Dr Malwina PILARSKA, Eng* ORCID: 0000-0002-1140-4161

DOI: 10.15199/180.2021.2.5

* West Pomeranian University of Technology in Szczecin
Faculty of Maritime Technology and Transport
Av., Piastów 41, 71-065 Szczecin
e-mail: malwinapilarska@wp.pl

EFFECT OF THE WIND SPEED AND DIRECTION ON ENERGY BALANCE IN BUILDING

WPŁYW KIERUNKU I PRĘDKOŚCI WIATRU NA BILANS ENERGII W BUDYNKU

***Summary**: In the present paper, the problems connected with the direction and velocities of the wind, having a significant effect on energy balance in a building, have been discussed. The discussed issue concerns the construction object (10-floor skyscraper) being shielded with many obstructions, which is affected by wind activity. The analysis concerns also the balance of heat energy of the discussed building which serves keeping of thermal comfort and by this, it is a summarization of heat profits in the building, obtained from internal heat sources and solar profits, connected with the losses, caused by heat transfer via external construction baffles and ventilation system. The problem connected with the wind and its role in the energy balance has been also presented. Apart from a good thermal insulation of external baffles, the coefficient of heat loss caused by heat transfer plays also a meaningful role. The mentioned building has been subjected to analysis which concerns the impact of the direction and speed of the wind on the heat transfer coefficient. The aim of the study was to determine the influence of the direction and speed of the wind on the value of heat transfer coefficient. As far as the dynamic values of surface heat coefficient are concerned, they have been presented in the Table.*

***Keywords**: wind, direction, speed, energy balance, building, thermal comfort*

***Streszczenie**: W artykule zostały poruszone zagadnienia związane z kierunkiem oraz prędkością wiatru, który ma istotny wpływ na bilans energii w budynku. Została poruszona tutaj kwestia, która dotyczy obiektu budowlanego (10 piętrowego wieżowca) osłoniętego wieloma przeszkodami, na który ma wpływ działanie wiatru. Analiza dotyczy również bilansu energii cieplnej budynku , która służy do utrzymania komfortu cieplnego, a tym samym stanowi sumaryczne zestawienie zysków ciepła w budynku otrzymanego z wewnętrznych źródeł ciepła oraz zysków solarnych związanych ze stratami spowodowanymi przenikaniem przez zewnętrzne przegrody budowalne oraz wentylację. Została również przedstawiona kwestia związana z wiatrem oraz jego rolą w bilansie energii. Oprócz dobrej izolacji termicznej przegród zewnętrznych duże znaczenie ma tutaj współczynnik strat ciepła przez przenikanie. Budynek został poddany analizie, która dotyczy kierunku i prędkości wiatru na współczynnik przenikania ciepła, badanie miało na celu ustalenie jaki wpływ na wartość współczynnika przenikania ciepła ma kierunek i prędkość wiatru. Jeżeli chodzi o wartości dynamiczne przejmowania ciepła na zewnętrznej powierzchni zostały przedstawione w pracy w tabeli.*

***Słowa kluczowe**: wiatr, kierunek, prędkość, bilans energii, budynek, komfort cieplny*

Introduction

Movement of the air, speaking in other words, wind, which is circulating around the surface of the Earth, is generated due to a difference in the existing pressures and also, depending on the relief of the land [9]. The mentioned phenomenon, as being described to a different extent, has the impact on heat transfer via heat loss; the ventilated premises play here a certain role, as well. It is connected with the aired rooms and construction vibrations; it includes also the evaluation of climatic comfort of inhabitant in the internal environment [1].

To obtain the appropriate microclimate in the closed rooms, there are intentionally designed construction baffles; their task is to ensure always the appropriate climatic conditions in the interior, irrespectively of the seasons of the year and varying air temperatures and the velocity and direction of the wind [2]. The quality of the performed external thermal partition affects the thermal sensation which results from the asymmetric radiation which is also significant for obtaining the approximate internal temperature of the surface as compared to the surfaces of other partitions, surrounding the premise.

Each other building object is affected by different effect of the wind what has an influence on its structure. The answer is dependent on many factors: mechanical conditions of the construction object, geometrical shape, direction and speed of the wind and the terrain roughness.

The issues connected with the wind load have the effect on a given building and it is dependent on the situation of the object as well as of its surrounding [2, 3, 4]. The separate buildings are always more sensitive to the wind effect. As far as wind turning point is concerned, it is found at 2/3 of the height for a given building where the segregation of the stream takes place. A part directed to downwards, to the earth, generates a shape of horseshoe; they are the so-called whirling forms which are spreading towards lateral walls, to the windward side of the building [6, 7]. The remaining stream of splitting the parts goes to lateral walls of the building where, as affected by the pressure, it exerts a negative impact on the loss via penetration of thermal bridges which are present in the discussed object. Such part of the mentioned stream begins to move at the leeward side whereas the remaining part of the air streams above 2/3 of the height of the building passes by higher floors and flows around the roof; then, it begins

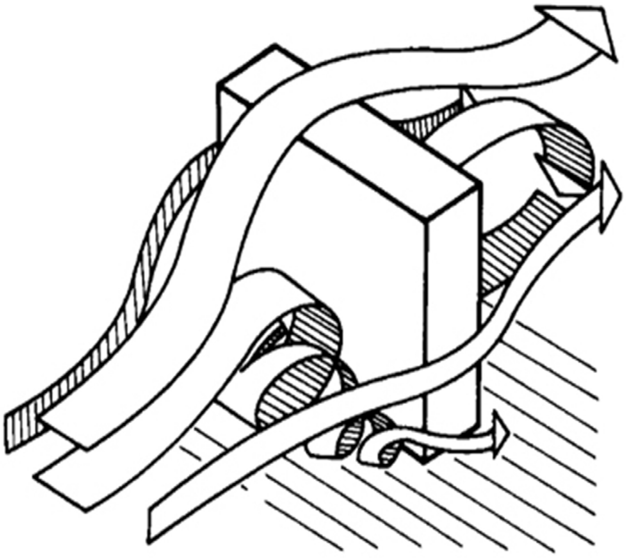

Fig. 1. The impact of the wind on the building [14]

to make a loop on the other side of the object [5, 7, 9]. It has been illustrated in Fig. 1.

As far as more complicated effect of wind is concerned, it is connected with the building which is found in the green surrounding and other construction objects. If the environment has similar geometric dimensions, we deal with the strong influence on the change in the building, caused by the impact of loads. Single buildings, separated due to contact with the stream of wind affect mutually each other. We may conclude that the improper situation of the objects may have a negative influence on the wind. In such case, the velocities of air stream are increased and the whirlwinds are generated; it causes heat losses in the buildings and high operating costs; it decreases also thermal comfort, existing in the building [7].

The aim of the work was to study the effect of the wind impact, its speed and direction which determines value of heat transfer coefficient U; it is the componential of heat loss coefficient via transfer of H_t, determining the demand of the building on heating energy.

Heat energy and its balance in the building

Keeping the comfort of heat energy in the building is consists in the summarized presentation of the heat profit balance in the mentioned building, considering profits and solar losses, caused by transfer of heat via building baffles and by ventilation system. Before designing of such building, or modernization of the existing one, we should strive at decrease of heat losses as to keep the heat comfort for the whole year [5, 8]. To obtain such effect, we have to eliminate heat losses, resulting from a low heat insulation of the discussed building. The unfavourable effect may be also caused by the incorrect position of the building in respect of its geographical situation as well as by the exposure of the discussed building to unfavourable wind influence. The role of the windows' distribution, shape of the building and its ventilation system is also significant from energetic balance viewpoint. The basic energetic balance elements include always profit coming from the sun, equipment, the inhabitants themselves and heat water. We may also mention heat losses which result from ventilation system, internal baffles and ground partitions.

Coefficient of heat transfer via building partition, U

The cause of the effect of the increased value of heat coefficient and its losses on the energy balance in the building includes design and performance errors. Heat losses due to heat transfer are determined by surfaces of partitions and the specified heat transfer coefficient U, characterizing the baffle between the external and internal environment [3, 4]. The role of the effect of other conditions in the building such as shape of the building, urban structure of our object on the losses in energy and the coefficient U are seldom considered. We should also mention the climatic conditions, occurring at a given territory.

To optimize the conditions, we should always analyze the stage of designing a building. When designing the construction of the building, we should pay attention to make it possible simple and compact, with the minimum number of bent parts. The most favourable solution includes a flat roof, or double-pitched (gable) roof with a small slope [7].

The effect of urbanistic structure of Poland on heat losses in building, resulting from a constant air flow to the building and its outflow inside

The post-war tendencies of urbanistic structure in Poland were mainly focused on building the dwelling houses such as multi-storey buildings and skyscrapers which were usually situated on the peripheries of the towns. Such solutions considered mainly the effect of the wind. The constructions inside the residential settlement caused change in the air movement; it was related to the increase in the wind speed inside the urbanistic structure. Additionally, it eliminated the possibility of estimating the heat losses in the building depending on its exposure to the wind. The determination of the wind movement is always important for climatic conditions on the separate territories, occupied

Fig. 2. The Settlement" Zachód" in Stargard [11]

by a group of buildings [7]. We can distinguish three types of exposure to wind: normal, protected (shielded) and the open one to atmospheric conditions and their effect. At the territory of Stargard, the settlement "Osiedle Zachód" is the best example, demonstrating the negative consequences of air stream activities inside the architectural structure (Fig. 2).

When designing the building, the attention was not paid to thermal parameters of building partitions and to the care of performance what resulted in a considerable number of thermal bridges, being the route of the heat escape from the building. It is demonstrated in Fig. 3. The neuralgic point of such building includes the sites of contact of two different constructional components or joining of the elements of different shape [7].

For multi-family houses which were constructed in the eighties of the 20th century, the heat transfer coefficient for the walls is equal to 1.12$W/m^2 \cdot K$ and for windows – 2.4 $W/m^2 \cdot K$. The inaccurate connections of the concrete plates with windows and with other concrete plates, what is also the important factor, have been illustrated in Fig. 3. Thermal modernization of the mentioned above buildings before 2013 was not effective as it resulted from the lack of precise analysis of the heat balance and also, due to the lack of the performed energetic audit; it did not meet the requirements of the set standards. After the introduction of the change in the rules, the analysis became more precise [4, 6] but it still did not consider the heat loss which was caused by effect of the wind on the buildings and their construction. The mentioned above analysis concerned the urban nature of the analysed area and climatic conditions at the territory of the country [7].

Fig. 3. Photography of the 'building plate', made with the use of thermal imaging camera [12]]

Wind and its role in energy balance

When calculating the energy balance of the building aiming at favourable thermal comfort of the inhabitants, we should also consider, apart from a good insulation, the coefficient concerning heat losses Htr, which includes one-dimensional heat exchange throughout the partitions as well as two-dimensional heat exchange due to the presence of thermal bridges [6]. The direction of the wind has also its effect in the case of a big amount of the heat escaping via thermal bridges. As far as climate in Poland is concerned, the western direction is most unfavourable. If we put direction and speed of the wind together, we will be able, on the grounds of simulation, calculate approximately the shape and height of the air stream, coming to the contact with the building façade [7].

The mentioned simulations may serve for analysis of the air movements and determination of the conditions affecting the turbulence, increase of the speed of the wind what is indispensable at the stage of designing the construction by the architects and urban planners. A high construction for, as dominating at the territory of Poland, has a shape of ring, surrounding the lower buildings; it dates back often to the pre-war period. it is exposed to especially strong effect of air streams during winter what is the reason for a higher pressure of wind on the external walls of the buildings. It causes thermal problems for the residents such

Fig..4. Photography of a single skyscraper of the settlement "Zachód" in Stargard, dating back to the eighties of the 20th century [13]

Fig. 5. Photography of the analysed building object [7]

as e.g. uncontrolled heat losses, penetration of cold air from the outside (windows and doors) as well as thermal bridges at the contact of concrete plates [6, 7].

To illustrate the effect of the wind in relation to the building, 10-storey skyscraper, situated at the settlement Zachód in Stargard, was analysed in the present study. The examined building was shielded with some protection elements such as some trees, bushes and other buildings which allowed a free flow of the wind. The measuring points were situated in the distance of 1 m from the walls of the analysed building. Also, the extreme measuring points were set at the space of 2 m and distance of 3 m from the ground of the examined building and ca. 1.5 m below the line of the roof [7, 8]. After 10-hour observation of the skyscraper, (Fig. 5) it was revealed that the speed of the air varied within the limits of 0.35 m/s; it concerned the central walls. The speed of the coming air stream in the highest corner of the building was equal to 4.12 m/s. It is resulted from our conclusions that the velocity of the wind is always changed together with the dimensions of the building [7, 8]. The initial value of the wind Vo is 4 m/s in the site of 10 m above the ground of the building. The speed of the wind at the level of 3 m above the ground level of the building was analysed for three directions: western, north-western and south-western. If we speak about western direction of the coming wind, it is always perpendicular to the object as the surrounding construction decreases always its speed. It reaches the lowest value in the middle of the building's facade on the windward side. It is illustrated in Fig. 6 [7].

When the wind comes from the north-west direction, the neighbouring object protects, in a certain degree, the analysed wall. The speed of the coming wind is decreased when it approaches the central part of the wall where the collision with the building occurs. The change in the wind direction takes place into the parallel in relation to the building. Together with the decline in the distance from the sharp edges, the air stream becomes separated and its velocity is increased (Fig. 7) [7].

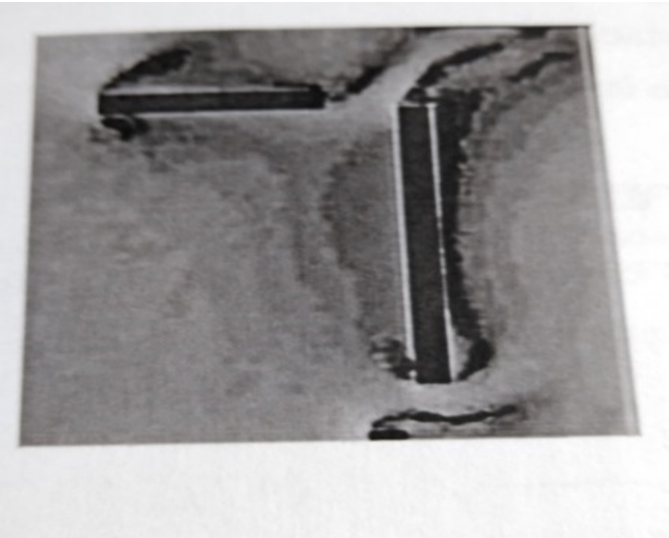

Fig. 6. Western wind [7]

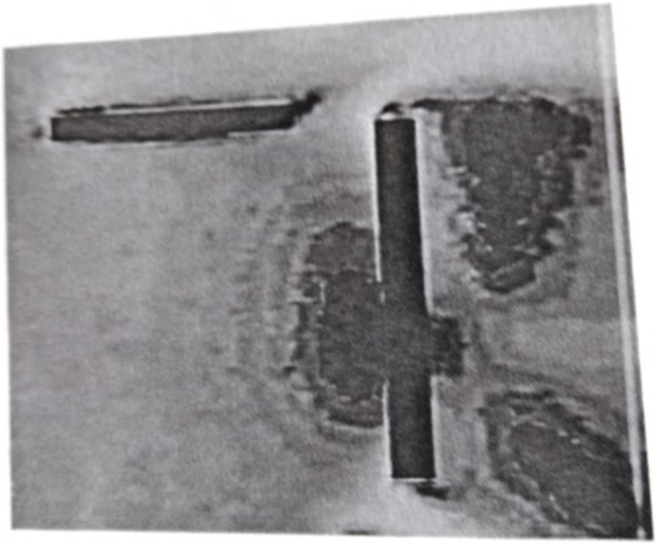

Fig. 7. North-western wind

At the south-west direction, the building is considerable less shielded; due to this fact, a zone of the lowest wind speed is shifted towards the south edge of the skyscraper. The highest speed of the wind flow was found above the corner and in the passage between the neighbouring objects (Fig. 8) [7].

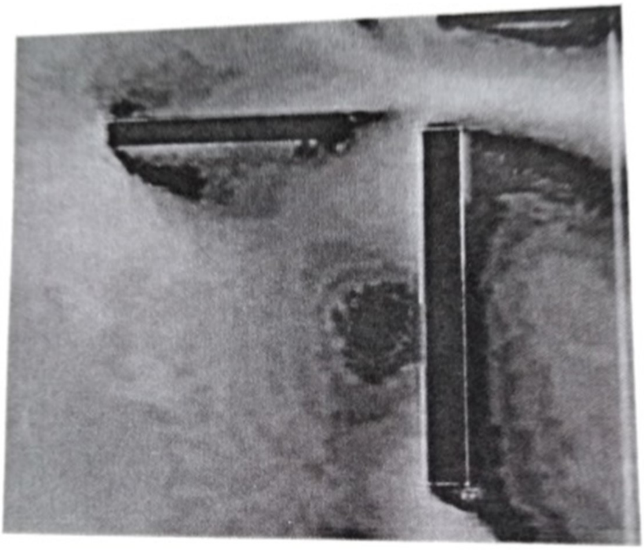

Fig. 8. South-western wind

A significant effect of the speed and direction of the wind on the heat transfer coefficient

The most important calculations concerning the wind effect which had a significant influence on value of heat transfer coefficient were carried out according to the relationships (9.1–9.6). The total thermal resistance begins to change together with the speed of the coming wind; it is related to the building partitions.

Table 1. Resistance to heat transfer on the external side of the surface and heat transfer coefficient

Ambient temperature	**Wind speed**	**Wind direction**	**Heat flow coefficient due to radiation**	**Heat flow coefficient via radiuses of back body**	**Heat flow coefficient on the external side**	**Ambient temperature**	**Dynamic resistance of heat flow on the external surface**	**Heat transfer coefficient**
tm [°C]	v[m/s]		$h_T=\varepsilon h_{T\sigma}$	$h_{T\sigma}=4\sigma Tm^3$	$h_\sigma=4+4v$	T_m[K]	$R_{se\ dynam}=1/(h_\sigma+h_T)$ [m²K)/W]	$U_v=1/[1/U)-R_{se}+R_{se\ dynam}]$ [W/(m²K]
2.8	0	0	4.23	4.6	4	275	0.11	1.3380
2.7	0	0	4.23	4.6	4	275	0.11	1.3379
2.5	0	0	4.22	4.5	4	274	0.11	1.3376

In connection with the above, we may distinguish the following formula:

$$U_v = 1/1/U\text{-}R_{se} + R_{se\ dynam}\ (9.2)$$

R_{se} – is thermal resistance of external partition; it is calculated from the following formula: $R_{se\ dynam} = 1/h_\sigma - h_T$ (9.3)

The heat coefficient, being measured at the external side is:

$$h_\sigma = 4 + 4\upsilon\ (9.4)$$

The heat coefficient, resulting from radiation:
$h_T = \varepsilon h_{T\sigma}$, where the surface of emissivity is $\varepsilon = 0.9$ (9.5)

Black body and the coefficient of its radiation: $h_{T\sigma} = 4\sigma T^3m$ where: T_m – absolute temperature. Black body and its radiation:

$$5.67 \times 10^{-8}\ W/m^2K4\ (9.6).$$

Resistance to heat transfer on the external side of the surface and heat transfer coefficient, which is greatly dependent on such factors as direction and velocity of the wind, have been presented in Table 1.

The velocities and direction of the coming wind have the greatest influence on the heat transfer coefficient, the value of which is U = 0.25 W/m² K. It is greatly dependent on the building, affected by the wind. The coefficient of heat transfer via the building partition has been calculated in accordance with the guidelines, contained in the Polish Standard PN-EN ISO 6946 [8].

Summing up

- Nowadays, in each modern construction sector, we strive at improvement of the external heat building partitions, employing the newer and newer constructional elements as to obtain the lowest heat transfer coefficient for the external partition,
- When designing the external walls, we should choose the most appropriate thickness of the material with the lowest heat transfer coefficient; it has a favourable impact on thermal insulation of the partitions and improvement of thermal comfort in the building,
- Good thermal insulation of the building is specified by basic assumptions of physics of the external walls of the building,
- The conducted analysis in the present study allows concluding that the differences in maximum speed of the wind and in the directions of its flow have the influence on the amount of the lost heat from the inside to the external environment,
- The difference between the external and internal environment, being separated by the discussed partition, is, however, the key aspect of the analysed problem,
- When designing the contemporary buildings with minimum energy use, we should carry out the simulation of the wind effect on the designed object, with the reference to the urban construction in a given area and to the maximum wind speed, occurring at the given area. It would be helpful in designing the external partitions and adaptation of the value of the heat transfer coefficient, being most appropriate for given conditions of the area. It would minimize the effect of wind stream on the heat loss from the inside to the external environment of the building.

Index of determination of the symbols, mentioned in the paper

Tm, K – ambient temperature,
$R_{se\ dyn}$, m² K/W – resistance of heat flow on the external side of the surface,
H_{tr} – heat loss coefficient, resulting from heat transfer,
Uv – heat transfer coefficient for different wind velocities,
v, m/s – wind speed,
t_m, °C – ambient temperature,
h_σ – heat transfer coefficient on the external side,
h_T – heat transfer coefficient, resulting from radiation,
$h_{T\sigma}$ – coefficient of radiation *via* black body,
σ – Stefan Boltzman constant,
ε – surface emission,
V_o – speed of blowing wind,
W – value of heat flow coefficient.

References

[1] Flaga A.: Inżynieria wiatrowa, podstawy i zastosowania, Wydawnictwo Arkady, Warszawa 2008 r.

[2] Heim D., Klemm K.: ,, The effect of wind loads on conduction heat looses in high rise building ", The 21 TH Conference on Passive and Low Energy Architecture , Eindhoven , The Netherlands 19-22 September 2004 r.

[3] Maludziński B.: Korekta wskaźnika EP dla lokali mieszkalnych w budynku wielorodzinnym ,,Czasopismo techniczne "Zeszyt 4 (2-B/2010), Kraków 2010 r.

[4] Neufert E.: Podręcznik projektowania architektoniczno- budowlanego, Wydawnictwo Arkady , Warszawa 2005r.

[5] Panek A., Rucińska J., Ekonomicznie uzasadniona możliwość poprawy wymagań energetycznych budynków w Polsce ,, Czasopismo techniczne " Zeszyt 4 (2-B/2010), Kraków 2010r.

[6] Klemm P. Budownictwo ogólne Tom 2, Fizyka Budowli, Wydawnictwo Arkady Warszawa 2010r.

[7] Szczepaniak P., Wesołowska M.: Projektowanie budynku mieszkalnego wielorodzinnego z wymaganą charakterystyką energetyczną. ,, Czasopismo techniczne " Zeszyt 4 (2-B/2010), Kraków 2010r.

[8] PN-EN ISO 6946:2008 Komponenty budowlane i elementy budynku . Opór cieplny i współczynnik przenikania ciepła. Metody Obliczenia .

[9] http://pl.wikipedia.pl

[10] htpp://fakt.pl

[11] http://e-stargard/wiadomości/

[13] http://stargard naszemiasto.pl

[14] htpp://inzynieriabudownictwa.pl.

Article reviewed

Received: 10.05.2021 r./Accepted: 18.05.2021 r.