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AIR TIGHTNESS: SUPERMARKETS AND SHOPPING MALLS

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SOMMAIRE

On a mesuré les fuites d'air totales dans neuf supermarché et un mail fermé, construits entre 1954 et 1979. Cinq de ces dix ensembles sont des bâtiments isolés, les autres sont semi-isolés. Les débits de fuite mesurés ont servi à classer l'étanchéité des supermarchés en trois catégories: excellente, moyenne et faible. Il s'est avéré que tous les magasins construits ces dernières années avaient une étanchéité faible. De plus, on a trouvé que les supermarchés avaient des débits de fuite d'air par unité de superficie extérieure supérieurs à ceux des écoles et des immeubles à bureaux en hauteur. On a aussi mesuré le débit de fuite d'air de divers parties de bâtiment comme les vitrines et les portes d'entrée. On analyse la contribution de celles-ci à la fuite d'air totale.

Air Tightness: Supermarkets and Shopping Malls

Over-all air leakage characteristics have been measured in several supermarkets and an enclosed shopping mall, all constructed between 1954 and 1979. Measured in three categories: tight, average and loose, air leakage rates for all the test stores constructed in recent years were in the loose construction category.

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THE modern supermarket is usually a free standing building or part of a closed shopping mall ranging in size from 1000 to 5000 m^2. The annual energy consumption of supermarkets varies from 300 to 1500 kWh per square metre of floor area.[1] This is among the highest rates for any type of building. The reasons for the high energy consumption are many, but air leakage is certainly one of them. The amount of energy loss due to air infiltration depends on the air tightness of a building. These data are rarely available for supermarkets and they can only be realistically estimated from the measurements conducted on existing stores. The project described here was undertaken to study the air leakage characteristics of supermarkets to obtain reliable air tightness data.

Air leakage tests were conducted on nine supermarkets and one closed shopping mall. Of the ten stores, five are detached buildings and the rest are semi-detachead with one or part of a wall attached to another store. A brief description of these stores is given in Table 1.

TEST METHOD

The air leakage rates of ten stores were measured using the pressurization method.[2] As shown in Fig. 1, a vane-axial fan used to create suction in a test store was connected by a 0.9-m diameter duct to an entrance where the door had been replaced by a plywood panel. The fan's capacity could be varied from 0 to 24 m^3/s by manually adjusting the pitch of the fan blades.

Air flow rates were measured upstream of the fan intake using either a set of total pressure averaging tubes or an orifice plate depending on the air tightness of the test building. The pressure differential across the building enclosure was measured with four pressure probes each located at the approximate center of an exterior wall and a reference pressure probe located inside the store. A diaphragm-type pressure transducer (with a static error band of 5% full scale) and a strip chart recorder were used to record these readings.

All tests were conducted under suction (depressurization) conditions to avoid possible damage to merchandise. For those stores with an active air-handling system, air leakage rates were obtained with the system in operation and with it shut down. When a semi-detached building was tested, the leakage of air through the common wall (*i.e.*, wall between a supermarket and a connecting mall) was assumed to be part of the over-all air leakage. To investigate the effect of a connecting mall on the air leakage through a common wall, Store MD was tested with the entrance doors to the mall both closed and opened.

The air leakage rate through the intake and exhaust openings of two stores (Stores CK and MS) was measured by comparing the over-all air leakage rates taken before and after these openings were sealed. Show windows and entrance doors of selected stores were also tested separately by the pressurization method using a portable fan to study their contribution to the over-all air leakage.

RESULTS

Fig. 2 shows the over-all air leakage rates per unit area of exterior wall with the building air-handling system (HVAC) shut down. The leakage values at a pressure differential of 50 Pa (0.2 in. of water) varied from 4.5 to 15.2 L/s · m^2 (0.9 to 3.0 cfm/ft^2). Since these leakage rates included leakage through a common wall of a semi-detached store, the area of the common wall was also included in calculating the over-all air leakage rates per unit area of exterior wall.

Two tests were conducted on a semi-detached store, Store MD, one with the entrance doors to the mall (PO) closed, and the other with them opened. The over-all air leakage rate with the mall door open was, at most, 5% higher than with it closed, which suggested that for Store OD the operation of the mall doors appeared to have a negligible effect on the overall store leakage.

The operation of an HVAC system had very little effect on the air leakage characteristics of most stores. In those stores where they were influenced by the HVAC system (Fig. 3), the over-all air leakage rate with the system in operation could be either higher (*e.g.*, Store RM) or lower (*e.g.*, Store OD) than that with it shut down at lower pressure differentials. The two leakage curves approached each other and finally crossed over as the pressure difference across the building envelope increased. This suggests that the leakage openings in the air-handling system change in size during the air leakage tests due to the imposed pressure differentials.

Air leakage data are usually expressed by an equation of the form

$$q = CA\,(\Delta P)^n \qquad (1)$$

where

- q = air leakage rate per unit area of exterior wall
- C = flow coefficient
- A = area of exterior walls
- ΔP = pressure difference across exterior walls
- n = flow exponent

The flow exponent is a function of pressure differential and its value varies from building to building.[3] However, Fig. 3 shows that for supermarkets the slope of each leakage curve (the exponent n as defined in Eq. 1) was independent of ΔP for a range of pressure differentials from 3.5 to 50 Pa (0.014 to 0.2 in. of water). Thus, for supermarkets, Eq. 1 with a constant n (*i.e.*, n is independent of ΔP) is valid for a pressure differential up to 50 Pa.

Air leakage rates through show windows and entrance doors are given in Fig. 4. Also shown in the figure is the corresponding maximum allowable air leakage rates as per ASHRAE Standard 90-75.[4] It was found that about 50% of show windows and entrance doors tested as installed, satisfied the ASHRAE requirement. Calculation using the measured window leakage and the measured total length of sash crack indicated that show windows contributed from 0.1 to 3% of the over-all air leakage. A similar calculation in-

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Table 1. Description of Test Stores

Stores	BH	CK	HC	MD	MK
Year tested	1979	1979	1979	1979	1979
Year constructed	1957	1963*, 1978*	1978	1977	1967
Building type	Detached	Detached	Semi-detached	Semi-detached	Semi-detached
Height, M	8.4	8.4	7.7	6.4	7.1
Area of exterior wall, m²	1489	1594	1770	1392	1250
Area of show window, m²	99.3	75.7	55.3	15.0**	76.7
Length of sash crack for show windows, m	191	139	130	—**	186.4
Length of door crack for entrance doors, m	24.4	32.2	25.72	—**	24.4
HVAC System	Central	Central	Central	Central	Central
Typical wall construction	10.2 cm Face brick 10.2 cm Concrete block (block plaster) 2.5 cm Insulation 20.3 cm Concrete block, plaster	10.2 cm Face brick 10.2 cm Concrete block, vapor barrier, plaster	10.2 cm Concrete block, Insulation 20.3 cm Concrete block	10.2 cm Face brick 3.8 cm Air space 2.5 cm Insulation 20.3 cm Concrete block,	20.2 cm Concrete block
Stores	**MS**	**OD**	**PO (including OD)**	**RM**	**WG**
Year tested	1978	1979	1979	1979	1979
Year constructed	1955	1979	1979	1957	1954
Building type	Semi-detached	Semi-detached	Detached	Detached	Semi-detached
Height, m	4.3	7.5	5.3 (mall), 7.5 (O.D.)	5.5	5.5
Area of exterior wall, m²	960	2014	3677***	772.5	1079
Area of show window, m²	119	35.7**	—	67.6	94.7
Length of sash crack for show windows, m	166	—**	—	112.8	167.6
Length of door crack for entrance doors, m	10.1	—**	—	12.2	12.2
HVAC System	Central	Central	Central	Central	Central
Typical wall construction	Porcelain enamel panel 40.6 cm Concrete block OR 10.2 cm Face brick 20.3 cm Concrete block wall	10.2 cm Concrete panel 5.1 cm Insulation 20.3 cm Concrete block	Ribbed pre-insulated precast concrete panel 6.4 cm Insulation vapor barrier	25.4 cm Concrete block 5.1 or 10.2 cm Insulation, dry wall	10.2 cm Face brick 20.3 cm Concrete block

*renovated in 1978 **inside PO ***including the exterior wall of OD

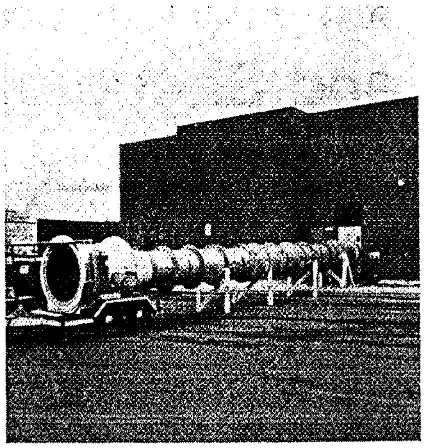

Figure 1. Building test set-up showing exhaust fan and duct connection

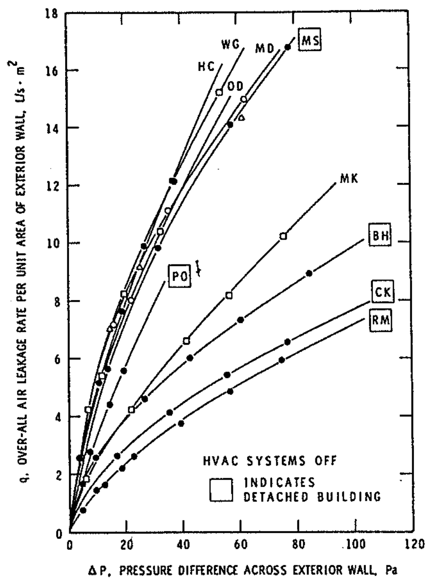

Figure 2. Overall air leakage rates with air-handling system shut off

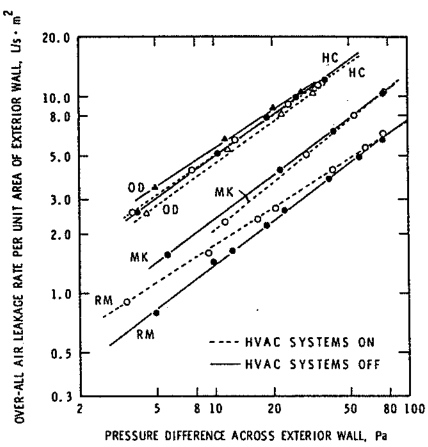

Figure 3. Relationship of air leakage rate and pressure differential

dicated that the contribution of entrance doors was about 4%. The air leakage rates through the openings of the HVAC system of Stores CK and MS were about 0 and 9% of their over-all leakage rates, respectively.

The area of show windows of some stores could be as much as 12% of the total wall area, but its contribution to the over-all air leakage was not significant. The generally leaky entrance door was not a major contributing component to the over-all store leakage either. Neither was there any clear evidence to show that one wall construction (Table 1) gave a lower leakage compared with any other.

The newly constructed stores were found to be generally much leakier than the older ones. An attempt was made, therefore, to look for potential leakage sources in those components which were unique to new stores. It was found that the opening around the receiving doors with a hydraulic ramp could be one of them.

Another leakage source appeared to be the doors to the separate storage room for parcel pick up. These doors could also be responsible for the difference in air tightness between Store MD and Mall PO of which the supermarket is part.

AIR LEAKAGE DATA

Based on the measured air tightness values, three leakage curves as

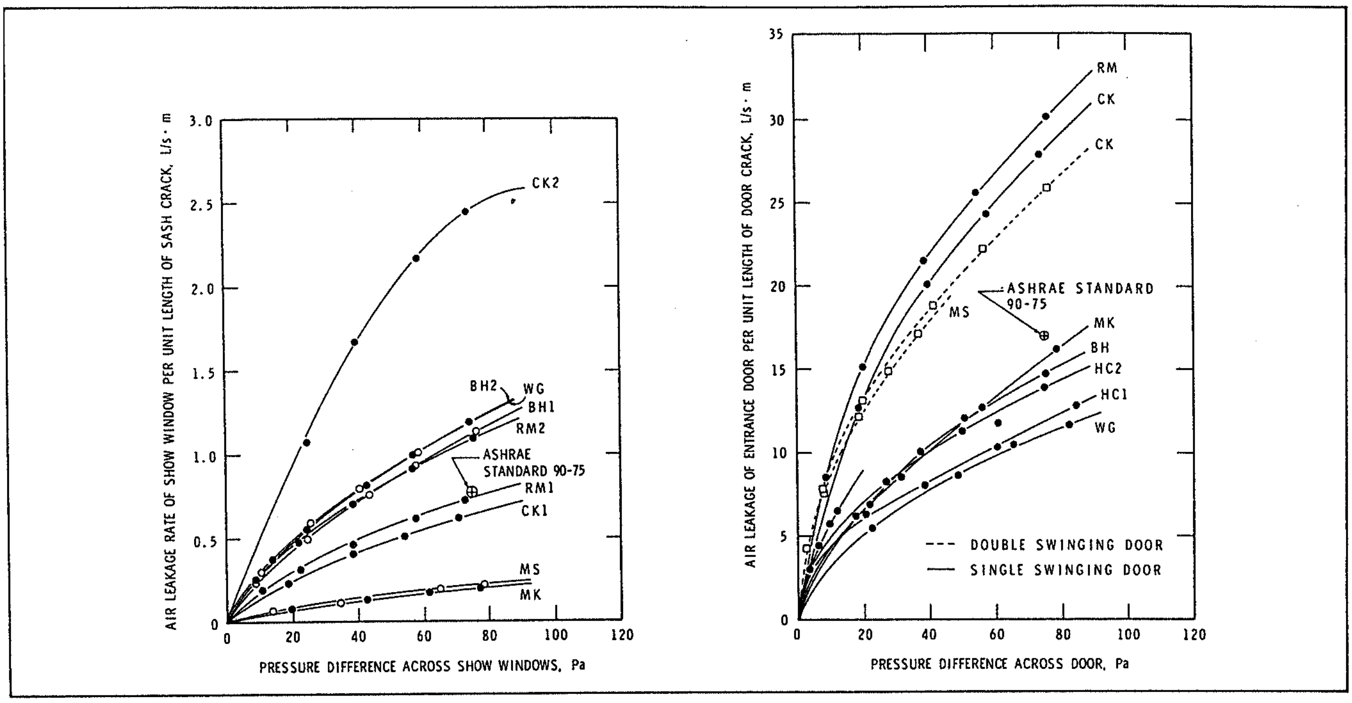

Figure 4. Air leakage rate through show windows and entrance doors

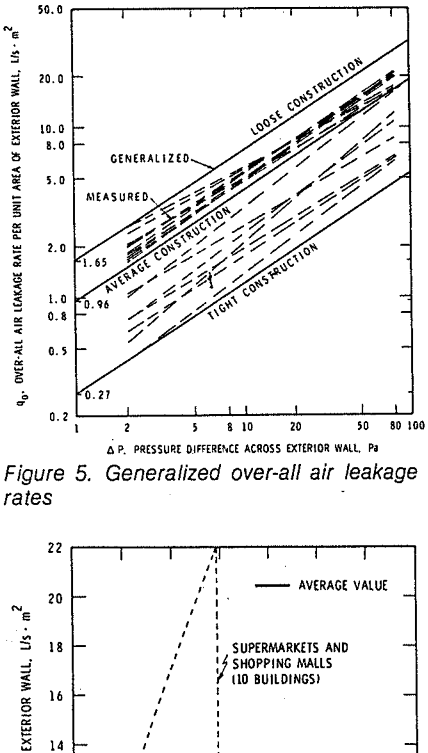

Figure 5. Generalized over-all air leakage rates

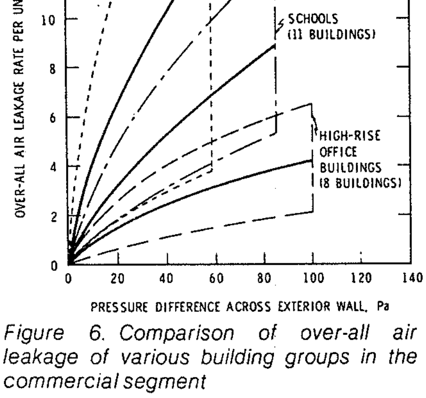

Figure 6. Comparison of over-all air leakage of various building groups in the commercial segment

defined by Eq. 1 were drawn, representing the lower and upper limits and the average value of the two (Fig. 5). They were assumed to be the air leakage characteristics of tight, loose, and average wall construction for supermarkets. The flow exponent of each leakage curve was assumed to be 0.65; the corresponding flow coefficients were 0.27, 0.96 and 1.65 $L/s \cdot m^2(Pa)^{0.65}$ for tight, average, and loose construction, respectively. Since some of the test stores were part of a closed shopping mall of similar building enclosure, these leakage values may also be approximately valid for shopping malls.

For comparision, Fig. 6 shows the air leakage rates for the three major building groups.[2,5] The results show that for a sample of buildings measured by DBR to date, the range of the over-all air leakage rates for supermarkets is the widest among the three building groups. The average air leakage of supermarkets is about twice the value for schools and four times the value for high-rise office buildings.

CONCLUSION

The flow coefficients for supermarkets, assuming a flow exponent of 0.65, range from 0.27 to 1.65 $L/s \cdot m^2 (Pa)^{0.65}$ Measurements on selected stores showed that with air-handling systems off, up to 9% of the over-all air leakage could be attributed to the intake and exhaust openings. The contribution of show windows and entrance doors was about 3 and 4% respectively.

All test stores constructed in the past three years were generally found to be leakier than those built previously. The high air leakage in new stores was attributed to receiving doors with a hydraulic ramp and the doors to the separate car order storage room, two unique facilities of new stores.

A comparison of the average air leakage rates of medium and large buildings indicates that supermarkets are two to four times leakier than schools or high-rise office buildings.

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