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3. Choice of optimal material solutions for the assessment of heat and humidity states of outer walls made using the technology of light steel framing

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Abstract: The subject of the article is the evaluation of thermal and humidity conditions of external partitions made in the light steel skeleton technology in terms of building physics requirements.

Keywords: heat, humidity, wall, steel framing

3.1. Introduction

A substantial part of investments is financed from mortgages. Therefore, investors search for optimal materials and designs. One of the solutions is offered by technology of light steel framing. Compared to conventional solutions, this technology can meet investors' expectations. With light structure, quick construction, the use of recycled material while meeting the requirements concerning heat and humidity in detached houses, light steel framing can be competitive with other technologies.

Temperature distribution in outer walls whose layers are homogeneous in individual cross-sections of the wall does not represent a computational problem. The use of steel framing structures for building a wall leads to the disturbance in temperature distribution and needs to be analysed in detail. It is justified to use numerical software to determine heat and humidity parameters in such a wall. This paper presents the examples of numerical analyses for external walls built using the modern technology of light steel framing and emphasizes the differences in physical parameters of the analysed design and material solutions resulting from the specific design. For numerical analysis of the heat flow the commonly known Ansys software was used (ANSYS 2013), (Flodr et al. 2015) and (Vican & Sykora 2013). Furthermore, to determine the humidity state of the wall WUFI software was employed (Kunzel 1995).

3.2. Heat and humidity protection of wall in the technology of light steel framing

In the outer walls of the light steel framing, the insulation layer is located between the load-bearing pillars. Therefore, this space has to be entirely filled with the insulating material to avoid thermal bridges. Reduction of the thermal bridge that is present in steel pillars can be achieved by using an additional layer of insulation or perforated sections.

From the standpoint of heat transfer, distances between steel sections and the thickness of the section itself are also very important. Therefore, the best solution is to use maximal distances between the pillars and relatively thin walls of the sections.

Maximal permissible values of thermal transmittance for outer walls up to the year 2017 were U = 0.23 W/m^{2}K, and, for 2021 this value will be U = 0.20 W/m^{2}K (Rozporządzenie w sprawie warunków technicznych, Dz.U. 2013). With light steel framing, and assuming adequate approach at the stage of design and construction, these levels can be already achieved.

Calculations of the material parameters are usually adopted for dry conditions. If the wall is insufficiently protected from humidity, its thermal insulation properties are lower and it is exposed at risk of corrosion of steel components (Urbańska-Galewska & Kowalski 2018).

Humidity of the walls depends on the effect of climate factors and their material and design properties. One of the major sources of humidity that gets to external walls is vapour contained in air.

One of the basic criteria for designing the wall and its joints is humidity criterion, obtained based on the condition of prevention from surface condensation of humidity. Examination of the risk of development of condensation and growth of mould in the interior is conducted by means of the comparison of the temperature factor $f_{Rsi(obl.)}$ with the threshold value of $f_{Rsi,(kryt)}$, which, according to (Rozporządzenie w sprawie warunków technicznych, Dz.U. 2013), is 0.72.

3.3. Computational assumptions

In the case of walls composed of non-homogeneous layers, thermal resistance of the wall should be computed according to the guidelines contained in PN-EN ISO 6946:2008. The method described in the standard is a simplified version.

More detailed results are obtained from the computations made using computer software based on the finite element methods (Pawłowski 2016), (Major & Kosiń 2016).

Further part of the study presents the results of heat and humidity analysis of the adopted material and design solutions of the walls using the technology of light steel framing.

Numerical analysis concerning the flow of heat was made using the Ansys software based on the finite element method. The analysis was performed for the assumption of homogeneity and isotropy of materials of individual layers. Furthermore, WUFI software was employed to determine the humidity state of the wall.

In the thermals analysis, the internal temperature was adopted as t_i = +20°C based on (ANSYS 2013), whereas the external temperature was adopted as t_e = -20°C according to PN-EN 12831:2006. Thermal transfer coefficients for the FEM analysis were adopted on the internal side for the horizontal flow as h_i = 7.69 W/(m^2·K), for the vertical flow downwards as h_i = 5.88 W/(m^2·K), for the vertical flow upwards as h_i = 10 W/(m^2·K) and on the external side as h_e= 25 W/(m^2·K). They represent the reverse value of the resistances R_{si}, R_{se} (m^2·K)/W (Pawłowski 2016) and (Pawłowski & Kosiń 2017). The boundary conditions for calculations of minimal temperature on the internal side of the wall t_{min} °C and the temperature factor f_{Rsi} are used according to PN-EN ISO 13788:2003, which is R_{si} = 0.13 (m^2·K)/W for frames and windows, whereas in other cases, this value is R_{si} = 0.25 (m^2·K)/W. In the case of humidity analysis, the material data and the data concerning the external climate were defined by the choice of the geographical location of the wall. The external climate conditions took into consideration the changes in temperature and relative air humidity according to the standard PN-EN ISO 13788:2003.

3.4. Thermal analysis of external wall corner

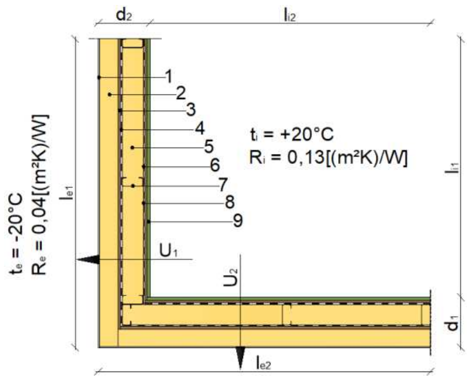
Six-layer walls were adopted for the analysis (Fig. 3.1), with their load-bearing components differing from each other (Fig. 3.2).

The C-shaped section was assumed in the analysed cases (Fig. 3.2c) with cross dimensions of h = 140 mm, b = 38 mm, c = 18 mm, t = 1.5 mm and internal radius of r = 3 mm.

Table 3.1 presents heat and humidity parameters of the analysed walls. Using the algorithm below through computer simulation, the thermal transmittance U [W/(m^2·K)] was evaluated for the individual parts of the joint (Gołaś at al. 2011):

- calculation of the value of the mean horizontal component of heat flux density for the part of joint q_1 W/m^2,
- calculation of the thermal transmittance for individual parts of the joint based on:

$$U_i = q_i/(t_i - t_e)\ [\mathrm{W/(m^2 \cdot K)}] \tag{3.1}$$



1 – thin-coat plaster, thickness 0.5cm - λ = 0.7 W/(m·K),

2 – mineral wool, thickness 16cm - λ = 0.035 W/(m·K),

3 – cement bound particle-board, thickness 1.2cm - λ = 0.215 W/(m·K),

4 – vapour-permeable membrane,

5 – mineral wool 140cm - λ = 0.215 W/(m·K),

6 – steel pillar C140, thickness 0.15cm - λ = 50 W/(m·K),

7 – vapour-barrier membrane,

8 – cement bound particle-board, thickness 1.2cm - λ = 215 W/(m·K),

9 – drywall, thickness 1.25cm - λ = 25 W/(m·K),

Fig. 3.1. Computational model and material characteristics for the analysed wall made using the technology of light steel framing

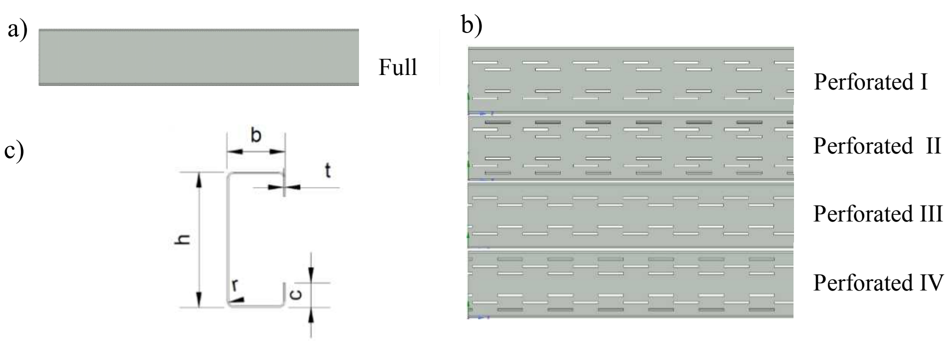


Fig. 3.2. Thin-wall C sections: a) solid section, b) perforated section, c) dimensions of the cross section

Thermal transmittance for the wall made of solid sections is U=0.137 W/m^{2}K. Furthermore, for the design based on perforated components, this value is U=0.144 W/m^{2}K. In light of the holes with small surface in a perforated section and the simplified grid of finite components in the numerical model, it can be presumed that building a more complex grid would reduce this difference.

Quite different situation is observed for the heat flux Φ [W] where energy loss through the joint in the form of the wall corner is smaller for the perforated sections, as shown in Table 3.1. The same pattern is observed for the linear thermal transmittance Ψ_e [W/(m·K)] (Tab. 3.1). A significant difference between the wall made of solid sections compared to perforated sections is observed (60%). This difference is insignificant between the design based on perforated components, with these sections differing in their arrangement and insignificant number of holes (Tab. 3.1).

Table 3.1. Heat and humidity parameters of the analysed external walls

		Profiles				
		Full	Perforated I	Perforated II	Perforated III	Perforated IV
Total heat flow through the wall [W] 1)		15.348	15.050	14.991	15.052	14.980
Temperature [°C] 2)	min	-20	-19.991	-19.991	-19.991	-19.991
	max	+19.743	+19.524	+19.521	+19.524	+19.520
Risk of condensation on the inside $f_{Rsi,calculative}$ ($f_{Rsi,critical}$=0.72) 3)		0.833	0.836	0.835	0.837	0.836
Linear heat transfer coefficient (the external dimensions) Ψ_e [W/(m·K)] 4)		-0.030	-0.070	-0.071	-0.069	-0.071

1), 2) Calculated using ANSYS; 3) Calculated on the basis of PN-EN ISO 13788:2003;
4) Calculated on the basis of PN-EN ISO 10211:2008

Fig. 3.3 presents temperature distributions for the variants of wall corner. Disturbances in temperature distributions can be observed in the location of structural pillars. Comparison of the solid section with perforated section reveals the difference in temperature distribution only for greater magnification. However, no changes are observed for the comparison of perforated sections.

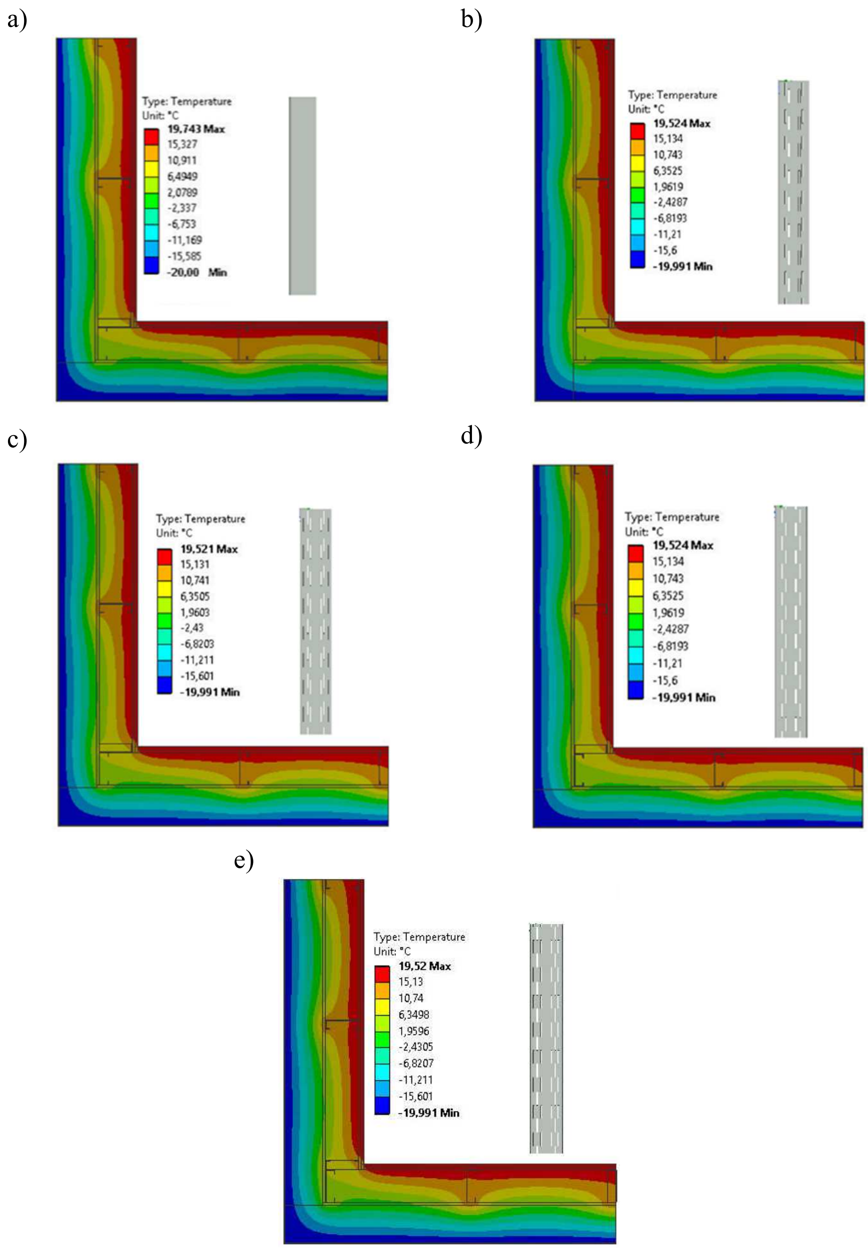


Fig. 3.3. Results of computer simulation for the adopted sections: a) solid section, b)÷c) perforated sections with different number and arrangement of holes (see Fig. 3.2b)

3.5. Analysis of humidity states

Fig. 3.4 and 3.5 presents various design and material solutions subjected to humidity analysis based on the finite element method. A 4-year period was analysed for the wall located on the western façade. The external climate was defined for the city of Kraków, Poland, whereas the internal climate takes into consideration the changes in temperature and relative air humidity according to the standard PN-EN ISO 13788:2003.

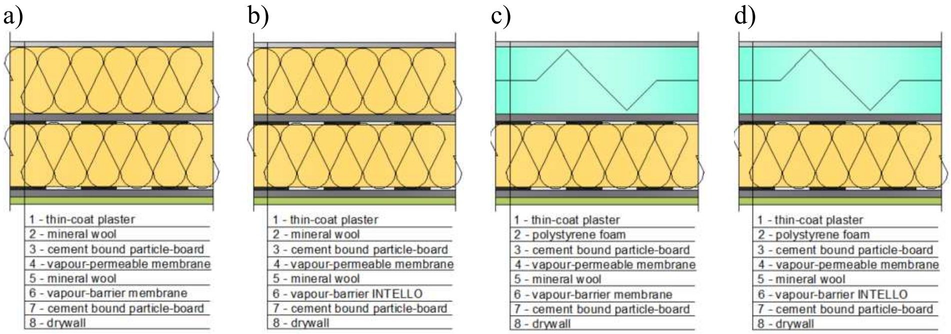


Fig. 3.4. Designs of the walls using the technology of light steel framing with sheathing made of cement board adopted for the humidity analysis: a) Wool - PE variant, b) Wool - Intello variant, c) Polystyrene - PE variant, d) Polystyrene – Intello variant

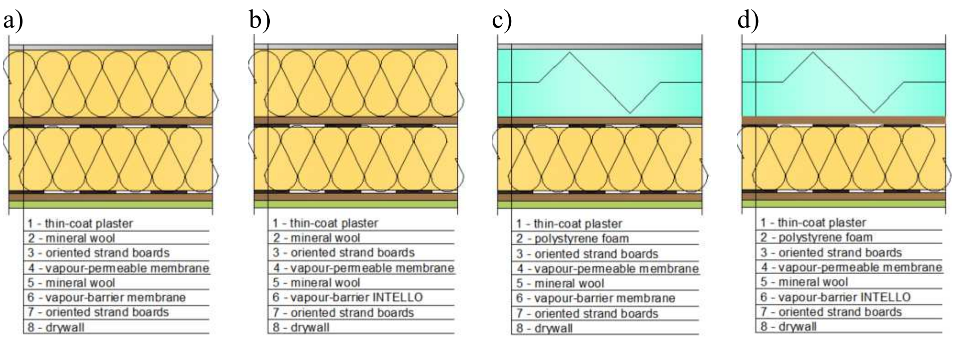
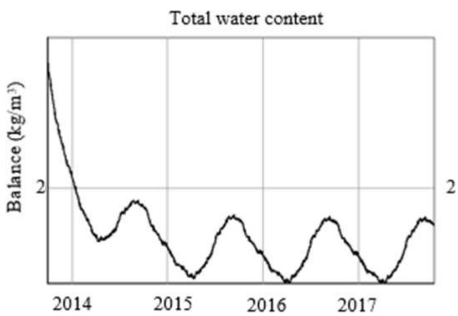


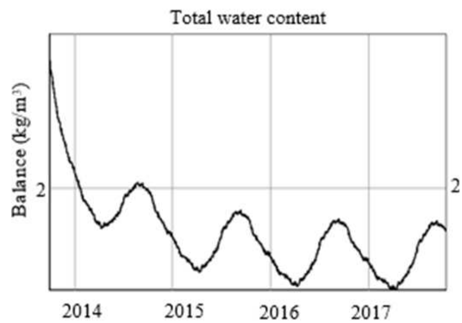
Fig. 3.5. Designs of the walls using the technology of light steel framing with sheathing made of OSB boards adopted for the humidity analysis: a) Wool - PE variant, b) Wool - Intello variant, c) Polystyrene - PE variant, d) Polystyrene – Intello variant

The results of computations of total water content are presented in Figs. 3.6 and 3.7, whereas for individual materials - in Figs. 3.8 and 3.9. As shown in Fig. 3.7, with the use of cement boards and a layer of external insulation made of polystyrene foam, humidity is substantially lower than in other solutions. The most favourable option with the OSB board is the wall with external insulation in the form of polystyrene foam and Intello vapour-barrier membrane (Fig. 3.6a). In all analysed cases, the use of Intello membrane was in initial period characterized by lower content of water compared to PE vapour-barrier membrane (Figs. 3.6 and 3.7).

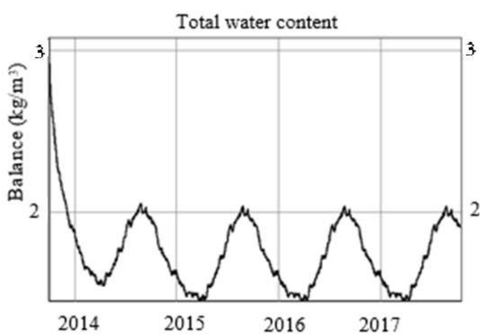
a)



b)



c)



d)

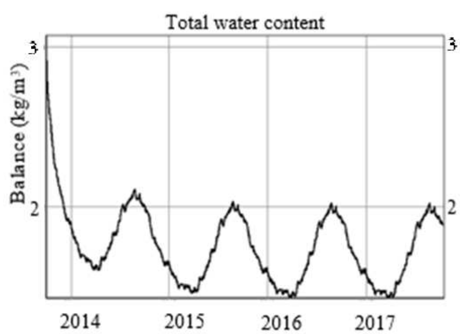


Fig. 3.6. Total water content [kg/m^3] in the analysed wall made using the technology of light steel framing with OSB boards: a) Polystyrene – Intello variant, b) Polystyrene - PE variant, c) Wool - Intello variant, d) Wool – PE variant

Analysis of the individual layers of material (Figs. 3.8 and 3.9) reveals a substantial difference in water content for the boards of sheathing made of OSB boards. For the functional life adopted in the analysis, water content for the OSB design on the internal side ranges from 60 to 75 kg/m^3. For the same arrangement but using the cement boards, the water content is 15 ÷ 25 kg/m^3. The disappearing humidity from the initial period is observed for all layers of the material, which confirms the rightness of the adopted solutions (Figs. 3.8 and 3.9).

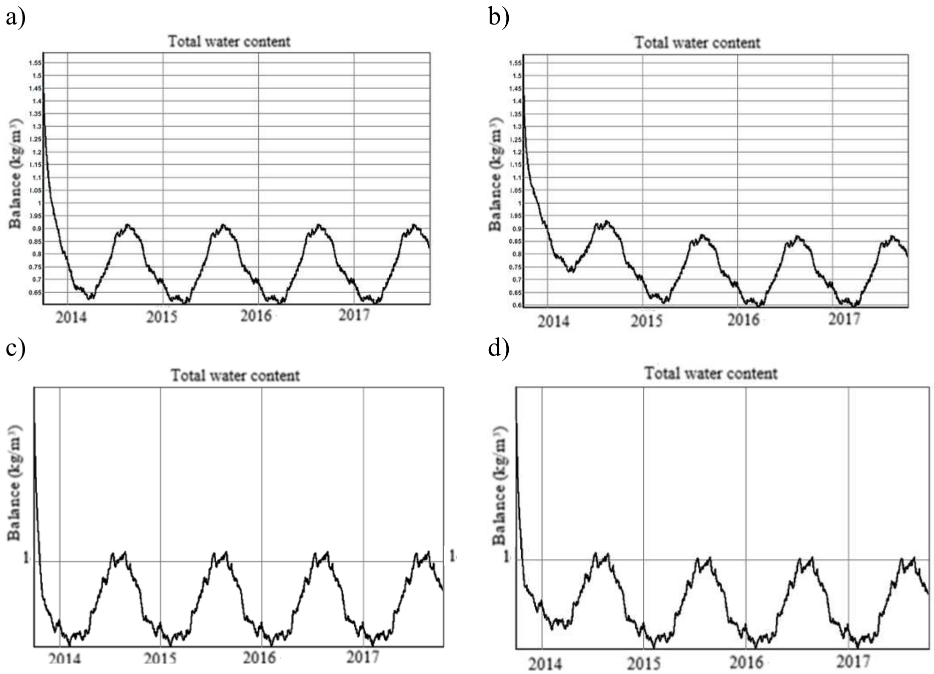


Fig. 3.7. Total water content [kg/m^3] in the analysed wall made using the technology of light steel framing with cement boards: a) Polystyrene – Intello variant, b) Polystyrene - PE variant, c) Wool - Intello variant, d) Wool – PE variant

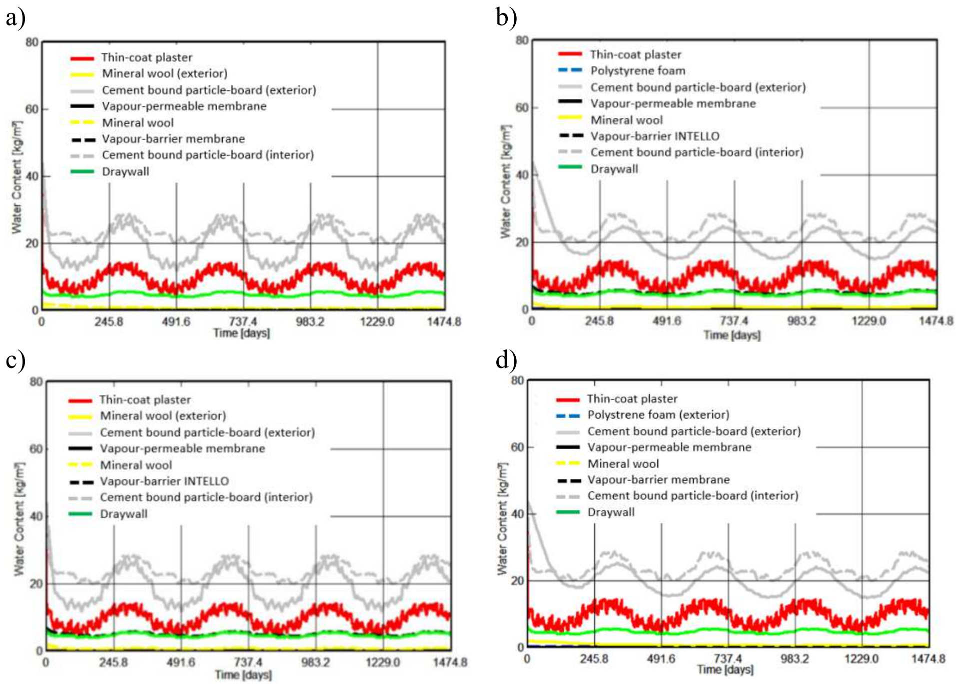


Fig. 3.8. Total water content [kg/m^3] for individual materials in the analysed wall made using the technology of light steel framing with cement boards: a) Wall – PE variant, b) Polystyrene - Intello variant, c) Wool - Intello variant, d) Polystyrene – PE variant

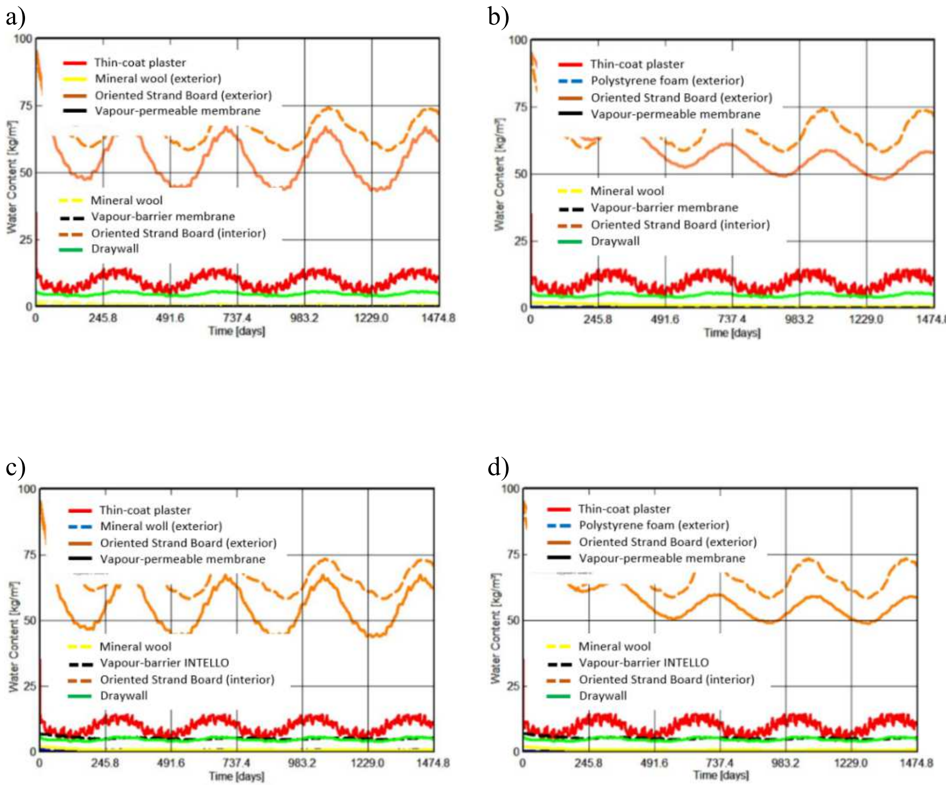


Fig. 3.9. Total water content [kg/m^3] for individual materials in the analysed wall made using the technology of light steel framing with OSB boards: a) Wall – PE variant, b) Polystyrene - PE variant, c) Wool - Intello variant, d) Polystyrene – Intello variant

3.6 Conclusions

The findings of the study lead to the following conclusions:

- Structures based on the technology of light steel framing made of perforated sections are characterized by improved thermal parameters compared to solid sections. This eventually leads to lower energy consumption and lower heating costs for the building.
- The effect of arrangement and number of holes in the perforated sections on thermal parameters is insignificant

- All the walls analysed in terms of humidity collect greater amount of water in the winter season which is evaporated in summer
- The state of wall humidity is affected by both the type of the material and its arrangement
- Numerical computations provide information about the physical parameters and they allow for a graphical representation of the distribution of these parameters in the wall. With the numerical computation, it is possible to identify, at the design stage, the weak points with highest heat loss, which consequently opens up opportunities for the improvement in the adopted design and material solutions.

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