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GEOMETRIC CLASSIFICATION OF NATURAL PHYSICAL CAVITIES

GEOMETRYCZNA KLASYFIKACJA NATURALNYCH SZCZELIN FIZYCZNYCH

Abstract

The new technology of double skin transparent facades based on the theory of natural physical cavities. Basic natural physical cavities with geometrically defined cross section and airflow trajectory for effective heights $H = 1$ to 4 floors in still air – convection flow, also under the effect of wind gusts. Modified natural physical cavities with geometrically defined cross section and undefined airflow trajectory for effective heights $H = 2$ to 4 floors in still air, also under the effect of wind gusts. Other natural physical cavities with geometrically undefined cross section and undefined airflow trajectory for effective heights $H = 1$ to 4 floors in still air, also under the effect of wind gusts.

Keywords: double skin transparent façade, natural physical cavity, airflow trajectory

Streszczenie

Nowa technologia przejrzystych fasad podwójnych oparta na teorii naturalnych szczelin fizycznych. Podstawowe naturalne szczeliny fizyczne o geometrycznie zdefiniowanym przekroju poprzecznym oraz trajektorii przepływu powietrza dla wysokości efektywnych $H = 1$ do 4 pięter w nieruchomym powietrzu – przepływ konwekcyjny, także poddane działaniu podmuchów wiatru. Modyfikowane naturalne szczeliny fizyczne o geometrycznie zdefiniowanym przekroju poprzecznym oraz niezdefiniowanej trajektorii przepływu powietrza dla wysokości efektywnych $H = 2$ do 4 pięter w nieruchomym powietrzu, także poddane działaniu podmuchów wiatru. Inne naturalne szczeliny fizyczne o geometrycznie niezdefiniowanym przekroju poprzecznym oraz niezdefiniowanej trajektorii przepływu powietrza dla wysokości efektywnych $H = 1$ do 4 pięter w nieruchomym powietrzu, także poddane działaniu podmuchów wiatru.

Słowa kluczowe: przejrzysta fasada podwójna, naturalna szczelina fizyczna, trajektoria przepływu powietrza

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1. Introduction

The development of new building facade technology is coupled with the wide application potential of double skin transparent facades based on the theory of natural physical cavities. The quantification of their energy performance requires thorough knowledge of their spatial definition as well as a geometric definition of air flow trajectory which remain in a mutually conditioning relation [1].

Underestimation of the geometric dimensioning of a natural physical cavity in the form of correctly quantified total aerodynamic resistance Z (-) and rejection of its interaction with air flow trajectory may lead to a serious defect of the double skin transparent facade which can be characterized by the condition of no dynamics – no movement of air in the cavity in a combination of climatic conditions in the course of the year. This situation has serious implications for the desirable features of the double skin transparent facade.

2. Natural physical cavity with geometrically defined cross section and air flow trajectory

The cross section of a natural physical cavity is geometrically defined [1]:

a) by horizontal plan parameters:
   - the length of the cavity L (m). It is the horizontal distance between the vertical dividing walls of the cavity (usually a transparent structure),
   - the width of the cavity b (m). It is the horizontal distance between the inner and outer wall of the double skin façade (Fig. 1);

b) by height parameters:
   - effective cavity height H (m). It is the vertical distance between the axes of the inlet and the outlet openings of the cavity air distribution channels,
   - distribution channel height h (m) for air intake and air exhaust from the cavity (Fig. 1).

What is geometrically defined airflow trajectory through a natural physical cavity? It is the path that moving air follows in a geometrically defined natural physical cavity determined by its geometry and direction.

Effective height H (m) of a natural physical cavity with geometrically defined cross section may be identical to the floor-to-floor height of the building $H \equiv H_{\text{FLOOR}}$ (m) – Fig. 1.

Effective height H (m) of a cavity with geometrically defined cross section may be identical to the height of several floors of the building $H \equiv 2\ H_{\text{FLOOR}}$ to $4\ H_{\text{FLOOR}}$ (m) – Fig. 2.

As we can see, the trajectory of geometrically defined natural physical cavities (Fig. 1), Figure 2 is defined, too. It should be noted that in still air, the trajectory of convection flow is always unidirectional – rising and its length is given by the relation $L_{PL} = (H+b)$ (m).

However, under the effect of wind, the length of flow trajectory is double in this case $L_{PL} = 2(H+b)$ (m) for every wind blast which is related to filling the cavity with air (blast) and emptying it of air (between the gusts of wind). Therefore, flow direction along this trajectory may be bidirectional under the effects of wind and will depend on the size of the highly variable aerodynamic coefficients of the external pressure C_{pe} (-) on both air inlet and air outlet openings in the cavity [6]. The conditions for C_{pe} = constant on both openings in a cavity are shown in Fig. 1. a i b.

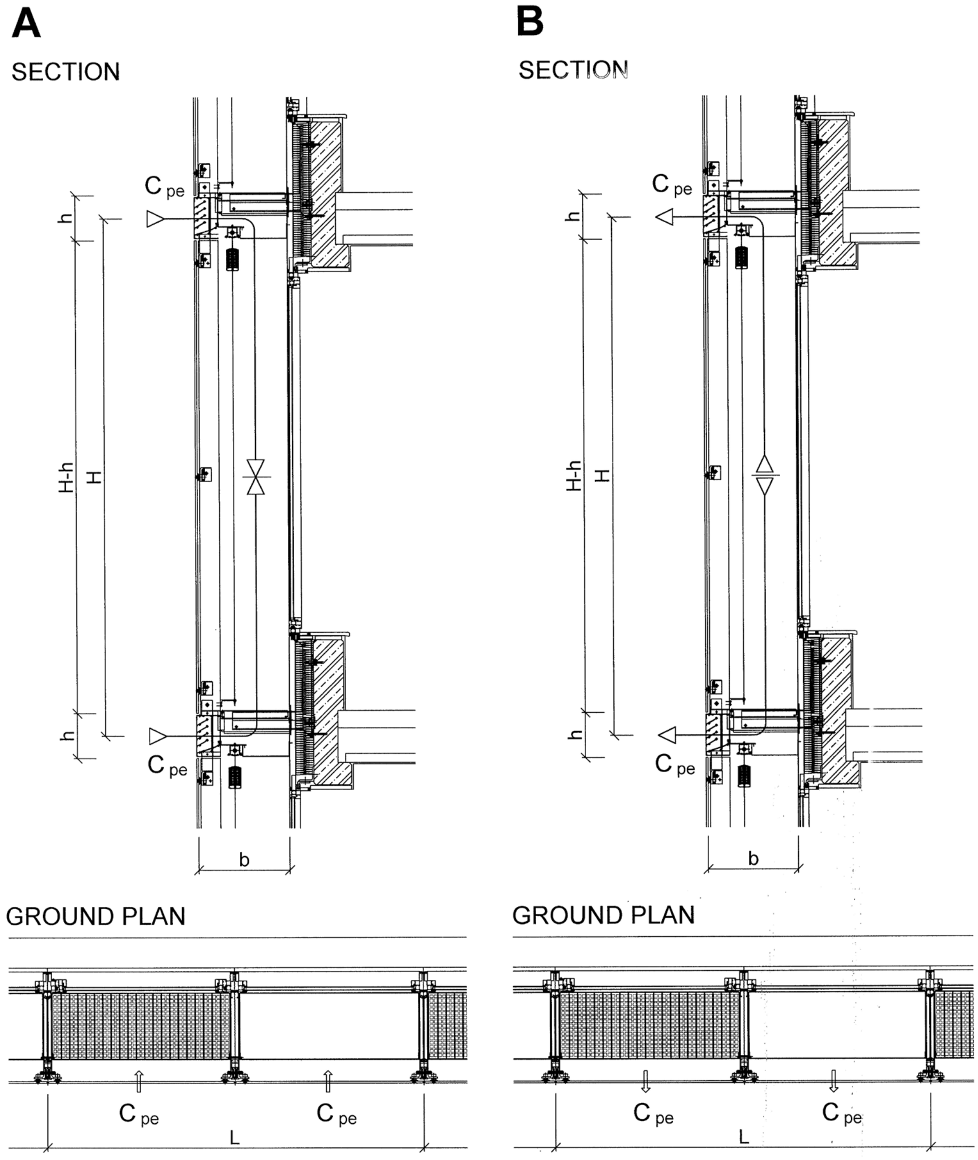

Fig. 1. Cavity with geometrically defined cross section and air flow trajectory
($H = H_{\mathrm{FLOOR}}$, effect of wind gusts, C_{pe} = constant):
a) wind gust – filling the cavity with air,
b) between wind gusts – emptying the cavity of air

Rys. 1. Szczelina o geometrycznie zdefiniowanym przekroju poprzecznym
oraz trajektorii przepływu powietrza ($H = \mathrm{H}_{\mathrm{PIĘTRO}}$, działanie podmuchów wiatru, C_{pe} = stała):
a) podmuch wiatru – wypełnienie szczeliny powietrzem,
b) między podmuchami wiatru – usuwanie powietrza ze szczeliny

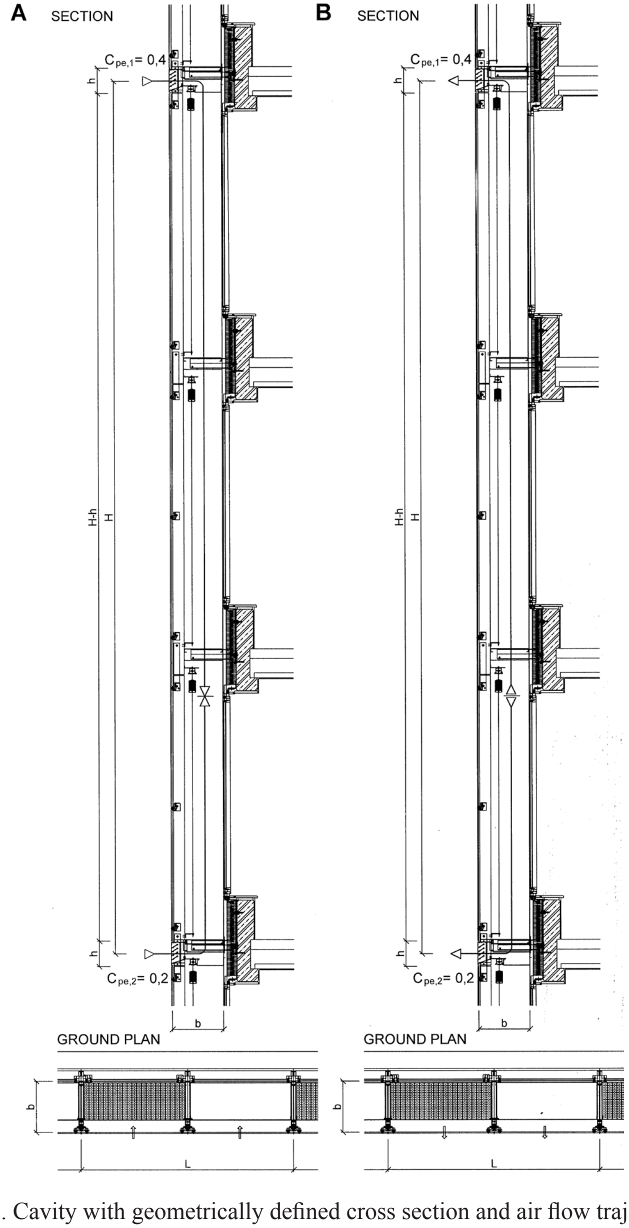

Fig. 2. Cavity with geometrically defined cross section and air flow trajectory
($H = 3\ H_{\mathrm{FLOOR}}$, effect of wind gusts, $C_{pe} \neq$ constant):
a) wind gust – filling the cavity with air,
b) between wind gusts – emptying the cavity of air

Rys. 2. Szczelina o geometrycznie zdefiniowanym przekroju poprzecznym
oraz trajektorii przepływu powietrza ($H = 3\ H_{\mathrm{PIĘTRO}}$, działanie podmuchów wiatru, $C_{pe} \neq$ stała):
a) podmuch wiatru – wypełnienie szczeliny powietrzem,
b) między podmuchami wiatru – usuwanie powietrza ze szczeliny

A building as a barrier modifies wind flows in its immediate vicinity [7]. Furthermore, the friction of wind air currents, the friction of air currents with obstacles, with terrain and the gustiness of wind cause high variability of the aerodynamic coefficient of the external pressure on the surfaces of a building. This leads to the fact that the aerodynamic coefficients of the external pressure C_{pe} (-) are different on the openings for air inlet and outlet from the cavity. The conditions for $C_{pe} \neq$ constant are shown in Figure 2.

For natural physical cavities with geometrically defined cross section and geometrically defined air flow trajectory (Fig.1). Fig.2 (always with only two openings for air inlet and outlet), the mass flow rate q_m (kg/s) or the volumetric flow rate q_V (m^3/s) are constant through the whole cavity (Fig. 3a). These are the basic types of natural physical cavities with geometrically defined cross section and geometrically defined air flow trajectory. We can theoretically quantify these natural physical cavities at the current level of scientific knowledge [2] and also experimentally verify them in situ [5]. This would be a quantification of their temperature, aerodynamic and energy regime under the non-stationary conditions on a model of the external climate, i.e. test reference year [4] (mathematical model simulation), or underthe non-stationary conditions of the real climate (in situ experiment).

3. Natural physical cavity with geometrically defined cross section and with geometrically undefined air flow trajectory

In addition to the abovementioned basic types, there are other less known or used types of natural physical cavities. One of them represents a modification of the basic cavity as it is shown in Figure 2. The disadvantage of these cavities is a high temperature rise in a cavity $\Delta\theta_{am}$ (K) because of their considerable effective height H (m) – Fig. 3a. If we need to reduce the temperature rise in a cavity, we use a modification of the cavity according to Fig. 3b.

This cavity has a geometrically defined cross section as well as a defined air flow trajectory for convective flow as we can see in Figure 3. This is also true for its modification of openings for air inlet (outlet) on each floor (Fig. 3b). Convective air flow flows upwards as long as we do not change its direction by the geometry of cross section (e.g. bends).

There is a constant air flow rate q_V (m^3/s) along the whole effective height H (m) of a typical cavity of the basic type (Fig. 3a). In a modified cavity (Fig. 3b), the air flow rate increases at the air inlet opening on each floor. Because of this fact, the rise in temperature in a cavity $\Delta\theta_{am}$ (K) decreases significantly (Fig. 3b).

A natural physical cavity under the effect of wind, according to Fig. 3b, can be still classified as a cavity with geometrically defined cross section. However, at the current level of the knowledge of this problem, we classify it as a cavity with undefined airflow trajectory.

4. Natural physical cavity with geometrically undefined cross section and with geometrically undefined air flow trajectory

If the basic type of a natural physical cavity with the effective height $H = H_{FLOOR}$ (Fig. 1) is not limited in length, i.e. vertical dividing walls (usually transparent) along the whole length of a double skin façade (Fig. 4), it represents a cavity with fictively geometrically defined

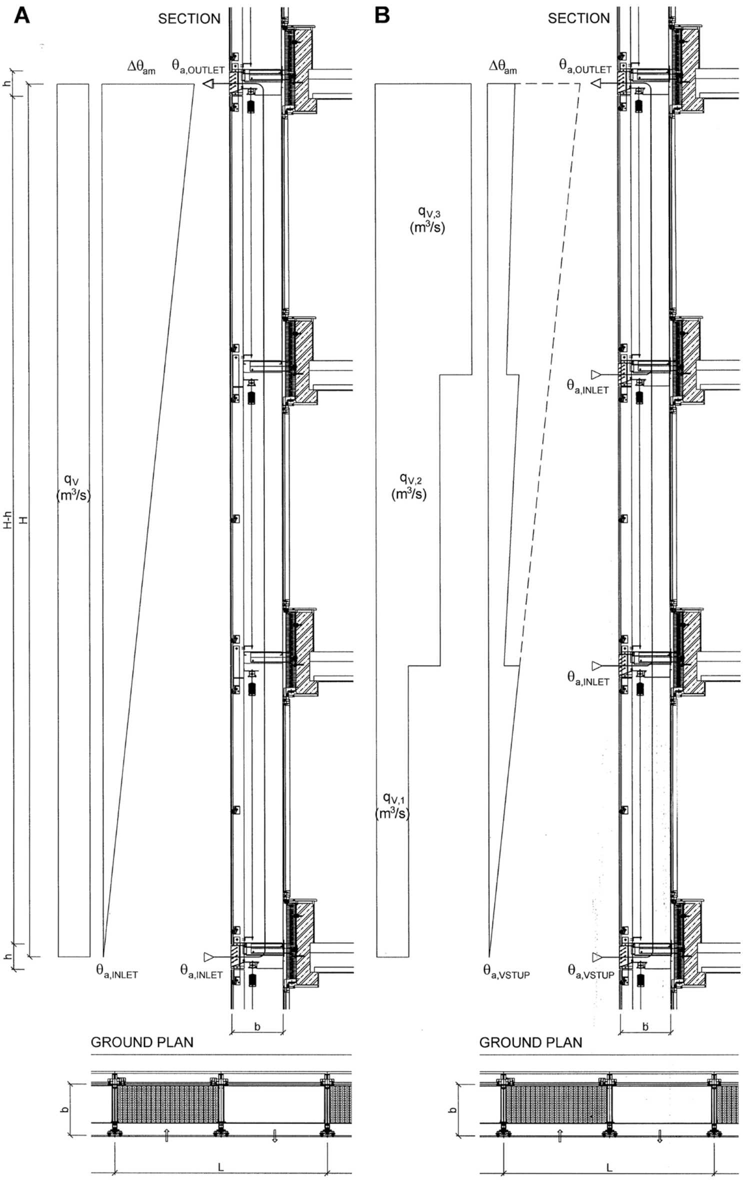

Fig. 3. Natural physical cavity with geometrically defined cross section and air flow trajectory
($H = 3\ H_{\mathrm{FLOOR}}$, still air – convective flow):
a) typical cavity with two openings for air flow,
b) modified cavity with openings for air flow on each floor

Rys. 3. Naturalna szczelina fizyczna o geometrycznie zdefiniowanym przekroju poprzecznym
oraz trajektorii przepływu powietrza ($H = 3\ H_{\mathrm{PIĘTRO}}$, nieruchome powietrze – przepływ konwekcyjny):
a) typowa szczelina z dwoma otworami dla przepływu powietrza,
b) modyfikowana szczelina z otworami dla przepływu powietrza na każdym piętrze

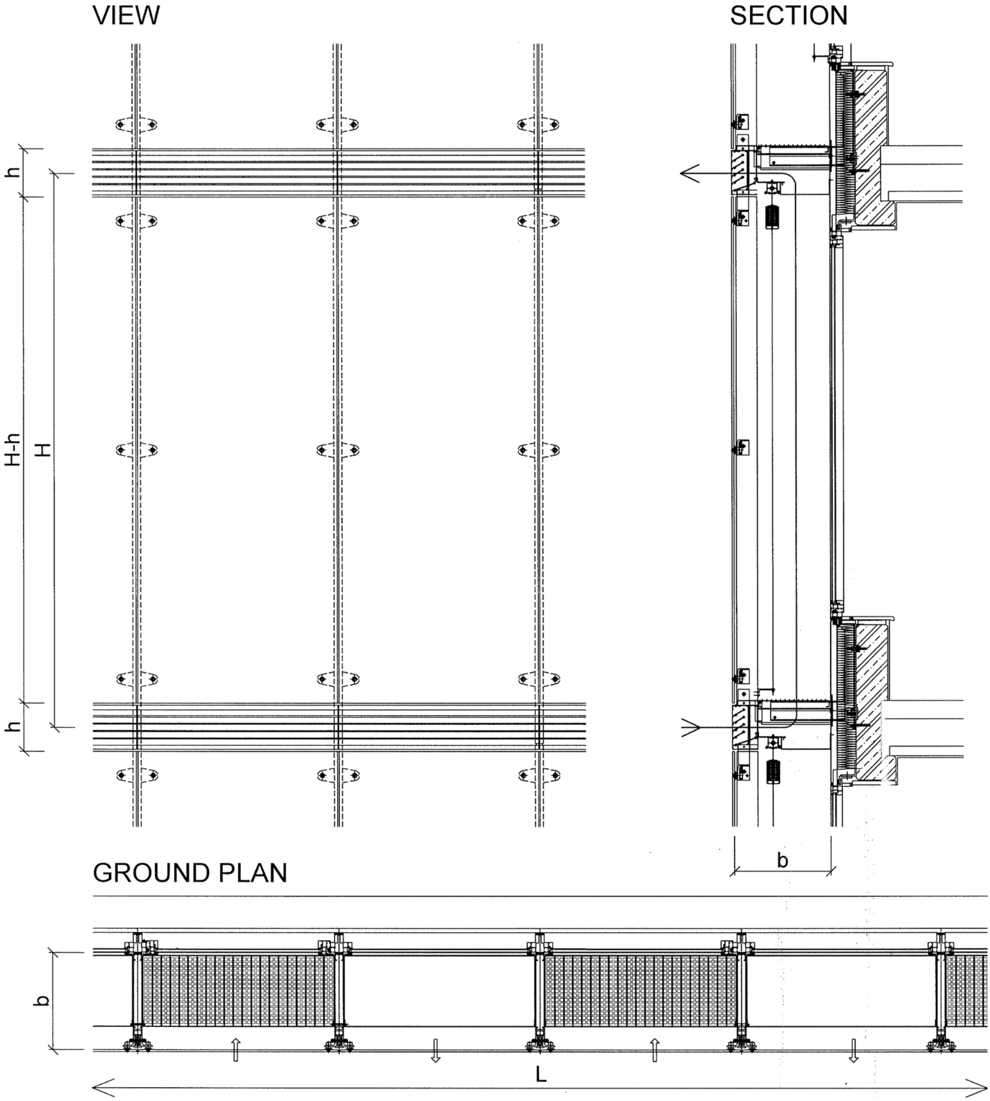

Fig. 4. Natural physical cavity with fictively geometrically defined cross section and air flow trajectory ($H = H_{FLOOR}$, still air – convective flow) and with geometrically undefined cross section and geometrically undefined air flow trajectory ($H = H_{FLOOR}$, effect of wind gust)

Rys. 4. Naturalna szczelina fizyczna o geometrycznie zdefiniowanym przekroju poprzecznym oraz trajektorii przepływu powietrza ($H = H_{PIĘTRO}$, nieruchome powietrze – przepływ konwekcyjny) i o geometrycznie niezdefiniowanym przekroju poprzecznym oraz geometrycznie niezdefiniowanej trajektorii przepływu powietrza ($H = H_{PIĘTRO}$, działanie podmuchu wiatru) cross section and air flow trajectory under convective flow and a cavity with undefined cross section and air flow trajectory under the effect of wind.

The same is true for the convective flow and a flow under the effect of wind for a cavity ($H \geq 3\ H_{\text{FLOOR}}$) that is not limited in length, i.e. vertical dividing walls (usually transparent) along the building perimeter or the whole length of a double skin façade.

We can also include a cavity created by constructing a transparent wall in front of the existing façade of a building among these types of natural physical cavities. It is used predominantly when renovating existing facades based on the typical silicate or light prefabricated metal basis.

A transparent outer wall consists of glass panels attached to vertical mullions. Open joints (6 to 10 mm wide) between the panels are present in both directions – vertical and horizontal. The cavity has a dominant air inlet opening in the ground floor and an air outlet opening on the roof level. The maximum effective height for these cavities is 6 floors.

5. Conclusions

Wide variations possible for the geometric design and equally broad application variations of the construction of natural physical cavities in double skin transparent facades, not always with the optimal choice, selection or assumptions, lead us to their geometric classification in terms of the definition of cross section and the definition of air flow trajectory in a cavity.

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Denotations

Z	–	total aerodynamic resistance (-)
C_{pe}	–	aerodynamic coefficient of the external pressure (-)
L	–	length of the cavity (m)
b	–	width of the cavity (m)
H	–	effective cavity height (m)
h	–	distribution channel height (m)
$\Delta\theta_{am}$	–	high temperature rise in the cavity (K)
q_V	–	air flow rate in cavity (m^3/s)
q_m	–	mass flow rate in cavity (kg/s)
L_{PL}	–	length of the flow trajectory (m)

References

[1] Bielek B., Bielek M., Palko M., *Double Skin Transparent Facades of Buildings*, 1st volume, Coreal, Bratislava 2002.

[2] Bielek B., Bielek M., Kusý M., Paňák P., *Double Skin Transparent Facades of Buildings*, 2nd volume, Coreal, Bratislava 2002.

[3] Bielek B., *Quantification of aerodynamic resistances of double skin transparent façade with open circuit*, Proceedings from conference "Building and Energy", TU Košice 1999, 61-66.

[4] Bielek B., Bielek M., *Test Reference Year Modification for Design of Double Skin Transparent Façade of the Slovak National Bank Building*, Proceedings from conference "Sustainable building & Solar Energy", Brno 2001, 56-59.

[5] Bielek B., Bielek M., Szabó D., *Natural Physical Cavity Regime of Double-Skin FAÇADE in Windless Climate Conditions – Long Term Experiment In-situ*, "Building Research Journal" 3-4/2009, 233-246.

[6] Ilg L., Bauhofer B., *Slowakishe Nationalbank Zentrale in Bratislava – Windruck auf der Gebäude – Külle – Windkanalstudie*, ETH, Zürich 1996.

[7] Sachs P., *Wind Forces in Engineering*, Second Edition, Pergamon Press, Oxford 1978.