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THE EFFECT OF THERMAL RESISTANCE OF BUILDING'S OPAQUE ELEMENTS AND WINDOWS SURFACE ON AIR EXCHANGE INTENSITY DURING THE SUMMER SEASON

WPŁYW OPORU CIEPLNEGO ŚCIAN BUDYNKU ORAZ POWIERZCHNI PRZESZKLENIA NA NATURALNĄ WYMIANĘ POWIETRZA W OKRESIE LETNIM

A b s t r a c t

The purpose of this work – connected with overheating process occurring in buildings – was to investigate the intensity of natural air exchange when a value of thermal resistant for outside walls is being increased together with the increase of the window's surface. To obtain higher thermal resistant the outside partition were covered with insulating material subsequently from 3 to 30 cm. Window surface to wall surface ratio (wwr) was changing from 5% to 50%. The window's test surface was facing east, south and west in turn while the wwr of the remaining orientations was kept at a constant 1/10 of the wall. The intensity of the buoyancy flux was analyzed as well. Three forms of ventilation airflow were considered – with assisting and opposing winds and no wind appearance. The process was examined in a single zone building, naturally ventilated, fitted with heat accumulating mass.

Keywords: *thermal resistance*, *buoyancy flux*, *natural air exchanger*, *solar heat gains*

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

Przeanalizowano wpływ sukcesywnie wzrastającego oporu cieplnego obudowy budynku oraz powierzchni okna na ilość wymienianego powietrza wentylacyjnego. Ściany zewnętrzne docieplano warstwami izolacji, poczynając od 3 cm, a kończąc na 30 cm. Dla każdej warstwy izolacji rozpatrywano przeszklenia obejmujące udział powierzchni okna w przegrodzie od 5% do 50% kolejno dla orientacji E, S, oraz W. Zbadano także zmiany strumienia wyporu termicznego powietrza. Obliczenia uwzględniały wpływ różnie ukierunkowanego wiatru.

Słowa kluczowe: *opór przenikania ciepła, wypór termiczny powietrza wewnętrznego, naturalna wymiana powietrza w budynku, słoneczne zyski energetyczne*

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1. Introduction

Untill recently, when energy performance in buildings was considered, the main areas of research were concentrated on the building envelope to keep its thermal transmittance values of opaque elements as low as possible. The aim was to design low energy buildings to perform well during heating season. This approach is still present in building regulations where maximum acceptable U-values are set. The U-values order was followed by the idea, generally forced by architects, of large window area facing south. The concept focused on window size rather then on the combined effect of low-emission glass and heat accumulation. The results show that the size of the energy efficient windows did not have a substantial influence on heating demand during winters, especially if glazing choice was disregarded and the thermal mass together with the heat accumulation is not followed either [9]. Energy demand in these circumstances during heating season was not especially lower when cold conditions are investigated. Moreover architectural solutions concerning transparent elements of a building envelope, which may influence energy reduction in heating seasons are very likely to generate its growth during summer periods.

The effects of: window size and its orientation, the kinds of glazing, as well as solar transmittance on heating and cooling demands have been published in a number of papers [2–7, 9].

According to the state of the art, the energy balance of a building is directly related to much higher number of parameters and factors then it used to be. The architectural design must be now more complex, especially where the first stage of designing is concerned. This stage will usually pay a significant role in the creation of the future energy performance of building. The research being carried out on energy balance needs a deeper understanding of the heat and air exchange processes undergoing in buildings. Influence of thermal mass, thermal properties of the glazing system and natural air exchange on indoor comfort should be of careful investigation among others. Building project cannot be designed to fulfill esthetics and functional expectation only but energy requirement in all of the aspects of the issue have to be analyzed. The architectural design parameters must show the influence on energy performance during heating season as well as for the cooling demand. Energy requirements for heating and cooling purposes should be analyzed separately especially in cold climate. The aim of this work is to show some relations among: windows size, their orientation, thermal resistance of buildings opaque partitions and air exchange. These basic, but not obvious, interdependences may help to get some alternatives in choosing the appropriate design when thermal comfort and energy consumption is discussed.

2. Results of calculation

The graphs presented in this chapter are based on computer simulation for unsteady exchange of heat and ventilation flow rates. The mathematical model and methodology of numerical computation can be found in [1]. The calculations have been made for a single zone building, naturally ventilated, fitted with an internal heat accumulating mass. Nowadays one-family houses are mainly designed as open space buildings. Three modes of airflow throughout the buildings have been simulated. The first one regards assisting wind, the second opposing one and the third simulates the process when wind does not appear. The weather parameters represent a typical July in Warsaw [1].

The thermal resistance of the whole building envelope is 0.66 $m^2 \cdot K/W$. The partitions were being covered with foam polystyrene. The first thickness of the insulation layer was 3 cm, the second was 5 cm and then with the step of 5 cm obtained 30 cm layer. Thermal resistance eventually reaches 7.8 $m^2 \cdot K/W$. The building is fitted with three windows facing east, south and west. The north wall has no window. Similarly to varying thickness of insulation the windows area was changed as well. Window to wall ratio (wwr) was changing from 5% to 50% with the step of 5%. The heat transmittance coefficient for a window equals 1.6 $W/(m^2 \cdot K)$. Heat adopted in the calculations came from solar energy that was being gained through windows, the heat generated by occupants and of the electrically supplied outfit the building is equipped in. Heat, except solar energy, had constant value and equaled 300 W. The computer simulations of ventilation air flow were carried out for numerous sets of varying parameters: the thickness of the insulation layer, wwr parameter, windows orientation and the forms of wind appearance in air exchange. For every thickness of insulation and every orientation: east, south and west the window to wall ratio was changing from 5% to 50%, while windows area of the remaining orientations were kept at constant 1/10 of the surface of the wall. The flow fluctuated due to thermal buoyancy and wind pressure. After collecting the time history of air flow for every set of parameters, minimum and maximum value can be easily obtained. The values of air change rate at different: insulation layer and window surface (wwr) at E and S orientation in July in Warsaw are presented by Fig. 3–6. Three forms of wind influence were taken in to account. Due to limited space, only selected, results have been presented. Additionally Fig. 1 shows time history of buoyancy flux for east, south and west window's orientation when surface to wall area (wwr) equals 50% and the insulation layer equals 30 cm. The algorithm to calculate buoyancy flux is enclosed in [8]. Fig. 1 shows the time history of indoor temperature as well as ambient temperature. The graphs present the calculations only when wind does not influence ventilation flows. It means that all the air flow is driven by buoyancy forces. The absence of wind can even generates a reversed flow [1]. It happens usually during hot hours and creates uncomfortable conditions. Although that may not occur very often, it may cause problems associated with overheating.

When the window is facing east (Fig.1a), the buoyancy flux reaches the highest value in the forenoon. In the afternoon the buoyancy flux is smaller because of smaller wwr parameter for the south and west windows. But it still is generated mainly by heat sources of 300 W and heat accumulated in partitions. At the window facing south (Fig. 1b), the buoyancy flux is almost symmetrical to 12 o'clock at noon and reaches the highest value of 0.805 m^4/s^3 at one o'clock. The maximum value is slightly lower in comparison with that created at the east oriented window when reaches 0.859 m^4/s^3 at nine o'clock in the morning. During the summer, solar gains gathered by the south perpendicular partitions, are lower to those being picked of the east or the west ones. The highest buoyancy flux at the west window is generated in the afternoon and is more intensive then the east one. It equals 0.834m^4/s^3 at four o'clock in the afternoon (Fig. 1c). Indoor temperature has more or less the same value in all three cases and it exceeds 30°C. However the time history

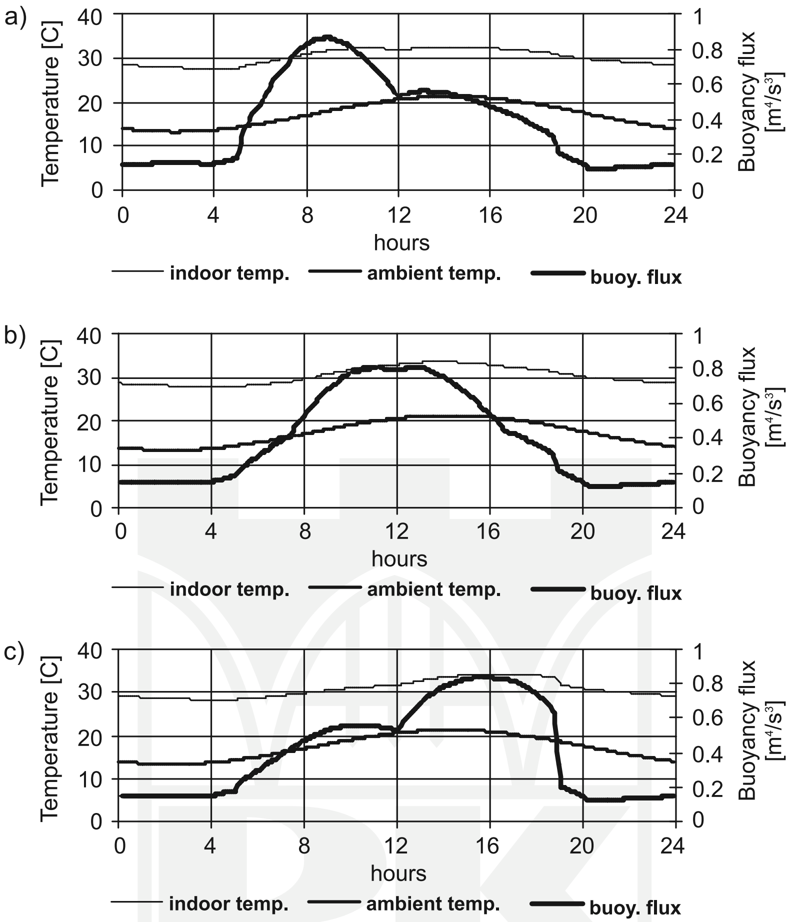

Fig. 1. Time history of indoor and outdoor temperature and buoyancy flux in July in Warsaw without influence of wind, wwr equals 50%, insulation layer equals 30 cm: a) east, b) south, c) west window

of indoor temperatures shows that their values are almost constant throughout 24 hours because of heat accumulation in partitions. Fig. 2 shows time history of air changes which reflect the intensity of buoyancy flux presented by Fig. 1. The air change rate at the West window must be higher in the afternoon because buoyancy flux is of higher value at that time. In turn at the south window more intensive air flow is observed in the early afternoon hours. But almost no differences in air exchange are observed among buildings insulated with 5, 10, 30 cm of foamed polystyrene. All the sets of the computer simulations were carried out to demonstrate the relative importance of parameters such as: outdoor temperature internal heat sources, solar gains, thermal conductance of the building envelope, windows surface and influence of wind on intensity of natural air exchange. For assisting wind the air flow is upwards. For the opposing one can be either upwards or downwards. The direction depends

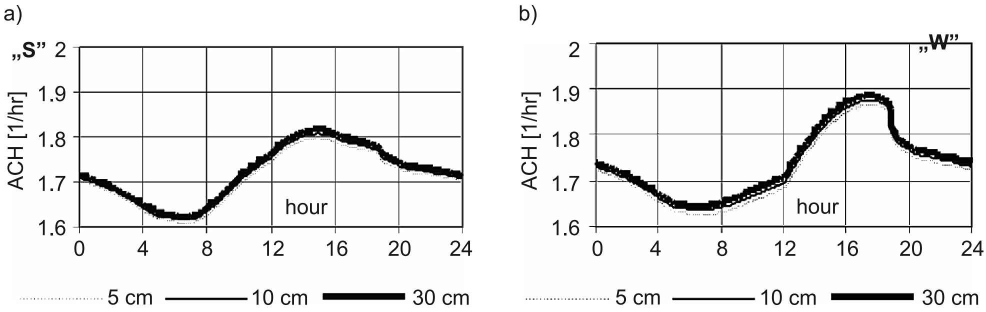

Fig. 2. Time history of air rate change rate at different insulation in July in Warsaw when wind appearances are not observed (without influence of wind), window surface to wall area (wwr) equals 50%: a) south orientation; b) west orientation

on relative strengths of wind and buoyancy forces [1, 8]. In well insulated buildings where buoyancy force substantially benefits from solar gains a reverse flow does not usually occur [1]. Sometimes the wind does not appear and the buoyancy force acts on its own. All the graphs presented by Fig. 3–6 display the highest and the lowest values of air change rates as the function of insulation thickness and window to wall rate (wwr). The layer of polystyrene is equaling 10, 20, 30 cm The wwr parameter is varying from 5% to 50%.

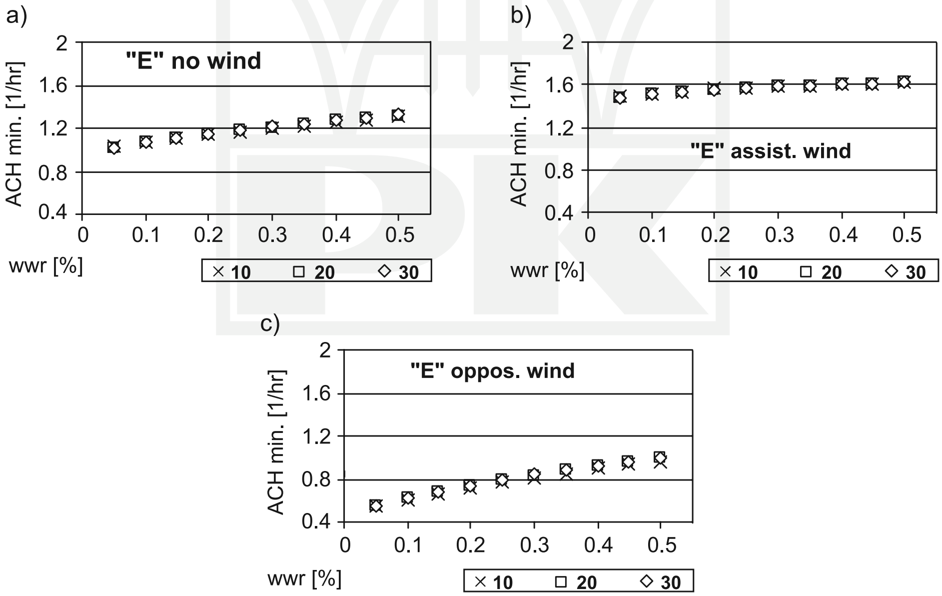

Fig. 3. Min. ACH at the east window in July in Warsaw: a) no wind, b) assisting, c) opposing wind

The common feature of all the graphs is, what is obvious, that the smallest value of air change rate is when wwr equals 5% because solar gains are the least intensive. The highest ones occur at wwr equal to 50%. At the considered thickness of layers the difference

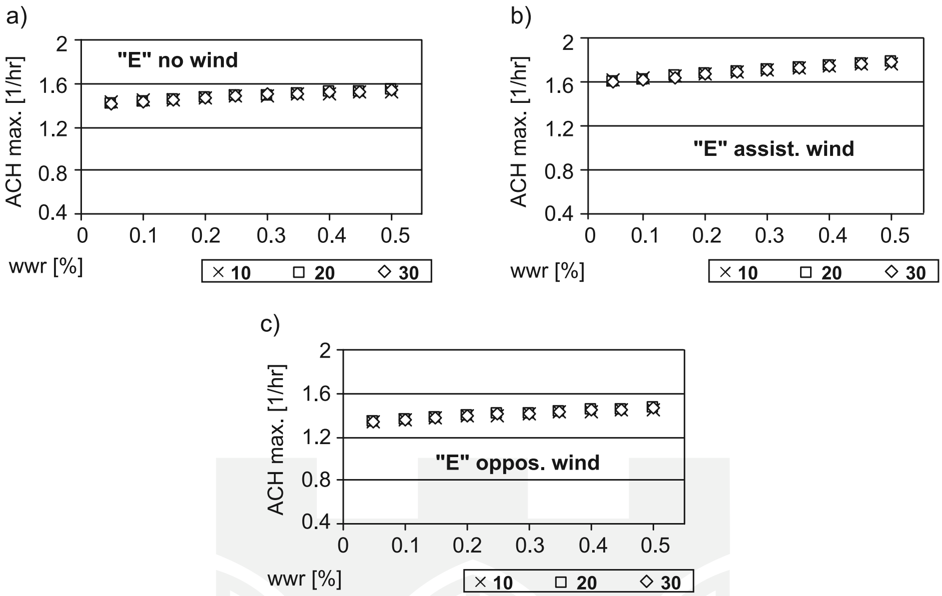

Fig. 4. Max. ACH at the east window in July in Warsaw: a) no wind, b) assisting, c) opposing wind

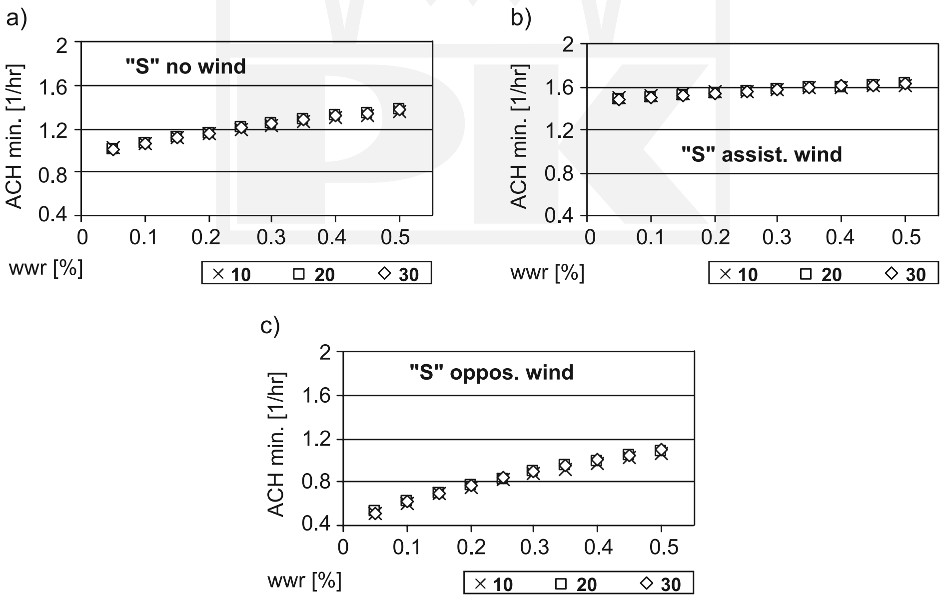

Fig. 5. Min. ACH at the south window in July in Warsaw: a) no wind, b) assisting, c) opposing wind

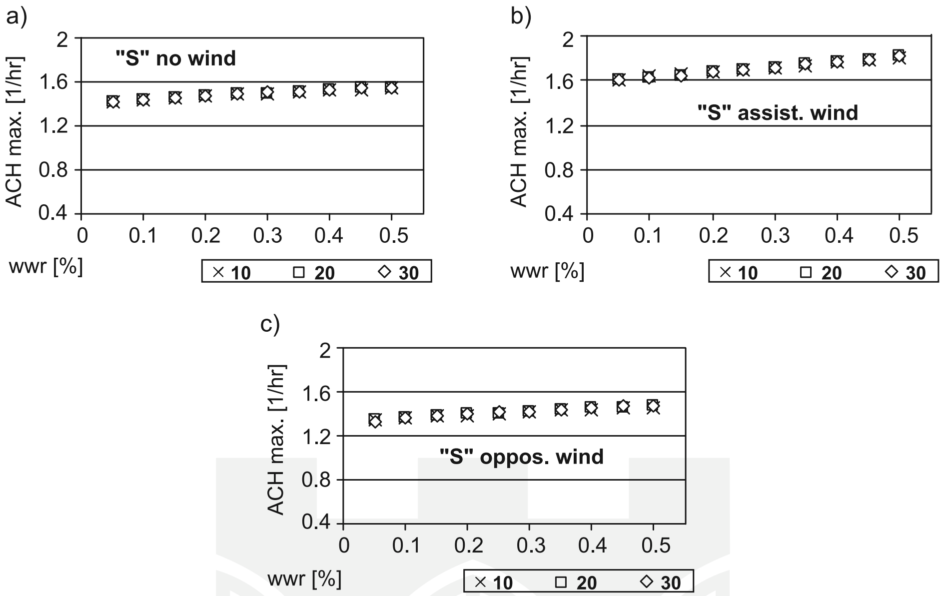

Fig. 6. Max. ACH at the south window in July in Warsaw: a) no wind, b) assisting, c) opposing wind

in intensity of air exchange is hardly visible. This is not true when the heat transmittance coefficient of the building envelope is not reduced by much, for instance between a not insulated and an insulated wall [1]. Then the wwr parameter decides about the intensity of air exchange. The results of these calculations are placed in Tab. 1. The further conclusion is then the intensity of air exchange depends mainly on the form of wind appearance. The value of buoyancy flux plays less significant role in the process [1, 8]. The lowest value is obtained at the opposing wind. No matter if the window faces east or south. Similarly the differences of the ACH rates are of less importance when orientation is concerned. The paper presents only the part of the research considering some aspects of overheating process that takes place in buildings during summer period.

Table 1

Minimum and maximum ACH values induced or not by wind at east and wouth oriented window

	no wind		assist. wind		oppos. wind	
	ACH		ACH		ACH	
	min.	max.	min.	max.	min.	max.
E min. – Fig. 3	1.02	1.33	1.47	1.62	0.54	1.0
E max. – Fig. 4	1.41	1.54	1.6	1.78	1.34	1.47
S min. – Fig.5	1.0	1.37	1.47	1.63	0.52	1.1
S max. – Fig. 6	1.41	1.55	1.6	1.8	1.33	1.48

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