ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering | e–ISSN: 2067 – 3809
Tome XIX [2026] | Fascicule 2 [April – June]

[1.] Ioana TEODORESCU, [2.] Ruxandra ERBAȘU, [3.] Daniela TAPUSI, [4.] Valeriu–Gabriel GHICA

THE BEHAVIOUR OF THERMAL INSULATION IN CLT PANELS SUBJECTED TO ROMANIAN CLIMATE CONDITIONS

[1–3.] Technical University of Civil Engineering Bucharest, ROMANIA
[4.] Faculty of Materials Science and Engineering, University POLITEHNICA of Bucharest, 313 Spl. Independentei, Bucharest, ROMANIA

Abstract: CLT (cross–laminated timber) is a revolutionary processed material that can be used in timber structures as a solution for surface structural elements. The present paper is following a study on different types of thermal insulation applied on CLT exterior panels having various thicknesses and technical characteristics, thermal requirements and simultaneously fulfilling structural, economical and sustainable demands. In the same time, some insulation solutions are ecological materials, thus representing a positive interest for the environmental impact. The present study analyses the propagation of temperature and moisture within successive layers when the pack is subjected to conditions that are specific for Romanian climate with high variations in temperature and relative humidity between winter and summer. In the calculation, the thickness of the wood layers, CLT panel, and insulation varies from 34.05 cm to 44.45 cm. Three types of insulations are considered for the analysis in the form of mineral wool, glass wool and wood fiber. It was found that in terms of results and properties of the layers, the hydrothermal characteristics do not vary except for different climatic conditions.
Keywords: CLT, insulation, moisture content, temperature, climate

INTRODUCTION

Engineering wood products have evolved in time in the form of different wood based composed materials that are more resilient regarding mechanical characteristics and present a longer duration in time. The Cross Laminated Timber (CLT) represents a structural panel formed by multiple layers of sawn timber, at least three, arranged crosswise and joined using adhesives [1],[2],[3]. Some advantages are linked to sustainability, efficiency, versatile configuration of the layers, systematized construction process, easy to execute, and positioned on-site, with a positive impact on the environment [4].

One of the disadvantages of wood is its hygroscopic nature, which causes it to absorb moisture in humid conditions or release it in dry ones. This moisture exchange creates gradients within wood-based materials leading to internal stresses and potential cracking [5].

As detailed in some previous materials [6], there is a difference in the elements' structural behavior related to the type of climate in which the structure is built with higher risks of biodegradation when temperature and relative humidity have higher values and the climate is drier or colder. Concurrently, the comfort of the indoor environment is considered an important part of a residential building [7].

The environmental impact across the entire life cycle of the building is set by the materials and technologies that are implemented. Therefore, sustainable design principles are applied by cutting CO_2 emissions, by using energy-efficient technologies, renewable energy sources and minimal use of processed materials [8].

When constructing an exterior wall of a building, thermal insulation is necessary in order to eliminate the thermal bridges and to prevent heat loss [9] by transferring heat from high temperature to low.

In terms of thermal insulation, Europe leads as the largest market due to diverse climate factors, awareness of sustainability and energy efficiency. Recently, natural plant fibers taken from agriculture or trees residues have grown more accessible and affordable [10], [11].

Among available materials, mineral wools (glass or rock) remain the dominant choice [12]. These materials are used for building envelopes or thermal equipment in order to conserve energy and limit heat transfer [13].

Wood fibers represent another material from sustainable resources that naturally regulate moisture and are harmless to humans [14].

MATERIALS AND METHODS

The materials used for the study are CLT and three types of thermal insulation: mineral wool, glass wool and wood fiber, a vapor retarder and several types of sheathing for the exterior and the interior wall.

Cross-laminated timber (CLT) represents a composed wood material produced at a larger scale in factories with different technological protocols that involve stacking solid sawn timber in 3-7 layers crosswise at 90° angles [12].

In terms of thermal insulations, wood fiber insulation has become a common solution due to its advantages of being a renewable, ecological and energy efficient material with good thermal performance and advantages in fire safety. Key disadvantages include raw material accessibility and moisture errors [15].

The main activity of the study is the analysis of two situations depending on thermal insulation types with four subsequent cases each.

The pack considered presents the same configuration of a CLT wall (presented below in Figure 1.2) with the difference of the thickness of the wall (57 mm and 161 mm) and type of insulation mineral wool/glass wool and wood fiber.

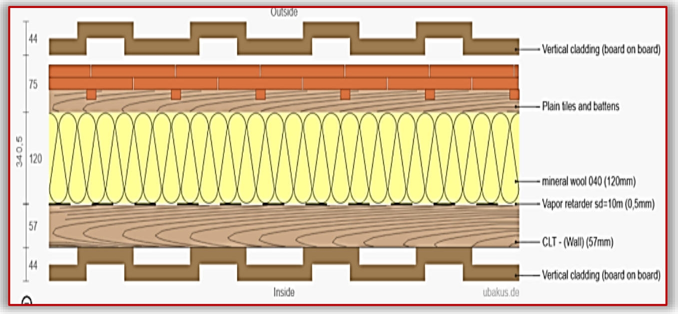


Figura 1.1 Configuration of the layers composing the wall (source: ubaqus.de)

The analysis is made following two climate scenarios one for winter and one for summer, with temperature and relative humidity specific for extreme weather conditions in Romania see (Tabelul 1.1).

Tabelul 1.1 Climate configuration of cases considered

Climate conditions	T interior [°C]	T exterior [°C]	RH interior [%]	RH exterior [%]
winter	15	–15	20	80
summer	30	40	10	5

The configuration considered for the CLT wall from the inside to the outside is vertical cladding of 44 mm, CLT wall of 57 mm and 161 mm, vapor retarder of 0,5 mm, insulation of mineral wool of 120 mm, plain tiles and battens of 75 mm and vertical cladding (arranged in a configuration of board on board) of 44 mm. The other characteristics for each layer is presented in the table below Table 1.2.

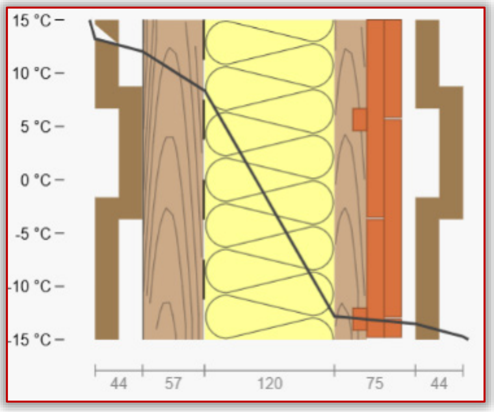
In the first situation for the first case scenario with the CLT wall of 57 mm in winter time, the dimensions of the wall pack is 34,05 cm with a total weight of 114,7 $\mathrm{kg/m^2}$. After the calculation, the R value that measures the resistance of a material to heat flow is 4,129 m^2K/W and the sd value is 13,33 m. The U value that measures the heat transfer coefficient of a building is 0,242 $\mathrm{W/(m^2}K)$. The measured temperature of the inside surface is $13{,}2℃$ and the temperature on the outside surface is $-14{,}7℃$.

Table 2. Reference values of thermal conductivity and thermal resistance of materials

Types of materials	d [mm]	λ [W /mK]	sd [m]	weight [kg/m²]	c [J / kgK]
vertical cladding	44	0,260	0,22	7,7	1600
CLT	57 / 161	0,110	1,14 / 3,22	26,8 / 75,7	1600
vapor retarder	0,5	0,220	10,00	0,1	1700
mineral wool	120	0,040	0,12	2,4	830
plain tiles and battens	75	0,750	0,75	70,0	840
vertical cladding (board on board)	44	0,260	1,10	7,7	1600

*where d represents the thickness of the material, λ represents the theoretical thermal conductivity coefficient, sd represents the diffusion resistance, weight represents the weight of each layer, c represents the specific heat capacity.

The R value is calculated by dividing the thickness of the material considered for the calculation by its thermal conductivity. The thermal insulation is considered better if the R value is higher. The reciprocal of the R-value (1/R) is known as the U-value that measures the heat transfer coefficient of a building. If the value is higher, the conduction of heat is better [16],[17].



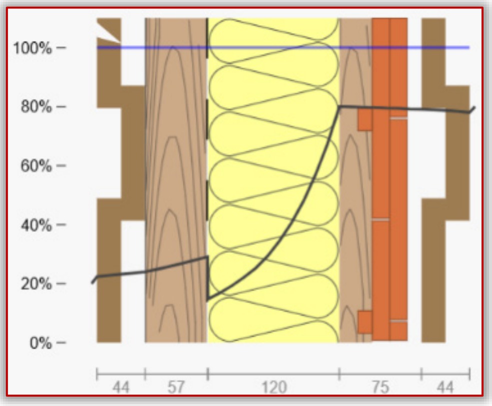


Figura 1.2 a) temperature; b) relative humidity (source: ubaqus.de)

In Figure 1.2 a) the distribution of the temperature among the layers of the wall package can be seen with the outside region represented on the right side. It can be clearly seen on the graph that inside the thermal insulation, in this case mineral wool, the temperature increases the most. The same happens in b) with the humidity that increases in the thermal insulation region.

In Figure 1.3 the temperature diagram with values for each layer composing the wall pack can be seen from the outside to the inside. The temperature of 0°C is reached in layer 3 represented by the mineral wool.

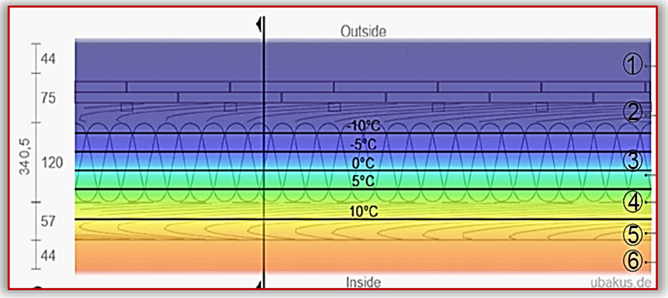


Figura 1.3 Temperature diagram wall pack (vertical cladding, plain tiles and battens, mineral wool, vapor retarder, CLT, vertical cladding) (source: ubaqus.de)

The same kind of configuration diagram but following the humidity distribution among the layers of the wall pack can be seen in Figure 1.4. From layer 3 which is the thermal insulation, in this case mineral wool, the humidity reaches 80% found in the outside region from 20%.

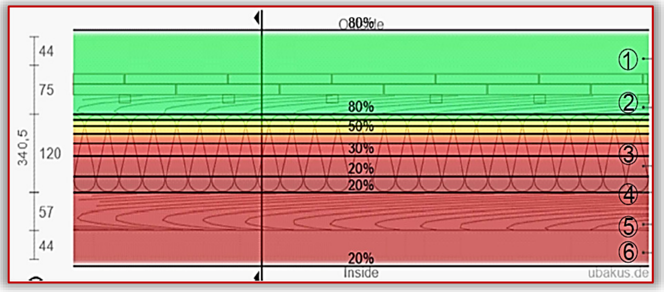


Figura 1.4 Humidity diagram wall pack (vertical cladding, plain tiles and battens, mineral wool, vapor retarder, CLT, vertical cladding) (source: ubaqus.de)

In the first situation for the second case scenario the same configuration of the wall is kept but the climate conditions of summer are taken into consideration. From the calculation, the R and U value are the same as for the winter season, the sd -value is 13,45 m. The measured temperature of the inside surface is 30,6°C and the temperature of the outside surface is 39,9°C.

The distribution of the temperature among the layers of the wall pack can be seen in Figure 1.5 a) with the outside region represented on the right side. The augmentation of the temperature is made in a constant manner with a higher increase in the insulation layer. Concerning the humidity, seen in the diagram b) the distribution is uniform between the layers.

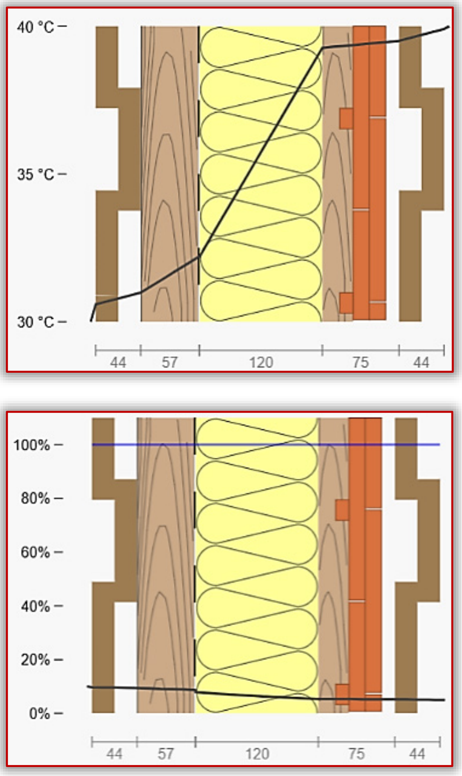


Figura 1.5 a) temperature; b) relative humidity (source: ubaqus.de)

The temperature diagram for each layer can be seen in Figure 1.6 with small differences between the layers. This happens because the temperature values have a difference of only 10 °C.

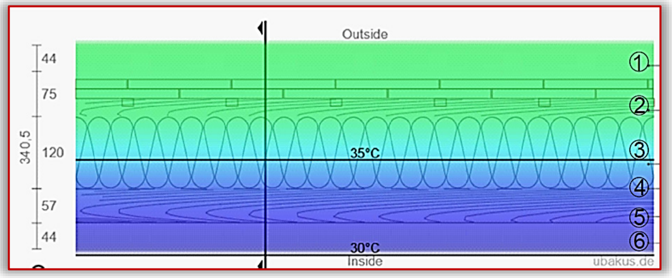


Figura 1.6 Temperature diagram wall pack (vertical cladding, plain tiles and battens, mineral wool, vapor retarder, CLT, vertical cladding) (source: ubaqus.de)

Concerning the humidity, the distribution is equal among all the layers of the wall pack (see Figure 1.7).

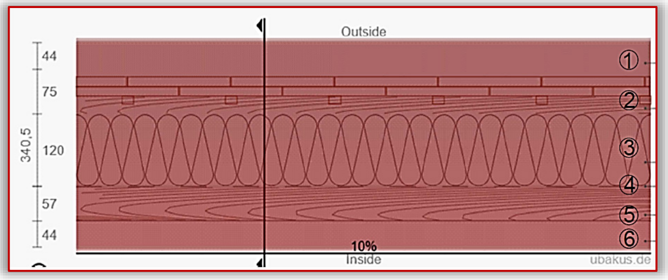


Figura 1.7 Humidity diagram wall pack (vertical cladding, plain tiles and battens, mineral wool, vapor retarder, CLT, vertical cladding) (source: ubaqus.de)

In the first situation for the third case scenario, the same configuration of the wall is considered; however, the thickness of the CLT wall is augmented to 161 mm. The climate conditions are considered for winter climate. The dimensions of the wall pack is 44,45 cm with a total weight of 163,6 $\mathrm{kg/m^2}$. After the calculation, the R value is 5,074 $\mathrm{m^2}K/W$ and the sd value is 15,41 m. The U calculated value is 0,197 $\mathrm{W/(m^2}K)$. The measured temperature for winter climate of the inside surface is $13{,}6°\mathrm{C}$ and the temperature of the outside surface is $-14{,}8°\mathrm{C}$.

In Figure 1.8 the distribution of temperature and humidity can be seen. The temperature has an increase in the CLT, because of the dimension of the wall, and the thermal insulation layer. For the humidity, the insulation layer presents the highest increase, with a small drop in the vapor retarder layer.

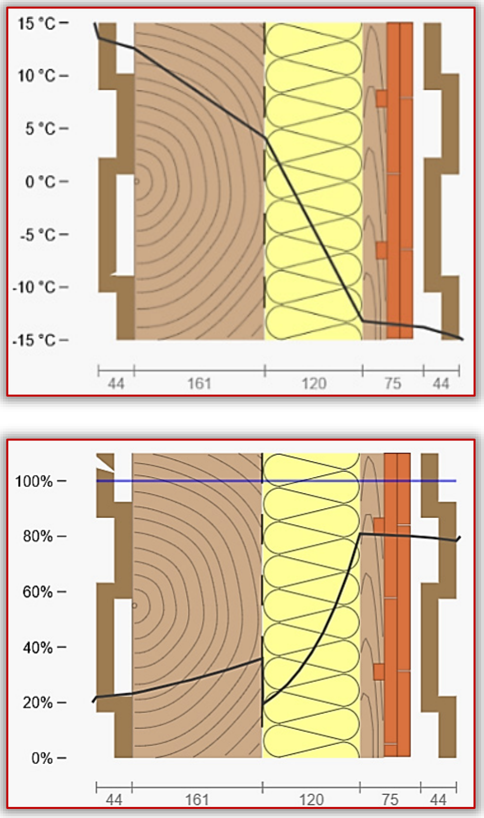


Figura 1.8 temperature; b) relative humidity (source: ubaqus.de)

The temperature diagram presented below in Figure 1.9, shows the changes among the layers with the increase of temperature in a constant manner.

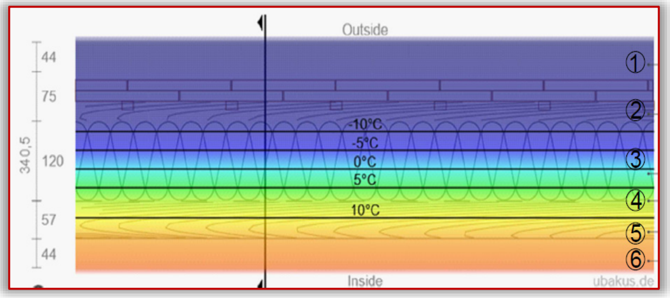


Figura 1.9 Temperature diagram wall pack (vertical cladding, plain tiles and battens, mineral wool, vapor retarder, CLT, vertical cladding) (source: ubaqus.de)

The humidity distribution from the outside to the inside can be seen in Figure 1.10 from 80% to 20%.

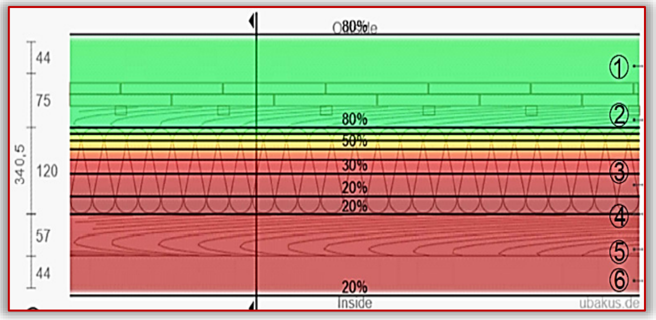


Figura 1.10 Humidity diagram wall pack (vertical cladding, plain tiles and battens, mineral wool, vapor retarder, CLT, vertical cladding) (source: ubaqus.de)

In the first situation for the fourth case scenario, the same configuration of the wall is considered. However, the thickness of the wall is augmented to 161 mm. The climate conditions are considered for summer climate. After the calculation, the R value is 5,074 $\mathrm{m^2}K/W$, the sd value is 15,53 m and the U calculated value is 0,197 $\mathrm{W/(m^2}K)$. The measured temperature for winter climate of the inside surface is $30{,}5°\mathrm{C}$ and the temperature of the outside surface is $39{,}9°\mathrm{C}$.

In Figure 1.11 the distribution of the temperature and humidity can be seen. The temperature increases exponential in the CLT wall and the thermal insulation layer while the humidity has an approximately uniform distribution.

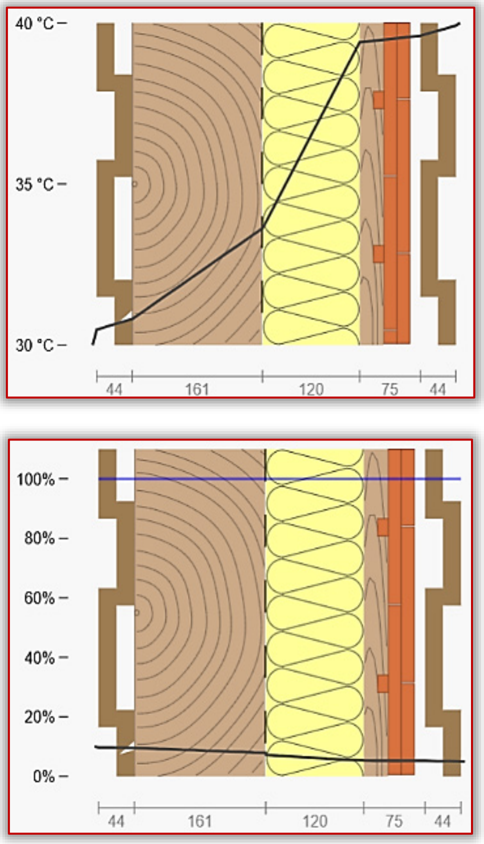


Figura 1.11 a) temperature; b) relative humidity (source: ubaqus.de)

The temperature diagram, seen in Figure 1.12 presents the distribution of temperature among the layers with a difference of 5°C until the thermal insulation layer.

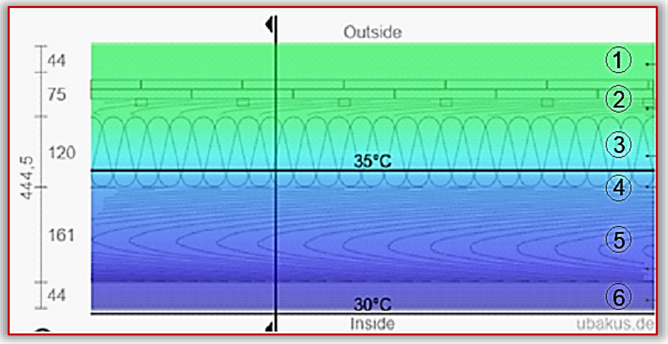


Figura 1.12 Temperature diagram wall pack (vertical cladding, plain tiles and battens, mineral wool, vapor retarder, CLT, vertical cladding) (source: ubaqus.de)

Concerning the humidity, the distribution is equal among all the layers of the wall pack, see Figure 1.13.

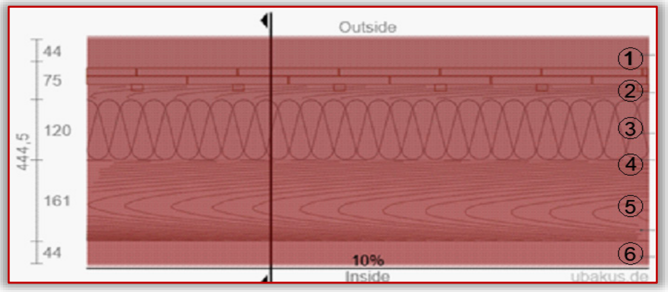


Figura 1.13 Humidity diagram wall pack (vertical cladding, plain tiles and battens, mineral wool, vapor retarder, CLT, vertical cladding) (source: ubaqus.de)

The second situation analyses the same wall configuration as for the previous ones but with a change in the thermal insulation in the form of wood fiber. All the four cases considered for the first situation depending on the climate conditions for winter and summer are taken into consideration for this situation as well.

The wall package is formed by a CLT wall of 5,7 cm another type of thermal insulation consisting of a wood fiber insulation board of 12 cm. The characteristics for the new thermal insulation are $\lambda = 0{,}044\ [\mathrm{W/mK}]$, $c = 2100\ [J/kgK]$ and the weight $= 19{,}2\ [\mathrm{kg/m^2}]$. The total dimension of the wall pack is 34,05 cm with a weight of $131{,}5\ \mathrm{kg/m^2}$.

The other type of wall pack considered is formed by a CLT wall of 16,10 cm with a total weight of $180{,}4\ \mathrm{kg/m^2}$.

RESULTS AND DISCUSSIONS

The results of the analysis of temperature and humidity distribution between the layers of the wall pack in the situations considered can be seen in Tabelul 1.3 for situation 1 and Tabelul 1.4 for situation 2. Between the two situations considered for the campaign the differences are given by R that has higher values for cases I and II for mineral wool/glass wool compared to wood fiber insulation. On the other hand, the sd and U values are higher for the wood fibers. The interior values for temperature in both situations for the climate conditions considered are almost the same.

Mineral wool and glass wool are considered the same in terms of characteristics and behavior in the wall pack.

Tabelul 1.2 Hydrothermal results for situation 1

Situation 1						
Cases	Insulation type	R $[\mathrm{m^2K/W}]$	sd [m]	U $[\mathrm{W/(m^2K)}]$	Inside T °C	Outside T °C
I	Mineral wool/glass wool	4,129	13,33	0,242	13,2	−14,7
II	Mineral wool/glass wool	4,129	13,45	0,242	30,6	39,9
III	Mineral wool/glass wool	5,074	15,41	0,198	13,6	−14,8
IV	Mineral wool/glass wool	5,074	15,53	0,197	30,5	39,9

Tabelul 1.3 Hydrothermal results for situation 2

Situation 2						
Cases	Insulation type	R $[\mathrm{m^2K/W}]$	Sd [m]	U$[\mathrm{W/(m^2K)}]$	Inside T °C	Outside T °C
I	Wood fiber	3,856	13,57	0,259	13,1	−14,7
II	Wood fiber	3,856	13,81	0,259	30,6	39,9
III	Wood fiber	4,802	15,65	0,208	13,5	−14,8
IV	Wood fiber	4,802	15,89	0,208	30,5	39,9

For the first and third case scenario in situation 1, in the winter climate considered for Romania, due to unknown solar and internal gains, the heating demand can only be estimated following the values used for the calculation. The temperature at the inside surface is 13,6 ℃ that leads to a relative humidity on the surface of 22 %. Concurrently, energy consumption and global warming potential can only be estimated. Under these conditions, mould formation is not expected between the layers.

If condensation forms at a certain boundary between two layers, the total condensed water is assigned to the moisture content of both layers, not divided in the same quantity between them.

For the second and last case scenario in situation 1, the temperature on the inside surface is 30,0 ℃ resulting in 10 % relative humidity on the surface which means that mould is not expected to appear. In these conditions, dry air and high values for the outside temperatures have a positive effect. The condensation process is the same as for the first case.

CONCLUSIONS

The multitude of variables such as materials and dimensions of the layers represent the main conclusion of the study. The variations take into considerations their positive behavior in terms of climate differences in temperature and humidity, their sustainability properties, the availability of the material and the manufacturing process and last but not least the economic point of view.

From the analysis made, it has been shown that the changes in the dimension of the CLT panel do not influence the propagation of the temperature and humidity.

When changing the thermal insulation, the differences are not significant, indicating that the properties and dimensions of the layers of insulation used for the current situations do not influence the total behavior of the wall pack.

The differences that have occurred in the analysis are the result of climate changes from winter to summer in terms of temperature and humidity.

The longer the component remains without changes, the more environmentally friendly it becomes, as production related emissions contribute less to the overall total cost.

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ISSN: 2067–3809