Measurement of the heat transfer decrement of different wall structures

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Abstract: - As it is well known nowadays, investigations of the thermal properties of different wall structures are so important from the point of view of exact designings of buildings. The most commonly used thermal insulating materials are the plastic foam and mineral wool materials. Nowadays, the use of the ceramic based insulating paints is 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. 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.

Key-Words: - thermal decrement factor, building structures, thermal energy, brick wall, hukseflux apparatus, hot box

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solutions of providing thermal comfort by extensive plantation oriented landscaping and heavy mass buildings are no longer valid because of land costs and shortage of building materials, in developing countries.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]

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

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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 ^oC) 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, 15-19] 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 ^oC), the following equation can be reached:

$$T_e = T_o + A_e \times \sin\left[\frac{\pi \times (t - t_c)}{w}\right] \quad (1)$$

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.

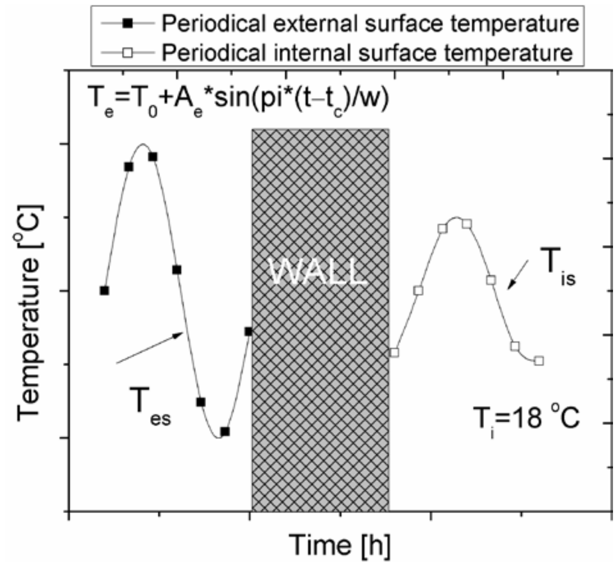

Fig. 1a: Demonstration of the external and internal surface temperature functions

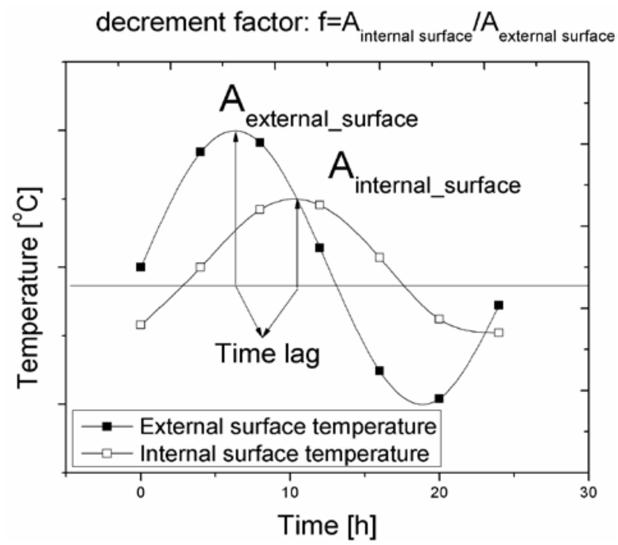

Fig. 1b: Demonstration of the definition of the decrement factor and time lag

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.

$$f_T = \frac{A_{internal\_surface}}{A_{external\_surface}} \quad (2)$$

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.

$$f_q = \frac{q_{insulated}}{q_{base\_wall}} \quad (3)$$

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.

3 Results and discussion

In this communication the measurement 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. 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. [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 2a, 2b and 2c 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 1. By using Eq. 2 the decrements were calculated.

Table 1. The measured decrement factors

	R [m^2K/W]	U [W/m^2K]	$A_{i\ (meas)}$	$A_{e\ (meas)}$	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.

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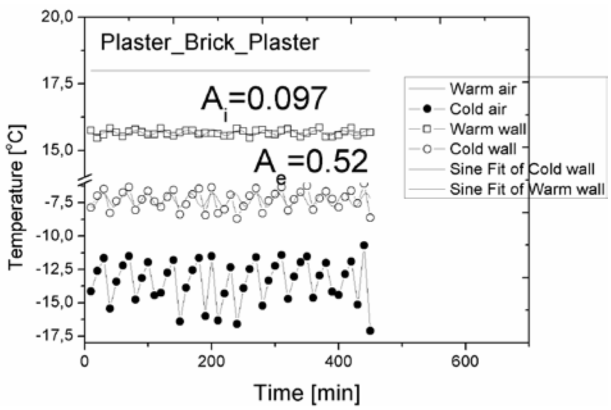

Fig.2a.: The temperature profile of the Plaster_Brick_Plaster system, and the results of the sinusoidal fits

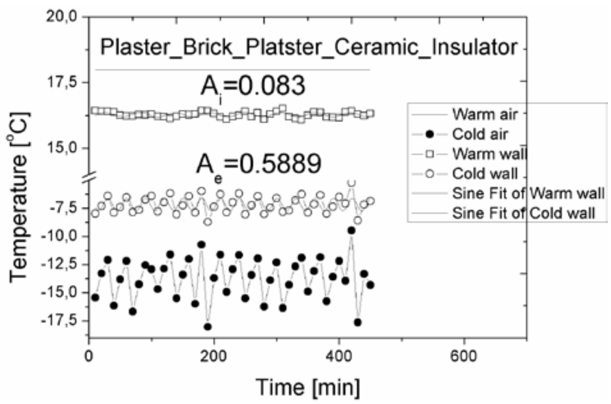

Fig. 2b.: The temperature profile of the Plaster_Brick_Plaster_2mm Ceramic insulator system, and the results of the sinusoidal fits

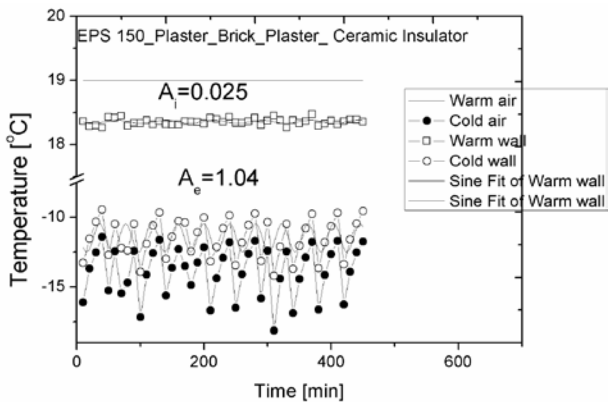

Fig.2c.: The temperature profile of the 5 cm_EPS 150_Plaster_Brick_Plaster_2mm Ceramic system, and the results of the sinusoidal fits

On the figures 2 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 3 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 2 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.

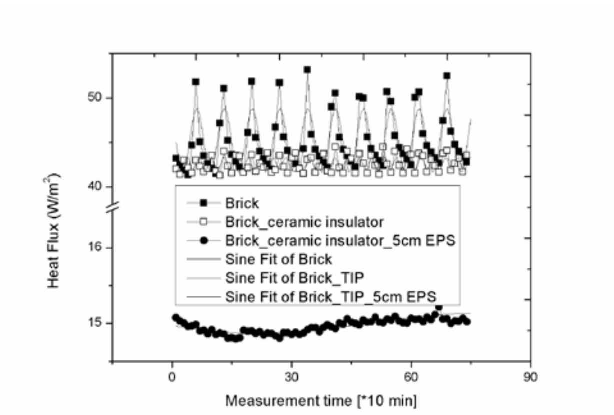

Fig. 3.: The measured Heat fluxes of the wall structures

Table 2. 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

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 investiagations of the overall heat transfer coefficients, can be safely used for measurements of the decrement factors.

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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