Effect of wetting time in the sorption and in the thermal conductivity of the most commonly used structural materials

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Abstract

During the thermal assessment of buildings, proper understanding and knowledge of the thermal behavior of the materials is required. Certain indoor and outdoor conditions can cause moisture transfer and could change the thermal properties of buildings (e.g.: thermal conductivity, resistance, thermal diffusivity, specific heat capacity, etc.). In this technical note, a research report can be found on the measured thermal conductivity after drying and wetting the samples. For the measurements we used a dry-heat laboratory oven (Venticell 111) apparatus to dry the samples and a climatic chamber (Climacell 111) to wet the materials in order to get the values. By applying these two chambers we were able to reach the moisture content of different humidity levels and create the kinetic wetting curves for each sample. Tomeasure the thermal conductivity, a heat flow meter type Holometrix 2000 was used. During the measurements five different types of materials were used (solid brick, lightweight and foam concrete, plasterboard, corkboard). In order to reach acceptable accuracy, three measurement series were carried out on the samples at each wetting times. During one series the thermal conductivity was measured ten times, and the average of the thirteen thermal conductivity results gave the final value. Moreover, from the measurement results new equations and functions were created to show the relationship between the thermal conductivity and the moisture content of the materials. Our results showed that after wetting the samples in a climatic chamber at 293 K and at 90% relative humidity, the kinetic function (time dependence) of adsorbed water increased in the cases of all the materials used, however, thermal conductivity only increased considerably in the cases of the two different types of concrete and of the plasterboard.

Keywords: moisture sorption, structural materials, thermal conductivity

Practical Application

The role of insulation materials in the building energy and moisture balance is more significant compared to the other materials of the building structures. The high moisture load will require the change of the thermal parameters of the materials. Moisture is a common cause of building degradation. In fact, much of what we know about applied building science today originates from early work investigating moisture impact on buildings. While the severity of moisture problems varies greatly depending on climate. These estimations based on the laboratory measurements of these values of the insulating materials are very important either for the manufacturers or the contractors, planners and designers.

1. Introduction

Nowadays, when the energy saving properties of buildings are vital, not only insulation but structural materials could mean a solution for the heat loss and the reduction of CO_2 emission of buildings. In the European Union up to 40% of the total energy consumption originates from buildings. In the building envelope the outer layer plays an important role in reaching energy efficiency. Moreover it also has a significant role in storing heat energy. [1, 2] As previously reported, the moisture content of building materials will not only change the heat transfer coefficient but it can also change the heat capacity of the materials [3, 4, 5, 6, 7, 8]. That is the main reason why the measurement of sorption capability of materials is essential. Building, structural and construction materials mostly have a porous structure, and due to this property their specific external surface is larger compared to materials that have smoother surface with the same specific volume. Materials with high porous rates can absorb and store more water than the others [9]. Therefore, if there is high relative humidity, moisture can appear mostly on the outer layer of building materials. Due to either the pressure difference or capillarity, moisture can pass through their entire volume, which is called moisture transport. Sorption capability of materials can be represented by their sorption isotherm. [10, 11, 12, 13, 14, 15, 16] For the wetting measurements we used two types of equipment: a Venticell (111) type laboratory-oven to dry the samples and a Climacell (111) type climatic chamber to wet the samples. These were combined with a milligram accuracy mass balance. The thermal conductivity of the dry and wet samples was measured by a heat flow meter type Holometrix 2000.

2. Case studies

2.1. Wetness effect

Moisture in building materials can appear in several ways [6, 18]. First, a slight amount of water can infiltrate into the material through the manufacturing process. Furthermore, materials can absorb moisture created by outer weather conditions. Buildings under constructions are particularly exposed to moisture stress since precipitation impacts on the structure in several ways. Besides, a large amount of moisture can appear on the internal side due to the function of the room, moreover the humidity of the indoor air can also increase as a result of the inhabitants' activities inside the buildings. These types of rooms include e.g.: indoor swimming pools, bathrooms, kitchens in which a huge amount of vapour is released, since the surface and the internal surfaces are exposed to moisture, or moisture appears due to other technological devices that have a relevant amount of moisture evaporation. In the above mentioned spaces prevention of vapour diffusion is not enough and a dehumidification system is also necessary to reach a lower humidity concentration in the interior of the building shell, because even the physical properties of the building materials can change in the presence of wetness. Vapor has a relevant changing effect on the overall heat transfer coefficient (U-value) and on the density of the material. [19, 20, 21] When the water content of the material is in liquid state it can increase the U-value and it can have some corrosive effect on the surface of the materials. In certain cases mould can appear on the cold surface. If the condensation in the structure is not prevented by an exterior layer and the exterior temperature is too low the inner wetness can turn into solid state. When this happens the volume will increase and cause irreversible processes that can damage the structure.

2.1. Material's sorption

Building materials can easily be divided into categories based on the type of their surface. The first one is when moisture only establishes chemical connection or adsorption on the outer surface of the solid material. In general metals have such properties: they corrode when exposed to moisture. Closed pores in the material can only adsorp moisture on the outer layer while foamy materials, such as foam concrete define another category. These porous materials can further be classified by the combination of the above mentioned processes that can occur through the wetting process. For example, bitumen bonded insulations do not show absorption, however capillarity and diffusion can be present; while at fibrous materials only diffusion occurs. Nonetheless, at most building materials such as brick all these three phenomena occur.

For saturation process moisture flow is required. One of the main driving forces of this phenomenon is the partial pressure difference. If the partial pressure of water vapor on the surface of the material is less than the partial pressure of the air, adsorption can happen. If the partial pressure of moisture in the material (or on the surface) is greater than the water vapor in the atmosphere, drying can occur which is called desorption [15]. Let me mention here that we wanted to investigate the materials before reaching the equilibrium state moisture content.

This article investigates the behavior of thermal conductivity of the five commonly used structural materials after wetting. One of them is the solid brick which is a homogenous clay material It is important to note, that the investigated solid brick samples were produced specifically for our measurements by the Wienerberger gmbh. Foam concrete (Ytong) is a load bearing material that is made of lime, gypsum and cement. As a result of the foamy structure which is achieved by aluminum powder using a special technique, it has good thermal property and low weight.

Lightweight concrete consists of concrete and EPS pearls which makes this material a better insulator than other types of concrete while it preserves its load bearing properties. Homogeneity had to be minded at the production, because the pearls can flow up to the surface.

Plasterboard, which is an essential part of light structure buildings, is also a popular design solution in interior architecture. It is gypsum table covered with cardboard at both sides.

Whereas corkboard is a natural material, it is most commonly used as an interior insulator for floors and walls to cover them. Moreover, it can be used as external insulator as well. The foam and lightweight concrete, the plasterboard and corkboard were easily accessible materials.

3. Experimental

Our measurements focused on the change in the thermal conductivity of materials at different moisture content levels. Our measurements were derived by taking into consideration of the rules the ISO 12571:2013 (Hygrothermal performance of building materials and products -- Determination of hygroscopic sorption properties), the BS EN 12664:2001 (Thermal performance of building materials and products. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods. Dry and moist products of medium and low thermal resistance) and BS EN 12667:2001 (Thermal performance of building materials and products. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods. Products of high and medium thermal resistance) standards.

The five commonly used structural materials were investigated: solid brick, corkboard, foam concrete, lightweight concrete and plasterboard. To express reference moisture content to dry the samples we used a Venticell dry-heat laboratory oven that utilizes a patented air flow system to achieve very accurate temperature distribution within the chamber. Air is moved both vertically and horizontally surrounding the media. A central fan in the top of the Venticell forces air through computer-engineered precision air ports located in the air distribution plates within the chamber. Drying lasts until a changeless weight is achieved at 343 K temperature with hot air circulation. At this temperature we prevented the samples from any deformation and from any physical changes; however it was also high enough to ensure the relatively fast drying process as well. To attain the different wetness levels a Climacell (CLC) type laboratory incubator, climatic chamber was used at 90% relative humidity and at 293 K temperature for 4, 8, 12, 16 and 20 hours. The 90 % relative humidity was chosen because it is the maximum humidity performance of the chamber. We wanted to load the samples with the moisture as much as we could. The reason to choose the 20 hours as the maximum wetting time comes from the directions of the ISO 12571 standard. The standard states that for reaching the sorption isotherm the materials should be wetted for at least 24 hours for reaching the equilibrium. In this case we did not want the exchange of the water vapor between ambient air and material to reach the equilibrium point. In order to avoid any natural desorption from the surface of the wetted samples a foil layer was applied onto it. This latter procedure had to be done as soon as it was possible [6, 7]. Here has to be mentioned that in all cases three measurement series were carried out.

3.1. Thermal conductivity measurements

For the measurements three samples were prepared from each material. The dried and wetted samples with 30 x 30 x 1.3 to 7.4 cm geometries with constant volume each were positioned in a Heat Flow meter (HFM) type Holometrix 2000. (The correct thicknesses of the samples are mentioned in Table 1) This apparatus is intended to determine the thermal conductivity of building materials in accordance with standard ASTM C518 and ISO 8301 protocols. Samples were placed in the measuring chamber between two adjustable plates which were maintained at different temperatures (T_1=285K and T_2=295 K, with T_{mean}=290 K) during the experiment. After attaining thermal equilibrium and forming a uniform temperature gradient throughout the sample, the thermal conductivity was determined [6, 7]. To define the average thermal conductivity of a sample at a given moisture level, ten individual samples were used. The thermal conductivity of the studied materials was the mean value of the results of these ten measurements. With the thickness and the mass density of samples, the device can calculate the thermal conductivity. To describe the calculation method, first the Fourier equation (Eq. 1) can give us the relationship between the test samples and the parameters of the sections.

$$q = \lambda \cdot A \cdot \frac{\Delta T}{\Delta x} \qquad \text{(Eq. 1)}$$

where q and ΔT is the heat flow and temperature difference across the sample, A is the area through which the heat flows, Δx is the thickness and λ is the thermal conductivity of the samples. During the measurement the HFM gives a signal in volt to the transducer representing the heat flow. By knowing that values are proportional the heat flow will be (Eq. 2)

$$q = N \cdot V \qquad \text{(Eq. 2)}$$

where N is a calibration factor and V is the voltage signal on the heat transducer. The calibration factor was given before the experiment series with a standard fibrous glass board sample ($\lambda_{calibration}$=0.05 W m^{-1} K^{-1}). Using Eqs. 1-2 the thermal conductivity can be determined as the following [6, 7].

$$\lambda = \frac{N \cdot V}{A} \cdot \frac{\Delta x}{\Delta T} \qquad \text{(Eq. 3)}$$

Three measurement series were carried out on the samples independently from each other. At first the thermal conductivity of one dried sample was measured ten times. It was done on the other two same materials too. From the average of the thirteen thermal conductivity values we gave the thermal conductivity of the samples after 0 h wetting with the average of the deviances from the mean value. Then we wetted three samples from one type of materials for 4 hours and measured their thermal conductivity ten times each and the average of the 30 measurement results gave the thermal conductivity value with the above mentioned errors. After the measurements we dried back the samples to changeless weight and then we wetted them (three samples) for 8 hours and measured their thermal conductivity ten times. Furthermore, for each wetting times (4-20 h) the same procedure was evaluated.

3.2. Wetting of the samples

The moisture content of the samples can be calculated as the following (Eq. 4)

$$\omega_{\%} = \frac{m_w - m_d}{md} \cdot 100 \qquad \text{(Eq. 4)}$$

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

3.3. Thermal conductivity

The thermal conductivity of wetted materials depends on their moisture content. Most of the time it will be conduction through the solid and the gas phase, however, if the pore size is "big" enough the convection of the filling gas can appear [6]. Due to the inhomogeneous structure of the materials theoretically it is very hard to calculate the moisture effect on the material [20, 21, 22]. Several models are available for the influence of the water content in the thermal conductivity of the materials:

For these building materials under given conditions the thermal conductivity value can be evaluated with the following see ref [20]:

$$\lambda_w = \lambda_0 C \cdot t \cdot \omega \cdot e^{-B\omega} \qquad \text{(Eq. 5)}$$

where λ_{W}, λ_0 are the thermal conductivity of the wet sample and the dried sample, furthermore C and B are constants for materials and can be determined from experiments; t is the wetting time and ω is the moisture content.

In practice the influence of the moisture on the thermal conductivity is given by the percentage of difference in wetness level. In Hungary, tables (taken from [20]) are used in design to give information about the result of the thermal conductivity at certain moisture content. This above mentioned book [20] suggests a more simple approximate calculation, we can use the following:

$$\lambda_w = \lambda_0 \cdot (1 + \frac{\omega Z}{100}) \quad \text{(Eq. 6)}$$

where Z is a material constant, the moisture supplement for the thermal conductivity, Z is defined 20 to solid brick, 12 to lightweight and foam concrete, 12.5 to plasterboard and 1 to corkboard, in [20]. This study draws on research also conducted by the investigations of the Z constant. Please note that, a similar formula is presented in Ref 22 and in Ref 23. Equations for the change of the thermal conductivity in function of the moisture content as:

$$\lambda_W = \lambda_0 \cdot (1 + \frac{b \cdot w}{\rho}) \quad \text{(Eq. 7)}$$

where ρ is the bulk density of the dry material and b is the thermal conductivity supplement. It has to be mentioned that w is the moisture content in kg/m^3.,

Moreover,

$$\lambda_W = \lambda_0 \cdot (1 + \frac{\gamma u}{100}) \quad \text{(Eq. 8)}$$

where u is the water content in (%) and γ is a material constant for the change of the thermal conductivity in function of water content. These three equations (6, 7 and 8) give the same results.

4. Results and discussion

In this paper, the discussion concentrates on the presentation of the measurement results. Two diagrams can be seen in each Figure (Figure 1 to 5). The upper one shows the function of the thermal conductivity in function of the wetting time, which is the so-called kinetic/time dependency curve; moreover, the lower one shows the connection between the thermal conductivity and the moisture content. The reason for the position of the diagrams is to simplify the determination process when we would like to show the thermal conductivity at different moisture levels. On the thermal conductivity -wetting time diagrams we can see the results of the box chart analysis of the measured values at six different wetting times. The mean value was also presented by dots. To examine the mean values, we fitted them with curves and/or lines and presented the functions of the fits for all the five materials. On the thermal conductivity versus moisture content diagrams only the mean values with the errors bars were presented with the fit curves correlating to Eq. 6. The best fit functions of these curves were also presented. In Table 2 to the change in the specific heat capacity in function of the wetting time is also presented.

It can easily be seen from Figures 1, 2 and Table 1 that in contrast to those graphs where the thermal conductivity did not change, the moisture content increased, furthermore where the thermal conductivity function was linear (Figures 3 and 4, Table 1) its moisture content function was also linear. Exponential thermal conductivity growth (Figure 5) belongs only to the foam concrete; moreover this material also has linear moisture content increase (See Table 1.)

4.1. Measurements performed on the solid brick samples

In Figure 1 one can see the function that belongs to the solid brick: the thermal conductivities in function of the wetting time and the moisture content. Since the thermal conductivity deviation did not follow any rules, and the deviation was relatively low, an average value was calculated. For the thermal conductivity an average value of 0.36 W $m^{-1}K^{-1}$ can be defined. We can assume that the moisture load had no effect on the thermal conductivity value of the solid brick during our measurements. In Table 1 the different moisture content levels with the wetting time can be found. Here it has to be emphasized that, after twenty hours wetting the water sorption stepped up to 0.6%. This small amount of water has no effect on the thermal conductivity. The high density, the closed porous structure and the relatively low moisture content change of solid brick should be the reason why the thermal conductivity is insensitive to wetting. Thanks to its low water sorption capability, the solid brick is an excellent material for structural elements since it does not allow the vapor to diffuse into its bulk. This property makes the solid brick an excellent load bearing material (as in cold climate freezing cannot cause relevant damage in the material) although its thermal conductivity values are high compared to the commonly used insulators [15]. We have to highlight the fact that the specificity of our tested brick gives these surprising values.

4.2. Measurements performed on the corkboard samples

During our measurements the corkboard's thermal conductivity values showed a much lower (less than 5%) deviation than the brick values. For this reason the thermal conductivity value was considered to be constant and it was calculated by the average of the mean values approximately 0.044 W $m^{-1}K^{-1}$. The data yielded by this study provide convincing evidence that the water sorption was more intense after twenty hours of wetting; it reached 12% moisture content, see Table 1. This moisture content level follows an increasing change. The course of the values was almost strictly increasing until the time reached the sixteenth and twentieth wetting hour where the moisture content duplicated again. The corkboard turned out to be a reasonable insulator, because at high moisture levels it can preserve its low thermal conductivity property.

Ref [20, 22, 23] give simple equations (eq. 6) where the change in the thermal conductivity of the materials in function of the moisture content can be found easily by knowing (ω) the moisture content and the moisture supplement for the thermal conductivity (Z). These results provide confirmatory evidence that this constant (Z) can be defined neither for the solid brick nor for the corkboard. Please note that for the calculations we use Eq. 6.

4.3. Measurements performed on the plasterboard samples

From Figure 3 and from Table 1, one can see a curiosity whereas, the thermal conductivity in function of the wetting time follows linear growths, however, in function of the moisture content it follows exponential dependence. Both of them were fitted with functions that are represented on the graph. It means that the curves have a strong correlation. Let me emphasize that from Figure 3 and from Table 1 between the changes we can find an order of magnitude difference in the changes of time dependence. The data seem to suggest that both the thermal conductivity and the moisture content change had a minor increase during our measurements. Compared to the results of the solid brick, it has lower thermal conductivity, though it still can be still considered as bad insulator. The mechanical properties are also weak for the plasterboard as a result of its structure. From this graph it is feasible to estimate the moisture supplement for the thermal conductivity of this material by using eq. 7, Z=7.6. In contrast to Ref [20] where Z=12.5 was given.

4.4. Measurements performed on the lightweight concrete samples

Similarly to the behavior of the plasterboard, the change of the thermal conductivity of the lightweight concrete in function of the wetting time also shows linear dependency (see Figure 4), however its change in the function of the moisture content follows exponential growth. From Table 1 one can observe that the changes of the moisture contents are significantly increasing. The thermal conductivity was increasing although the moisture content change was below 1% after 24 h wetting. The small sorption rate could be owing to the fact that the concrete has a closed cell structure and the vapor only condensates on the outer layer of the material. From Eq.6 we evaluated 22.3 for the moisture supplement of the thermal conductivity of this material in contrast to Z=12 presented in Ref 20.

4.5. Measurements performed on the foam concrete samples

From the investigated materials only the foam concrete had an open porous structure that results in an exponential growth in the thermal conductivity both in the function of the wetting time and the function of moisture content (see Figure 5). The available evidence seems to suggest that after twenty hours wetting the material doubles its thermal conductivity value. The 4% moisture content change was relatively low compared to the thermal conductivity change (see Table 1). This moisture increase presented in Table 1 can also be considered linear. Moreover, the foam concrete presented the highest change among the examined materials. These results provide confirmatory evidence that the foam concrete is extremely sensitive to water up-take. Similarly to the above mentioned, we deduced Z=12.6 for the material constant approaching the Z value presented in Ref. 20.

To be much clearer Figure 6 was created, where the change of the logarithm of the moisture contents of the materials in function of the wetting times are presented. From the graph one can see that, the

4.6. The reached equations and table of constants

Finally we present the reached equations of the thermal conductivity in function of the wetting time. The results based on the measurements carried out on the materials are presented in Table 3, where the thermal conductivities, the coefficients of the equation belonging to Eq. 9 and 10, as well as the moisture supplement factors (Z) for each materials can be found. The reached Z constant and the Z constants from the literature are also presented in Table 3.

The changes can be described with the following functions:

$$\lambda_{tj} = \lambda_0 + t \cdot A_1 \qquad \text{(Eq. 9)}$$

where:

λ_0 - is the material thermal conductivity at dry state [W mK^{-1}],

A_1 - is the constant of the linear fit,

t - is the wetting time [h],

λ_{tj} - is the thermal conductivity at a given wetting time [W mK^{-1}].

and

$$\lambda_{tj} = \lambda_0 + t \cdot A_1 \cdot e^{\frac{t}{t_1}} \qquad \text{(Eq. 10)}$$

where:

λ_0 - is the material thermal conductivity at dry state [W mK^{-1}],

A_1 is the constant of the linear fit,

t_1 – are constants of the exponential fit [W mKh^{-1}],

t - is the wetting time [h],

λ_{tj} - is the thermal conductivity at a given wetting time [W mK^{-1}]. [7-10]

5. Conclusions

Nowadays we have various options to choose structural elements for energy efficient buildings. Current research appears to validate the view that it is important to know the behaviour of their thermal properties from the point of view of energy efficiency. The main goals and innovations of this article were the investigations of the effect of water in the thermal conductivity of solid brick, lightweight and foam concrete, plasterboard and corkboard structural materials. We presented new thermal conductivity supplements for the materials, new equations and functions for the thermal conductivity change in the function of wetting time and moisture content at 90% relative humidity. The samples were put under wetting treatment at 293 K and 90 % relative humidity for 0-20 hours, in 4 hours steps. Literature constants presented by Eq. 6. were corrected, and we showed that the previous equations worked at intervals. Where moisture is absorbed into a material, it is uniformly distributed through the material (foam concrete, lightweight concrete, plasterboard) and the moisture is able to conduct heat through the material. Where moisture is adsorbed onto the surface of the material (brick, cork), the interior of the material remains dry and the thermal conductivity is therefore less affected. This study draws on research conducted by the moisture supplements for the thermal conductivities of each material: we showed that they changed from 20, 12-12, 12.5, 1 to ∅, 7.6, 22.3, 12.6, ∅ for the solid brick, lightweight and foam concrete, plasterboard and corkboard respectively.

List of symbols:

q: heat flow across the sample [W m^{-2}]

ΔT: temperature difference across the sample [K]

Δx: thickness of samples [m]

λ: thermal conductivity of samples [W mK^{-1}]

N: calibration factor

V: voltage signal on the heat transducer [V]

ω, u: moisture content [%]

c_d: specific heat of the damped samples [J kgK^{-1}]

c_w: specific heat of the dried samples [J kgK^{-1}]

C, B, Z, and γ: constants for materials

λ_0: is the material thermal conductivity at dry state [W mK^{-1}]

A_1: is the constant of the linear fit

t_1: are constants of the exponential fit [W mKh^{-1}]

t: is the wetting time [h]

λ_{tj}: thermal conductivity at a given wetting time [W mK^{-1}]

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Figure Captions

Figure 1. The thermal conductivity as well as the moisture content in function of the wetting time for the brick

Figure 2. The thermal conductivity as well as the moisture content in function of the wetting time for the corkboard

Figure 3. The thermal conductivity as well as the moisture content in function of the wetting time for the plasterboard

Figure 4. The thermal conductivity as well as the moisture content in function of the wetting time for the lightweight concrete

Figure 5. The thermal conductivity as well as the moisture content in function of the wetting time for the foam concrete

Figure 6. The half logarithm of the moisture contents in function of the wetting time

Tables:

Table 1. Measured densities and moisture contents at 293K before and after wetting

Wetting time	**Thickness**	**0 h**	**4 h**	**8 h**	**12 h**	**16 h**	**20 h**

Corkboard [kg m^{-3}] [%]	0.074 m	107	0	219	3.20	221	4.02	222	4.80	225	6.04	239	12.06
Foam concrete [kg m^{-3}] [%]	0.013 m	483	0	491	0.75	495	1.62	496	1.89	504	3.38	505	3.53
Lightweight concrete [kg m^{-3}] [%]	0.015 m	1349	0	1350	0.24	1351	0.37	1354	0.54	1358	0.96	1358	0.85
Plasterboard [kg m^{-3}] [%]	0.062 m	679	0	681	0.49	690	1.04	688	1.43	690	1.75	698	1.77
Solid brick [kg m^{-3}] [%]	0.073 m	1854	0	1861	0.07	1863	0.15	1863	0.14	1865	0.29	1866	0.60

Table 2. Calculated specific heat capacities for the materials at 293K

Wetting time	**0h**	**4 h**	**8 h**	**12 h**	**16 h**	**20 h**
Foam concrete [J kg^{-1} K^{-1}]	1	1.02	1.05	1.06	1.107	1.11
Lightweight concrete [J kg^{-1} K^{-1}]	0.88	0.888	0.892	0.897	0.911	0.908
Plasterboard [J kg^{-1} K^{-1}]	1.09	1.1	1.12	1.13	1.14	1.14

Table 3. Parameters of the thermal conductivity changes

Material	Thermal conductivity [W mK^{-1}]	A_1 [W mKh^{-1}]	t_1 [h]	Z from Fekete et al. [20]	Z from our measurements
Corkboard	0.044	-		1	0
Foam concrete	0.099	0.021	11.73	12	12.6±2.43

Lightweight concrete	0.372	0.003		12	22.3±2.58
Plasterboard	0.139	0.001		12	7.6±1.2
Solid brick	0.362	-		20	0