CZASOPISMO INŻYNIERII LĄDOWEJ, ŚRODOWISKA I ARCHITEKTURY
JOURNAL OF CIVIL ENGINEERING, ENVIRONMENT AND ARCHITECTURE
JCEEA, t. XXXV, z. 65 (1/18), styczeń-marzec 2018, s. 161-166, DOI:10.7862/rb.2018.17

Iveta BULLOVÁ[1]

ANALYSIS OF THE AIR FLOW IN SELECTED BUILDINGS

Airflow properties are most apparent adjacent to the surface of the building, because there take place any reactions between liquid and solid object. Air exchange rate is associated with air flow through a building by natural – through small openings and cracks in the structure. Due to leakages in the building construction, opening and closing of windows, the air in the building shifts. The value of air exchange rate is hard to predict and depend of several variables – wind speed, difference between outside and inside temperatures, the quality of the building construction. The paper analyzed the air flow in selected buildings and quantified the value of air pressure differences and the air exchange rate with the emphasis on specification of aerodynamic coefficients.

Keywords: air flow, aerodynamic coefficients, wind speed, air exchange rate

1. Introduction

The interior of the building allows prevailing comfortable climate, whereas the outside is determined by the weather. Building envelope - façade - protects the internal environment from external adverse climatic factors - temperature, sun, water, snow, wind. From these climatic factors is the wind most variable meteorological element in the surface layer of the atmosphere. The article analyses factors influencing the air flow and quantified the air pressure difference and the air exchange rate for selected buildings types.

2. Analysis of air flow in the building

An important component is analysis of the air flow in a building which influences: decrease (increase) in energy use for heating, sizing of the heating system, hygienic comfort, studying the movement of smoke.

Buildings and the building façade forms in real environment the interface between the internal and external environment as a result are formed air pressure differences. Air flow in buildings is complex, time dependent and multi-directional.

[1] Corresponding author: Iveta Bullová, Institute of Architectural Engineering, Faculty of Civil Engineering, TU of Košice,Vysokoškolská 4, 04200 Košice, Slovakia, +421 55 60246, iveta.bullova@tuke.sk

Air flow through and within buildings has been based on the requirement for continuity of mass and momentum caused by wind forces and thermal effects and these two components operate concurrently. Total air pressure difference is expressed:

$$\Delta p_C = \Delta p_\theta + \Delta p_v = \pm h_0 . g . (\rho_e - \rho_i) + C_p . \frac{\rho v^2}{2} \tag{1}$$

where: h – height from the the Neutral Pressure Plane - NPP (m),
ρ_e, ρ_i – outside and inside air density (kg/m^3),
C_p – overall aerodynamic coefficient (-),
v – air velocity (m/s).

Due to the fact that the wind is the most variable meteorological element in the surface layer of the atmosphere and the building with its properties - shape, surface, air permeability - affects the air flow in the surface layer, is the quantification of the pressure difference from the wind effects Δp_v quite difficult.

2.1. Air flow – wind

Wind flow is substantially influenced by pressure differences - in weather maps depicted by isobars. In real conditions are isobars curved, because an air flow operates the centrifugal force and with respect to the movement of the earth around the vertical axis there is also some deviation - so-called Coriolis force. Wind power is expressed by a gradient wind speed v_G, which is considering the influence of temperature gradient, Coriolis force and centrifugal force.

Air velocity - wind speed - depends on factors operating in the boundary layer which are: change of height above ground, terrain roughness - expressed by the vertical gradient b, dependent on the type of locality. Change of wind speed with height change is expressed mostly in the form of power law:

$$v_Z = v_{10} \cdot \left(\frac{z}{z_{10}} \right)^b \tag{2}$$

where: v_{10} – wind speed at 10 m above ground (m/s),
v_z – wind speed at a height of above ground (m/s),
b – exponent characterizes the locality - roughness of the terrain,
b = 1/4–1/7 = 0,25– 0,14 (-).

2.2. Interaction wind – building

For assessing of natural ventilation it is necessary the knowledge of distribution of air pressure on the buildings facades. Wind effects on buildings (pressure, respectively suction) and their size are expressed using the aerodynamic coefficients of external pressure C_{pe} [-], the internal pressure C_{pi} [-] and the overall pressure C_p [-].

Aerodynamic coefficients of external pressure C_{pe} [-] can be expressed by: calculations according to national standards, experimental measurements in–situ, experimental measurements in the aerodynamic tunnel, simulation using CFD calculation software.

Aerodynamic coefficient of external pressure can be affected by a large number of parameters – geometry of the building, details on facade, positions on facade, wind speed and wind direction.

2.3. The air permeability of the facade

Facade and openings show a certain degree of the air permeability which causes the changes of external and internal pressure. Therefore, by the wind effects, the size of the internal pressure coefficient must be taken into consideration.

For engineering practice is very important knowledge of the value of the internal aerodynamic coefficient, because it can cause result in increased values at leeward and lateral sides, because infiltration may cause alteration of aerodynamic coefficients of positive total pressure (pressure) to negative (suction) value.

To determination of the internal aerodynamic coefficient it is important to know the modification of the building changes in the interaction of internal and external pressure.

We distinguish 5 different modifications of buildings [3]:

a) buildings without the internal partitions and:
   - without openings,
   - with the openings located in one peripheral wall,
   - with openings situated on two opposite peripheral walls,
   - with openings situated in all external walls,

b) buildings with internal partition walls and with openings situated in all external walls.

Given that in the current period there are no legislative requirements for the quantification of the air permeability of all separating structures of buildings (partitions, doors, etc.) it is possible to deal with aerodynamic coefficients of internal pressure only for buildings without internal dividing by partitions.

For the building without internal dividing by partitions and with window construction of the same dimensions and of the same air permeability coefficient of joint i_{LV} [$m^2/(s.Pa^n)$] will by values of internal aerodynamic coefficient C_{pi} expressed from the graphical [2,5] as a function *f(a)* and *a* determined from equation:

$$C_{pi} = f(a) \ (\text{ - }),\ a = \frac{S_{(+)}}{S_{(-)}} \tag{3}$$

where: $S_{(+)}$ –total surface of the openings on the windward side of a building, (m^2),
$S_{(-)}$ – total surface of the openings on the leeward sides and lateral sides of a building (m^2).

3. Air pressure difference and air exchange rate in the reference building

Values of external and internal aerodynamic coefficients - for different mutual ratio of openings and for the selected reference building – simple building with 8 floors – h = 22.4 m, rectangular ground-plan, middle plate-type building, with spatial proportionality: 0.5≤h/b = 1.25≤1.5 and with the surface area proportionality: 1.5≤ l / b = 2.8 ≤4.0 are in Table 1.

Table 1. Values of external and internal aerodynamic coefficients

	Windward side - longer side			Windward side - shorter side		
	$C_p = C_{pe}$	$C_p = C_{pe} - C_{pi}$		$C_p = C_{pe}$	$C_p = C_{pe} - C_{pi}$	
		2:1	3:1		2:1	3:1
Windward side	+0.7	+0.9	+0.85	+0.8	+1.4	+1.6
Lateral side	-0.5	-0.3	-0.35	-0.5	+0.1	+0.3
Leeward side	-0.3	-0.1	-0.15	-0.1	+0.5	+0.7

Based on the updated values of aerodynamic coefficients were calculated the pressure differences from the temperature and wind effect and air exchange rate. The values are shown graphically in Figure 1 and 2 for the selected day - January 06, 2017 in Kosice - wind direction 360^0 acts on the longer side, with considering of the impact of openings with a mutual ratio 2:1 and 3:1 (C_p=C_{pe}-C_{pi}) and without considering the impact of openings (C_p=C_{pe}) on windward and lateral side.

Figure 1 shows that the pressure difference from the differences of temperature Δp_θ (Pa) is relatively uniform (from 8.7 to 10.1 Pa), but the pressure difference from the wind effect Δp_v is considerable (15.5÷126.6 Pa – pressure on the windward

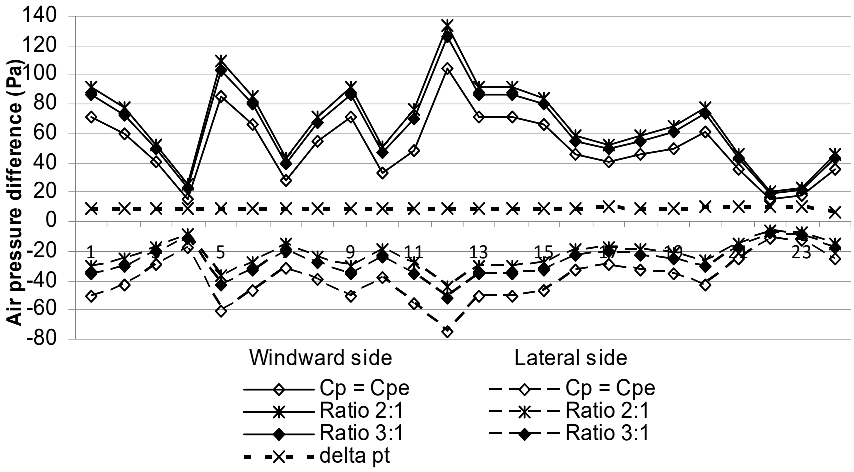

Fig. 1. Comparison of the air pressure difference for windward and lateral side with considering and without considering the impact of openings – open terrain

side, -6.6 to -74.5 Pa - suction on the lateral side), which ultimately influences the overall pressure difference and air exchange rate.

As shown in Figure 1 on the windward side are values of the pressure difference from the wind without considering of openings significantly higher than in the lateral side. Influence of openings on the windward side increases the wind effects and on the lateral side vice versa - reducing.

The air exchange rate in the reference room can be generally defined by calculation and measurement. Is developed the methodology for determining of the air exchange rate based on experimental measurements of carbon dioxide [6]. The values of air exchange rate can by calculated from the equation:

$$n = 3600.\frac{V_{\inf}}{V_m} = 3600.\frac{\left[\Sigma\left(i_{l,v}.l\right).\Delta pc^m\right]}{V_m} \qquad (4)$$

where: V_{inf} – volume of infiltrated air in the room with natural airflow, (m^3),
V_m – room volume, (m^3),
$i_{l,v}$ – gap permeability coefficient, [$m^3/(m.s.Pa^{0,67})$],
l – length of the gap, (m),
Δp_C – overall air pressure difference, (Pa).

Values of air exchange rate are calculated by the formula (4) for reference room oriented to windward and the lateral wall with the volume V=53 m^3, $i_{l,v}=0{,}4.10^{-4}$ $m^3/(m.s.Pa^{0,67})$ and length of joint 14 m.

As can be seen from Figure 2, on the windward side are the values of air exchange rate without considering the impact of openings higher than the specified standard value - n = 0.5 1/h. When considering the impact of openings, these values increase. On the lateral side are the values without considering of the openings lower and, due to the influence of the holes, are even more reduced.

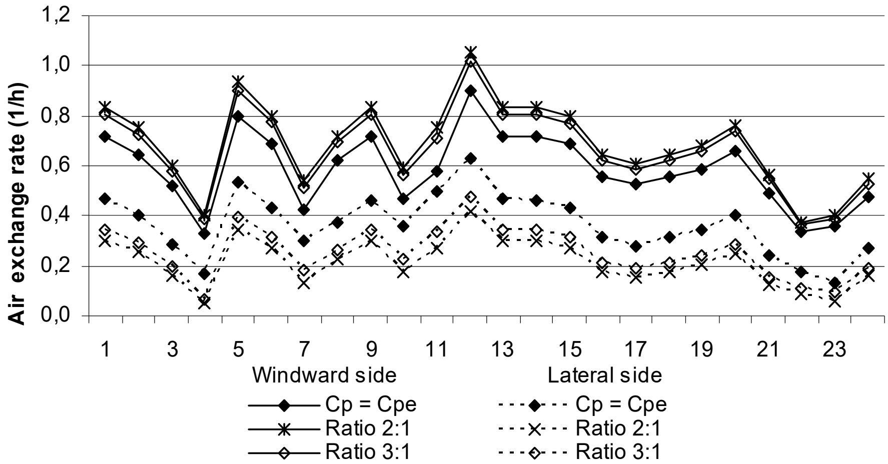

Fig. 2. Comparison of the air pressure difference for windward and lateral side with considering and without considering the impact of openings – open terrain

4. Conclusion

The theoretical analysis and the exact results of the values of the air pressure differences and air change rate for selected building show that acceptance of the air permeability of the façade affecting the pressure conditions in the interior is very important.

Pressure difference from different temperatures Δp_θ is relatively uniform, but pressure difference from the wind effects Δp_v is very variable during the day, significantly influence the air exchange rate and therefore is necessary already in urban planning accurately know and define the type of climate data and the expected urban form.

Redistribution of air pressure inside the building is influenced by the layout and orientation of openings towards the direction of the applied wind, as well as their size and mutual ratios on every side of the building. Due to this fact, the consideration of the air permeability of building envelope is very important, especially because significantly influence the redistribution of pressure in the interior resulting in high variability of the air pressure difference and consequently the air exchange rate.

Acknowledgements: *This article was elaborated within the framework of the project VEGA 1/0835/14.*

References

[1] Amin, J. A., Ahuja, A. K. Effects of side ratio on wind-induced pressure distribution on rectangular buildings. Journal of Structures, 2013.

[2] Bielek M., Bielek B. Interakcia budova – vietor v teórii energetickej potreby budov, In: 6.vedecká konferencia Budova a energia 2005, Podbanské 12-14.10.2005, pp. 64–69.

[3] Bielek M., Bielek B. et al. Vplyv stavebných materiálov a konštrukcií na kvalitu života. Parametrizovanie energeticko-environmentálneho hodnotenia stavebných konštrukcií a budov. Aerodynamika budov pre kvantifikáciu ich prirodzeného vetrania. Bratislava: PROFING, spol.s.r.o., 2005.

[4] Bielek M., Černík, P., Tajmír, M.: Aerodynamika budov, Alfa, Bratislava, 1990.

[5] Holmes, J. D. Mean and fluctuating internal pressures induced by wind. Colorado: Proceedings of 5th international wind engineering conference, 1979.

[6] Kapalo P., Voznyak O. Experimental measurements of a carbon dioxide concentration for determining of a ventilation intensity in a room at pulsing mode. In: Czasopismo Inżynierii Lądowej, Środowiska i Architektury – Journal of Civil Engineering, Environment and Architecture, JCEEA (ISSN 2300-8903), t. XXXII, z. 62 (4/2015), p. 201–210, DOI:10.7862/rb.2015.189.

[7] STN EN 1991-1-4:2007, Eurokód 1. Zaťaženie konštrukcií. Časť 1-4. Všeobecné zaťaženia. Zaťaženie vetrom. Bratislava: Slovenský ústav technickej normalizácie, 2007.

Przesłano do redakcji: 24.03.2017 r.
Przyjęto do druku: 31.03.2018 r.