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AIR THERMAL BRIDGES

POWIETRZNE MOSTKI CIEPLNE

Abstract

The paper presents the phenomenon of air thermal bridges. The results of thermal simulation are presented. The impact of air infiltration on the surface temperature adjacent to air thermal bridges is discussed.

Keywords: *air thermal bridge*, *infiltration*, *air tightness of building envelope*

Streszczenie

W artykule przedstawiono zjawisko powietrznych mostków cieplnych. Przedstawiono wyniki symulacji cieplnych. Omówiono wpływ infiltracji powietrza na zmiany pola temperatury znajdującego się w pobliżu powietrznego mostka cieplnego.

Słowa kluczowe: *powietrzne mostki cieplne*, *infiltracja*, *szczelność powietrzna budynków*

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1. Introduction

Thermal Bridges in a building envelope can be defined as those parts of a construction in which the thermal resistance is significantly less than the adjacent portions. The reason for this may be the total or partial occurrence of a material with higher thermal conductivity or a decreased thickness of the building envelope. Both situations often occur simultaneously. Thermal bridges are situated in the connections between building components or in places where the building structures alter the composition. Thermal bridges in building constructions cause changes in heat flow rates and surface temperatures compared with those of the unbridged sides and also cause three-dimensional or two-dimensional heat flows. In recent years, the interest in a new type of thermal bridges that were previously marginalized in the building heat calculations has been growing. These are places of increased air infiltration and are named in the article as air thermal bridges (in brief ATP). The paper presents selected issues relating to the identification of technical and computing issues in these types of defects in building envelopes and highlights the importance of air infiltration in the heat balance of buildings.

2. The issue of air thermal bridges

Air thermal bridges are a special type of heat loss problem whose driving force is the movement of air. This phenomenon may apply to both linear and point zones, as in the case of structural thermal bridges. ATBs differ from structural bridges with regard to the complexity of the heat transfer, since their impact on increasing the heat demands in buildings is much larger. There are two types of ATB. The first type concerns the case of channel flow in which the air flows through the entire thickness of the construction with the inlet and outlet, so the bridge may be described as a slotted air bridge. The air flow, at a specified temperature and humidity, changes the magnitude of the local heat flux and temperature in the vicinity of the channel. The second type concerns the case in which the air affects one side of the element without the possibility of channel flow, so the bridge may be described as a one-sided air bridge. It particularly applies to porous and fibrous materials exposed both locally or to the wind. Due to the prevalence of this case, it will be discussed first.

2.1. One-side air thermal bridge

This type of heat disorder occurs primarily in the outer layers of the building envelope in cases where a wind barrier was damaged or incorrectly constructed. One-sided air bridges concern porous and fibrous materials protected faulty or not protected against wind force. This problem particularly affects improperly made lightweight constructions, mainly in the attic zones, where poor protection against air filtration is the most frequently appearing failure. One-sided ATBs arise as a result of the wind pulsation action, however, higher temperatures during summer cause the air movement as well. The impact of one-sided ATBs on heat transfer through the building envelope, despite it prevalence, is so far little explored

Fig. 1. Picture of poorly constructed roof and corresponding thermogram illustrating the impact of one-sided ATBs on heat transfer. Interior temperature $t_i = 18°C$, exterior $t_e = -10°C$

apart from a few works [1] rarely seen in the literature. Fig. 1 presents a poorly constructed roof (no continuity of a windproof membrane) and its corresponding thermogram.

2.2. Slotted air thermal bridge

Slotted ATBs arise as a result of pressure differences on both sides of the building envelope and can be caused by natural forces, i.e., thermal buoyancy or 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 window and door, construction joints, contacts of materials of different structures and textures, holes for the installation cables and many others. Potential leaks gaps and cracks in a building envelope may be caused by building exploitation or due to improper manufacture of elements.

Slotted ATBs are often investigated by scientists, but the main issue is the impact of air filtration on natural ventilation effectiveness, moisture degradation of porous elements and the distribution of contaminants in buildings. The impact of air filtration on heat transfer processes and temperature distribution in the vicinity of the cracks is rarely discussed. Dufour, Derome and Zmeuranu used thermography to measure the surface temperature of single-layer walls subjected to air flow through surrogates of cracks in laboratory conditions. The authors solved an inverse problem using developed image-processing methods of recorded thermograms, i.e., using the edge detection technique and correlations for peak height and missing attenuation to estimate the widths of cracks with an error of less than 4% [2].
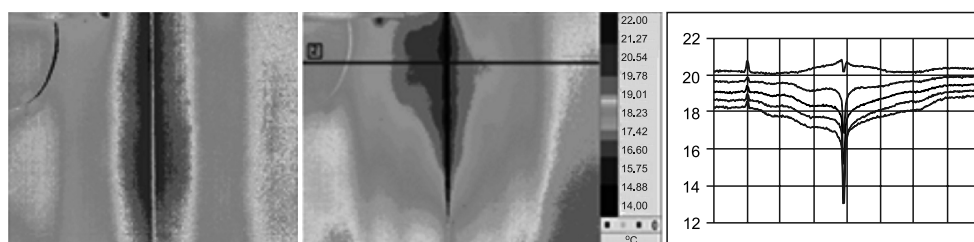

Fig. 2. Thermograms and graph illustrating the impact of slotted ATBs on surface temperature of the inner side of the frame wall

Fig. 2 presents thermograms of a defective board contact zone on the inner side of the frame wall filled with loose mineral wool, unprotected against air filtration. A model investigation, with highly sensitive (20 mK temperature) infrared camera FLIR SC 7200, was conducted in a non-isothermal climatic chamber in a Building Physics Laboratory at the University of Warmia and Mazury in Olsztyn. The thermograms present the impact of the slotted ATBs on surface temperature in a contact zone of gypsum boards. The boundary conditions are: interior temperature $t_i = 21°C$; exterior $t_e = 0°C$; wind speed by the colder side $v = 2$ m/s. The presented thermograms were recorded at 0 and 40 minutes. The temperature curves in the graph illustrate cooling of the crack and the adjacent area at 0, 10, 20, 30 and 40 minutes.

3. Thermal bridge calculation in the heat flux through the building envelope

Existing procedures address structural thermal bridges: linear and point in the calculation of the heat flux through the building envelope. Thermal transmittance of linear thermal bridges can be approximately substituted from catalogues of thermal bridges in ISO 14683 [3] or calculated using more advanced computational methods according to ISO 10211 [4]. These procedures include an error up to 20%. Neither of them include an infiltration phenomenon. Even the ISO standard 10077-2 [6] for thermal calculations for window frames do not take into account this phenomenon. The only form of taking air flow into account in energy calculation is using a convective coefficient on the internal and external surfaces of the construction according to ISO 6946 [5].

Air filtration significantly changes the temperature and heat transfer process on the surface of air permeable construction, this is caused by a certain amount of heat moving by air flux. During infiltration, air flows through the construction in the opposite direction to the conducted heat flow, so the air receives part of the heat, therefore, the intensity of heat transfer on the internal surface of construction is reduced. The heat flux on the internal surface of the construction reaches its maximum value, but the closer to the outer surface, the smaller the heat flux is. It is due to the recovery of heat that warms up the air flowing toward the internal side.

During the exfiltration process, air flow and conducted heat has the same direction therefore, the heat transfer intensity on the internal surface increases.

4. A case study of air thermal bridges

A new apartment envelope was chosen for this investigation. The wall consists of autoclaved aerated concrete ($\lambda = 0.17$ W/mK) with a width of 24 cm and expanded polystyrene EPS ($\lambda = 0.040$ W/mK) with a width of 15 cm, plastered and painted both sides. In the construction layer, PVC windows with 6-ventricular frames (width 7 cm), double glazing (thickness 4 mm) and packed with 16 mm of argon were mounted.

The thermogram, made by infrared camera FLIR B335 with thermal sensitivity 50 mK, was recorded on the inner side of the apartment with the conditions: $t_e = -8°C$, $t_i = 23°C$;
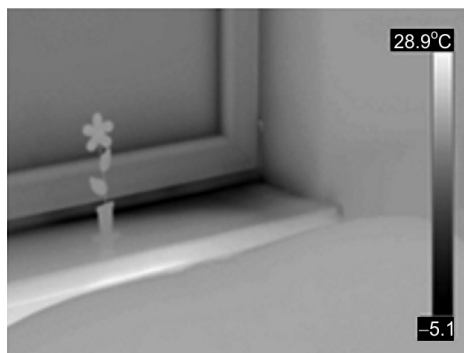
Fig. 3. An analyzed thermogram

wind speed of 0 kilometers per hour; RH inner – 50%; distance – 1 m; emissivity – 0.91. The lowest temperature in the contact zone of the window frame and window sill was 4.4°C.

A thermal simulation of this wall area based on the construction details was computed. For the purpose of simulation, a model of the wall and window was simplified, i.e., frame and glazing were changed by substitutes with the same thermal resistance. Plaster and painted layers were omitted. An air gap, 2 mm thickness, was placed under the external windowsill and between the window frame and PUR foam under the frame sealing the window's joint with the wall. Such a gap width, according to ISO 10077-2, qualifies it as a non-ventilated.

The simulation was performed on the basis of ISO 10211 in Autodesk Simulation Multiphysics with selected steady-state heat transfer model, based on the fundamental equations of heat conduction. The calculations that were performed for the two cases differ in the values of heat transfer resistance on the internal and external surfaces designated in accordance with ISO6946. In the first case, the default values of the heat transfer resistance
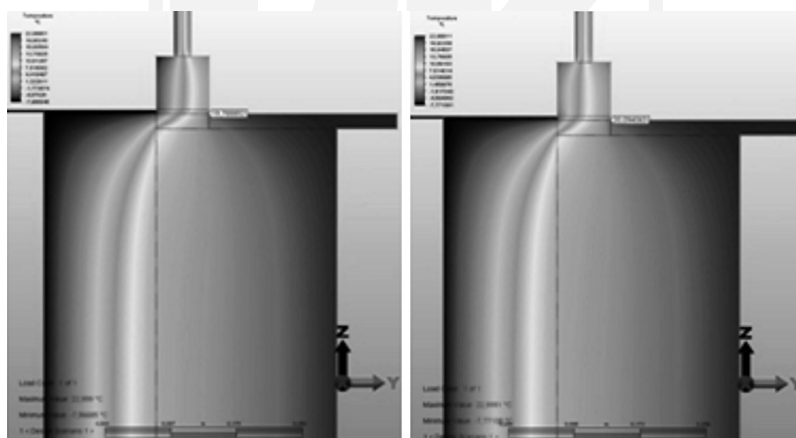

Fig. 4. The results of the simulation performed in the steady-state conditions, on the left side $R_{se} = 0.04$ m²K/W, $R_{si} = 0.13$ m²K/W, on the right $R_{se} = R_{si} = 0.128$ m²K/W. Thermal load applied to edges adjacent to environment

for the horizontal direction of heat flow were used: R_{se} = 0.04 m²K/W, R_{si} = 0.13 m²K/W, while in the second case, the values were calculated for the boundary conditions: R_{se} = R_{si} = 0.128 m²K/W. The heat transfer coefficients and temperature were applied only to the edges adjacent to the internal and external environment. No load was applied to the air gap. In the first case, the temperature at the contact zone of the window frame and windowsill is 19.79°C while in the second, it is 20.09°C.

The results were different from those in reality, so the model was modified by applying an external heat transfer coefficient and temperature to the air gap surfaces. The phenomenon of heating the air flowing into the room was omitted. In the first case, there was a temperature of 14.29°C in the contact zone, in the second,14.35°C. R_{se}, R_{si} are the same as in the previous step.
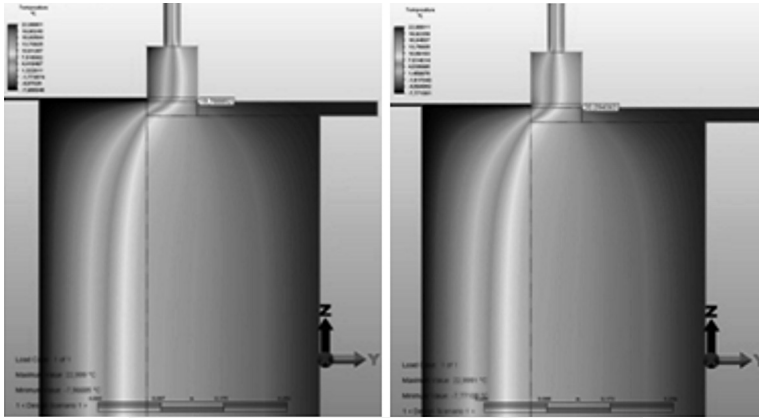

Fig. 5. The results of the simulation performed in the steady-state conditions, on the left side R_{se} = 0.04 m²K/W, R_{si} = 0.13 m²K/W, on the right R_{se} = R_{si} = 0.128 m²K/W. Thermal load applied to edges adjacent to the environment and the air gap

The results of simulations performed in both of the above cases do not reflect the real problem. In the next approximation step, the thermal simulation was performed for a wall cross-section using the test based on the extended equation of heat and mass balance. For this purpose, the calculation software Delphin 5 was used. Initially, the simulation was performed in analogy to the Autodesk based solely on the fundamental laws of heat conduction, omitting the air filtration. In analogy to the previous step, the heat transfer resistance was the same, in the first case: R_{se} = 0.04 m²K/W, R_{si} = 0.13 m²K/W, while in the second: R_{se} = = R_{si} = 0.128 m²K/W. In the first case, there is a temperature of 17.93°C in the contact zone, in the second,18.50°C.

In the next step, the extended equation of heat and mass balance was used. A pressure difference of 5 Pa was calculated for the boundary conditions. The simulation included the same R_{se} and R_{si} as in the previous step. In the first case, the temperature was –6.34°C in contact zone, while in the second, –5.83°C.

The study supports the notion that in addition to the traditionally conceived structural thermal bridges resulting from the change of material or structure of the barrier, there are air
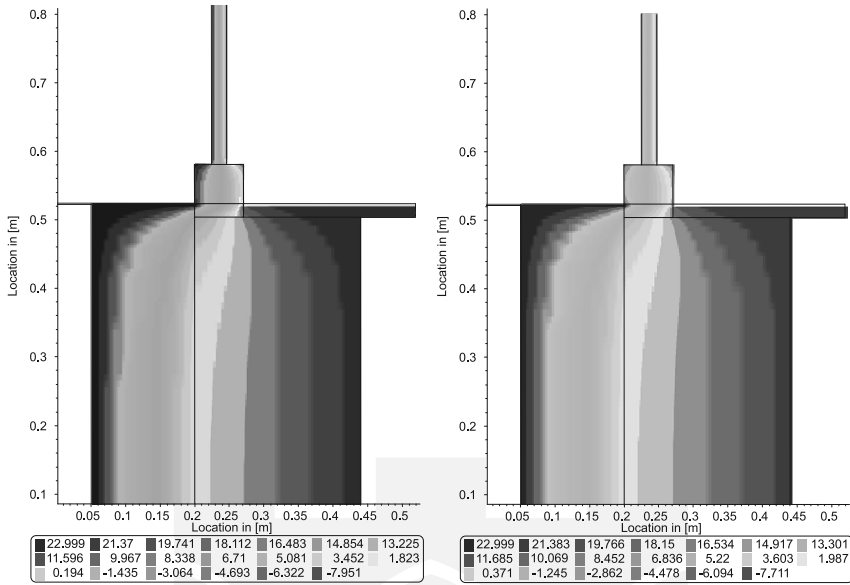
Fig. 6. The results of the simulation performed with the extended balance equation, on the left side R_{se} = 0.04 m²K/W, R_{si} = 0.13 m²K/W, on the right R_{se} = R_{si} = 0.128 m²K/W. Thermal load applied to edges adjacent to environment
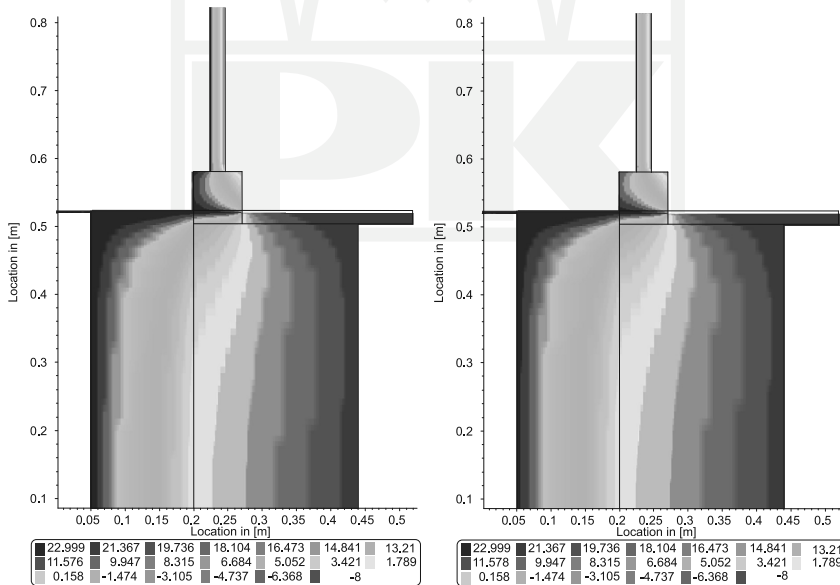

Fig. 7. The results of the simulation performed with the extended balance equation, on the left side R_{se} = 0.04 m²K/W, R_{si} = 0.13 m²K/W, on the right R_{se} = R_{si} = 0.128 m²K/W, Δp = 5 Pa

thermal bridges, caused by the movement of air. In winter, when the air temperature inside the rooms and exterior differ considerably, a thermal buoyancy phenomenon in air permeable compartments occurs almost all the time. It is only mitigated during the airing of rooms. Wind is another causative factor of air filtration, but in buildings equipped with an exhaust ventilation system, there is an additional driving force causing air channel flows.

Currently, in the Building Physics Laboratory at the University of Warmia and Mazury in Olsztyn, there are conducted researches on one-sided ATBs of fibrous materials, one side exposed to wind forces. So far, achieved results show that heat loss resulting from pulsed wind force in areas not protected against wind is at least several times more than in the adjacent protected areas. In parallel, there are conducted researches underway to repair the existing air gaps under difficult of only one-sided possible access to them (internal or external).

5. Conclusions

The implementation of this simulation should enhance the knowledge about the impact of air thermal bridges on the temperature of surfaces adjacent to them. The difference between results in the last step and reality may be due to variable dimensions of air gaps. The differences between models are due to different balance equations. Air thermal bridges should be included in heat balance calculations. In most cases, the air tightness measurements are obligatory in order to determine the presence of such defects in the building envelope.

R e f e r e n c e s

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