Investigation of Heat Transfer Decrement of Wall Structures comparison of Measurements And Calculations

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Abstract: - In these days, the examinations of the thermal behavior of different wall structures are so important from the point of view of reducing energy efficiency of Buildings. The mainly used thermal insulating materials are the plastic foams (expanded and extruded) and the mineral wool materials. Nowadays, the use of the ceramic based insulating paints is also spread over. Thermal parameters of buildings, such as thermal capacity, heat-loss coefficient, time constant, thermal delay, etc. are useful in the analysis of the dynamic thermal behaviour and the characterization of buildings. This paper presents measurement methods to reach the decrement factor of different building structures by using a heat flux meter and hot box method. Moreover, calculations for the investigation of the decrement factor of wall structures were also presented. Here has to be emphasized that this method can be useful as well for everyone who is about to describe and carry out thermal sizing of buildings. In this paper three types of building structures were measured. These measurements were accomplished through an inbuilt plaster/brick/plaster wall construction insulated internally with a ceramic material at the first time and externally with an Expanded Polystyrene later. The calculations were carried out on a concrete and brick based walls covered with different insulators.

1 Introduction

Energy savings in a building can be achieved by appropriate energy efficient design of a building. Traditional solutions of providing thermal comfort by extensive plantation oriented landscaping and heavy mass buildings are no longer valid because of land costs and shortage of building materials, in developing countries. The so-called low-energy buildings and passive houses are generally based on high insulation levels. Previously several authors (including us) evaluated the influence of the wall's thermal properties on the building energy performance, by comparing different construction systems. [1-14] The decrement factor is very important characteristics of materials and buildings structures. They are strongly depending from the type of the materials and their thicknesses. At the cross-section of the outer wall of a building, there are different temperature profiles during a 1-day period. These profiles are functions of the inside temperature, the outside temperature and the thermo physical properties of the wall. The magnitude of the heat wave on the outer wall's surface depends from the solar radiation and the convection in between the air and the wall. In this paper measurement methods for the decrement factor can be found. The thicker and more resistive the material, the longer it will take for heat waves to pass through. The reduction in cyclical temperature on the inside surface compared to the outside surface is known as the decrement. [11-14] In Section 2 the methods for the measurements and for the calculations will be presented in 3 parts. There will be presented the measurement methods to reach the decrement factor of different building structures by using a heat flux meter and hot box method. Moreover, calculations for the investigation of the decrement factor of wall structures will also be presented.

2 Theory and measurements

2.1 Measurement method for the decrement factor of the temperature profiles

In order to measure the thermal resistance and the thermal properties of in-built layer structures, an isolated chamber is available for us. The chamber is surrounded with 0.3 m thick EPS 200, as well as divided into two rooms (cold and warm) with 2.2x3.4 m areas each by 0.5 m thick EPS 200 insulating system The cold room can be cooled down to 250 K by three separated cryogenics. The warm room can be heated up to 298 K by a basic

portable, electric radiator. In the EPS dividing-wall 0.35 m over the ground a small solid brick wall window, with 0.25 m thickness and 1.44 m^2 surface area can be found. This brick wall is mortared with 0.015 m plaster both at the warm and the cold side. The determination of decrement factor of wall structures by calibrated hot box (CC) was executed. The measurement set-up is well presented in one of our previous paper see [14]. The calibrated hot box is surrounded by air with fixed temperature parallel to its own, so as zero heat transfer can be expected through the wall of the box. Furthermore the box is made of 0.1 m thick EPS 200 enclosed between two sheets of wood with 0.02 m thickness. Temperature over the hot box was kept by basic portable, electric radiator. Measurement of temperature both of the air ($T_{i,e}$) and on the wall surfaces ($T_{is,es}$) at both sides are measured by Pt-100 type thermocouples. The surface temperature of the walls was measured at 9 points arranged in equal distances from each other and the results were stored at data storage. The average value of surface temperature was calculated both at the warm and the cold sides from the measurement data. Inside the box a small fan was used for circulating air, and was heated by two bulbs and was kept to 291 K (18 °C) with 40 W electric power either. At the cold side, one fan as well as two air baffles were used in order to reach a good air temperature homogenisation. The periodical air temperature was developed by the above mentioned three chillers. [11, 13, 14] As a result of the sinusoid cold air temperature and the fixed (constant) warm air temperature both at the cold and the warm surface a periodical (sinusoid) temperature changing forms. Several methods are available to calculate the decrement factor of building structures [3, 5-9, 15-22] This article represents a specific method to reach the decrement factor of buildings structures, nonetheless it can be used with any arbitrary periodical temperature fluctuation. If we have periodically changing external air temperatures see Figure 1a, where the outside air temperature (T_e) is defined as a periodical (sinusoidal) function and the temperature of the air inside (T_i, room temperature) is fixed (in our case T_i=18 °C), the following equation can be reached:

$$T_e = T_o + A_e \times \sin\left[\frac{\pi \times (t - t_c)}{w}\right]$$

(1)

This function was fitted to the measurement result of both the warm and the cold wall temperatures. Corresponding both to the changing outer air

temperature and to the building structure the external and internal wall surface temperatures are changing, as periodical functions (see Figure 1a). The main goal here is to examine and to fit the fluctuations on the internal surface and the external surface of the wall with sinusoid functions, since their amplitude was registered, while the indoor air temperature is fixed. In order to understand the definition of the time lag and decrement factor, Figure 1b was created.
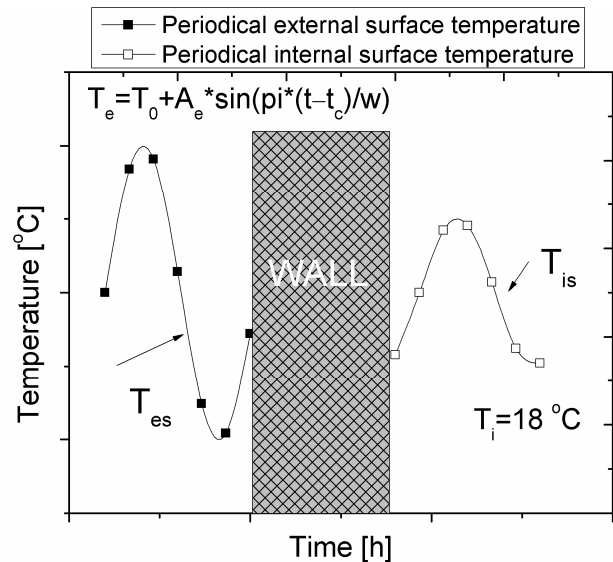

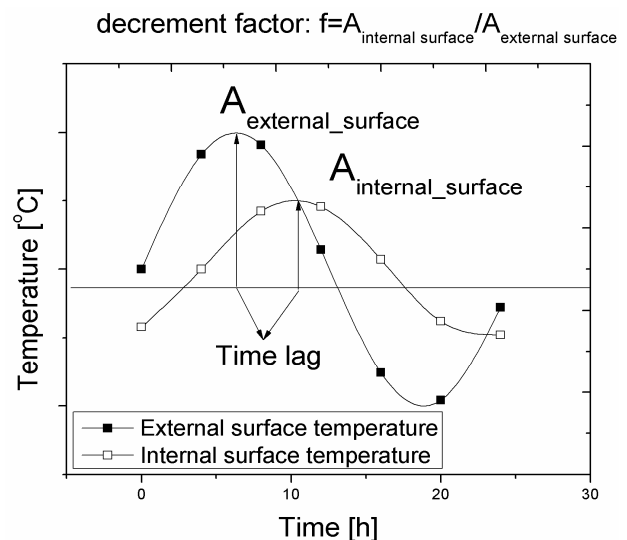Fig. 1a: Demonstration of the external and internal surface temperature functions

Fig. 1b: Demonstration of the definition of the decrement factor and time lag

The decrement factor (f_T) of a building structure is the ratio of the amplitude of the internal surface (defended side) temperature ($A_{internal\_surface}$) and the amplitude of the external surface (attacked side) temperature ($A_{exterrnal\_surface}$) of the wall.

$$f_T = \frac{A_{internal\_surface}}{A_{external\_surface}} \tag{2}$$

2.2 Measurement method for the decrement of the Heat flux

Hukseflux HFP01 heat flux sensors serve the reason to measure the heat flux that flows through the object in which it is incorporated or on which it is mounted. Besides thermopile sensors measure the differential temperature across the ceramics-plastic composite body of HFP01. Working completely passive, HFP01 generates a small output voltage proportional to the local heat flux. The heat flux is calculated from the voltage. This instrument can measure the Heat Flux, and the R-value of building envelopes according to ISO 9869, ASTM C1046 and ASTM C1155 standards. These apparatus can be used from 250 K-350 K temperature range and it can measure from 2000 to -2000 Wm^2 range with about 5% accuracy. The measurements were carried out by using two HF sensors with 50.24 cm^2 rounded surface for good spatial averaging fixed up at different points on the wall. For measuring the air temperatures at both warm and cold sides 2 pairs of thermo-couples belong to this apparatus. This measurement order is clearly written in Ref 15. With the Hukseflux apparatus one can measure the heat flux transported through a wall structure. If we keep a periodical temperature change at the external (cold) side and we fix the temperature at the internal (warm) side, a periodical heat flux will be resulted transporting through the walls. If we measure first the heat flux of the base wall and then we measure the heat flux of the insulated wall, since their ratio will give a similar value as f_T presented previously.

$$f_q = \frac{q_{insulated}}{q_{base\_wall}} \tag{3}$$

where f_q is the decrease in the heat flux, $q_{insulated}$ and q_{base_wall} are the amplitudes of the fitted sinusoidal heat flux functions of the insulated and base brick wall.

2.3. Calculations for the decrement factor

As above mentioned, if we have aperiodically changing external air temperatures see Figure 1a, where the air temperature (Te) is defined as a periodical (sinusoidal, 1-day) function and the temperature of the air inside is fixed (in our case Ti=22 ^{o}C).

This function was fitted to the data presented in Table 1 taken from the relevant Hungarian Standard. Corresponding both to the changing outer air temperature and to the building structure the external and internal wall surface temperatures are changing, as a periodical function.

Table 1: The used temperature values given for a Hungarian summer day taken from Ref [24]

Time [h]	1	2	3	4	5	6	7	8	9	10	11	12
External air temperature [^{o}C]	17.2	17	17.2	17.9	18.9	20.2	21.8	23.5	25.2	26.7	28.1	29.1
Time [h]	13	14	15	16	17	18	19	20	21	22	23	24
External air temperature [^{o}C]	29.8	30	29.8	29.1	28.1	26.7	25.2	23.5	21.8	20.2	18.9	17.9

In figure 2 one sample for the calculation can be seen. First the external surface temperature function is presented by calculating the temperature change in function of the changing outer air temperature. By fitting with a sinus function, its amplitude value (Aexterrnal surface=6.23) can be reached. Then, the calculation of the internal surface temperature function follows, shifted by the time lag reached by using Eq. 9. The amplitude of this function is: Ainternal surface=1.11.
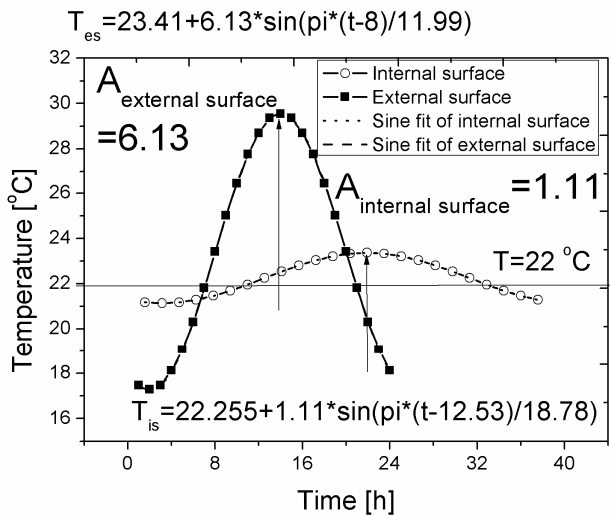
T_{es}=23.41+6.13*sin(pi*(t-8)/11.99)

Fig. 2. The calculated functions for the decrement

3 Results and discussion

In this communication the measurement and calculations of the decrement factor of the temperature profiles and the decrement in the heat flux can be found. For the measurements three different building structures were tested. The first structure contains 0.015 m_plaster outside/0.25 m_small solid brick/0.015 m_plaster inside. For reaching the second structure the first wall was covered by 2 mm thick ceramic insulating paint at the warm side and then it was supplied by with 5 cm Expanded Polystyrene (EPS) at the cold side.

For the calculations two hypothetic building structures were created. The first structure contains 0.02 m_plaster outside/0.3 m_B30_small solid brick/0.015 m_plaster inside. Altough, the other structure is nearly the same except for the brick is substituted with 0.3 m concrete. Both of them are supplied with 4 insulators (EPS 30, 200, XPS and Fibrous) with 0.01 to 0.22 m thicknesses each. Each thermal conductivity was measured.

Polystyrene foamy materials (EPS, XPS) are proved to be reasonable insulators, since by using them relatively high efficiency can be reached, and they have relatively low price compared to for example poly-urethane (PUR). EPS is mainly used as frontage insulators. But, they cannot be used in all cases so that the thermal insulating paints could be the answer for those cases. The use of them is clearly described by others in several papers and in our previous works also. Fibrous (mineral-wool) one can be used at frontage as well as at roofs. Their filamentous structure does not allow us to use them at plinth, but this property allows air permeability. The extruded polystyrene (XPS) with its closed cells

can be used as a plinth insulator also. Therefore these cells cannot be filled easily with water. [1-19]

3.1 Decrement factor resulted by the measured temperatures

During the measurements the temperature of the cold air (T_e) and warm air (T_i) was measured in three-three different vertical points, moreover the wall surface temperatures (T_{es}, T_{is})) were averaged from 9 individual temperature values. In Figure 3a, 3b and 3c one can see the temperatures in function of the measurement time of the warm and cold air and the warm and cold walls. All of the wall temperatures were fitted with a sinusoidal function and their amplitudes ($A_{i\ (meas)}$, $A_{e\ (meas)}$) were registered and collected in to Table 2. By using Eq. 2 the decrements were calculated.

Table 2. The measured decrement factors

	R [m²K/W]	U [W/m²K]	A_i (meas)	$A_{e\ (meas)}$	f_{meas}
Plaster_Brick_Plaster	0.434	1.665	0.097	0.520	0.187
Plaster_Brick_Plaster_2mm_Ceramic insulator	0.530	1.435	0.083	0.589	0.141
Plaster_Brick_Plaster_2mm Korund_EPS	1.781	0.513	0.025	1.040	0.024

The measurements were all done for about 7 hour after reaching the homogenous periodical external air temperature profile.
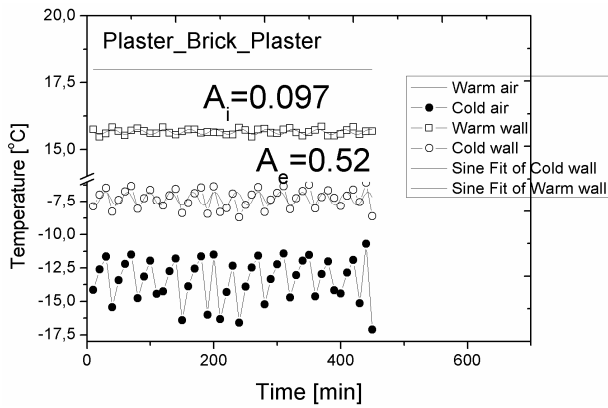
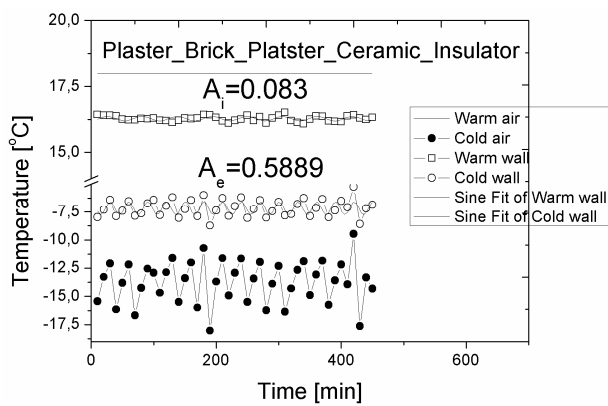Fig.3a.: The temperature profile of the Plaster_Brick_Plaster system, and the results of the sinusoidal fits

Fig. 3b.: The temperature profile of the Plaster_Brick_Plaster_2mm Ceramic insulator system, and the results of the sinusoidal fits
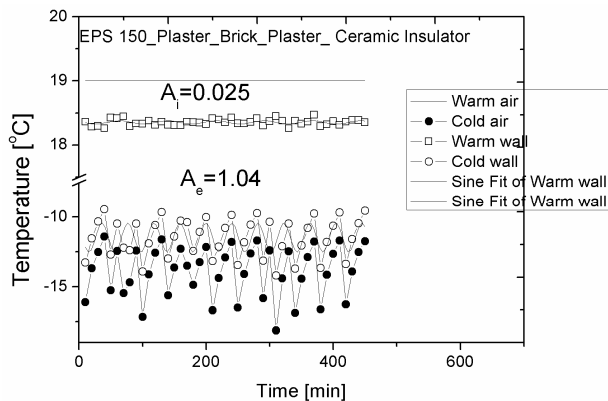

Fig.3c.: The temperature profile of the 5 cm_EPS 150_Plaster_Brick_Plaster_2mm Ceramic system, and the results of the sinusoidal fits

On the figures 3 a-c one can see that the highest warm wall temperature and the lowest cold wall temperature belonging to the last structure and the worst insulating capability (lowest warm wall and highest cold wall temperature) belongs to the basic brick wall.

On the figures decreasing internal and increasing external surface temperatures can be observed. Linked to this the amplitudes of the temperature profiles obey the same. As a result of the high insulating capacity of the EPS material the periodic cold wall temperature is nearly overlap with the periodic cold air, furthermore the amplitude of the warm air function is nearly zero.

3.2 Decrement of the heat flux

In figure 4 we can see the resulted heat flux periodical functions after 700 min measurements. As in previously presented these profiles were fitted with sinusoidal functions, and their amplitude was registered. In table 3 these amplitudes and their ratios are presented. We can observe, that if we cover the brick wall with 2mm ceramic insulator we reach a decrease with 0.220, furthermore if we cover the previous wall structures we will reach 0.055 more decrease.
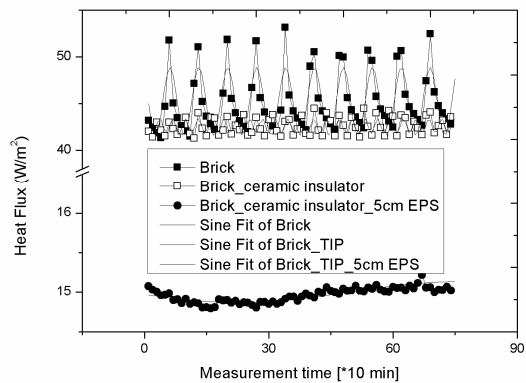

Fig. 4.: The measured Heat fluxes of the wall structures

Table 3. The measured heat fluxes and their decrements

	Plaster_Brick_Plaster	Plaster_Brick_Plaster_2mm_Ceramic insulator	Plaster_Brick_Plaster_2mm Korund_EPS
Amplitude of Heat Flux	3.630	0.800	0.200
Decrement of Heat Flux		0.220	0.055

3.3. The calculations

In Figure 5a and 5b one can see the decreasing decrement factor in function of the thickness of the insulators. Each decrement factor was calculated from the amplitudes reached by fitting the changing external and internal surface temperature data with the sinusoidal function. These graphs were created by using the calculated values taken from Table 2a and b, here only the decrement factors are presented. On the graphs one can see that with increasing insulation thickness the best decrement can be reached by the fibrous material, than followed by EPS 200, XPS and EPS 30. This can be observed both for the brick and for the concrete based wall structures. It is notable that 0.22 m EPS30 can be replaced by about 0.17 m thick fibrous slab to reach the same decrement. Smaller decrement is presented by the brick based wall structures, compared to the concrete walls.
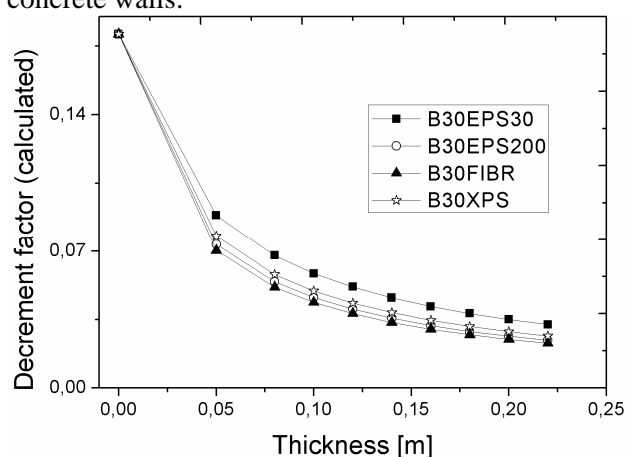

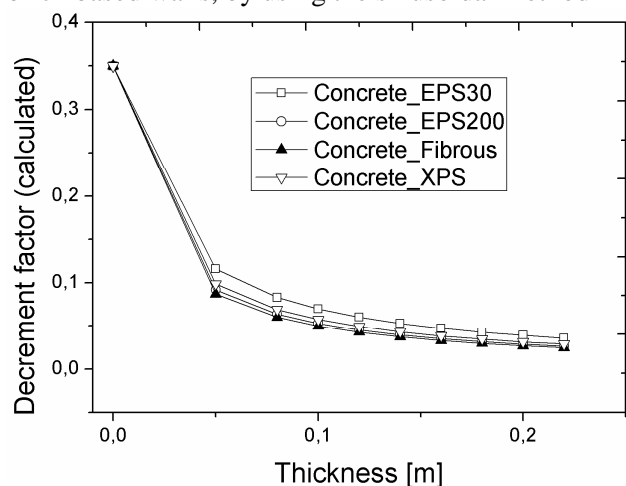Fig. 5a.: The calculated decrement factors of the brick based walls, by using the sinusoidal method

Fig. 5b.: The calculated decrement factors of the concrete based walls, by using the sinusoidal method

4 Conclusions

The comparison of the results of laboratory measurements of the building and structural materials with computations, predictions, modeling and simulations are also important when one designs a building. As a result based on our measurement, in this comprehensive report a mathematical approach to the determination of the decrement factor of building structures and the decrease in the periodical heat flux is presented. The algorithms were worked out by using measured temperature and heat flux data.

For the investigations three different building structures were created. The first structure contains 0.015 m_plaster outside/0.25 m_small solid brick/0.015 m_plaster inside. Then it was covered first with 2 mm thick ceramic insulating paint and then with 5 cm thick EPS 150. We proved that the measurement methods worked out from investiagtions of the overall heat transfer coefficients, can be safely used for measurements of the decrement factors. For the calculations two hypothetic building structures were created. The first structure contains 0.02 m_plaster outside/0.3 m_B30_small solid brick/0.015 m_plaster inside. Altough, the other structure is nearly the same except for the brick is substituted with 0.3 m concrete. Both of them are supplied with 4 insulators (EPS 30, 200, XPS and Fibrous) with 0.01 to 0.22 m thicknesses each. Each thermal conductivity was measured.

We can conclude that, as a result of the measurements we can reach the real and correct decrement factors, however computations and calculations give us "safe" (higher) values. This method should be very useful for building scientists working in energy conservations and savings, and for designers building nearly zero energy or passive houses as well, independently from place and residence.

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