Thermal functioning of a transparent barrier equipped with a system of external thermal insulation shields

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Abstract. The article presents the results of tests of the thermal operation of a transparent barrier, which is equipped with an external thermal insulation roller blind. The tests were carried out under real climatic conditions. The barrier in question was mounted on the south façade in two external test chambers. The aim of the research was to determine whether and to what extent the external thermal insulation roller blind influences the flow of heat through the transparent barrier. The second goal was to propose a way of programming the position of the blind so that it would be beneficial in both limiting of overheating in the adjacent room during the high summer sunshine and minimizing the need to reheat the room in the case of high clouds and low temperatures in the outside air. During the tests, the following values were measured: the intensity of solar radiation, temperature (outside air, indoor air and the internal surface of the barrier), as well as the heat flux density on the internal surface of the barrier. The test results indicate that the use of an external thermal insulation roller blind has a significant impact on the thermal operation of the transparent barrier and thermal comfort in the room adjacent to the barrier. The method of programming of the position of the blind should take into account both the temperature of the outside air and the value of the intensity of solar radiation, as well as the temperature of the air in the room adjacent to the barrier, and the direction and values of the heat flux passing through this barrier.

1 Introduction

In summer, in utility rooms where glazing constitutes a large area of external barriers, they may overheat and reduce comfort during their use. At the same time, the demand for energy needed to cool these rooms increases. The use of external blinds can favourably affect the temperature stabilization in these rooms. In various centres, tests are being carried into the possibility of using blinds to limit the flow of thermal energy through glazing towards the room during the summer, as well as the possibility of using them to limit heat losses during low outdoor temperatures [1–2].

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In article [3], the authors presented the possibility of using internal and external blinds in order to limit thermal energy losses during the night through glazing. They showed that energy savings in the case of internal blinds may amount to 33%, while in the case of external blinds, energy savings were 45%. In the study in article [4] the authors used a room in a full-sized building, designed in the Italian style, in terms of the shape of the body and the material. They analysed the thermal and lighting efficiency of different arrangements of shading systems, comparing them to automatic systems of external blinds, controlled by means of external parameters. The authors confirmed the beneficial effect of automated blinds on the thermal and lighting efficiency of the room under examination.

Paper [5] presents an analysis of the influence of a curved Venetian blind situated in a window of a building located in a tropical climate. The authors compared experimental and theoretical studies. The tests were carried out with the blinds set at three angles of the slats. The tests took into account the influence of the amount of solar radiation, depending on the set angle of the blind slats, on the thermal comfort indicator of a person near the window with the blind being tested. The authors of article [6] confirmed the necessity to apply appropriate control of blinds, depending on the need for thermal comfort of people in the room. Two stages were established in the research, in which the first factor took into account the reflection coefficients of the blind's surface, in the second one the angle of the slats and the control of the up-down movement of the blinds were taken into account. In the first case, about 25% energy savings were obtained, in the second study about 29% energy savings were obtained. In article [7] the authors describe a method for determining the network radiation and optical properties of the solar glazing by means of shading. Some numerical tests were compared with measurements taken in an external test chamber. More similar results for both measurements were for a cloudy period than for a sunny period. The author of article [8] confirms how important it is to create the right conditions for thermal comfort in utility rooms in which glazing constitutes a significant area of the external barrier. He analysed the influence of sunshades in a public building. On the basis of analyses, it was found that the best thermal comfort was obtained when using an external blind and an internal blind. However, the use of an interior blind is most advantageous in the presence of high insolation and high outside temperature.

External blinds can be used not only for window openings, but also for collector-accumulative walls [9] in which glazing is the outer layer. In such barriers, in the summer period, adjacent rooms may also be overheated.

Research on external blinds is also conducted in the area of sound insulation [10–11], which also affects the comfort of the rooms used. Blinds are an important element of retrofitting the glazed building envelope. Therefore, it is necessary to conduct further research into their use, to improve the thermal comfort of utility rooms.

2 Description of research implementation

2.1 Description of the test stand

The study of the thermal operation of the transparent barrier in real climatic conditions was carried out in external climate chambers, located at the Rzeszów University of Technology (Fig. 1). The barrier in question is mounted in the southern façade of two research chambers. The stand is located so that the barrier being considered is not subject to shade during the day, thanks to which it is possible to analyse the influence of the intensity of solar radiation on the flow of heat through the wall under consideration. During the tests, a shutter made of an external thermal insulation roller blind was used, the position of which was programmed depending on the value of the measured climate parameters.

Fig. 1. Stand for examination of solar active barriers – a) view of the chambers used in the research, b) view of the entire test stand.

2.2 Description of the apparatus used during the tests

During the tests, the following were recorded: intensity of solar radiation (total, direct and dispersed), temperature and humidity of the external air, temperature and humidity of air inside the test chamber, the density of heat flow passing through the transparent barrier.

A standard plastic blind was used for testing.

Selected properties of the glazing:

- total solar energy transmittance factor: 50%,
- thermal transmittance factor: $0.6 \text{ W}/(\text{m}^2\text{K})$.

The following devices with the listed technical parameters were used to record the abovementioned parameters:

- star-shaped pyranometer (Fig. 2a):
 - measuring range: 0 to $1500 \text{ W}/\text{m}^2$,
 - resolution: $0.1 \text{ W}/\text{m}^2$,
 - cosine effect: <3% of the measured value,
 - azimuth inclination effect: <3% of the measured value,
 - temperature effect: <1% of the measured value (-20 to $+40^\circ\text{C}$),
 - accuracy: max. cosine effect + azimuth effect + temperature effect;
- albedometer (Fig. 2b):
 - total radiation range: 0 to approx. $1300 \text{ W}/\text{m}^2$,
 - cosine correction: <5% of the measured value,
 - linearity: <1% of the measured value,
 - absolute error $\leq \pm 10\%$ of the measured value;
- multi-sensor meteorological sensor (Fig. 2c):
 - wind direction: azimuth: 0 to 360° , resolution max. 1° , accuracy: max. $\pm 3^\circ$,
 - wind speed: range: 0.5 to 60 m/s, resolution max. 0.1 m/s with max value and average, accuracy: 0 to 35 m/s: max. $\pm 0.3 \text{ m/s}$ or max. $\pm 3\%$ (higher value), 36 to 60 m/s: max. $\pm 5\%$,
 - barometric pressure: range: 600 to 1100 mbar, resolution: max. 0.1 mbar, accuracy: max. $\pm 0.5 \text{ mbar}$ for 0 to 30°C , max. $\pm 1 \text{ mbar}$ for -52 to $+60^\circ\text{C}$,
 - air temperature: range: for -52 to $+60^\circ\text{C}$, max. 0.1 K resolution, accuracy: max. $\pm 0.3 \text{ K}$ for 20°C ,

- relative humidity: range: 0 to 100%RH, resolution max. 0.1%RH, accuracy: max. $\pm 3\%$ RH in 0 to 90%RH, max. $\pm 5\%$ RH for 90 to 100%RH;
- heat flow and temperature flow sensor (Fig. 2d):
 - calibration accuracy at temperature 5%,
 - nominal temperature 23°C, temperature coefficient -0.12%/K,
 - temperature accuracy of ± 0.5 K within the range of 0°C to 80°C
 - measuring range -50.0 to +125.0°C;
- multi-channel digital recorder (Fig. 2e):
 - up to 100 measuring inputs,
 - up to 100 measuring channels with the possibility of installing various measuring cards,
 - 5 output sockets for digital interfaces, analogue outputs, triggers, alarm connectors,
 - internal RAM memory 2 MB, supported by a battery, with a capacity of up to 400,000 measured values.

a) b) c) d) e)
Fig. 2. Test apparatus – a) star-shaped pyranometer, b) albedometer, c) multi-sensor meteorological sensor, d) heat flow sensor, e) multi-channel recorder.

2.3 Research methodology

The research was carried out in two helioenergetic chambers located in the Rzeszów University of Technology. Two chambers located side by side were used for direct tests. Both chambers face the front of the tested barriers to the south and have identical structure and form, thanks to which it is possible to conduct comparative tests for different types of barriers. In this study, two transparent barriers of the same structure were tested, both equipped with a system of heat-insulating shading blinds. Thanks to their identical structure, it is possible to determine the influence of the thermal insulation roller blind on the functioning of the transparent barrier. The following assumptions were made and followed during the research:

- frequency of reading test values at the level of twelve readings in one hour (one reading every five minutes),
- in chamber no. 1 during the summer period, the thermal insulation roller shutter was raised and did not affect the thermal operation of the transparent barrier,
- in chamber no. 2 during the summer period, the thermal insulation roller blind was programmed as follows:
 - a) in a situation where the value of the solar radiation intensity exceeded 250 W/m^2 , the blind was lowered covering the barrier against excessive overheating,
 - b) in a situation where the value of solar radiation intensity decreased below 150 W/m^2 , the blind was raised in order not to limit the cooling of the barrier by the outside air.
- in both chambers for the presented test period the internal air temperature was not stabilized.

3 Results and analysis

The research was carried out over a long period of time. The time interval from April 11 to June 18 in 2017 was selected for the presentation of the results, because in this period for most of the Rzeszów area there were days without cloud cover. This was the reason for strong insolation of the tested barriers. The values of solar radiation intensity for this period are shown in the graph (Fig. 3).

Fig. 3. The values of solar radiation intensity for the period from April 11 to June 18 in 2017.

The graph shows that over a period of more than two months there were only 5 days in which the maximum value of solar radiation did not exceed 400 W/m² and a total of 9 days during which this value was lower than 600 W/m². At the same time, in the same period in more than half of the days (39 out of 67) there was a maximum solar radiation intensity of over 1000 W/m². The high solar impact on the tested barrier during the period considered made it possible to investigate the influence of the application of thermal insulation of external blinds on the thermal operation of the transparent barrier. The graph (Fig. 4) presents the obtained values of heat flux density, measured on the internal surface of the barrier in question in the two test chambers.

Fig. 4. Heat flux density values on the internal surface of the barrier for the period from April 11 to June 18 in 2017.

In the case of chamber No. 1 – for 37 out of 67 days, the maximum value of the heat flux density measured in the daily period exceeded 60 W/m^2 . In the same period such a situation occurred only once in chamber No. 2 and this was caused by the lack of response of the blind to high solar exposure – the blind was not lowered due an electrical power failure in the test chambers. Table 1 presents the values of: minimum, maximum and average heat flux density determined for chambers 1 and 2.

Table 1. Values: minimum, maximum and average heat flux density, determined for the barrier area in chambers 1 and 2 for the period from April 11 to June 18 in 2017.

	chamber nr 1	chamber nr 2
	W/m^2	
minimum value	-10.40	-11.10
maximum value	146.10	78.90
average value	11.59	-1.57

It can be seen that for the analysed time period the mean value of the heat flux on the inner surface of chamber 1 is over 11.5 W/m^2 , while the average value determined in chamber 2 is negative. This is due to the fact that during strong insolation (above 250 W/m^2), the blind in chamber 2 was lowered and cut off the energy stream associated with direct radiation, not allowing excess energy into the chamber. As a result of such operation, the temperature inside chamber 2 was a few degrees lower than in chamber 1. The temperature distribution of the outdoor air and air inside chambers 1 and 2 is shown in the graph (Fig. 5).

Fig. 5. Values of outdoor air temperature and air inside chambers 1 and 2.

Due to the fact that in the test chambers, the internal air temperature was not stabilized, it was directly dependent on the outside temperature value. In analysing the graph, it should be noted that the selected period can be divided into two time periods characterized by different features. In the first period (April 11 to May 14), the outside air temperature is low. It can be seen that for the first time interval, limiting the direct solar interaction to the barrier in chamber 2 is not advantageous because the low air temperature (compared to the values obtained in chamber 1) is not always within the comfort range of use. In the second time period (15 May to 18 June) the trend is reversed.

The value of the outdoor air temperature significantly increases, and with this phenomenon the interior of the test chambers overheats. In this case, the application in chamber 1 of the reduction of the penetrating heat flux by closing the blind during a period of high insolation is desirable. Table 2 presents a summary of the values of: minimum, maximum and average air temperature in chambers 1 and 2, including the division into two time periods (from April 11 to May 14 and from May 15 to June 18).

Table 2. Values: minimum, maximum and average air temperature in chambers 1 and 2.

	chamber nr 1	chamber nr 2
11 April ÷ 14 May	°C	
minimum value	9.08	9.40
maximum value	25.80	22.56
average value	16.74	15.69
15 May ÷ 18 June	°C	
minimum value	18.96	19.26
maximum value	34.48	32.11
average value	27.53	25.53

4 Conclusions

The test results indicate that the use of an external thermal insulation roller blind significantly affects the thermal operation of the transparent barrier and the temperature of the internal air in the adjacent room. This has a direct impact on the comfort of use of this room. The external blind slightly increases the thermal resistance of the barrier, but significantly reduces the effect of direct sunlight on the heating of the adjacent room. Therefore, the use of an external blind is indicated and should be recommended especially for the southern facade of a building. The method of programming the position of the blind as an insulation system should depend on both the value of the intensity of solar radiation and the temperature of the outside air as well as the temperature of the air inside the room. A correctly programmed roller blind position control system should allow a significant improvement in the comfort of use of rooms and a reduction of energy consumption for purposes related to heating and cooling of a building in conditions of unfavourable values of climatic influences.

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