WALL PANEL DESIGN PRESSURES IN SEALED BUILDINGS WITH DUCTED AIR-CONDITIONING SYSTEMS

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INTRODUCTION

The identification of Legionaire's Disease as a function of air-conditioning systems, and the subequent emergence of 'Sick Building Syndrome', have forced both developers and health professionals to re-consider the existing requirements for fresh air flow in urban office and factory buildings. Increased air flows increase running costs of the air-conditioning systems, and several designers have incorporated 'economy cycles' which rely upon external differential pressures to assist the fan driven units. The use of external differential pressure is possible because architectural trends have encouraged smaller plant rooms which can be easily concealed on building facades.

This paper investigates internal pressures in air-conditioned buildings. The basic mathematical model incorporates external wind pressures on (four) faces of a typical building, with separate intake and exhaust plenums, independent intake and exhaust duct systems, flexible wall (or window) panels, internal pressure resonances (Helmholz resonances (1), duct losses and panel radiation losses. The mathematical model is subjected to wind tunnel (measured) pressures, and the maximum internal and wall pressures are computed from the modelled dynamic response.

MODELLING THE SYSTEM RESPONSE

A typical storm is modelled as a fifteen minute event. Within the time scale of fifteen minutes, the majority of incoming fluctuating wind energy falls below 1 Hz. Separation zones can experience significant fluctuations of the order of 10 Hz. Thus, the input energy time scales can vary with the location of the individual plant rooms, and these can fall between 0.1 seconds and 1 minute (2).

Within the mechanical/acoustical characteristics of the model, intake ducts with fan coil units have response times of approximately 10 to 20 seconds, while low loss exhaust ducts have response times of 1 to 5 seconds. Wall panels fall typically in the range of 1 to 5 Hz, giving response times of .2 to 1 second, and roof panels are in the range of 1 to 2 Hz, producing response times of .5 to 1 second. Helmholz room frequencies can vary greatly depending upon the size of the room, the size of opening, and upon the duct length. Large buildings can experience .5 to 3 Hz frequencies, while small unducted buildings can experience 5 to 10 Hz frequencies.

The combination of input and response times create a potential for both amplification and filtering in design building pressures. In addition, damping can be either high (in the ductwork) or low (in the room air resonances). The model used in this study is restricted to individual building floor levels with rigid floors and flexible walls. The model has been modified to analyse large factories with rigid walls and a flexible roof.

MATHEMATICAL EQUATIONS

For simplicity, the mathematical equations can be demonstrated for a single room with one opening, one window, and a duct with one 'element'. The model is shown in FIG. 1. The air stiffness can be derived from a constant-temperature pressure-volume relationship in each 'cell', i.e. the room or duct:

$$dp = p_{atm}/V_0 * dV$$

$$dV_{room} = A_2 x_2 + A_3 x_3$$

$$dV_{duct} = A_1 x_1 - A_2 x_2$$

coupled to a spring-mass equivalent of the wall panel:

$$K = K(EI/H^{**}3)$$

where EI = panel rigidity and H = panel height. The resultant equations, give:

$$\begin{Bmatrix} p_1 A_1 \\ 0 \\ p_3 A_3 \end{Bmatrix} = \begin{bmatrix} \rho A_1 L_1 & & \\ & \rho A_2 L_2 & \\ & & (M_3 + \rho A_3 L_3) \end{bmatrix} \begin{Bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \end{Bmatrix} + \begin{bmatrix} k_{11} & k_{12} & \\ k_{21} & k_{22} & k_{23} \\ & k_{32} & (k_{33} + k_3) \end{bmatrix} \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix}$$

where: ρ = air density
L_i = length of air mass (duct=dx/2) (opening = $0.8\sqrt{A_i}$)
$k_{ij} = p_{atm}/V_o * A_i A_j$

The equations represent the undamped dynamic responses.

Damping in the system can be divided into two parts: a) losses in the air-conditioning system and b) radiation losses from the panel motions. The former can be representd either as a linear function of velocity or as a square law of velocity, and the loss coefficients can be calculated directly from the steady state power consumption and the duct velocity:

Linear:	$p = C\dot{x}$	$C = \text{Power} / (A\dot{x}^2)$
Quaadratic:	$p = C\dot{x}\lvert\dot{x}\rvert$	$C = \text{Power} / (A\dot{x}^3)$

The radiation losses have been modelled as 5% of critical damping for an idealised wall panel. (3)

COUPLED WIND TUNNEL/MATHEMATICAL MODEL

Input to the mathematical model was obtained from pressure measurements on a square cylinder (FIG. 2). Eight pressure taps were manifolded to give an average 'face' pressure. In addition, one tap was placed near the corner of each face to test local pressures in a zone of potential flow separation. The mathematical model (FIG. 3) could locate plant rooms in any combination of faces. Only zero degree wind incidence was tested.

MODEL RESULTS

The model was tested for a variety of air-conditioning systems and room parameters. The various systems included ducted and non-ducted systems, and systems with re-cycled air paths. Since the major loss component is the intake fan coil unit, the effect of ductwork was not found to be significant in terms of internal pressure fluctuations. Long ducts were significant, however, in terms of lowering the lowest Helmholz frequency of the room. Table 1 gives the base resonant frequency for 4 room models.

TABLE 1
FUNDAMENTAL ROOM FREQUENCIES
30 x 30 x 3

Model	Frequency	Description
1	0.87	No ducting, Input or Exhaust
2	1.01	No Input Duct, Ceiling Exhaust
3	0.58	Input Duct, Ceiling Exhuast
4	0.35	Input Duct, Exhaust Duct

Maximum panel pressures were calculated from the maximum dynamic motions of the panels and compared to the individual internal and external pressures. Sixteen combinations were tested from the four faces. Typical results are given as ratios of the peak positive and peak negative dynamic results to the static peak positive and peak negatives due to external pressures only:

TABLE 2
AVERAGE FACE PRESSURES (NESW)
PEAK POSITIVE PRESSURE RATIOS

Room	Intake:	N	N	N	N	E	E	E	E
	Exhaust:	N	E	S	W	N	E	S	W
10x10x3		.30	1.65	1.40	1.63	.51	1.87	1.59	1.81
20x20x3		.30	1.63	1.40	1.63	.49	1.85	1.59	1.80
30x30x3		.38	1.60	1.36	1.54	.56	1.80	1.54	1.72
		S	S	S	S	W	W	W	W
		N	E	S	W	N	E	S	W
10x10x3		.47	1.81	1.57	1.79	.51	1.83	1.60	1.86
20x20x3		.46	1.79	1.57	1.79	.49	1.81	1.60	1.83
30x30x3		.53	1.74	1.50	1.69	.55	1.78	1.53	1.72

TABLE 3
AVERAGE FACE PRESSURES (NESW)
PEAK NEGATIVE PRESSURE RATIOS

Room	Intake:	N	N	N	N	E	E	E	E
	Exhaust:	N	E	S	W	N	E	S	W
10x10x3		1.28	.62	.74	.63	1.18	.53	.59	.53
20x20x3		1.25	.65	.72	.61	1.15	.51	.62	.52
30x30x3		1.42	.73	.88	.88	1.31	.63	.78	.70
		S	S	S	S	W	W	W	W
		N	E	S	W	N	E	S	W
10x10x3		1.20	.54	.67	.55	1.18	.52	.65	.52
20x20x3		1.18	.52	.64	.54	1.16	.49	.62	.52
30x30x3		1.34	.64	.80	.72	1.32	.64	.79	.71

The results indicate that large amplifications of inward panel pressures (positive) occur when the intake and exhaust plenums are on the suction faces of the buildings. In practical design terms, the inward load case should have an inherently large factor of safety. The more critical outward panel pressures can have 30% increases in load if the plenums are located on the windward face. The inward results show little correlation with room size, while the outward results generally increase with room size.

Results using only corner locations produced a 15% increase in the outward loads, and a 200% increase in inward loads. Both average face and corner inputs could be predicted from the mean internal pressure plus the peak external pressure, with a 15% loading the internal mean. Combinations of peak internal and peak external loads grossly over-estimated the panel design loads.

CONCLUSION

The use of ducted air-conditioning systems with localised input and exhaust plenums has the potential of increasing design panel pressures. Estimates of the increases (or decreases) can be calculated from the steady state mean internal pressures and the external peak pressures. A 1.15 multiple of the internal mean appears to envelope the worst cases.

REFERENCES

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2) Matsui, G., Suda, K. and Higuchi, K. Full Scale Measurement of Wind Pressures on a High Rise Building of Rectangular Plan, Journal of Wind Engineering and Industrial Aerodynamics, Vol. 10, 1982.

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Mathematical Model

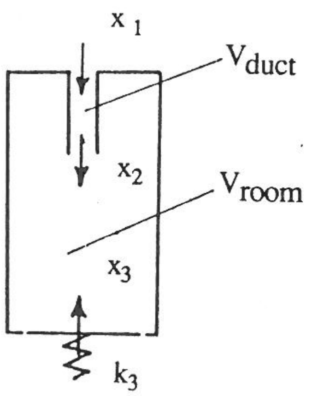


FIG. 1

Wind Tunnel Model

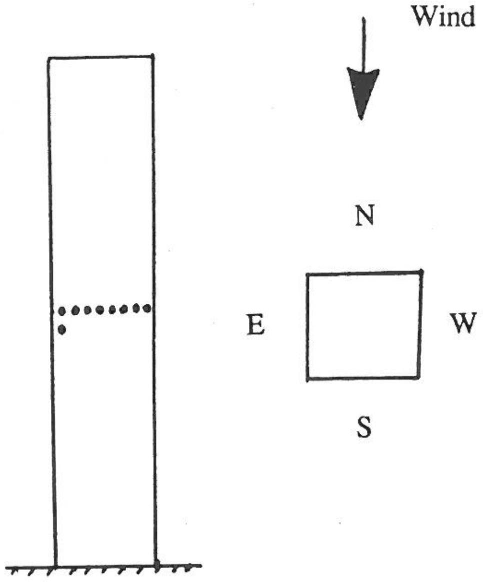
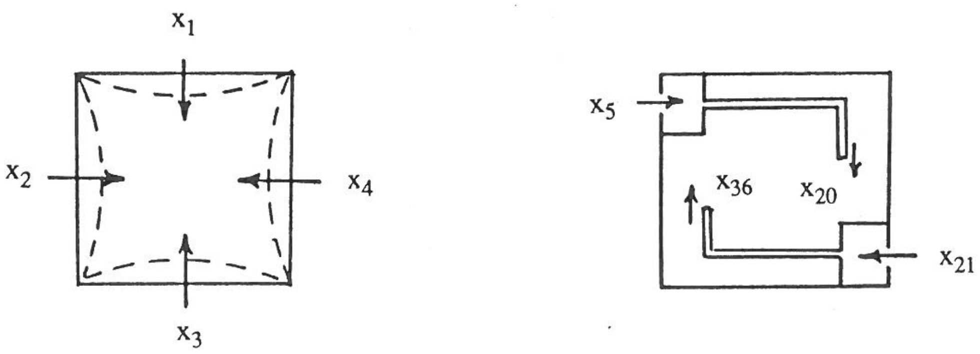


FIG. 2

Room Simulation



Wall Panels

Ductwork

FIG. 3