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STUDY OF CONDENSATION RISK IN ECOLOGICAL BLOCKS WITH RECYCLED WOOD AGGREGATE

BY

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Abstract. Concrete is a building material with a continuous demand in the construction industry due to the convenient price-performance ratio. On the other hand, concrete is not an environmentally friendly material. Thus, in order to obtain a sustainable material, wood waste can be recycled and used as light aggregates in the manufacture of precast ecological building blocks. Block walls must satisfy not only structural criteria but also functional requirements. In addition, thermal contribution is important in reducing energy consumption over the life of the building. The presence of moisture on the exterior walls due to the appearance of condensation will decrease the thermal performance of building materials. This paper analyses the occurring of condensation risk and its location in the outer wall made of wood-concrete blocks by the Glaser method, for different situations of arrangement and composition of the layers.

Keywords: vapor permeability, lightweight blocks, eco-products, recycled wood, condensation, Glaser method.

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1. Introduction

The sand and fine or coarse aggregates used to obtain the concrete or different types of blocks constitute a natural resource that does not regenerate. Thus, sufficient studies have been carried out to obtain different masonry blocks with light aggregates from the recovery of wood waste as independent element or as a formwork system (M. Li, *et al.*, 2017, Scotta and Trutalli, 2021, Dominguez-Santos et al, 2019). The block walls used on the exterior wall have to satisfy mechanical and thermal performances (Thandavamoorthy, 2016, Entuc, *et al.*, 2018, 2019). The using of wood waste as a light aggregate in concrete conducts to higher thermal characteristics of the blocks. The hygrothermal behaviour shows the physical properties of the material and the possibilities to ensure an adequate comfort inside of building. (M. Li, *et al.*, 2019). Thermal properties are influenced by variation of material density and relative humidity of the environment condition (Brzyski, 2016).

The aim of this study is to analyse the condensation risk in the exterior wall made by ecological blocks, to check if the possibility of not thermally insulating the walls is a viable solution. he studied blocks are made with large holes, which include a thermal insulation layer and a reinforced concrete element to assure improved thermal resistance and required mechanical performance for the exterior wall.

For the analysis there were supposed a variation of few parameters: the thickness of the exterior shell, the empty core or concrete filled in it, the joint between ecological blocks and the hygro-thermal behaviour through inner web and exterior shell.

The method used for the analysis was the Glaser graphical approach. According with this, the study emphasises the appearance of the risk of condensation and its location in the wall structure taking into account different conformations of the wood-concrete block.

2. Properties of building materials

The ecological blocks are mare from concrete with 40% recycled wood waste.

To increase thermal resistance of the wall, a mineral wool insulation is included in blocks core. In addition, in order to achieve mechanical performance of the wall, concrete is filled in core.

The thermal conductivity of the plaster, concrete and mineral wool are extracted form norms. In case of wood-concrete material, the thermal conductivity was carried out by experimental work in the in the Civil Engineering Laboratory of the Faculty of Civil Engineering and Building Services from Iasi. There were made 5 measurements for the thermal properties using the portable

equipment ISOMET 2114, shown in Figure 1, and the mean value was 0.141 W/mK (Table 1).

The geometry of the precast blocks for exterior walls is presented in Figure 2. The vapor resistance factor for the wood-concrete, used in table 2, was considered the one for the concrete with vegetable aggregates with the density of 800 kg/m^3, presented in C107-2005. [C107, 2005]

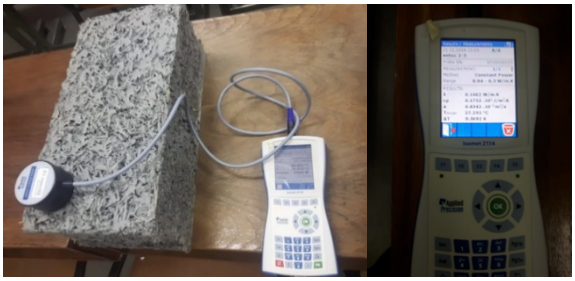


Fig. 1 − Thermal conductivity measurements on the wood - concrete material with 40% wood aggregates

Table 1

Thermal properties of the wood-concrete material measured with Isomet equipment

Measurements No.	Thermal conductivity [W/mK]	The mean value of wood - concrete thermal conductivity [W/mK]
1	*0.1579*	*0.1411*
2	*0.1602*	
3	*0.1187*	
4	*0.1255*	
5	*0.1462*	

Table 2

Properties of materials used in the analysis

Material layer	Width [m]	Vapor resistance factor	Vapor permeability, [m/s]	Thermal conductivity [W/mK]
Interior plaster	*0.02*	*8.5*	*91.8*10^7*	*0.87*
C16/20 concrete	*0.15*	*21.3*	*1725.3*10^7*	*1.74*
Mineral wool insulation	*0.1*	*1.5*	*81*10^7*	*0.042*
Wood-concrete studied material	*0.04*	*5,3*	*114.48*10^7*	*0.141*
	0.06	*5.3*	*171.72*10^7*	
	0.33	*5.3*	*944.46*10^7*	
	0.35	*5.3*	*1001.7*10^7*	
Exterior plaster	*0.02*	*8.5*	*91.8*10^7*	*0,87*

The analysis is based on an approximate method, namely Glaser's Graphic Method. The condition for avoiding the risk of condensation is that the partial vapor pressure does not reach the value of the saturation pressure at any point inside the element. The checking was performed for both distinct areas of the wall, respectively the reinforced concrete area and through to the spaces not filled with concrete. The characteristics of the material layers are presented in Table 2.

In order to perform this study, the following steps were taken:

a. Establishing the temperature variation in the wood-concrete blocks wall (considering the calculation outdoor temperature corresponding to the climatic zone of the site):

$$T_k = T_i - \frac{T_i - T_e}{R} \cdot \sum_{j=1}^{n} R_{j-1,j} \text{ [ºC]} \quad (1)$$

b. Establishing the resistance of vapor permeability

$$R_{Vi} = d_i \cdot \mu_{Di} \cdot M \text{ [m/s]} \quad (2)$$

where,

d_j – the thickness of the material layer [m]

$\mu_{Dj} = 1/K_{Dj}$, is the vapor resistance factor, [m/s], with the values extracted from the C107 normative.

$M = 54 \cdot 10^8$ [s^{-1}] – vapor diffusion coefficient.

c. Estimation of the vapor saturation pressures. The values are extracted from the C107 normative and are calculated according to the temperatures determined at the first step.

d. Computation of partial vapor pressures of indoor and outdoor air, p_{vi} and p_{ve}. The analysis was performed for an average load, respectively for the relative humidity of the indoor air of 60% and the relative humidity of the outdoor air 80%. The partial vapor pressure values of the indoor and outdoor air are:

$$p_{vi} = 60 \cdot 2340/100 = 1404 \text{ [Pa]}$$
$$p_{ve} = 80 \cdot 125/100 = 100 \text{ [Pa]}$$

e. Drawing the vapor pressure variation diagram

- on the abscissa are represented the values of the resistances to the passage of water vapor, and on the ordinate the values of the pressures.
- the variation diagram of the vapor saturation pressures is obtained by joining the "p_{sk}" points, marked on the graph representing the section of the building envelope on the permeability resistance scale;
- the diagram of the partial vapor pressures results from the union of the points p_{vi} and p_{ve}.

f. Analysis of results

- if the curve of the partial vapor pressures does not intersect the graph of saturation pressures, it results that there is no risk of condensation occurring in the construction element;
- if the two curves intersect at a single point, then a condensed surface will result near the intersection point;
- if the two curves intersect at two points, then a condensation zone will result between the two points and a new check is required, namely "Checking the progressive non-accumulation of water, from year to year, as a result of condensation of water inside the building element" [C107/6 - 02].

3. Case Studies

There were considered 6 cases for verification, as follows [Figure 2]:

The 1st Case. The block has an outer shell with a 40 mm thickness and the core filled with concrete and mineral wool. The analysis was made through the core filled with mineral wool and concrete;

The 2nd Case. The block has an outer shell with a 60 mm thickness and the core is filled with concrete and mineral wool. The analysis was made through the core filled with mineral wool and concrete;

The 3rd Case. The block has an outer shell with a 40 mm thickness and in the core is fitted only the mineral wool. The analysis was made through the core considered as an unventilated air layer;

The 4th Case. The block has an outer shell with a 60 mm thickness and in the core is fitted only the mineral wool. The analysis was made through the core considered as an unventilated air layer;

The 5th Case. The block has an outer shell with a 40 mm thickness. The analysis was made through the web;

The 6th Case. The block has an outer shell with a 40 mm thickness. The analysis was made through the mortar joint.

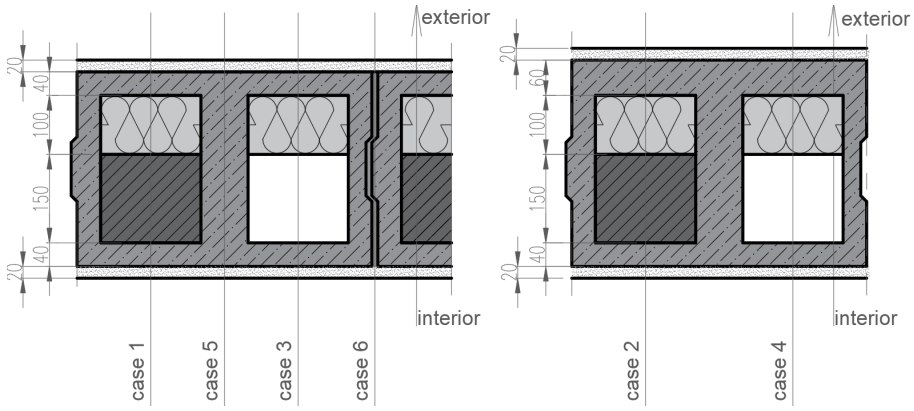


Fig. 2 – Horizontal section of the block. The case studies proposed.

For the first two cases, the interstitial temperatures were calculated, the results being presented in Table 3, with the values of the air saturation pressures at the respective temperatures. The changing of the outer shell thickness from 40 mm to 60 mm due to minor differences between temperatures and saturation pressures.

Table 3

Interstitial saturation temperatures and pressures – 1st and 2nd cases

Layer boundaries	Description	Temperature [°C]		Saturation pressure [Pa]	
		1st Case	2nd Case	1st Case	2nd Case
i	*Indoor*	*20*	*20*	*2340*	*2340*
is	*Inner surface*	*18.537*	*18.598*	*2136.81*	*2125.76*
1	*The contact area between the inner plaster and the inner shell of the block*	*18.268*	*18.341*	*2100.52*	*2113.26*
2	*The contact area between the inner shell of the block and the concrete layer*	*14.948*	*15.160*	*1700.28*	*1721.8*
3	*The contact area between the concrete layer and the thermal insulation layer*	*13.939*	*14.193*	*1592.29*	*1610.77*
4	*The contact area between thermal insulation and the block's outer shell*	*-13.924*	*-12.504*	*181.76*	*207.92*
5	*Contact area between the outer shell of the block and the outer plaster*	*-17.243*	*-17.275*	*134.14*	*133.5*
es	*Exterior (outer) surface*	*-17.512*	*-17.533*	*130.76*	*130.34*
e	*Exterior (outdoor)*	*-18*	*-18*	*125*	*125*

The pressure variation diagram for the 1st Case is illustrated in Figure 3.a. It is observed that a condensation zone appears which comprises the outer limit zone of the mineral wool isolation layer, the entire outer shell of the precast block and the inner limit zone of the plaster layer. There is a risk of condensation occurring in that area (Figure 3.b). This phenomenon may cause damaged of building materials, may negatively influence the thermal insulation and mechanical performances of the material.

In the second case, taking into account the 60 mm thickness of the outer shell, the diagram of pressure variation is illustrated in Figure 4.a. It is observed that a condensation zone appears which comprises the outer limit zone of the insulation layer, the entire outer shell of the wood-concrete block and the inner limit zone of the plaster layer (Figure 4.b). Water will accumulate during the cold

season in this area. The increasing of the shell thickness will change the pressure values insignificantly.

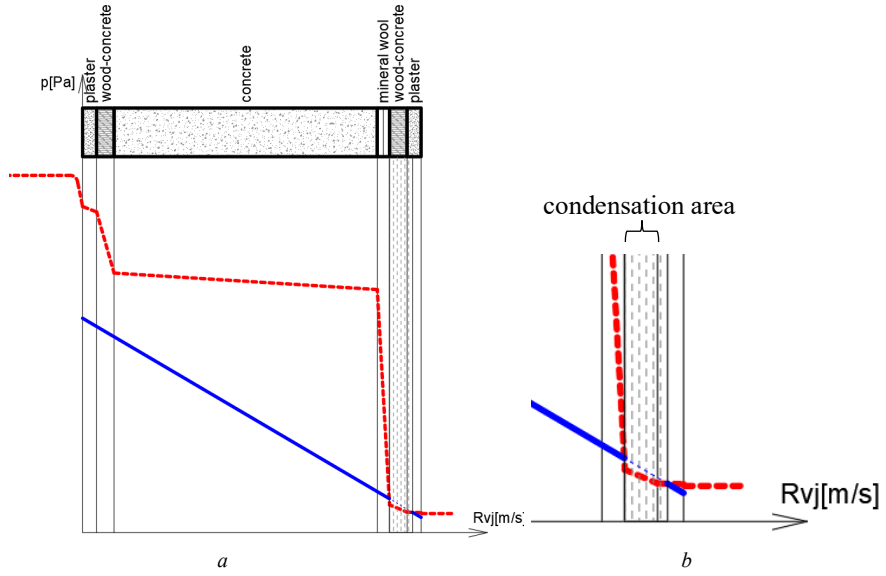


Fig. 3. – The variation of saturation vapor and effective pressures for the 1st Case (*a*) and the condensation area location for the 1st Case (*b*)

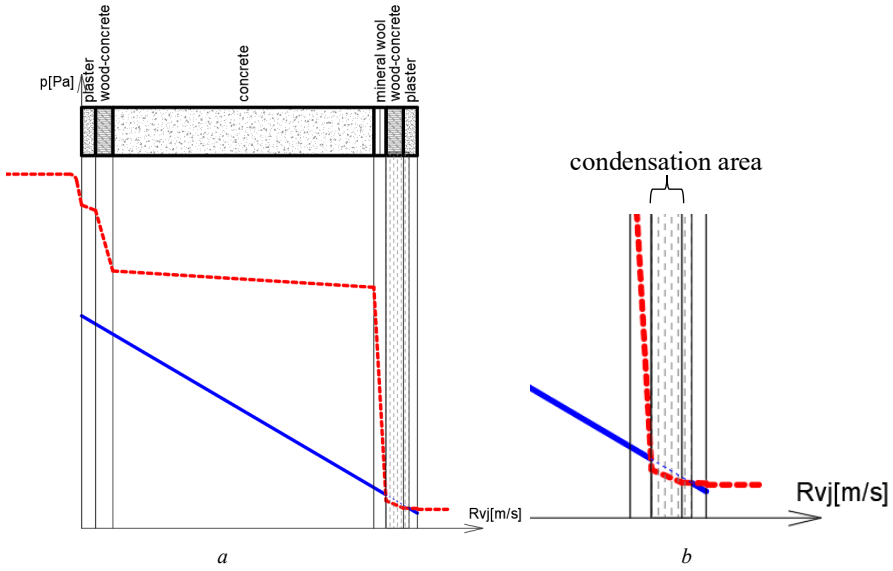


Fig. 4. – The variation of saturation vapor and effective pressures for the 2nd Case (*a*) and the condensation area location for the 2nd Case (*b*)

For the next two cases, 3rd and 4th, the interstitial temperatures were calculated, the results being presented in table 4. The values of the air saturation pressures at the respective temperatures are presented in the same table. The resistance values of the vapour permeability of each layer are shown in Table 2.

Table 4

Interstitial saturation temperatures and pressures – 3rd and 4th Cases

Layer bound-aries	Description	Temperature [°C]		Saturation pressure [Pa]	
		3rd Case	4th Case	3rd Case	4th Case
i	*Indoor*	*20*	*20*	*2340*	*2340*
is	*Inner surface*	*18.578*	*18.636*	*2136.81*	*2153.32*
1	*The contact area between the inner plaster and the inner shell of the block*	*18.317*	*18.385*	*2107.38*	*2107.1*
2	*The contact area between the inner shell of the block and the unventilated air layer*	*15.090*	*15.290*	*1711.28*	*1730.1*
3	*The contact area between the unventilated air layer and the thermal insulation layer*	*13.043*	*13.326*	*1502.3*	*1535.4*
4	*The contact area between the thermal insulation layer and the block outer shell*	*-14.038*	*-12.652*	*180.62*	*206.96*
5	*Contact area between the outer shell of the block and the outer plaster*	*-17.265*	*-17.295*	*133.7*	*133.1*
es	*Exterior (outer) surface*	*-17.526*	*-17.545*	*130.48*	*130.1*
e	*Exterior (outdoor)*	*-18*	*-18*	*125*	*125*

The pressure variation diagrams for the third and fourth cases, are illustrated in Figure 5 respectively in Figure 6. According to Figure 5, the appearance of a condensation area is observed which comprises a wider area at the outer limit of the thermal insulation layer, the entire outer shell of the precast block and almost the entire thickness of the plaster layer. Water will accumulate during the cold season in this area.

Figure 6 shows the variation of the vapour pressure for the 4th Case. It is observed that a condense area appears which comprises a wider area at the outer limit of the thermal insulation layer, the entire outer shell of the precast block and almost the entire thickness of the plaster layer. Water will accumulate during the cold season in this area. Increasing the thickness of the outer shell to 60 mm comparative to 40 mm, does not significantly influence the variation of saturation vapour pressures.

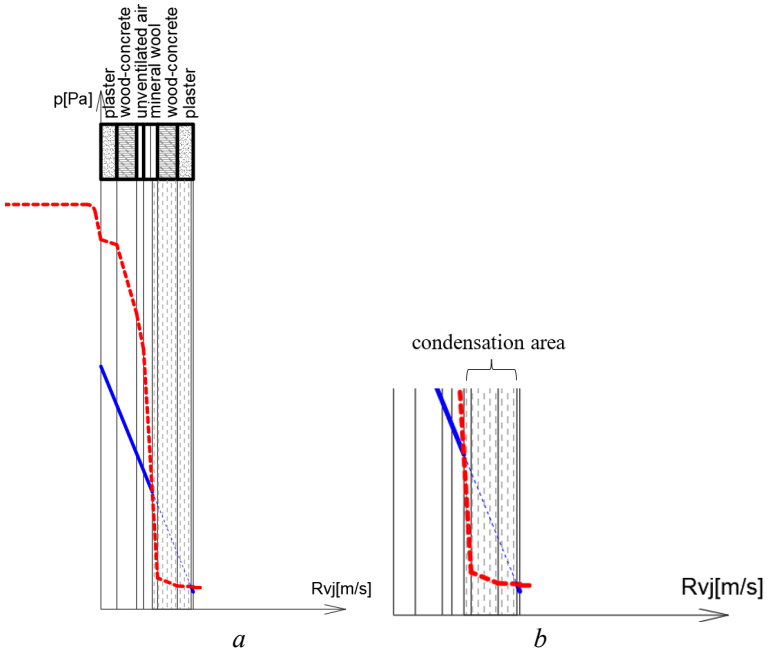


Fig. 5. – The variation of saturation vapor and effective pressures for the 3rd Case (*a*) and the condensation area location for the 3rd Case (*b*).

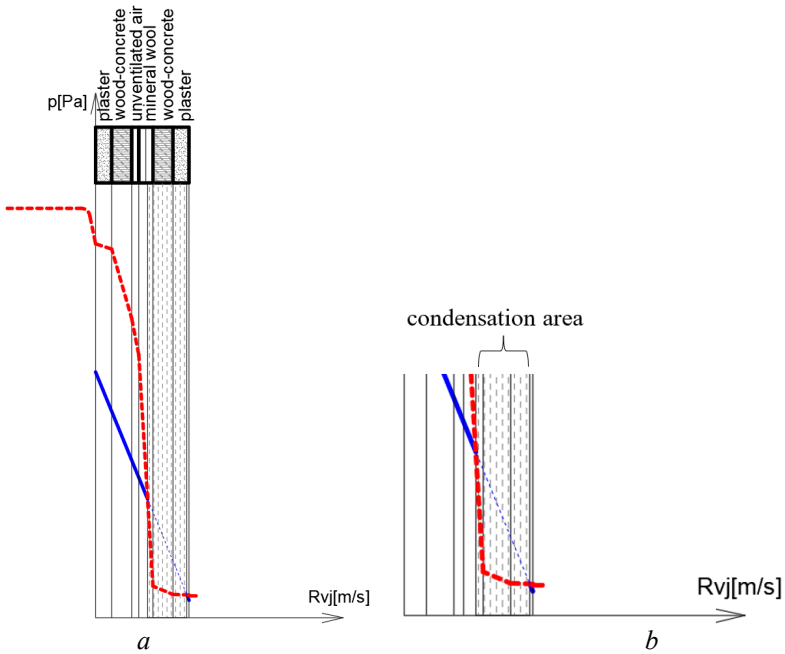


Fig. 6. – The variation of saturation vapor and effective pressures for 4th Case (*a*) and the condensation area location for the 4th Case (*b*).

The values of vapour saturation pressures, for the 5th Case, are shown in Table 5. The interstitial temperatures were calculated and the values of the air saturation pressures at the respective temperatures are presented in the same table. The resistance values of the vapour permeability of each layer are shown in Table 2.

Table 5

Interstitial saturation temperatures and pressures – 5th Case

Layer boundaries	Description	Temperature [°C]	Saturation pressure [Pa]
i	*Indoor*	*20*	*2340*
is	*Inner surface*	*10.430*	*1267.6*
1	*The contact area between the inner plaster and the wood-concrete web*	*8.670*	*1119.4*
2	*The contact area between the wood-concrete web and plaster layer*	*-13.050*	*197.5*
es	*Exterior (outer) surface*	*-14.810*	*167.9*
e	*Exterior (outdoor)*	*-18*	*125*

In Figure 7 is highlighted the variation of the vapour pressure through the web in case of 40 mm thickness of outer shell. Respecting this fact, the block width is 330 mm.

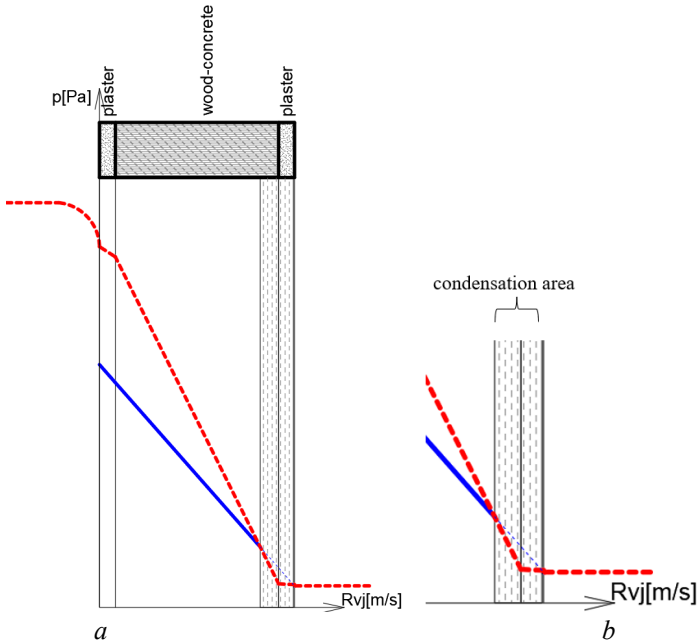


Fig. 7. – The variation of saturation vapor and effective pressures for the 5th Case (*a*) and the condensation area location for the 5th Case (*b*).

In figure 7.b is observed that a single condense area appears which comprises the outer limit of the wood-concrete layer and almost the entire thickness of the outer plaster layer. Water will accumulate during the cold season in this area.

In the case 6, the analysis was made through of mortar joint for a 330 mm block's width. Table 6 presents the interstitial temperatures and the vapour saturation pressures for this conformation. The resistance values of the vapour permeability of each layer are in Table 2.

Table 6

Interstitial saturation temperatures and pressures – 6th Case

Layer boundaries	Description	Temperature [°C]	Saturation pressure [Pa]
i	*Indoor*	*20*	*2340*
is	*Inner surface*	*11.976*	*1396.16*
1	*The contact area between the inner plaster and the mortar joints*	*10.500*	*1270*
2	*The contact area between the mortar joints and plaster layer*	*-13.850*	*183*
es	*Exterior (outer) surface*	*-15.325*	*160.5*
e	*Exterior (outdoor)*	*-18*	*125*

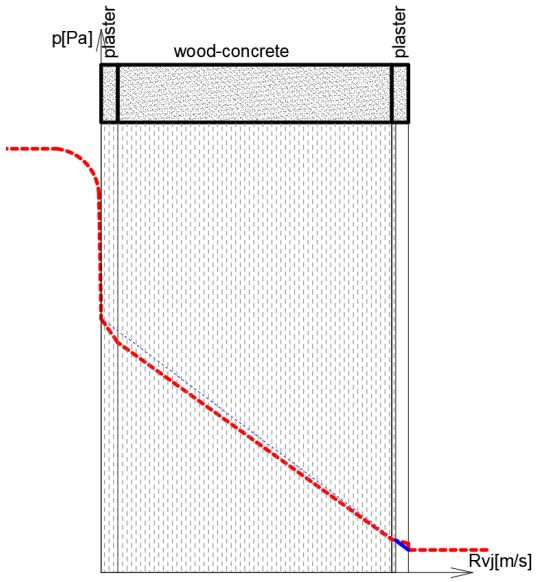


Fig. 8 – The variation of saturation vapor and effective pressures for the 6th Case.

Figure 8 shows the variation of saturation vapor and effective pressure for the 6th Case. In this case, the appearance of a single condensation area is highlighted that covers almost the entire section of the joint.

4. Conclusions

Regarding the behavior on steady state mass transfer, for the precast block considered as an individual element, it is observed that there are areas of condensation on the outside, areas that develop to the layer of unventilated air if the vertical holes are not filled with concrete. From the graphics, it can be deduced that water accumulations occur during the cold season, which should be avoided, the wood-concrete being sensitive to moisture.

In addition, the analyzed wall also includes mortar joints. The analysis carried out in the 6th Case shows that these areas are very sensitive to mass transfer and favor the appearance of condensation over the entire depth of the joint. This should be avoided due to the good behavior of the wall over time.

Following the analysis performed, it is considered that it is a risk to use the analyzed block in the execution of the exterior walls, without of an additional thermal insulation. Although the solution has many advantages, from the point of view of mass transfer, it is recommended to prevent the accumulation of water in the structure of the material, a phenomenon that determines the degradation of the material. Thus, additional thermal insulation is required to move the condensation areas as far as possible from the block's web.

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C107 / 6 – 02*, Normativ general privind calculul transferului de masa (umiditate) prin elementele de constructive / General norm regarding the calculation of mass transfer (humidity) through the construction elements.*

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STUDIUL ASUPRA RISCULUI APARIȚIEI CONDENSULUI ÎN BLOCURI ECOLOGICE CU AGREGATE DIN LEMN RECICLAT
(Rezumat)

Betonul este un material de construcții cu o cerere continuă în industria construcțiilor datorită raportului convenabil dintre preț și performanțe. Pe de altă parte, betonul nu este un material prietenos cu mediul. Astfel, pentru obținerea unui material mai ecologic, deșeurile lemnoase se pot recicla și folosi ca agregate ușoare în fabricarea

unor blocurilor ecologice prefabricate pentru zidării. Pereții realizați din blocuri prefabricate trebuie să îndeplinească nu numai criterii structurale, ci și cerințe funcționale. De asemenea, comportarea termică este importantă în reducerea consumului de energie pe durata de viață a construcției. Prezența umezelii pe pereții exteriori ca urmare a apariției fenomenului de condens va scădea performanța termică a materialelor de construcții. Această lucrare analizează apariția condensului în peretele exterior realizat din blocuri prefabricate obținute prin înglobarea așchiilor de lemn în beton prin metoda Glaser, pentru diferite situații de conformare a acestuia.