Natural Ventilation of Houses

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Introduction

The air-flow through a building can cool its occupants by increasing convective and evaporative heat loss from the surface of a person's body. This cooling effect from indoor air-flows of up to 2 m/s, which could be induced by fans or wind driven natural ventilation is beneficial in hot, humid climates. Pressure differences across openings in the building envelope (ie. windows, louvres, ventilators) in prevailing breezes facilitate natural ventilation. Natural ventilation, which only requires controllable openings in the building envelope and no auxiliary power, is also appealing as an energy saving design strategy.

The wind driven air-flows though openings of a building can be estimated from the orifice flow theory, based on discharge coefficients and pressure differences. Aynsley (1982) and Vickery and Karakatsanis (1987) have derived techniques for estimating air-flows though various building configurations. The potential for natural ventilation, when temperatures exceed 30^{o}C and indoor air movement is desirable, depend on the wind climate in the locality and the configuration of the building and its openings.

Combining data from full-scale or wind tunnel model studies with analytical methods is the best means of estimating indoor air-flows. This paper describes the method used by Aynsley (1982) for calculating air-flows through various compartments of a building, which can then be used to quantify its natural ventilation performance. The characteristics of external and internal pressures measured on the full-scale Texas Tech building with a range of openings are analysed. The natural ventilation performance of common house configurations are studied based on pressure distributions obtained from a wind tunnel model study.

Theory

In steady flow conditions, the volume flow rate, Q through an opening of area A_o is related to the pressure drop Δp across it by Eqn 1, where the discharge coefficient C_d is 0.65 for a sharp edged opening, U_o is the area averaged flow velocity and ρ is the density of air.

$$Q = U_o A_o = A_o C_d \, (2\Delta p/\rho)^{0.5} \tag{1}$$

The continuity equation for flow through a room located in turbulent flow with windward and leeward openings of areas A_W and A_L and discharge coefficients C_{dW} and C_{dL} gives Eqn 2, where $\bar{p}_W, \bar{p}_L$ and $\bar{p}_I$ are windward, leeward and internal mean pressures respectively. The pressure coefficients are defined as $C_p = p/\left(\frac{1}{2}\rho \bar{U}_z^2\right)$, where $\bar{U}_z$ is the approach mean velocity at a reference height z.

$$Q = A_W C_{d_W} \left(2(\bar{p}_W - \bar{p}_I)/\rho\right)^{0.5} = A_L C_{d_L} \left(2(\bar{p}_I - \bar{p}_L)/\rho\right)^{0.5} \tag{2}$$

$$Q = \left(\frac{2(\bar{p}_W - \bar{p}_L)}{\rho}\right)^{0.5} \Bigg/ \left[\frac{1}{A_W^2 C_{d_W}^2} + \frac{1}{A_L^2 C_{d_L}^2}\right]^{0.5} = \bar{U}_z \left(C_{\bar{p}_w} - C_{\bar{p}_L}\right)^{0.5} \Bigg/ \left[\frac{1}{A_W^2 C_{d_W}^2} + \frac{1}{A_L^2 C_{d_L}^2}\right]^{0.5} \tag{3}$$

$$C_{\bar{p}_I} = \left(\frac{C_{\bar{p}_W}}{1 + \left(A_L^2 C_{d_L}^2 / A_W^2 C_{d_W}^2\right)}\right) + \left(\frac{C_{\bar{p}_L}}{1 + \left(A_W^2 C_{d_W}^2 / A_L^2 C_{d_L}^2\right)}\right) \tag{4}$$

Applying $C_{dW} = C_{dL}$, for similar types of openings on windward and leeward faces,

$$C_{\bar{p}_I} = \left(\frac{C_{\bar{p}_W}}{1+(A_L/A_W)^2} \right) + \left(\frac{C_{\bar{p}_L}}{1+(A_W/A_L)^2} \right) \qquad (5)$$

Experimental Study

External and internal pressures were measured on the 13.7 × 9.1 × 4.0 m full-scale Texas Tech building shown in Fig 1, for θ of 90° and 270° for a range of windward and leeward wall openings. The background porosity of the Texas Tech building was 2.5×10^{-4}. The pressures sampled at a frequency of 40 Hz for 15 min were analysed to give pressure coefficients referenced to the mean dynamic pressure at roof height of 4m.

Typical 15° roof pitch 16 × 8 m, 2.5 m tall low-set and 5 m tall high-set house configurations shown in Fig 2, were constructed at a length scale of 1/50 and tested in isolation in a simulated terrain category 3 AS1170.2 (1989) boundary layer in the wind tunnel. External surface pressures were measured at locations shown, representative of windows and doors on walls and roof vents for approach wind directions (θ) of 0° to 337.5° in steps of 22.5°. The fluctuating pressures at each location were sampled at 500 Hz for 30 secs. These pressure coefficients were referenced to the mean dynamic pressure at z = 10m in terrain category 2.

Results

Fig 3 shows windward, leeward and internal C_p vs time measured on the Texas Tech building with A_W = 2.0 m^2 (ie. 5% of wall) and A_L = 0.8 m^2 (ie. 2% of wall). The fluctuating pressure inside the building reflect the nature of the external pressures. Fig 4 illustrates the variation of $C_{\bar{p}_I}$ with A_W/A_L and shows that the measured $C_{\bar{p}_I}$ s are in good agreement with the theoretical analysis of Eqn 5 for $C_{\bar{p}_W} = 0.65$ and $C_{\bar{p}_L} = -0.30$.

Figs 5 and 6 show the variation of external $C_{\bar{p}}$ with θ measured in the wind tunnel at selected positions on the walls and roof of the low-set and high-set houses respectively. These plots identify wall and roof areas experiencing positive and negative pressures for each approach wind direction. Ventilation can be achieved in a room if the windward and leeward areas experience a large ΔC_p and are aligned with prevailing breezes. The temperatures on roof surfaces and ceiling spaces can exceed the surroundings by 10 - 15 °C. The ridge on the roof experiences large suctions for all approach wind directions, and is therefore the most suitable location for installing a ventilator to exhaust hot air from the ceiling space.

Table 1, gives the minimum approach wind speeds from each direction which would generate an indoor air-flow velocity of 1.0 m/s in the room connecting WA1 and WG1. The size of the openings at WA1 and WG1 are taken to be 1.0 m^2 and the C_ds are taken as 0.65. The data in Figs 5 and 6, and Table 1, show that the larger ΔC_ps in the high-set house compared to the comparable low-set house, mean that smaller approach wind speeds provide the required 1.0 m/s indoor velocity and clearly a better ventilation performance.

In most cases, houses are located close to other features of similar size which obstruct the approaching flow, unlike these tests which were carried on an isolated house. According to Lee et al (1980), when there are obstructions of similar size within 6h of the target house, the ΔCp between the windward and leeward openings obtained for an isolated house, must be reduced by a factor ranging from 0% to 50% to 75% to 100% for spacings of 6h to 2.6h to 1.4h to ~0h.

References:

1. Australian Standard SAA Loading Code Part 2 Wind Loads AS1170.2 (1989)
2. R. M. Aynsley, (1982) "Natural ventilation model studies", Proc. of the Int. workshop on wind tunnel modelling criteria and techniques for Civil Engg. Applications, Gaithersburg, USA.
3. B. E. Lee, M. Hussain and B. Soliman, (1980), Predicting natural ventilation forces upon low-rise buildings,
4. B. J. Vickery and C. Karakatsanis, (1987), External wind pressure distributions and induced internal ventilation flow in low-rise industrial and domestic structures", ASHRAE Transactions, Vol. 93, Pt2.

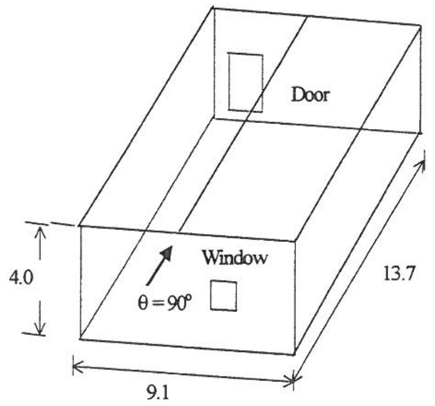

Fig. 1 13.7 × 9.1 × 4.0 m Texas Tech full-scale building showing 0.8 m^2 (2% wall) window and 2.0 m^2 (5% wall) door.

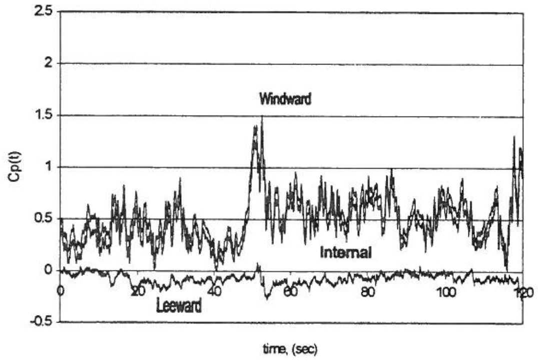

Fig. 3 Variation of windward, leeward and internal pressure coefficients with time, for Texas Tech full-scale building with 5% windward wall and 2% leeward wall openings.

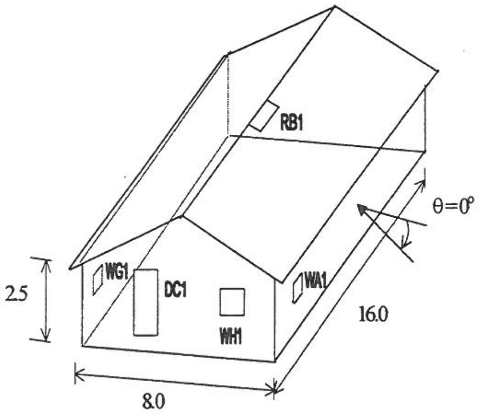

Fig. 2 8 × 16 × 2.5 m low-set house and high-set house placed on 2.5m stilts (ie. 5.0m to eaves), tested at 1/50 in the wind tunnel. Roof pitch = 15°

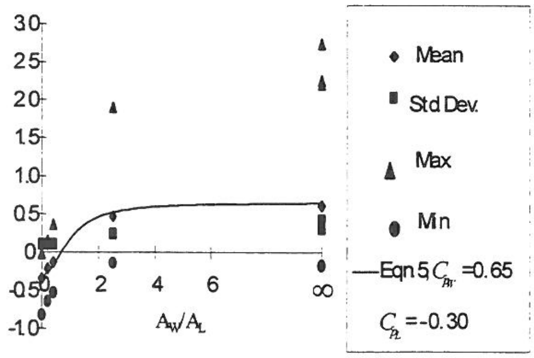

Fig. 4 Mean, standard deviation, maximum and minimum internal pressure coefficients vs. A_W/A_L for Texas Tech full-scale building.

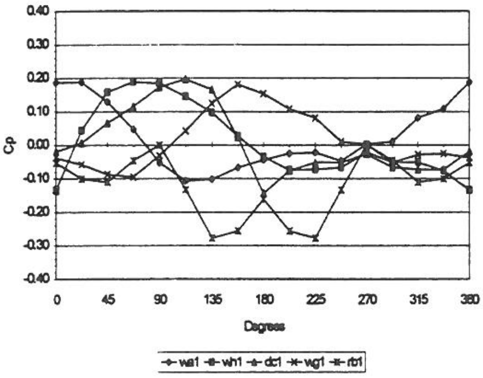

Fig. 5 Variation of mean external pressure coefficients with θ, on the low-set model house in the wind tunnel.

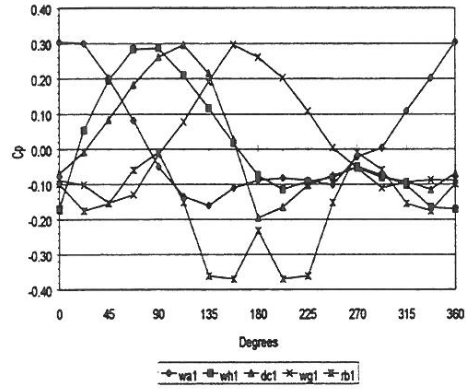

Fig. 6 Variation of mean external pressure coefficients with θ, on the high-set model house in the wind tunnel.

Table 1 Pressure drop between WA1 and WG1 and the approach wind speeds required at z = 10m, for an indoor air-flow velocity of 1.0 m/s in the low-set and high-set houses.

θ	Low-set		High-set	
deg	ΔCp	U_z, m/s	ΔCp	U_z, m/s
0	0.22	4.59	0.39	3.47
22.5	0.25	4.58	0.40	3.58
45	0.22	5.72	0.36	4.47
67.5	0.14	11.40	0.21	9.37
90	0.02	-	0.03	-
112.5	0.15	11.16	0.21	9.34
135	0.23	5.59	0.35	4.49
157.5	0.25	4.55	0.41	3.56
180	0.20	4.90	0.35	3.68
202.5	0.13	6.22	0.28	4.25
225	0.10	8.29	0.20	6.01
247.5	0.06	18.08	0.10	13.28
270	0.00	-	0.03	-
292.5	0.06	17.22	0.11	12.75
315	0.11	8.06	0.20	5.94
337.5	0.13	6.20	0.29	4.22
360	0.22	4.59	0.39	3.47

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