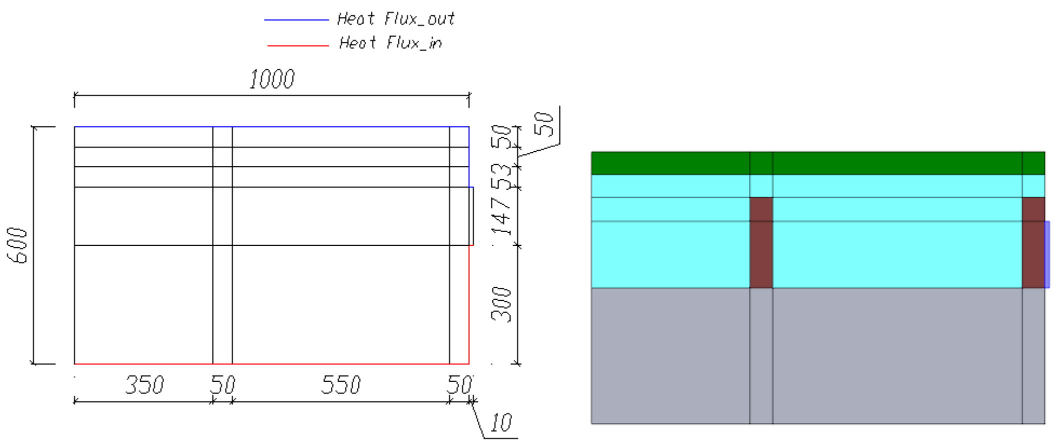


FIGURE 8886. Computational geometry and materials in COMSOL Multiphysics

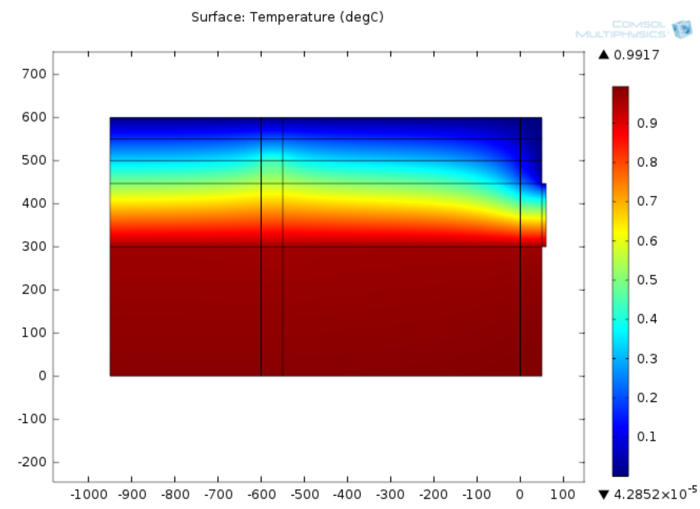


FIGURE 89. Temperature inside the Joint 9

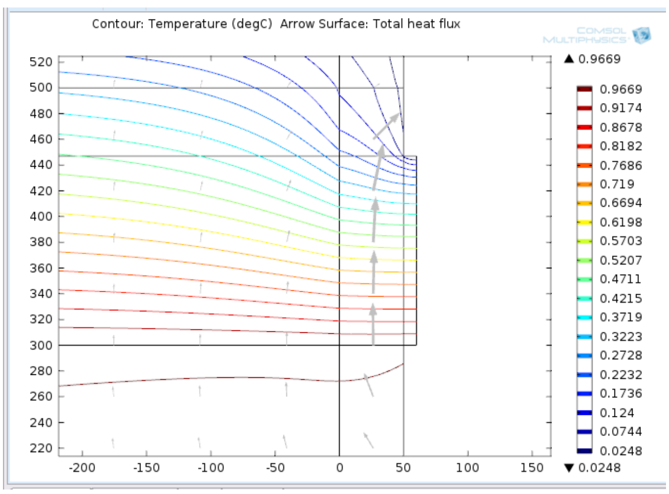


FIGURE 90. Isothermal contours inside the Joint 9

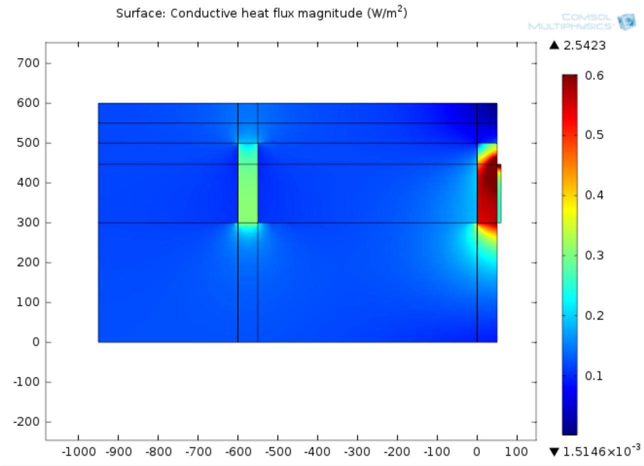


FIGURE 91. Heat flux inside the Joint 9

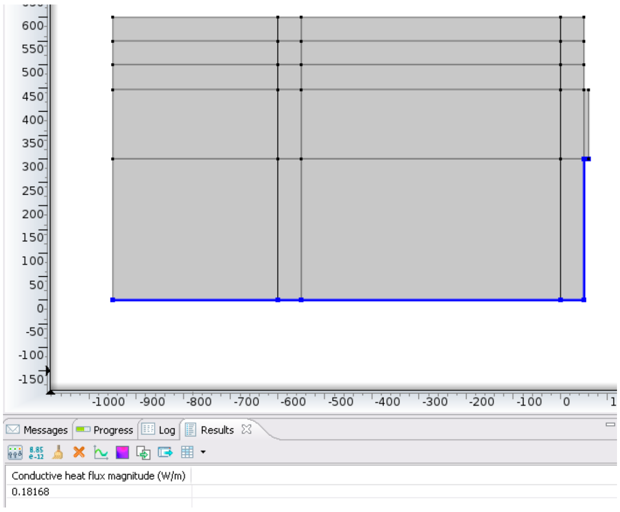


FIGURE 92. Determination of coupling coefficient for Joint 9

From figure 92 we take $L_{2D} = \frac{0{,}18168\ \mathrm{W/m}}{1\ K - 0\ K} = 0{,}18168\ W/mK$

$\psi = 0{,}18168\ W/(mK) - (0{,}1277\ W/(m^2K) \cdot\ 1\ m) = 0{,}05394\ W/(mK)$

<u>Joint 11</u>

(Appendix 1, original drawing - 163-002) – junction of window and external wall US3

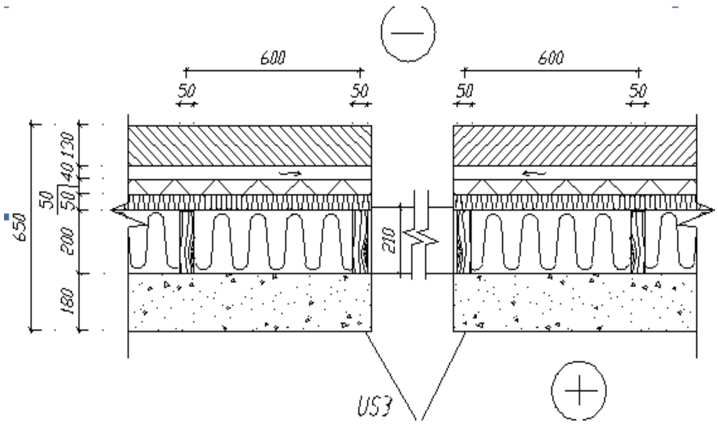


FIGURE 93. Original structure of the Joint 11

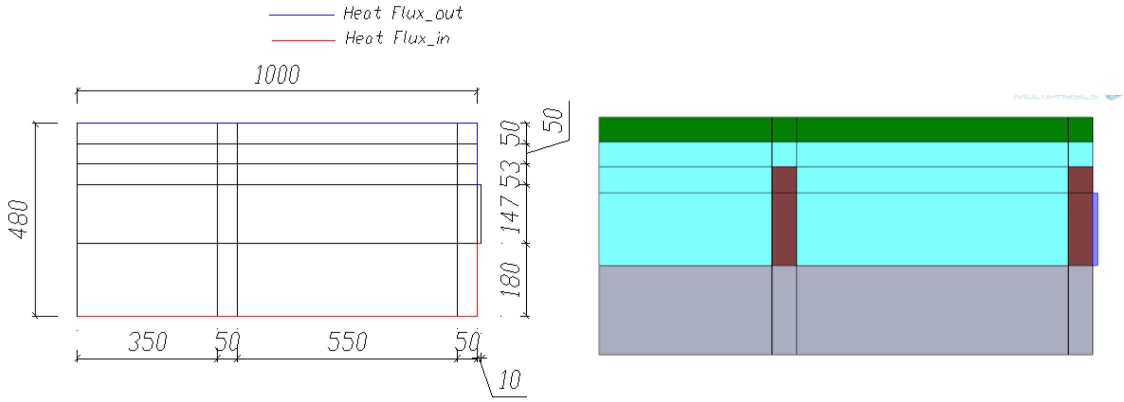


FIGURE 94. Computational geometry and materials in COMSOL Multiphysics

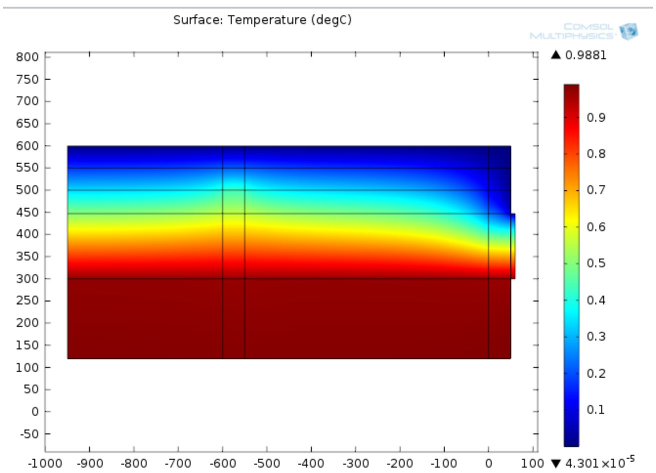


FIGURE 95. Temperature inside the Joint 11 structures

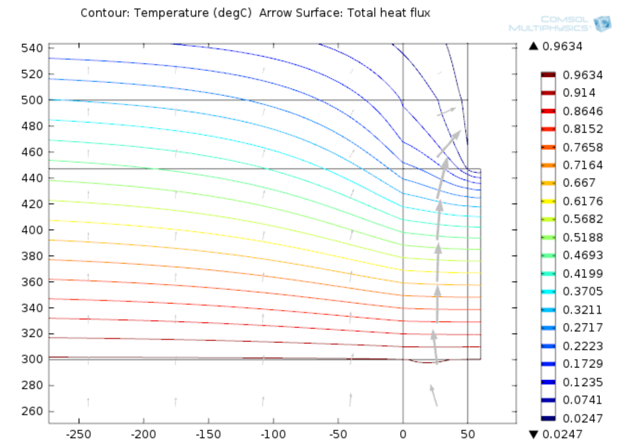


FIGURE 96. Isothermal contours inside the Joint 11

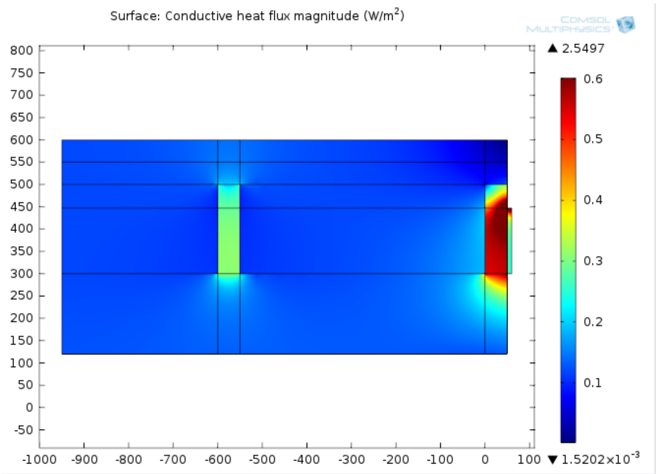


FIGURE 97. Heat flux inside the Joint 11

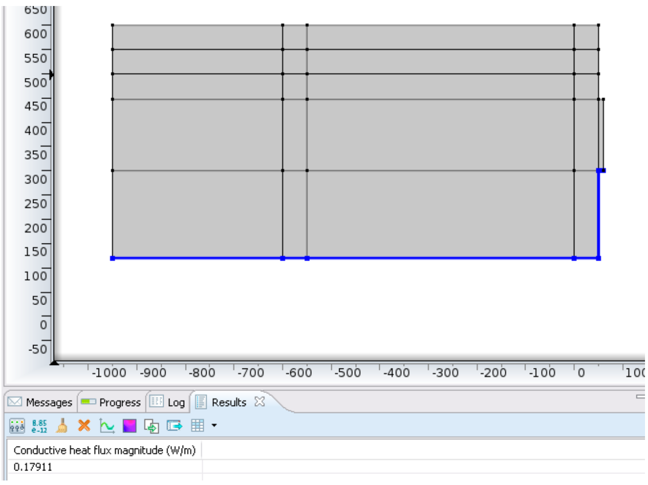


FIGURE 98. Determination of coupling coefficient for Joint 11

From figure 98 we take $L_{2D} = \frac{0{,}17911\ \mathrm{W/m}}{1\ K - 0\ K} = 0{,}17911 W/mK$

$\psi = 0{,}17911\ W/(mK) - (0{,}1266\ W/(m^2K) \cdot\ 1\ m) = 0{,}05250\ W/(mK)$

<u>Joint 12</u>

(Appendix 1, original drawing - 163-013) – junction of window and external wall US1

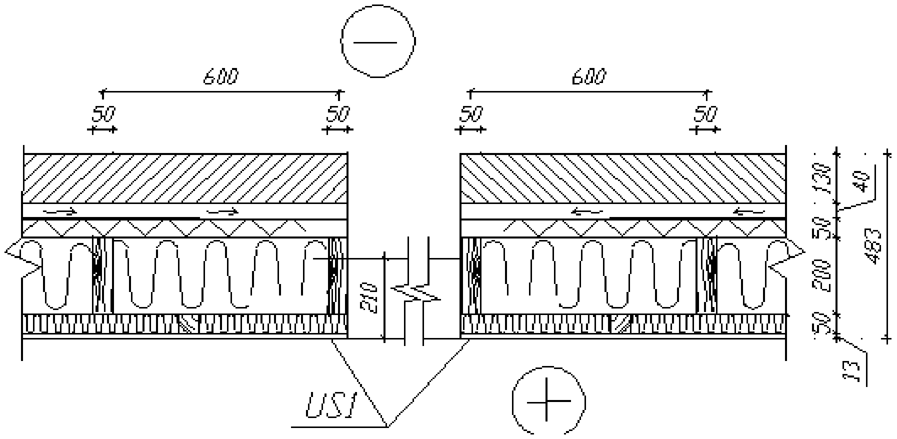


FIGURE 99. Original structure of the Joint 12

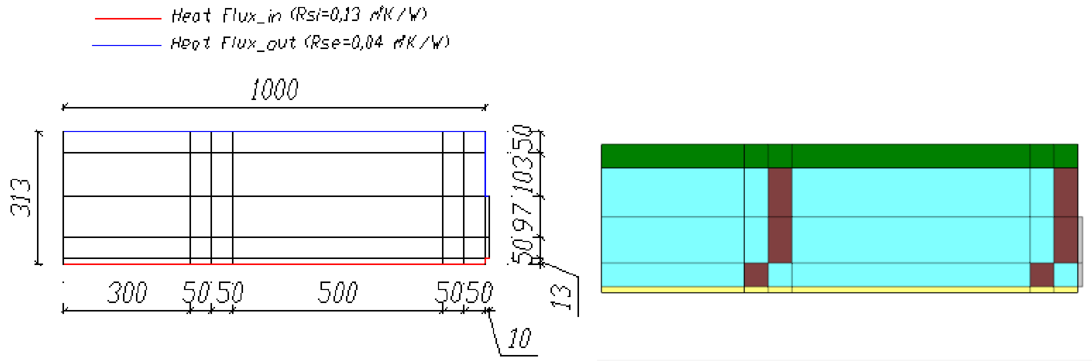


FIGURE 100. Computational geometry and materials in COMSOL Multiphysics

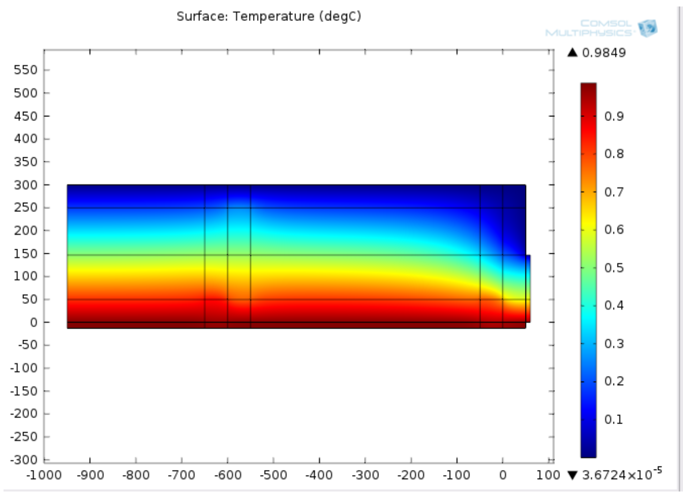


FIGURE 101. Temperature inside the Joint 12

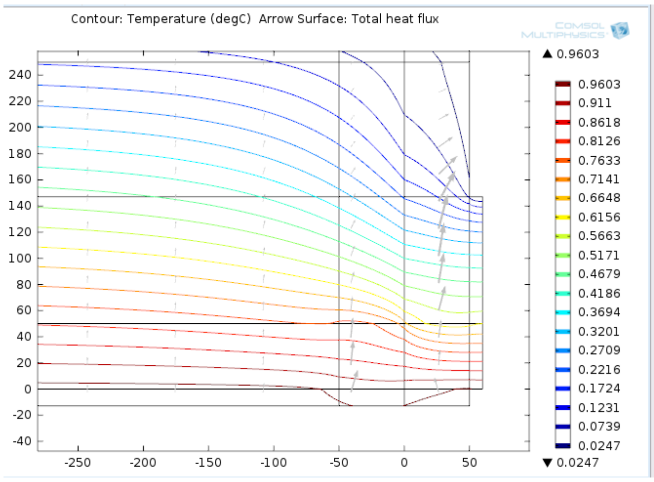


FIGURE 102. *Isothermal contours inside the Joint 12*

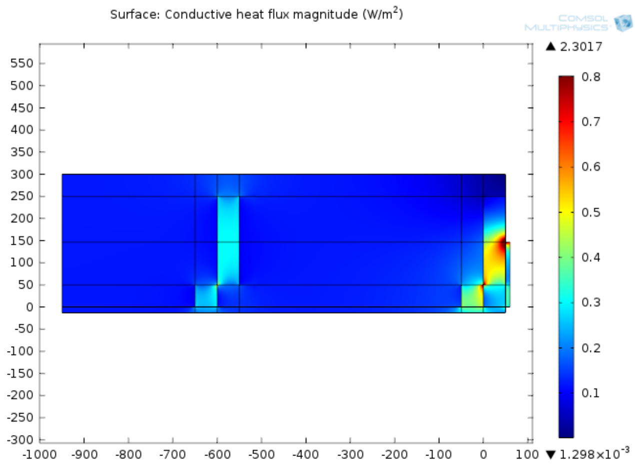


FIGURE 103. Heat flux inside the Joint 12

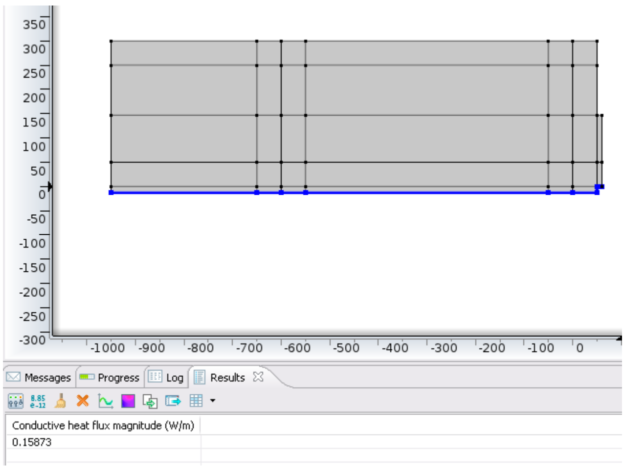


FIGURE 104. Determination of coupling coefficient for Joint 12

From figure 104 we take $L_{2D} = \frac{0{,}15873 \mathrm{W/m}}{1\,K - 0\,K} = 0{,}15873\ W/mK$

$\psi = 0{,}15873\ W/(mK) - (0{,}1296\ W/(m^2K) \cdot 1\ m) = 0{,}02909\ W/(mK)$

Joint 16

(Appendix 1, original drawing - 163-00?) – junction of window and external wall US2.1

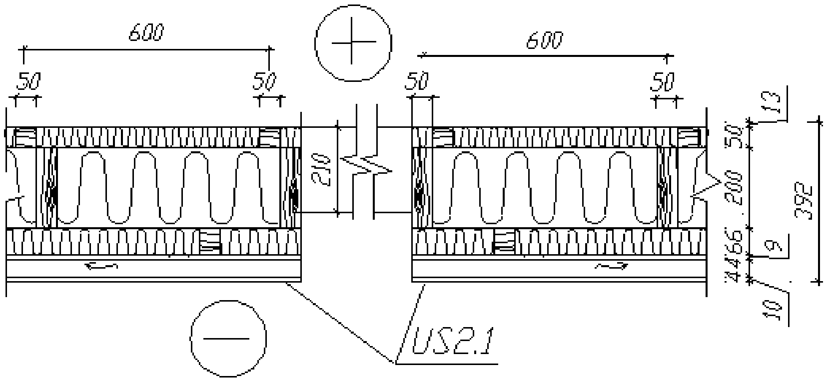


FIGURE 105. Original structure of the Joint 16

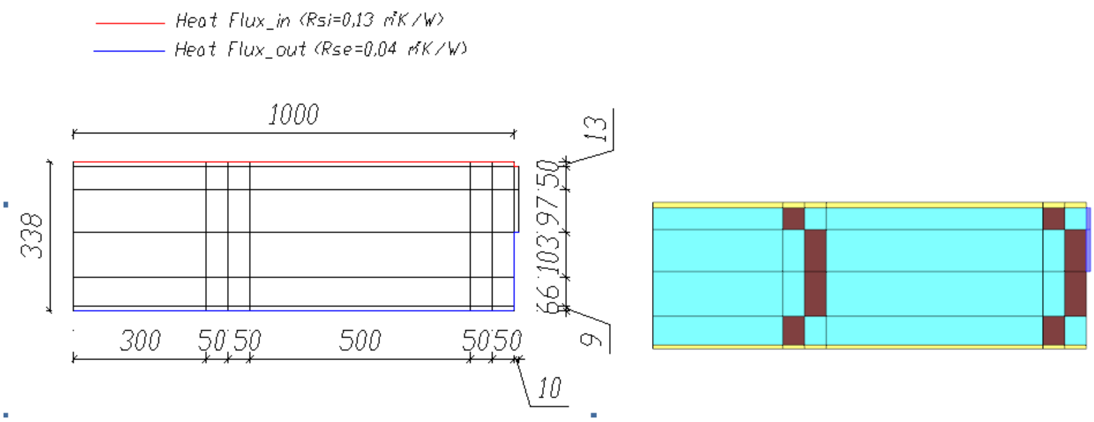


FIGURE 106. Computational geometry and materials in COMSOL Multiphysics

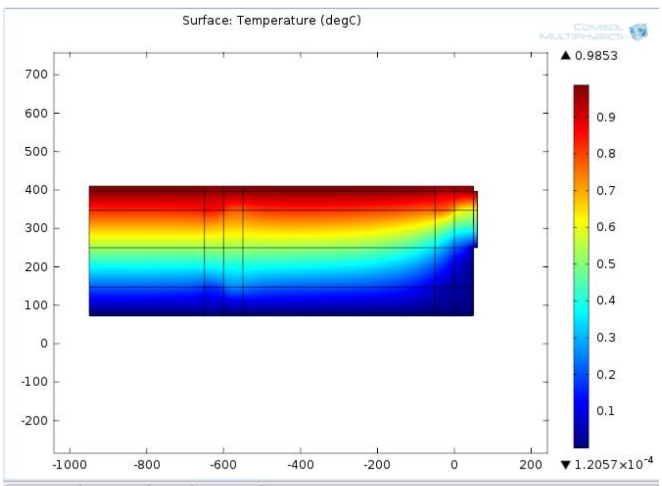


FIGURE 107. Temperature inside the Joint 16

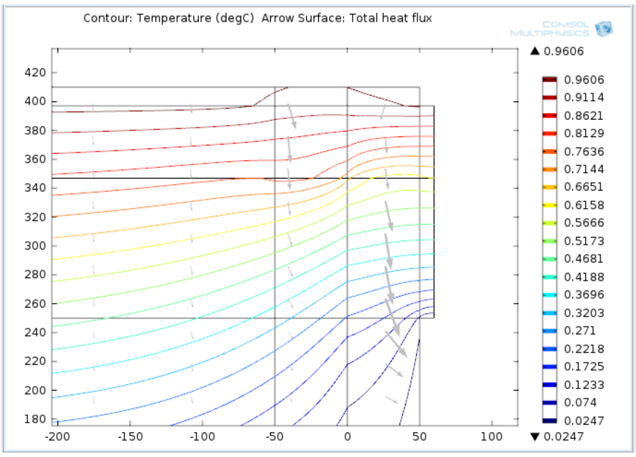


FIGURE 108. Isothermal contours inside the Joint 16

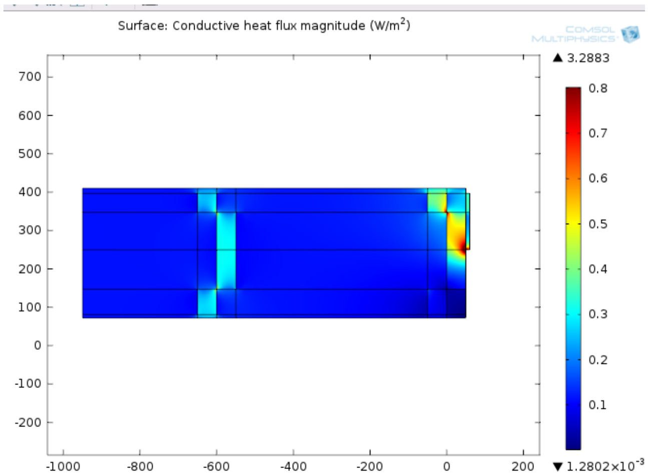


FIGURE 109. Heat flux inside the Joint 16

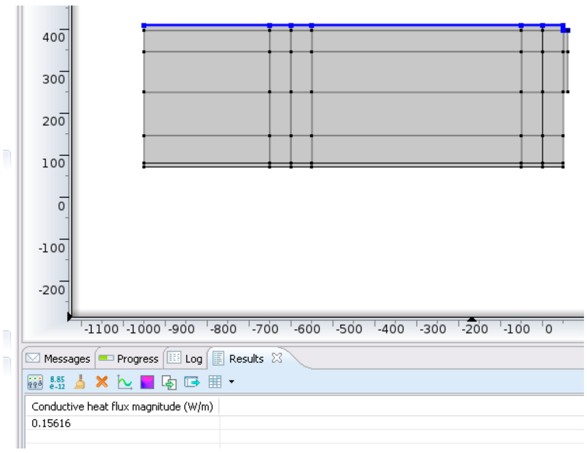


FIGURE 110. Determination of coupling coefficient for Joint 16

From figure 110 we take $L_{2D} = \frac{0{,}15616\ \mathrm{W/m}}{1\ K - 0\ K} = 0{,}15616 W/mK$

$\psi = 0{,}15616\ W/(mK) - (0{,}1262\ W/(m^2K) \cdot\ 1\ m) = 0{,}02999\ W/(mK)$

<u>Joint 7</u>

(Appendix 1, original drawing - 163-008) - bottom junction of window and external wall US4

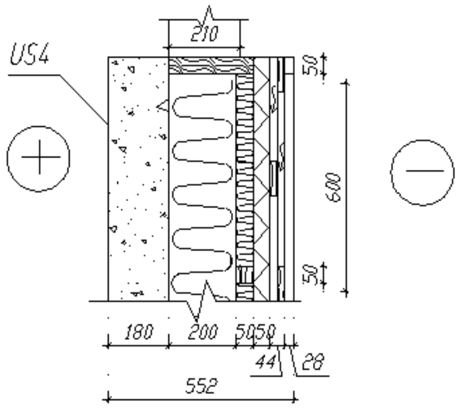


FIGURE 111. Original structure of the Joint 7

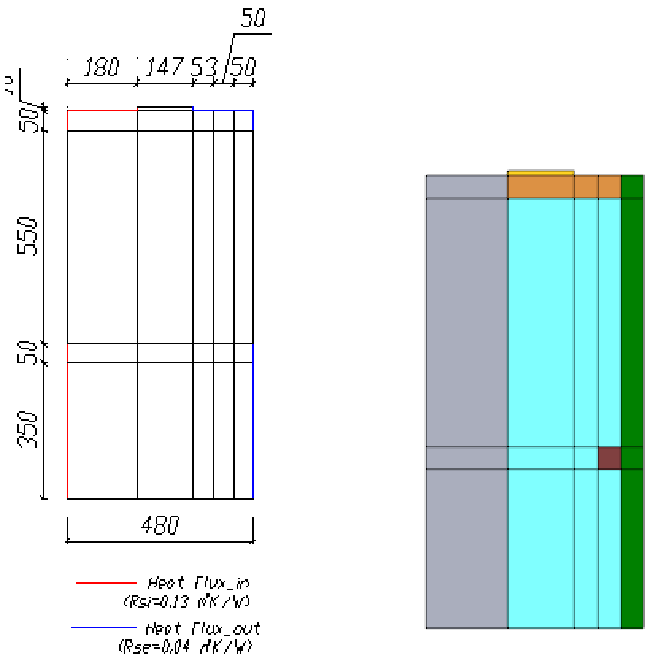


FIGURE 112. Computational geometry and materials in COMSOL Multiphysics

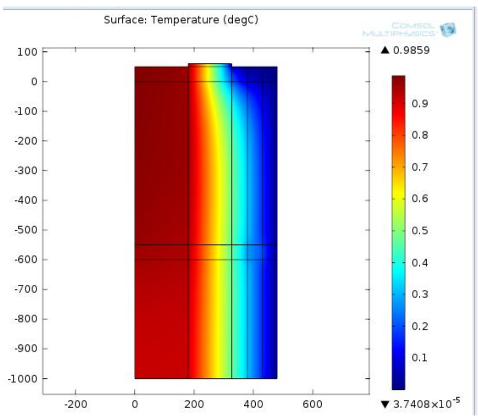


FIGURE 113. Temperature inside the Joint 7

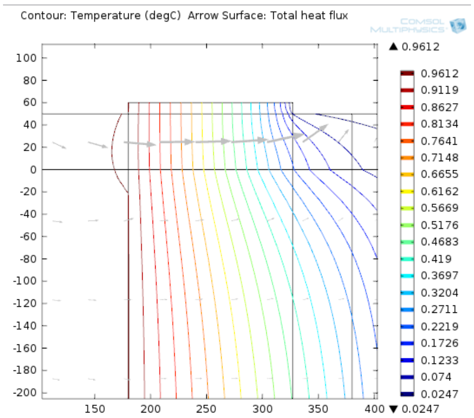


FIGURE 114. Isothermal contours inside the Joint 7

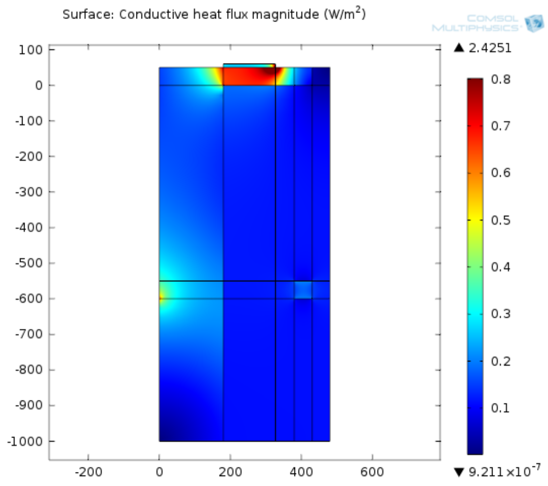


FIGURE 115. Heat flux inside the Joint 7

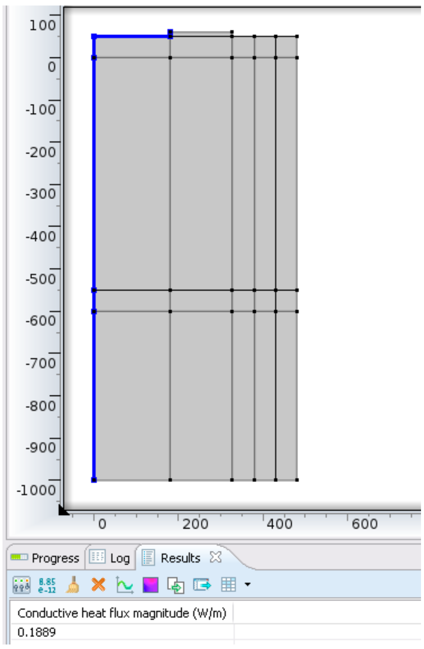


FIGURE 116. Determination of coupling coefficient for Joint 7

From FIGURE we take $L_{2D} = \frac{0{,}1889\ W/m}{1\ K - 0\ K} = 0{,}1889\ W/mK$

$$\psi = 0{,}1889 \frac{W}{mK} - \left(0{,}1289 \frac{W}{m^2K} \cdot 1{,}05\ m\right) = 0{,}05355 \frac{W}{mK}$$

Joint 19

(Appendix 1, original drawing – 302925-17). Joint between external walls US3 and US2.1

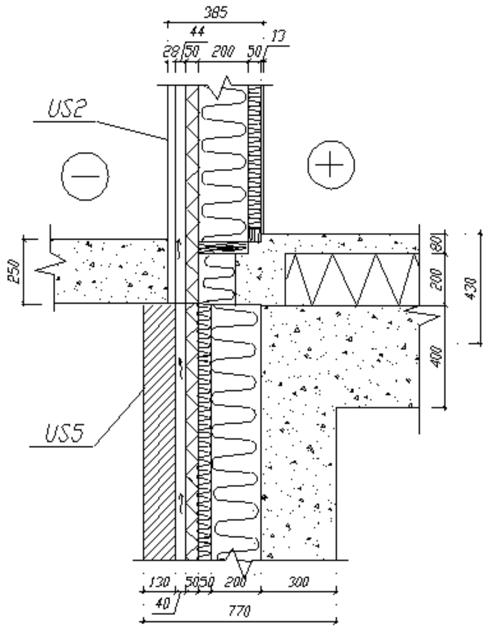


FIGURE 117. Original structure of the joint 19

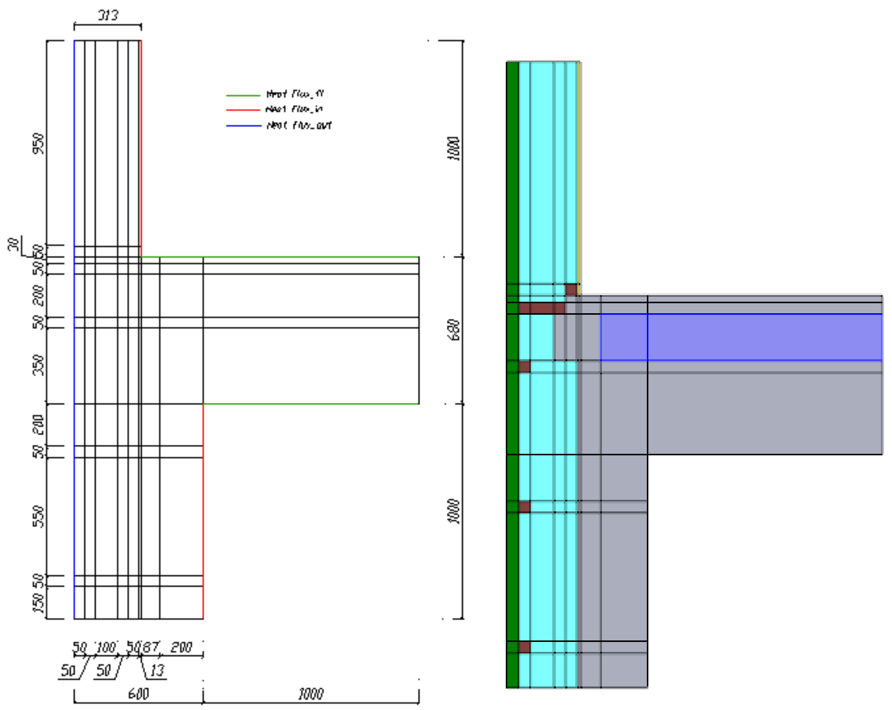


FIGURE 118. Computational geometry and materials in COMSOL Multiphysics

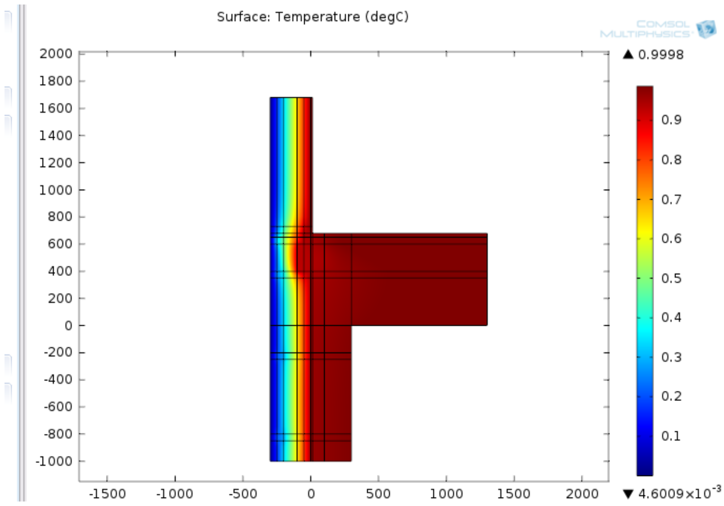


FIGURE 119. Temperature inside the joint 19 structures

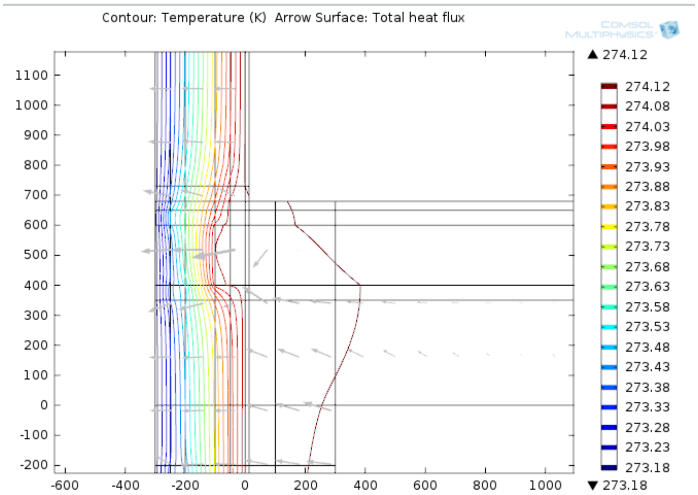


FIGURE 120. Isothermal contours inside the Joint 19

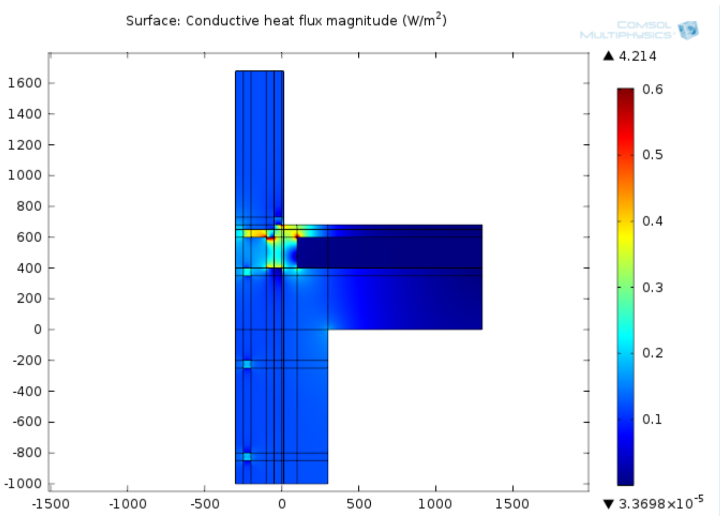


FIGURE 121. Heat flux inside the Joint 19

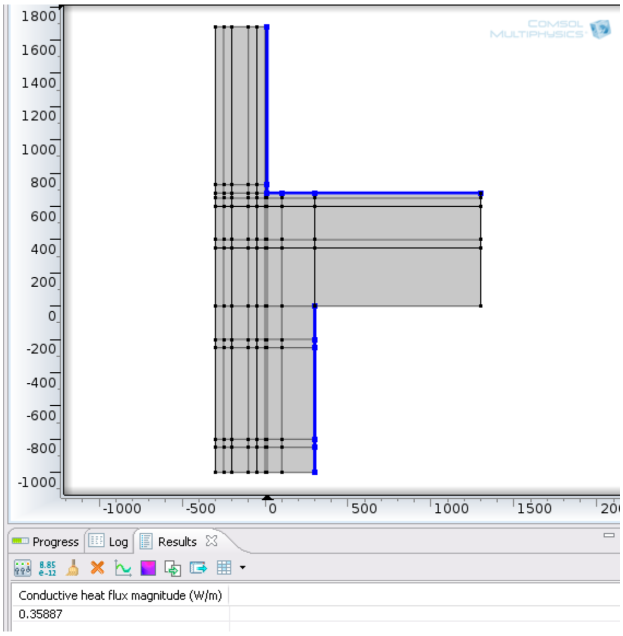


FIGURE 122. Determination of coupling coefficients for the Joint 19

From figure 122 we take $L_{3D} = \frac{0{,}35587\ W/m}{1\ K - 0\ K} = 0{,}35587 W/mK$

$$\psi = 0{,}35887\ W/(mK) - (0{,}1296\ W/(m^2K) \cdot 1{,}08\ m) - (0{,}1277\ W/(m^2K) \cdot 1{,}6\ m) =$$
$$= 0{,}01447\ W/(mK)$$

Joint 20

(Appendix 1, original drawing – 302925-23) – joint of floor structure and external walls US2

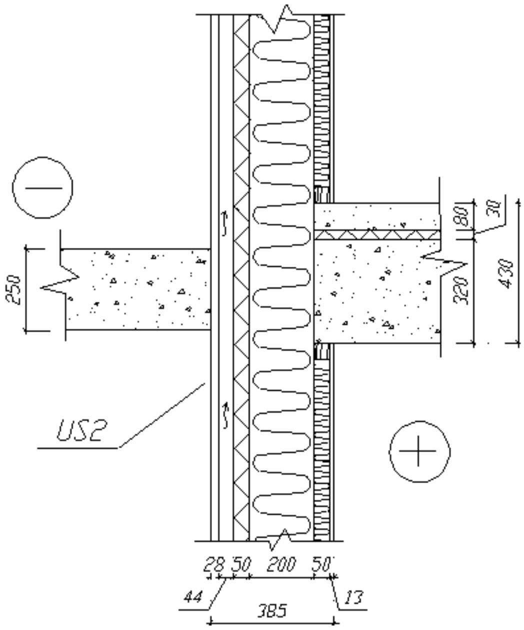


FIGURE 123. Original structure of the Joint 20

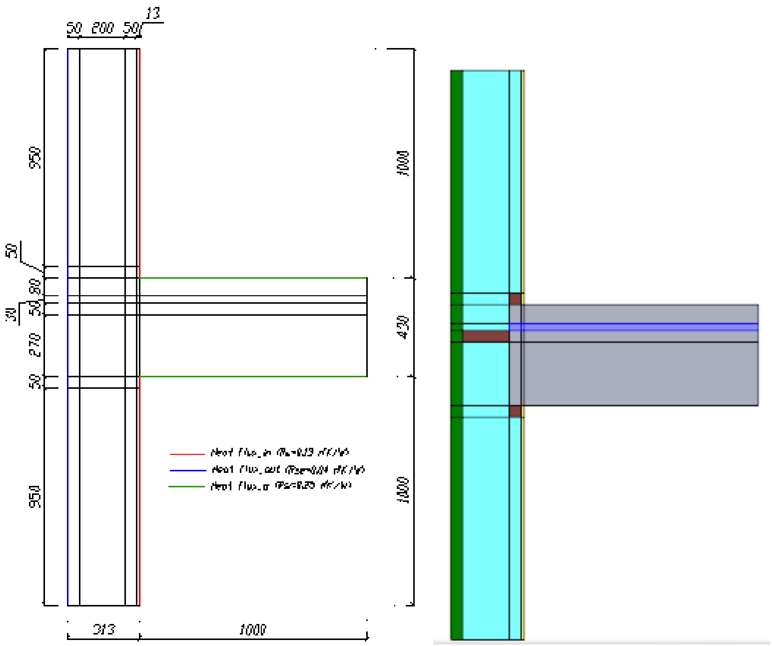


FIGURE 124. Computational geometry and materials in COMSOL Multiphysics

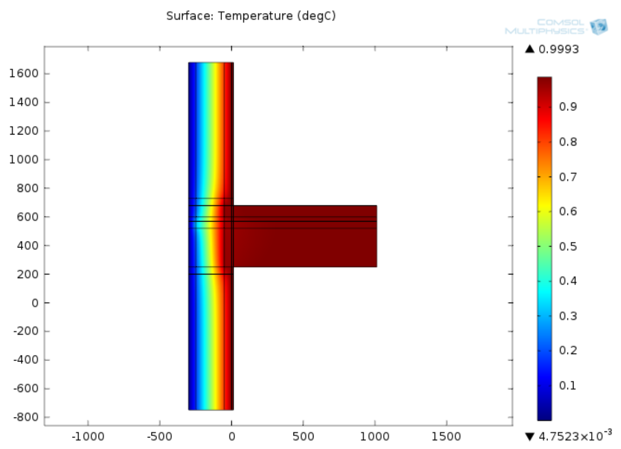


FIGURE 125. Temperature inside the Joint 20

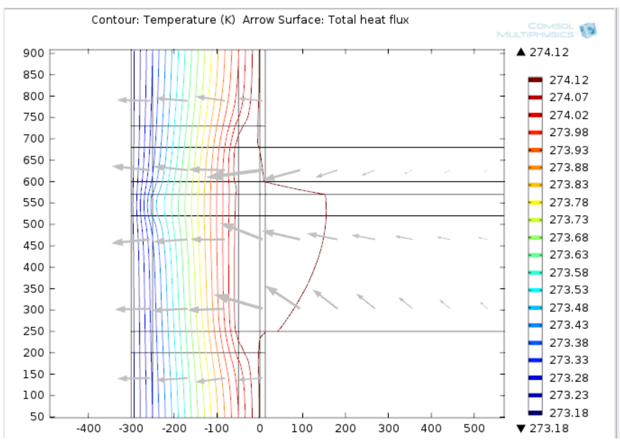


FIGURE 126. Isothermal contours inside the Joint 20 structures

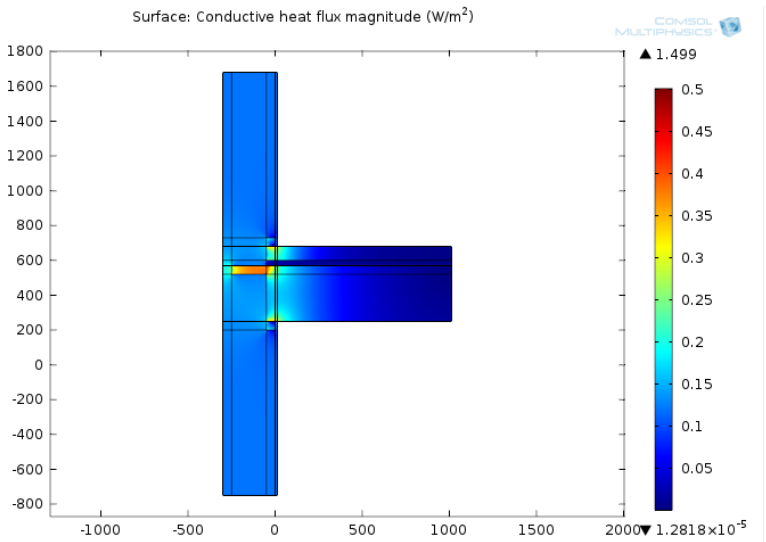


FIGURE 127. Heat flux inside the Joint 20

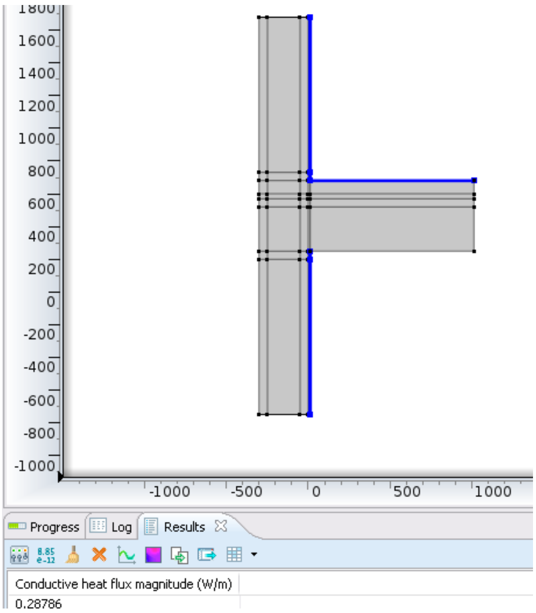


FIGURE 128. Determination of coupling coefficients for the Joint 20

From FIGURE 128 we take $L_{2D} = \frac{0{,}28786 \mathrm{W/m}}{1\,K - 0\,K} = 0{,}28786 W/mK$

$\psi = 0{,}28786\ W/(mK) - (0{,}1296\ W/(m^2K) \cdot 2{,}43\ m) = -0{,}02716\ W/(mK)$

<u>Joint 22</u>

(Appendix 1, original drawing – 302925-24). Jjunction of the roof YP1 and external wall US2

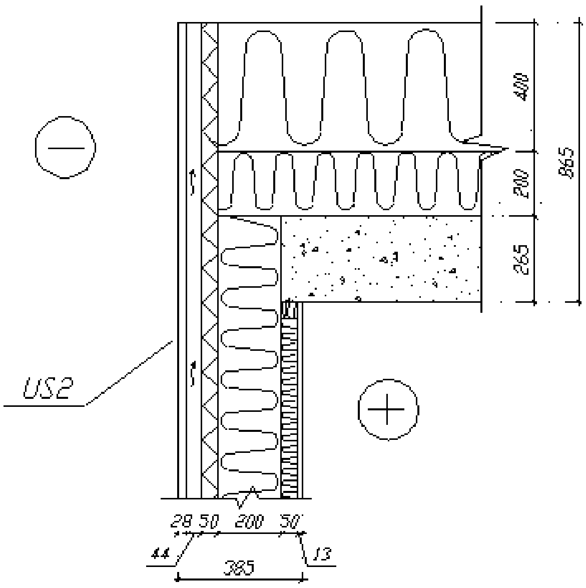


FIGURE 129. Original structure of the Joint 22

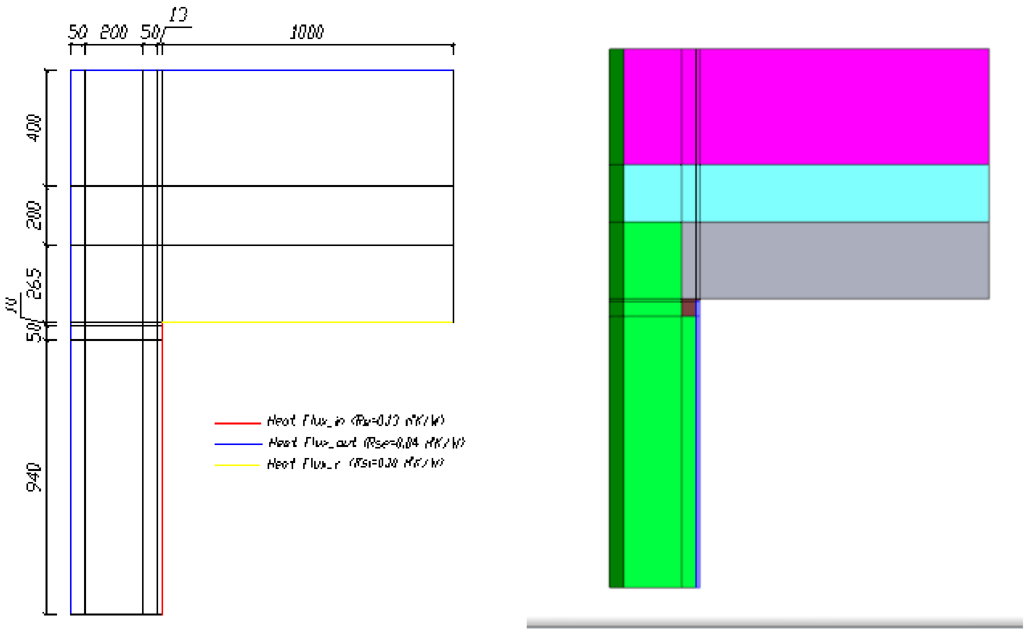


FIGURE 130. Computational geometry and materials in COMSOL Multiphysics

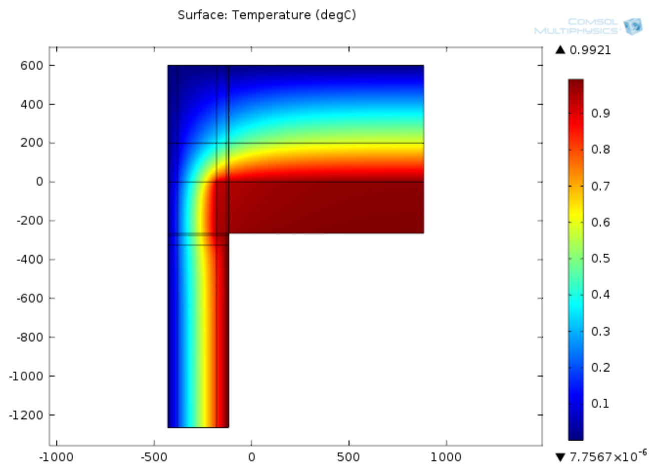


FIGURE 131. Temperature inside the Joint 22 structures

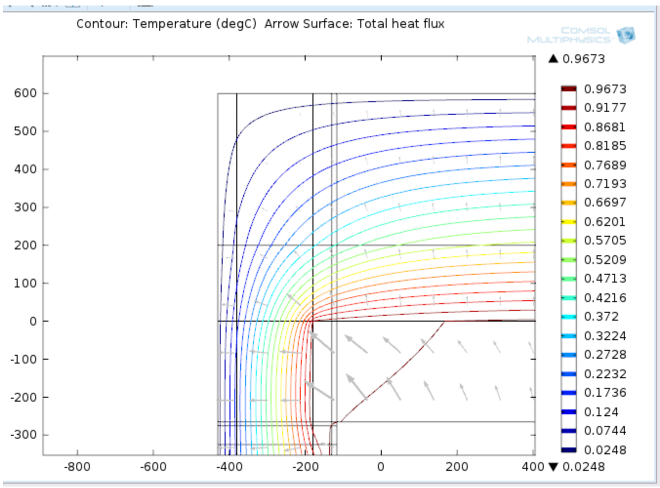


FIGURE 132. Isothermal contours inside the Joint 22 structures

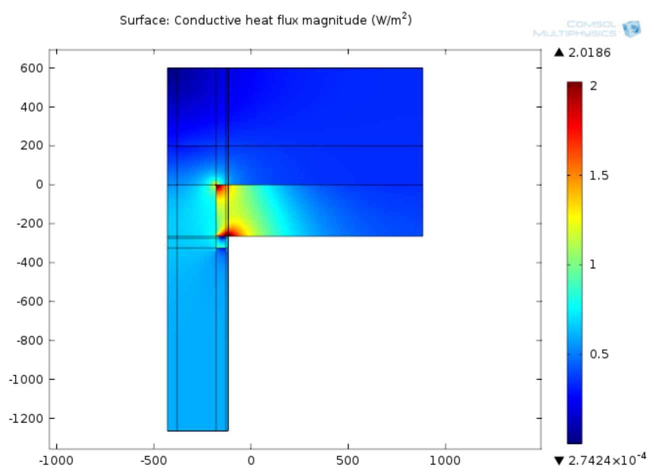


FIGURE 133. Heat flux inside the Joint 22

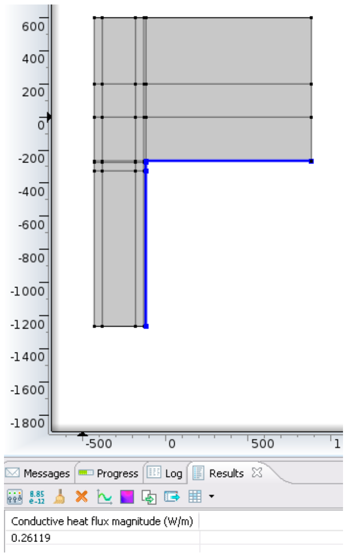


FIGURE 134. Heat flux magnitude of the Joint 22

From figure 134 we take $L_{2D} = \frac{0{,}26119\ \text{W/m}}{1\ K - 0\ K} = 0{,}26119\ W/mK$

$\psi = 0{,}26119\ W/(mK) - (0{,}1296\ W/(m^2K) \cdot 1m) - (0{,}06712\ W/(m^2K) \cdot 1{,}313m) =$

$= 0{,}13155\ W/(mK)$

Joint 18

(Appendix 1, original drawing - 163-008) – junction of the roof and wall US2

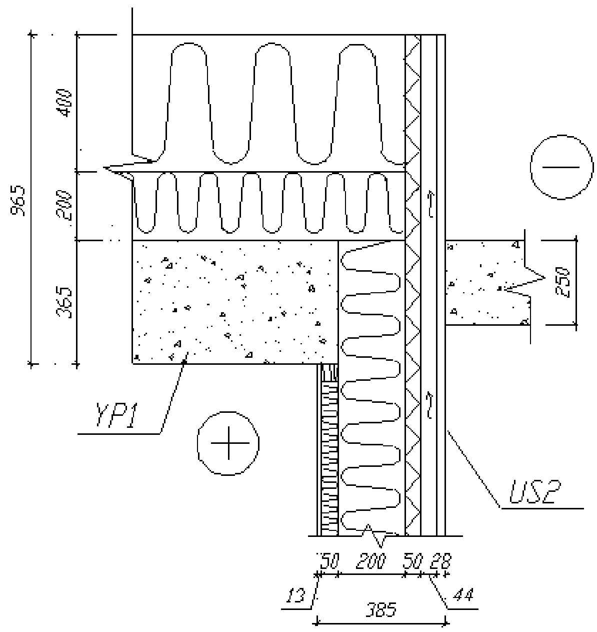


FIGURE 135. Original structure of the Joint 18

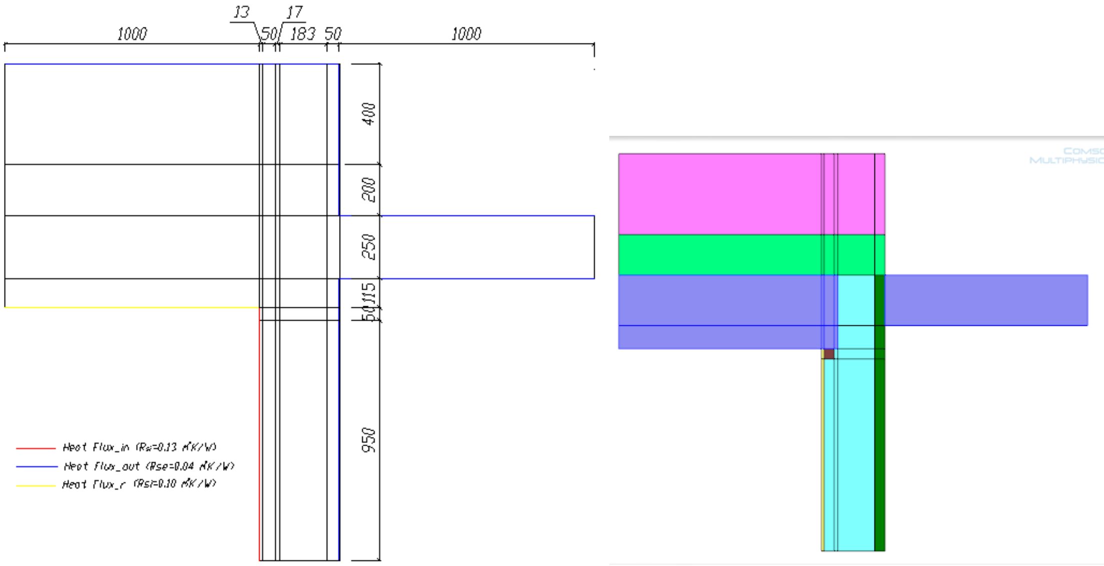


FIGURE 136. Computational geometry and materials in COMSOL Multiphysics

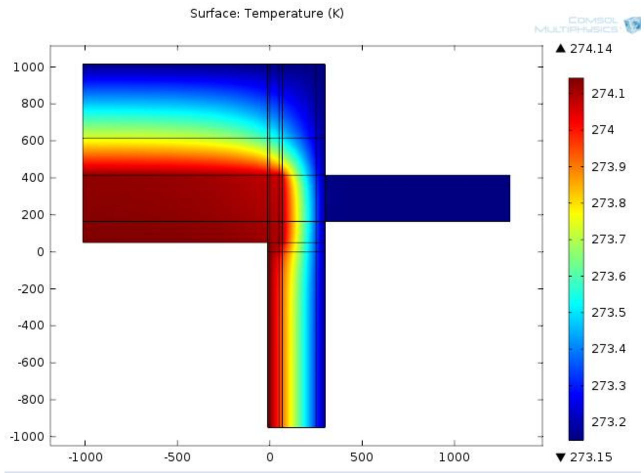


FIGURE 137. Temperature inside the Joint 18 structures

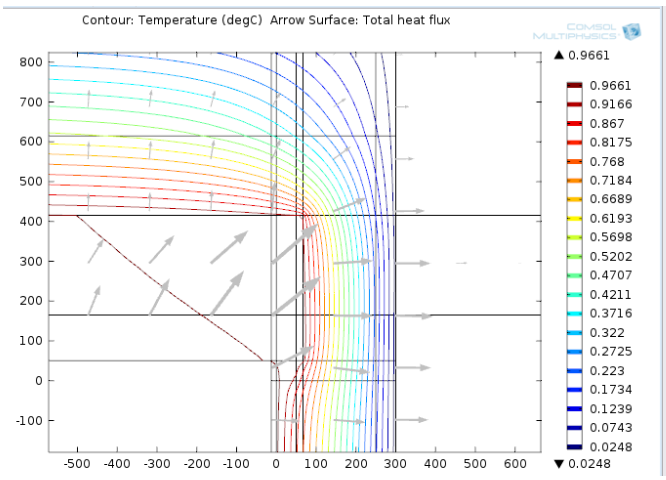


FIGURE 138. Isothermal contours inside the Joint 18 structures

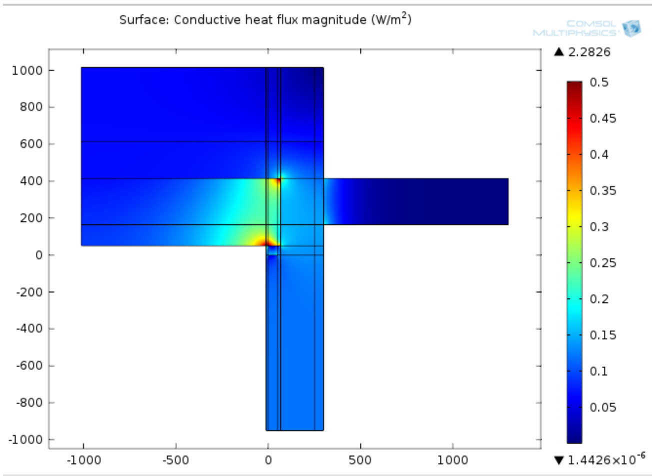


FIGURE 139. Heat flux inside the Joint 18

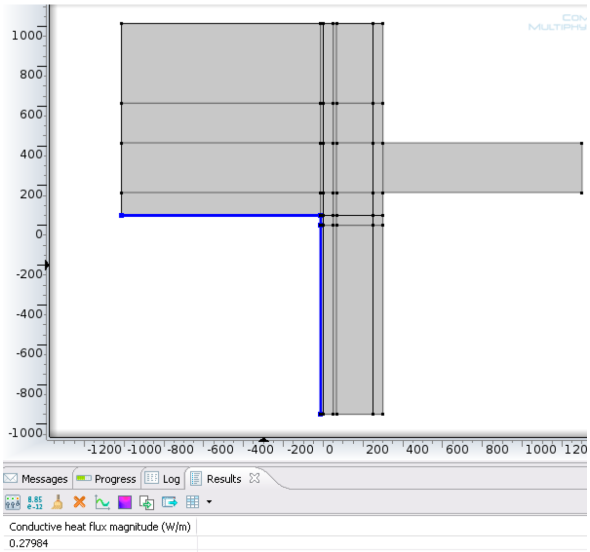


FIGURE 140. Heat flux magnitude of the Joint 18

From figure 140 we take $L_{2D} = \frac{0{,}27984\ \mathrm{W/m}}{1\ K - 0\ K} = 0{,}27984\ W/mK$

$$\psi = 0{,}27984\ W/(mK) - (0{,}1296\ W/(m^2K) \cdot\ 1m) - (0{,}06685\ W/(m^2K) \cdot\ 1{,}313m) =$$
$$= \ 0{,}15020\ W/(mK)$$