THE INFLUENCE OF LEAKAGE OF INSULATING LAYER ON THERMAL PARAMETERS OF ETICS SYSTEM

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Summary:
The purpose of this paper is to show a part of results of research in examination of rigid material used for thermal insulation with modified structure. Modification of the material was relying on making of parallel perforations to the direction of the heat and moisture flow. The base solid material was an expanded polystyrene (15EPS-70-040) with board thickness of 5 cm. In the base material the circular perforations with diameter of 1, 3 and 5 mm were done, on the 2 cm x2cm grid (for 15EPS-70-40 material additional samples were done with perforations 7,9 and 11 mm). The researches were divided to preliminary and essential ones. The scope of research included the measurement of water vapour factor's transfer as well as the measurement of heat conductivity factor; the thermographic control of bulkhead insulated by solid and perforated Styrofoam, the simulation of thermal-moisture phenomena in analyzed bulkheads. The essential research was conducted in the Laboratory of Solar Energy Usage in the Faculty of Architecture. Two wall arrangements were analyzed in the research. The common element was the wall's carrying construction. The first bulkhead was insulated by the material with a modified structure - the styrofoam with 5mm perforation. The relative temperature and humidity of external and internal air was registered, on the border of the bulkhead layers as well. The external climate parameters were registered by the Kombi weather station. In the framework of research the mathematical model of coaxial transport processes was verified. Moreover, selected thermal-moisture parameters of wall arrangements were specified. These were as follows: the heat conductivity factor U, the dimensionless temperature of internal surface f_{Rsi}, the water vapour flow

Keywords: thermal insulation, thermal conductivity factor, water vapour factor, thermal-moisture process in bulkhead

Introduction

The styrofoam is today, alongside the mineral wool, the most common material used in thermal insulation. Its physical properties as a thermal insulation material used in architectural engineering were researched as early as 30 years ago. One of its physical properties – the low water vapour penetrability – was at these times acknowledged as disadvantageous. The good thermal insulation, easiness in treatment, low absorption capacity and low density cause that this material found its implementation in the jointless thermal insulation systems of buildings (ETICS, Instruction 447/2009). The styrofoam, as each building material, has its disadvantages. The low water vapour penetrability is one of them. The fast pace of building works and willingness for putting to use the newly erected buildings cause that styrofoam is often used in bulkheads containing large (considerable) amounts of technological moisture (such as the newly erected walls made from the close dimensional elements). In case of using the styrofoam as a thermal insulating material in the newly erected walls there may be concern of water vapour condensation in the plane of bulkhead, or on its internal surface. The low water vapour penetrability of styrofoam may be in these cases the obstruction in the process of drying of the newly erected wall, or the reason of moisture growth in the cause of thermal insulation of the existing wall.

One of the possible structure modifications of the analyzed material such as the styrofoam used for thermal insulation was, in order to change its properties bound up with water vapour penetration, the making of holes in boards. The argument of selection of the diameters, the spacing and the inclination of holes as well as their influence on thermal and diffusive properties in reference to the water vapour was the main object of the Author's research.

Measured amounts and their analysis

Heat conductivity factor of the material

The studies were conducted for material called: solid material and perforated material. The base material was a solid expanded polystyrene board (EPS-70-040) of 5 cm thickness. The base material was perforated using 2 cm x 2 cm grid pattern in parallel to the direction of the heat and moisture flow. The perforations in the boards were made with the help of the heated up rods. Thanks to that the smooth, circular holes were obtained with diameters accordingly as follows: 1, 3 and 5 mm (additional samples with diameters 7, 9 and 11 mm for material EPS-70-040 were also made).

At the first phase of research the heat conductivity of the material was specified, with usage of the HFM 8301 board apparatus.

The apparatus is equipped with automatic control arrangement of parameters serving for determination of heat conductivity factor, which calculates its value also. The control arrangement assures the quick acquisition of the stationary heat flow in the sample. The other values such as heating and cooling plates' temperature, heat flow's density, sample thickness and the time from the moment of start of the measurement program are also displayed.

The measurements were conducted for the samples with dimensions of 0.30 m x 0.30 m with board thickness of 0.05 m. the field of measurement amounted 0.18 m x 0.18 m. There were constant thermal-moisture conditions in the measurement room – the external air temperature of 22°C and the cooling plate temperature of 0°C. The stabilisation of the heat's flow came up in approx. 30 minutes. After that time came up the reading of the parameter's values such as the temperature of the plates, heat's flow density, the decrease of temperature on particular plates. The readings came up every 3 minutes.

The research was conducted for the three samples arrangement, representing both the solid material and the every type of perforated one. The goal for acquisition of the high accuracy of results was to make the samples a subject of the multiplied measurements in the apparatus. The values of the heat conductivity factor were determined on the base of heat's flow density value, flowing through the sample as well as on the base of values read from the apparatus at the time of research.

The research of the heat conductivity was also conducted using samples with diameters $\varphi7$, $\varphi9$, $\varphi11$. The goal of these studies was to check to what borderline the hole diameter can be increased without decreasing the value of the heat conductivity factor (λ)

– by simultaneous increase of the material's diffusion. The results of the research show (Fig. 1) (Orlik, Ślusarek) that the borderline value is diameter of 5 mm, because the heat conductivity factor increases along with the growth of perforation. Analyzing the values of the heat conductivity factor for various types of diameters (Fig. 1), we may suspect that in case of perforations with diameter φ1, φ3 mm we have to deal with conductivity in the apertures, what causes the decrease of the lambda factor value. In the holes with diameter of φ5 mm there might occur the phenomenon of the convectional heat transfer, what causes a slight increase of the heat conductivity.

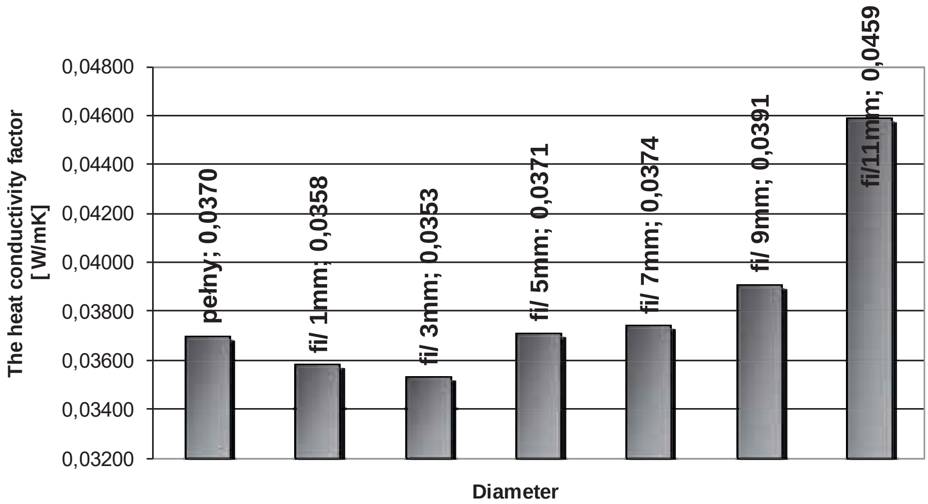
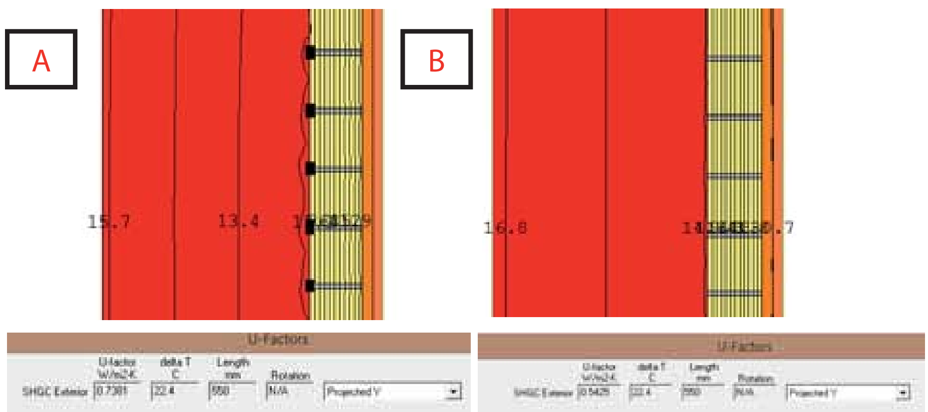


Fig. 1. Values of the heat conductivity factor for various types of perforations

Aiming at thinking through of the heat transfer phenomena in the researched material the simulation model was done using Therm 7beta computer program. This program was based on MES.



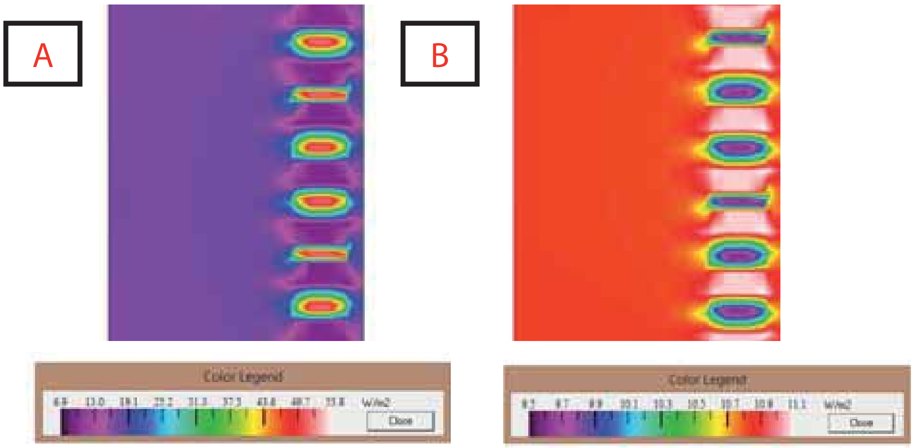


Fig. 2. The arrangement of isotherms and heat flow density in the bulkhead insulated with perforated material with hole diameter of 5 mm. Variant A) straight conductivity in the apertures; Variant B) conductivity in the apertures plus the free convection.

For further analysis of that phenomenon the mathematical model of the flow based on Jacob's empirical relations was formulated (Wiśniewski 1997). During the little intensive heat transfer we observe a straight conductivity, and after the occurrence of the convective currents the conductivity and convection came within a definition of the equivalent heat conductivity factor λ_r (Fig.3). The relation of the λ_r/λ factors (λ – air factor) is characterized by the potentiation of the heat exchange intensity caused by the free convection, in relation to straight heat conductivity. For analyzed apertures their dimensions such as thickness and height were taken into account. In the description of the phenomena the Jacob's empirical relations were put to use (Bloem 1996, Wiśniewski 1997):

$$\frac{\lambda_r}{\lambda} = 0.18 \cdot Gr^{0.25} \left(\frac{H}{l}\right)^{-\frac{1}{9}} \tag{2.1}$$

where:

λ – heat conductivity factor for the gas filling the aperture [W/mK],
λ_r - equivalent heat conductivity factor [W/mK],
l – width of the aperture [m],
H - height of the aperture [m].

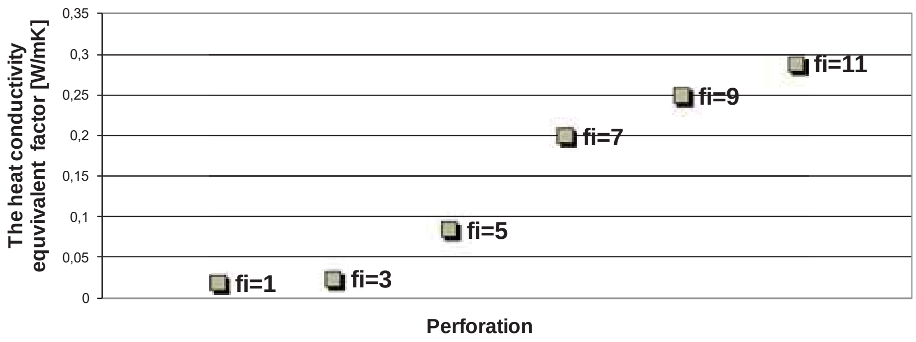


Fig. 3. Equivalent heat conductivity factor in analyzed bulkheads

The Grashof's number determines the free convection's intensity. As the theoretical arguments and experimental researches have shown, the movement in the liquid appears only when the critical value of Rayleigh's number Ra_{kr} = 1700 will be exceeded (Bloem 1996, Wiśniewski 1997):

$$Ra = \mathrm{Pr} \cdot Gr \tag{2.2}$$

where:

Gr – Grashof's number,
Pr – Prandtl's number
Ra - Rayleigh's number.

At the 1700 < Ra < 45 000 the movements in liquid are appearing. When the Ra > 45 000 the liquid's flow goes through laminar into turbulent one, the liquid's movements became irregular (Bloem 1996, Wiśniewski 1997, Bergman 2011).

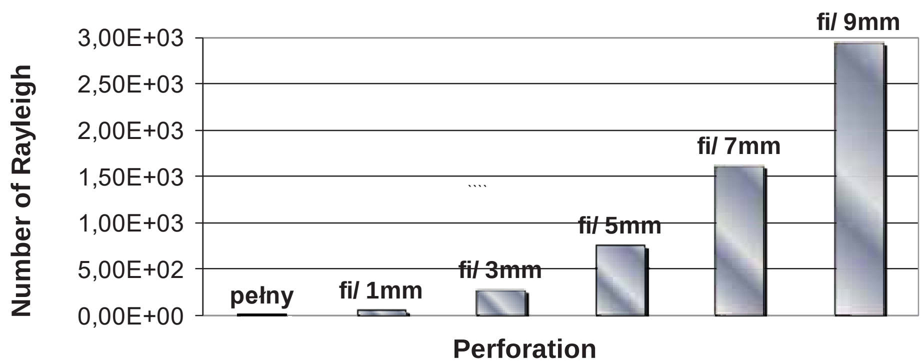


Fig. 4. Calculated Rayleigh's number for analyzed bulkheads

At the picture No. 4 the values of Rayleigh's number for analyzed bulkheads are shown. Its value increases proportionally to the diameter size of the holes. According to (Klemm, Collective work: Physics of the buildings, 2005; Wiśniewski 1997) at the 7 mm thickness of the air aperture the convection doesn't occur and we have to deal with the straight heat conductivity (the calculations shown confirm this). The closed air aperture serves as an insulator. For apertures from the range of φ7 mm ÷φ11 mm we already observe the appearance of movement in the aperture, what probably causes the increase of heat conductivity. Additionally, the heat flow as a result of radiation as well as the radiational characteristics of the surfaces adjoining to the sample affects on the results of the researches. That's why the heat's flow property incorrectly called the heat conductivity – calculated from the determined formulas and results of the heat's flow measurement as well as the difference of temperatures and sample dimensions – should be called the heat exchange factor.

3.2. Bulkhead's heat infiltration factor

The designation of the heat infiltration factor was done relying on heat flow's density researches (Fig. 7 – example – P2 bulkhead) for both types of bulkheads, according to the procedure included in the ISO 9869:1994 norm: *Thermal insulation. Building elements. In situ measurement of thermal resistance and thermal transmittance* (9).

In the researches two wall arrangements were analyzed: P1 – the wall insulated by the solid material; P2 – the wall insulated by the perforated material (Orlik, Ślusarek 2010). The density measurement was done by the gauge with sensor type *auxiliary wall* (Brandtke 1958, Bloem 1996, Taler 1995).

The researches of such a scale were conducted in the field conditions on the measurement station consisting of three separate chambers, where one of these was modernized for the purpose of the research. On the selected wall of the chamber the insulation was laid , made from solid and perforated research material. The used measurement system allowed registration of the data such as relative humidity and temperature distribution in particular bulkhead planes and in the chamber. Additional measurement apparatus installed on the building allows for measurement of quantities which characterize the external environment: wind speed, insolation, amount of rainfall, relative humidity and external air temperature – the weather station type Kombi WS 2305.

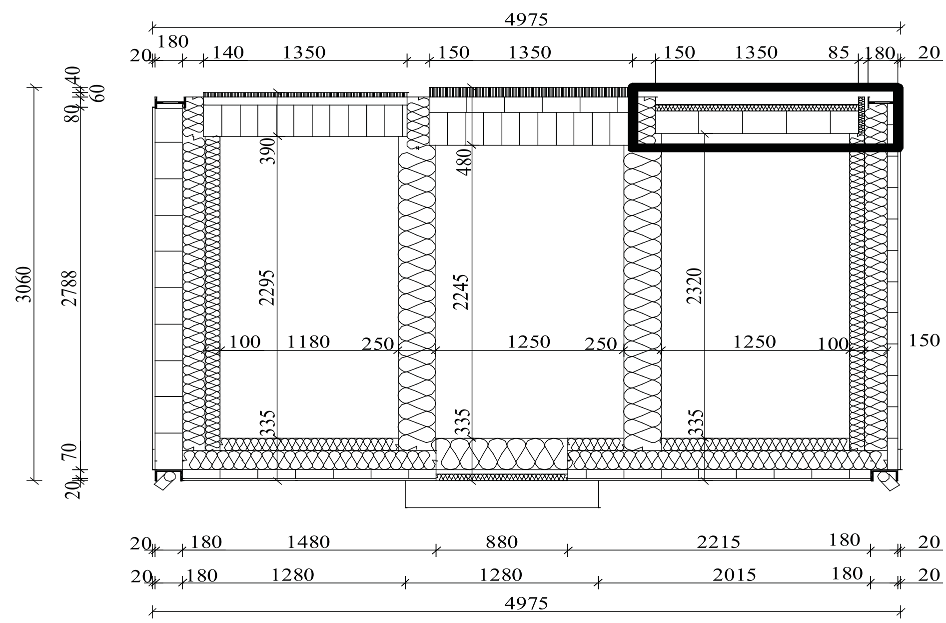


Fig. 5. Projection of a research station with a bulkhead under research marked

Fig.6. Picture of a research station in the laboratory of an Architectural Engineering Faculty of a Silesian Technical University [author's photo]

The chamber was situated against points of compass in order to expose the researched wall elements to the south. The internal bulkheads separating the rooms were designed as adiabatic ones in order to prevent the heat's flow among them. In the rooms three independent heating-cooling arrangements were used. The research station was equipped with computer – assisted registration and data gathering system, describing the basic thermal-moisture parameters of the analyzed chamber and its bulkheads. The measurement apparatus which was put to use on the research station is:

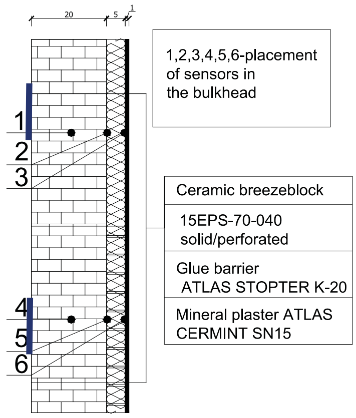


Fig. 7. View of the research station

Fig. 8. Scheme of the analyzed bulkheads and arrangement of the sensors on their surfaces

The goal of these measures was to calculate the real thermal resistance R as well as the heat infiltration factor U for the researched bulkheads. In case of conducting of the continuous measures in time not shorter than 72 hrs, for calculations should be used the formulas included in the ISO 9869 (Bloem 1996, Haupt 2008, ISO 9869). The complete thermal resistance should be calculated from the formula ISO 9869):

$$R_n = \frac{\sum_{j=1}^{n} T_{sij} - T_{sej}}{\sum_{j=1}^{n} q_j} \tag{3.1}$$

where:

R_n – complete resistance of the bulkhead's surfaces without taking into consideration the resistances of heat's interception on the surfaces of the bulkhead [m^{2}K/W],
T_{sij} – measured temperature on the internal surface of the bulkhead [^{o}C],
T_{sej} – measured temperature on the external surface of the bulkhead [^{o}C],
Q_j – measured heat's flow density on the surface of the bulkhead [W/m^2].

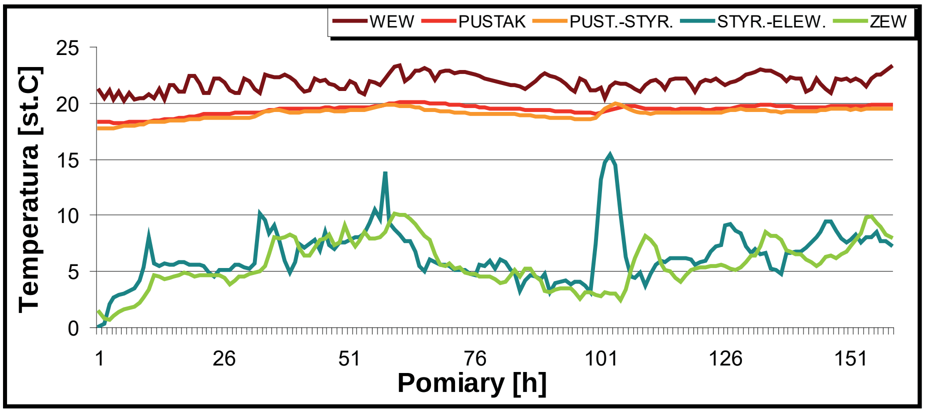


Fig. 9. The process of temperature's alternation in layers of a bulkhead insulated with solid material

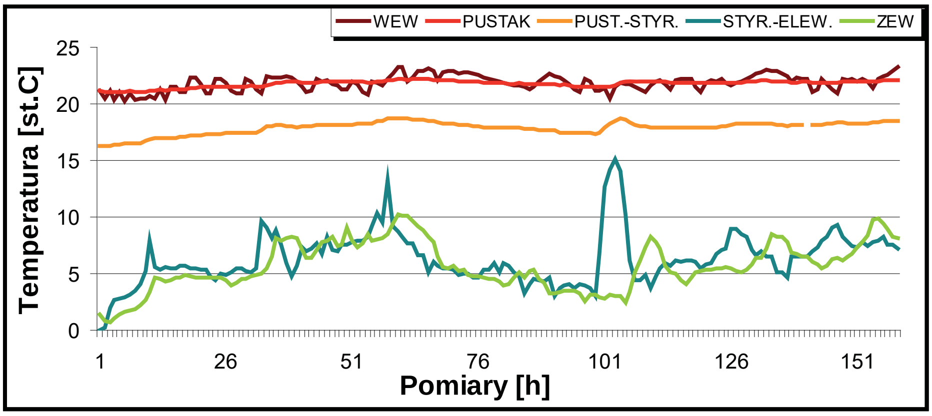


Fig. 10. The process of temperature's alternation in layers of a bulkhead insulated with perforated material

On the graphes illustrating the proceeding of temperaturę's alternation on the surfaces of bulkhead insulated by the solid material, the significant discrepancies in temperature distribution on the surfaces of the analyzed bulkheads can be observed. For the bulkhead insulated by the perforated material on the surface of ceramic block, the temperature obtains the value between 1,5°C÷4°C, which is higher than on the same surface in the wall insulated by the solid material. On the point of junction of the ceramic block – the styrofoam the sudden decrease of temperature follows in the bulkhead insulated by the perforated material, it is bound up with simultaneous increase of moisture on that surface and accruing of it in the direction of the external environment (Orlik, Ślusarek).

As a result of application of the 3.1 formula, as well as the values gained within the measures, the following values were received for the analyzed bulkheads:

R_{n1} = 1,144 m^2K/W R_{n2}= 1,476 m^2K/W

The complete thermal resistance of the bulkhead R_T taking into account the resistances of the heat's interception on the surfaces of the building bulkhead amounts to:

R_{T1} = 1,314 m^2K/W R_{T2} = 1,649 m^2K/W

where:
R_{T1} – complete resistance of the P1 bulkhead [m^2K/W].
R_{T2} - complete resistance of the P2 bulkhead [m^2K/W].

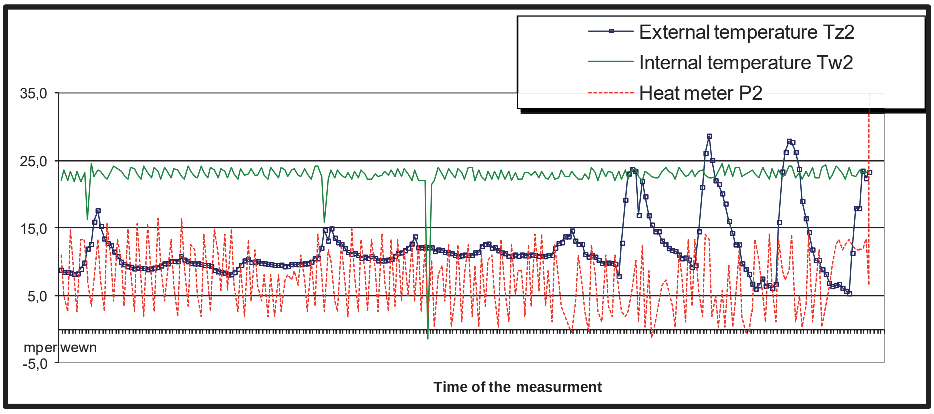


Fig. 11. Track record of the temperatures and heat's flow density for the bulkhead insulated by the P2 perforated material

According to the PN EN ISO 6946 (PN EN ISO 6946) the heat interception factor U is calculated in the compliance with the formula:

$$U = \frac{1}{R_T} \tag{3.2}$$

$U_1 = 1/R_{T1}$ = 0,76 W/m^2K $U_2 = 1/R_{T2}$ = 0,61 W/m^2K

4. Loss of heat by the analyzed bulkheads

The complete loss of heat in the heating season by the building bulkhead can be calculated according to the norm PN-B-02025:1999 *Calculating of the seasonal demand for the warmth for heating of the habitable and public utility buildings*, by the formula:

$$Q_u = 8{,}64 \cdot 10^{-5} \cdot S_d \cdot A \cdot U \quad [\text{GJ/year}] \tag{4.1}$$

where:

- Q_u - loss of the heat in the heating season [GJ/year],
- S_d - number of grading days (calculated according to the above norm for the nearest meteorological station - Katowice, $S_d = 2616.6$),
- A - surface field of the bulkhead [m^2],
- U - complete heat infiltration factor [$W/(m^2K)$].

Both researched bulkheads can be qualified as the solid walls without windows and doors. For the purpose of calculations the field of surface A=100 m^2 was accepted.

$$Q_{u1} = 8{,}64 \cdot 10^{-5} \cdot 2616{,}6 \cdot 100 \cdot 0{,}76 = 17{,}1 \text{ GJ/year}$$
$$Q_{u2} = 8{,}64 \cdot 10^{-5} \cdot 2616{,}6 \cdot 100 \cdot 0{,}61 = 13{,}7 \text{ GJ/year}$$

where:

- Q_{u1} - loss of the heat in the heating season for the bulkhead P1 [GJ/year],
- Q_{u2} - loss of the heat in the heating season for the bulkhead P2 [GJ/year],

According to the requirements known in *Technical conditions* the bulkhead of this type should be characterized by the heat infiltration factor U not bigger than 0,30 [W/m^2 K].

$$Q_u(WT) = 8{,}64 \cdot 10^{-5} \cdot 2616{,}6 \cdot 100 \cdot 0{,}30 = 6{,}78 \text{ GJ/year}$$

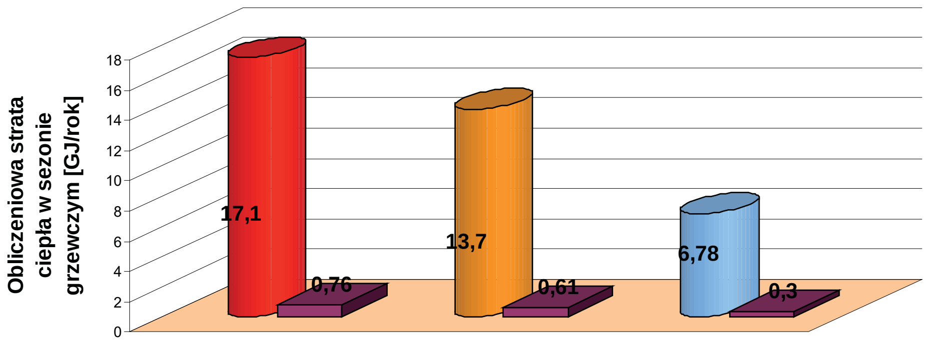


Fig. 12. Computational heat loss trough 100m^2 bulkhead

Summary

The researches presented in this paper are a part of the whole research cycle on the material with modified structure and about the behavior of this material in the bulkhead (Orlik, Ślusarek). Part of this research, dedicated to determining of the thermal parameters of the material and its behaviour in the wall, has shown that the modified boards beneficially cooperate with the whole wall arrangement, improving its thermal parameters (U factor). It should be remembered that the implementation of the new materials and technologies requires a full recognition of the very important physical conditions accompanying the associated phenomena of the heat and mass transfer. The observation and analysis of the water vapour diffusion phenomena through the analyzed wall arrangements, characterized by the discontinuity in the styrofoam layer, considerably increase the possibility of the water vapour flow, changing the moisture potential of the whole bulkhead. The further analyses show, that the places of the intensive water vapour flow due to the difference of the partial pressures, may contribute to the weakening of the plaster's layer adhesion to the base in places of the perforation. As a result of the thermal – moisture phenomena the emerging tensions may cause the damage of the elevation layer, what in turn may cause a greater penetration of the moisture into the particular bulkhead layers. The usage of a rigid insulating materials (styrofoams) in the methods of the thermal insulation should be preceded with additional research connected with the obsolescence of the whole arrangement, so as to eliminate the disadvantageous phenomena of the weakness of the external layers (glue, netting, plaster) in the places of the styrofoam's perforation.

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