PRESSURE INSIDE BUILDINGS - A DOMINANT PARAMETER FOR CALCULATING EFFECTIVE NATURAL VENTILATION

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Abstract

For the calculation of air exchange and effective ventilation of buildings the difference between the external and internal pressure induced by wind is an important dominant parameter. Whereas the external pressure has been investigated rather extensively, very little progress has been made in the reassessment of internal pressure in buildings. By a systematical study the internal pressure inside of different cubical buildings was determined in a boundary layer wind tunnel. The approach flow characteristics were scaled to correspond to typical natural conditions. The shape of buildings, the opening ratio, ϵ, and the porosity, μ, were varied in order to determine their influence on the mean internal pressure. The relationship between ϵ, μ and the mean internal pressure is demonstrated.

1. Introduction

In recent years as a consequence of the demand for reducing heating costs and saving energy a trend exists in housing construction towards airtight buildings. As a consequence the air exchange rates between outside area and inside of the buildings are reduced drastically. For the calculation of the infiltration rate of buildings it is necessary not only to know the area of porosity, A_n, and the flow resistance of cracks expressed by k_n, but also detailed information about the pressure difference between inside and outside of the building. The leakage flow, Q_n, can be calculated by

$$Q_n = k_n \cdot A_n \cdot \left(\frac{2 \cdot |p_{e_n} - p_i|}{\rho}\right)^{\gamma} \qquad (1)$$

where $A_n = \mu A$ is the flow part of the outside area A of the building.

By changing the porosity, μ, of a building the discharge coefficient, k_n, the flow area, A_n, and the flow exponent, γ, are influenced directly but the internal pressure p_i is also varying.

There are only a few studies about the relation between internal pressure, p_i, and building porosity, μ, shape of the building and approaching flow conditions. Full scale measurements are time-consuming and expensive. In most cases the characteristic parameters of the building can not be varied. But for systematical studies they have to be changed.

In a preliminary study it has been found that the wind tunnel is indeed a suitable aid for such investigations. In (1) a comparison is given between pressure measurements in full scale and in model scale for pressure distributions in and around a covered tennis court. The relevant laws of modelling are described and similarity between the full scale and the model results is demonstrated.

The present paper deals with the problem of the internal pressure of porous, one room cubical buildings in a turbulent boundary layer. The pressure inside of buildings induced by wind is dependent on both meteorological parameters and parameters which are characteristic of the building. The internal pressure, p_i, can be written as

$$p_i = f(u, \beta, I_u, L_u, \alpha, H/B, L/H, \varepsilon, \mu, \text{position of openings}) \quad . \tag{2}$$

The present study describes experimental findings for the influence of the opening ratio, ε, and the porosity, μ, on the pressure difference $p_{e_n} - p_i$.

2. Experimental Configuration

The experiments were performed in a boundary layer wind tunnel. Its test section is about 15 m long, 1.8 m wide and 0.8 m high. A thick boundary layer was generated which corresponded to conditions in full-scale (wind profile exponent $\alpha = 0.26$). A total of 14 bluff-body-models were tested. The buildings ratios varied within a range of

$$0.15 \leq H/B \leq 2.0 \quad ; \quad 0.50 \leq L/B \leq 2.0 \quad .$$

Each side of the models was furnished with a large number of cylindrical holes for simulation of building porosity (slits and cracks). The porosity, μ, is defined as

$$\mu = \frac{\Sigma \text{ area of leaks (distributed among all building surfaces)}}{\Sigma \text{ surface areas of the building}} \tag{3}$$

The value of μ varied within $0\% \leq \mu \leq 1.0\%$, the front openings (windows, doors) could be varied over a range of $0\% \leq \varepsilon \leq 33\%$. The opening ratio, ε, is defined as

$$\varepsilon = \frac{\text{area of the openings in the front surface}}{\text{area of the front surface}} \quad . \tag{4}$$

The opening in the front surface consisted of a vertical slit in the centre of the front wall. The differences, $p_i - p_{ref}$, were converted into pressure coefficients according to

$$c_{pi} = \frac{p_i - p_{ref}}{1/2 \cdot \rho \cdot u_{ref}^2} \quad , \tag{5}$$

where p_{ref} is the reference pressure at the side wall of the wind tunnel.

To ensure the transferability of model data to prototype data the decisive modelling laws have to be considered. In the present study three groups of modelling laws have been used:

a) Similarity of the approach flow
   (velocity- and turbulence intensity profile, spectrum of turbulence)

b) Similarity of the flow field around the building
   (Reynolds number, blockage effect)

c) Similarity of the flow through the building
   (Similar flow through openings and porosities) .

The modelling laws which have been used are described comprehensively in (1) and (2).

3. Results

Both the external pressures on the building outside and the internal pressure are dependent on the building ratios, H/B, and L/H. The relation between building shape and wind induced pressure for the models used in this study is described in (1).

Fig. 1 shows the influence of the opening ratio, ε, and the porosity, μ, on the internal pressure, as obtained by the wind tunnel experiments. Side and back walls have an uniform porosity. In the case of small openings ($\varepsilon = 2\%$) at the front wall, the influence of the porosity, μ, on the internal pressure is dominant, in the case of large openings the influence is negligible as shown in Fig. 1a. Fig. 1b presents the relationship between opening ratio, ε, porosity, μ, and internal pressure as a function of the wind direction. The maximum internal pressure results from $\beta = 0°$, the minimum internal pressure from $100° \leq \beta \leq 120°$.

If the external pressure distribution around a building and the porosity is given the internal pressure can be calculated by use of equation (1) for all leaks. In the case of one large opening the value of γ is 0.5, for leakages through many small openings such as slits and cracks γ will be within the range of $0.5 \leq \gamma \leq 0.95$ (3). For the calculation of air leakage rates in prototype buildings the flow exponent, γ, usually is assumed as $\gamma = 0.67$. If there is flow through all four walls the equation of continuity can be written simplistically:

$$\Sigma\, Q_{1n} = \pm\, \Sigma\, Q_{2n} \pm \Sigma\, Q_{3n} \pm \Sigma\, Q_{4n} \quad , \tag{6}$$

where 1,2,3,4 are the wall numbers. Fig. 2 shows measured and calculated data according to equation (6) with $\gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = 0.50$ and in the second case with $\gamma_1 = 0.5$, $\gamma_2 = \gamma_3 = \gamma_4 = 0.67$. The measured data agree well with the calculated curve for the second case, i.e., the flow through the building is similar in model and prototype. Such calculations were done for all models. The results are shown in Fig. 3.

The dependence of the internal pressure on the building ratio and the opening ratio can be seen clearly. There are great differences in c_{pi} for constant opening ratios depending on the shape of the building. E.g., with $\Psi = 10$ the pressure coefficient c_{pi} differs between -0.15 and -0.50.

It must be realized, however, that not only the shape of the building and the meteorological parameters affect the external pressure distribution and consequently the internal pressure, but these quantities are also affected by buildings in vicinity. A systematic investigation of these effects is planned for the near future.

The present paper is a result of a project funded by the DFG through Project No. PL 60/33 and Project No. C3 of SFB 210.

4. List of Symbols

A	flow area
B	width of the building
c_p	pressure coefficient
H	height of the building
I_u	longitudinal turbulence intensity
k	discharge coefficient
L	length of the building
p	pressure
Q	volume rate of flow
u	wind velocity
α	wind exponent
β	wind direction
γ	flow exponent
ε	opening ratio
μ	porosity
Ψ	opening ratio

Indices

e	external
i	internal

5. References

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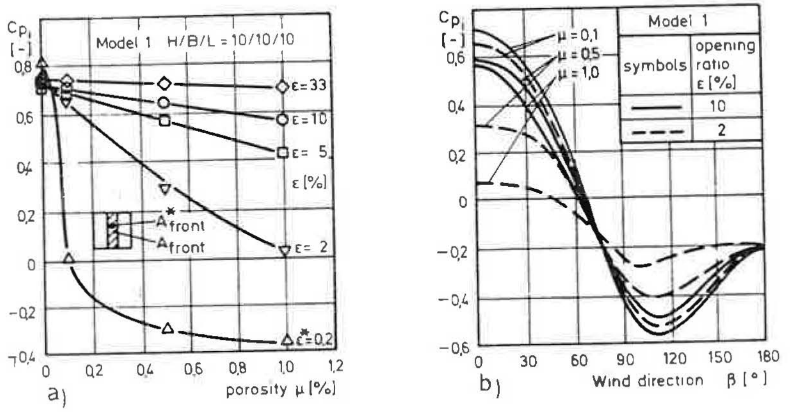

Fig. 1: Relationship between the opening ratio ε, the porosity, μ, and the internal pressure coefficient c_{pi}.

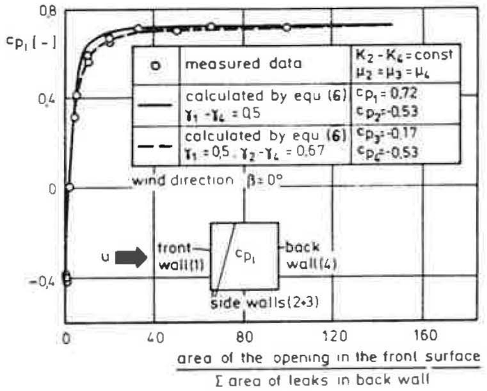

Fig. 2: Comparison between measured and calculated internal pressure for a permeable building

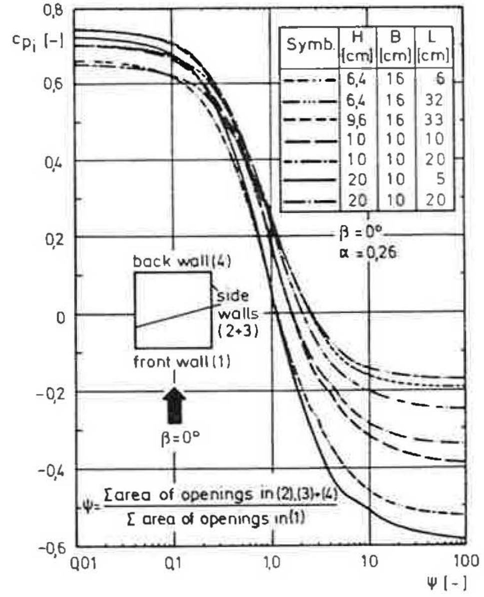

Fig. 3: The mean internal pressure in dependence of the opening ratio, Ψ, for different building ratios