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Original Research Article

GEOMETRY OPTIMALIZATION OF THE VENTILATED INSULATING PANEL

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Abstract

An EPS ventilated panel, which may be applied as an external insulation to humid walls, is investigated. Dimensions of the air channel sections have been determined using the Ansys software. Afterwards, the drying rate of the walls externally insulated with EPS, mineral wool and EPS ventilated panel has been compared using the WUFI software. The ventilated panel increases the drying rate when compared with the standard polystyrene panel and increases the heat loss through the wall by less than 20%.

Keywords: ventilated panel, ventilated channels, drying rate of wall

1. INTRODUCTION

The building stock is responsible for appr. 36% of the CO_2 emissions in the European Union. Recently, the European Parliament indicated the need for comprehensive energy transformation of the existing buildings [1]. Particular attention during thermal renovation process should be paid to the moisture content of building walls, which is often disregarded. It may be necessary to remove the moisture, what can be a costly and time-consuming process. Some technologies

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have been proposed to enable thermal insulation of the existing buildings containing some moisture in the walls. One of such solutions for insulating humid walls is an expanded polystyrene (EPS) panel with the drainage cavities at the rear of the insulation layer. The panels with drainage cavities, but of different geometry, have been studied and applied in the past [2, 3]. Usually, such ventilated cavities are used in the Ventilated Façade Systems, with the ventilated air cavity between the insulation and the cladding. The air gap is supposed to decrease humidity of the thermal insulation, while the cladding protects it from external sources of humidity, wind and solar radiation. Nizovtsev et al. [4] presented results of hygro-thermal behaviour of façade system with ventilated channels located in the thermal insulation at the surface close to the external environment. Borodulin and Nizovtsev [5] proposed mathematical model for the analyses of façade systems with ventilated channels. Falk and Sandin [6] investigated air exchange in the walls with ventilated cladding for different directions of the wooden battens, indicating significant variations depending on the solar radiation and the wind velocity. The experimental study of the drying potential of the cavity ventilation has been performed also by Vanpachtenbeke et al. [7]. Langmans et al. [8] investigated hygrothermal conditions in the cavities, reporting higher humidity level for smaller ventilation rates. In the analysed panel, the humid air exchange in the channel system is enabled through narrow inlets and outlets, arranged with an interval of 1 storey vertically and 1 m horizontally, due to convective air flow. The cold air is heated from the wall and distributed through a system of horizontal and vertical channels along the masonry surface. Cross-sections of the vertical air channel and a photograph of the analysed EPS panel are presented in Fig 1.

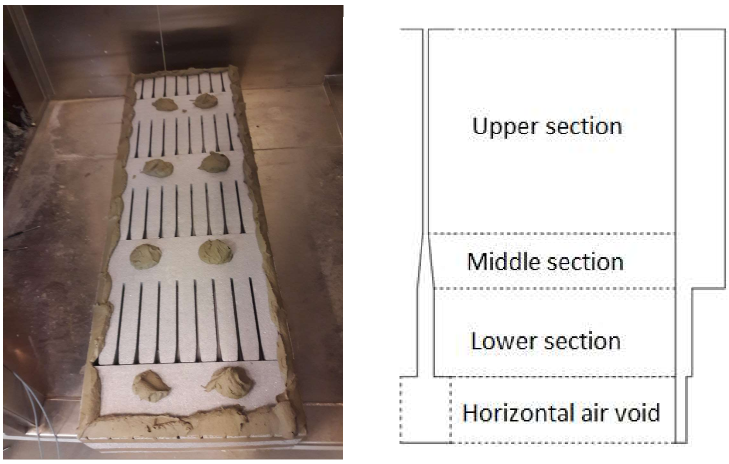

Fig. 1. Photograph of the analysed EPS panel (A). Cross-section through a single vertical channel in the direction parallel to the wall's surface and perpendicular to it (B)

2. NUMERICAL SIMULATIONS

The procedure and sequence of the numerical simulations and consequent experimental research are presented in Fig. 2.

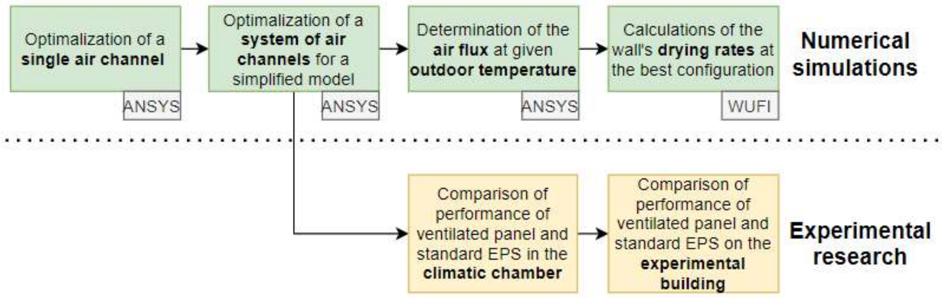

Fig. 2. The schematic flow chart of the numerical simulations and experimental research

2.1. Analysis of the air flow in the air voids system

The calculations of the air flux in the channels have been performed using the ANSYS-FLUENT 18 software. The effect of wind has not been considered due to the fact that its variability in direction and speed depends strongly on the local conditions. The material parameters defined in the Ansys program are given in Table 1. It has been assumed that the air voids should not increase the heat loss through the wall by more than 15 %. Thickness of the insulation has been determined in such a way that the wall thermal transmittance would not be greater than 0.20 W/(m^{2}K). The plaster has not been taken into account due to its small thermal resistance and heat capacity. In the analyses, the temperatures on internal and external surfaces are defined as equal to 20°C and 0°C, accordingly, unless stated otherwise. The heat transfer coefficient has been assumed as h_{si} = 7.69 W/(m^{2}K) and h_{se} = 25.00 W/(m^{2}K), respectively.

Table 1. Material parameters assumed in the ANSYS program

Material	Thickness, d [m]	Thermal conductivity, λ [W/(mK)]	Density, ρ [kg/m^3]	Specific heat, C_p [J/(kg K)]
Brick	0.25	0.77	1800	900
EPS	0.22	0.032	20	1460

The dimensions of the vertical voids' upper section (width and depth of the air channel), middle section (height), and lower section (width and depth of the air void, height of the section) have been investigated and the main elements suppressing the air flow have been modified accordingly. The system of 7 panels, connected with horizontal surfaces, has been modelled, see Fig. 3A. The distance between subsequent vertical air channels is equal to 5 cm.

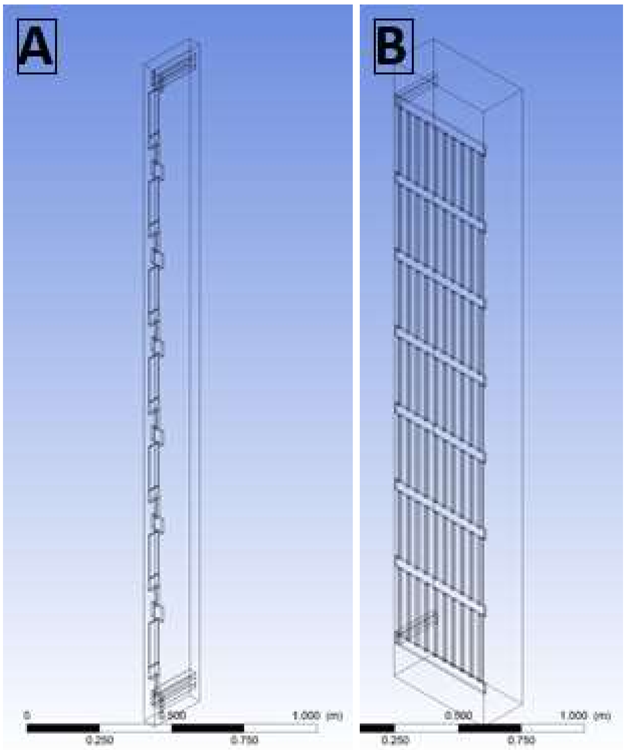

Fig. 3. Geometry of the model for the Ansys program in the analyses of a single vertical air channel (A) and a system of channels (B)

The computed temperature distribution in the air channels is presented in Fig. 4A. It can be noted that the cold air causes a local decrease of temperature at the interface between the EPS and the brick, what has been further investigated at the experimental stage.

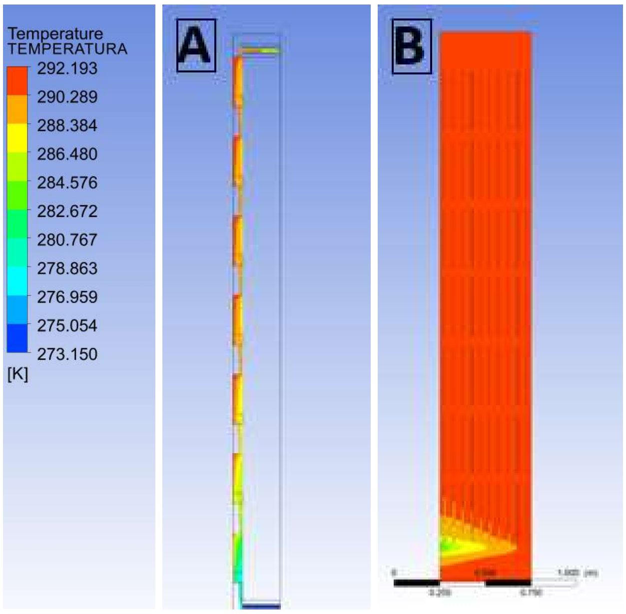

Fig. 4. Temperature distribution in the air channels (A) and on the surface between the ventilated panel and brick (B)

For further analyses, the simplified model of the same height and flow resistance, but with the modified cross-section of air void, has been defined (Fig. 3B). The horizontal air void dimensions, inlet and outlet diameters, and placement of inlets and outlets have been optimized. The temperature map on the surface between the brick and the EPS layers is presented in Fig. 4B. The heat flux through the wall with ventilated panel is larger by 11.57% when compared against the wall with unventilated panel. The effect of distance between the inlet and outlet is presented in Tab. 2, while that of horizontal distance between the inlets in Tab. 3.

Table 2. Effect of the distance between the inlet and the outlet on the air

Variant	Distance between the inlet and the outlet, [m]	Air flux through the outlet, Q_{outlet} [mg/s]
A13-1	0.375	19,00
A13-2	1.125	41,23
A13-3	1.875	57,18
A13-4	2.625	69,96

Table 3. Effect of the horizontal distance between the inlets on the air flux through the outlet

Variant	Horizontal distance between the inlets, [m]	Air flux through the outlet, Q_{outlet} [mg/s]
A14-1	1.0	69,96
A14-2	1.5	71,94
A14-3	2.0	72,57

Afterwards, the impact of external temperature on the outlet air flux has been investigated and the air exchange rate in air channel system for the Typical Meteorological Year (TMY) meteorological data has been determined (Fig. 5). As can be seen, air flow in the summer months is negligible.

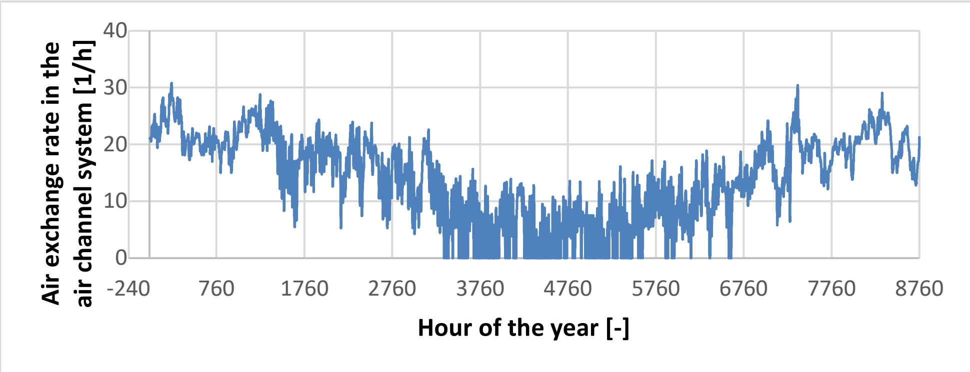

Fig. 5. The air exchange rate in the air channel system during the year

2.2. Analysis of the wall's drying rate

The analyses of drying process of the wall were performed using the WUFI 2D software, which enables to investigate hygrothermal phenomena in two-dimensional building elements. The main material parameters used in simulations are given in Tab. 4. The climatic conditions of TMY for Warsaw (Poland) and indoor conditions as for the 3rd class of humidity [9]. The wall on the northern façade of a light colour has been considered. Performance of three external thermal insulation systems has been compared: expanded polystyrene (EPS), mineral wool (MW) and the ventilated EPS panels (VP). Then, different wall finishing has been assumed, with S_d = 0.057 m, while internal with S_d = 0.19 m or

S_d = 2.0 m. Comparison of the performance of the three materials is presented in Fig. 6. It can be noted that the drying rates of walls insulated with the VP panels are higher when compared against the standard EPS. When the finishing on the internal side of wall has lower diffusion resistance, only a slight improvement can be noted; however, when a layer of high diffusion resistance is assumed, the drying rate in such a wall is higher for the VP.

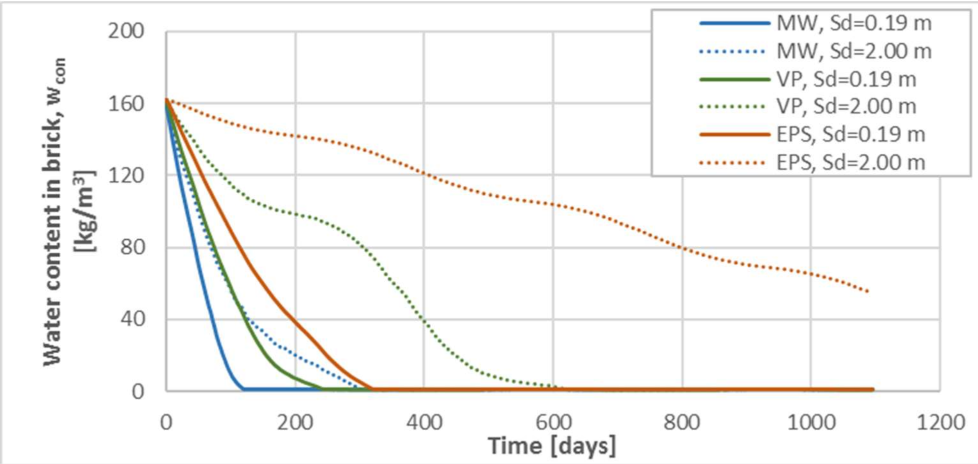

Fig. 6. Comparison of the water content evolution in brick during the period of 3 years for different insulating materials

Table 4. Main parameters used in the analyses in the WUFI 2D program

Material	Brick	EPS	MW	VP
Thickness, d[m]	0,25	0,22	0,22	0,22
Thermal conductivity, λ [W/(mK)]	0.77	0.032	0.04	0.032
Water vapour diffusion resistance factor, μ [-]	7	60	1.3	60
Initial water content, w_{con} [kg/m^3]	162	0.18	1.8	0.18

3. EXPERIMENTAL RESEARCH

The experimental research was performed in a set of two climatic chambers, separated by the investigated building component. A ceramic brick wall (d = 12 cm), insulated from the colder chamber with the EPS (d = 22 cm, λ = 0.042 W / (m K)) or the VP (d = 22 cm, λ = 0.032 W / (m K)), and finished with acrylic plaster (d = 0.15 cm), was examined. The conditions in the warm chamber were kept at a constant level of 20±2 °C and relative air humidity of 50±10 %. On the cold side, the temperature varied in the range of -20 up to +20 °C.

Two wall variants were tested in the research: with a foil on the warm surface and not insulated one (which allowed for free evaporation on the inner surface). The parts of walls with the EPS and the VP were separated with a vertical layer of waterproofing. The wall was moistened with water from the colder chamber by intensive sprinkling for 48 hours. The mass moisture content of the brick was equal to appr. 9%. The experimental setup is presented in Fig. 7. For more detailed analysis of the warm surface temperature, a thermal imaging camera was used (see Fig. 8). It can be noted that the surface, the air inlet is colder.

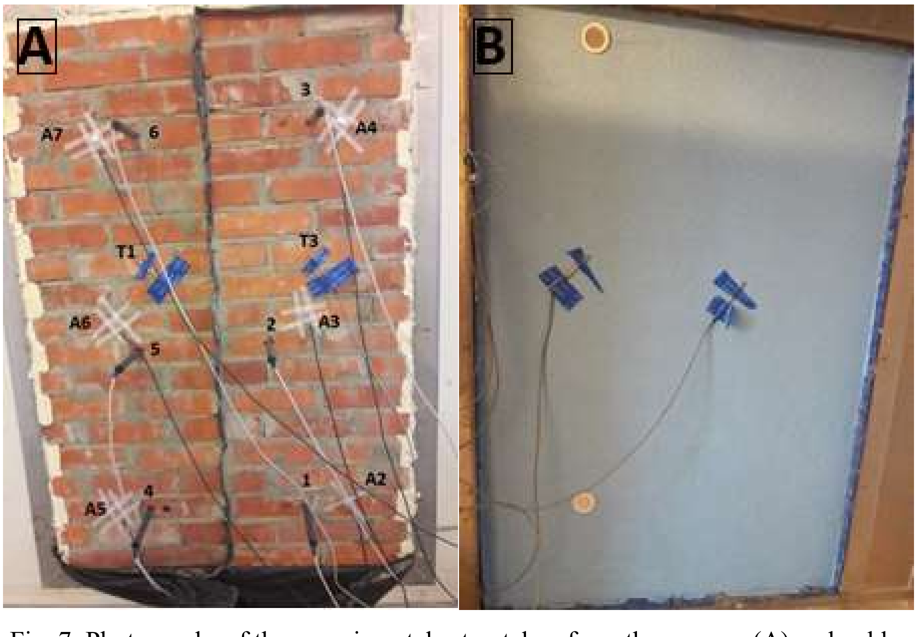

Fig. 7. Photographs of the experimental setup taken from the warmer (A) and colder chambers (B)

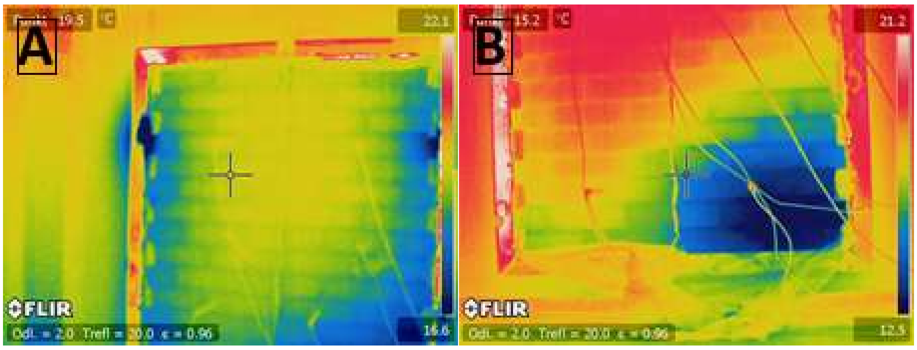

Fig. 8. Comparison of the temperature on the internal side of the wall insulated with the EPS (A) or the VP (B)

Afterwards, the VP was investigated in the model test building, equipped with a mechanical ventilation and an air-conditioning system to maintain constant indoor conditions. The thermographic examination was performed with outdoor temperature of 2°C (Fig. 9). It can be noted that the outlet is significantly warmer, proving that the air is transported through the air channels.

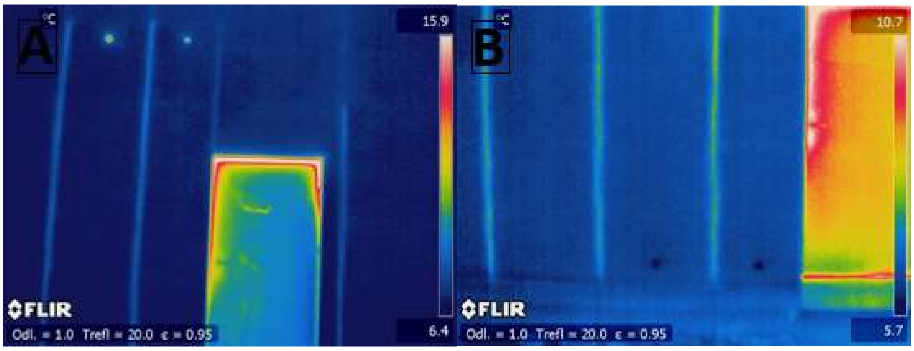

Fig. 9. Comparison of the temperature on the external side of the experimental wall in the outlet (A) or inlet (B)

4. CONCLUSIONS

The ventilated panel performance has been investigated using the numerical simulations and both the laboratory and real scale experimental research. Similar conclusions were drawn from the results obtained during each stage of the research. The drainage cavities influence the drying rate of the wall – water content in the brick decreases faster in the walls insulated with VP when compared against the standard EPS panels. The drying process in the walls insulated with mineral wool is the fastest, however, this material would be strongly deteriorated in such conditions. A local thermal bridge is observed close to the inlet.

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