Moisture and Thermal Conductivity of Lightweight Block Walls

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Abstract. This article examines thermal properties of lightweight block walls and their changes over the course of time. Three different types of lightweight blocks and two types of heat insulation are used in construction. Aeroc aerated concrete blocks are in use, as well as compacted LECA (Lightweight Expanded Clay Aggregate) Fibo blocks made from burned clay and Silbet blocks produced from oil shale ash. Expanded Thermisol EPS60F polystyrene plates and glass wool Isover OL-P plates are used for thermal insulation. The actual and computational values of thermal conductivity and the water draining properties of walls over time are compared in this article. Water draining from glass wool walls is relatively fast. Water-draining can take over a year in polystyrene insulated walls. All four wall constructions can be used as external walls, but care must be taken regarding the moisture content of the blocks during construction (the construction should be handled with care to minimise the moisture in the blocks), especially in polystyrene board-insulated walls.

1. Introduction
Based on Estonian weather conditions (colder period of five days in Tallinn -26.5°C, in Tartu -31.9°C), the recommended maximum thermal transmittance [2] of the external walls of a small house is \( u = 0.12...0.22 \text{ W/m}^2\text{K} \) [1]. This value will be lowered at least one time in five years period. In order to meet this standard, it is necessary to insulate walls made of small blocks. The required insulation thickness is calculated based on the maximum allowable thermal transmittance, the heat conduction of stone wall material and thermal conductivity of surface layers. Thermal transmittance calculations are done on the basis of a material’s thermal conductivity provided by the manufacturer (\( \lambda_{10} \), which is the thermal conductivity at +10°C in a laboratory). It is recommended that calculations are in accordance with the building material real thermal conductivity (\( \lambda_a \)). These figures are in accordance with a plate of glass wool (Isover OL-P) \( \lambda_{10} = 0.037 \) and \( \lambda_a = 0.041 \text{ W/m}^0\text{K} \) [9].
There are often difficult climatic conditions (rain, cold, etc.) while doing masonry, insulation and finishing work. The aim of this study has been to determine how low temperature and humidity during construction will impact the wall thermal condition throughout the term of the building use. It is generally known that moisture in the wall material reduces directly thermal transmittance. It is necessary to identify possible water condensation and moisture dry-out conditions in walls. The aim of this study has been also to determine whether such walls may be used only with well moisture leading glass wool (moisture resistance factor $\mu = 1.0$) or also in tight polystyrene ($\mu = 60$).

In order to study the technical heat characteristics of a wall built in early winter, it is necessary to measure the wall’s real thermal conductivity and relative air humidity, as well as the temperature of a cross-section of different layers of the wall. A wide variety of methods are available for exploring the technical characteristics of a wall. De Gracia et al (2011) [3] built different thermal boundary wall designs and traditional designs of wall cubes (2.4 x 2.4 x 2.4 m) to investigate such properties. They compared the thermal performance of the walls in different cubes and after reaching a stable temperature, they calculated the thermal transmittance of the walls ($u$ figures).

Skujans et al (2007) [5, 6] studied thermal conductivity by measuring the heat of multilayer porous gypsum plate walls with a heat flow measurement plate and the temperature in different layers with thermocouples. Air temperature was also measured, as was the temperature in different layers of the wall. Thermal conductivity was calculated according to the measurements obtained from the wall. The wall was tested using this method in a laboratory and outdoors. The differences of the results were within error limits.

Four different test walls were built in window openings of the laboratory in order to investigate the technical condition of the walls. The laboratory room made one side of the wall and the other side was exposed to the external environment. By simultaneously measuring the wall’s thermal physical characteristics (temperature and moisture on the surface of the wall, and in various layers, heat flow through the wall), comparable thermal conductivity data were obtained for four different wall constructions.

A new short time method makes it possible to determine the water vapour diffusion coefficient versus relative humidity function during a single experiment. The basic idea of the method consists in exposing a material specimen to different climate conditions concerning relative humidity and monitoring the moisture level in the specimen, whereas the experiment is carried out under isothermal conditions. The basic difference between the proposed method and all other methods for determination of water vapor diffusion coefficient is that it provides the relative moisture level within the analyzed specimen. This greatly simplifies the data evaluation procedure because the methods of inverse analysis known in heat transfer and liquid moisture transfer problems can be used with only slight modifications. It must be taken into account that this method was tested on one material only [17].

In conclusion, the thermal diffusion is of no importance for building physical applications, leaving vapor pressure as the sole significant transport potential for the diffusion of water vapor in porous materials [18] [19].

Also concrete masonry units (CMU) are in use to build thermal efficient walls. CMUs are available in a variety of configurations. Some are simple and consist of only a single material, while others have interlocking paths of structural and insulating materials. Within this experiment, simple two-core hollow block CMUs (common in the U.S.) and more advanced multicore and interlocked CMUs (common in Europe) were used. As a result, the use of lightweight concretes has improved the thermal performance of the walls more than using complex insulations structures [15].
Thermal conductivity and elastic module are fundamental properties of the porous building materials. For isotropic materials the relative thermal conductivity or the relative elastic modulus can theoretically be calculated from the other via the cross-property relation as soon as one of them has been measured [16].

2. Materials and methods

2.1. Used Materials
To solve the assigned task (water drying out and U-value change in the usage conditions of outside walls built in autumn and winter) different outer walls were built in place of laboratory windows. Small blocks most widely used in Estonia – Aeroc, Fibo, Silbet – were used to build the walls, whose main technical indicators are presented in table 1. Density in table 1 was taken from the manufacturer data.

Table 1. General properties of lightweight blocks [11, 12, 13].

| Property                      | Block | Aeroc | Fibo | Silbet |
|-------------------------------|-------|-------|------|--------|
| Density [kg/m³]               |       |       |      |        |
| Thermal conductivity λ₁₀ [W/mK]|   0.10|  0.19 |  0.12|        |
| Thermal conductivity λₙ [W/mK] |  0.134|  0.24 |  0.16|        |
| Diffusion constant μ          |  5–10 |  5–10 |  6–10|        |

Two types of insulation materials were used to insulate walls. The general properties of these materials are presented in table 2.

Table 2. General properties of thermal insulation materials [9, 10].

| Property                      | Insulation mat. | Thermisol | EPS60F | Glass wool |ISOVER OL-P |
|-------------------------------|-----------------|-----------|--------|------------|-------------|
| Density [kg/m³]               |                 |  65       |        |  77        |
| Diffusion constant            |                 |  60       |        |  1         |
| Thermal conductivity λ₁₀ [W/mK]|                 |  0.0375   |        |  0.037    |
| Thermal conductivity in building λₙ [W/mK] |     |  0.039   |        |  0.041    |

Sakret PM Super Diffusion constant is 15/35 and Thermal conductivity λ₁₀ is 0.83 W/mK. Different outer walls were built from these materials in place of laboratory windows. The constructions of these walls are in table 4. The thermal conductivity of the walls was calculated with two thermal conductivity numbers, λ₁₀ and λₙ.

Thermal conductivity is heat-energy transfer from the hotter body (or body part) to the colder body (body part) as a result of particle interactions. To put it simply – the thermal conductivity of the wall shows how fast the wall cools down at various internal and external temperatures. The lower the number, the better insulation qualities it has and the less we must heat the rooms. The calculated thermal transmittance of the walls are calculated in accordance with EVS-EN ISO 6946:2008 Building components and building elements – Thermal resistance and thermal transmittance – Calculation method [8].
Table 4. Structure of tested walls.

| Material                          | Wall A1 | Wall A2 | Wall F1 | Wall S1 |
|----------------------------------|---------|---------|---------|---------|
| Plaster Sakret [mm]              | 5+5     | 5+5     | 5+5     | 5+5     |
| Insulation [100 mm]              | Isover OL-P | Thermisol EPS60F | Isover OL-P | Isover OL-P |
| Block 250 mm                     | Aeroc classic | Aeroc classic | Fibo F3 | Silbet  |
| Plaster Sakret [mm]              | 5       | 5       | 5       | 5       |
| Total thickness of the wall [mm] | 365     | 365     | 365     | 365     |
| Thermal transmittance U, by λ10  | 0.186   | 0.187   | 0.238   | 0.201   |
| Thermal transmittance U, by λn   | 0.223   | 0.217   | 0.273   | 0.239   |

**Thermal transmittance (U-value)** in test walls was calculated based on the inside and outside temperature and heat flow through the wall.

\[
U = \frac{q}{\Delta T}, \text{ W/(m}^2\text{K)}
\]  

where:
- \( q \) heat flow rate, W/(m\(^2\)K);
- \( \Delta T \) the difference of temperature between the indoor and outdoor environments.

2.2. Test methods

The walls were erected at the end of December 2007 according to figure 1 and measurements began in early January 2008.

The walls were erected in the north-east direction and shielded from direct sunlight. Aeroc blocks were transported directly from the factory. Other test blocks were taken from shop, where they were kept in external weather conditions.

Figure 1. Alignment of walls in window openings of the laboratory.
To measure the walls’ thermal physical characteristics, sensors were placed in the walls during the construction. Sensors (temperature and moisture on the surface of the wall, and in various layers, heat flow through the wall) and other equipment were placed according to figure 2.

Figure 2. The measurement devices to determine the construction element’s heat transfer coefficient: 1) construction element, 2) sensors, 3) data logger, 4) computer with software.

Temperature sensor, relative humidity sensor, heat flow plate and data logger with software were used. The placement of sensors for wall types A1, F1 and S1 are shown in figure 3a and for wall A2 – in figure 3b.

Figure 3. Sensors placement schemes for insulated lightweight walls.

- a) – wall A1, wall F1 and wall S1 (glass wool); b) – wall A2 (polystyrene), where
  - T&RH_e – temperature and relative humidity of outside air;
  - T_e – temperature of external wall surface;
  - T&RH_{E50} – relative humidity and temperature between external plaster and insulation;
  - T&RH_{I50} – relative humidity and temperature between insulation and block;
  - T_{200} – temperature of inside block, 200 mm from inside surface;
  - T_{100} – temperature of inside block, 100 mm from inside surface;
  - T_i – temperature of wall inside surface;
  - T&RH_i – temperature and relative humidity of inside air
  - q – heat flow
The test objective was to study the temperature, the relative air humidity in the wall and in the ambient environment, and to measure the heat flow through the wall. Based on the measurements, the wall’s thermal conductivity was calculated, as was its change during wall moisture regime change. In addition, the moisture dry-out dynamics was calculated for the autumn–winter period for walls with glass wool insulation (walls A1, F1, S1) or polystyrene (wall A2).

3. Results and discussion

3.1. Temperature and moisture in wall

Data was recorded in the data logger at 60-minute intervals with the sensors located as shown in figure 3. Measurements were performed for 500 days from 1 January 2008.

Monthly average temperatures were relatively high and the average monthly temperature between thermal insulation layer and masonry did not fall below +10°C. The relative humidity content between the insulation layer and masonry in Aeroc was 100% at the beginning of the test, but in Silbet and Fibo walls 70 to 80%. The difference is explained by the fact that Aeroc blocks still had production moisture inside, but Silbet and Fibo blocks were stored in the laboratory in a 20 degrees for several weeks.

Wall A1
The relative humidity between insulation layer and blocks was 99% more than ~ 32 days after construction.
Outer plaster had more than 99% relative humidity ~ 148 days after construction. During this period, the temperature was below 0 degrees on 26 days (-8°C min.).

Wall A2
Relative humidity between insulation layer and blocks was 99% more than ~ 376 days after construction (the lowest temperature of +11 degrees).
Outer plaster had more than 99% relative humidity ~ 66 days after construction. During this period, the temperature was below 0 degrees on 11 days (-8°C min.).

Wall F1
Amount of relative humidity in the outer plaster was more than 99% after ~ 74 days of construction. During this period, the temperature was below 0 on 7 days (-6°C min.).

Wall S1
The relative humidity between insulation layer and blocks was 80% during the construction of the wall. Due to room heating in wintertime, the humidity started to decrease. The humidity level in the summer was sufficient and started to decrease again during the next heating period.

As the thickness of the insulation in the walls was sufficient, the 0-point of the walls was inside the insulation layer, and therefore minus degrees temperature could not get in the blocks. In the polystyrene board wall (wall 2) the moisture content remained at more than 99% between the insulation and blocks throughout the period of the experiment. However, since there was no extreme frost during the test period, and the thickness of the insulation was sufficient, the temperature between the blocks and insulation did not drop below 0 degrees.

This would suggest that in case of insufficient thickness of insulation, the blocks would have had to endure several freeze cycles.

In our climatic conditions it is necessary to add extra insulation layer outside the block wall. Even when we use multicore or multilayer insulated blocks. To have U value under 0.12 W/m2K means that R-value must be over 8.3 m2K/W.
3.2. Calculation of wall condensation risks

Moisture moves in various ways in the wall. A wall "breathing" cannot be estimated with the diffusion constant of a material [14]. The walls’ ability to allow movement of moisture is not important, but the location between each layer of the wall is. The outer wall of a room does not have to easily let out moisture, because it is known that 99% of the moisture must be removed by ventilation.

The outer walls of buildings must be airtight and therefore there cannot be ventilation through the walls [1]. It is important to build walls that prevent water condensation. A common occurrence in calculating condensation is the Glaser method, which is described in EVS-EN ISO 13788:2012[7].

It is necessary to find the diffusive moisture barriers of the layers of the walls:

\[ S = \mu \cdot s, [m] \]  

(5)

where:
- \( \mu \) diffusive barrier constant of material
- \( s \) thickness of layer [m].

It should be Insured that the wall layers of vapour barriers reduce from the inside out. To compose graphs, partial moisture pressures are necessary in the external and internal environments:

\[ P = P_s \cdot \varphi, [Pa] \]  

(6)

where:
- \( P_s \) saturated vapour pressure [Pa]
- \( \varphi \) relative air humidity [%]

The abovementioned values will be taken during the condensation period:

Outdoor climate -10°C, 80% relative humidity; indoor +20°C, 50% relative humidity. After measuring the saturation vapour pressure value for each layer found by temperature, we can create the necessary charts and find the amount of condensation and dry-out water that occurs.

It is important in the construction of walls that condensation between wall layers is avoided. It depends on the material’s diffusion constant, the thickness of the layer, heat conductivity, temperatures, humidity, and moisture.

All wall types have one condensation level and it is located under the exterior (cold) layer of plaster. The water amount emerging during the condensation period (\( W_T \)) and the amounts of water drying out in the drying period (\( W_V \)) are shown in table 5 [7].

| Wall | \( W_T \) [kg/m²] | \( W_V \) [kg/m²] |
|------|------------------|------------------|
| A1   | 0.67             | 2.33             |
| A2   | 0.20             | 2.11             |
| F1   | 0.45             | 2.23             |
| S1   | 0.31             | 2.16             |

According to standard EVS-EN ISO 13788:2012 [7], the following should be observed:
- the condensate during the condensation period must dry out during the drying period;
- wall construction must not be damaged due to condensate;
- condensate amount must not exceed 2.4 kg/m²;
- in case of capillary non-absorbent construction materials, condensation is restricted to 0.5 kg/m$^2$.

In these types of walls all requirements are met and all of them can be used in real constructions.

4. Summary
This study showed that moisture dry-out from wall depends on the thermal insulation type. Under EPS boards placed on relatively wet lightweight blocks, relative humidity remained at 100% for nearly a year, while the walls that were covered with mineral wool dried up faster, and this moisture level persisted for up to two months.

In calculation of a wall’s thermal conductivity, a minimum of 5% moisture in lightweight blocks should be considered, and preferably an even greater year-round moisture level.

The diffusion of all observed wall types is similar. The tests showed that there was condensate under the external plaster in all types of walls, but it all dries out in summer. EPS board insulation walls also had condensate under the insulation.

All four wall structures can in principle be used for external walls, but care must be taken in the moisture content of the blocks during construction, especially in polystyrene board-insulated walls. These walls made of blocks should be dried for some time before being covered with insulation and plaster.

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