Evaluation of the performance of enclosed balconies based on temperature monitoring

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Abstract. Enclosed, glazed balconies influence the energy balance of the flats thanks to the temperature rise caused by solar gains in unheated sunspaces. The potential benefits, however, may differ depending on the inhabitants’ behaviour. To evaluate these effects, internal temperature in multi-family buildings located in Zamość (a city in the eastern part of Poland) was monitored at the turn of the years 2017 and 2018. The temperature was registered with the use of iButton sensors located in flats and sunspaces. Three dwellings with the same orientation were included in the research – two with glazed balconies, differing by the area of the living space, the number of the inhabitants, and their behaviour (flats no. 1 and 2), and one with an open balcony, used for comparison (flat no. 3). Air temperature within the glazed balconies was usually higher than the external air temperature, and the sunspaces helped to reduce heat losses from the adjoining rooms by 10.7% (flat no. 1) and 26.6% (flat no. 2). The apartments also showed some differences as far as the comfort of use during summer is concerned, flat no 1 being the most prone to overheating.

1. Introduction
The heating demand of both newly designed and existing multifamily buildings may be lowered to some extent by passive greenhouse systems in the form of glazed balconies or loggias. In addition, sunspaces provide acoustic protection of the interiors and are considered visually attractive [1]. Besides these benefits, however, the unconditioned and highly glazed spaces have some drawbacks. They may be subject to temperature fluctuations, which restrict their use at the time of extreme temperatures outside and have some influence on the thermal comfort in the living space (especially during summer heatwaves) [2].

2. Experimental research on glazed balconies
Even though sunspaces are most common in warm and mild climates, many publications prove that they can effectively reduce energy demand also in colder regions [3, 4, 5]. Comprehensive monitoring of flats with glazed balconies was accomplished in Finland in 2010 [6, 7]. The outcomes proved that almost in all cases the air temperature within the space of the glazed balconies was higher than that of the air outside and that the energy savings depended to a great extent on the orientation of the balcony and the tightness and the thermal insulating properties of the casing [7].

Experimental research on greenhouse systems in buildings under usage may meet a series of problems, mostly arising from the fact, that it disturbs the everyday life of the inhabitants. Such analyses are usually carried out in more easily accessible single-family buildings [8, 9], or they are based on computer simulations [10, 11, 12].
Adverse effects of sunspaces, connected with excessive temperature rise during periods of intense solar radiation, are mentioned in the literature but attract less attention [13, 14]. The risk of overheating the dwellings with sunspaces based on temperature monitoring was evaluated in Spain [15]. The results showed the occurrence of high internal temperature and a significant influence of the users’ behaviour (e.g. using curtains or ventilating the greenhouse) upon the conditions inside. Similar results were presented in studies from Portugal, based on measurements in a historical, single-family building with a glazed balcony [16, 17]. It was possible to keep internal conditions in summer there within the comfort range only by passive means, thanks to the high thermal mass of the building partitions (delaying the heat transfer into the living space).

The presented paper broadens this research area, analysing the influence of sunspaces on the thermal conditions in flats with glazed balconies, based on long-term temperature monitoring including summer months, transitional period, and a major part of the heating season. The dwellings were located in prefabricated multifamily buildings in Zamość, a city situated in the south-eastern part of Poland and belonging to the warm-summer humid continental climate area (classification Dfb [18]).

3. Monitoring campaign
The monitoring took place thanks to the cooperation of the housing estate managers and individual flat owners. The temperature was recorded in 3 flats, two with fully enclosed balconies and one with an open balcony, used as a benchmark for summer conditions. The balconies were enclosed by the users for utility and safety reasons. The area of the flats and the number of the residents differed, but the balconies’ size, exposure, and construction were the same (Table 1).

| No. | Location       | Area of the flat and the balcony [m²] | Monitoring period       | Number of users | Average internal gains [W/m²] | Airflow at the ventilation grille [m/s] | Balcony’s glazing | Balcony’s orientation |
|-----|----------------|------------------------------------|------------------------|----------------|------------------------------|----------------------------------------|-------------------|-----------------------|
| 1.  | Tower block 11th floor | 62.34 6.36 | 3 VII 2017 – 27 III 2018 | 5              | 7.0                          | 0.3 – 0.4                              | Single uncoated | SE                    |
| 2.  | Tower block 11th floor | 35.35 6.36 | 3 VII 2017 – 27 III 2018 | 1              | 5.6                          | 0.4 – 0.5                              | Single uncoated | SE                    |
| 3.  | Tower block 8th floor | 62.34 6.36 | 11 VII 2017 – 11 X 2018 | 2              | 5.8                          | 0.4 – 0.5                              | None              | SE                    |

Internal gains were estimated based on interviews with the inhabitants, and the airflow at the ventilation grille was measured with a vane anemometer. The temperature was recorded by the iButton loggers, type DS1922L with enhanced memory and accuracy of ±5°C. They had a small size, independent power supply, and the enhanced memory ensured the possibility of seldom readouts, not interfering with the occupants’ daily activities. The data readings were made using the interface MP00206 connected to the computer with a USB cable. Recording of temperatures was carried out in the sunspaces and in the chosen rooms adjoining the glazed balconies, in half-hour intervals. In the living space, loggers were placed far from the windows and in the non-sunlit spots. In the sunspaces, sensors were fixed on the lintel walls or at the bottom side of the balcony slab, to shade them from solar radiation. Climatic data regarding the external conditions came from the station of the Polish Institute of Meteorology and Water Management – National Research Institute (IMWM – NRI), located in Zamość (identifier 350230595).

The recording of temperature started 3 July 2017, in two flats with glazed balconies. Eight days later, the temperature loggers were mounted in the third flat with an open balcony. In the first two flats, the measurements lasted until 27 March 2018 (9.5 months), in the third one, the owners withdrew from the research after 3 months. The dwellings were located in 11-storey buildings with external partitions of reinforced concrete layer prefabricates (Figure 1, 2). The buildings were insulated after their completion.
with graphite polystyrene 100 mm thick (flat no. 1 and 3) or mineral wool 80 mm thick, fitted among a wooden grid, and covered with trapezoidal metal sheets (flat no. 2). Thermal transmission coefficients of the outer partitions were respectively 0.19 W/(m²·K) and 0.21 W/(m²·K). The balconies were enclosed based on a design made on behalf of the housing cooperative in 2011. The enclosure was constructed with the use of powder-coated aluminium profiles, with the horizontal guide rails holding the panes. The glass panels were made of plain 10 mm thick toughened safety glass. At the bottom part of the enclosure, a polycarbonate chamber plate 6 mm thick was fixed to the existing railing.

![Figure 1. Glazed balconies in flats: a) no. 1, b) no. 2.](image)

3.1. Temperature profiles

Air temperature within the glazed balcony was usually higher than the external air temperature (Figure 3a). The temperature in the open balcony area also exceeded outdoor temperature, thanks to shielding from the wind. Profiles of the sunspace temperatures in flats no. 1 and 2 were similar, the temperature in the first case being slightly higher from July until November and slightly lower in the following months. The average room temperatures in summer were also comparable, but starting from September (the beginning of the heating season), they varied because of the individual heating preferences of the owners.

To evaluate the impact of the encased balconies on the heat losses from the conditioned living spaces, the temperature correction factor $b_{tr}$ was used [19], calculated for the averaged monthly temperatures:

$$b_{tr} = \frac{(\theta_{in} - \theta_{b})}{(\theta_{in} - \theta_{ex})}$$

where: $\theta_{in}$ – internal temperature in a heated room [°C], $\theta_{b}$ – air temperature in the balcony’s area [°C], $\theta_{ex}$ – external temperature [°C].

Based on the recorded data, the highest temperature correction factors were noted during the autumn and winter months (from October until January). Until October, in flats with glazed balconies the factors were similar, and the differences between $b_{tr}$ values did not exceed 5% (Figure 3b). Since November
some variations started, and in March, despite the same construction and direction of the balconies, the values of $b_{tr}$ coefficients differed by almost 40%. This probably resulted from different heating set-point temperatures – in flat no. 2 internal temperature was on average lower by 3.5ºC than in flat no. 1, due to lower internal gains and inhabitant’s preferences as to the heating intensity. In the flat with the open balcony, temperature correction factors were higher because of the lower temperatures in the balcony’s area.

![Figure 3. Results of the temperature recording: a) average monthly temperatures, b) temperature correction factors.](image)

3.2. Heat loss reduction

Heat losses through the casing of the flats were calculated during the months belonging to the heating season. The calculations took into account the internal temperatures registered during the monitoring and the experimentally determined temperature reduction coefficients $b_{tr}$. Heat transfer coefficient $H_{tr}$ [W/K] and heat losses $Q_{tr}$ [kWh] through the external partitions of the flats were estimated according to the ISO 13790 standard [20] with a monthly time-step:

$$H_{tr} = H_{tre} + b_{tr} \cdot H_{trb}$$  \hspace{1cm} (2)$$

$$H_{tre} = \sum_j A_{ej} \cdot U_{ej} + \sum_k l_{ek} \cdot \psi_{ek}$$  \hspace{1cm} (3)$$

$$H_{trb} = \sum_j A_{bj} \cdot U_{bj} + \sum_k l_{bk} \cdot \psi_{bk}$$  \hspace{1cm} (4)$$

$$Q_{tr} = H_{tr} \cdot (\theta_{in} - \theta_{ex}) \cdot t_M \cdot 10^{-3}$$  \hspace{1cm} (5)$$

where: index “e” – partitions in direct contact with external air, index “b” – partitions between the heated rooms and the sunspace, index “j” – number of partitions, index “k” – number of thermal bridges, $A$ – partition area [m$^2$], $U$ – thermal transmittance coefficient [W/(m$^2$·K)], $l$ – length of a thermal bridge [m], $\psi$ – linear thermal transmittance coefficient [W/(m·K)], $\theta_{in}$ – averaged internal temperature, $\theta_{ex}$ – averaged external temperature, $t_M$ – duration of a calculation period [h].

The heat losses were then compared with heat losses calculated for the same flats, but with open balconies (Table 2).

![Figure 3. Results of the temperature recording: a) average monthly temperatures, b) temperature correction factors.](image)

**Table 2. Heat losses reduction in the monitored flats (accuracy of the estimation ±1.2%).**

| Flat no. | IX  | X   | XI  | XII | I   | II  | III | Average |
|---------|-----|-----|-----|-----|-----|-----|-----|---------|
| 1       | 15.6| 11.7| 9.4 | 8.8 | 8.8 | 10.9| 13.0| 10.7    |
| 2       | 27.9| 21.8| 23.8| 22.3| 23.6| 29.3| 35.1| 26.6    |
| 3       | 8.1 | 3.9 | –   | –   | –   | –   | –   | 5.6     |

In the smaller flat (no. 2), the glazed buffer area gave significantly better effects – the average decrease of heat losses there was 26.6%. In flat no. 1, of a bigger area, the efficiency of the sunspace
was lower, and the decrease of heat losses amounted to 10.7% on average. The lower thermal transmission coefficients of the external walls could also contribute to this. The influence of the glazed balconies was the biggest in transition periods, and the heat transfer reduction reached a maximum in September and March. The shading from the wind of the balcony in flat 3 also gave some positive, but much smaller, results.

3.3. Overheating assessment

The literature on the subject presents various methods of the quantitative estimation of overheating in buildings without air-conditioning, where the temperature in the rooms is regulated with passive methods (such as opening or closing the windows, using curtains, or night ventilation) [21, 22, 23]. In this paper, the method of the EN standard 16798-1 was used [24], introducing the concept of “adaptive comfort” [25]. According to this method, the comfort temperature is not constant but depends on the outside air temperature.

The exponentially weighted running mean of the daily mean external air temperature was calculated from the formula [24]:

\[
\theta_{rm} = (1 - \alpha) \cdot (\theta_{ed-1} + \alpha \cdot \theta_{ed-2} + \alpha \cdot \theta_{ed-3})
\]

where: \(\theta_{rm}\) – running mean temperature for today [ºC], \(\theta_{ed-1}\), \(\theta_{ed-2}\), \(\theta_{ed-3}\) – daily mean external temperatures for the previous day, the day before, and so on [ºC], \(\alpha\) – constant between 0 and 1, the recommended value is 0.8 [–].

The comfort temperature \(\theta_c\) was presumed as:

\[
\theta_c = 0.33 \cdot \theta_{rm} + 18.8.
\]

The standard [24] describes four categories of the internal environment (from I to IV), where the acceptable deviations from the temperature of comfort for the categories I to III are respectively +2ºC and ‒3ºC, +3ºC and ‒4ºC, +4ºC and ‒5ºC.

Flats no. 1 and 2, despite the same orientation and the construction of the balcony, showed some differences as far as the comfort of use during summer is concerned (Figure 4, 5). In flat no. 1 the periods of overheating in rooms 1 and 2 were shorter than in the kitchen, while in room 2 (with a smaller area) the length of time with higher temperature was greater. The kitchen was the least comfortable place, as the length of time with the temperature exceeding the conditions of categories II and III was about 39% and 18% of the observation time. It was caused by significant internal gains and the problems with air exchange – the ventilation grille of the air duct was partly clogged up, and the airflow measured at the ventilation grille was the smallest among the flats (Table 1). What is more, the external walls of the dwelling were better insulated than in flat no. 2, adding to the effect of a less intensive heat transfer to the outside. All of the rooms exceeded the default conditions of the IIIrd category of the internal environment, however room 1 – only by 2 hours (Table 3).

![Figure 4. Indoor temperature as a function of the exponentially-weighted running mean of the outdoor temperature, flat no. 1: a) July 2017, b) August 2017.](image)
Table 3. Number of hours exceeding the categories of the indoor environment, flat no. 1.

| Monitoring period | Category I above | Category I below | Category II above | Category II below | Category III above | Category III below |
|-------------------|-----------------|-----------------|-------------------|-------------------|-------------------|-------------------|
|                   | R1              | R2              | R1/R2/K           | R1                | R2               | R1/R2/K           |
| 3 VII – 31 VIII   | 277             | 322             | 1004              | 0                 | 95               | 129               |
|                   | 559             | 2               | 43                | 257               | 0                | 0                 |

Share of hours in the observation time [%]

| Monitoring period | Category I above | Category I below | Category II above | Category II below | Category III above | Category III below |
|-------------------|-----------------|-----------------|-------------------|-------------------|-------------------|-------------------|
|                   | R               | K               | R/K               | R accumulate      | K accum            | R/K               |

In flat no. 2 the room adjacent to the balcony almost fulfilled the requirements of the IIIrd category of the internal environment, exceeding the default values only by 2 hours (Figure 5, Table 4). Internal temperatures pointed not only to periodical overheating but also cooling of the rooms, caused by the individual preferences of the inhabitant and more intense ventilation of the flat than in the previous case. Despite similar external conditions (such as orientation and shading), thanks to the smaller insulating properties of the external walls, lower internal gains, and the user’s behaviour oriented at lowering the internal temperature, this flat is less prone to overheating than flat no. 1.

Table 4. Number of hours exceeding the categories of the indoor environment, flat no. 2.

| Monitoring period | Category I above | Category I below | Category II above | Category II below | Category III above | Category III below |
|-------------------|-----------------|-----------------|-------------------|-------------------|-------------------|-------------------|
|                   | R               | K               | R/K               | R accumulate      | K accum            | R/K               |
| 3 VII – 31 VIII   | 166             | 261             | 29                | 12                | 65                | 145               |
|                   | 1                | 0               | 2                 | 48                | 0                 | 0                 |

Share of hours in the observation time [%]

Figure 5. Indoor temperature as a function of the exponentially-weighted running mean of the outdoor temperature, flat no. 2: a) July 2017, b) August 2017.

The room next to the balcony in flat no. 3 conditionally fulfilled the requirements of the IIIrd category of the internal environment (Figure 6, Table 5). Both in July and August, no temperatures below the lower comfort range were registered. Regardless of relatively low internal gains, conditions in the living space were worse than in flats 1 and 2, with glazed balconies. The owner of the flat was a retired couple, preferring not so intense summer ventilation. During the measurements, the door leading to the balcony was opened a little and windows facing the balcony were constantly closed. As the gravity ventilation was functioning well in the dwelling, the low rate of air inflow and poor venting were probably the main reasons for overheating, as well as the higher insulating properties of the external walls.
Figure 6. Indoor temperature as a function of the exponentially-weighted running mean of the outdoor temperature, flat no. 3: a) July 2017, b) August 2017.

| Monitoring period | Category I | Category II | Category III |
|-------------------|------------|-------------|--------------|
|                   | above      | below       | above        | below       | above | below |
|                   | R2         | R2          | R2           | R2          | R2    | R2    |
| 11 VII – 31 VIII  | 404        | 0           | 163          | 0           | 24    | 0     |

| Share of hours in the observation time [%] | 33.0 | 0 | 13.3 | 0 | 2.0 | 0 |

4. Conclusions
Presented flats had many similarities: the same construction and thermal mass of building partitions and sunspace encasement, the same location and exposition. However, the effects of glazing of the balconies varied both during winter and summer.

In the heating season, sunspace in the smaller, less insulated flat (no. 2) helped to reduce heat losses to a greater extent than in the bigger, better-insulated dwelling (no. 1). During summer, flat no. 2 was the least prone to overheating, compared not only with the flat no. 1 with a sunspace, but also with the flat no. 3 with an open balcony. This suggests, that lowering internal temperatures in the warmer period of the year depends first of all on the inhabitants' behavior and not on the presence or the absence of the passive system itself.

The interviews made with the participants of the research concluded that their perception of the glazed balconies was positive. They mentioned the noticeable improvement of the thermal conditions in the flats in winter, even though the energy saving was not a reason for the modernization. In the subjective estimation of the owners, the summer conditions in the rooms were acceptable, and encasing the balconies did not deteriorate the quality of the internal environment noticeably.

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