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SIMULATION ANALYSIS OF MICROCLIMATE CONDITIONS IN A MULTI – FAMILY LARGE PANEL BUILDING

ANALIZA SYMULACYJNA WARUNKÓW MIKROKLIMATU W WIELORODZINNYM BUDYNKU WIELOPŁYTOWYM

A b s t r a c t

When analyzing large panel buildings, it is very rare to take into consideration the requirements connected with the overheating effect. This issue is closely related to the thermal comfort of the building, especially during the summer months. Based on the simulations conducted in the Design Builder program, the authors determined the influence of building orientation, individual flat location and thermal insulation on the thermal comfort of the different flats of a large multi-family panel building.

Keywords: *large panel building*, *thermal comfort of the panel buildings*, *PMV* (*Predicted Mean Vote*), *PPD* (*Predicted Percentage of Dissatisfied*)

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

W analizie budynków wielkopłytowych bardzo rzadko uwzględnia się problem przegrzania pomieszczeń. Problem ten jest ściśle związany z komfortem cieplnym budynku, szczególnie w miesiącach letnich. W oparciu o symulacje przeprowadzone w programie Design Builder autorzy określili wpływ orientacji, lokalizacji poszczególnych lokali oraz termomodernizacji na komfort cieplny w mieszkaniach wielkopłytowego budynku wielorodzinnego.

Słowa kluczowe: *budynek wielkopłytowy*, *komfort cieplny w budynkach wielkopłytowych*, *PMV*, *PPD*

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1. Description of problem

Based on statistical information, about 4 million flats in Poland are made of prefabricated elements in different systems. Moreover, almost a quarter of Poles live in large system panel buildings. That is why the issues related to this subject are very important and common. The most important aspect is the improvement of the building energy certificate of those buildings. It is connected with the thermal modernization of the building envelope.

Unfortunately, when considering and designing the thermal modernization, no one takes into consideration the thermal comfort and overheating issues which seems to be very important from the occupants' point of view. The average usable area of dwelling in a prefabricated building is about 55 m^2 and the average number of occupants is 4, which gives less than 15 m^2 for one person [8]. It makes those issues even more essential.

2. Thermal comfort

Thermal comfort is related to the thermal balance of the body which is affected by different parameters: personal and environmental such as human activity; clothing insulation; environmental parameters (air temperature, average radiation temperature, air flow speed and relative humidity). These factors make up what is known as the 'human thermal environment'. Evaluation of thermal comfort is based on the PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) indexes.

International standard PN-EN ISO 7730 (Ergonomics of the thermal environment. Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria) uses Fanger's method to estimate thermal comfort. The Predicted Mean Vote (PMV) model stands among the most recognized thermal comfort models. It was developed using principles of heat balance and experimental data collected in a controlled climate chamber under steady state conditions. Fanger's method combines the following environmental features: air temperature, air velocity, mean radiant temperature and relative humidity and two personal variables (clothing insulation and activity level) into the index that can be used to predict the average thermal sensation of a large group of people. Also, psychological parameters such as individual expectations may affect thermal comfort. The thermal sensation 7 level scale with values between –3 and 3 describes the thermal sensation between 'hot' and 'cold'.

Occupants can control their thermal environment by means of clothing, operable windows, fans, heaters, internal and external sun shades.

3. Description of analyzed building

The aim of the building simulations was to analyze the influence of thermal insulation and flat location on the thermal comfort of particular parts of the panel building. The simulations were conducted for part of W70, a 5 storey large panel dwelling building, the usage area of analyzed building part was 150 m^2. The basement is below entire building and the building has a flat roof. Visualizations of different building elevations are presented in Fig. 1.

The building has natural ventilation and a central heating system with convection heaters. A communication area is located in the central part of each building level. In the analyzed part of the building, there are three flats at every level. Exterior walls made of prefabricated panels in the W70 system, insulated with 15 cm of styrofoam with plasters at both sides: U = 0.20 [W/m^{2}K] (before thermal modernization U = 0.75 [W/m^{2}K], double glazing windows: U = 1.5 [W/m^{2}K]).

Fig. 1. South-east and south elevations of analyzed building

The calculations were carried out in Design Builder v.3. The program has been specifically developed around Energy Plus, allowing the simulation of the building envelope and building interiors. The simulations conducted for the Polish climatic conditions (building located in Cracow) allowed the evaluation of the microclimate conditions of the entire building as well as of particular dwellings.

4. Simulation settings

The main aim of simulations was to determine the temperature and PMV index of particular flats at different elevations during the summer months. Figure 2 presents typical arrangements of dwellings on a storey of the building.

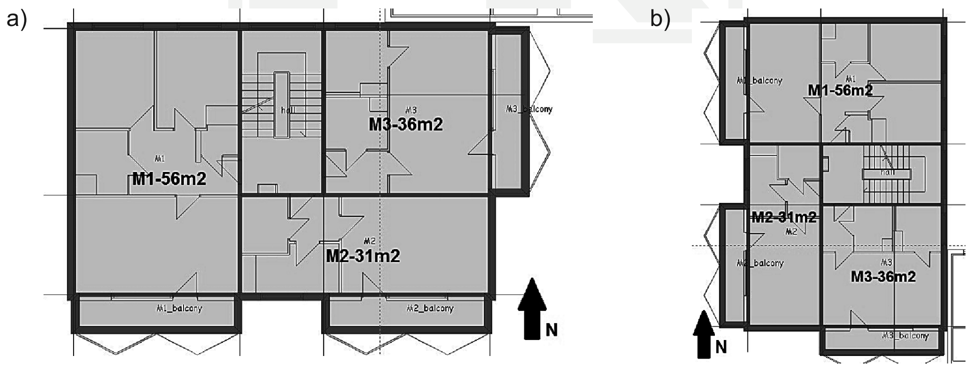

Fig. 2. Typical zones' visualization on every building level: a) Two rows of balconies at south elevation, b) Building rotated 90 degrees clockwise – two rows of balconies at west elevation

Every single flat was modelled as separate thermal comfort zone due to the small usage area of different flats. It was assumed that the doors between rooms are usually opened. Three different flats were analyzed:

1. Flat M1 – usage area 56 m^2, balcony at south elevation.
2. Flat M2 – usage area 31 m^2, balcony at south elevation.
3. Flat M3 – usage area 36 m^2, balcony at east elevation.

Area of balcony windows is 5.2 m^2.

Three simulation steps were analyzed – the building model before thermal modernization (two different building rotations, as shown in Fig. 2) and the building model after thermal modernization. Data for three different flats located at four different levels were compared. The period of time between 15th of May and 15th of September was taken into consideration because at this time in Poland, there is a risk of overheating.

The assumptions for the simulations:

1. Heating system on from September to March (22°C), 7 days a week, 24 hours a day.
2. Occupancy density: flats – about 1 person per 15 m^2,
3. Operating schedule: flats – 100% occupancy density between 4 pm and 7 am, 5 days a week; at the weekends and between 6 pm and 9 am; 50% reduced occupancy between 9 am and 6 pm.
4. Metabolic activity: factor 1.2 met, winter clothing – clo = 1.0, summer clothing clo = 0.5.
5. Ventilation requirements per polish national standards PN-83/B-03430 [2], in every flat 70 m^3/hour for kitchen and 50 m^3/hour for bathroom.

5. Test results

All simulation results presented below, have shown that during few days between 15th of May and 15th of September the average interior air temperatures of different dwellings exceed 30°C and the PMV factor is higher than 2. Those microclimate building conditions exceed the optimal internal summer temperature of 25°C and recommended value $-0.5 < PMV < +0.5$.

5.1. Building before thermal modernization – base case

Simulations of the building before thermal modernization have shown that in all dwellings, on all levels the operative temperature for most of the time is significantly higher than 25°C. The daily maximum interior temperature is 33.80°C (flat M2) and the PMV value is above 2.9. The number of discomfort hours, with the temperature above 25°C, in the assumed period of time is 1555. Those negative flat conditions continue almost for the entire day and do not change significantly during the night. The flats can be cooled by occupants during the night through the opening of windows.

Figures 3a, 3b and 3c present the number of discomfort hours for all three flats at different levels. The most unfavorable microclimate conditions are noticeable in flat M2 where the number of discomfort hours with temperatures above 32°C is the highest. Regarding the influence of the building storey, the worst conditions can be observed on the fourth floor (Fig. 4).

Comparing flats M1 and M2, both with balcony windows at the south elevation, thermal comfort conditions are worse in flat M2 due to its smaller usage area (31 m^2 compared to 56 m^2).

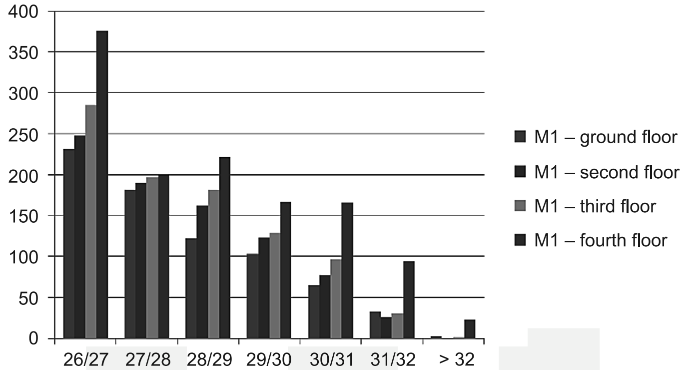

Fig. 3a. Number of overheating hours for flat M1 (south-west) at four levels – base case

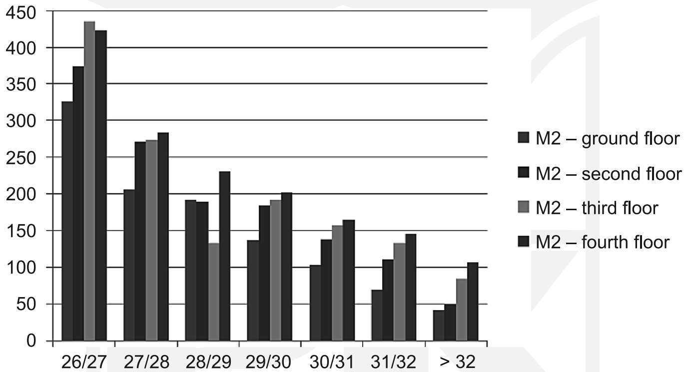

Fig. 3b. Number of overheating hours for flat M2 (south-east) at four levels – base case

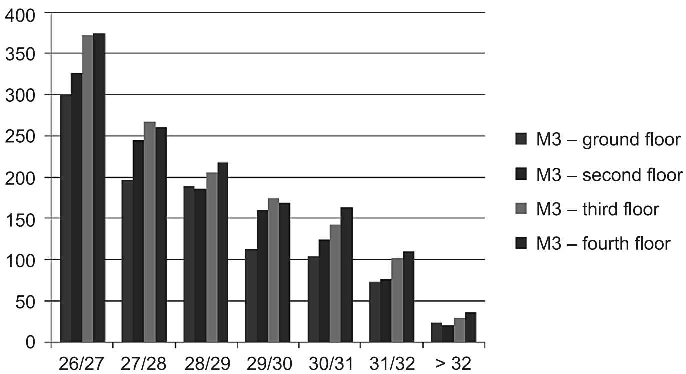

Fig. 3c. Number of overheating hours for flat M3 (east) at four levels – base case

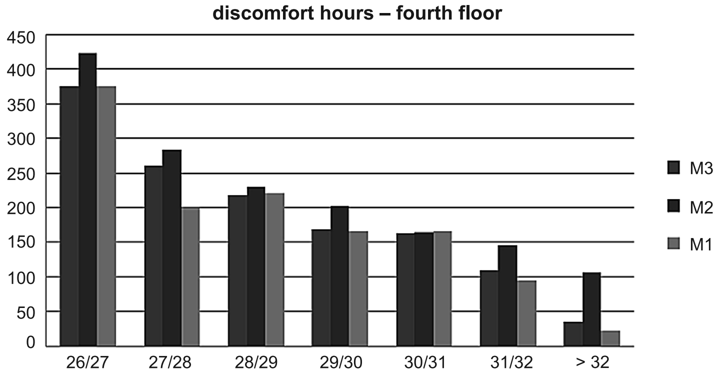

Fig. 4. Number of overheating hours for different flats at fourth floor – base case

5.2. Building before thermal modernization rotated 90 degrees clockwise

The overheating problems are closely related to the orientation of glazing and the worst thermal conditions are usually observed in rooms with windows oriented to the west. It is connected with the angle of solar radiation. In the analyzed building, the windows located at south elevation are shaded by the balconies at higher levels which lessen the solar gains. In the next step of simulation, the building was rotated 90 degrees clockwise to analyze the microclimate conditions in the rooms with balcony windows located at the west.

After rotation of the buildings the worst microclimate conditions are also observed in flat M2, the number of discomfort hours increased from 1555 to 1618. Again, comparing the M2 with flat M1 (balcony windows at the same elevations), less favorable results are noticeable in flat M2 due to its smaller usage area. Figure 5 presents the number of discomfort hours for flat M2 and Figure 6, a comparison of PMV indexes for all three flats located on the fourth floor. The daily maximum interior temperature is 34.70°C and the PMV value is above 3.1.

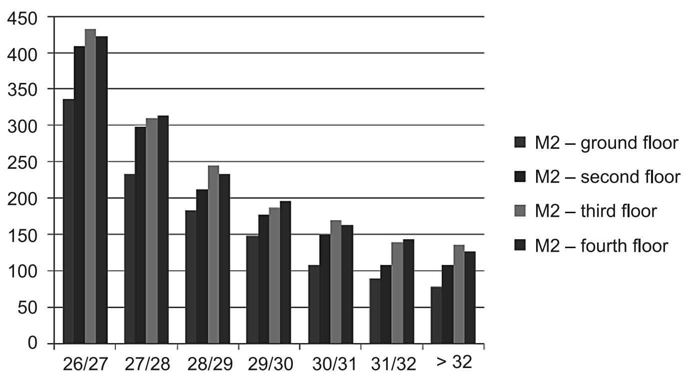

Fig. 5. Number of overheating hours for flat M2 by floors – rotated building

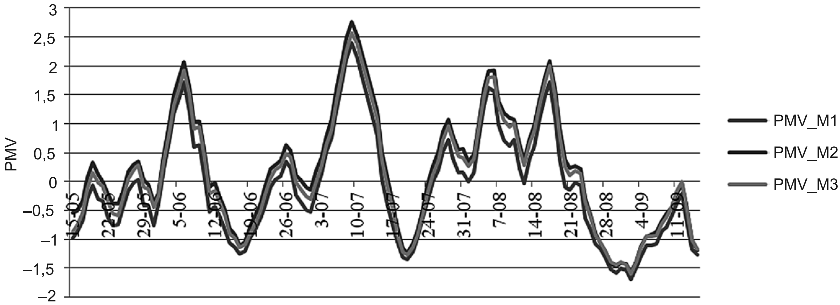

Fig. 6. PMV comfort indexes for three flats located on the fourth floor – rotated building

5.3. Building after thermal modernization

Due to the recast to the European Energy Performance of Buildings Directive, buildings designed and modernized after 2021 should be zero-energy buildings. In connection with those provisions, since 1st of January 2014, the new requirements regarding building envelope thermal insulation were introduced Warunki Techniczne 2013 [4]. According to those regulations, thermal transmittance U of the heated building components cannot exceed 0.25 W/m^{2}K and after 1st of January 2021, 0.2 W/m^{2}K.

In the next step, the simulations were conducted for the building after thermal modernization fulfilling the requirements of the standard [4] being in force since 2021. Only external walls were insulated with 15cm of styrofoam (λ = 0.04 W/mK).

Figure 7 presents the number of discomfort hours for flat M2 with the most unfavorable microclimate conditions. The worst conditions are again on the fourth floor (Table 1). The daily maximum interior temperature is 34.5°C and the number of discomfort hours in the assumed period of time is 2392. After thermal modernization, the number of overheating hours in flat M2 on the fourth floor increased from 1555 to 2392.

Table 1 presents the number of overheating hours in all flats, at all analyzed levels before and after thermal modernization. A significant increase can be observed in all flats of even up to 60%.

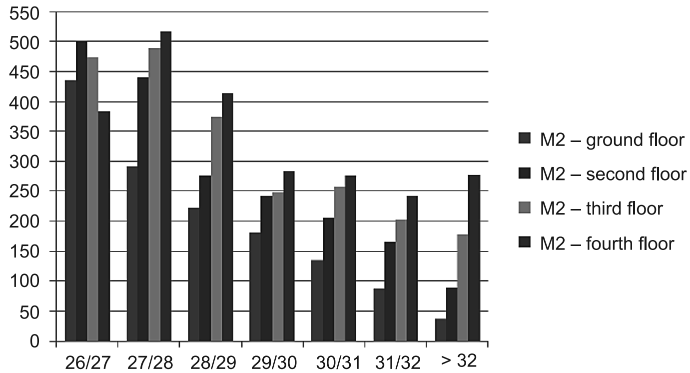

Fig. 7. Number of overheating hours for flat M2 at different levels

It appears that the reduction of heat losses connected with the thermal modernization of the building envelope unfavorably affects the microclimate conditions in the leaving spaces.

Both before and after thermal modernization, the worst conditions for all flats, are noticeable on the fourth floor, however, the percentage increase in case of flat M1 and M2 is noticed on the third floor. It can be explained by the fact that the roof was not insulated so the transmission gains through this part of the building stay at the same level.

Table 1

Number of discomfort hours for all analyzed flats before and after thermal modernization

		Number of discomfort hours – before thermal modernization	Number of discomfort hours – after thermal modernization	Percentage increase [%]
M1	1st level	736	946	29
	2nd floor	827	1235,5	49
	3rd floor	920,5	1477	60
	4th floor	1245	1746,5	40
M2	1st level	1073	1391,5	30
	2nd floor	1317,5	1916	45
	3rd floor	1409	2225,5	58
	4th floor	1555	2392	54
M3	1st level	999,5	1377	38
	2nd floor	1137	1718	51
	3rd floor	1293,5	1985	53
	4th floor	1329	2153,5	62

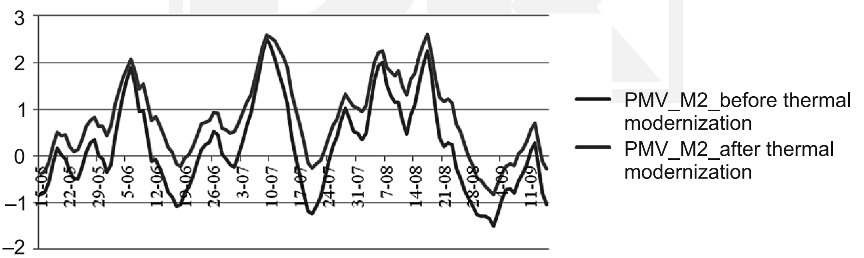

Fig. 8. PMV comfort indexes for flat M2 before and after thermal modernization

6. Conclusions

The results of the conducted analysis show that the overheating problem appears in large panel buildings, both before and after thermal modernization. Windows in the prefabricated panel buildings in most cases are poorly shaded from solar radiation. Glazing is the source of the excessive heat gains and results in the overheating of the dwellings. The microclimate conditions in all flats are very uncomfortable and the parameters describing thermal comfort exceed the acceptable values.

Modernization of the building should be preceded by the extensive analysis of how the changes influence thermal comfort of the particular flats. The priority is heating cost reduction in the winter season. The conducted analyses show that improvement of the building envelope thermal insulation alone can unfavorably affect the internal conditions during the summer season. In the process of thermal modernization of panel buildings, use of internal or external shadings to reduce summer overheating should be taken under consideration. Those solutions are the subject of the authors' further researches.

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