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QUANTIFICATION OF HEAT BALANCE FOR WINDOWS WITH VARYING NUMBERS OF WINDOW PANES AND GEOGRAPHICAL EXPOSURE IN THE CLIMATE OF THE WIELKOPOLSKA REGION

Summary

The paper presents results of simulation tests for the heat balance of double, triple and quadruple glazed windows with eastern, southern, western and northern exposure, conducted for the climate conditions of the city of Poznań and the Wielkopolska region in response to the needs of eco power engineering. It was shown that in the summer period a greater number of window panes and a change in exposure from southern to eastern, western and northern result in a considerable reduction of heat balance for these windows. In the summer months from May to August heat balance of windows with eastern, southern and western exposure is comparable. The heat balance of windows with the northern exposure is much lower in each month of the summer period. In the winter period the highest and positive heat balance is recorded for windows with the southern exposure. Windows facing the other geographical directions have a comparable balance with values around zero. At all the exposures an increased number of window panes to a relatively limited extent improves heat balance, in general for the entire winter period and in its individual months.
***Key words**: window, heat balance, number of window panes, exposure, summer period, winter period*

KWANTYFIKACJA BILANSU CIEPLNEGO OKIEN O RÓŻNEJ LICZBIE SZYB I ORIENTACJI GEOGRAFICZNEJ W WARUNKACH KLIMATYCZNYCH WIELKOPOLSKI

Streszczenie

Przedstawiono wyniki badań symulacyjnych bilansu cieplnego okien 2-, 3- i 4-szybowych ustawionych na wschód, południe, zachód i północ dla warunków klimatycznych Poznania i regionu Wielkopolski oczekiwane w ekoenergetyce. Wykazano, że w okresie letnim wzrost liczby szyb i zmiana ustawienia okien z południa na wschód, zachód i północ powodują znaczne zmniejszanie bilansu cieplnego okien. W miesiącach okresu letniego od maja do sierpnia bilans cieplny okien zorientowanych na wschód, południe i zachód jest zbliżony. Bilans okien skierowanych na północ jest znacznie niższy w każdym miesiącu okresu letniego. W okresie zimowym najwyższy i dodatni bilans cieplny mają okna skierowane na południe. Okna zorientowane na inne kierunki mają podobny bilans cieplny i oscylujący około zera. Przy wszystkich zorientowaniach geograficznych okien zwiększana liczba szyb dość mało polepsza bilans cieplny ogólnie w okresie zimowym i w poszczególnych jego miesiącach.
***Słowa kluczowe**: okna, bilans cieplny, liczba szyb, orientacja geograficzna, okres letni, okres zimowy*

1. Introduction

Energy performance parameters of windows affect not only the thermal comfort of buildings and rooms, but also heating costs in the winter period and cooling costs in the summer period. In these periods the heat balance of windows is crucial, consisting mainly of the volume of heat energy losses caused by heat transfer outside through windows and heat gain resulting from the transmission of solar radiation indoors. These energy parameters are dependent primarily on the outdoor climate and the indoor microclimate, as well as technical parameters of windows.

Energy performance parameters of buildings and rooms are dependent on the diverse climate conditions in Europe [1, 2], including also Poland [3, 4, 5]. Climate conditions in Poland are relatively varied, as e.g. differences in solar radiation may be as high as approx. 30%; to date energy performance parameters have been specified for average conditions in Poland or only selected regional locations [3, 4, 8]. Energy performance studies in Poland are typically conducted assuming a comprehensive approach to the effect of various structural elements of buildings and rooms [5-7]. In turn, there is a shortage of experimental results for energy performance parameters for windows specifically under climate conditions of the city of Poznań and the Wielkopolska region. The area is located in climate zone 2 of Poland (PN-EN 12831:2006), with the climate being different from that in the other regions [3, 4].

Heat balance of windows depends on their exposure, determining first of all heat gains produced by the solar radiation penetrating indoors. Another major window parameter is connected with the window pane structure, mainly the number of window panes and cavities between panes, determining the amount of energy transmitting indoors and losses resulting from heat transfer outdoors. Presently glazing units are manufactured as heat-insulating units of several glass panels connected at edges with spacer bars or other spacer materials and sealants at the glazing edge. The cavity may be filled with air or a high molecular weight noble gas. In single-family housing single chamber mineral glass glazing units have been used most frequently, while recently double and triple chamber glazing units are increasingly common.

When glazing windows with neutral or absorption glass window panes reflective, sun protection and low-emissivity coatings with varying light reflectance values are used to limit heat losses or excessive heat gains due to insulation.

The aim of this study was to determine heat balance of windows differing in their geographical exposure and the number of window panes for the climate conditions in the city of Poznań and the Wielkopolska region. Simulation testing provided heat balance values for windows facing the 4 geographical directions, i.e. the east, south, west and the north, providing overall values for the entire summer and winter periods as well as successive months of the year.

2. Methods

Tests were conducted on typical, commercially available tilt and turn windows of 1230 x 1480 mm in size. They were performed on double, triple and quadruple glazed windows, thus the windows were single, double and triple chambered. Calculations were made for windows placed vertically and facing the east, south, west and the north. Setting angles β were denoted as follows: the east 0°, south 90°, west 180° and the north 270°. Testing results were obtained for example solar radiation transmission and heat transfer coefficients adopted within the ranges specified in the new technical conditions for buildings and their locations enforced by the Regulation of the Minister of Transport, Construction and Maritime Economy of 5th July 2013 (the Journal of Laws Dziennik Ustaw of 2013, item 926). Other parameters of the windows were assumed to be constant.

Heat balance [in kWh] was based on heat gains and losses for the summer period and for the winter period as well as successive months of the year. These parameters were determined in simulation studies applying the recommended simplified method, following the methodology specified in the Regulation of the Minister of Infrastructure and Development of 27th February 2015 [9] and respective Polish standards. The summer period was assumed to be from the 1st of April to the 30th of September, while the winter period lasted from the 1st of October to the end of March based on mean outdoor air temperatures for a multi-annual period for Poznań [10] and observations of heating system operation dates as well as recommendations of the PN-EN ISO 13790;2009 standard.

Heat gains for windows [9] generated by solar radiation $Q_{solb,H}$, in kWh, were calculated from the equation:

$$Q_{solb,H} = C_i \cdot A_i \cdot I_i \cdot F_{sh,gl} \cdot F_{sh} \cdot g_{gl} \quad (1)$$

where: mean monthly solar radiation energy I_i [kWh·m^{-2}], C_i - the ratio of glazed surface area to the total surface area of the window (averaged value of 0.7) [-], A_i - surface area of the window [m^2], F_{sh} - reduction factor for adjustable shading systems in accordance with the PN-EN ISO 13790:2009 standard, $F_{sh,gl}$ - reduction factor for shading in accordance with the PN-EN ISO 13790:2009 standard, g_{gl} - total transmittance of solar radiation for the window panes.

Heat balance was determined following the PN-EN ISO 13790;2009 standard by deducting the assessed heat losses $Q_{tro,ie}$ from heat gains $Q_{solb,H}$. A positive balance indicates excess heat on the indoor side of the window.

Total heat losses for the window $Q_{tr,ie}$, in kWh were determined applying the simplified method [9] from the equation:

$$Q_{tr,ie} = f_k \cdot U_w \cdot A_i \cdot (\theta_{int,s,H} - \theta_{e,n}) \cdot t_M \cdot 10^{-3} \quad (2)$$

where: mean outdoor air temperatures $\theta_{e,n}$ (K), $\theta_{int,s,H}$ - mean indoor air temperature in the heated zone [K], t_M - the number of hours for period [h], f_k - correction factor for temperature in accordance with the PN ISO 13831:2006 standard [-], U_w - overall heat transfer coefficient for the window [W·m^{-2}·K^{-1}].

Mean monthly solar radiation energy I_i [kWh·m^{-2}] hitting a vertically placed surface of the window pane was established experimentally in the years 1971-2000 by the Institute of Meteorology and Water Management (IMGW). Data are entered and made available at the website of the Ministry of Infrastructure and Construction (MIiB) [10]. Mean monthly outdoor air temperatures were collected from a 29-year period (11) at a weather station in Poznań (Stacja Hydrologiczno-Meteorologiczna SHM and Lotniskowa Stacja Meteorologiczna LSM, no. 123300). These data were adopted as representative for the Wielkopolska region located in the Dfb climate zone of Poland (according to the PN-EN 12831:2006 standard) (Table 1). Moreover, the following values were adopted in the calculations: A_i=1.82 m^2 (in accordance with PN-EN ISO 10077-1:2017-10); C_i = 0.7; $F_{sh,gl} = 1$, F_{sh} = 0.9, $\theta_{int,s,H}$ = 295.16 K (22°C); f_k =1. The number of hours t_M was determined based on the dates marking the summer and winter periods and for the number of days in months. The assumed coefficients g_{gl} and U_w for the windows are given in Table 2.

Table 1. Mean outdoor temperatures $T_{śr}$ for Poznań from a 29-year period [10]
Tab.1. Średnie temperatury zewnętrzne $T_{śr}$ dla Poznania z okresu 29 lat [10]

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
$T_{śr}$ [°C]	0.2	-1.8	2.7	8.3	13.0	16.8	18.3	18.4	13.5	7.0	2.2	-0.1

Table 2. Overall heat transfer coefficient U_w and total transmittance of solar radiation g_{gl} for analysed windows adopted in the calculations
Tab. 2. Przyjęte w obliczeniach współczynniki przenikania promieniowania słonecznego U_w i przewodzenia ciepła g_{gl} analizowanych okien

Value				
Coefficients	Units	Double glazed window	Triple glazed window	Quadruple glazed window
U_w	W·m^{-2}·K^{-1}	1.3	1.0	0.7
g_{gl}	-	0.8	0.7	0.6

Source: own study / Źródło: opracowanie własne

3. Results and discussion

In this study testing results were obtained for the heat balance of windows differing in their exposure and the number of window panes for the climate conditions of Poznań and the Wielkopolska region. The results may be used to ensure more accurate design of buildings and optimal selection of more energy efficient and cost-effective heating and cooling systems in eco power engineering.

3.1. Heat balance in the summer period

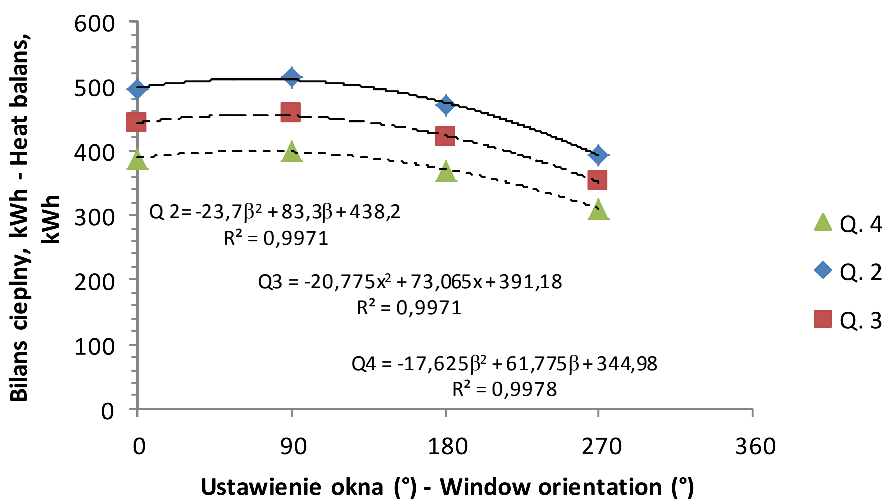
As can be seen in Fig. 1, in the summer period the total heat balance of analysed windows differing in the number of window panes and exposure is high and positive. This is primarily the effect of high solar radiation and high outdoor air temperatures generating small heat losses [10].

The study generally shows that both window exposure and the number of window panes have a relatively marked effect on the total heat balance of windows in the summer period, ranging from approx. 513 to approx. 311 kWh (Fig. 1). As it results from that Figure, the greatest heat balance of windows facing south decreases at exposures in the following order: the eastern, western and the northern. The dependence of heat balance on window exposure is very well described by parabolas with the vertexes at the southern exposure. These parabolas are similar for double, triple and quadruple glazed windows (Fig. 1). Windows facing the east and west have a heat balance lower by approx. 16.6 and 41.8 kWh, i.e. 3 and 8%, than that of the window facing the south. Generally a comparable heat balance of windows facing the south, east and west results directly from a similar amount of solar radiation energy generated at similar heat losses [10]. The radiant flux of high intensity as a result of the Sun high over the horizon falls at a small angle on the vertical window facing the south and a smaller amount of energy transmitted indoors. The radiant flux of a lower intensity as a result of the Sun being located lower over the horizon falls at a large angle onto the vertical window facing the east and west, with a similar amount of energy transmitting indoors as in the case of the window facing the south. The window with the northern exposure has a much lower heat balance - by approx. 120 kWh (approx. 23%) than the window facing the south, which results from the much weaker, reflected and scattered solar radiation.

Generally heat balance decreases with an increase in the number of window panes to a similar degree in all the variants of window exposure. This is described by the parabolas, which for a greater number of window panes are plotted at lower values of heat balance (Fig. 1). With an increase in the number of window panes heat balance decreases on average by approx. 11%/1 window pane and in terms of percentages it is comparable for the analysed window exposure variants. In absolute values it ranges from approx. 55 kW/1 window pane for the southern exposure to approx. 41 kW/1 window pane for the northern exposure. A lower heat balance of a quadruple glazed window results from a lesser transmissivity of solar radiation through the window with a larger number of window panes to the inside of the room at a slightly decreased heat losses as a result of higher outdoor temperatures in the summer (Tables 1 and 2).

3.2. Heat balance in months of the summer period

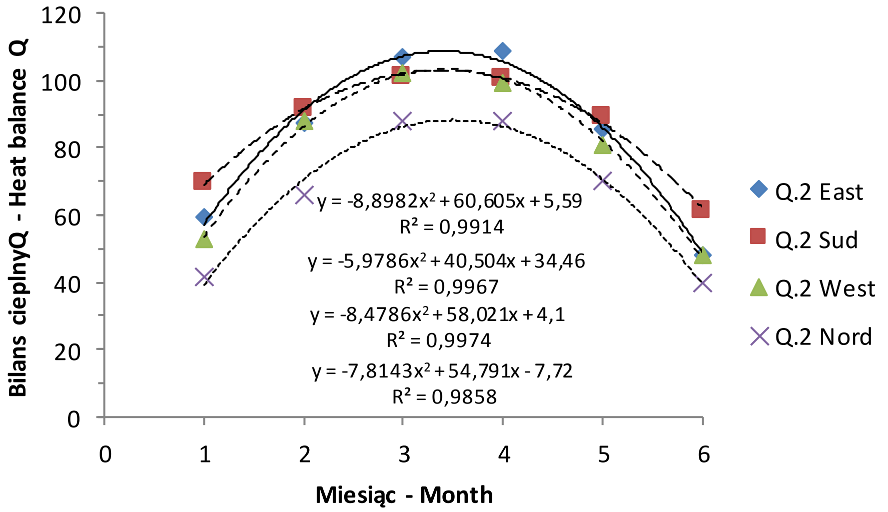
Changes in the heat balance of windows in the successive months of the summer period were very well described for all the window exposure variants and window pane numbers by inverted parabolas with the vertexes at the turn of June and July (Figs. 2–4). Heat balance of windows increases considerably from April to Jun and July, while in the successive months it decreases comparably. An increase in the balance results both from the considerable increase in the emission of radiation and the marked reduction in heat losses due to growing outdoor temperatures in the period from June and July, whereas a decrease in the balance results from the reverse trend in changes of these parameters.



Source: own study / Źródło: opracowanie własne

Fig. 1. Summer heat balance *Q* of double (Q.2), triple (Q.3) and quadruple (Q.4) glazed windows facing different geographical directions (0 – east, 90 – south, 180 – west, 270 – north)

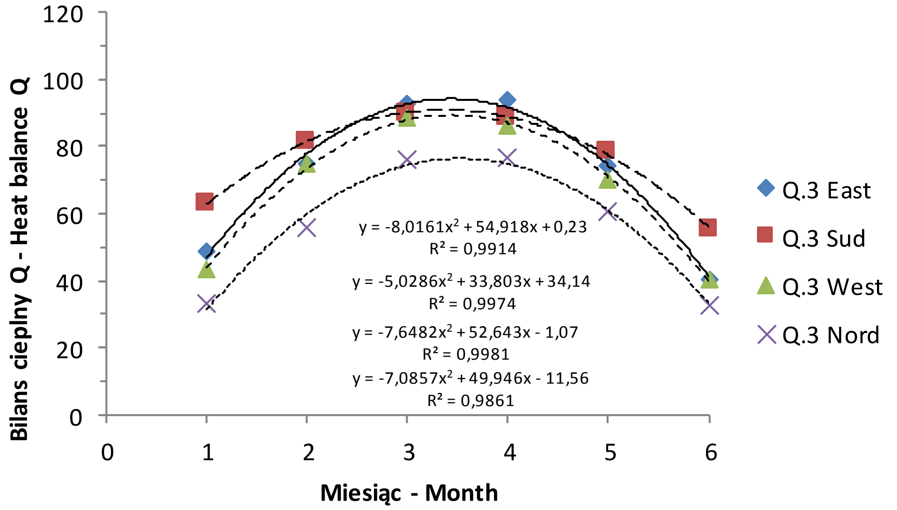
Rys. 1. Letni bilans cieplny Q okien 2-, 3- i 4-szybowych (Q.2, Q.3, Q.4) zorientowanych na kierunki świata (0 – wschód, 90 – południe, 180 – zachód, 270 – północ)



Source: own study / Źródło: opracowanie własne

Fig. 2. Heat balance, in kWh, for a double glazed window at different exposure variants in the successive months of the summer period (1-6), 1-6 successive months of the summer period.

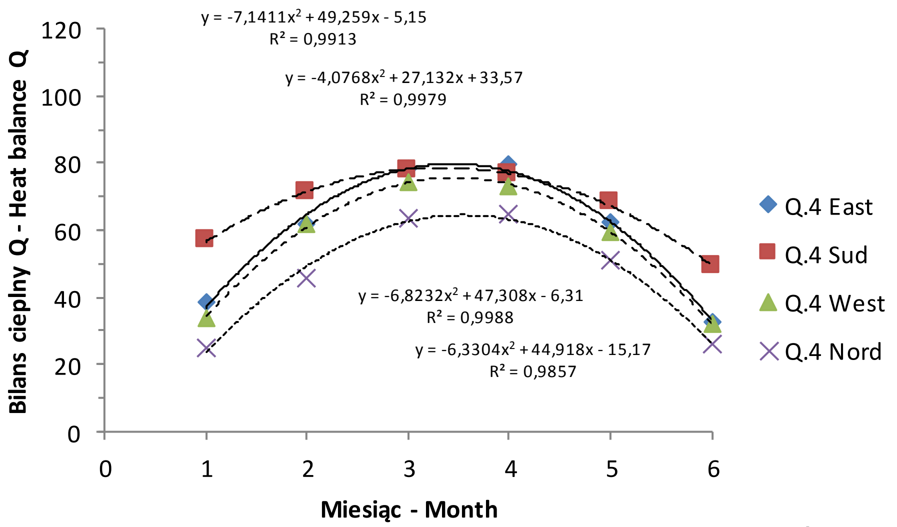
Rys. 2. Bilans cieplny, w kWh, dla okna 2-szybowego o różnej orientacji geograficznej w kolejnych miesiącach roku okresu letniego (1-6), 1-6 kolejne miesiące okresu letniego



Source: own study / Źródło: opracowanie własne

Fig. 3. Heat balance for a triple glazed window at different exposure variants in the successive months of the summer period (1-6)

Rys. 3. Bilans cieplny dla okna 3 szybowego o różnej orientacji geograficznej w kolejnych miesiącach roku okresu letniego (1-6)



Source: own study / Źródło: opracowanie własne

Fig. 4. Heat balance for a quadruple glazed window at different exposure variants in the successive months of the summer period (1-6)

Rys. 4. Bilans cieplny dla okna 4 szybowego o różnej orientacji geograficznej w kolejnych miesiącach okresu letniego (1-6)

Heat balance of windows facing the north, for each window pane structure, is much lower in comparison to the other exposure variants on average by approx. 20 kWh in each month of the summer period. The eastern, southern and western exposure of windows has a slightly different effect on the heat balance of windows in individual months of the summer period, whereas it was generally comparable for windows differing in the number of window panes (Figs. 3-5). In April and September heat balance of windows facing the south is greater than that of windows facing the east and the west. This results from the greatest amount of radiation transmitting inside through that window in those months at heat losses comparable to those for windows facing the east and the west. In the period from May to August heat balance of windows with the eastern, southern and western exposure is comparable, mainly due to the similar levels of energy collected through these windows.

Generally the number of window panes has a similar effect on the heat balance of windows differing in terms of their exposure in individual months of the summer period (Fig. 3-5).

3.3. Heat balance in the winter period

Heat balance in the winter period for the analysed window pane variants is presented in Fig. 5. In that period heat balance of windows changes under the influence of the investigated factors from approx. -62 to approx. 86 kWh, total by approx. 150 kWh (Figs. 1 and 5). Changes in heat balance caused by window exposure are maximum approx. 117 kWh, while those related to the number of window pane are much smaller, amounting to approx. 60 kWh.

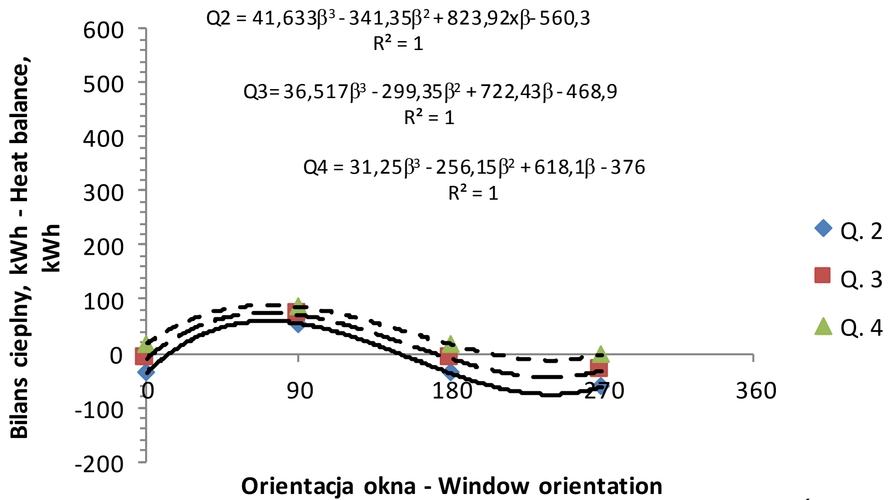
Generally the best positive heat balance ranging from approx. 55 to approx. 85 kWh is recorded for windows facing the south. Windows with the eastern, western and northern exposure generally have a comparable heat balance around zero, ranging from approx. +0.17 kWh to approx. -62 kWh. A lower value of heat balance for these three windows results from a lower amount of direct radiation reaching those windows as a result of the Sun being located lower over the horizon and a shorter travel over the horizon. Changes in heat due to window exposure are very well described by 3rd degree regression with the sinusoid-like shape with the maximum for windows facing the south and the minimum for window exposure close to the northern one (Fig. 5). These curves are similar for the number of the number of window panes and plotted at progressively lower values for the windows with the successively lower number of window panes. However, the increment in heat balance in the period of 6 months is rather low, ranging on average from approx. 15 kWh/1 window pane in the case of the northern exposure to approx. 30 kWh/1 window pane at the southern exposure. These results show that in the winter period the use of quadruple glazed windows instead of 2 window panes has the greatest effect at the southern exposure, providing the greatest heat gain of approx. 60 kWh, while it was lowest at the northern exposure, with the heat gain balance of approx. 30 kWh.

3.4. Heat balance in months of the winter period

Figures 6, 7 and 8 present heat balance for the analysed windows with differing numbers of window panes and exposure in the successive months of the winter period. Heat balance for all the windows is generally positive in March and October and generally negative in the period from November to February, being the lowest in December. Changes in the heat balance of windows in the successive months of the winter period are very well described by inverted parabolas with the vertexes in December (Figs. 6-8). Curves for the various exposure and window pane variants are similar. The lowest heat balance in December results mainly from the lowest emission of solar radiation in that month [10] at relatively higher heat losses due to rather low outdoor air temperatures (Table 1).

The most advantageous heat balance of windows facing the south was recorded generally in all the months of the winter period. Heat balance of windows facing other geographical directions is similarly lower on average from approx. 15 to approx. 30 kW, in comparison to the heat balance of windows with the southern exposure in each month of that period.

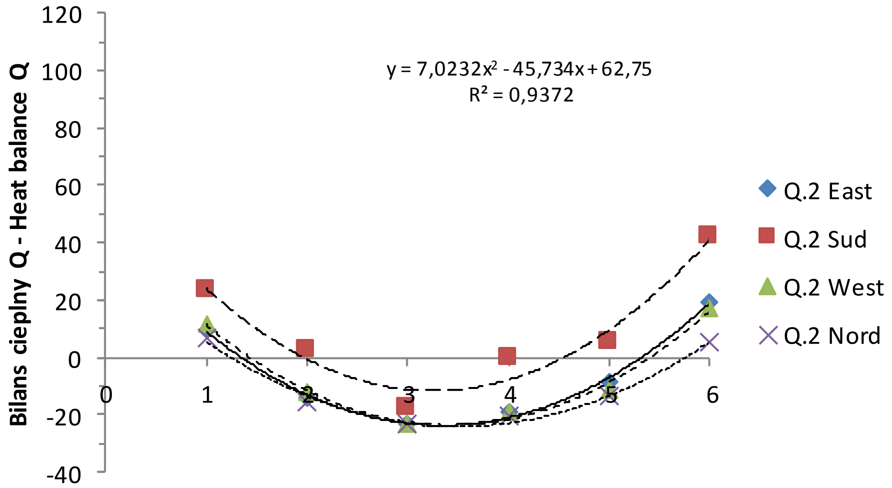
The effect of the number of window panes on heat balance of windows facing various geographical directions in individual months of the winter period is similar. The most



Source: own study / Źródło: opracowanie własne

Fig. 5. Winter heat balance *Q* for double (Q.2), triple (Q.3) and quadruple (Q.4) glazed windows with different exposure variants

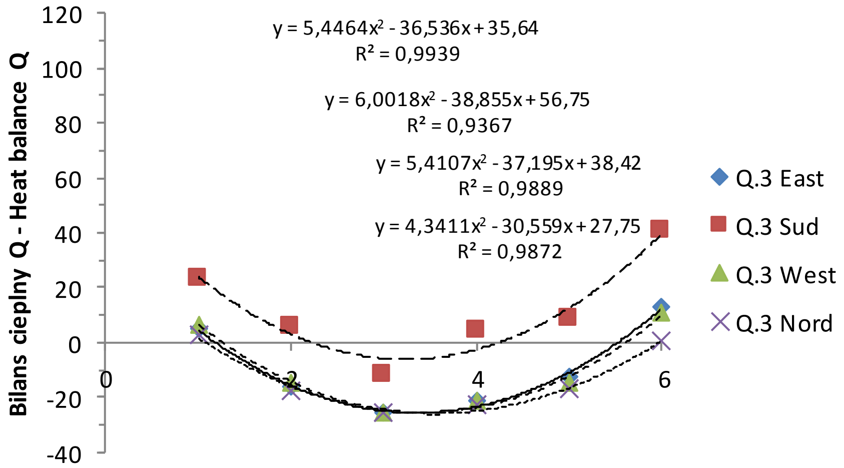
Rys. 5. Zimowy bilans cieplny Q okien 2-, 3- i 4-szybowych (Q.2, Q.3, Q.4) zorientowanych na kierunki geograficzne



Source: own study / Źródło: opracowanie własne

Fig. 6. Heat balance for double glazed windows differing in exposure in the successive months of the winter period: 1 - 6 successive months of the winter period

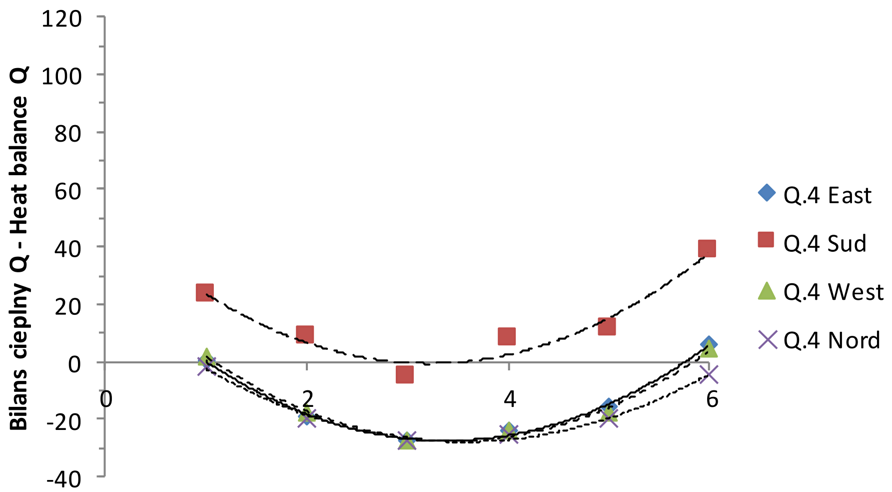
Rys. 6. Bilans cieplny dla okna 2-szybowego o różnej orientacji geograficznej w kolejnych miesiącach roku okresu zimowego: 1-6 kolejne miesiące okresu zimowego



Source: own study / Źródło: opracowanie własne

Fig. 7. Heat balance for triple glazed windows differing in exposure in the successive months of the winter period 1-6

Rys. 7. Bilans cieplny dla okna 3-szybowego o różnej orientacji geograficznej w kolejnych miesiącach roku okresu zimowego 1-6



Source: own study / Źródło: opracowanie własne

Fig. 8. Heat balance for quadruple glazed windows differing in their exposure in successive months of the winter period 1-6

Rys. 8. Bilans cieplny dla okna 4-szybowego o różnej orientacji geograficznej w kolejnych miesiącach okresu zimowego 1-6 advantageous positive heat balance was observed for quadruple glazed windows with the southern exposure mainly in the beginning and end of the winter period.

4. Conclusions

The paper presents results of simulation studies obtained for the study assumptions concerning heat balance of three design variants of windows facing the east, south, west and the north for the climate conditions of Poznań and the Wielkopolska region. Results may facilitate more rational selection of windows for buildings and designing energy efficient and cost-effective heating and cooling systems.

– In the summer period the highest and comparable total heat balance was recorded for windows facing the east, south and the west, particularly in the months from May to August. Heat balance of windows facing the north is generally much lower in each month of the summer period.

– An increase in the number of window panes in the windows facing the 4 geographical directions results in a considerable reduction of heat balance in the summer period by approx. 11%/ 1 window pane. This decrease is generally similar in individual months of the summer period.

– In the winter period the highest and positive heat balance ranging from approx. 55 to approx. 86 kWh was recorded for windows facing the south. Windows facing other geographical directions have similar heat balances, ranging from approx. +17 kWh to approx. -60 kWh. Heat balance of windows facing the 4 geographical directions typically decreases in a similar manner to December and January and increases similarly in the successive months.

– In the winter period the increment in the heat balance value at the increase in the number of window panes is lowest for windows facing the north and on average it is approx. 15 kWh/1 window pane, while it is greatest in the case of the southern exposure and on average amounts to approx. 30 kWh/1 window pane. These increments are generally similar in individual months of the winter period.

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[10] Wskaźniki emisji i wartości opałowe paliwa oraz typowe lata meteorologiczne i statystyczne dane klimatyczne do obliczeń energetycznych budynków. http://mib.gov.pl/2-Wskazniki_emisji_wartosci_opalowe_paliwa.htm. Dz. U. 2013 poz. 926.

[11] Dz. U. 2013 poz. 926. Rozporządzenie Ministra Transportu, Budownictwa i Gospodarki Morskiej z dnia 5 lipca 2013 r. zmieniające rozporządzenie w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie.

Standards

[12] PN-EN 12831: 2006. „Instalacje ogrzewcze w budynkach. Metoda obliczania projektowego obciążenia cieplnego".

[13] PN-EN ISO 13790:2009. „Energetyczne właściwości użytkowe budynków. Obliczanie zużycia energii na potrzeby ogrzewania i chłodzenia".

[14] PN-EN ISO 10077-1:2017-10. Cieplne właściwości użytkowe okien, drzwi i żaluzji. Obliczanie współczynnika przenikania ciepła.

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