

Examination of the change of the overall heat transfer coefficients of building structures in function of water content

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Abstract

Nowadays the most applied insulation material in the building sector is the expanded polystyrene (EPS). Different types of EPS are used but more and more is spread the graphite added type. Our research focuses on the analysis of heat conductivity and sorption properties of EPS since these two physical properties are the most important from energy saving point of view. In this paper the variation of heat transfer coefficient of an insulated wall is analysed in function of humidity content of insulation material. Brick and concrete walls with 0.4 m thicknesses were chosen for substrate and 0.1 m EPS (30, 100, 150, 200 and the so-called grey EPS) materials were applied as insulating layer. The investigations of sorption behaviour of the materials are important from the point of view of fundamental research and building technology as well. Sorption data taken from our previous measurements results were used for predicting the change of the overall heat-transfer coefficients of different wall structures constituted like this.

Practical application

The present technical note is based on our previous measurement results. Water can cause undesirable changes in the building structures and introduced in this article. During the fixing procedure of the additional insulating of a given building bad weather conditions (high relative humidity and/or low external temperature) can dominate. These phenomena can be imagined for building new houses. By the “in-building” of the moisture into the wall-structure, numerous and measurable change can happen in the U-value of the building envelope. The presented changes are estimations only, but can be used and can help for planning and executing the insulating process.

Acknowledgements

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1. Introduction

By additional insulating one can not only reduce heat losses so probably energy bills of the buildings, but also can make his house more comfortable. Efficient building insulating can shorten the heating period as well as the effects of the thermal bridges can be reduced. The energy minimizing, and reducing the CO₂, as well as the green house gases are well known concepts. Other reasons for the “thermal packing” of the buildings are the extension of the lifetime of the buildings, the protection of the bearing layer against the ice and mechanical impacts furthermore the market value of the buildings are increasing. EPS is thought to be a

reasonable insulating medium which exhibits consistent thermal performance. Its low price and relatively low thermal conductivity can anticipate its extensive application.

2. Materials and methods

In this publication we give predictions for the change of the overall heat transfer coefficients of the building structures in function of water content. Water can cause undesirable changes in the physical, chemical and mechanical properties of the solid materials. It is reported in Ref 1-7. Our calculations are based on our previous measurement results [5, 6].

2.1. Measurement methods

Both the sorption and the thermal conductivity measurements were carried out after drying the samples in a VentiCell drying instrument. With this device materials can be dried setting different air temperatures (up to 523 K). It works with hot air circulation using an inbuilt ventilator. For the sorption measurements three EPS samples with 8 cm x 8 cm x 5 cm geometries were prepared from the original pieces in order to perform the measurements on three specimens from the same material. The expanded polystyrene materials were produced in the Cellplast Plastic Ltd in Hajduszoboszló. The main steps through the sample preparations were the followings. After the preparation of the raw material, the samples were taken to the pre-expander and were heat-treated at 368 K. From the pre-expander the dried materials were exposed to a half day conditioning. Then the moulding and the second conditioning of the semi-prepared samples came after. On completion of the sample preparing they can be dimensioned. The results were obtained by averaging of three measurements. Before treating the samples in the CLC climatic chamber, samples were dried to changeless weight at 343 K under normal atmospheric pressure (10^5 Pa) at all times. This temperature was chosen because it is fairly under the melting point of the polystyrene (about 373 K) and

during the dehydrating process at this temperature; the material does not suffer losses in its physical and chemical properties. To determine the sorption curves (moisture content of material in function of relative humidity (RH %) of air at 293 K) the samples were kept in the CLC chamber under 25, 50, 63, 76 and 90 % RH for 240 minutes. The moisture content (ω %) of a solid material can be calculated from the next simple equation (Eq. 1):

$$\omega = \frac{m_w - m_d}{m_d} \quad (\text{Eq. 1})$$

where m_d and m_w are the mass of the dried and the damped samples respectively.

For measuring the thermal conductivity of each polystyrene samples, Lambda 2000 Heat flow meter (HFM) was used. This equipment is designed to determine the thermal conductivity of insulation materials in accordance with standard ASTM C518 and ISO 8301 protocols. A sample with 30 cm x 30 cm x 5 cm geometry is placed in the test section between two plates which are maintained at different temperatures ($T_1=285$ K and $T_2=295$ K, with $T_{\text{mean}}=290$ K) during the test. After achieving thermal equilibrium and establishing a uniform temperature gradient throughout the sample, thermal conductivity is determined. To determine the thermal conductivity of a sample, three independent measurements were carried out. The thermal conductivity of analysed material was the mean value of the three measured results. The measurement methods and orders are clearly written in our previous publications. [5-8].

2.2. The calculation procedure

For evaluating the initial thermal conductivities (λ_0) of the different EPS materials $\chi=0,42$ (the so-called correction factor) was applied using the following equation regarding to the MSZ-04-140-2:1991 standard.

$$\lambda_0 = \lambda_{\text{measured}} \times (1 + \chi) \quad (\text{Eq. 2})$$

where $\lambda_{\text{measured}}$ is the measured thermal conductivity reported in Ref 5 before.

$$\lambda = \lambda_0 \times \left(1 + \frac{\omega \times Z}{100}\right) \quad (\text{Eq. 3})$$

For calculating the change of the thermal conductivity of a given material in function of moisture content the above mentioned equation (Eq. 3) can be used [9]. In this equation λ is the predicted thermal conductivity, ω is the moisture content [5] and Z is constant and can be found in Table 1 (taken from Ref 9). There are some investigations, measurements and simulations for predicting the thermal conductivity at given moisture content degree. The most of them are presenting linear dependency, some of them are presenting initially linear and then polynomial/exponential equation so plots [5, 10, 11, 12]. By using the following equations the thermal resistance of a given wall structure and the overall heat transfer coefficient can be calculated:

$$\sum R = \frac{1}{\alpha_i} + \sum \frac{d}{\lambda} + \frac{1}{\alpha_e} \quad (\text{Eq. 4})$$

where, $\alpha_{i,e}$ are the heat transfer coefficients on the surface, $\frac{1}{\alpha_i}$ and $\frac{1}{\alpha_e}$ are giving the internal and the external surface resistivities respectively, d is the thickness of the wall (in m) represented in Table 1, furthermore λ is the above mentioned thermal conductivity. So that, the overall heat transfer coefficients can be calculated.

$$U = \frac{1}{R} \quad (\text{Eq. 5})$$

3. Results and discussions

3.1. The U-values in function of moisture content

Before representing the calculations some assumptions have to be noticed. The values in the first and second rows of Tables 2, 3, 4, 5 and 6 representing the sorped amount of water in function of the relative humidity belonging to the different EPS materials. Here the measured and previously introduced [5] moisture contents of the given materials can be found. For calculating the change of the thermal conductivities of the EPS, brick and concrete the above mentioned moisture content values were applied. By using these data values, Eq. 2 and 3 the thermal conductivities of the wetted EPS, concrete and brick materials can be calculated. It is feasible to calculate the overall heat transfer coefficients for the 0.4 m_Concrete/0.1m_EPS and 0.4 m_Brick/0.1 m EPS systems by applying Eq. 5. For the EPS materials 0.1 m thickness was chosen to be significantly under the $U=0.45 \text{ W/m}^2\text{K}$ value. This value is the requirement for the overall heat-transfer coefficients for outer walls in Hungary. It can be found in the decree of the minister without portfolio in Hungary No 2006/7. For thicknesses of EPS 30, 100, 150, 200 and Grey to meet the requirements as additional insulating in combination with 0.4 m brick or concrete calculated values are presented in Table 7. One can see that thicknesses are varying from 0.07 to 0.09.

As results, we plotted our estimated values, since on Figure 1.a and b one can see the estimated U-values (Concrete+EPS and Brick+EPS) taken from tables 2, to 6 in function of the moisture contents. Linear plots can be found as expected from Eq. 3 and 5. In these diagrams the requirement for the U-value as well as a suggested U-value are represented. One can see that with this thickness (0.1 m for EPS) neither of them can reach this suggested value. Observable either the increasing U-values in function of moisture content but none of the estimated U-values reaches the required $0.45 \text{ W/m}^2\text{K}$. All of the data points were fitted with linear functions and follows the next formula:

$$U=U_0 + m * \omega \tag{Eq. 6}$$

where U and U_0 are representing the overall heat transfer coefficients after wetting and in dried state, m is the slope and ω is the moisture content one after the other. In these two cases (concrete and brick) all of the above mentioned plastic foam insulators can be used. For choosing those the pros and cons can only be their prices or their resistance against the outer physical and mechanical effects. In Figure 2 one can see the slopes (m) belonging to Eq. 6 taken from Figure 1.a and b in function of the used, different EPS materials. One belonging to the concrete and the other belonging to the brick, combined with the different test insulators. One can observe that the curve of the brick is highly above the curve of concrete. The data values are following linear increasing.

3.2. The percental change in the U -values

We calculated a percental change compared to the greatest amount of sorped water by using the next equation and represented in Figure 3:

$$Y (\%) = \frac{U_{95\%} - U_0}{U_0} \times 100 \quad (\text{Eq. 7})$$

where $U_{95\%}$ is the overall heat transfer coefficients for the moisture content belonging to 95 % relative humidity and U_0 is the same value without any moisture for a given structure combination (eg. 0.4 m Brick+0.1 EPS 150 etc.). Figure 3 shows that for similar moisture contents the higher deviances can be observed in the values of brick then in the values of concrete. It should be noted that there similar decrease of in the two curves from EPS 30 to EPS 200. This can be referred to the density of the samples. The density of the EPS materials is increasing with the increasing EPS Label number (30, 100, 150 and 200). The highest density is the lowest moisture up taking capability. This phenomenon is clearly written in [13-16]. Can be noticed that the highest percental change belongs to the EPS 30 and to the grey, however the lowest belongs to the EPS 200. For the concrete about 4 and for the brick nearly 6 % percental changes were found by applying the graphite doped one.

4. Conclusions

In this paper we presented possible applications of different EPS materials as additional insulations. Five different expanded polystyrene with 0.1 m thickness were tested (EPS 30, 100, 150, 200 and Grey). These materials were combined with concrete and with brick with 0.4 m thicknesses. We have shown that the change in the overall heat transfer coefficient of the wall structures is caused by on the one hand the water content, on the other hand the density of the insulating material. We verified that the water causes greater increase in the U-value of the brick than the concrete's. The highest degradation degree can be found at the application of the grey EPS. It can happen by the "nature" of this material. This grey EPS is pure polystyrene enhanced with carbon particles. Carbon has good getter properties and it has relatively low density, so these two parameters can cause the great water adsorbing capability. Furthermore, we can conclude that about 0.5-1 % water content can cause approximately 5-6% increasing in the U-value of a wall structure with 0.5 m thickness.

5. Acknowledgements

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Figure captions:

Figure 1.a: The calculated U-values in function of moisture content for 0.4 m thick Concrete wall in combination with different EPS materials with 0.1 m thicknesses

Figure 1.b: The calculated U-values in function of moisture content for 0.4 m thick Brick wall in combination with different EPS materials with 0.1 m thicknesses

Figure 2.: The slopes of the curves taken from Figure 1a and b belonging to different EPS materials

Figure 3.: The percental changes of the U-values compared to the highest relative humidity (95 %) in function of the different EPS materials

Tables:

Table 1.: The used constants.

Z_{brick}	20	$d_{b,c}$ (m)	0.4
$Z_{concrete}$	12	d_{eps} (m)	0.1
Z_{eps}	2	$R_{i,e}$ [m ² K/W]	0.16667

Table 2. The data with EPS 30.

EPS 30 /rh %	0.00	25.00	50.00	63.00	75.00	95.00
Moisture content (%)	0.0000	0.8800	0.8910	0.9200	0.9360	1.0460
Thermal conductivity [W/mK]. brick	0.7200	0.8467	0.8483	0.8525	0.8548	0.8706

Thermal conductivity [W/mK]. concrete	0.7000	0.7739	0.7748	0.7773	0.7786	0.7879
Thermal conductivity [W/mK]. EPS 30	0.0596	0.0607	0.0607	0.0607	0.0608	0.0609
R_b [m²K/W]	0.5556	0.4724	0.4715	0.4692	0.4680	0.4594
R_c [m²K/W]	0.5714	0.5168	0.5162	0.5146	0.5137	0.5077
R_{eps} [m²K/W]	1.6767	1.6477	1.6474	1.6464	1.6459	1.6424
U_{brick+eps} [W/m²K]	0.4168	0.4373	0.4375	0.4382	0.4385	0.4408
U_{concrete+eps} [W/m²K]	0.4141	0.4290	0.4291	0.4296	0.4299	0.4316
Percental change. EPS 30+brick	0.0000	4.9040	4.9608	5.1102	5.1923	5.7516
Percental change. EPS 30+concrete	0.0000	3.5852	3.6284	3.7422	3.8049	4.2338

Table 3.: The data with EPS 100

EPS 100 /rh %	0.00	25.00	50.00	63.00	75.00	95.00
Moisture content (%)	0.0000	0.7930	0.8400	0.8500	0.8600	0.9800
Thermal conductivity [W/mK]. brick	0.7200	0.8342	0.8410	0.8424	0.8438	0.8611
Thermal conductivity [W/mK]. concrete	0.7000	0.7666	0.7706	0.7714	0.7722	0.7823
Thermal conductivity [W/mK]. EPS 100	0.0540	0.0548	0.0549	0.0549	0.0549	0.0550
R_b [m²K/W]	0.5556	0.4795	0.4756	0.4748	0.4740	0.4645
R_c [m²K/W]	0.5714	0.5218	0.5191	0.5185	0.5180	0.5113
R_{eps} [m²K/W]	1.8532	1.8243	1.8226	1.8222	1.8219	1.8176

$U_{\text{brick+eps}}$ [W/m ² K]	0.3883	0.4048	0.4057	0.4059	0.4061	0.4084
$U_{\text{concrete+eps}}$ [W/m ² K]	0.3859	0.3980	0.3987	0.3988	0.3990	0.4007
Percental change. EPS 100+brick	0.0000	4.2495	4.4841	4.5337	4.5833	5.1728
Percental change. EPS 100+concrete	0.0000	3.1275	3.3067	3.3448	3.3828	3.8370

Table 4: The data with EPS 150

EPS 150 /rh %	0.00	25.00	50.00	63.00	75.00	95.00
Moisture content (%)	0.0000	0.6000	0.6200	0.6500	0.6700	0.8700
Thermal conductivity [W/mK]. brick	0.7200	0.8064	0.8093	0.8136	0.8165	0.8453
Thermal conductivity [W/mK]. concrete	0.7000	0.7504	0.7521	0.7546	0.7563	0.7731
Thermal conductivity [W/mK]. EPS 150	0.0511	0.0517	0.0518	0.0518	0.0518	0.0520
R_b [m²K/W]	0.5556	0.4960	0.4943	0.4916	0.4899	0.4732
R_c [m²K/W]	0.5714	0.5330	0.5319	0.5301	0.5289	0.5174
R_{eps} [m²K/W]	1.9562	1.9330	1.9322	1.9311	1.9303	1.9227
$U_{\text{brick+eps}}$ [W/m ² K]	0.3734	0.3853	0.3856	0.3862	0.3866	0.3902
$U_{\text{concrete+eps}}$ [W/m ² K]	0.3712	0.3798	0.3801	0.3805	0.3808	0.3836
Percental change. EPS 150+brick	0.0000	3.1868	3.2874	3.4378	3.5376	4.5186
Percental change. EPS 150+concrete	0.0000	2.3389	2.4149	2.5287	2.6045	3.3556

Table 5.: The data with EPS 200

EPS 200 /rh %	0.00	25.00	50.00	63.00	75.00	95.00
Moisture content (%)	0.0000	0.5000	0.5250	0.5350	0.5680	0.6885
Thermal conductivity [W/mK]. brick	0.7200	0.7920	0.7956	0.7970	0.8018	0.8191
Thermal conductivity [W/mK]. concrete	0.7000	0.7420	0.7441	0.7449	0.7477	0.7578
Thermal conductivity [W/mK]. EPS 200	0.0483	0.0488	0.0488	0.0488	0.0488	0.0489
R_b [m²K/W]	0.5556	0.5051	0.5028	0.5019	0.4989	0.4883
R_c [m²K/W]	0.5714	0.5391	0.5376	0.5370	0.5350	0.5278
R_{eps} [m²K/W]	2.0713	2.0507	2.0497	2.0493	2.0480	2.0431
U_{brick+eps} [W/m²K]	0.3580	0.3673	0.3678	0.3679	0.3685	0.3706
U_{concrete+eps} [W/m²K]	0.3560	0.3628	0.3631	0.3632	0.3637	0.3653
Percental change. EPS 200+brick	0.0000	2.6084	2.7329	2.7826	2.9459	3.5349
Percental change. EPS 200+concrete	0.0000	1.9174	2.0112	2.0487	2.1722	2.6206

Table 6.: The data with EPS grey

EPS Grey /rh %	0.00	25.00	50.00	63.00	75.00	95.00
Moisture content (%)	0.0000	1.0100	1.0500	1.0900	1.1160	1.1600
Thermal conductivity [W/mK]. brick	0.7200	0.8654	0.8712	0.8770	0.8807	0.8870
Thermal conductivity [W/mK]. concrete	0.7000	0.7848	0.7882	0.7916	0.7937	0.7974
Thermal conductivity [W/mK]. EPS Grey	0.0454	0.0464	0.0464	0.0464	0.0465	0.0465
R_b [m²K/W]	0.5556	0.4622	0.4591	0.4561	0.4542	0.4509
R_c [m²K/W]	0.5714	0.5097	0.5075	0.5053	0.5039	0.5016
R_{eps} [m²K/W]	2.2007	2.1571	2.1554	2.1538	2.1527	2.1508
U_{brick+eps} [W/m²K]	0.3421	0.3589	0.3596	0.3602	0.3606	0.3612
U_{concrete+eps} [W/m²K]	0.3403	0.3529	0.3534	0.3539	0.3542	0.3547
Percental change. EPS grey+brick	0.0000	4.9152	5.0942	5.2723	5.3874	5.5814
Percental change. EPS grey+concrete	0.0000	3.7179	3.8595	4.0007	4.0923	4.2469

Table 7. The calaculated insulation thicknesses for the insulating materials

	Brick	Concrete
U₂₀₀₆ [W/m²K]=0.45	d [m]	
EPS 30	0.09	0.09
EPS 100	0.08	0.08
EPS 150	0.08	0.08
EPS 200	0.07	0.07
EPS Grey	0.07	0.07

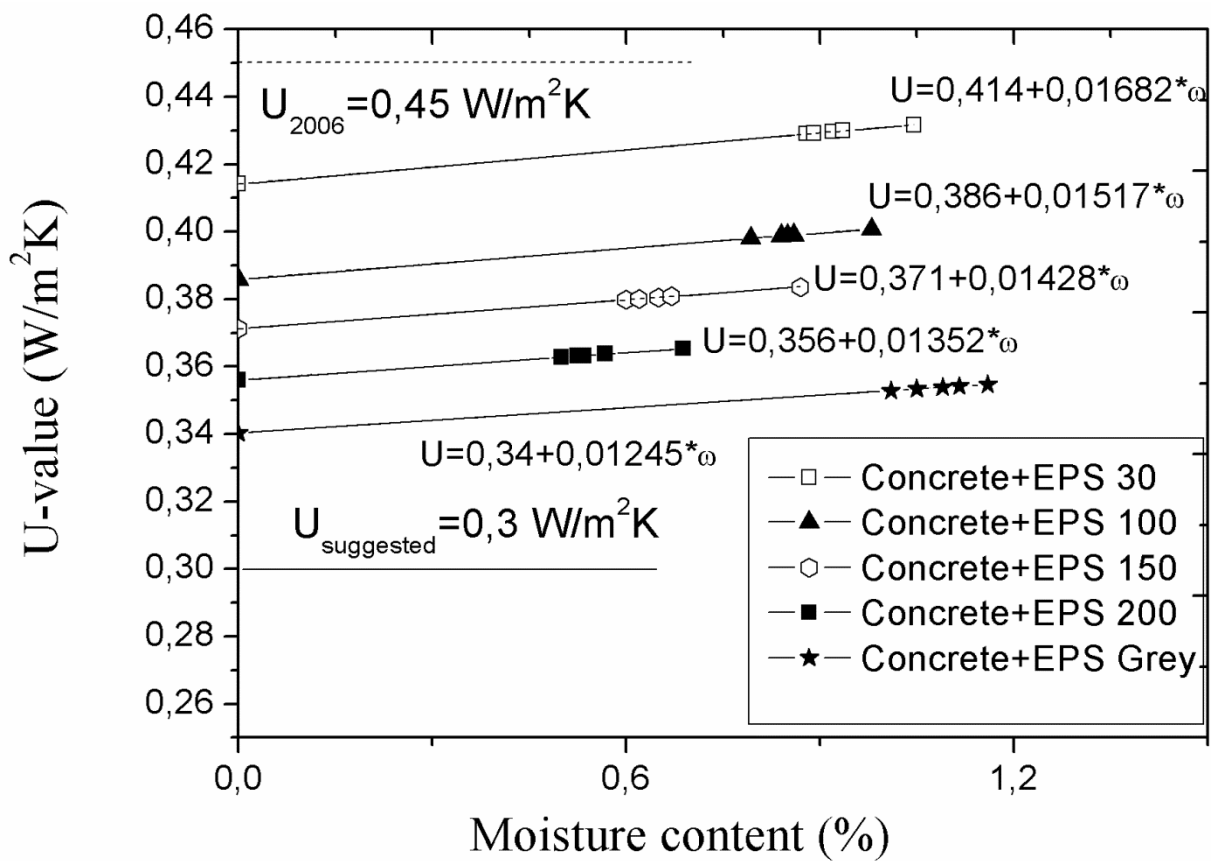


Figure 1.a: The calculated U-values in function of moisture content for 0.4 m thick Concrete wall in combination with different EPS materials with 0.1 m thicknesses

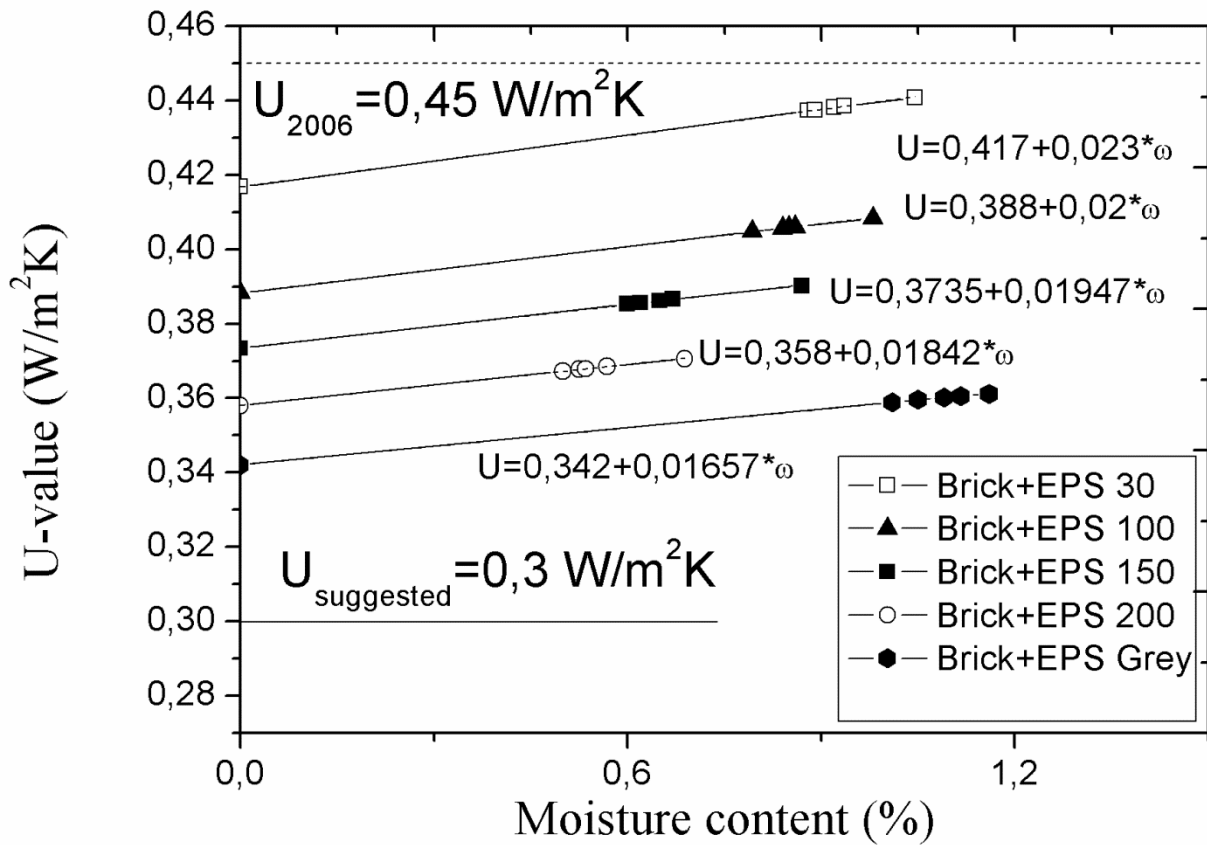


Figure 1.b: The calculated U-values in function of moisture content for 0.4 m thick Brick wall in combination with different EPS materials with 0.1 m thicknesses

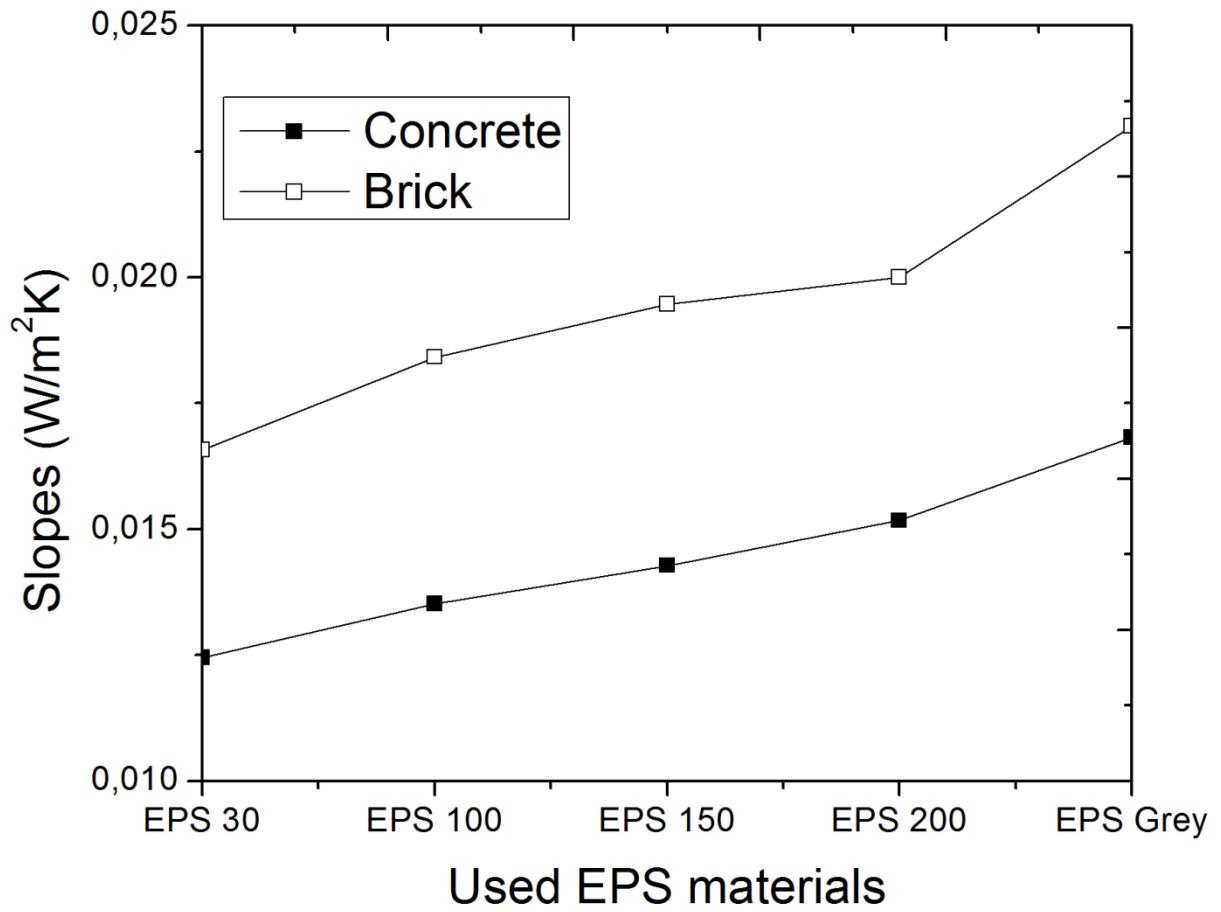


Figure 2.: The slopes of the curves taken from Figure 1a and b belonging to different EPS materials

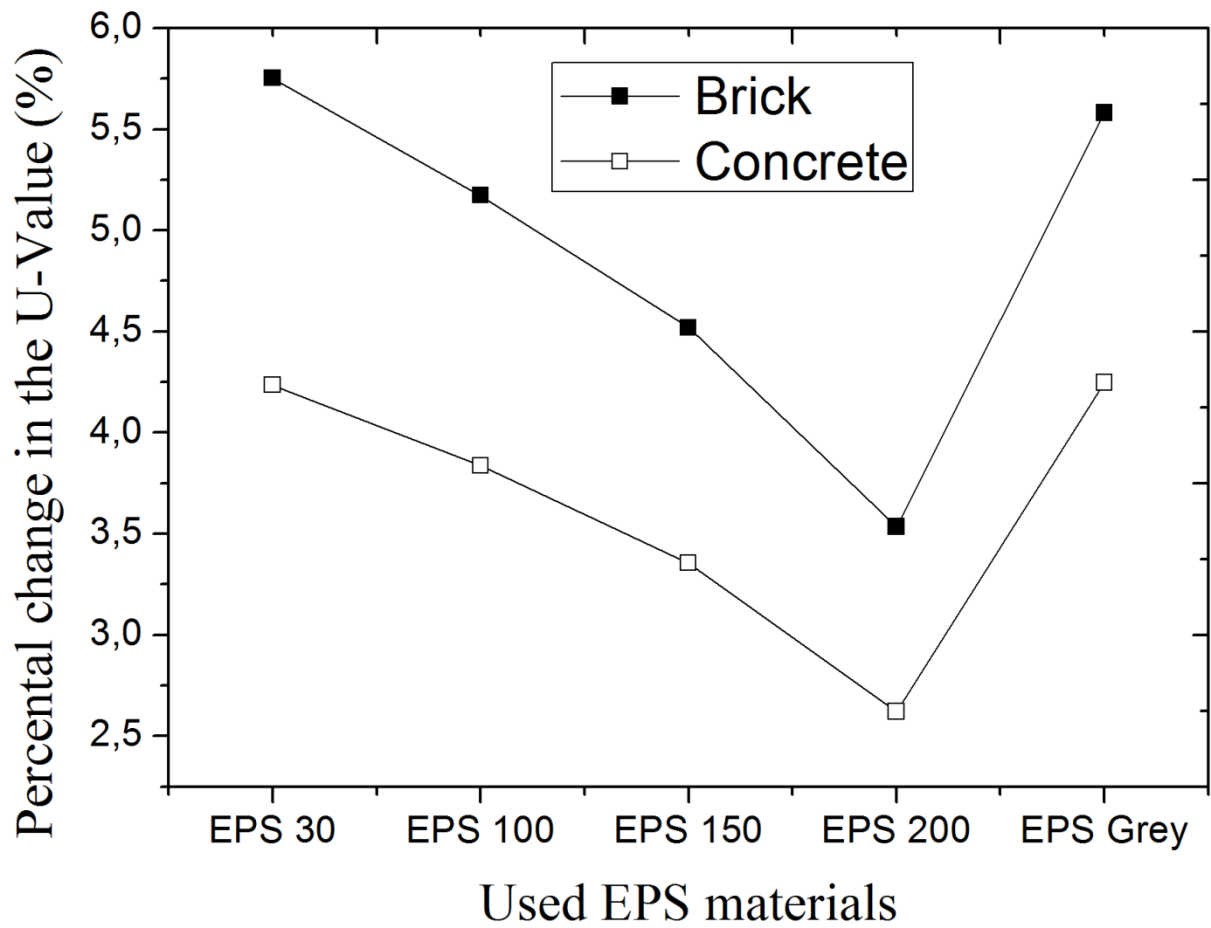


Figure 3.: The percental changes of the U-values compared to the highest relative humidity (95 %) in function of the different EPS materials