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THERMAL BRIDGE EFFECT OF AIR GAPS IN WALL CONSTRUCTION

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Abstract

The paper presents the phenomenon of thermal bridges caused by air infiltration. The problem of poor air tightness is very common in the former Eastern Bloc countries. The laboratory investigation was set up to recognize the impact of air infiltration on heat flux through the building envelope. The frame wall model insulated with loose mineral wool was investigated in non-isothermal climatic chamber. As a result of cold air infiltration, surfaces of gaps and areas adjacent to them were cooled, which is illustrated on temperature profiles. The forty minutes infiltration of 0°C air resulted as a 3.5°C cooling of gap area. The thermal simulation in Delphin confirmed the laboratory results.

Introduction

Air infiltration is one of the most serious reasons of moisture problems in building partitions. In addition, harmful matters like microbes and radon gas transport can flow inside the building through the gaps during infiltration. In many cases the infiltration is considered as the cause of drafts, cold air inflows, and thus the loss of ventilation heating. Rarely, the researchers note another, equally important problem caused by infiltration, which is cooling of the area adjacent to the air gap, and thus creation of a thermal bridge in the problematic area. Due to mechanism of air infiltration, in which the air flows through the entire thickness of the construction with the inlet and outlet like in a channel flow, this thermal anomaly can be named as thermal bridges of air gaps and should be analyzed in conjunction with the traditionally perceived thermal bridges. In the paper there are presented selected issues of identifica-

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tion of thermal bridges caused by air infiltration (ATB). The work includes laboratory investigation results of ATB and validation of the experiment in the Delphin software. Simulation model benchmarked in the paper will be used in future work to assess ATB values.

Air flow through the gaps in building envelope

Air filtration through the building envelope arise as a result of pressure difference on both sides of the partition and can be caused by nature forces, i.e., thermal buoyancy, wind, or by an internal air distribution system. Air leaks can occur in many zones of the building envelope, i.e., gaps occurring in the joinery windows and doors, construction joints, contacts of materials of different texture and structure, holes for the installation systems and many others. Potential leaks, gaps and cracks in a building envelope can be caused by building exploitation or due to improper manufacture of elements.

Air flow through the gaps in building envelope are the objects of interest for many researchers. In most cases, these studies, relate primarily to the impact of air filtration for an efficiency of ventilation, pollutants distribution in rooms and moisture content inside building elements. Changes in the processes of heat transfer and temperature distribution in the gaps and their surroundings are less frequently described. Deseyve, Bednar described the laboratory investigation of heat losses during wind washing the fibrous roof insulation. 5 m/s wind speed can increase heat transfer through a roof by 9 times (DESEYVE, BEDNAR 2008). Kalamees, Kurnitski, Vinha et al. described Blower Door airtightness measurements in 37 Finnish buildings. Pressure air tightness measurements were supplemented by infrared radiation detection. Authors suggested that some air leakages, especially round the windows, overlap with thermal bridges (KALAMEES et al. 2008). Dufour, Derome and Zmeureanu used thermography to measure in laboratory conditions the surface temperature of single-layer walls subjected to air flow through surrogates of cracks. Authors solved an inverse problem and using developed image-processing methods of recorded thermograms (i.e., the edge detection technique and correlations for peak height and missing attenuation) to estimate the dimensions of cracks with an error of lesser than 4% (DUFOUR et al. 2009).

Air filtration through a building envelope is particularly significant in buildings located in the former Eastern Bloc countries. Traditional constructions in these countries did not include air and wind barrier layers in building partitions. As a result of aging and watering, thermal fibre materials swell and creep which lead to constriction of ventilation gap between insulation and cladding. Former Eastern Bloc countries have not participated in the oil crises of 1970s' and that may be the reason why a problem of airtightness was not noticed there relatively quickly (BOMBERG, ONYSKO 2002).

Depending on the pressure difference through the building envelope the flow may be directed inwards or outwards. Both can cause moisture problems and energy losses. It can be assumed that infiltration occurs in a half of air leaks. Air thermal bridges occur mostly in joints of lightweight construction but appear in the other places as well. ATB, for example, often occurs in the traditional construction of attics. In a single building there are at least few hundred meters of joints between the cladding boards. These joints are the potential air leaks and therefore in many cases – ATBs (WÓJCIK, KOSIŃSKI 2014, KOSIŃSKI 2014).

Air flow through the gaps in building envelope – the heat flux calculation

Heat transfer coupled with air mass transport may occur in gaps and in porous materials. It means that a classical method of computing the heat transfer coupled with air mass transport, only by the Fourier law, should be modified by adding an equation describing the air filtration. It was described by GRUNEWALD, NICOLAI, ZHANG (2007) and by KUBIK (2008). For this reason, the local energy balance including convective heat transfer, can be described as a differential equation (1):

$$\frac{\partial}{\partial t}(\rho U) = \nabla \cdot \left(\lambda \nabla T + \kappa \frac{c_p \Delta T}{\nu}(\nabla p + \rho g)\right) + \rho r \tag{1}$$

where:
ρU – the internal energy density [J/m^3],
λ – the heat conduction coefficient [W/(m · K)],
∇T – the temperature gradient [K/m],
κ – the intrinsic permeability of porous medium [m^2],
c_p – the specific heat of dry air [J/(kg · K)],
ΔT – the temperature difference [K],
ν – the kinematic viscosity of air [m^2/s],
∇p – the pressure gradient [Pa/m],
ρ – the dry air density [kg/m^3],
g – the gravity acceleration [m/s^2],
ρr – the internal heat source density [W/m^3].

Laboratory experimental set-up of thermal bridges caused by air infiltration

The laboratory investigation was performed in non-isothermal climatic chamber, which was specially constructed to carry out the research of the impact of air filtration on heat transfer through buildings elements. The chamber consists of two sections: a hot and a cold one. In cold part there is placed a fan system to generate wind (Fig. 1). Natural dimensions specimen is mounted in climatic chamber between cold and hot parts. An investigation analyzed in this work was a part of another experiment, so on Figure 2 there is shown the selected specimen area corresponding to current investigation.

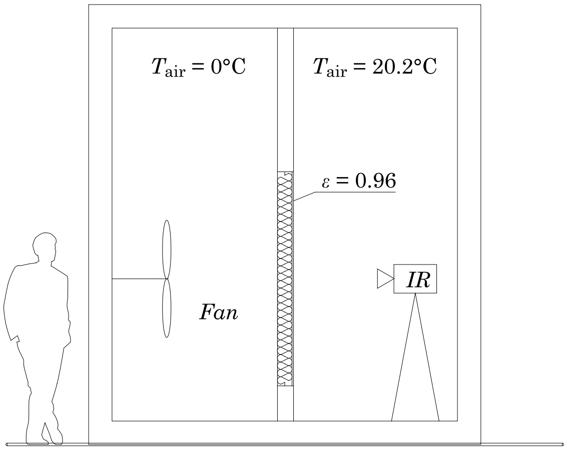

Fig. 1. Schematic representation of the laboratory set-up

Due to presenting the impact of air filtration on the air temperatures' distribution in a wall, there was prepared a light frame partition. A wall filled with loose mineral wool and aluminum support structure was constructed in the climatic chamber. Inner cladding was made with gypsum boards, which were mounted with a 3 mm gap between them. The surfaces of boards were painted in order to achieve the emissivity $\varepsilon = 0.96$. In the specimen wall, an air barrier, vapor retarder and external cladding where not mounted in order to achieve total exposition for wind force. This extreme situation corresponds to the actual conditions found in traditional buildings located on the area of the former Eastern Bloc countries. Many steep and mansard roof construction do not include wind and air barriers. In order to achieve a natural situation of the partition insulated with loose mineral wool fibers in existing buildings, the thermal insulation was initially compacted manually. During the experiment,

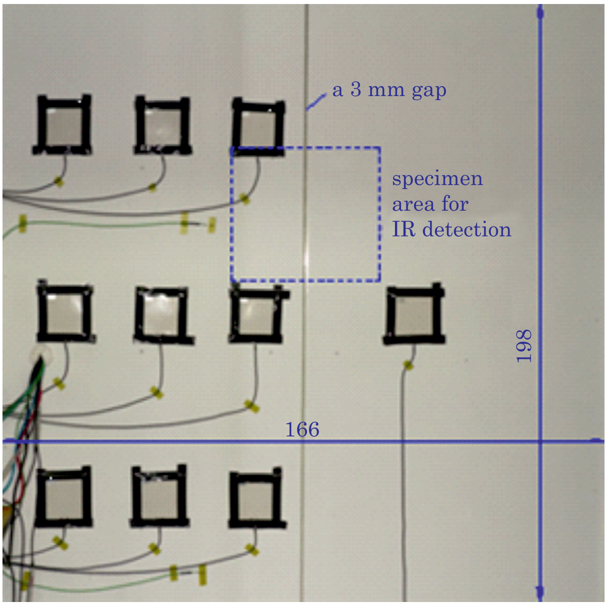

Fig. 2. Front view of the specimen with selected area for IR detection

the temperature on both sides of the specimen was measured using thermocouples while wind speed was measured by the cold side of climatic chamber using thermo anemometers. There was used Ahlborn system for acquisition data. The pressure difference was measured by the differential pressure gauge DG 700. In the table 1 there are summarized properties of the materials used in the model.

Table 1

Properties of building materials used to construct laboratory model

Layer	Conductivity, [W/(m ·)]	Thickness, [m]	Airtight	The intrinsic permeability of porous medium κ [m^2]
Gypsum board	0.22	0.0125	YES	–
Mineral wool	0.036	0.125	NO	$4.42 \cdot 10^{-5}$

The internal temperature (on the warm side) was set at 20.2°C, the outer temperature (cold side) was set at 0°C. After reaching the thermodynamic equilibrium the system of fan started to generate wind. Wind speed 3.2 m/s corresponds to pressure difference Δp = 5 Pa. Measurement procedure consisted of infrared detection on hot surface of specimen wall and temperature data acquisition using thermocouples mounted on the specimen. IR measurement were conducted using FLIR SC7200 system, which consists of infrared detector

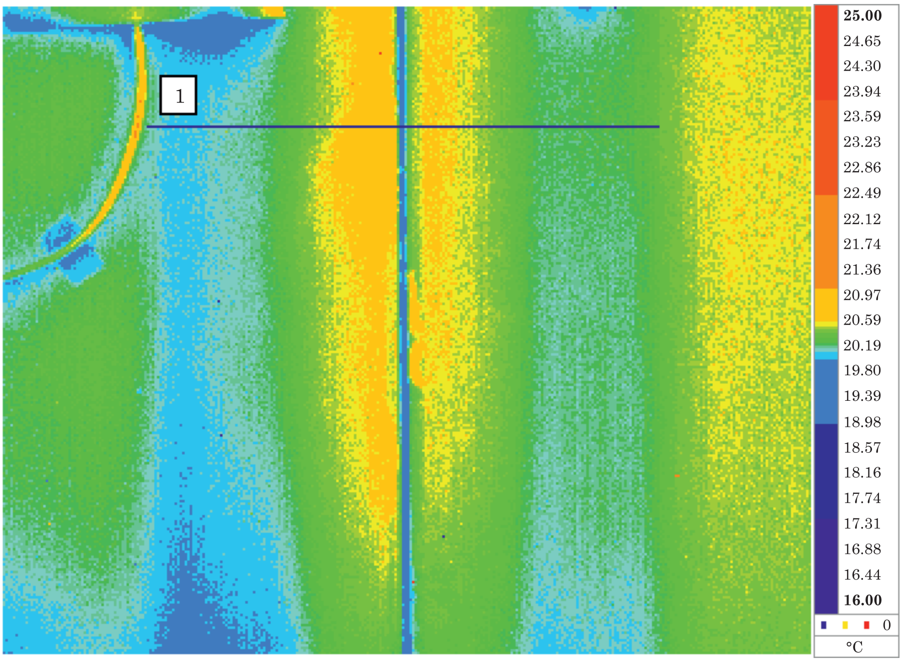

Fig. 3. Thermogram of the specimen wall with air gap in initial state at time step $t = 0$ min

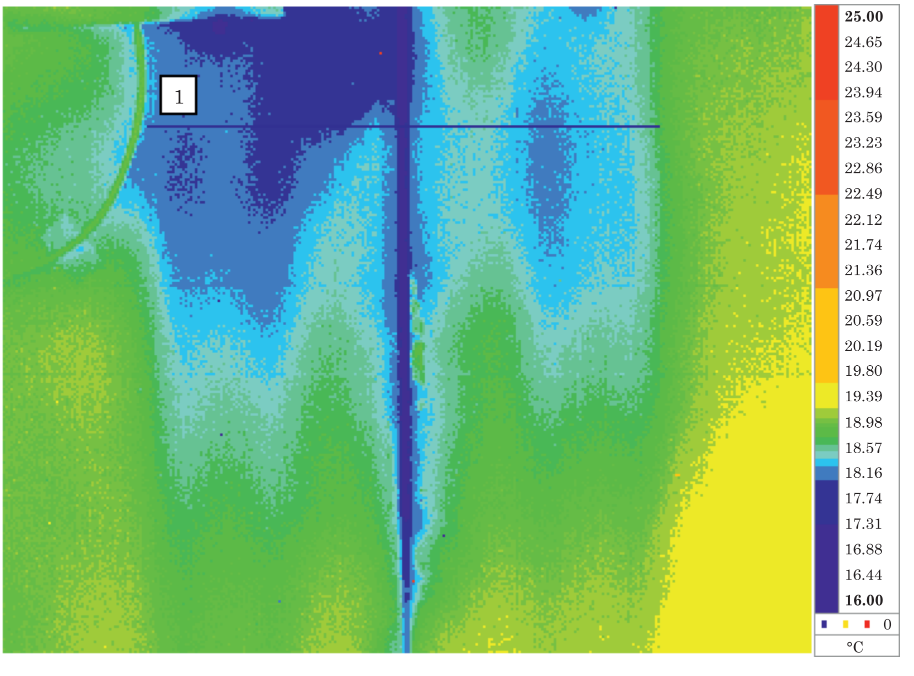

Fig. 4. Thermogram of the specimen wall with air gap, wind loaded, at time step $t = 40$ min

with a resolution of 320 × 256 pixels and has a thermal sensitivity of 20 mK. The camera allows to record thermal images in continuous mode. The measurements were performed in the area adjacent to the air gap. A small size of the IR specimen area (35 × 30 cm) resulted from a narrow angle of IR camera lens.

On Figure 3 there is presented a thermogram of the specimen wall in initial state, after reaching thermodynamic equilibrium before the fan has started. This state is set as a time step $t = 0$ min. On Figure 4 there is presented a thermogram of the specimen wall after 40 minutes of continuous fan work, it means wind speed of 3.2 m/s. This state is set as a time step $t = 40$ min.

The temperature curves on the graph on Figure 5 illustrate cooling of the gap and adjacent area of 20 cm width in five steps, at time 0, 10, 20, 30 and 40 minutes. The temperature profile is situated on Figures 3 and 4 as a line number 1. The temperature curves of the whole area do not show a homogeneous temperature distribution. The lowest temperature is in the middle of the gap, what is clear, but the temperature near gap is higher than further from the gap. The edges of the gap are geometric disturbances and during application of loose insulation, there may have been the obstacle which caused the

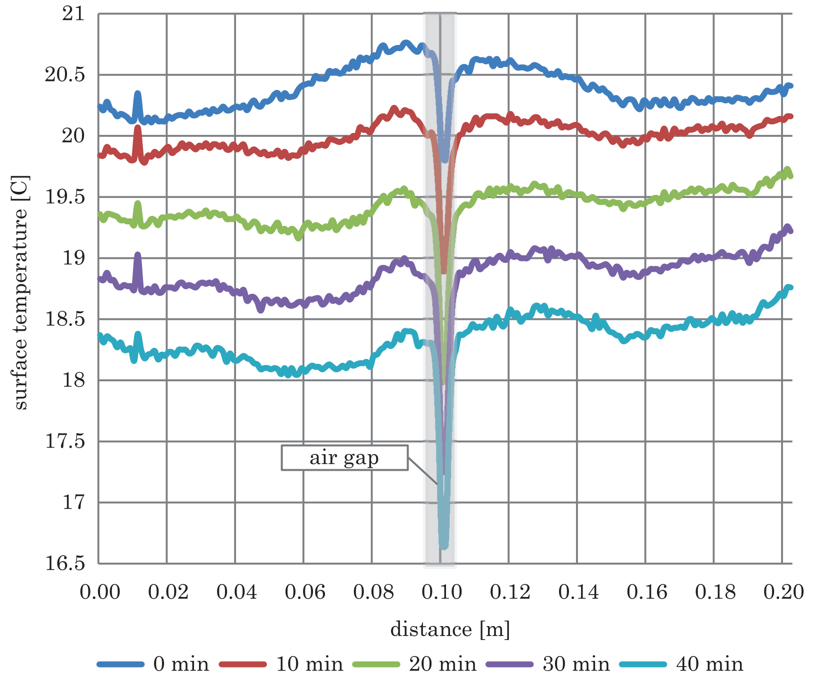

Fig. 5. Temperature curves illustrating laboratory cooling the air gap and the adjacent area in five time steps

partial occurrence of higher density of mineral wool in the wall. Such a situation is very common in practice due to quality differences in workmanship.

Simulation of thermal bridges caused by air infiltration

Thermal simulation of experiment was performed according to ISO 10211 standard using the Delphin 5.8 software based on Control Volume Method. An implementation of physical model of air filtration through a building element is constructed on parabolic partial differential diffusion – convection balance equations (1).

A simulation model was based on known characteristics of the materials examined first in Heat Flow Meter and Air Permeability Meter. Temperature values recorded in the specimen model in the climatic chamber allowed to set an initial temperature state of the simulation model. Boundary conditions and dimensions were the same as in laboratory measurements, the inner temperature 20.2°C, the outer temperature 0°C. Reynolds number calculated for the wind speed 3.2 m/s and dimensions of the air gap was Re = 722, which corresponded to laminar flow. Heat transfer resistance were calculated according to ISO 6946: $R_{si} = 0.125$ ($m^2 \cdot K$)/W and $R_{se} = 0.047$ ($m^2 \cdot K$)/W.

Figure 6 presents results of simulation on cross section of a part of the model. Left picture presents the temperature image of the thermal equilibrium situation before the wind load started (step $t = 0$ min). On the right there is the temperature image after 40 minutes of wind load (step $t = 40$ min).

Temperature curves on the graph on Figure 7, illustrate surface temperatures in the 20 cm wide adjacent area to the gap. The dotted lines illustrate the effect of air infiltration while the solid lines without air infiltration. The results showed on Figure 7 are presented in five steps, at time: 0, 10, 20, 30 and 40 minutes.

Discussion of the results

Laboratory investigation highlights that the lowest temperature values occur in the middle of an air gap. Even in the initial state, there is a small difference between the middle of the gap, its surrounding and the adjacent area. Temperature difference is rising while the air is flowing through the gap. More time the filtration takes, more extensive the changes of temperature are.

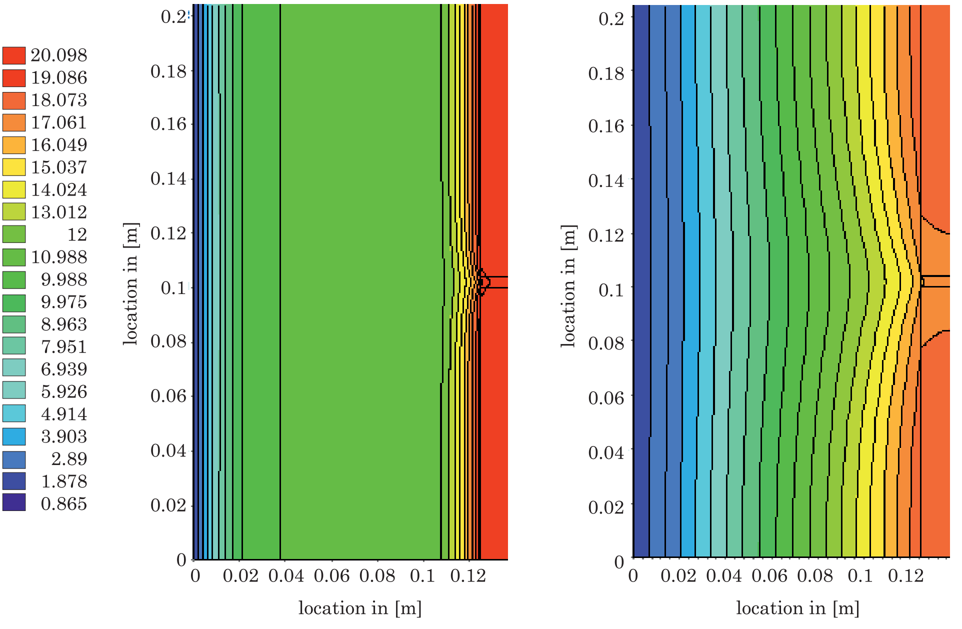

Fig. 6. The results of simulation performed to extended balance equation including air filtration, initial state on the left side and state after 40 minutes wind load on the right side

On Figures 3 and 4 it is shown, that along the gap, the temperature maps differ a little. It might be a result of non-homogeneity of materials used in laboratory investigation, especially the thermal insulation of loose mineral wool fibers is not isotropic. In order to achieve a natural situation of the partition insulated with loose mineral wool fibers in existing buildings, the thermal insulation was initially compacted manually. That may be a reason for partial occurrence of higher mineral wool density. Additionally there may be texture difference on surface of the gypsum boards.

Figures 6 and 7 illustrate results of computational simulation using Delphin software. Averaged properties of materials and dimensions used in simulation affect the symmetry of isotherms in cross section of specimen. In reality, as presented on thermograms on Fig. 3 and 4, the symmetry does not exist. Figure 5. emphasizes the range of thermal impact of air gap on its surrounding. In the initial state there were imperceptible changes in temperature fields, while after 10 minutes of infiltration, the changes are significant.

The lowest temperatures, similar in values, both in laboratory and simulation results, occurred in the middle of the gap. Differences in the area adjacent to gap may be due to imperfections in hand made specimen wall in climatic chamber.

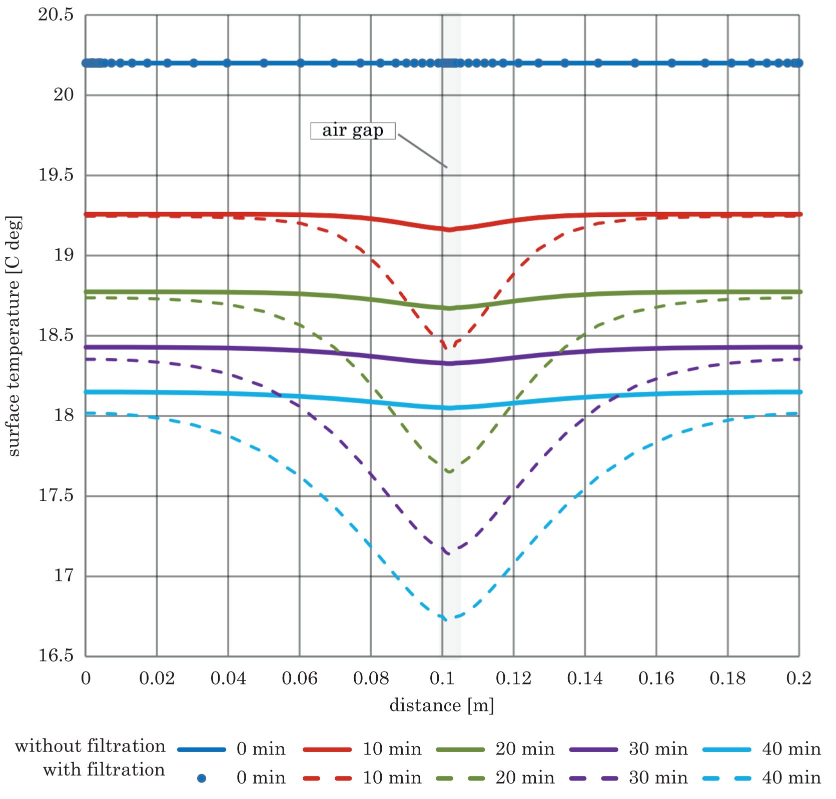

Fig. 7. Temperature curves illustrating simulation cooling the air gap and the adjacent area with and without air infiltration in five time steps

Conclusions

The implementation of laboratory study and simulation should enhance the knowledge about the impact of thermal bridges caused by air infiltration on the surface temperature adjacent to them. Although in many countries it is forbidden to construct building elements without wind and air barriers, unexpected cracks may occur everywhere. Many defects of building envelope appear after few years of using a building. In such situation, ATB should be included in heat balance calculations.

Comparison of the simulation and laboratory experiment results is positive. It means that the simulation model can be used to assess ATB values in the future. The actual work will be extended by thermal research in non-isothermal climatic chamber on other thermal insulation materials and other types of construction. There is also a need for a statistical analysis of pressure load on the heat losses in the air gaps.

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