7th International Building Physics Conference

IBPC2018

Proceedings

SYRACUSE, NY, USA

September 23 - 26, 2018

Healthy, Intelligent and Resilient Buildings and Urban Environments

ibpc2018.org | #ibpc2018

Thermal stability of lightweight frame partitions exposed to pulsed wind load

Piotr Kosiński[1,*], Robert Wójcik[1], Beata Semen[1]

[1]University of Warmia and Mazury in Olsztyn, Olsztyn, Poland

[*]*Corresponding email: piotr.kosinski@uwm.edu.pl*

ABSTRACT
Much has been said about air infiltration, especially of ventilation losses and air quality. There is less information on heat losses through increased convection. This problem particularly concerns on one sided wind washing of the building envelope characterised with seeming airtightness of construction partitions. On the base of measurements undertaken in existing buildings constructed as lightweight timber structures filled with fiber materials it can be seen that air filtration also contributes to increased heat transfer through the building envelope. This paper presents the results of the research on the thermal stability of building partitions insulated with fiber materials and exposed to pulsed air filtration due to the wind load.

KEYWORDS
wind washing, air tightness, frame lightweight constructions, loose thermal insulations

INTRODUCTION

Fibrous thermal insulation materials, such as mineral wool, glass wool or natural materials, are characterized by high porosity. The tendency to reduce thermal conductivity of such materials causes increase of porosity and thus increased air permeability. Finally, thermal properties can be different than planned, because high air permeability increases natural convection in pores, which results in increased heat transmission through thermal insulation (Økland, 1998, Deseyve and Bednar 2006, Gullbrekken et al 2015). In addition, heat losses can also be caused by forced convection, e.g. wind washing. A qualitative and quantitative recognition of thermal losses caused by convection in fibrous insulation materials is particularly important, especially in lightweight frame constructions.

In many buildings the value of the heat transfer coefficient of the building envelope is significantly higher than the results of thermal calculations based on the thickness and thermal conductivity of embedded materials. As observed by the authors, the main reason for this phenomenon is the wind washing the porous thermal insulation. Nowadays, frame constructions are usually covered with barriers protecting against air filtration and wind washing. However, not all countries have the technical requirements for air and wind protection of the partitions. Hence many buildings are still constructed with thermal insulation layer exposed to wind washing. Although in the case of new buildings weather barrier requirements are well understood, the use of an exterior air barrier in existing buildings may not be feasible. What is important is that air sealing of the building envelope from the inside of the building partitions does not guarantee that the heat transfer coefficient of the envelope will meet the energy conservation criteria. If the inner layers (like vapour barrier) are set up continuously, the air tightness test can give a satisfactory result, despite the fact that the entire layer of thermal insulation is unprotected or only partly protected against wind washing (lack of weather barrier). Wójcik and Kosiński (2015) described this phenomena as the seeming air tightness of the building envelope, which is relevant for both existing and new buildings.

A PROBLEM OF WIND WASHING IN EXISTING BUILDINGS

Figure 1 presents thermograms registered within the attic (4^{th} floor) of a public building. The building was renovated few years before this research and the attic was adopted for utility purposes. The knee and interior walls, as well as ceiling were constructed in the lightweight steel skeleton technology. The sheathing was made of single layer gypsum boards, while the thermal insulation consisted of loose mineral wool 12-20 cm thick. On the internal side, between the boards and thermal insulation, a polyethylene film was installed as a vapour retarder. The knee wall construction did not include wind prevention layers while in the roof construction the wind barrier membrane was used but its junctions were not glued (Figure 1a). The air tightness of the attic was measured using the Blower Door test, corresponding to standard EN 13829. The achieved n_{50} was lower than 3.0 h^{-1} for method B, which is claimed in Polish regulations. No leakages between sheathing boards were found, which shows a continuous sheath of polyethylene film. Leakages occurred at the electrical outlets area (Figure 1f) and in few roof window frames. A Flir B335 infrared camera with 50 mK thermal sensitivity was used to assess the thermal quality of the whole attic envelope The boundary conditions of measurements: average internal temperature +17 °C, external temperature -15.3 °C and average wind speed 3 m/s.

Figure 1b presents the junction of the interior and knee walls with roof and roof window, while Figure 1c presents the thermogram of this area. Figure 1d presents the junction of knee and interior walls with roof, while Figure 1e presents the thermogram of this area. Figure 1f presents the thermogram of the electrical socket installed in the knee wall during the air tightness measurements at 50 Pa underpressure. The hypothermia of the analyzed areas was caused by the wind washing of the mineral wool filling the frame partitions. Infrared (IR) analysis, based on surface and surrounding air temperature comparison revealed a 75% reduction of thermal resistance of the investigated partition.

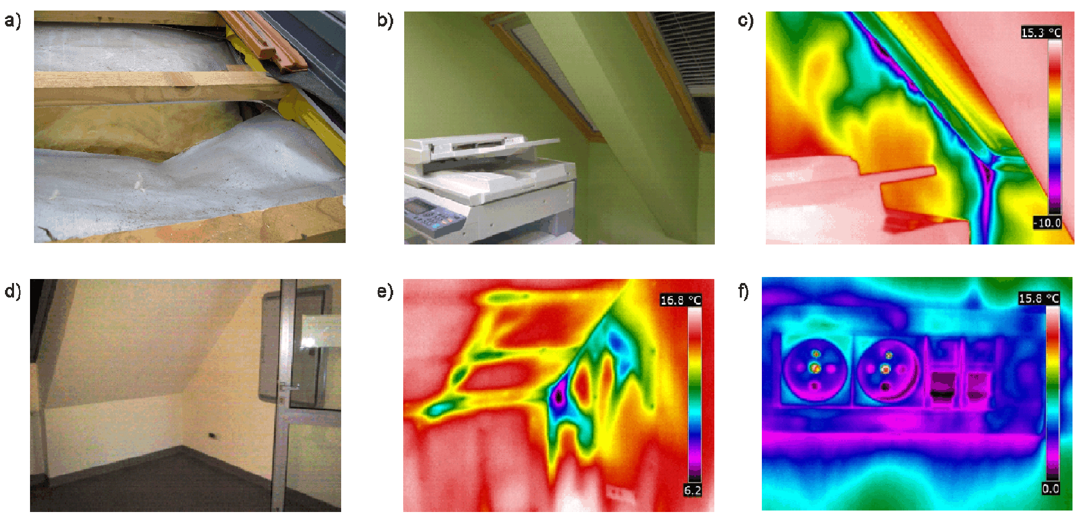

Figure 1. The described roof and attic. a) View of the roof construction, b-c) Problematic area of the walls and roof junction and its thermogram, d-e) Problematic area of the walls and roof junction and its thermogram, f) Thermogram of the electrical socket.

LABORATORY SET UP

A laboratory investigation was based on the results of air filtration measurements in existing Polish buildings. The purpose of the study was to investigate the thermal stability of lightweight frame partitions filled with loose mineral wool exposed to wind washing. Figure 2 presents the scheme of the laboratory investigation – the climatic chamber and models.

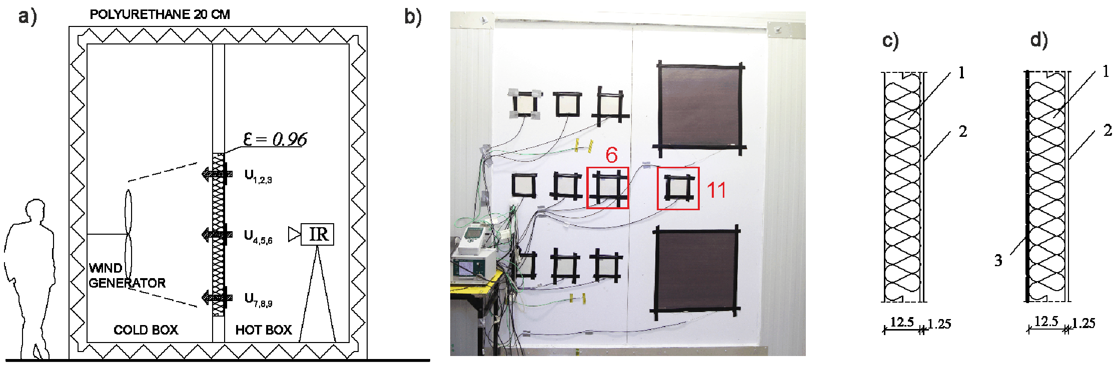

Figure 2. Schematic representation of the laboratory set-up. a) Cross section of the climatic chamber with a mounted specimen, b) View of the inner surface of the wall specimen, c, d) Cross sections of the specimen: c) 1st model, d) 2nd model, 1 – loose mineral wool, 2 – gypsum board, 3 – partial wind barrier.

For the purpose of this work, two wooden frame model partitions (Figure 2c, d) were investigated in a special non-isothermal climatic chamber at the building physics laboratory at the University of Warmia and Mazury in Olsztyn. The chamber (Figure 2a) allows the measurement of air filtration impact on heat transfer through building elements. Samples of natural dimensions are mounted in an inspection frame between hot and cold sections of the chamber. In the cold part an air supply system of adjustable power is used to generate wind. The chamber is mainly used for carried out tests with the wooden frame partitions filled with loose fiber materials.

The constructed models correspond to existing buildings, where authors found the seeming air tight partitions. The 1st model (Figure 2c) consists of frame partition, gypsum cardboards (1.25 cm) on the internal side, insulation (12.5 cm) made of loose mineral wool with a mean density of 120 kg/m^3. The areas of different density were deliberately made in order to carry out a detailed analysis of the impact of fiber compaction on the thermal stability of partition (in future). The 2nd model (Figure 2d) – the same layers as the 1st, but with an additional wind retarder made of polypropylene membrane on the exterior side. The membrane junction was intentionally not connected or glued to imitate the leaks for wind washing and is placed at the level of sensors $U_{1,2,3}$ (Fig. 2a). Heat flux sensors (Figure 2b), thermocouples and thermal anemometers were placed on the wall surfaces. The Ahlborn system was used to measure and record the thermal parameters. During the research, the heat flux density (according to ISO 9869) and the temperature changes were registered in a function of wind speed. Simultaneously, infrared radiation emitted by the test specimen was being detected by the FLIR scientific camera SC7200 with a thermal sensitivity of 17 mK.

Two considered measurements areas (250 x 250 mm) are presented on Figure 2b. Both of them are in a distance from the windproof membrane junction. The 6th area is placed almost in the middle of the specimen height, 480 mm from the left and 770 mm from the upper edge of the specimen), while the 11th is placed 900 mm from the left and 770 mm from the upper edge. Four wind speeds corresponding to average local windy conditions were generated (0.46 m/s, 1.43 m/s, 2.36 m/s, 3.24 m/s). The wind load was generated in intervals: 4.5-5.0 hours of wind, 18.5-19.5 hours calm. The intervals were determined based on previous measurements and experience, but a manual control was the reason for the differences in intervals length. The cycle for each wind speed was repeated 4 times. Thermal changes were converted to thermal resistance changes. During the measurements, the door to the hot part of the chamber was intentionally left open to imitate the daily thermal changes in the buildings.

RESULTS

Figures 3 and 4 present the changes of thermal resistance surface to surface for both models caused by the constant speed of wind washing the insulation. The results are presented for two analyzed areas: 6th and 11th differing with the position in examined models. The graphs present the results for 44.5 hours, what is almost two full cycles. Figures 3a and 4a present the results of the 1st model (without wind protection), while Figures 3b and 4b the results of the 2nd model (partial wind protection). The initial thermal resistance for both analyzed areas is approx. 5 m^2K/W, while theoretical value around 4 m^2K/W. It can be clearly seen that in the 1st model the reduction of thermal resistance starts simultaneously with the wind operating. The higher the wind speed, the faster the reduction.

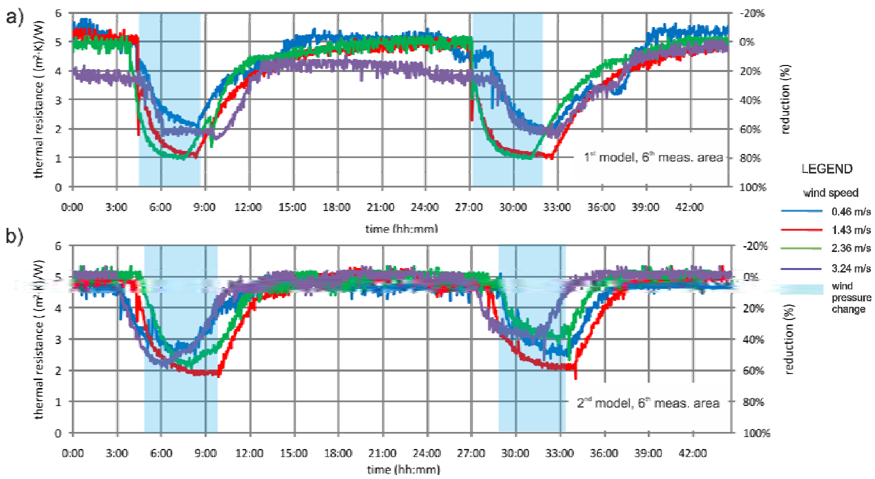

Figure 3. Changes of thermal resistance at constant wind speeds registered for the 6th measurement area for both models.

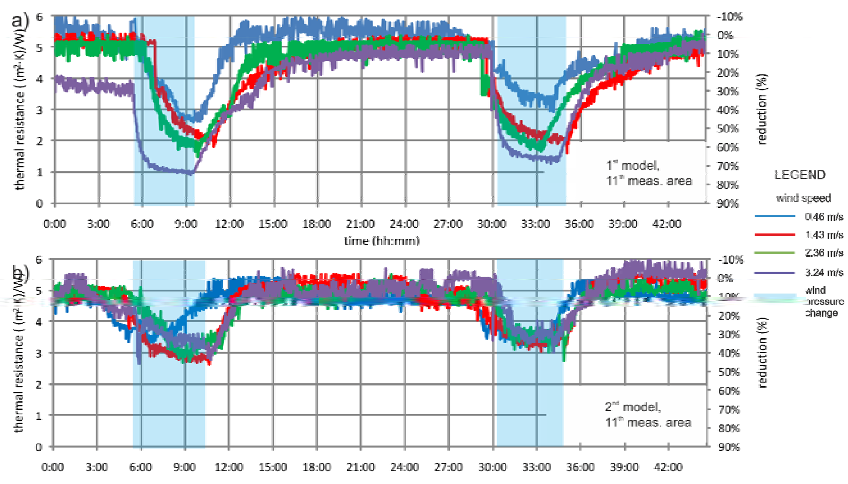

Figure 4. Changes of thermal resistance at constant wind speeds registered for the 11th measurement area for both models.

For the 1st model at a wind speed of 0.54 m/s, the reduction of the thermal resistance to the minimum value takes average 3 hours 18 min, for speed 3.24 m/s it is 1 hour 50 min. In the case of the 2nd model, the at a wind speed of 0.54 m/s, the reduction of the thermal resistance to the minimum value takes average 3 hours 20 min, while for speed 3.24 m/s it takes 2 hours 28 min. A detailed summary of the time needed to achieve the maximum reduction of the thermal resistance due to the wind speed is shown in a Figure 5a.

Table 1. The maximal reduction of thermal resistance surface to surface during wind washing

Symptom or Condition	0.54 m/s	1.43 m/s	2.46 m/s	3.24 m/s
1st model	52-64%	69-82%	70-80%	60-75%
2nd model	35-49%	48-65%	46-60%	46-58%

The reduction of thermal resistance surface to surface is presented in the Table 1. The time required for the partition to return to the thermal equilibrium after wind washing depends rather on the protection against wind than on the wind speed. For the 1st model the needed return time varies in the range 4 hours 50 min - 6 hours 04 min, while for the 2nd model varies in the range 2 hours 46 min - 4 hours 11 min. Detailed data are presented in the Figure 5b.

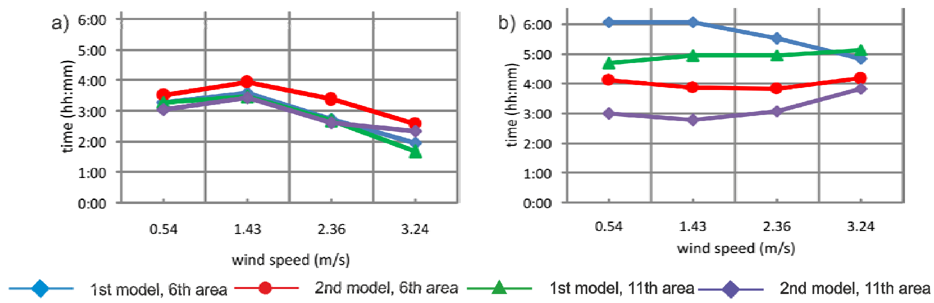

Figure 5. Time needed to achieve: a) Maximal thermal resistance reduction, b) Thermal equilibrium after wind washing.

DISCUSSIONS

The results of the study are similar to those presented in the work of Wójcik and Kosiński (2015). Slightly lower reduction of thermal resistance in this work results from higher density of loose mineral wool and thus its lower air permeability. The averaging during the data recording was used to eliminate accidental peaks resulting from the use of the building. However, even this procedure did not protect against irregular and various course of the thermal resistance changes curves. This is possible due to both the interaction of the environment as well as the natural convection which occurs in the fibrous thermal insulation even under windless conditions. The character of changes of the thermal resistance allows analysis of changes of its value due to the wind speed. In both models the maximum reduction of the thermal resistance was obtained for the average wind speed of 1.43 m/s, not for 3.24 m/s. This may be due to the loose fibers's susceptibility to deformation under the influence of wind pressure. In the case of the fastest wind the material was compressed and thus it obtains lower air permeability in this area.

The temperature of the cold side of chamber was maintained at the level of 0.5-1.3°C, while of the hot side, depending on the building heating, temperature range was 14.2-18.7°C. Exceptionally, during the test with a wind speed 3.24 m/s on the 1st model, the temperature range of the cold side was 3.9-7.9°C, which could have been caused by a cooling system failure. Fortunately, even in this case, the temperature range of the hot side was 17.4-18.7°C and the temperature difference between hot and cold sides during the windless intervals did not drop below 13.0°C.

The time that models need to return to equilibrium does not depend on the wind speed, but on the reduction of thermal reduction caused by forced convection. The higher the changes the longer the return time. The time required to stabilize the partition is longer than the period of maximal reducing of the thermal resistance. It is also important to analyze the values registered for the maximum wind speed (3.24 m/s). As it is visible in the Figures 3a and 4a, the initial thermal resistance of both analyzed areas for this wind speed was smaller than in the other cases. Just after the second cycle, the resistance value was similar to the other cases. This may have resulted from measurement error or problems with the cooler, or the lack of full thermodynamic stabilization of the model. It should be also noticed that the measurements were conducted on the loose fiber thermal insulation which may deform under the wind load. This can be a source of potential differences between measurement cases.

CONCLUSIONS

Based on the research it can be stated that the thermal losses induced by wind washing in frame lightweight partitions filled with loose fiber insulation depend on many factors, including wind speed and construction of the partition. The greater the air permeability of the insulation, the more rapid thermal changes due to wind washing. The partial wind barrier causes a minimal reduction of heat losses due to air filtration in the partition, though only fully sheltered areas of partition are characterized by lower heat losses. Several hours of wind washing results in a longer period of transition of the partition into a state of thermal equilibrium, even 3 times longer than time needed to achieve a maximum reduction.

Current research is directed towards determining moisture distribution in the models. This may give an answer on the depth of the wind penetration in the frame lightweight partitions.

ACKNOWLEDGEMENT

This paper is supported by University of Josip Juraj Strossmayer Osijek, Croatia, under research project titled “Innovative simulation model for determination of heat losses in buildings due to infiltration”, 2017 - 2018, IZIP 2016 and by the by the Polish Ministry of Science and Higher Education with the statutory research.

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