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A STUDY ON THE USE OF EXPANDED POLYSTYRENE FOR EXTERNAL MASONRY WALLS THERMAL INSULATION

BY

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Abstract. The thermal protection level for dwellings has constantly increased during recent decades. Therefore, in areas with very low outside temperature during the cold season, very thick thermal insulations are required. When expanded polystyrene (EPS) is used for the thermal protection of the external walls made from clay bricks or from autoclaved aerated concrete (AAC) masonry, the issue that arises is how this layer influences the mass transfer through the envelope element.

The paper presents the evaluation of the global insulation coefficient of a low rise building whose external walls are protected with 15 cm of EPS. The analysis is performed for two different technical solutions for the walls, namely, hollow clay brick (HCB) and AAC masonry. The paper also assesses the EPS layer influence on the mass transfer through the external wall, considered in the same two different technical solutions.

Finally, some conclusions are drawn with regard to both the advantages and disadvantages of thermal protection with EPS and the influence of the heat losses through the external walls in the building thermal balance.

Key words: thermal insulation; heat and mass transfer; masonry walls; thermal balance.

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1. Introduction

In the present context, wherein the effects of climate change are more severe (Biesbroek *et al.*, 2010; McCright & Dunlap, 2011; Van Vuuren *et al.*, 2011), satisfying the aspects of sustainability should be the main priority. In the construction industry, the effort of reducing the negative environmental impact of buildings should be accelerated and to this end, the design of energy efficient buildings is mandatory. By using classical solutions for the envelope of the building, the level of thermal protection is insufficient, the use of thermal insulations proving to be necessary. The thickness of insulation varies depending on the climate of the location and the degree of thermal protection required. In our country, and especially in climate zones III (outside design temperature T_e = –18°C) and IV (outside design temperature T_e = –21°C), the thermal insulation thickness may reach 15...20 cm in order to have an annual heating energy consumption of less than 100 kWh/m^2 per year, as the legislation requires (EPBD, 2008). Regarding the thermal protection of masonry closure walls with EPS or Extruded Polysterene (EPX), because of the substantial thickness of insulation, the mass transfer is influenced by the possibility of the water vapour condensation in the masonry layer.

Therefore, a case study has been conducted to assess the degree of thermal protection of a building with exterior walls of HCB masonry protected with EPS insulation. The overall thermal coefficient is calculated considering the same building exterior walls made of AAC masonry, thermally protected in the same way. Both sets of calculations are made according to Romanian regulations and to determine the effect of thermal bridges, numerical modelling has been conducted using RDM 6® software.

Finally, a numerical analysis has been performed using WUFI Pro 5.1 1D to assess the influence of thermal insulation on mass transfer.

2. The Calculation of the Global Thermal Insulation Coefficient

The overall insulation coefficient of a tertiary building, G_1, is the hourly heat losses through its envelope elements, for a one degree temperature difference between the indoor and the outdoor, related to its heated volume (RC, 2011).

The overall effective thermal insulation coefficient, G_1, is calculated with the expression (RC, 2011)

$$G_1 = \frac{1}{V}\left(\sum_j \frac{A_j \tau_j}{R'_{mj}}\right) \left[\frac{\mathrm{W}}{\mathrm{m^3.K}}\right]. \qquad (1)$$

To calculate the overall coefficient, G_1, the following steps have been taken:

a) determination of the specific unidirectional thermal resistance of enevelope elements, R;

b) determination of the specific thermal resistance corrected with the value of thermal bridges, R', of enevelope elements;

c) determination of the overall thermal insulation coefficient, G_1.

2.1. Determination of the Specific Unidirectional Thermal Resistance of Enevelope Elements, *R*

Table 1 presents the envelope elements, their surface and structure, the thickness of the material layers and the designed thermal conductivity.

Table 1

Geometrical Characteristics of the Envelope and the Closure Elements Structure

No	Envelope elements			Material layer	d	λ
			A, [m^2]		m	W/m.K
1.	Opaque exterior wall	N	188.72	Inner plaster M5	0.015	0.87
		S	177.84	HCB masonry	0.24	0.75
				AAC masonry	0.24	0.27
		E	60	EPS insulation	0.15	0.044
		W	60	Mineral plaster	0.005	0.87
2.	Ground slab		404	Laminate flooring	0.01	0.204
				Levelling screed M10	0.02	0.93
				EPX. insulation	0.15	0.044
				Reinforced concrete slab	0.15	1.74
				Waterproof insulation	0.002	0
				Capillary breaking layer	0.1	0.7
				Earth filling – layer 1	3,398	2
				Earth filling – layer 2	4	4
3.	Attic		404	Reinforced screed M10	0.02	0.93
				Rigid mineral wool insulation	0.25	0.04
				Reinforced concrete slab	0.15	1.74
				Inner plaster M5	0.015	0.87
4.	External joinery	N	53.68	The value of the overall thermal resistance of the windows, R', is considered to be the minimum required value presented in Romanian regulation (RC, 2011)	–	–
		S	64.56		–	–
		E	–		–	–
		E	–		–	–
	Envelope surface, A				1,412.80 m^2	
	Heated volume , V				2,424 m^3	

The specific unidirectional thermal resistance is determined by the sum of the unidirectional resistances of the material layers and is calculated using the data presented in Table 1, and the superficial resistance to the convective and radiative heat transfer of the inner and outer surfaces, respectively:

$$R = \frac{1}{\alpha_i} + \sum \frac{d}{\lambda} + \frac{1}{\alpha_e}, \tag{2}$$

where α_i and α_e are the convective and radiative heat transfer coefficients of the inner and outer surfaces, respectively.

The values of the α_i and α_e coefficients, as well as the specific unidirectional thermal resistance, are presented in Table 2.

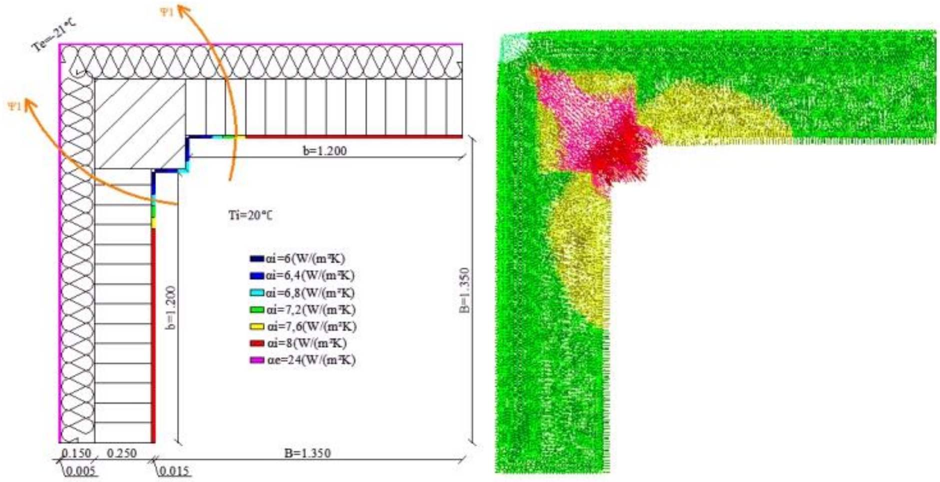
Table 2
Specific Unidirectional Thermal Resistance of the Envelope Elements

No.	Element	α_i W/m^2.K	α_e W/m^2.K	R m^2.K/W
1.	Exterior HCB masonry wall	8	24	3.92
2.	Exterior AAC masonry wall	8	24	4.49
3.	Ground slab	6	0	6.57
4.	Attic	8	12	6.58

2.2. Determination of the Specific Thermal Resistance Corrected with the Value of the Thermal Bridges, *R′*, of the Enevelope Elements

In order to determine the specific overall thermal resistance, R', an identification of the thermal bridges which influence the unidirectional thermal resistance and of their numerical modelling to obtain the linear thermal bridges coefficients (Ψ-value) has been proven necessary. The thermal bridges have been analysed using the RDM 6 software. The Ψ-values are presented in Table 3. Fig. 1 shows both the vertical thermal bridge, represented by the intersection between the exterior walls in an outer corner, and the heat flow intensity map of the thermal bridge. The numerical analysis has been performed for both solutions of the wall. The thermal properties of the materials have been extracted from specialized literature and the national regulation.

In order to obtain a more accurate image of the heat transfer through vertical and horizontal thermal bridges, the heat transfer coefficient by convection and radiation of the inner surface has been set to variable (Ştefănescu, 2012). Therefore, starting at the value of 8 W/m^2.K in the current field, the α_i coefficient decreases with an increment of 0.4 W/m^2.K every 5 cm to 6 W/m^2.K the last 5 cm near the intersection.



a *b*

Fig. 1 – Vertical thermal bridge: *a* – outer corner; *b* – heat flow intensity map of the thermal bridge

Table 3
Linear Thermal Bridges Coefficients, Ψ

<table>
<tr><td>Thermal bridge name</td><td colspan="2">HCB+EPS.</td><td colspan="2">AAC+EPS</td></tr>
<tr><td colspan="5">Vertical</td></tr>
<tr><td>Outer corner</td><td colspan="2">0.06439</td><td colspan="2">0.10689</td></tr>
<tr><td>Interior and exterior walls intersection</td><td colspan="2">0.000006</td><td colspan="2">0.00803</td></tr>
<tr><td>Concrete post embedded in the masonry walls</td><td colspan="2">0.00196</td><td colspan="2">0.01898</td></tr>
<tr><td colspan="5">Horizontal</td></tr>
<tr><td rowspan="2">Exterior walls and current slab intersection</td><td colspan="2">Ψ superior: 0.00413</td><td colspan="2">Ψ superior: 0.00298</td></tr>
<tr><td colspan="2">Ψ inferior: –0.0026</td><td colspan="2">Ψ inferior: 0.02178</td></tr>
<tr><td rowspan="2">Exterior walls and attic intersection</td><td colspan="2">Ψ slab:0.1478</td><td colspan="2">Ψ slab: 0.15487</td></tr>
<tr><td colspan="2">Ψ wall: 0.14689</td><td colspan="2">Ψ wall: 0.15398</td></tr>
<tr><td>Interior walls and ground slab intersection</td><td colspan="2">0.01194</td><td colspan="2">0.00316</td></tr>
<tr><td rowspan="2">Exterior walls and ground slab intersection</td><td colspan="2">Ψ wall:0,1368</td><td colspan="2">Ψ wall: 0.03469</td></tr>
<tr><td colspan="2">Ψ slab:0,34159</td><td colspan="2">Ψ slab:0.34769</td></tr>
<tr><td rowspan="3">Exterior joinery contour</td><td>Ψ lateral: 0.1368</td><td rowspan="3">0.11677*</td><td>Ψ lateral: 0.07125</td><td rowspan="3">0.08938*</td></tr>
<tr><td>Ψ inferior: 0.10583</td><td>Ψ inferior: 0.07125</td></tr>
<tr><td>Ψ lintel: 0.13095</td><td>Ψ lintel: 0.13493</td></tr>
</table>

*The Ψ-values for the external joinery contour represent the average of the three values obtained using the RDM 6 numerical analysis software.

The specific thermal resistance values corrected with the values of the thermal bridges, R', of the envelope elements are presented in columns 3 and 4 of Table 4. The calculation has been made according to the Romanian code C107-2005 following the expression (RC, 2011):

$$R' = \frac{1}{U'}, \ [\mathrm{m^2.K/W}], \tag{3}$$

where U' is the thermal transmittance of the element, calculated with the expression:

$$U' = \frac{1}{R} + \frac{\sum \Psi l}{A} + \frac{\sum \chi}{A}, \ [\mathrm{W/m^2.K}], \tag{4}$$

where: Ψ is the linear thermal bridges coefficients; l – the length of linear thermal bridges; χ – punctual thermal bridges coefficients; A – the surface of the envelope element.

Table 4

Overall Effective Thermal Insulation Coefficient, G_1

Envelope element	A, [m^2]	R', [m^2.K/W]		τ	$A\tau/R'$, [1/K.W]	
		HCB	AAC.		HCB	AAC
Exterior walls facing North	188.72	2.70	3.23	1	69.90	58.43
Exterior walls facing South	177.84	2.70	3.13	1	65.87	56.82
Exterior walls facing East	60	3.23	3.70	1	18.58	16.22
Exterior walls facing West	60	3.23	3.70	1	18.58	16.22
Exterior joinery North	53.68	0.77*	0.77*	1	69.71	69.71
Exterior joinery South	64.56	0.77*	0.77*	1	83.84	83.84
Exterior joinery East	0	0.77*	0.77*	1	0	0
Exterior joinery West	0	0.77*	0.77*	1	0	0
Attic	404	5.26	5.26	1	76.81	76.81
Ground slab	404	8.33	7.69	0.5	24.25	26.27
Reports sum $A\tau/R'$					**427.54**	**404.32**
Total envelope surface, [m^2]					A = 1,412.80	
Building heated volume, [m^3]					V = 2,424	
Overall effective thermal insulation coefficient, G_1, [W/m^3·K]					**0.350**	**0.340**

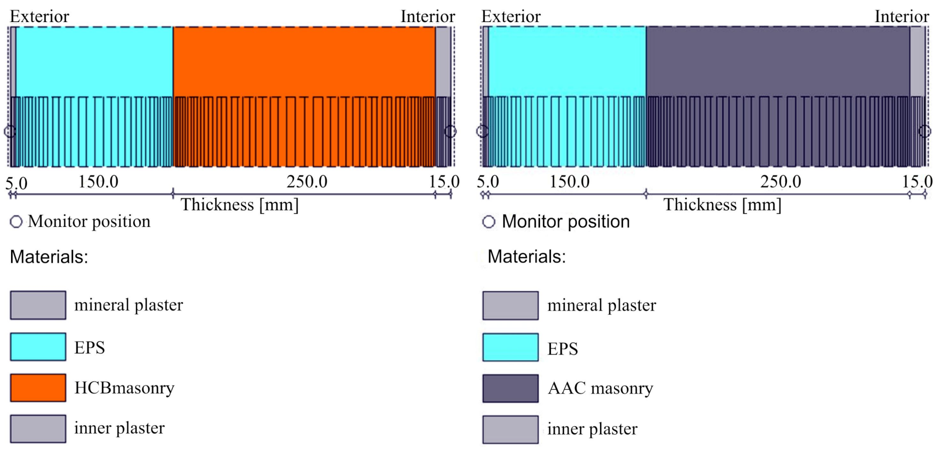
*the value of the exterior joinery overall thermal resistance is the minimum required value imposed by the Romanian Code C107-2005 (RC, 2011).

3. Mass Transfer Analysis

The mass transfer through the exterior walls is analysed using the WUFI® Pro 5.1 1D program developed by the Fraunhofer-Institute of Building Physics in Holzkirchen, Germany. The program simulates mass transfer through building elements, providing information on the water content (vapour or liquid) of the material. The analysis has been carried out for a period of seven years.

Table 5
Materials Properties (RC, 2011)

Material	Bulk density, kg/m^3	Designed thermal conductivity, W/m.K	Heat mass capacity, J/kg.K	Water vapour resistance factor, J/kg.K
Inner plaster (M5)	1,700	0.87	840	8.5
EPS	20	0.044	1,460	30
HCB masonry	1,700	0.75	870	5.3
AAC masonry	700	0.27	840	3.8
Mineral plaster	1,700	0.87	840	8.5



a *b*

Fig. 2 – The wall composition of the two analysed solutions: *a* – HCB masonry+EPS; *b* – AAC masonry+EPS.

3.1. Analysis of the Condensation Potential on the Inner Surface of the Outer Wall

Condensation on the inner surface of the envelope elements arises when the inner surface temperature falls below the dew point temperature. The program automatically generates dew point functions of the indoor climate parameters, temperature and relative humidity. The graph from Fig. 3 shows the curves of variation of the inner surface temperature and the dew point temperature.

The curves presented in Fig. 3 do not intersect in the duration of seven years and the difference between the two curves is approximately 5°C. The graph in the figure is valid for both technical solutions, as the temperature of the dew point depends on the relative humidity and on the temperature of the indoor air, set similarly in the two modellings, and the temperature of the inner surface varies depending on the thermal resistance of the envelope elements, approximately the same.

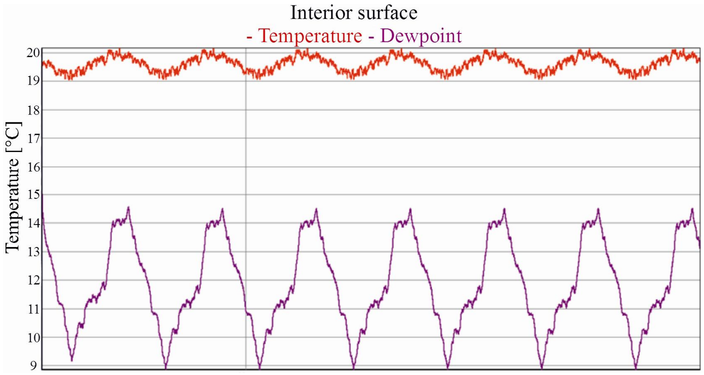


Fig. 3 – Variation *vs*. time of the inner surface temperature and of the dew point temperature.

3.2. Analysis of Condensation in Exterior Wall Structure

In order to check the appearance of condensation in the element structure, the water content (vapour and liquid) variation graphs are drawn for the layers of the two technical solutions shown in Figs. 4 and 5. The analysis is made during the seven-year period only for mineral plaster layers, EPS and masonry, as the interior plaster layer is considered to be without risk of condensation. The variation curves of the water content are influenced by the alternation of cold and warm seasons, with the gradual accumulation of water during the cold season and its evaporation during the hot season.

It should be noted that during the first analysed period, the amount of water from the structure of the masonry layer is evaporating and migrating towards the outside. This phenomenon leads to increased moisture in EPS and mineral plaster layers. The initial relative humidity of the polystyrene insulation was 60%. The accumulation of water during the cold season involves the increase of the relative humidity and thermal conductivity of the material, as it can be deduced from the graphs presented both for the HCB and the AAC masonry walls, respectively. Therefore, the EPS thermal insulation performance decreases during the cold season. If during the first cold season the water content variation in polystyrene is also influenced by the water which migrates from the masonry layer, in the last cold seasons there is a smoothing of the water content peak value caused by the vapours migration through the masonry layer and its condensation in the polystyrene layer. In the layer of the AAC masonry, due to the hygroscopic nature of the material, the water content is higher than in the HCB masonry layer. Nevertheless, the graphs do not show a progressive accumulation of water, so that the mechanical properties of this structural layer are not affected.

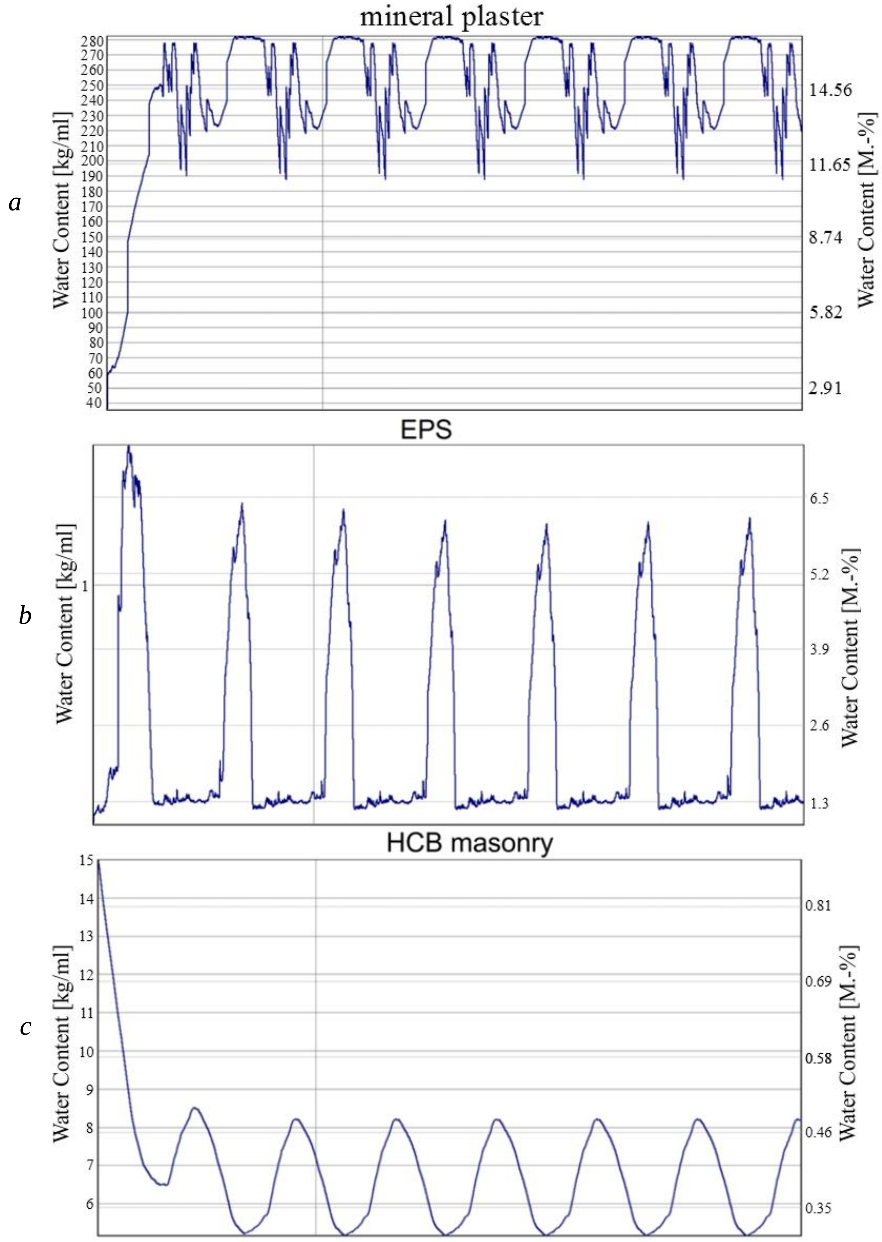


Fig. 4 – Variation of water content in the HCB masonry outer wall layers: *a* – mineral plaster; *b* – EPS; *c* – HCB masonry.

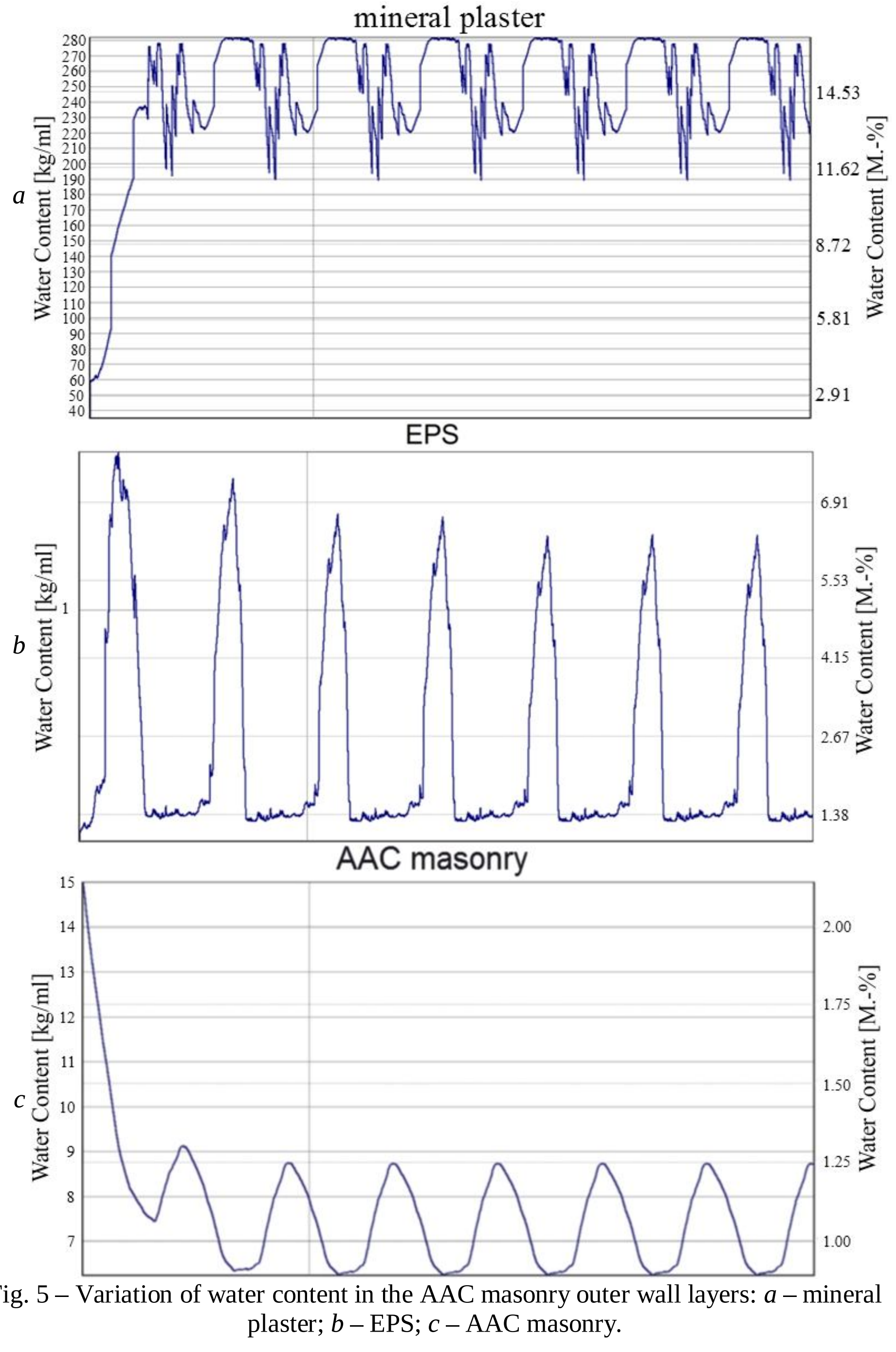


Fig. 5 – Variation of water content in the AAC masonry outer wall layers: *a* – mineral plaster; *b* – EPS; *c* – AAC masonry.

4. Conclusions

The HBC and the AAC masonry layers cannot provide the required minimum of thermal protection, making the use of thermal insulation a requirement. Masonry layers behave very well to mass transfer without barring the migration of water vapour to the outside, this phenomenon being influenced by the choice of insulation. If the vapour permeability resistance of insulation is high, such as for polystyrene, the thermal insulation acts like a vapour barrier, water exchange with the external environment is slowed, resulting in the accumulation of high levels of water during the cold season and the decrease of the insulation thermal performance.

Therefore, it is highly recommended to protect the exterior masonry walls with thermal insulation which allows water vapour migration to the exterior. If the thermal insulation is made from EPS, it is recommended to use the design thermal conductivity, corrected with a coefficient, in order to take into account the high water content, in the calculation of the thermal diffusion resistance of this layer.

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STUDIU PRIVIND UTILIZAREA POLISTIRENULUI EXPANDAT LA IZOLAREA TERMICĂ A PEREȚILOR EXTERIORI DIN ZIDĂRIE

(Rezumat)

În ultimile decenii, gradul de protecție termică recomandat în normele de proiectare pentru clădirile de locuit a crescut constant. Astfel, în zonele cu temperaturi foarte joase, în timpul sezonului rece se impune utilizarea unor grosimi mari de izolație termică. În cazul protejării termice cu polistiren expandat a pereților exteriori realizați din zidărie de cărămidă ceramică sau din beton celular autoclavizat (BCA), se pune problema influenței acestui strat asupra transferului de masă prin elementul de anvelopă.

Se prezintă calculul coeficientului global de protecție termică al unei construcții ai cărei pereți exteriori sunt protejați cu un strat de polistiren expandat de 15 cm. Calculul este efectuat pentru două soluții tehnice diferite de realizare a pereților şi anume: zidărie de cărămidă cu goluri verticale (GVP) şi zidărie de BCA. De asemenea, este analizată influența stratului de polistiren asupra transferului de masă prin peretele exterior.

În final se formulează unele concluzii privind avantajele şi dezavantajele izolării termice a pereților cu polistiren şi se analizează ponderea pierderilor de căldură prin pereții exteriori în bilanțul termic al clădirii.