This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

RE^4 Project

REuse and REcycling of CDW materials and structures in energy efficient pREfabricated elements for building REfurbishment and construction

D3.4

Hygrothermal Modelling

Author(s)[1]:	STRESS, RINA-C
Date:	29/05/2019
Work package:	WP3 - Innovative concept for modular/easy installation and disassembly of eco-friendly prefabricated elements
Distribution[2]	PU
Status[3]:	Final
Abstract:	The document describes the outcome of the SubTask 3.4.2, based on hygrothermal analyses of the developed RE^4 timber façade and concrete sandwich panel. In particular, Finite Element Analyses have been performed in order to assess a global transmittance value (U value) to both building elements, followed by surface and interstitial condensation analyses.
File Name	RE4_D3.4_Hygrothermal_Modelling_Final_V2.0.docx

Version	Date	Description	Written By	Approved by
V0.0	21/05/2019	First version for quality check	RINA-C, STRESS	RI.SE
V1.0	28/05/2019	Revised version	RINA-C, STRESS	RI.SE
V2.0	29/05/2019	Final version ready for submission	RINA-C, STRESS	CETMA

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[1] *Just mention the partner(s) responsible for the Deliverable*

[2] *PU: Public, RE: restricted to a group specified by the consortium, CO: Confidential, only for members of the consortium; Commission services always included.*

[3] *Draft, Revised, Final*

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LIST OF ACRONYMS AND ABBREVIATIONS

CAD	Computer Aided Design
FE	Finite Element
FEM	Finite Element Modelling
NE	Northern Europe
SE	Southern Europe

1. EXECUTIVE SUMMARY

This document describes the results of the *Subtask 3.4.2. Hygrothermal Modelling*, under the work package *WP3 - Innovative concept for modular/ easy installation and disassembly of eco-friendly prefabricated elements*.

The aim of the Subtask is to assess the global transmittance (U value) of the RE^4 timber façade and of the RE^4 concrete sandwich panels, evaluating the influence of possible thermal bridges through thermal Finite Element (FE) analyses. The results of the latter form the input parameters for the evaluation of the superficial and the interstitial condensation.

Starting from technical drawings, FE models have been developed by modelling the layering of the repetitive units for each type of RE^4 timber façade and concrete sandwich elements. Specifically, different designs for Northern Europe and Southern Europe have been analysed. By using a defined and widely described approach, the temperature distribution has been employed with the aim of evaluating the effect of thermal bridges in both types of elements. Concerning the timber façade an impactful effect of the studs has been verified, assessing the global transmittance by including the effect related to its presence. The obtained results have shown a U value lower than 0.3 W/m^{2}K for each type of façade analysed. Following the same approach, the effect of the pin connectors on the temperature distribution of the concrete sandwich panel has been studied. The results have demonstrated that these thermal bridges could be neglected, assessing a U value lower than 0.3 W/m^{2}K for the structure employed in cold climate and a value lower than 0.4 W/m2K for the one addressed to warm climate.

The output of FE analyses has been finally used in order to evaluate possible surface or interstitial condensation. The calculations have shown that no condensation phenomena occur in each structure.

2. INTRODUCTION

The aim of this deliverable is to present the numerical Finite Element calculation performed on the structures named RE^4 timber façade and RE^4 concrete sandwich panel, by verifying the following performance:

- thermal performance,
- condensation performance.

The approach and the procedure adopted in order to assess the hygrothermal behaviour of the analysed components are described in Chapter 3.

Chapter 4 reports the main results obtained by the preliminary simulations performed in order to support the definition of the final structures. The used software is briefly described in Chapter 5.

Chapter 6 summarizes the layering and the dimension of each timber façade and of the two concrete sandwich panels analysed, listing, in addition, the employed material properties.

The development of the FE models and the related assumptions are described in Chapter 7, while the boundary conditions are defined in Chapter 8.

Finally, the obtained results and the conclusions are exposed in Chapter 9 and Chapter 10 respectively.

3. HYGROTHERMAL ASSESSMENT APPROACH

The aim of the work is to assess the thermal transmittance or heat transfer coefficient (U value) of the components/elements according to the relevant standards:

- "EN ISO 6946: Building components and building elements- Thermal resistance & thermal transmittance – calculation method"; [1]
- "EN ISO 10211: Thermal bridges in building construction. Heat flows and surface temperatures. Detailed calculations" [2].

The overall thermal performances have been carried out by means of 1D analytic calculation, mainly according to the standard EN ISO 6946. 2D and 3D detailed analyses of the possible thermal bridges will be carried out by means of FE analysis (considering mainly the standards EN ISO 6946 [1] and EN ISO 10211 [2]). The analysis has been performed in steady-state condition.

Finally, the outputs of the thermal FE analyses have provided the necessary data for the hygrothermal analysis (condensation performance).

3.1. Thermal assessment approach

The global heat transfer coefficient Ug has been calculated according to the following formula that takes into account the 2D and 3D thermal bridges coefficients C_1 and C_2:

$$U_g = \frac{U_{1D} \cdot S + \sum_i C_{1,i} \cdot L_i + \sum_j C_{2,j} \cdot n_j}{S}$$

where:

- U_{1D} : 1-D U value (according to EN ISO 6946 [W/m^{2}K])
- S: exchanging surface
- $C_{1,i}$: i^{th} 2-D thermal bridge ([W/mK] according to EN ISO 10211)
- L_i: length of the i^{th} 2-D thermal bridge
- C_2: j^{th} 3-D thermal bridge [W/K]
- n_j: number of j^{th} 3D thermal bridges
- U_g: total heat exchange coefficient [W/m^{2}K]

The 2D and 3D thermal bridges coefficients, C1 and C2, have been calculated according to the following formulas:

$$C_{1,i} = \frac{(U_{g-2D} - U_{1D}) \cdot S}{L_i}$$

$$C_2 = \frac{U_g \cdot S - U_{1D} \cdot S - \sum_i C_{1,i} \cdot L_i}{n}$$

where:

- $U_{g\text{-}2D}$: total heat exchange coefficient arising from 2D FE analysis,
- $U_{g\text{-}3D}$: total heat exchange coefficient arising from 3D FE analysis.

The total heat exchange coefficients has been calculated according to the following formula:

$$\mathrm{U}_g = \frac{\dot{Q}}{\Delta T * S}$$

where $\dot{Q}$ is the heat calculated from the FE analysis [W].

Figure 1 illustrates an example of a building façade with identification of 1-D, 2-D and 3-D domains for thermal transmittance calculation.

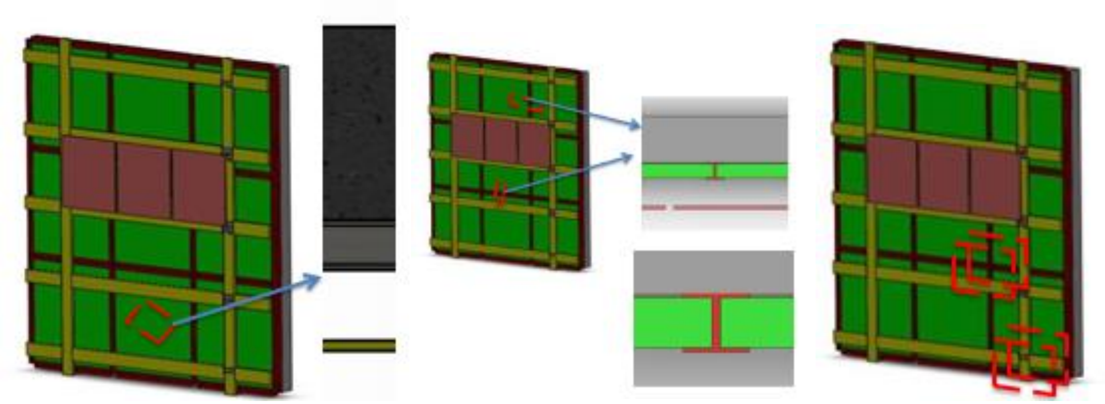


Figure 1. Example of a building façade: identification of 1-D, 2-D and 3-D domains for thermal transmittance calculation

3.1.1. Input required for the thermal assessment

The basic information for performing the calculations were:

- the geometry of the prototypes/components (CAD models and/or drawings), with a description of each design element (i.e. number of layers, material type and thickness of the layers),
- thermal material properties (at least thermal conductivity of each layer and of each material of the prototype/component),
- boundary conditions (indoor and outdoor temperatures, heat transfer coefficients).

3.1.2. Thermal assessment steps

The main activities to be carried out for the thermal assessment are summarized hereafter:

- analysis of the geometry of the prototypes/components for the identification of the 1-D, 2-D and 3-D domains,
- boundary conditions definitions,
- 1-D analysis for thermal transmittance assessment without considering the bi-dimensional and tri-dimensional thermal bridges,
- 2-D thermal bridge calculation by means of FE analysis,
- 3-D thermal bridge calculation by means of FE analysis,
- global heat transfer coefficient U_g calculation.

3.2. Hygrothermal analysis

The hygrothermal analysis has been developed mainly according to the standard ISO 13788: "Hygrothermal performance of building components and building elements — Internal surface temperature to avoid critical surface humidity and interstitial condensation — Calculation methods" [3].

The two main aspects of the standard that have been considered are:

1. the critical surface humidity likely to lead to problems such as mould growth on the internal surfaces of the components;
2. the interstitial condensation within the building component.

The approach proposed by the standard is a simplified calculation method that could be used as preliminary hygrothermal assessment of the building components. Some of the main hypotheses to be considered deal with:

- absence of material properties variation with moisture content,
- absence of capillary and liquid moisture transfer within materials,
- steady state conditions,
- absence of air movements through air gaps and spaces.

3.2.1. Surface condensation assessment

According to the standard ([3]) there is a risk of mould growth when monthly mean surface relative humidity are above a critical humidity, $\phi_{si,cr}$, which is defined as 0,8 (= 80 % rh).

The surface condensation risk is linked to the internal surface temperature. As a consequence, the presence of thermal bridges critical.

The assessment is based on the thermal and hygrometric analysis of the components. The basic data needed for the assessment, which should be carried out for each month of the year, are:

- external boundary conditions (external air temperature and humidity, T_e and ϕ_e),
- internal boundary conditions (internal air temperature, T_i).

These data could be derived from other standards (e.g. national standards) or from tables foreseen by the standards itself. Considering that the purpose of the activity deals with a preliminary assessment, only data related to the most critical month of the year could be considered (i.e. one winter month). In case of multidimensional heat flow (e.g. in presence of thermal bridges) the effective surface temperature should be calculated by finite element analysis according to [2].

The procedure foresees:

- calculation of the internal air humidity (ϕ_i) and the internal vapor pressure p_i (according to the approach described in the paragraph 4.3.2 of the cited standard),
- calculation of the minimum acceptable saturation vapor pressure $p_{sat} = p_i / \phi_{si,cr}$ (i.e. at T_{si}),
- calculation of the minimum acceptable surface temperature ($T_{si,\ min}$), from the previous calculated minimum acceptable saturation vapor pressure p_{sat} with the formulas at annex E.1 of the standard ("Water vapor saturation pressure as function of temperature"),
- from the minimum acceptable temperature $T_{si,\ min}$ the minimum temperature factor, $f_{Rsi,min}$, is calculated according to:

$$f_{Rsi,min} = \frac{T_{si,min} - T_e}{T_i - T_e}$$

- The effective temperature factor (f_{Rsi}), i.e. the effective surface temperature (T_{si}), is calculated according to the component thermal resistance ($R=d/\lambda$, component thickness and thermal conductivity):

$$f_{Rsi,min} = \frac{T_{si} - T_e}{T_i - T_e}$$

In case of multidimensional heat flow (e.g. in presence of thermal bridges) the effective surface temperature is calculated by finite element analysis according to [2],

- To avoid surface condensation the effective temperature factor should be greater than the minimum temperature factor:

$$f_{Rsi} > f_{Rsi,min}$$

The check should be carried out for the month of the year with the highest $f_{Rsi,min}$ (the most critical month). In case the analysis is carried out for only one month the T_{si}, the effective surface temperature, should be greater than the critical surface temperature $T_{si,\ min}$, i.e. the one dealing with 80% humidity.

$T_{si} > T_{si,\ min}$

3.2.2. Interstitial condensation assessment

The aim of the assessment is not to study in detail the water mass transport within the component prototype but only to carry out a preliminary assessment to verify whether interstitial condensation within the different layers of the elements occurs or not. The procedure is based on the Glaser method [3] and foresees the following assumptions:

- mass transport is governed only by diffusion mechanism,
- steady-state conditions,
- monodimensional heat and mass transport,
- homogenous and isotropic material with properties independent from temperature and water vapour concentration.

The ISO 13788 provides the method for the calculation of the condensation/evaporation rates for each month of the year to finally assess the annual moisture balance and to calculate the accumulated moisture due to interstitial condensation. The application of this time consuming procedure is outside the purpose of the RE4 project since the project aim is not to certify a building component/prototype from a hygrothermal point of view but is only to investigate the overall performance of the solution envisaged and to compare different components solutions that will be developed during the project.

As a consequence, the proposed activity has not gone through the whole annual hygrometric analysis, but only one situation (e.g. considering the boundary condition related to the most critical month) has been analysed. Finally, by building the Glaser diagram for that situation an assessment of the potential interstitial condensation has been carried out.

The method consists in:

1. thermal analysis of the multi-layer building components to calculate the temperature distribution profile,

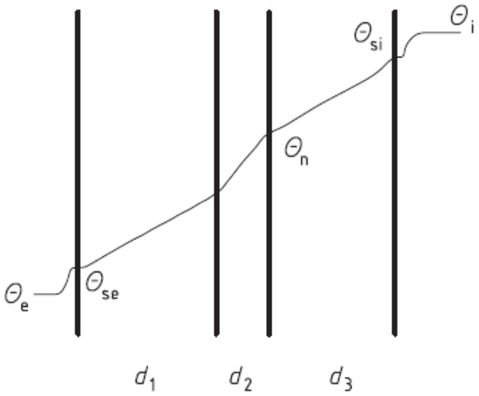


Figure 2. Temperature distribution in a multi-layer building element

2. calculation of the <u>saturation vapour pressure</u> from the temperature distribution at each interface between material layers (according to the expression in the Annex E of the standard [3].
3. building-up the Glaser diagram (pressure vs layer thickness) based on the thickness of each layer equal to its water vapour diffusion-equivalent layer thickness, s_d (diagram abscissa). Draw straight lines joining the saturation vapour pressures at each interface between materials (P_{sat}). Draw the vapour pressure profile as a straight line between the internal and external vapour pressure (p_i and p_e).
4. if the vapour pressure does not exceed the saturation pressure at any interface, condensation does not occur.

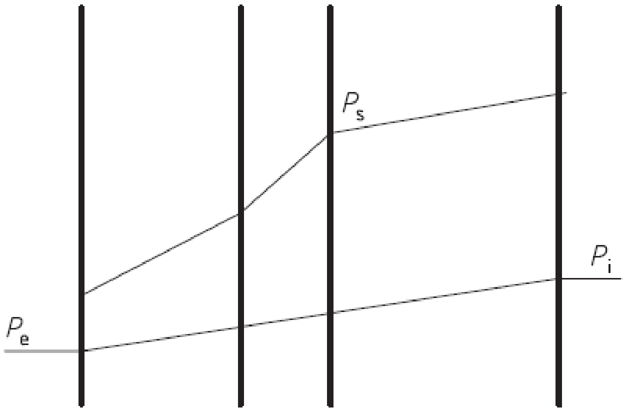


Figure 3. Water vapour diffusion in a multi-layer building element without any interstitial condensation

Data needed to carry out the activity are:

- The boundary conditions: internal and external air temperatures and humidity (T_i, T_e, ϕ_I, ϕ_e). In case the internal conditions are not known they will be derived according to paragraph 4.3 of ISO 13788 Standard [3].
- The internal and external vapour pressure calculated according to:

$$P=P_{sat}(T)*\phi$$

- The water vapour diffusion-equivalent layer thickness of each layer (i.e. the thickness of a motionless air layer which has the same water vapour resistance as the material layer in question), s_d is:

$$s_d=\mu*d$$

where:

d is the layer thickness and μ is the water vapour resistance factor. For standard materials, μ could be obtained from the tables provided by the standard ISO 10456 [4].

3.2.3. Input required for the hygrothermal assessment

The basic information needed to carry out the activities deal with:

- the geometry of the prototypes/components (CAD models and/or drawings), with a description of each constituent of the prototypes (i.e. the layers stratification and the material and thickness of each layer),
- Thermal material properties (thermal conductivity of each layer and of each material of the prototype/component),
- Water vapour resistance factor (μ) for each material. For standard materials, μ could be obtained from the tables provided by the standard ISO 10456 [4].
- Boundary conditions (internal and external air temperatures and humidity, heat transfer coefficients). In case the internal conditions are not known they will be derived according to ISO 13788 Standard [3].

Table 1. Hygrothermal properties

Hygrothermal properties		
layer/constituent of the component	Thermal conductivity (W/m*K)	water vapor resistance factor[1]
1	λ	μ
2	λ	μ
3	λ	μ
…	λ	μ
n	λ	μ

[1] *μ=air permeability to water vapor/material permeability to water vapor*

μ: for standard materials, tabulated values can be found in ISO 10456

3.2.4. Interstitial condensation particular case: highly water tight layers

The ISO 13788 standard is not well suited in case of **water tight layers** (e.g. VIP panels) as water vapour pressure continuum, between internal and external boundary conditions, is not a valid assumption.

In this cases, the most reasonable hypothesis is to assume the water vapour transfer across the water tight layers as negligible, and water-vapour equilibrium should be modelled between the materials on each side of the water tight layers towards its respective boundary condition [5].

3.2.5. Interstitial condensation particular case: edge effects

The ISO 13788 modelling approach is suitable to verify that condensation does not occur within a full-1D assumption. However, in real cases, the component/prototype could be composed by various elements that could provide edge effects**.** To deal with this, another approach could be adopted and in which the calculation could be carried out only for the architectural details where the temperature field is calculated by 2D-3D finite element models, and the water vapour path is defined in the weakest path [5] (cold-spot condensation), by defining an equivalent 1D moisture transfer path. This implies that materials such as metals, plastics, and VIP envelopes are considered as completely watertight surfaces/elements and that mass transfer is assumed to be negligible across them.

In this case the approach is:

- calculation of thermal field by means of 2D/3D FE analysis,
- definition of critical path,
- definition of equivalent 1D moisture transfer path along the critical path,
- imposition of the thermal field along the critical path from data calculated in the 2D/3D FE analysis,
- calculation of saturation pressure,
- calculation of water vapour pressure according to the glazer method on the equivalent 1D path,
- condensation assessment.

4. PRELIMINARY ANALYSES

In order to support the definition of the final analysed structures, a set of preliminary analyses have been performed on previous version of the timber façade and of the sandwich panel. Also, a third façade made of lightweight concrete has been analysed, but its development has been stopped during the project. Specifically, concerning the timber façade, a preliminary thermal analysis has been performed on a previous version of the structure, which is reported in Figure 4.

The temperature distribution and the global transmittance have been calculated, following the approach described in Par. 3.1. Moreover, in order to understand the effect of the insulation layer, a sensitivity analysis based on its thickness has been performed, for a total of seven simulations. Figure 5 and Figure 6 report the mentioned results.

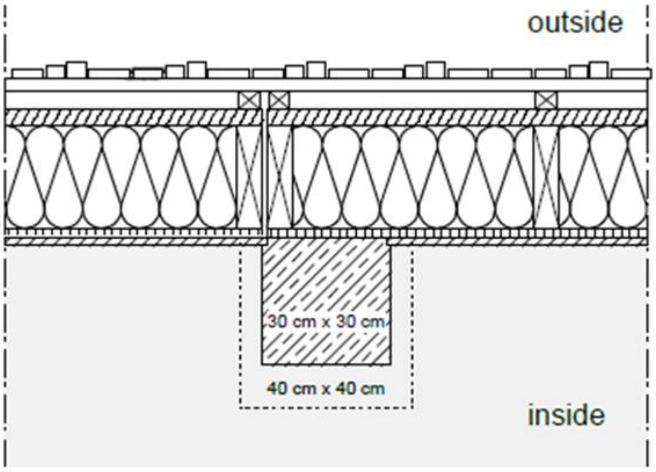


Figure 4. Preliminary version of the timber façade

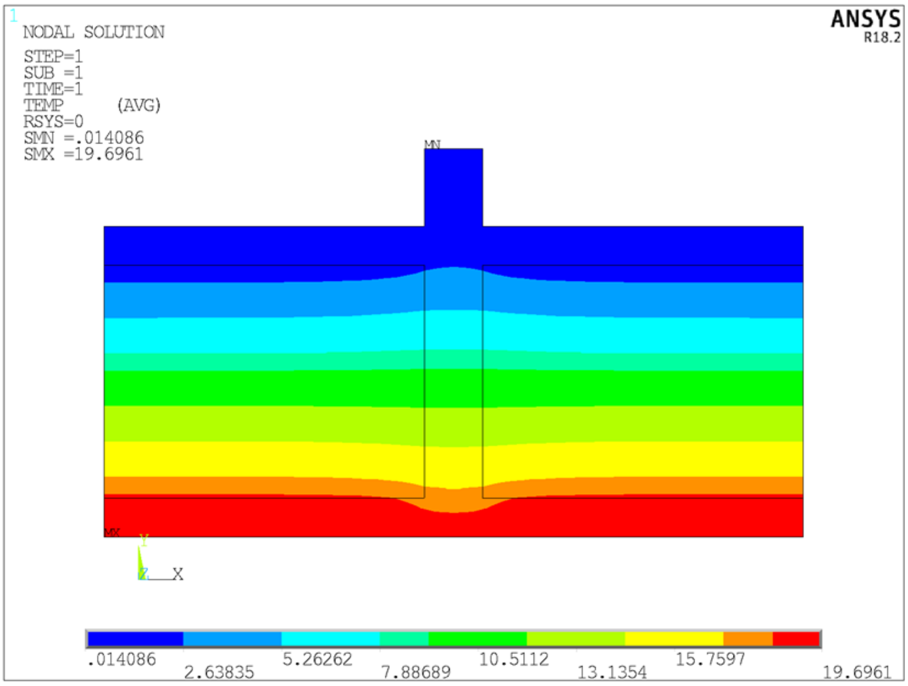


Figure 5. Temperature distribution on the first version of the timber façade

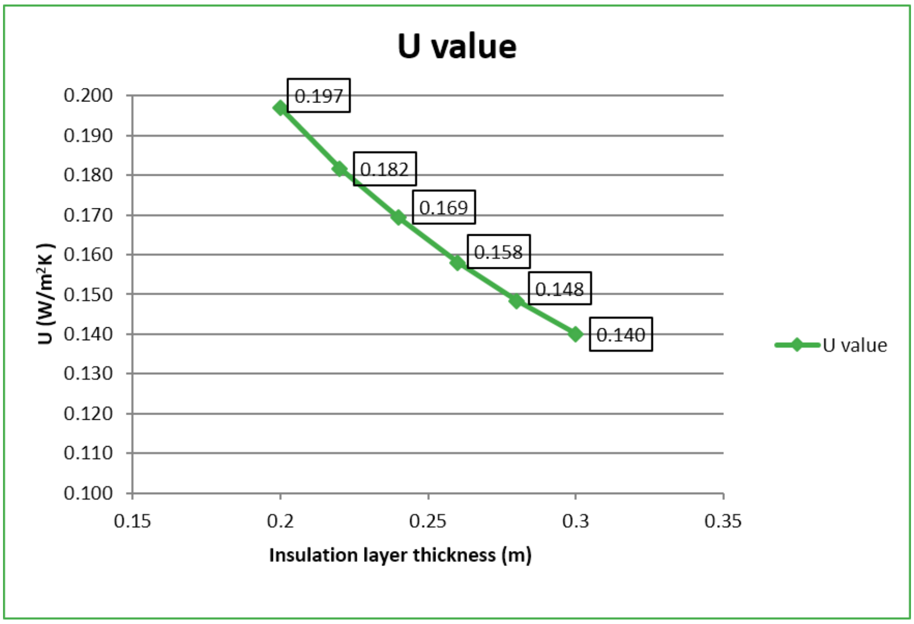


Figure 6. Sensitivity analysis of the transmittance as function of the insulation layer thickness – timber façade

Similarly, Figure 7 shows the first version of the concrete sandwich panel, with its results displayed in Figure 8 and Figure 9. Also, in this case a total of seven simulations have been developed.

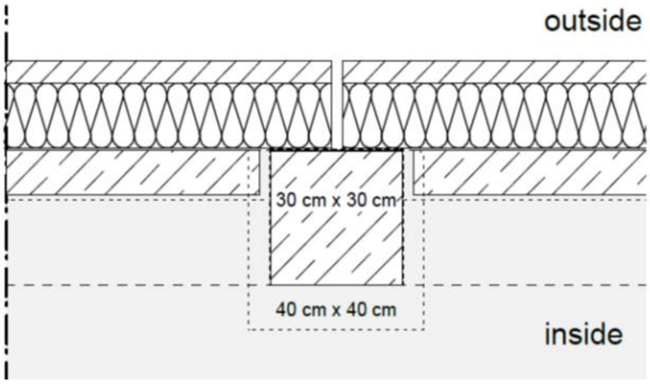


Figure 7. First version of the sandwich panel

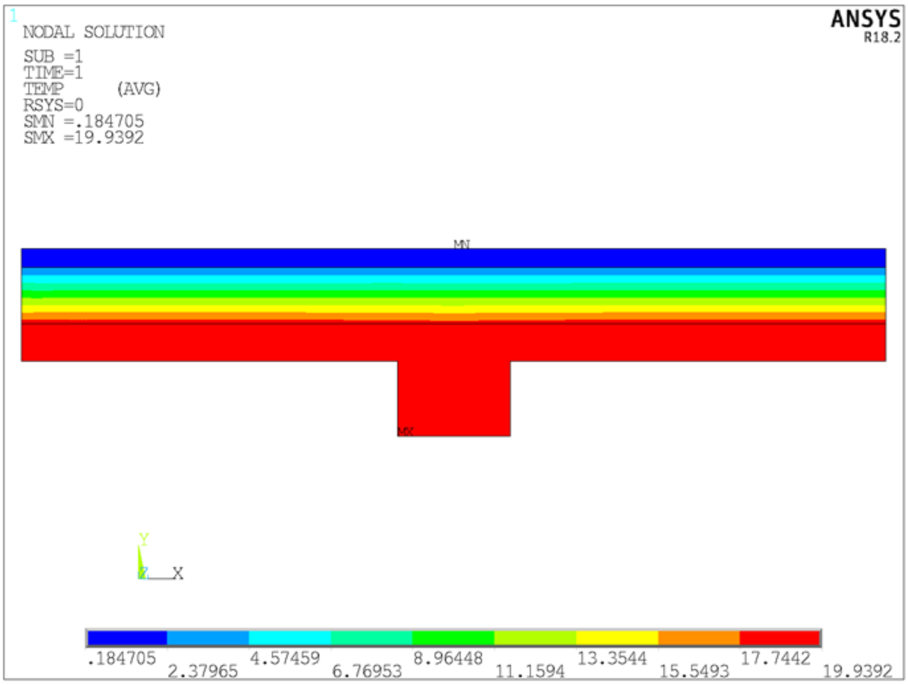


Figure 8. Temperature distribution on the first version of the sandwich panel

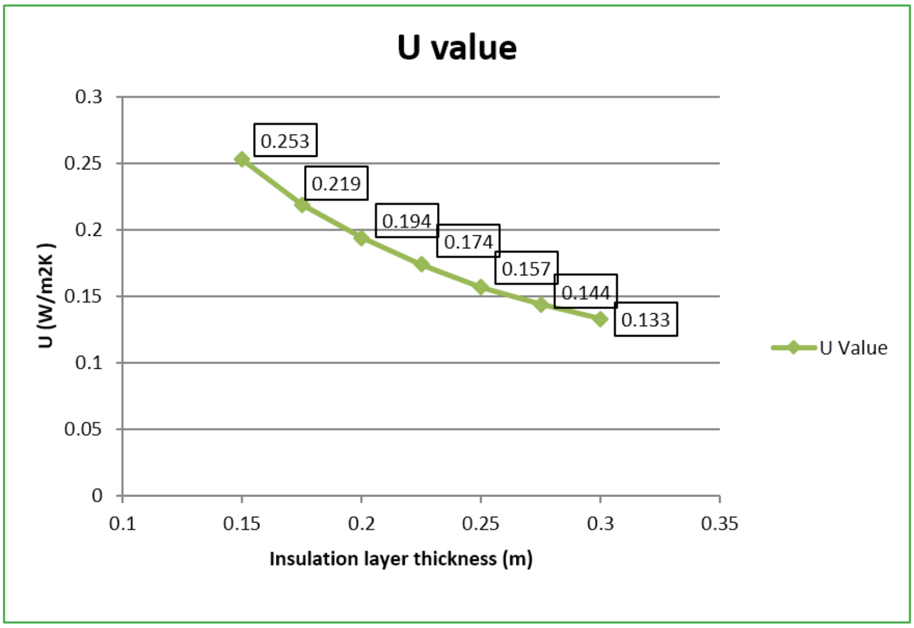


Figure 9. Sensitivity analysis of the global transmittance as function of the insulation layer thickness – Sandwich panel

5. SOFTWARE

The following code has been used to carry out the numerical FEM analyses within the RE^4 project:

- ANSYS Enterprise is a general purpose FE (Finite Element) software for structural analysis, including linear, nonlinear and dynamic studies. The engineering simulation software provides a complete set of elements behavior, material models and equation solvers for a wide range of mechanical design problems

6. GEOMETRY AND MATERIAL PROPERTIES

The geometry of the RE^4 timber façade has been provided by ZRS Architekten Ingenieure [6], while the dimensions and the layers of the RE^4 concrete sandwich panel have been given by RI.SE (Research Institutes of Sweden) [7] and ACCIONA [8]. Both structures present different geometries related to Northern Europe climate and Southern Europe climate. In particular, FEM analyses have been performed on one version of the RE^4 timber façade for cold climate and on two different geometries appropriated to warm climate. In addition, also two conventional façades have been analysed, with the aim to compare the thermal performances of the structures developed within the RE^4 project with the conventional ones. Concerning the RE^4 concrete sandwich panel, hygrothermal assessment has been performed on the structure for cold climate and on another one related to warm climate.

The following paragraphs describes the geometry of the analysed components, including also the material properties employed for the thermal and condensation assessments.

6.1. RE^4 Timber Façade

All the information related to geometry, layer thicknesses and material properties of the following timber facades have been provided by ZRS Architekten Ingenieure [6].

6.1.1. Conventional timber façade for Northern Europe

Figure 10 shows a portion of the timber façade for NE climate, including the dimension of each layer and the related materials, whose properties are listed in Table 2.

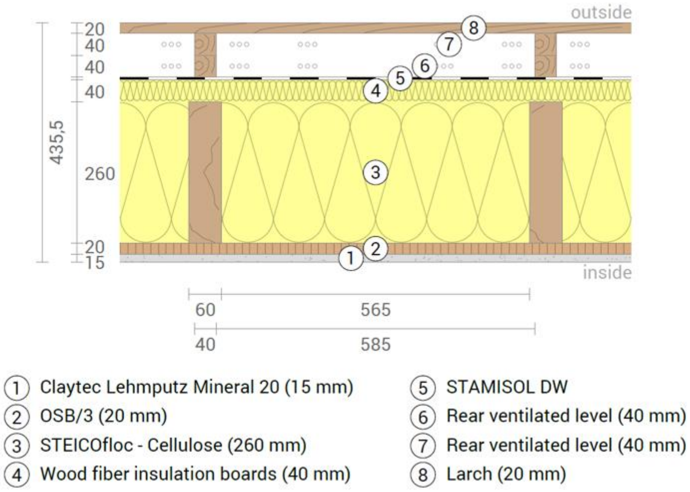


Figure 10. Conventional timber façade for NE climate

Table 2. Thicknesses and material properties of NE Conventional timber façade

Layer / Material	Status	Thickness [mm]	Water vapour resistance factor [μ]	λ [W/mK]
Earth mineral plaster	commercial	15	5 / 10	1,1
OSB	commercial	20	150 / 300	0,13
Cellulose insulation	commercial	260	1 / 2	0,039
Timber Stud - Spruce	commercial		20 / 50	0,13
Wood fibre board	commercial	40	3 / 5	0,044
Larch (Weatherboard)	commercial	20	20 / 50	0,13

6.1.2. RE^4 CDW Timber Façade for Northern Europe

The repetitive unit of the timber façade, developed in RE^4 project, for the cold climate, is shown in Figure 11. It differs from the conventional façade because of the employed materials and the different thickness of its layers. The material properties are listed in Table 3.

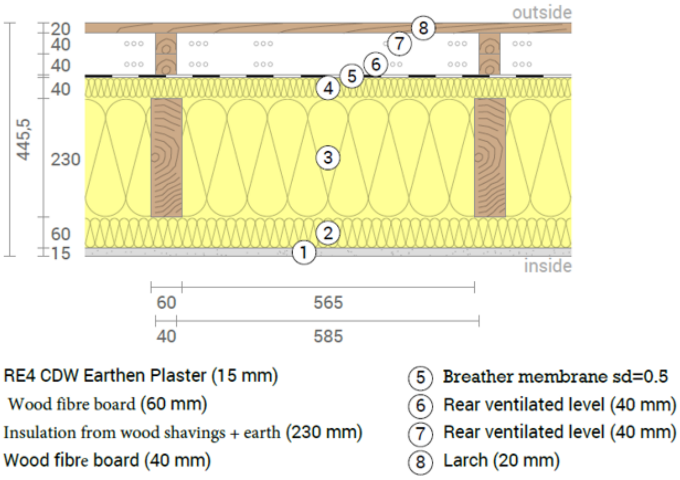


Figure 11. RE^4 CDW Timber façade for NE climate

Table 3. Thicknesses and material properties of NE RE^4 CDW timber façade

Layer / Material	Status	Thickness [mm]	Water vapour resistance factor [μ]	λ [W/mK]
RE4 CDW Earthen plaster	RE4 product	15	5 / 10	1,1
Wood fibre board	commercial	60	5 / 5	0,048
Insulation from wood shavings + earth	commercial	230	2 / 3	0,045
Timber Stud - Spruce	RE4 product		20 / 50	0,13
Wood fibre board	commercial	40	3 / 5	0,044
Breather membrane	commercial	0.5	n/a	0,2

6.1.3. Conventional Timber Façade for Southern Europe

The geometry and the layering of the repetitive unit of the conventional timber facade for warm climate is shown in Figure 12. Compared to the façades employed for Northern Europe, it presents an additional layer made of earth block and a thicker insulation layer. Table 4 lists the properties of the employed materials.

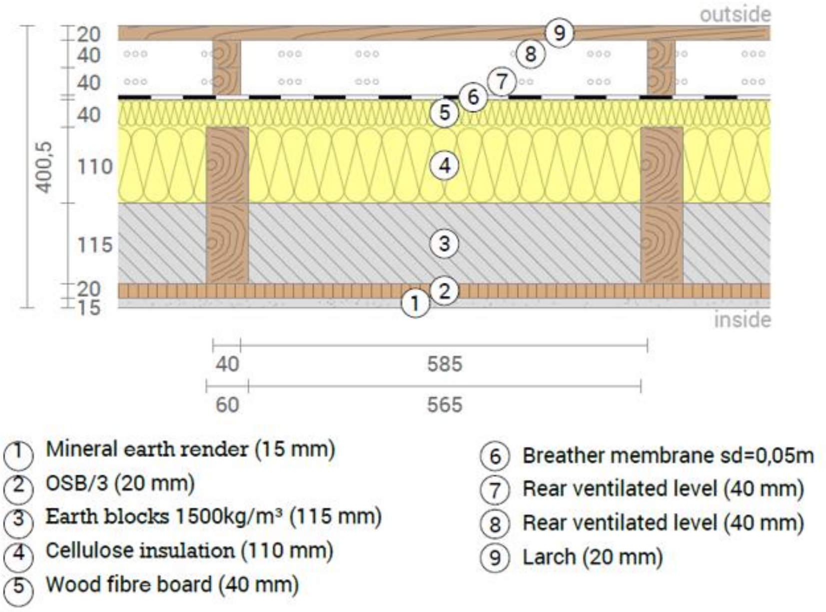


Figure 12. Conventional timber façade for SE climate

Table 4. Thicknesses and material properties of SE Conventional timber façade

Layer / Material	Status	Thickness [mm]	Water vapour resistance factor [µ]	λ [W/mK]
Earth mineral plaster	commercial	15	5 / 10	1,1
OSB	commercial	20	150 / 300	0,13
Earth blocks	commercial	115	5 / 10	0,66
Timber Stud - Spruce	commercial		20 / 50	0,13
Cellulose insulation	commercial	110	1 / 2	0,039
Timber Stud - Spruce	commercial		20 / 50	0,13
Wood fibre board	commercial	40	3 / 5	0,044

6.1.4. RE^4 CDW Timber Façade for Southern Europe

Concerning Southern Europe climate, two different solutions have been developed within the RE^4 project. The first one (Option 1) is represented in Figure 13, where its repetitive unit is shown, while the material properties of each layer are listed in Table 5. The second one (Option 2) is shown in Figure 14 with its related material properties summarized in Table 6. The main difference between the two structures is based on the presence of a layer of earth blocks in the Option 1.

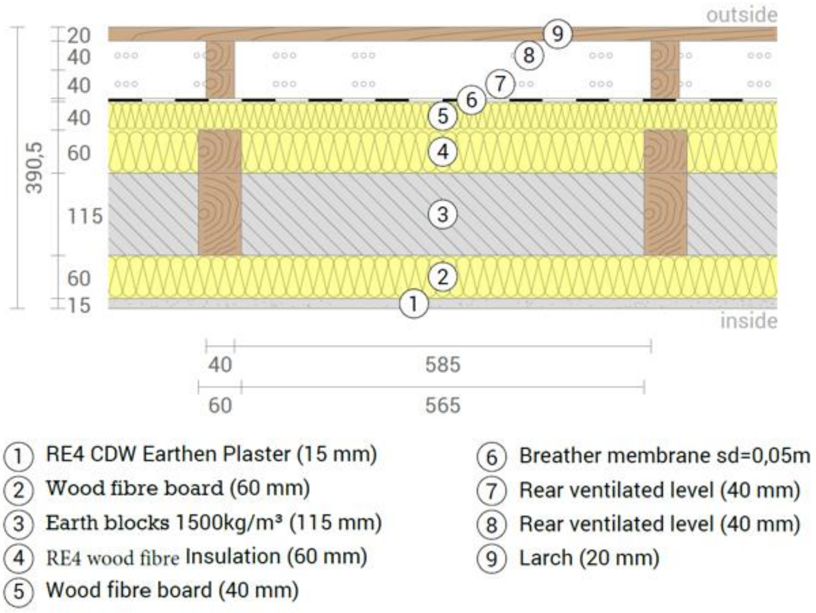


Figure 13. RE^4 CDW Timber façade for SE climate – Option 1

Table 5. Thicknesses and material properties of SE RE^4 CDW Timber façade – Option 1

Layer / Material	Status	Thickness [mm]	Water vapour resistance factor [μ]	λ [W/mK]
RE4 CDW Earthen plaster	RE4 product	15	5 / 10	1,1
Wood fibre board	commercial	60	5 / 5	0,048
Earth blocks	commercial	115	5 / 10	0,66
Timber Stud - Spruce	RE4 product		20 / 50	0,13
RE4 Wood fibre insulation (CETMA)	RE4 product	60	3/5	0.05
Timber Stud - Spruce	RE4 product		20 / 50	0,13
Wood fibre board	commercial	40	3 / 5	0,044

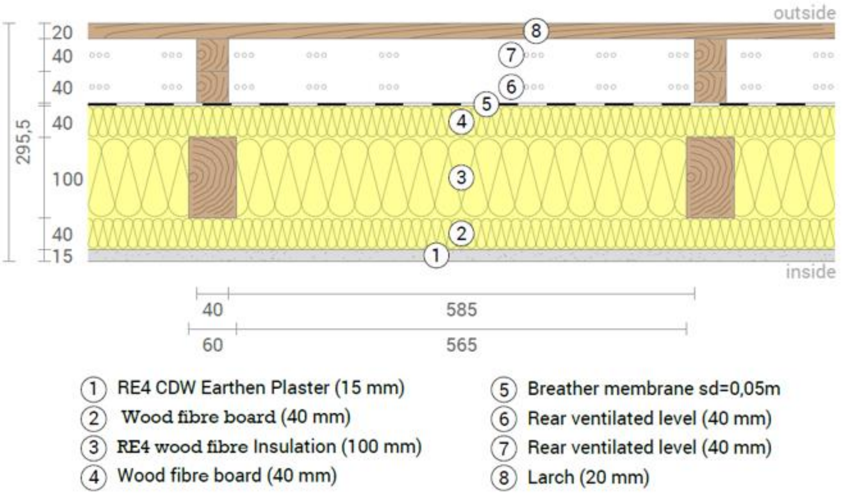


Figure 14. RE^4 CDW Timber façade for SE climate – Option 2

Table 6. Thicknesses and material properties of SE RE^4 CDW Timber façade – Option 2

Layer / Material	Status	Thickness [mm]	Water vapour resistance factor [µ]	λ [W/mK]
RE4 CDW Earthen plaster	RE4 product	15	5 / 10	1,1
Wood fibre board	commercial	40	5 / 5	0,038
RE4 Wood fibre insulation (CETMA)	RE4 product	100	3/5	0,05
Timber Stud - Spruce	commercial		20 / 50	0,13
Wood fibre board	commercial	40	3 / 5	0,044

6.2. RE^4 Concrete Sandwich Panel

6.2.1. RE^4 Concrete Sandwich Panel for Northern Europe

The layering and the materials employed in the RE^4 Concrete sandwich panel for cold climate are shown in Figure 15. The material properties of the inner layer and of the outer one have been defined by using [4], while, concerning the insulation layer, its properties have been taken from the commercial datasheet provided by RI.SE [9]. In addition, the inner layer and the external one are connected through pin connectors made of composite fiberglass (the conductivity has been defined by using [10]. The pins are placed approximatively 600 mm x 550 mm, for a total of about 2.78 pins per m^2.

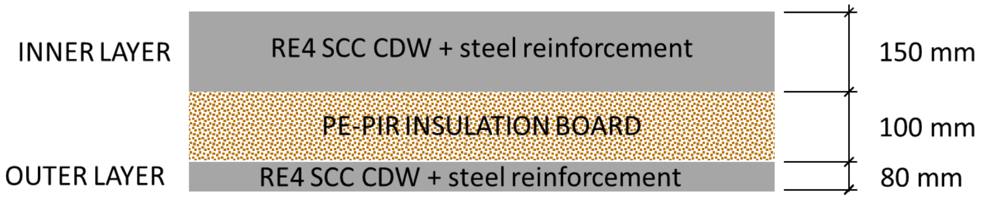


Figure 15. Layering of the sandwich panel for cold climate

Table 7. Thicknesses and material properties of the sandwich Panel for cold climate

Layer / Material	Status	Thickness [mm]	Water vapour resistance factor [µ]	λ [W/mK]
RE4 SCC CDW	RE4	150	120	1.6
PE-PIR	commercial	100	60	0.022
RE4 SCC CDW	RE4	80	120	1.6
Fiberglass composite	commercial	/	/	0.25

6.2.2. RE^4 Concrete Sandwich Panel for Southern Europe

The RE^4 Concrete sandwich panel for warm climate mainly differs from the previous one because of the thicknesses of the layers (Figure 16). The considered material properties (Table 8) are the same of the panel for cold climate. In the end, the distribution of the pin connectors is different since they are placed 385 mm x 400 mm apart from each other, as reported in technical drawing in Appendix A, for a total of about 6.73 pins per m^2.

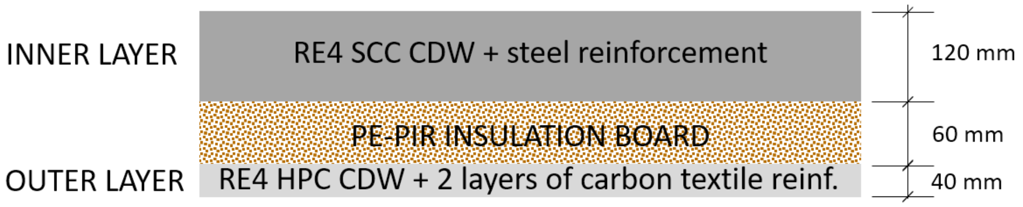


Figure 16. Layering of the sandwich panel for warm climate

Table 8. Thicknesses and material properties of the sandwich panel for warm climate

Layer / Material	Status	Thickness [mm]	Water vapour resistance factor [µ]	λ [W/mK]
RE4 SCC CDW	RE4	120	120	1.6
PE-PIR	commercial	60	60	0.022
RE4 HPC CDW	RE4	40	120	1.6
Fiberglass composite	commercial	/	/	0.25

7. DISCRETIZED MODEL

7.1. RE^4 Timber Façade

The FE models of the timber façade have been developed by considering a bi-dimensional repetitive unite of the entire structure. In particular, a portion of the geometry around the stud, which is a possible 2D thermal bridge, has been modelled. The length of the model is equal to the sum of distance between two consecutive studs and the length of this latter one. In addition, the external layer (larch) has been neglected by using a corrective value for the external convective thermal coefficient (following the procedure in [1]). This strategy has been adopted for each typology of timber façade analysed.

7.1.1. Conventional Timber Façade for Northern Europe

The FE model of the conventional timber façade for cold climate is shown in Figure 17. 2205 quadrilateral PLANE 55 elements and 2311 nodes have been used, with an average element size equal to 0.01 m. More information related to the element typology can be found in section 7.3.

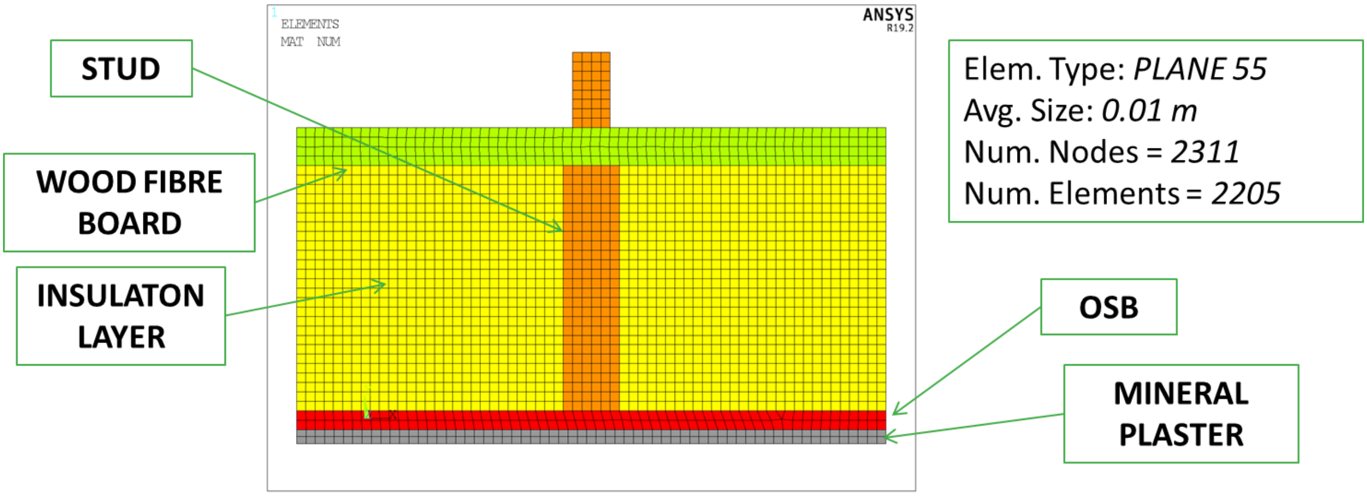


Figure 17. FE model of the conventional timber façade for cold climate

7.1.2. RE^4 CDW Timber Façade for Northern Europe

Figure 18 shows the discretized model of the timber façade for Northern Europe developed within RE^4 project. 2374 nodes and 2267 quadrilateral PLANE 55 elements have been used, with an average element dimension equal to 0.01 m. More information related to PLANE 55 element can be found in section 7.3.

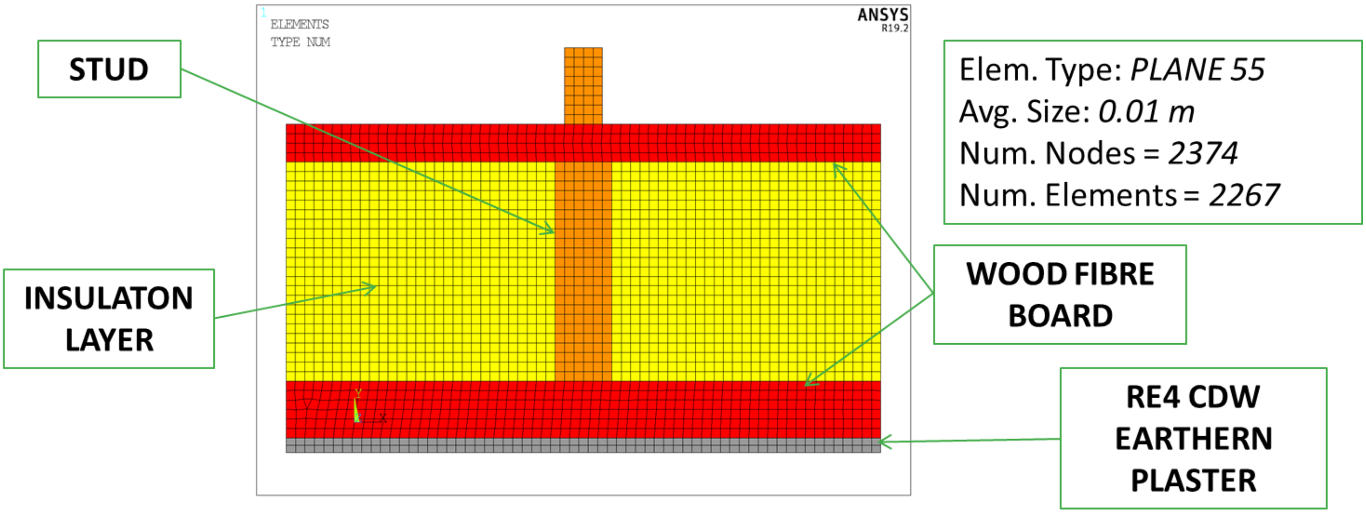


Figure 18. FE model of the RE4 CDW Timber façade for cold climate

7.1.3. Conventional Timber Façade for Southern Europe

The FE model of the conventional timber façade for Southern Europe (Figure 19) has been built by using 2116 nodes and 2013 quadrilateral PLANE 55 elements.
More information related to PLANE 55 element can be found in section 7.3.

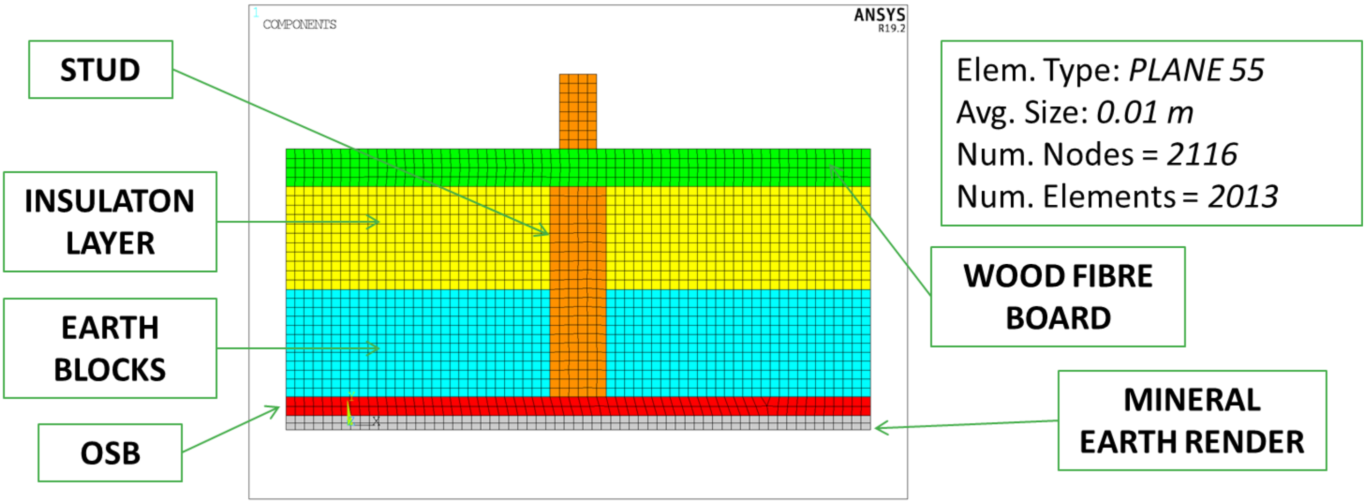


Figure 19. FE model of the conventional timber façade for warm climate

7.1.4. RE^4 CDW Timber Façade for Southern Europe (Option 1)

Figure 20 shows the FE model of the first option of the RE^4 CDW timber façade for warm climate. It has been created by using 2049 nodes and 1947 PLANE 55 elements.
More information related to PLANE 55 element can be found in section 7.3.

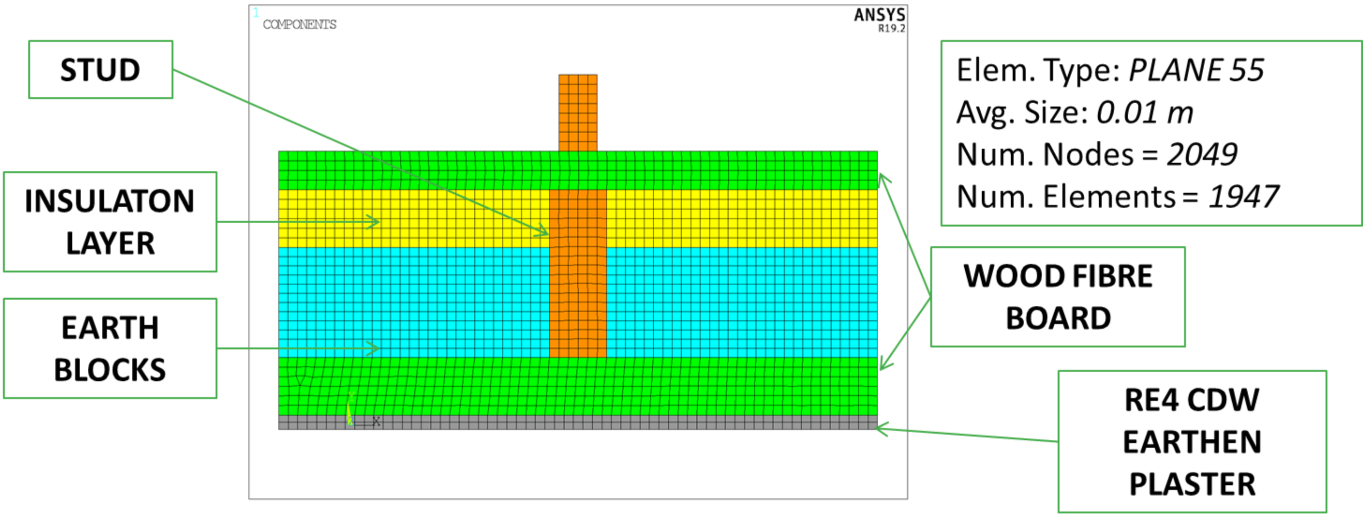


Figure 20. FE model of the RE4 CDW Timber façade for warm climate – Option 1

7.1.5. RE^4 CDW Timber Façade for Southern Europe (Option 2)

The FE model of the second option of the RE^4 CDW timber façade for warm climate is shown in Figure 21. 1530 nodes and 1436 PLANE 55 elements have been employed in order to build the model.
More information related to PLANE 55 element can be found in section 7.3.

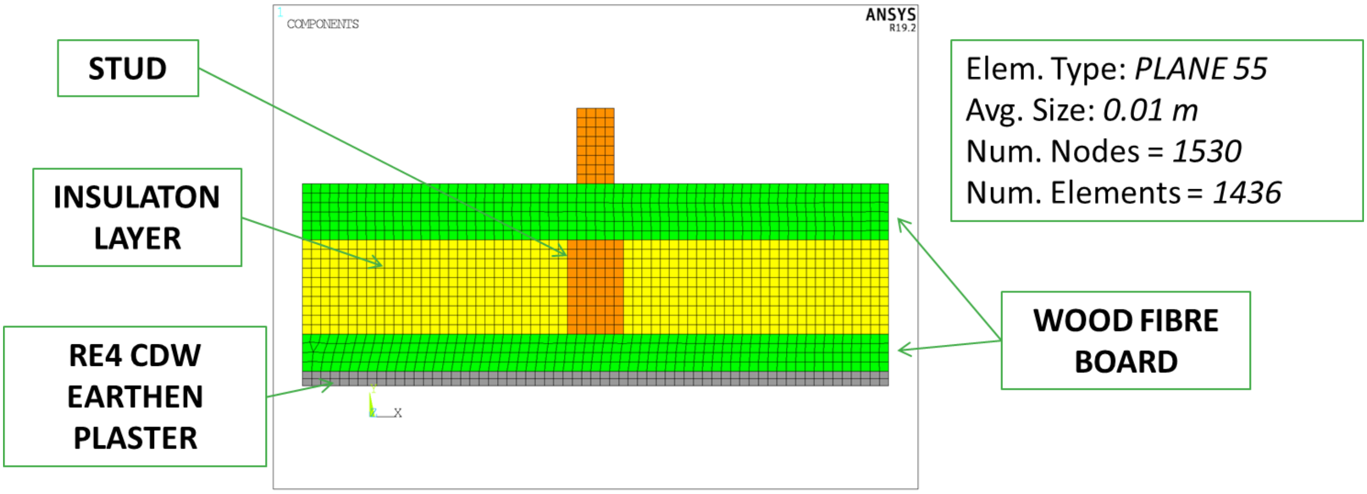


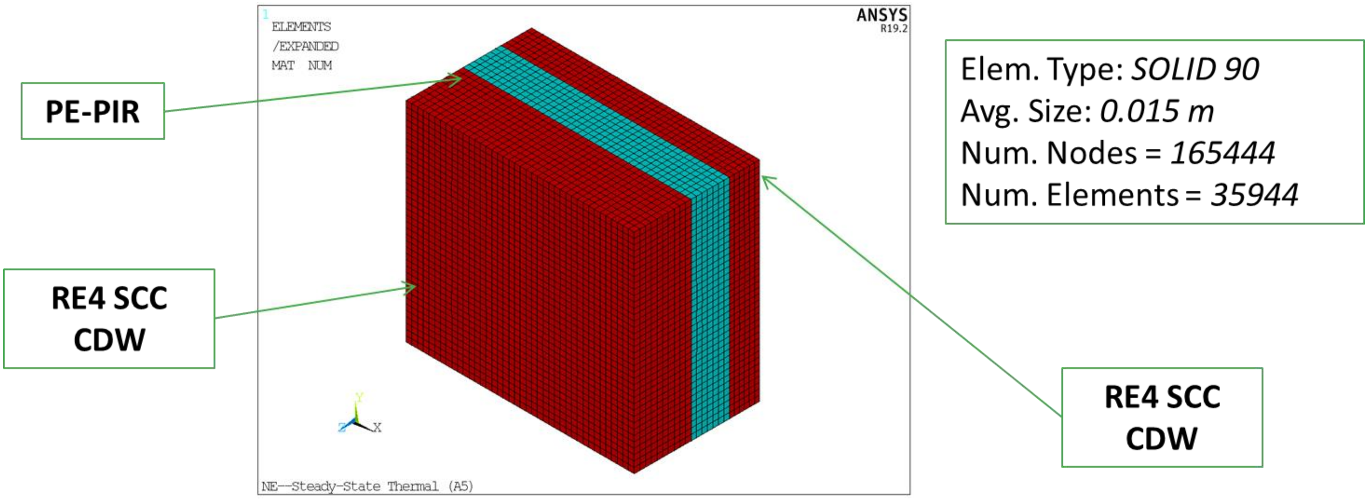
Figure 21. FE model of the RE4 CDW Timber façade for warm climate – Option 2

7.2. RE^4 Concrete Sandwich Panel

The FE model of the sandwich panel have been modelled by using a 3D portion of geometry surrounding a pin connector, which could be a possible 3D thermal bridge. The dimensions of the repetitive unit have been established by fixing the length of the model as equal to the distances between the pins, see section 6.2.1 and section 6.2.2. In particular, concerning the panel for cold climate, the dimension was 600 mm x 550 mm x 330 mm, while for the panel employed in warm climate the size was 385 mm x 400 mm x 220 mm. The pin connectors have been simplified and modelled as cylinders with radius equal to 6 mm and length equal to 170 mm. These dimensions have been extrapolated from connector datasheet [11].

7.2.1. RE^4 Concrete Sandwich Panel for Northern Europe

The FE model of the RE^4 concrete sandwich panel for Northern Europe is shown in Figure 22. 165444 nodes and 35944 SOLID 90 elements, with an average element size equal to 0.015 m. Figure 23 shows a section of the model where the pin connector is visible.
More information related to SOLID 90 element can be found in section 7.4.



Elem. Type: *SOLID 90*
Avg. Size: *0.015 m*
Num. Nodes = *165444*
Num. Elements = *35944*

Figure 22. FE model of the sandwich panel for cold climate

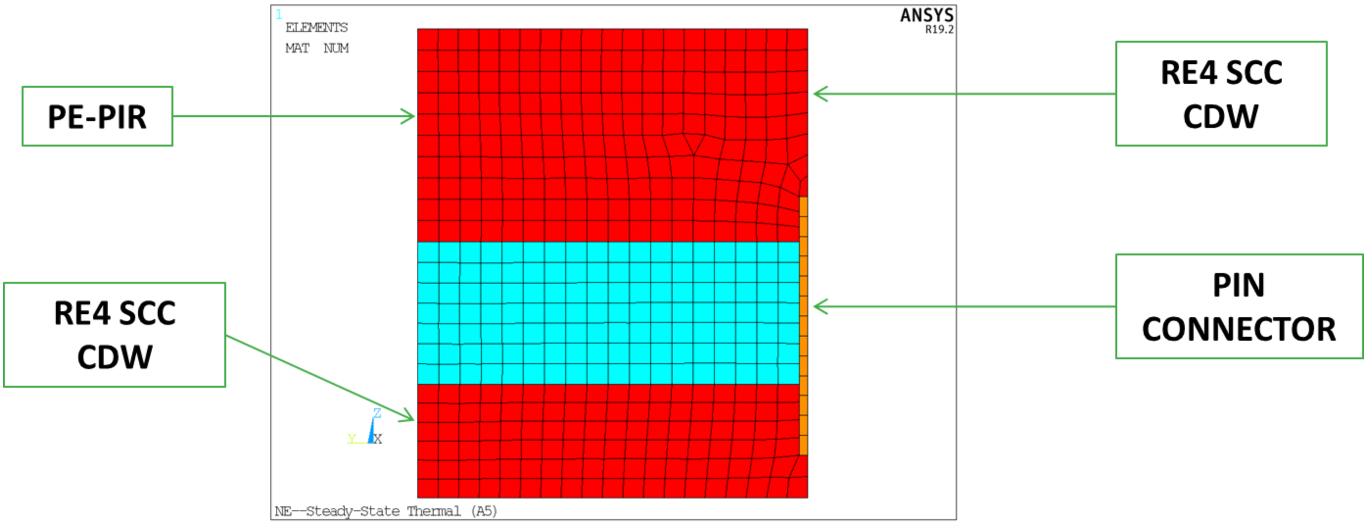


Figure 23. FE model of the sandwich panel for cold climate - Section

7.2.2. RE^4 Concrete Sandwich Panel for Southern Europe

Figure 24 shows the 3D FE model of the RE^4 concrete sandwich panel for warm climate. The model has been built with 58051 nodes and 13259 SOLID 90 elements.
More information related to SOLID 90 element can be found in section 7.4.

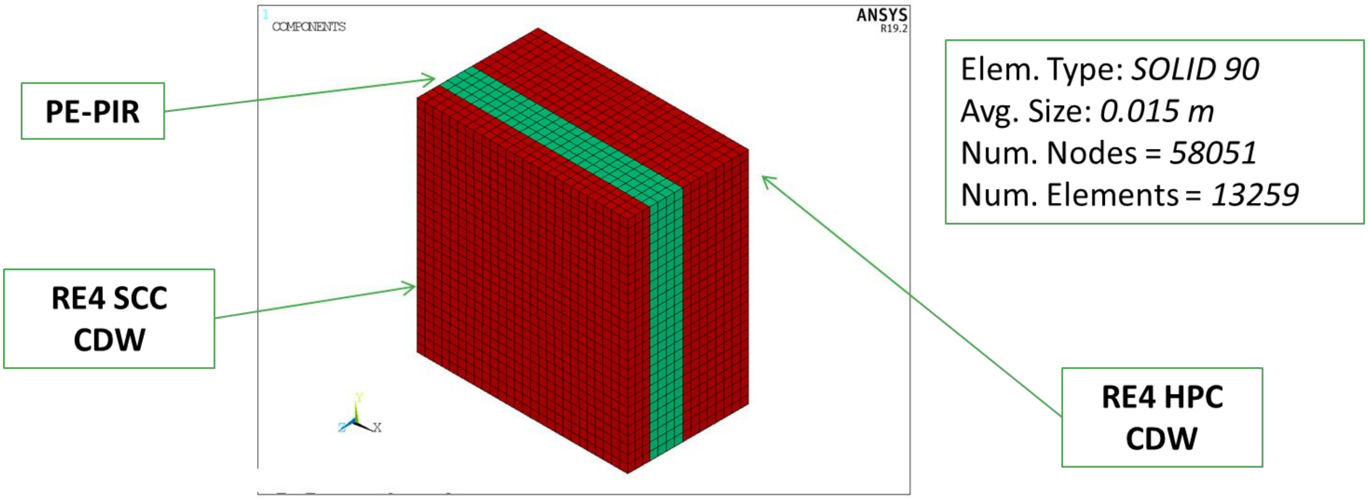


Figure 24. FE model of the sandwich panel for warm climate

7.3. PLANE 55

PLANE 55 can be used as a plane element or as an axisymmetric ring element with a 2-D thermal conduction capability. The element has four nodes with a single degree of freedom, temperature, at each node. The element is applicable to a 2-D, steady-state or transient thermal analysis [12].

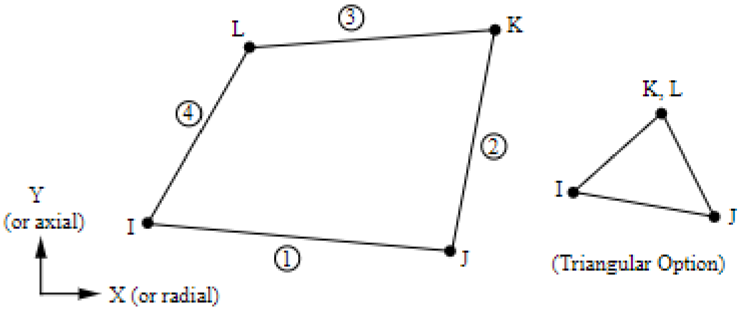


Figure 25: PLANE 55 Geometry

7.4. SOLID 90

SOLID 90 has 20 nodes with a single degree of freedom, temperature, at each node. The 20-node elements have compatible temperature shapes and are well suited to model curved boundaries. The 20-node thermal element is applicable to a 3-D, steady-state or transient thermal analysis [12]

8. BOUNDARY CONDITIONS

Two set of boundary condition have been established as function of the analysis type. The aim of the thermal analysis is to evaluate the global transmittance of the analysed structure and the thermal boundary conditions have been established by following the cited standards in Par. 3.1.
The boundary conditions related to the hygrothermal analysis has been determined by using the weather data of Berlin (for Northern Europe structures) and of Madrid (for Southern Europe structures), available in the database at *https://energyplus.net/weather* [13], and by using the approach described in Par 3.2, i.e. by choosing the climatic condition of the critical month

8.1. Thermal analysis

8.1.1. Timber façade boundary conditions

The boundary conditions related to all the analysed timber façade for cold climate can be summarized as follows:

- Convection on the outer surface with air temperature equal to -5°C and film coefficient equal to 25 W/m^{2}K (**Tbulk = -5 C°, h$_{ext}$ = 25W/m^{2}K)**;
- Convection on the inner surface with air temperature equal to 20 °C and film coefficient equal to 7.7 W/m^{2}K (**Tbulk = 20 C°, h$_{int}$ = 7.7 W/m^{2}K**);
- Adiabatic condition on the lateral surfaces.

The parameters related to convection on the inner and on the outer surfaces have been provided by ZRS [6].
Concerning the structure for warm climate, the boundary conditions are the same, however the parameters related to convention can be found in [1].

- Convection on the outer surface with air temperature equal to 0°C and film coefficient equal to 25 W/m^{2}K (**Tbulk = -5 C°, h$_{ext}$ = 25W/m^{2}K)**;
- Convection on the inner surface with air temperature equal to 20 °C and film coefficient equal to 10 W/m^{2}K (**Tbulk = 20 C°, h$_{int}$ = 10 W/m^{2}K**);
- Adiabatic condition on the lateral surfaces.

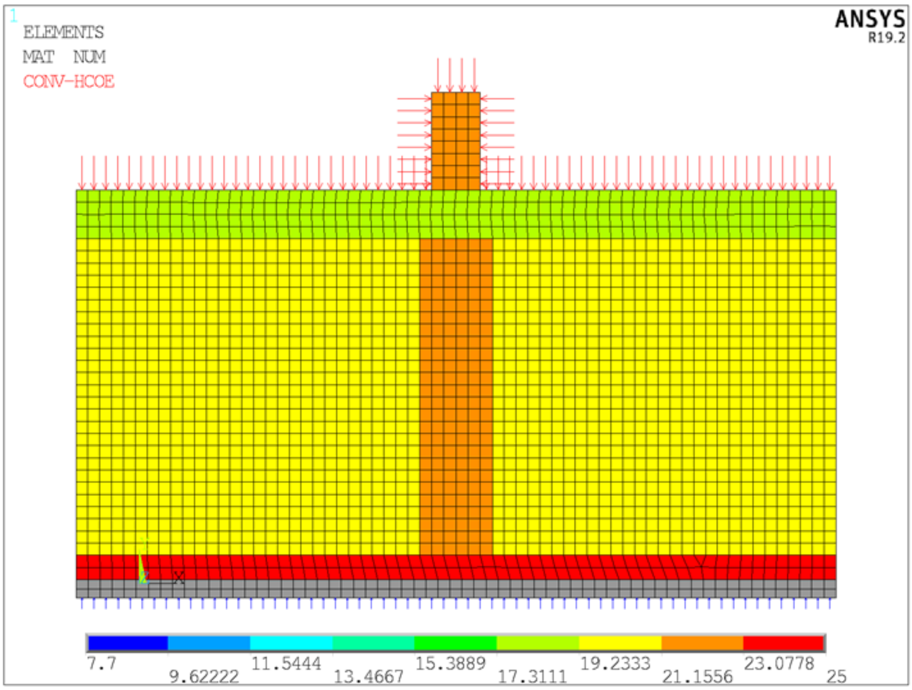


Figure 26. Film coefficient on the inner and on the outer surface of the timber façade

8.1.2. Sandwich panel boundary conditions

The boundary conditions employed for the sandwich panel for cold climate can be summarized as follows:

- Convection on the outer surface with air temperature equal to -5°C and film coefficient equal to 25 W/m^{2}K (**Tbulk = -5 C°, h$_{ext}$ = 25 W/m^{2}K)**;
- Convection on the inner surface with air temperature equal to 20 °C and film coefficient equal to 10 W/m^{2}K (**Tbulk = 20 C°, h$_{int}$ = 10 W/m^{2}K**);
- Adiabatic condition on all the other surfaces.

Concerning the sandwich panel for Southern Europe, boundary conditions are:

- Convection on the outer surface with air temperature equal to 0°C and film coefficient equal to 25 W/m^{2}K (**Tbulk = 0 C°, h$_{ext}$ = 25 W/m^{2}K)**;
- Convection on the inner surface with air temperature equal to 20 °C and film coefficient equal to 10 W/m^{2}K (**Tbulk = 20 C°, h$_{int}$ = 10 W/m^{2}K**);
- Adiabatic condition on all the other surfaces.

The temperatures of the air related to convection on inner and outer surfaces are the same of the timber façade in order to have the possibility to make a comparison, taking into account that the temperature difference does not influence the calculation of the U value. While the film coefficient can be found in [1].

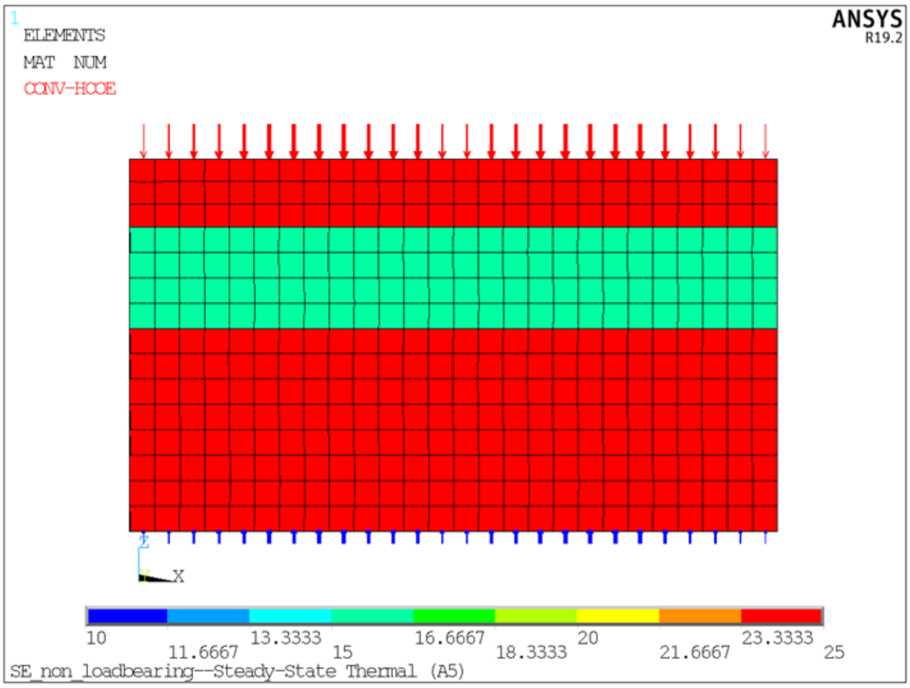


Figure 27. Film coefficient on the inner and on the outer surface of the sandwich panel

8.2. Hygrothermal analysis

Table 9 and Table 10 summarizes, respectively, the employed weather data of Berlin and Madrid. In particular, the daily average temperature (Temp.) and the daily average relative humidity (RH) for each month are reported. These values have been founded in the database [13].

Table 9. Weather data of Berlin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp (°C).	1.9	0.3	5.4	8.3	14	17.6	19.1	18.5	15	10.2	4.4	1.9
RH (%)	80	80	78	70	64	64	63	65	71	77	83	87

Table 10. Weather data of Madrid

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp (°C).	6.2	7.4	9.9	12.2	16	20.7	24.4	23.9	20.5	14.8	9.4	6.4
RH (%)	73	65	54	53	53	45	37	38	48	61	70	74

9. RESULTS

9.1. Thermal analysis – Timber Façade

9.1.1. Conventional Timber Façade for Northern Europe

Figure 28 shows the temperature distribution on the conventional timber façade for cold climate. The maximum temperature is equal to 19.59°C, on the inner surface, while the lowest one occurs on the outer surface and it is equal to -4.99 °C. An irregularity is visible on the stud and the effect of this thermal bridge is confirmed in Figure 29, where the vector total heat flux is shown with a peak equal to 9.37 W/m^2.

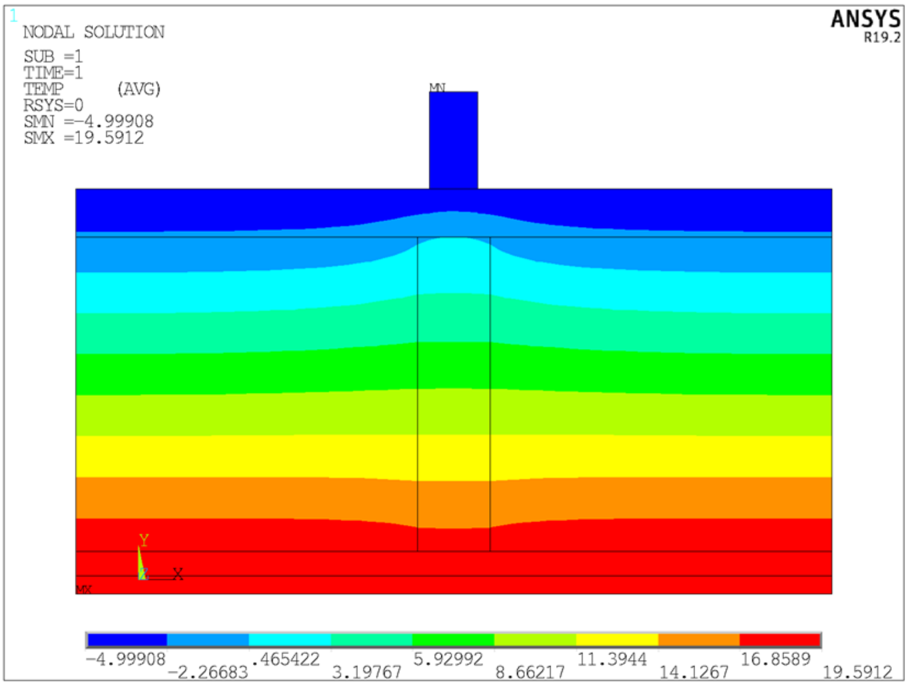


Figure 28. Temperature distribution on conventional timber facade for Northern Europe

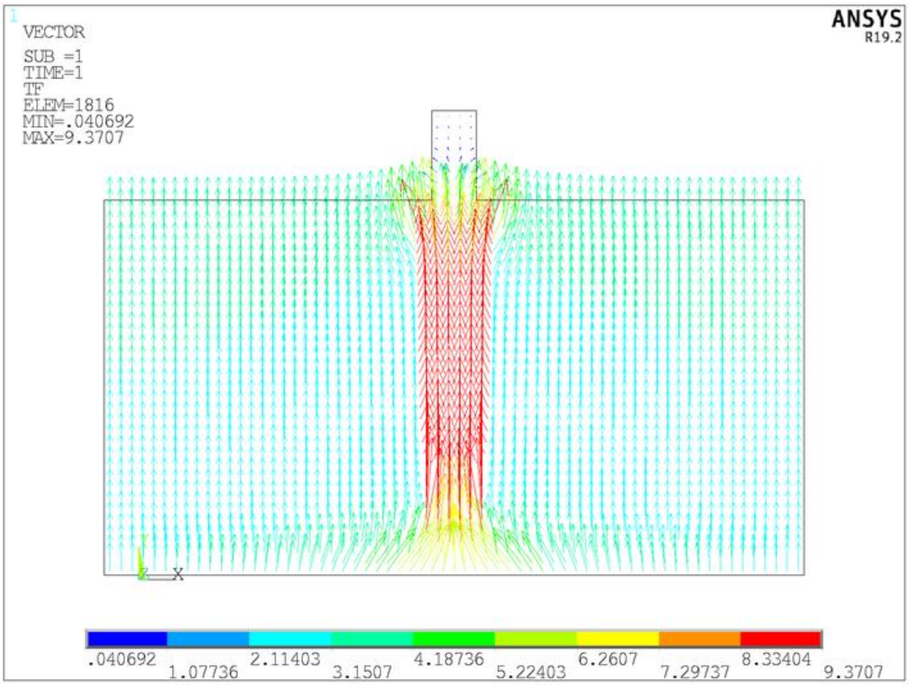


Figure 29. Total heat flux on conventional timber facade for Northern Europe

The U value in absence of thermal bridge has been evaluated as

$$R = \frac{1}{hext} + \frac{1}{hint} + \frac{dplaster}{kplaster} + \frac{dinsul}{kinsul} + \frac{dosb}{kosb} + \frac{dwoodboard}{kwooboard} = 7.91\ [m2 * \frac{K}{W}\ ]$$

$$U_{1D} = \frac{1}{R} = 0.126\ [\mathrm{W/m^2K}\ ]$$

Considering the presence of the thermal bridge and the procedure to evaluate its effect described in Par. 3.1, the heat rate $\dot{Q}$ and the contribution related to thermal bridge C_1 have been evaluated.

- $\dot{Q}$ = 2.29 W
- C_1 = 0.0126 W/mK

The length of the timber façade is equal to 4.4 m (from ZRS [6]) and by dividing it for the length of the considered repetitive unit (equal to 0.625 m), a total amount of seven thermal bridges has been calculated. The global transmittance has been evaluated as follows:

$$U_{g2D} = \frac{U_{1D} \cdot Stot + \sum_i C_{1,i} \cdot L_i}{Stot}$$

$$U_{g2D} = 0.146\ \mathrm{W/m^2K}$$

9.1.2. RE^4 CDW Timber Façade for Northern Europe

Figure 30 and Figure 31 show respectively the temperature distribution and the total heat flux on the RE^4 CDW timber façade for cold climate. The highest temperature I equal to 19.56 °C and it is located on inner surface. The lowest temperature is equal to -4.99 °C and it is locate on the outer surface. The irregularity in both plots highlights the effect of the stud as thermal bridge. Following the consideration of the previous results, the same quantities have been evaluated and the global transmittance have been calculated.

$$R = \frac{1}{hext} + \frac{1}{hint} + \frac{dplaster}{kplaster} + \frac{dinsul}{kinsul} + \frac{dwoodboard\_1}{kwooboard} + \frac{dwoodboard\_2}{kwooboard} = 7.56\ [m2 * \frac{K}{W}\ ]$$

$$U_{1D} = \frac{1}{R} = 0.132\ [\mathrm{W/m^2K}\ ]$$

- $\dot{Q}$ = 2.26 W
- C_1 = 0.0078 W/mK

$$U_{g2D} = \frac{U_{1D} \cdot Stot + \sum_i C_{1,i} \cdot L_i}{Stot}$$

$$U_{g2D} = 0.144\ \mathrm{W/m^2K}$$

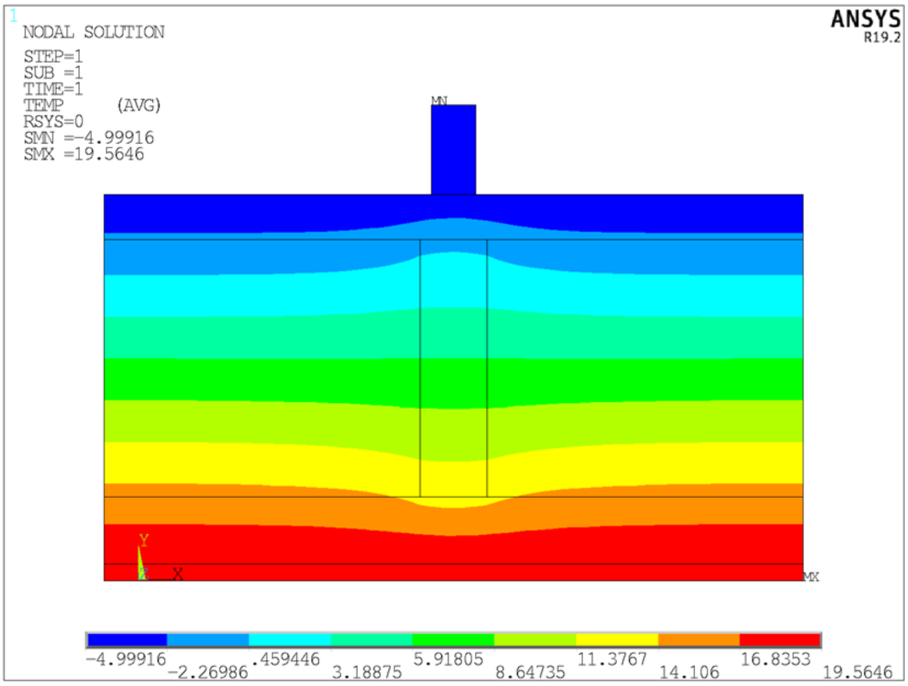


Figure 30. Temperature distribution on RE^4 CDW Timber façade for Northern Europe

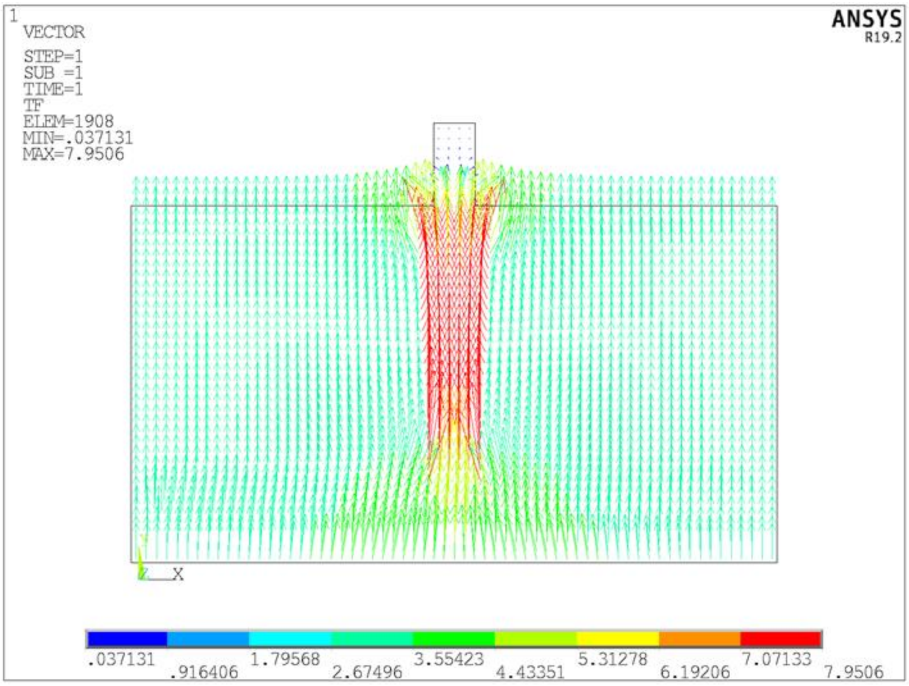


Figure 31. Total heat flux on RE^4 CDW Timber façade for Northern Europe

9.1.3. Conventional Timber Façade for Southern Europe

The temperature contour plot of the conventional timber Façade for warm climate is shown in Figure 32. The highest temperature has been reached on the inner surface and it is equal to 19.54 °C. On the outer surface, the lowest value is located and it is equal to about 0°C. The effect of the stud is visible on the irregularity in the temperature distribution and in Figure 33 where the heat flux vector plot is shown. The global transmittance has been calculated by evaluating the following quantities.

$$R = \frac{1}{hext} + \frac{1}{hint} + \frac{drender}{krender} + \frac{dOSB}{kOSB} + \frac{dearthblock}{kearthblock} + \frac{dinsul}{kinsul} + \frac{dwoodboard}{kwooboard} = 4.21\ [m2 * \frac{K}{W}\ ]$$

$$U_{1D} = \frac{1}{R} = 0.237\ [\mathrm{W/m^2K}\ ]$$

- $\dot{Q}$ = 3 W
- C_1 = 0.0016 W/mK

$$U_{g2D} = \frac{U_{1D} \cdot Stot + \sum_i C_{1,i} \cdot L_i}{Stot}$$

$$U_{g2D} = 0.239\ \mathrm{W/m^2K}$$

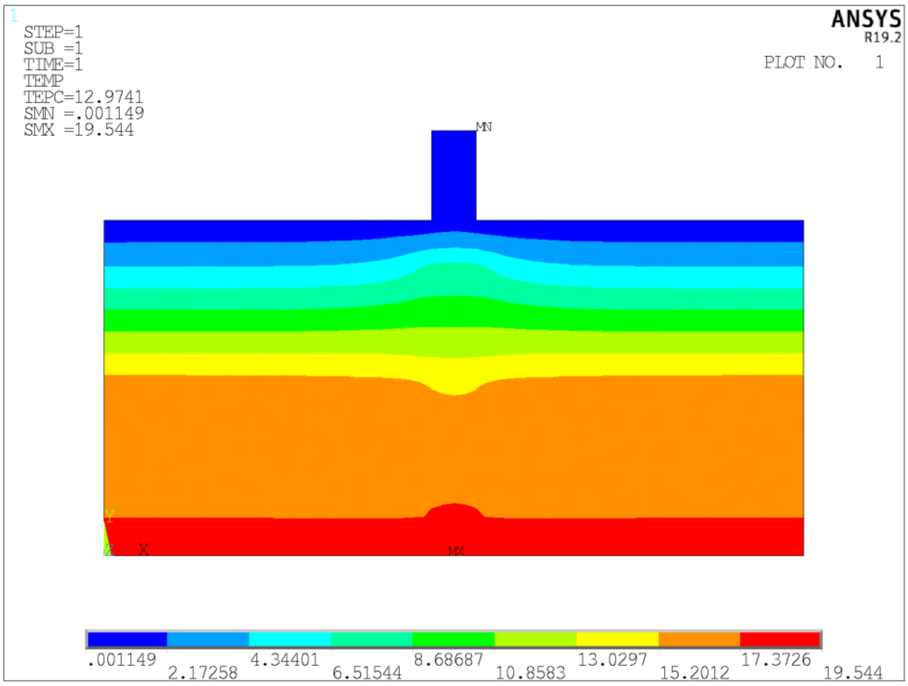


Figure 32. Temperature distribution on conventional timber façade for Southern Europe

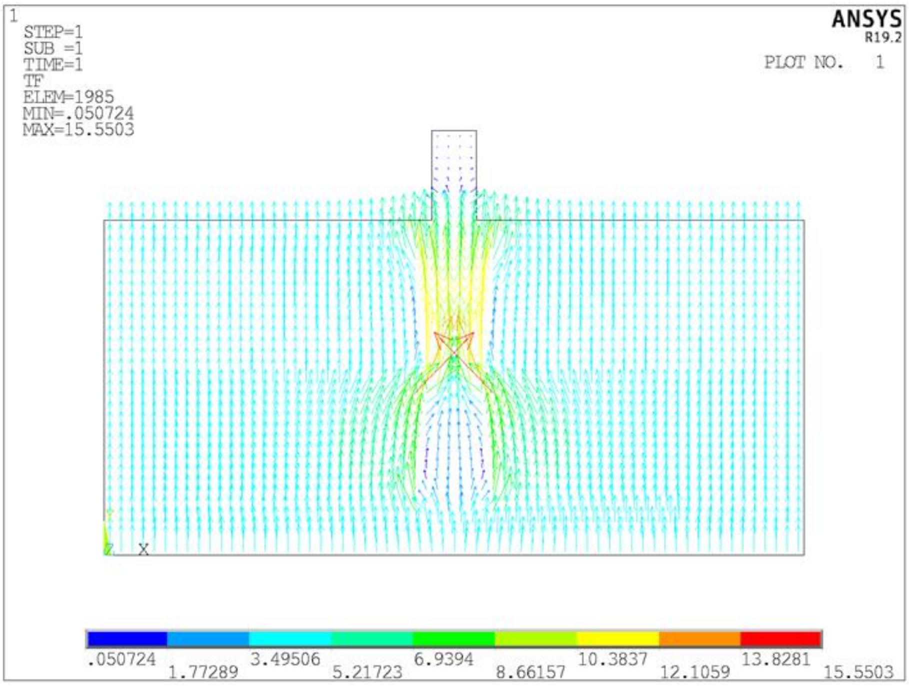


Figure 33. Total heat flux on conventional timber façade for Southern Europe

9.1.4. RE^4 CDW Timber Façade for Southern Europe (Option 1)

The temperature distribution contour plot and the heat flux vector plot, on the first option of RE^4 CDW timber façade, are shown in Figure 34 and Figure 35. A peak of temperature equal to 19.47 °C is visible on the inner surface, while the lowest value (0°C) is located on the outer one. The plots show the irregularity due to the presence of the stud and its effect on the global transmittance has been calculated.

$$R = \frac{1}{hext} + \frac{1}{hint} + \frac{dplaster}{kplaster} + \frac{dwoodboard1}{kwoodboard} + \frac{dearthblock}{kearthblock} + \frac{dinsul}{kinsul} + \frac{dwoodboard2}{kwooboard} = 3.8\ [m2 * \frac{K}{W}\ ]$$

$$U_{1D} = \frac{1}{R} = 0.263[\mathrm{W/m^2K}\ ]$$

- $\dot{Q}$ = 3 W
- C_1 = 0.003 W/mK

$$U_{g2D} = \frac{U_{1D} \cdot Stot + \sum_i C_{1,i} \cdot L_i}{Stot}$$

$$U_{g2D} = 0.268\ \mathrm{W/m^2K}$$

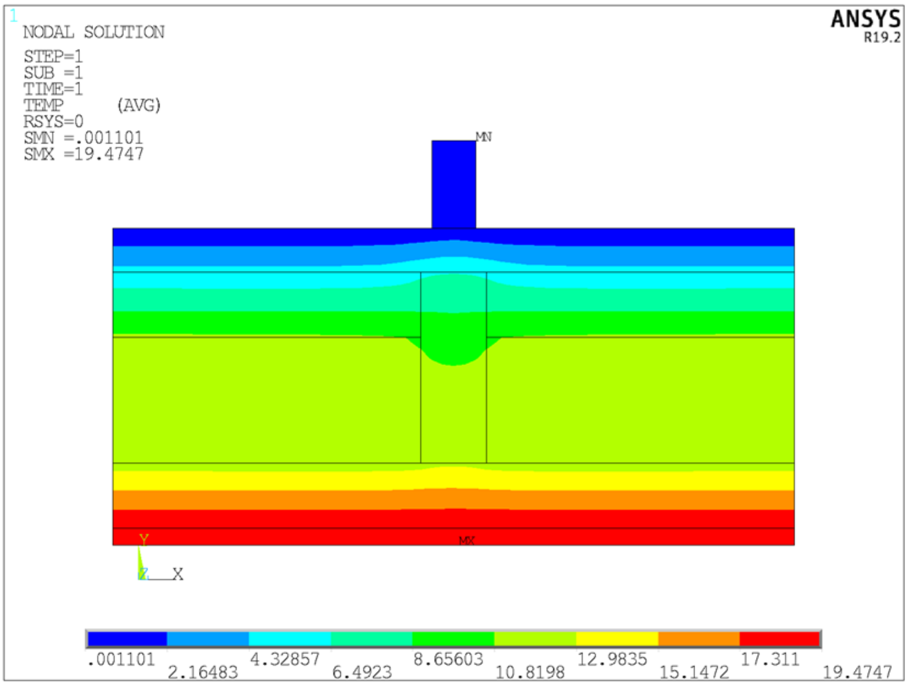


Figure 34. Temperature distribution on RE^4 CDW Timber façade for Southern Europe – Option 1

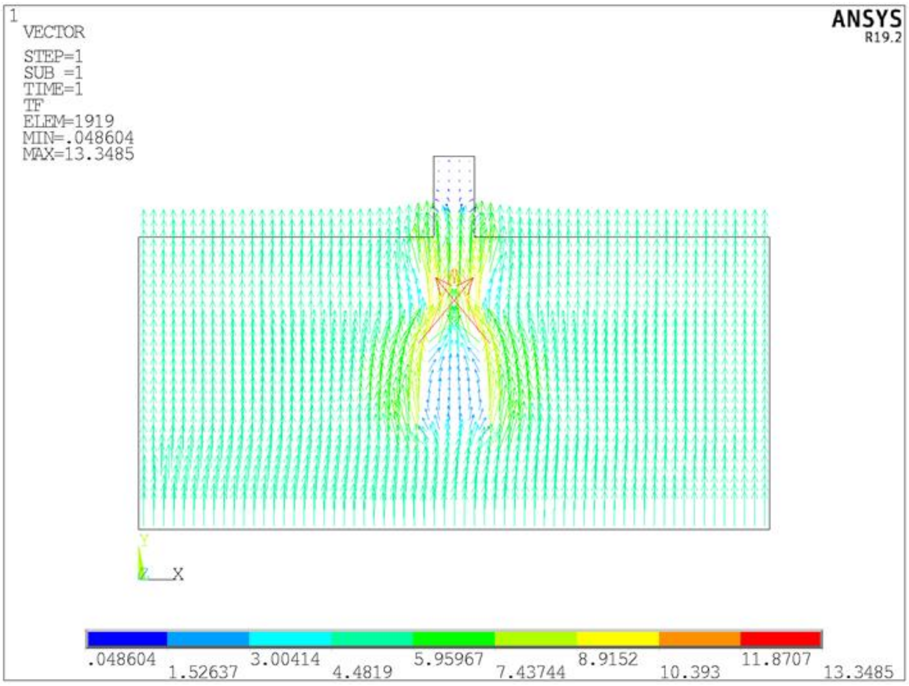


Figure 35. Total heat flux on RE^4 CDW Timber façade for Southern Europe – Option 1

9.1.5. RE^4 CDW Timber Façade for Southern Europe (Option 2)

Concerning the second option of the RE^4 CDW timber façade for warm climate, the temperature contour plot and the heat flux vector plot are shown in Figure 36 and Figure 37. The highest temperature is equal to about 19.55°C on the inner surface, while the lowest one is equal to about

0°C and it is located on the outer surface. The effect of the thermal bridge (the stud) has been calculated as follows.

$$R = \frac{1}{hext} + \frac{1}{hint} + \frac{dplaster}{kplaster} + \frac{dwoodboard1}{kwoodboard} + \frac{dinsul}{kinsul} + \frac{dwoodboard2}{kwooboard} = 4.42\ [m2 * \frac{K}{W}\ ]$$

$$U_{1D} = \frac{1}{R} = 0.226[\mathrm{W/m^2K}\ ]$$

- $\dot{Q}$ = 2.95 W
- C_1 = 0.0063 W/mK

$$U_{g2D} = \frac{U_{1D} \cdot Stot + \sum_i C_{1,i} \cdot L_i}{Stot}$$

U_{g2D} = 0.236 W/m^{2}K

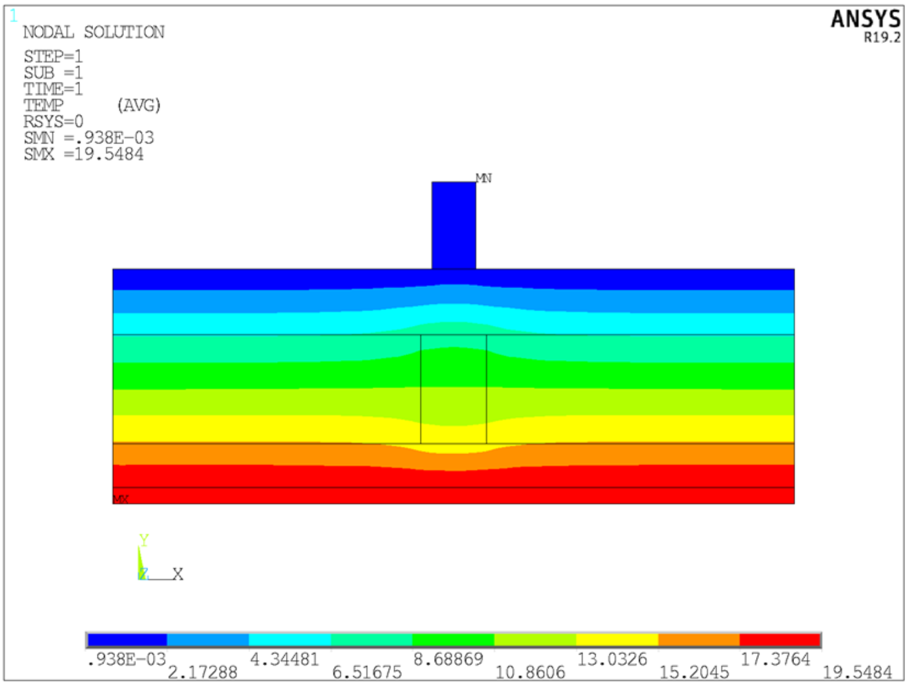


Figure 36. Temperature distribution on RE^4 CDW Timber façade for Southern Europe – Option 2

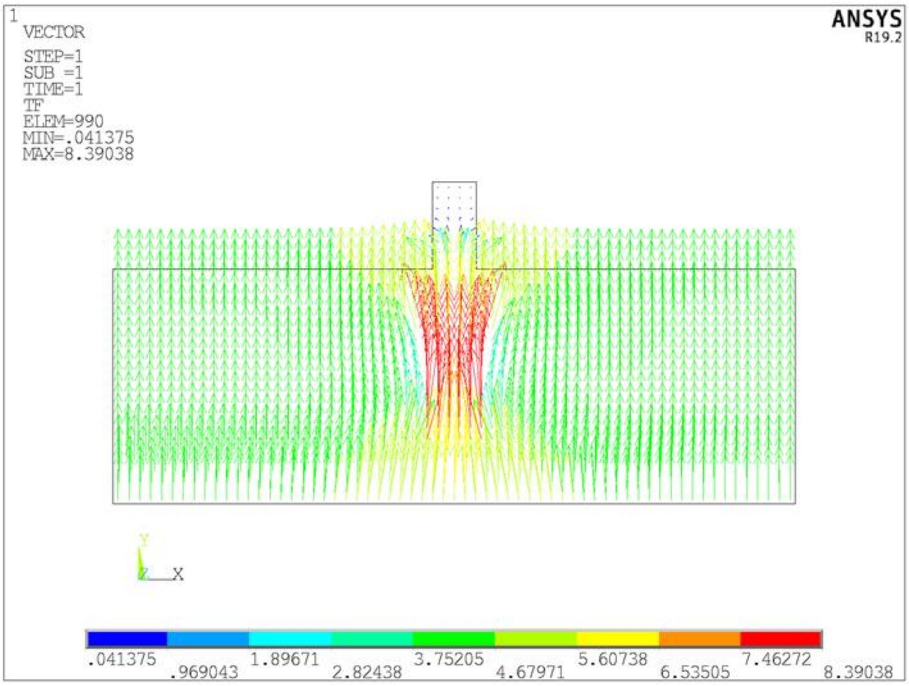


Figure 37. Total heat flux on RE^4 CDW Timber façade for Southern Europe – Option 2

9.2. Thermal analysis – Sandwich Panel

9.2.1. Sandwich Panel for Northern Europe

The temperature contour plot of a section of the sandwich panel model is shown in Figure 38. The section has been chosen in order to highlights the behaviour of the pin connector as possible thermal bridge. The highest temperature is located on the inner surface with a value equal to 19.48°C, while the lowest one is located on the outer surface with a value equal to -4.79 °C. The most important aspect is related to the absence of evident irregularities on the temperature distribution. As consequence the effect of the pin as thermal bridges could be neglected. In order to confirm this approximation, the transmittance in absence of thermal bridges has been evaluated and compared with the global transmittance derived from the heat rate calculated from the FEM results.

$$R = \frac{1}{hext} + \frac{1}{hint} + \frac{dconcrete}{kconcrete} + \frac{dinsul}{kinsul} + \frac{dconcrete}{kconcrete} = 4.83\ [m2 * \frac{K}{W}\ ]$$

$$U_{1D} = \frac{1}{R} = 0.207\ [\mathrm{W/m^2K}\ ]$$

From FEM results:

$\dot{Q}$ = 1.712 W

$$U_g = \frac{\dot{Q}}{L*l*\Delta T} = 0.2075\ [\mathrm{W/m^2K}\ ]$$

With:

L=0.55 m
L=0.6 m
ΔT = 25 K

The two values of transmittance (the analytical one and the one derived from FE model) are the same, validating the approximation of neglecting the effect of pin connectors.

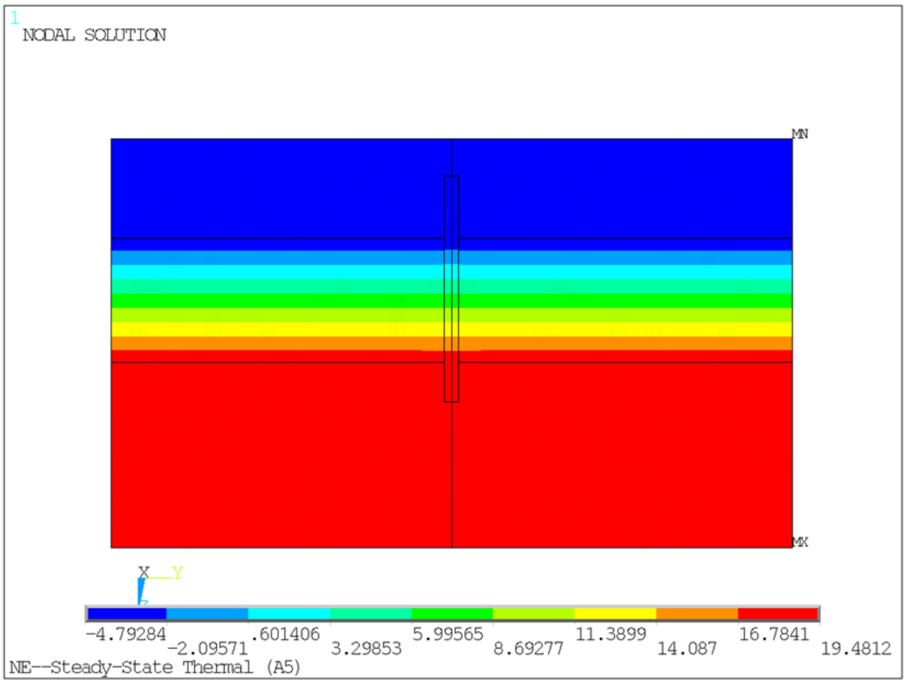


Figure 38. Temperature distribution on sandwich panel for Northern Europe - Section

9.2.2. Sandwich Panel for Southern Europe

The conclusions related to the previous panel result to be valid also for the sandwich panel for Southern Europe. The temperature distribution is shown in Figure 39, exhibiting a maximum value and a minimum one equal to 19.32 °C and 0.26 °C respectively, on the inner and on the outer surface. Evaluating the analytical value of transmittance and the one obtained from FEM calculation, they are the same also for this panel, confirming that the effect of the pin could be neglected.

$$R = \frac{1}{hext} + \frac{1}{hint} + \frac{dconcrete}{kconcrete} + \frac{dinsul}{kinsul} + \frac{dconcrete}{kconcrete} = 2.978\ [m2 * \frac{K}{W}\ ]$$

$$U_{1D} = \frac{1}{R} = 0.0.3358\ [\mathrm{W/m^2K}\ ]$$

From the FE results
$\dot{Q}$ = 1.035 W

$$U_g = \frac{\dot{Q}}{L*l*\Delta T} = 0.336\ [\mathrm{W/m^2K}\ ]$$

With:

L=0.385 m
l=0.4 m
ΔT = 20 K

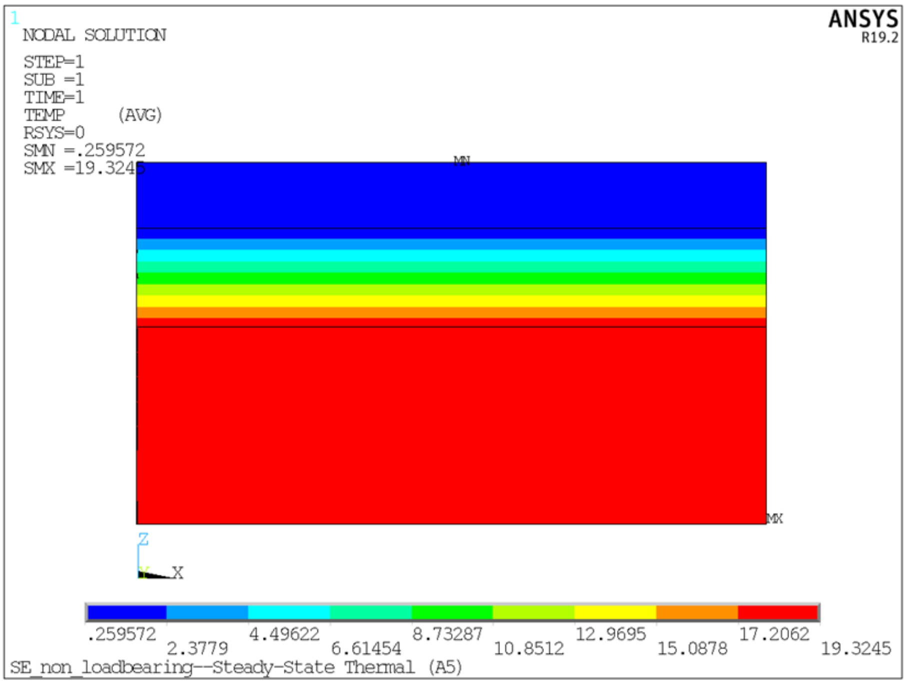


Figure 39. Temperature distribution on sandwich panel for Southern Europe - Section

9.3. Thermal analysis – Summary of results

The results of the thermal analyses are summarized in the table below. Specifically, Table 11 and Table 12 list the results obtained for timber façade. The evaluated global transmittances show how the developed timber façade for Northern Europe is characterized by thermal performances really similar to the ones related to the conventional structure. Concerning the timber façade for Southern Europe, the U value calculated for the Option 2 is comparable with the one of the conventional structure while, on the other hand, the Option 2 seems to show slightly inferior characteristics. Its layering is quite the same of the conventional facade, but a thicker thickness of the insulation layer seems to be the responsible of the transmittance difference.

Table 13 and Table 14 are referred to sandwich panel. They show a global U value for the structure addressed to Northern Europe equal to 0.2075 W/m^{2}K while, concerning the structure for Southern Europe, a transmittance equal to 0.336 W/m^{2}K.

Table 11. Thermal analysis results: Timber facades for Northern Europe

North Europe	R W/m^{2}K	U_{1D} W/m^{2}K	C_1 W/mK	U_{2d} W/m^{2}K
Conventional structure	7.91	0.126	0.0126	0.146
RE^4 CDW	7.56	0.132	0.0078	0.144

Table 12. Thermal analysis results: Timber facades for Southern Europe

South Europe	R W/m^{2}K	U$_{1D}$ W/m^{2}K	C$_1$ W/mK	U$_{2d}$ W/m^{2}K
Conventional structure	4.21	0.237	0.0016	0.239
RE^4 CDW (Option 1)	3.8	0.263	0.003	0.269
RE^4 CDW (Option 2)	4.42	0.226	0.0063	0.236

Table 13. Thermal analysis results: Sandwich panel for Northern Europe

North Europe	R W/m^{2}K	U$_{1D}$ W/m^{2}K	U$_g$ W/m^{2}K
RE^4 Sandwich Panel CDW	7.56	0.207	0.2075

Table 14. Thermal analysis results: Sandwich panel for Southern

South Europe	R W/m^{2}K	U$_{1D}$ W/m^{2}K	U$_g$ W/m^{2}K
RE^4 Sandwich Panel CDW	2.978	0.3358	0.336

9.4. Hygrothermal analysis – Timber Façade

The procedures to evaluate the surface condensation and interstitial condensation are described Par. 3.2. Concerning surface condensation assessment, using the climatic data listed in Par.8.2, for each analysed structure, January and February result to be the most critical months, regardless of Europe zone considered (Berlin or Madrid). The results of the calculations are listed in Table 15 and Table 16.

Table 15. Surface condensation assessment results – Northern Europe – Timber facade

North Europe	Critical month	f_{Rsi}	$f_{Rsi,min}$	Condensation
Conventional structure	January	0.97	0.46	No condensation
RE4 CDW	February	0.97	0.49	No condensation

Table 16. Surface condensation assessment results – Southern Europe – Timber facade

South Europe	Critical month	f_{Rsi}	$f_{Rsi,min}$	Condensation
Conventional structure	February	0.97	0.485	No condensation
RE4 CDW (Option 1)	January	0.972	0.487	No condensation
RE4 CDW (Option 2)	January	0.973	0.487	No condensation

Concerning interstitial condensation analysis, by using the data of the most critical months of the surface analysis, Glaser diagrams have been built following the procedure described in Par. 3.2. They are showed for each analysed structure in the following figures. Since vapour pressure (Pvap) does not exceed the saturation pressure (Psat) at any interface, condensation does not occur in each façade.

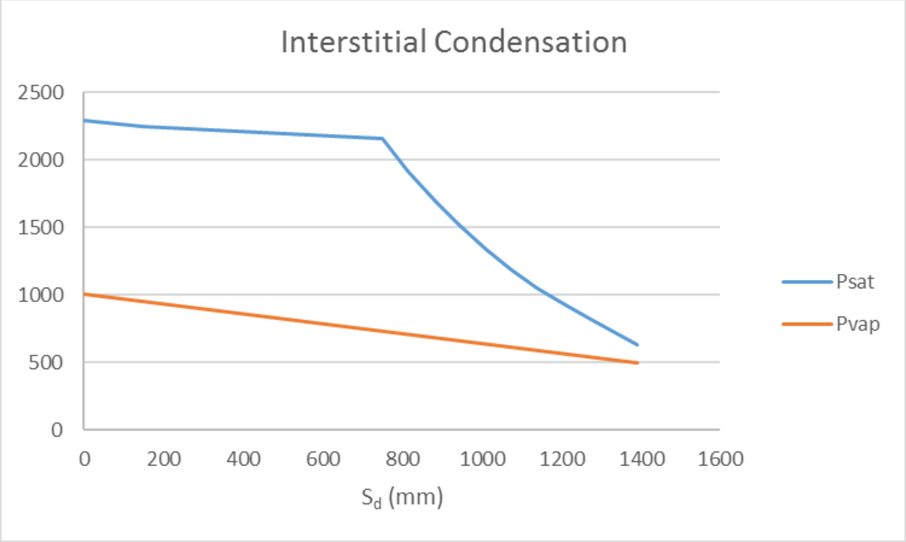


Figure 40. Glaser diagram of conventional timber façade for Northern Europe

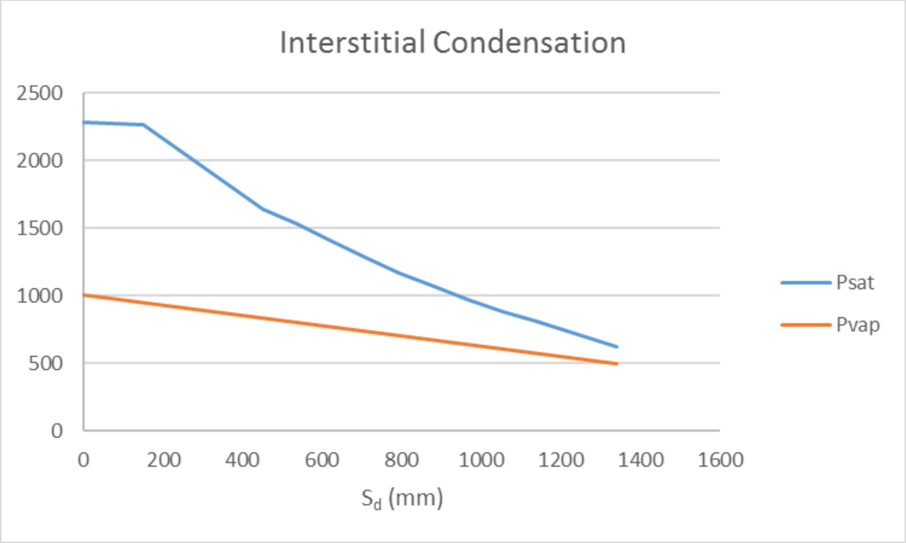


Figure 41. Glaser diagram of RE4 CDW Timber façade for Northern Europe

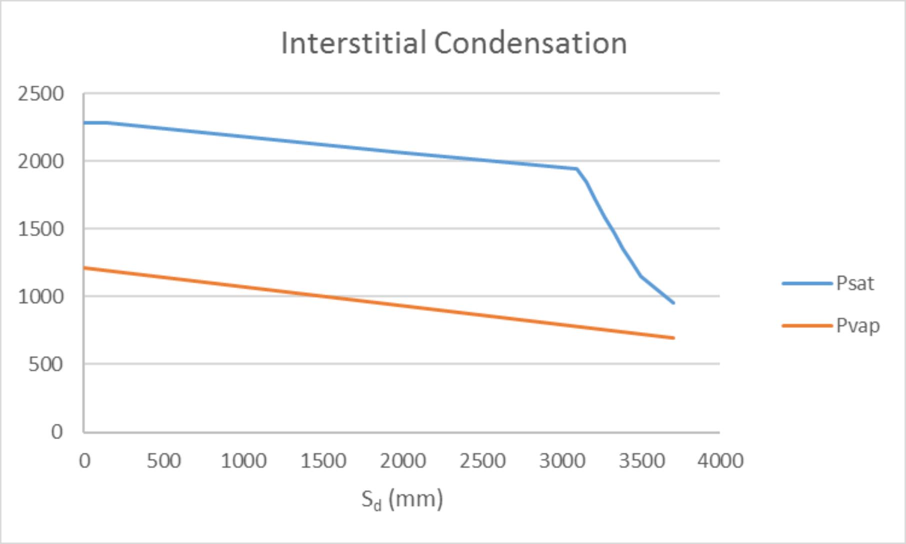


Figure 42. Glaser diagram of conventional timber façade for Southern Europe

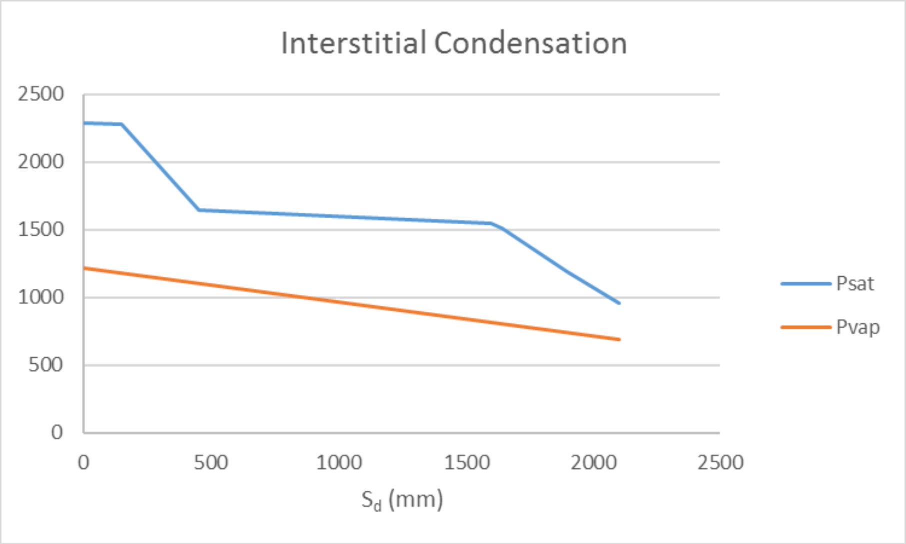


Figure 43. Glaser diagram of RE4 CDW Timber façade for Southern Europe – Option 1

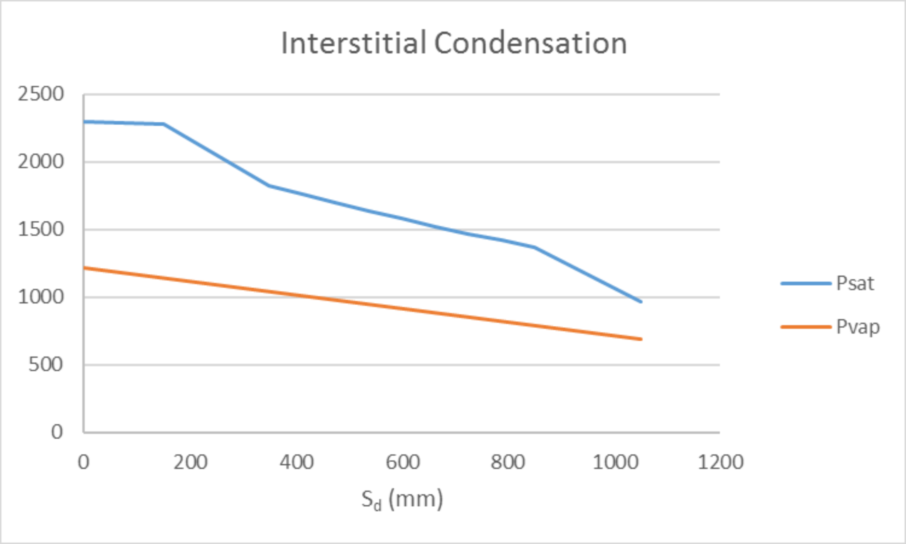


Figure 44. Glaser diagram of RE^4 CDW Timber façade for Southern Europe – Option 2

9.5. Hygrothermal analysis – Sandwich Panel

As seen for the timber facades, from the weather data of Berlin and Madrid, February has been calculated as the most critical month for surface and interstitial condensation. Following the approach and the procedure described in Par.3.2, the obtained results related to surface condensation are shown in Table 17 and Table 18, highlighting that no condensation occurs in both cases.

Table 17. Surface condensation assessment results – Northern Europe – Sandwich panel

North Europe	Critical month	f_{Rsi}	$f_{Rsi,min}$	Condensation
RE^4 Sandwich Panel CDW	February	0.837	0.479	No condensation

Table 18. Surface condensation assessment results – Southern Europe – Sandwich panel

South Europe	Critical month	f_{Rsi}	$f_{Rsi,min}$	Condensation
RE^4 Sandwich Panel CDW	February	0.748	0.468	No condensation

Concerning interstitial condensation, Figure 45 and Figure 46 show the Glaser diagram of the sandwich panel for cold climate and of the one for warm climate, respectively. In both graphs, the vapour pressure (Pvap) does not exceed the saturation pressure (Psat) at any interface, consequently condensation does not occur.

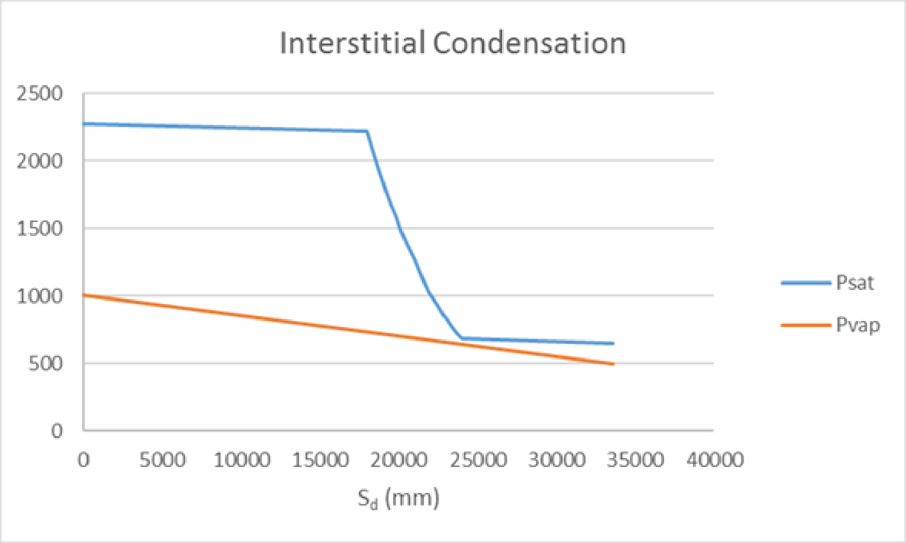


Figure 45. Glaser diagram of sandwich panel for Northern Europe

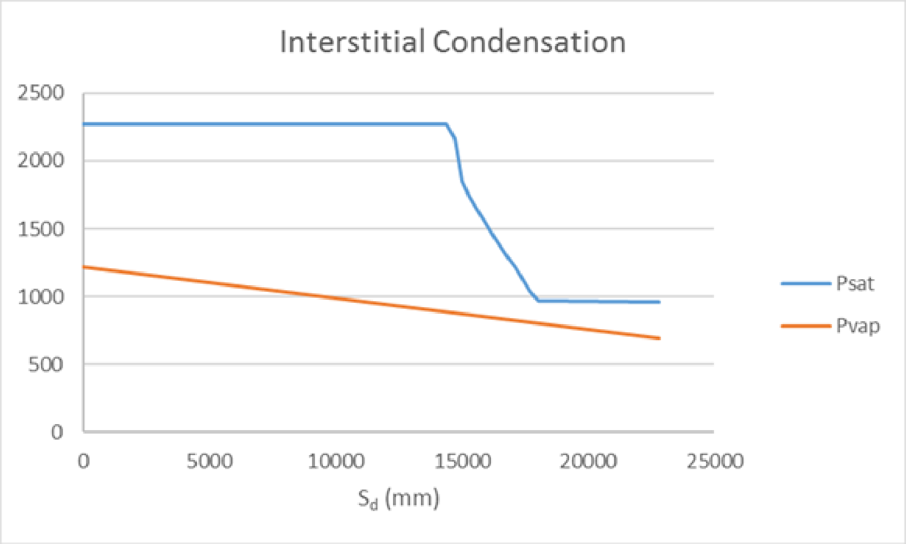


Figure 46. Glaser diagram of sandwich panel for Southern Europe

10. CONCLUSIONS AND RECOMMENDATIONS

This document describes the outcome of the *SubTask3.4.2,* namely *Hygrothermal Modelling*. As a first step, the approaches used in order to assess the U value and to establish if condensation (superficial/interstitial) occurs, have been widely described. Subsequently, the hypotheses, the approximations and the strategy used to create the FE models have been exposed. Starting with the timber façade, for each analysed structure a repetitive unit of the entire geometry has been considered and a 2D discretized model centred on the stud (thermal bridge) has been generated. Following the described approaches, the FEM analyses have been performed and the results have shown that the structures for cold climate are characterized by a transmittance lower than 0.3 w/m^{2}K, while the ones used for warm climate have shown a U value lower than 0.4 W/m^{2}K. Concerning, the sandwich panel, the representative unit of the geometry has been defined as a 3D model surrounding a pin connector, which could be a possible thermal bridge. The results have shown that the effect of the latter one could be neglected and the structure for North Europe exhibits a transmittance lower than 0.3 W/m^{2}K and the one addressed to warm climate is characterized by a U value lower than 0.4 W/m^{2}K. In each structure, the target value of the project has not been overtaken. In the end, the results obtained by FEM analyses have been employed for condensation assessment. The calculations have shown that condensation does not occur in timber facades and sandwich panels.

It is really important to stress the aspects related to material properties and material characterization. Most of the employed materials are not commercial one and both experimental and literature data have been employed for the development of FE analyses.

11. BIBLIOGRAPHY

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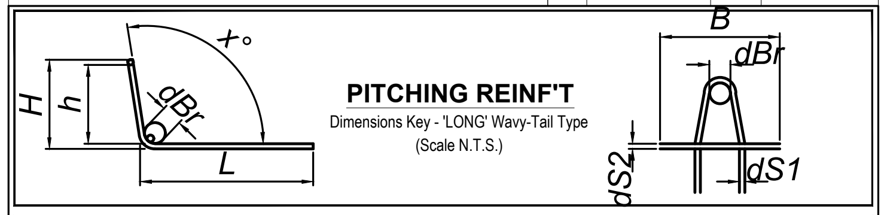
DISCLAIMER

FACTORY QUALITY CHECK PRODUCTION PRE POUR		
DATE CAST		
	CHECKED	SIGNED
REQUIRED COVER 25mm		
ALL DETAILS & DIMENSIONS CORRECT		
RD36 LIFTERS IN CORRECT POSITION		



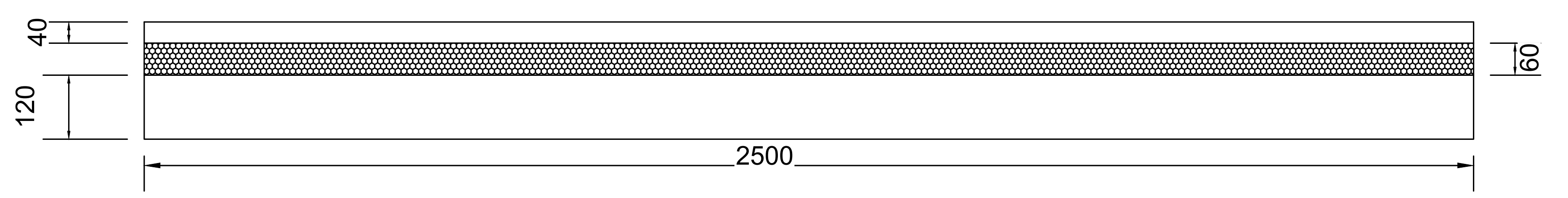
PITCHING REINF'T

Dimensions Key - 'LONG' Wavy-Tail Type

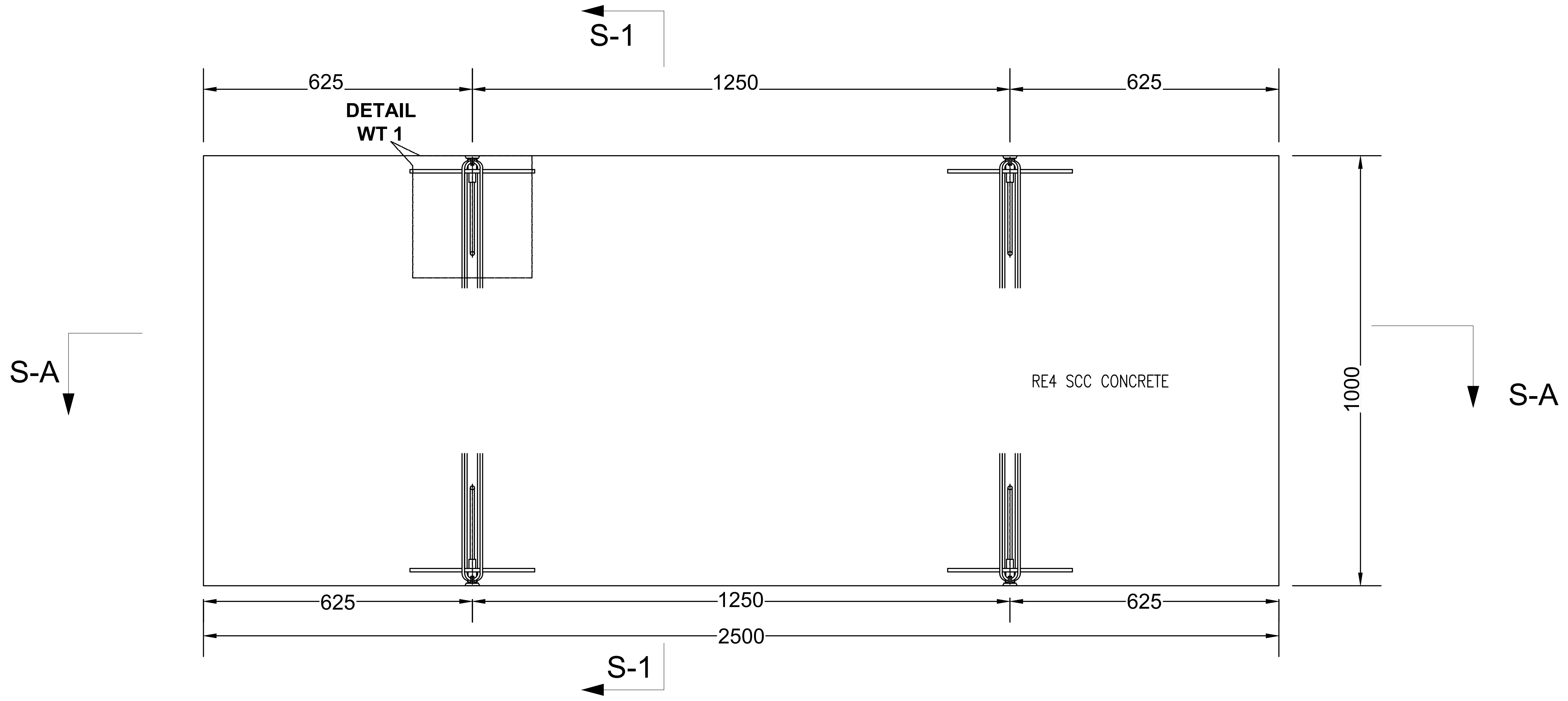
(Scale N.T.S.)

Lifter Size ('Long')	Min Unit Thk (mm)	dS1 (mm)	L (mm)	h (mm)	H (mm)	dBr (mm)	angle (x°)	B (mm)	dS2 (mm)
RD20	110	10 Ø	490	44	64	40	105°	490	14 Ø

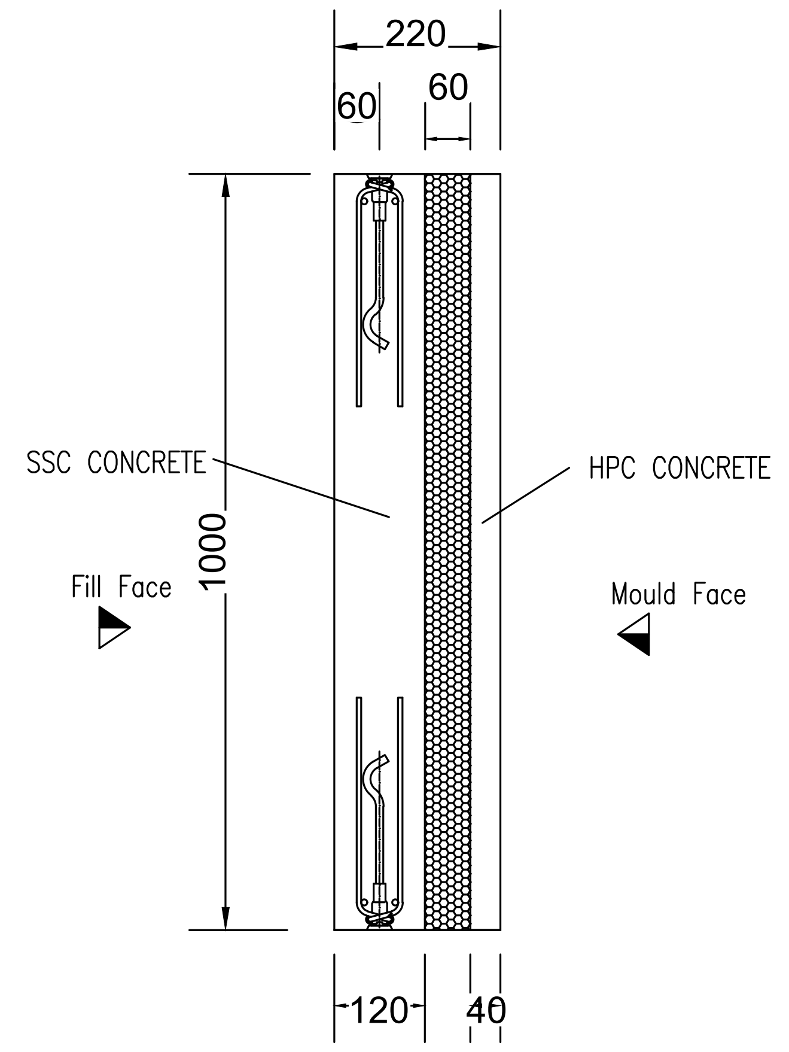
dS1 Pitching Bar Factory Pre-Pour Check Completed & Bar In Place	☐	**dS2** Longitudinal Bar Factory Pre-Pour Check Completed & Bar In Place	☐
SUPERVISOR SIGNATURE & DATE:			



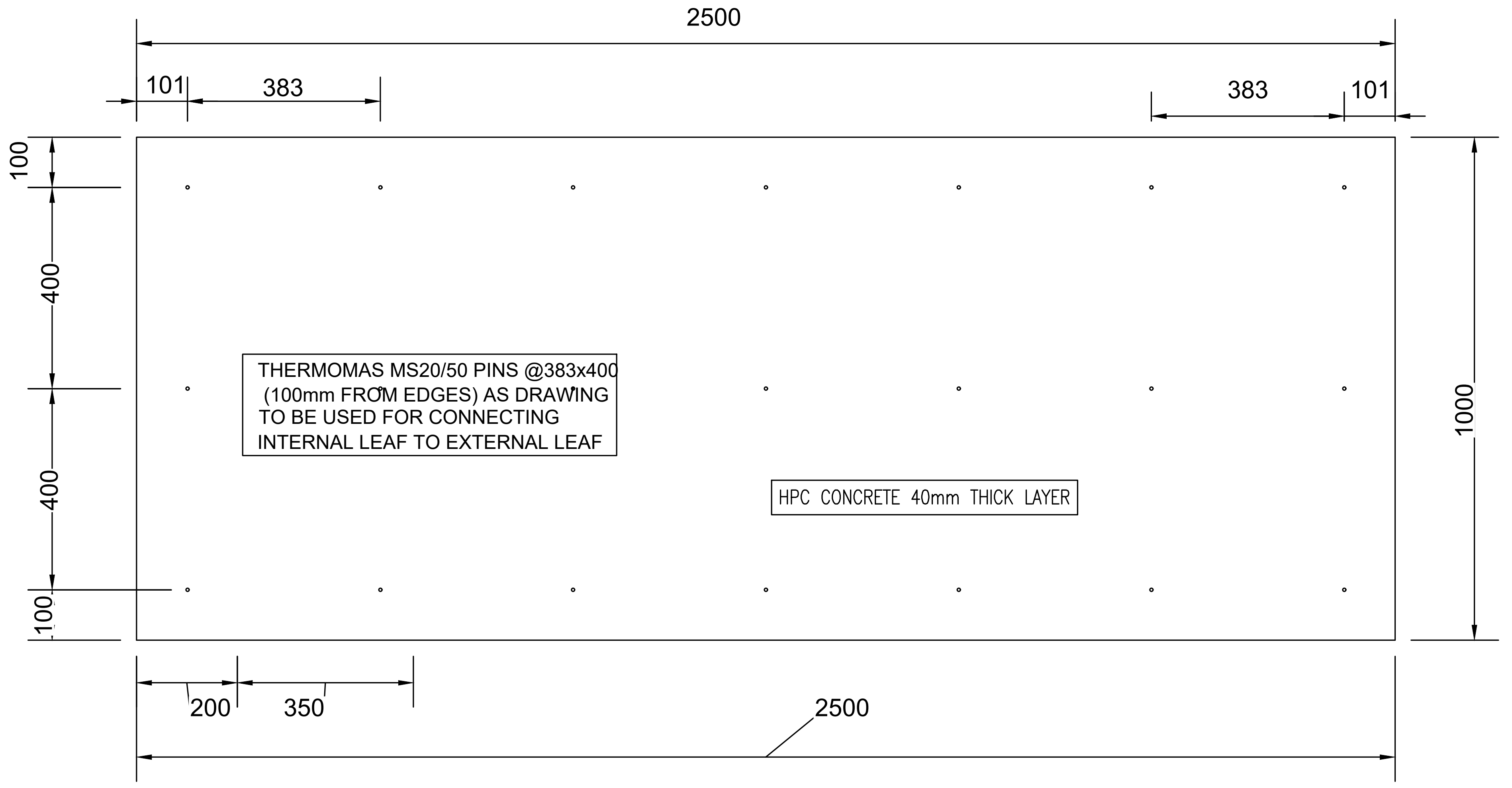
Section S-A
1/10



Elevation - Structural layer (Fill Face)
sc: 1/10

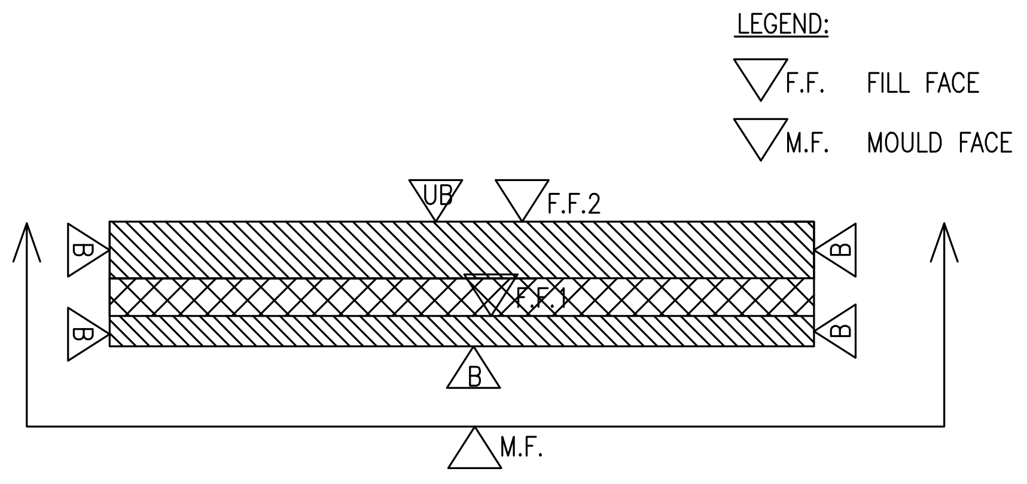


Section S-1
1/10



THERMOMAS MS20/50 PINS @383x400 (100mm FROM EDGES) AS DRAWING TO BE USED FOR CONNECTING INTERNAL LEAF TO EXTERNAL LEAF

Elevation - Outer layer (mould face)
sc: 1/10



FINISHES

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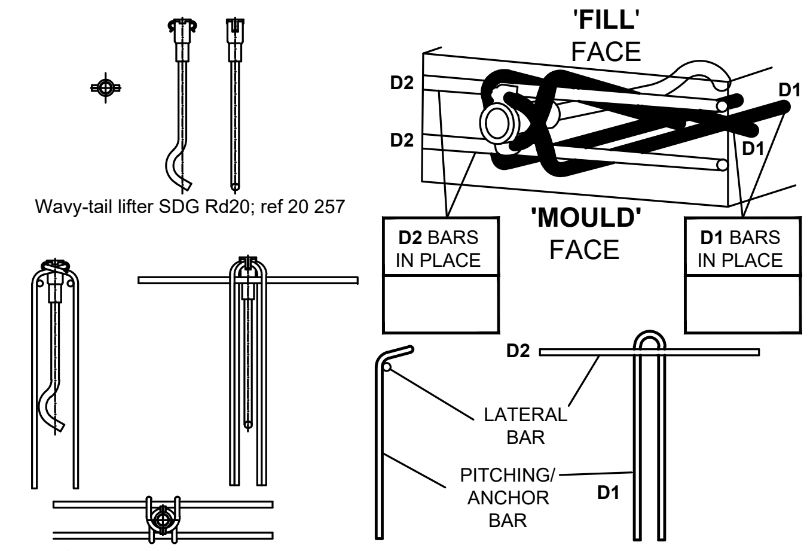
DATE CAST		
	CHECKED	SIGNED
ALL DETAILS & DIMENSIONS CORRECT		
LIFTERS IN CORRECT POSITION		



WAVY TAIL (Long Type)	D1 BAR Ø	D2 BAR Ø
RD12 RD16 RD20	Ø8 Ø8 Ø10	Ø8 Ø12 Ø12
RD24 RD30 RD36	Ø12 Ø12 Ø16	Ø14 Ø16 Ø16
RD42 RD52	Ø16 Ø20	Ø16 Ø20

DETAIL 'WTL1'
WAVY-TAIL LIFTER PITCHING REBAR
(MULTI-DIRECTIONAL)

(Scale N.T.S.)

CONCRETE	MIX TYPE	COVER	FINISH
RE4 SCC	C40/50	25mm (Strc. layer)	Type B ; UB As shown in sketch
RE4 HPC	C50/60	15mm (outer layer)	

VOLUME OF CONCRETE Structural Layer (SCC) PER UNIT = 0.300m^3

VOLUME OF CONCRETE Outer Layer (HPC)PER UNIT = 0.100m^3

TOTAL WEIGHT OF EACH UNIT = 1.05 t

EACH PANEL CONTAINS :

	TYPE :	No. / PANEL
SITE LIFTERS	RD20 ZP WAVY TAIL 257MM long	4
DEMOULDERS		0
VOID FORMER		0
		0
CAST-IN FIXING SOCKETS		0
FIXED EARTHING TERMINAL ET		0
CAST IN CHANNEL		0
WIRE ROPE BOXES		0

ID NUMBER: SP-HPC – T – n

03 No REQUIRED AS DRAWN REF SP-HPC-T.R

SP-HPC-T.R

Concrete	
Concrete Grade	C40/50
Exposure Class	XC3, XD2
Finish	TYPE B; UB
Reinforcement	
Inner/Structural layer:	
Cover To Reinforcement	25mm
Rebar	500B
Outer/Mould layer:	
Cover to Reinforcement	15mm
Rebar	Carbon Reinf. type: Solidian GRID Q85/85 CCE-21

NOTE FOR REBAR DETAILS RELATING TO THIS PANEL REFER TO CREAGH DRAWING No. 16-RE4- SP-HPC-T.R

ID NUMBER: SP-HPC - T - n

PIECE COUNT

REF. no	No.
SP-HPC - T - 1	1
SP-HPC - T - 2	1
SP-HPC - T - 3	1
TOTAL	3

3 No. REQUIRED

REV.	DATE	MADE BY	CHECKED BY	DETAILS
		RC		FOR CONSTRUCTION

CREAGH
CONCRETE PRODUCTS LTD
Blackpark Rd, Toomebridge,
Co. Antrim, N. Ireland. BT41 3SE
Tel : 028 79650500 Fax : 028 79650804

CONTRACTOR RE4 project– RISE

CONTRACT WP5

TITLE Production Details
Drawing Ref: SP-HPC-T.M

DRAWN BY: RISE DATE:	CHECKED BY: RC DATE:	INSPECTED BY: DATE:
BASE SCALE: 1:10 @ A1	ISSUE STATUS: CONSTRUCTION	
CONTRACT No. 16-RE4	DRG. No. SP-HPC-T.M	REV.