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MEASUREMENT OF THERMAL TRANSMITTANCE OF MULTI-LAYER GLAZING WITH ULTRATHIN INTERNAL GLASS PARTITIONS

POMIAR WSPÓŁCZYNNIKA PRZENIKANIA CIEPŁA WIELOWARSTWOWEGO OSZKLENIA Z WEWNĘTRZNYMI ULTRACIENKIMI SZYBAMI

A b s t r a c t

Currently, the most technologically advanced building walls have an overall heat transfer coefficient U at a level of 0.10 W/(m^{2}K) which corresponds to the passive house standard. Less demanding requirements are set for building windows for which the thermal performance has not yet been significantly improved. Therefore, there is a demand for developing new technologies for glazing with superior thermal performance, good optical quality and of the lowest possible weight. In the paper, measurements of thermal performance of multi-layer glazing with ultrathin internal glass partitions are presented.

Keywords: fenestrations, calorimetric hot box, thermal transmittance measurement

S t r e s z c z e n i e

Obecnie współczynnik przenikania ciepła ścian w budynkach energooszczędnych jest rzędu 0.10 W/(m^{2}K), co odpowiada standardowi budynków pasywnych. Z kolei mniej rygorystyczne wymagania w standardzie pasywnym dotyczą okien, gdzie współczynnik przenikania ciepła wynosi około 0.7 W/(m^{2}K). Tak więc istnieje potrzeba rozwoju technologii okien z bardzo niskimi wartościami współczynników przenikania ciepła i jednocześnie posiadających dobre walory optyczne a także niską wagę. W artykule zaprezentowano wyniki pomiarów izolacyjności cieplnej wielowarstwowego oszklenia z wewnętrznymi ultracienkimi szybami wykonane w komorze klimatycznej zgodnie z odpowiednimi normami.

Słowa kluczowe: oszklenia, komora kalorymetryczna, pomiar współczynnika przenikania ciepła

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1. Introduction

In recent times, there has been an increased focus on lowering the energy demands in buildings [1, 8, 9] leading to a reduction of transmission heat losses through the building envelope and the development of buildings that are almost air tight. However windows, to a large degree, still contribute to the total building heat loss with respect both to the cooling and heating demands [1].

The triple glazed windows are readily available on the market. Their thermal transmittance is about U_w = 0,7 W/(m^{2}K). In the paper, the heat transfer through multi-layer glazing has been analyzed. The glazing consists of two standard glass panes (internal and external) and 11 ultra-thin organic glass panes separated by 12 argon gaps. The investigated glazing prototype made by the Vis Inventis Company was placed in a Styrofoam frame. The view of the analyzed glazing is given in Fig. 1. The calorimetric hot box instruments were used to determine the thermal transmittance of the analyzed glazing [1–5, 7]. The measurements were based on PN-EN ISO 12567-1 procedure [10].

2. Measurement test stand

Experimental work focusing on measurements of the thermal transmittance of glazing presented in Figure 1 was performed in order to validate the simulation and calculation results. All investigations were carried out at Cracow University of Technology. The calorimetric hot box (CHB) was used with the test method in compliance with the PN-EN ISO 12567-1 [10] standard [3].

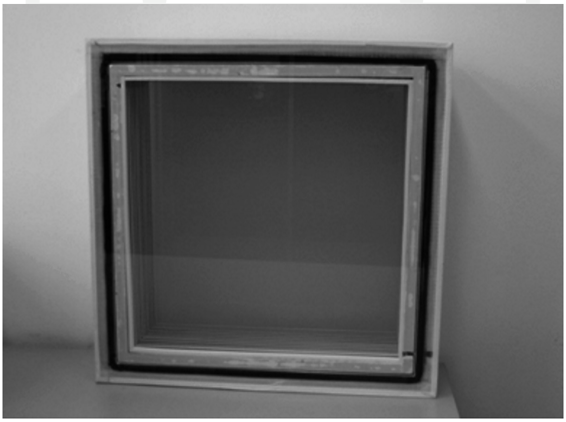

Fig. 1. The view of the glazing

The CHB system consists of a metering box, simulating the indoor environmental condition (warm side), and a climate box, simulating the outdoor environmental condition (cold side). The metering box is surrounded by a guarding box in order to minimize the heat flow rate through the metering box walls. The test specimen glazing is mounted into the opening of a surround panel. The tested glazing and surround panel are placed between the metering box and the climate box. The steady state heat flow rate through the glazing due to the constant indoor and outdoor temperature difference is measured in order to calculate the thermal transmittance [3, 10]. Figure 2 shows the schematic cross-section of the CHB system in thermal transmittance measurement mode [3, 10]. The view of the CHB system is presented in Fig. 3.

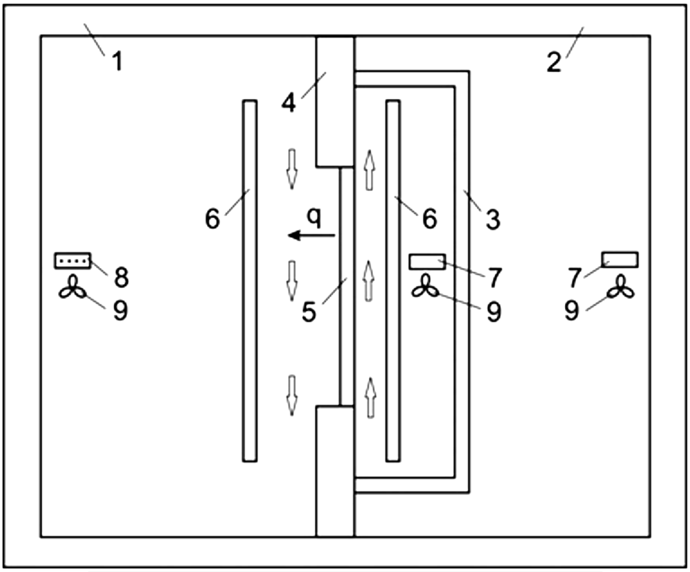

Fig. 2. CHB system scheme: 1 – climate box (outdoor side), 2 – guarding box (indoor side), 3 – metering box, 4 – surround panel, 5 – tested specimen, 6 – isothermal baffle, 7 – heater, 8 – cooling element, 9 – fan

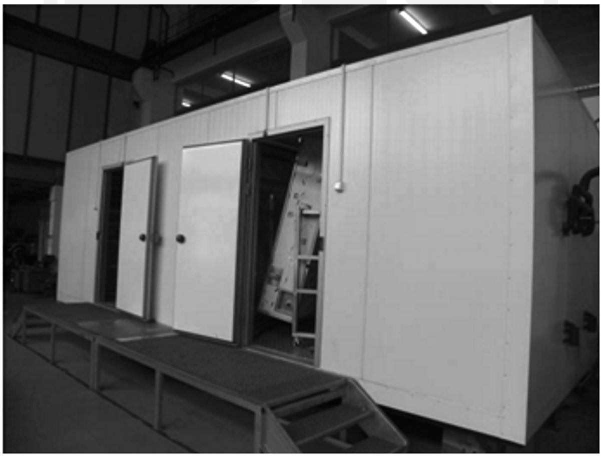

Fig. 3. General view of calorimetric hot box (CHB) system

A PID-controller based upon the measured temperature difference across the metering box walls controlled the environment in the guarded box. The cold side temperature was kept at a 0.1°C with 0.5% discrepancy of the overall temperature difference in a steady state condition. It was assumed that the stability was attained if within two hours, the measurement results were stable with fluctuations of ± 0.05% in the measured values.

The metering box was kept at an environmental temperature of 19.9°C using the same kind of PID-controller as the guarded box. The surface resistance on the cold side was established by controlling the air speed along the specimen using a set of regulated ventilators - a similar arrangement as on the warm side of the specimen in the metering box. Measurements were performed with an accuracy that meets the demands specified in the PN-EN ISO 8990 standard [7, 12].

3. Measurement results

Measurement results with the calorimetric hot box (CHB) apparatus are listed in Table 1.

Table 1

Measurement results

Air temperature in the metering box (warm side)	19.9°C
Baffle surface temperature in the metering box	19.°C
Surround panel surface temperature on the metering box side	19.5°C
Air temperature in the climate box (cold side)	0.1°C
Baffle surface temperature of the surround panel on the climate box side	0.5°C
Reveal surface temperature in the climate box	1.2°C
Surround panel surface temperature on the climate box side	0.9°C
Input power in hot box	13.81 W
Air speed on the warm side, down	0.1 m/s
Air speed on the cold side, up	1.7 m/s

The calculation results of the glazing according to the EN ISO 12567-1 [10] standard are as follows:

- environmental temperature on the warm side θ_{ni} = 19.8°C,
- environmental temperature on the cold side θ_{ne} = 0.3°C,
- total surface resistance $R_{s,t}$ = 0.253 m^{2}K/W,
- thermal transmittance of the glazing (measured) U = 0.310 W/(m^{2}K),
- total surface resistance (standardized) $R_{(s,t)st}$ = 0.17 m^{2}K/W,
- thermal transmittance of the glazing (standardized) U_{st} = 0.319 W/(m^{2}K).

A total surface resistance of 0.253 m^{2}K/W was calculated according to measured air velocities and adjacent air temperatures on the warm and cold side. With known total surface resistance, the U value of the glazing calculated according to the measurement results was equal to 0.310 W/(m^{2}K). The measured total surface resistance is then replaced by

0.04 m^{2}K/W on the cold side and 0.13 m^{2}K/W on the warm side in thermal transmittance calculation procedure [10] to achieve the standardized U value which was finally equal to 0.319 W/(m^{2}K).

4. Uncertainty analysis

With the CHB system, the heat flow through the specimen can be obtained with certain accuracy. The accuracy in each separate measurement not only depends upon the complexity of the construction being measured, but also on heat exchange with the surroundings, errors of temperature and input power measurements etc. The measurement error is not constant from specimen to specimen.

To determine the uncertainty of the calculated heat transfer coefficient, the uncertainty in each performed measurement was estimated and then combined to give a single value according to the law of propagation based on the root square formula [1–4, 10]. The thermal transmittance U is a function of n independent variables x_k, which are known with an uncertainty Δx_k. The global uncertainty of the thermal transmittance ΔU can be written as follows [2]:

$$\Delta U = \sqrt{\sum_{k=1}^{n} \left[\frac{\partial U(x_k)}{\partial x_k} \right]^2 \Delta x_k^2} \tag{1}$$

The glazing thermal transmittance uncertainty depends on the following values of parameters and their uncertainties:

$$\Delta U = \Delta U(H_{sp}, w_{sp}, d_{sp}, H_{sur}, w_{sur}, d_{sur}, \theta_{ci}, \theta_{ce}, \theta_{si,b}, \theta_{se,b}, \theta_{si,sur}, \theta_{se,sur}, \theta_{se,p}, \Phi_{in}) \tag{2}$$

where:

- U – overall heat transfer coefficient [W/(m^{2}K)],
- θ_{ci} – air temperature on hot side [°C],
- θ_{ce} – air temperature on cold side [°C],
- $\theta_{si,b}$ – baffle surface temperature on hot side [°C],
- $\theta_{se,b}$ – baffle surface temperature on cold side [°C],
- $\theta_{si,sur}$ – surround panel surface temperature on hot side [°C],
- $\theta_{se,sur}$ – surround panel surface temperature on cold side [°C],
- $\theta_{se,p}$ – reveal surface temperature on cold side [°C],
- d_{sp} – specimen thickness [m],
- d_{sur} – surround panel thickness [m],
- H_{sp} – specimen height [m],
- H_{sur} – surround panel height [m],
- w_{sp} – specimen width [m],
- w_{sur} – surround panel width [m],
- Φ_{in} – input power in hot box [W].

The U-value uncertainty is connected with the measurement errors of dimensions, temperatures and input power in the hot box, equal to 0.001 m, 0.1 K or 0.01 K and 0.52 W respectively.

The calculated value of the glazing overall heat transfer coefficient measurement uncertainty is equal to 0.070 W/(m^{2}K), this means a measurement error of about 20%.

5. Conclusions

The *U*-value measurement results of multi-layer glazing with ultrathin internal glass partitions have been presented. The calorimetric hot box method has been applied as prescribed in the PN-EN ISO 12567-1 [10] standard.

The measurement results can be compared to CFD simulation results as well as analytical calculation results given in [6]. The comparison is presented in Table 2.

Table 2

Measured and calculated results of thermal transmittance (*U*-value) of multi-layer glazing

Calculated *U*-value of glazing – CFD numerical simulation	0.3 (0.297) [W/(m^{2}K)]
Measured by a calorimetric hot box CHB system *U*-value of glazing – measurement results according to PN-EN ISO 12567-1 [6, 10]	0.3 (0.319) [W/(m^{2}K)]
Analytically calculated *U*-value of glazing –calculation according to PN-EN 673 [6, 11]	0.2 (0,181) [W/(m^{2}K)]

On Table 2, one can see a very good correlation between thermal transmittance values obtained from measurements done at the hot box calorimeter test stand and those obtained from CFD simulations. The deviation between them is about 7%.

The calculation and measurement results show that the method described in the PN-EN 673 [11] standard is not appropriate for the kind of multi-layered glazing that was investigated.

The obtained data stipulates that the CFD approach can provide a good agreement between the measured and calculated thermal transmittance (*U*-value) of multi-layer glazing. The investigation points out that it is possible to obtain a significant improvement in the thermal transmittance value of glazing that can lead to an even further lowering of heat demand of residential and commercial buildings without compromising comfort expectations.

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