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THEME 2/6

Engineering Concept and Design of Controlling Infiltration and Traffic through Entrances in Tall Commercial Buildings

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SYNOPSIS

In the metropolitan cities around the world, the present trend of increasing numbers of skyscrapers (and population) in which stack effects are large and entrance traffic is heavy has called for the need of a better design of entrance for controlling not only infiltration but also traffic. In the course of introducing a unique design of entrance, this paper analyses the causes of infiltration; discusses the effect of the various parameters; presents, through recent research, design charts for estimating heating and air conditioning loads through swinging-door and revolving door entrances; outlines the engineering concept of controlling infiltration; and reviews the requirement of the entrances. Since data has not been available for the calculation of the air infiltration through the new type of entrance, an approximate method is suggested. The features of the new design are compared with the conventional ones from the viewpoint of technology, serviceability, and economy.

SOMMAIRE

L'augmentation croissante des gratte-ciels et de la population dans les grandes capitales du monde est la cause de l'intensité grandissante de la circulation des piétons et nécessite une amélioration des voies d'accès afin de contrôler, non seulement la circulation, mais aussi l'infiltration de l'air extérieur. En présentant un projet unique de moyens d'accès, cette étude analyse les causes de l'infiltration, discute les divers paramètres et présente, après examen, différents projets pour l'estimation du chauffage et de la climatisation, par le moyen de portes à tambour et de portes à va-et-vient. On tient compte des conditions requises des voies d'accès et la conception du génie pour la construction, est exposée. Les données pour le calcul de l'infiltration de l'air pour les nouvelles voies d'accès n'ayant pu être obtenues on a suggéré une méthode approximative. La comparaison du point de vue technologique, du point de vue de l'utilisation et du point de vue économique est effectuée entre les conceptions nouvelles et les anciennes.

ZUSZMMENFASSUNG

Die augenblickliche starke Zunahme in den Großstädten der Welt von Wolkenkratzern (und Bevölkerung) mit deren Tendenz zum Ubereinande schichten und starken Zugangsverkehr macht es unbedingt notwendig, daß bessere Entwürfe für Gebäudeeingänge nicht nur zur Kontrolle der Lufteinsickerung, sondern auch des eigentlichen Verkehrs geschaffen werden. Die Abhandlung befaßt sich mit der Einführung eines einzigartigen Eingangsentwurfes und untersucht dabei die Ursachen der Einsickerung, diskutiert die Auswirkung verschiedener Parameter, legt Entwurfstabellen vor, die zur Abschätzung des Ausmaßes von Heizung und Kühlung an Pendel- und Drehtüren dienen und sich auf neue Forschungsergebnisse stützen, und beschreibt ferner in goßen Zügen die technische Planung für die Kontrolle der Lufteinsickerung, wobei notwendige Eigenschaften der Eingänge selbst ebenfalls erörtert werden. Da die notwendigen Daten zur Berechnung der Lufteinsickerung noch nicht erhältlich sind, wird eine Annäherungsmethode vorgeschlagen. Der neue Entwurf wird in seinen Einzelheiten vom technischen Standpunkt aus sowie nach Zweckmäßigkeit und Wirtschaftlichkeit mit herkömmlichen Eingangsarten verglichen.

AIR entering building entrances causes draught and reduced room temperature which results in discomfort, particularly on the ground floor at the area near the lobbies. Excessive heating (or cooling) is required to maintain comfortable conditions. In fact, entrance infiltration has been recognised[1, 2, 3, 4] as an important consideration in estimating heating and air conditioning loads, especially in tall commercial buildings. It also causes a pressure differential across the entrance which makes it difficult to open a door, and thus slows down the traffic. The present trend in the metropolitan cities around the world of increasing numbers of skyscrapers in which chimney effects are large, and heavy traffic prevails, has augmented the problem. The need of a better design of entrance for controlling not only infiltration but also the traffic is apparent.

The purpose of the paper is to introduce a unique design of entrance to meet this need. In order to accomplish this purpose, causes of infiltration and effect of various parameters are first discussed. Also, for the comparison of controlling infiltration and traffic, design charts for conventional entrances are prepared, and requirements of an entrance are reviewed.

ANALYSIS OF CAUSES OF INFILTRATION

Air leakage through the envelope of a building is caused by the simultaneous presence of leakage openings in the envelope of the building and the pressure differential between the inside and outside space of the building.

The leakage opening may be cracks or interstices around window, door, through wall, floor, and roof. It could also be some opening such as chimney, roof ventilator, exhaust vent, inlet opening for fuel-burning appliances, or opening of doors due to traffic of people. The pressure differential may be a result of wind velocity, stack effect due to the differences in air densities inside and outside the building, and supply and/or exhaust fan operation.

The magnitude of pressure differential due to wind velocity depends upon the wind speed and direction with respect to the exposure of the building, the proximity of other structures, and obstruction. The magnitude of pressure differential due to stack effect is influenced by that of the air temperature difference, the height of the building, and the distance from the neutral zone. The magnitude of pressure differential due to fan operation is affected by the volume of the air occupied by the building and the rate of supply of exhausted air. The pressure differential, regardless of whether caused by wind velocity, temperature difference, or fan operation, varies also with the degree of freedom of air communication between rooms and stories and the relative area and resistance of opening for in-flow and out-flow.

EFFECT OF VARIOUS PARAMETERS UPON INFILTRATION IN GENERAL

In order to help better understand the pressure differential characteristics, simplified diagrams are provided in the following cases. In all cases, it is assumed that throughout the tall building the resistance of internal obstruction is negligible, i.e., the interior is open from bottom to top, the relative areas and resistances of openings for in-flow and out-flow are equal, and the envelopes are sealproof elsewhere except for the openings at the bottom and top as indicated.

The distribution of pressure differential due to wind velocity in the building is shown in Fig. 1. Figure 2 shows the pressure differential distribution in the building, due to stack effect, under winter heating and summer cooling

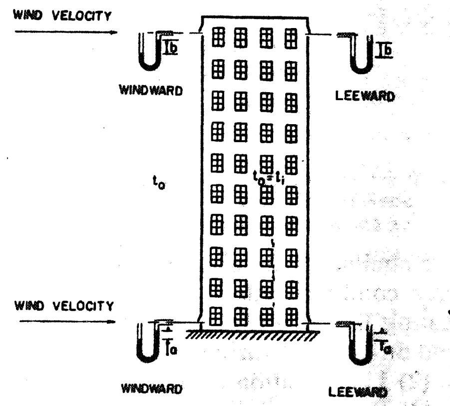


Fig. 1 Pressure differential due to wind velocity

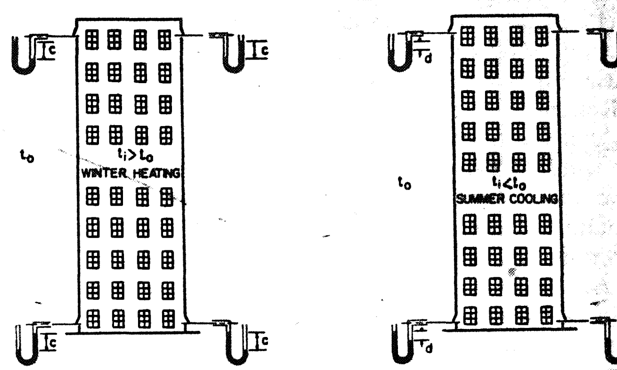


Fig. 2 Pressure differential due to temperature force

conditions. The temperature differences between inside and outside from bottom to top throughout the building are assumed to be uniform.

The effect of fan operation on pressure differential is demonstrated in Figure 3.

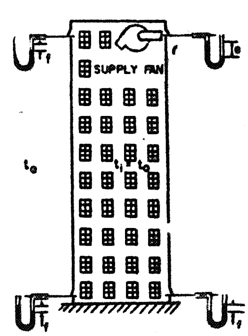


Fig. 3 Pressure differential due to fan operation

The combined effect of Figures 1, 2 and 3 is illustrated in Figure 4.

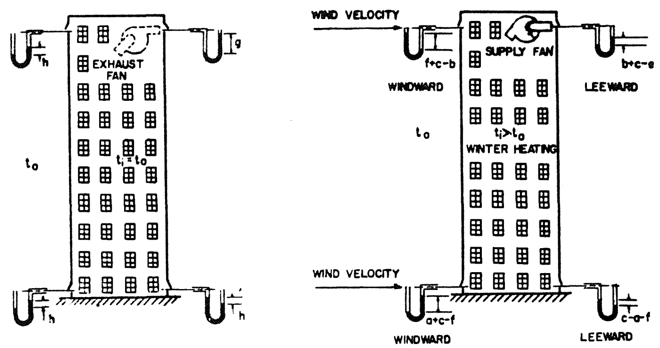


Fig. 4 Pressure differential due to the combination of wind velocity, temperature force under winter heating conditions, and supply fan operation

In actual buildings, the distribution of pressure differential under combined effect is extremely complex. The complicating factors include: (1) the variation of wind speed and direction at various levels and exposure during the day. (2) The variation of outside temperature during the day. (3) The variation of inside temperature at different levels and rooms. (4) Variation of internal resistances between rooms and stories, such as lift shafts, stairways, escalators, mail chutes, etc. (5) Variation of resistance of inlet and exit openings such as door opening and closing due to traffic of people, dampers, roof ventilators. (6) Variation of fan operation.

Regarding the relative importance, it was indicated (*5*) that the temperature force is more pronounced than the wind velocity in the low building such as a residence. Due to the obstruction of nearby houses, trees, and ground the effect of wind is nullified. The neutral zone for residence was found to be about 0.8 height of the house (*5*).

In tall commercial buildings, the wind pressure was found to be insignificant and the temperature forces dominate at the ground level (*1*). This is again obviously due to the proximity of other buildings and the obstruction of the ground. However, it would be expected that the effect of wind would become more important at the higher level.

SWINGING-DOOR ENTRANCE

(*A*) *Additional Parameters Affecting Infiltration Through Entrance*

As mentioned before, air leakage is caused by both the leakage openings and the pressure differentials. Pressure differential alone, no matter how big, does not cause air leakage or flow unless it is accompanied by the presence of the leakage openings.

Furthermore, if a pressure differential exists across an opening, and all the rest of the envelopes of the building are sealtight for possible ingress or egress of air, there still will be no continuous air leakage or infiltration at the opening because the temporary excess of pressure outside will soon be equalised by a momentary inflow.

In any actual building, continuous infiltration and exfiltration occurs because of the presence of inlet and outlet openings in the envelopes and pressure differentials across them.

The pressure differential across an opening, as pointed out before, depends upon wind velocity, temperature difference, fan operation, internal resistance of the building, and resistances of inlet and exit openings. The air leakage through swinging-door entrances, however, is further complicated by the opening and closing of doors and other variables related to the entrance. They are:

1. Type of entrance (*a*) single-bank doors (*b*) vestibule-type.
2. Dimension of doors.
3. Arrangement of doors (*a*) opposite-swinging (*b*) parallel-swinging.
4. Direction of swinging of doors (*a*) all swinging out (*b*) one swinging in, the other swinging out (*c*) all swinging in.
5. Depth of vestibule.
6. Size of door crack.
7. Size, location of marquee.
8. Type of door operators or closers.
9. Traffic rate and pattern.
10. Effect of human obstruction.
11. Tightness of other parts of the building.

For engineering purpose, laboratory and field tests indicate, however, that the infiltration through swinging-door entrances in conventional tall buildings under winter heating conditioning can be evaluated if the following parameters are known:

1. The pressure differential across the entrance of a building of any height at any outside design temperature and wind velocity, and for any inside design temperature and blower action.
2. Entrance co-efficient[1] for certain type of entrance and traffic rate.

In a tall building under winter heating conditions the wind and temperature difference co-operate to increase infiltration through doors at street level in windward direction. However, field tests in tall buildings indicated that the wind is practically ineffective near the ground because of the presence of ground and other structures.

Therefore, the pressure differential is essentially due to temperature difference, height of building, tightness of the envelopes, and blower action, or fan operation.

(*B*) *Simplified Design Chart*

Based on a recent research[1] a simplified chart for design purpose is prepared. The infiltration can be easily evaluated by following the flow diagram if height of building, inside-outside temperature difference, net supply or exhaust air change, type of entrance and traffic rate are known. An example is given below to illustrate the use of the chart.

Example:

Given: A conventional building 350 feet (106.68 metres) high has a net cubage of 4,200,000 cu.ft. (118,930 cu. m.). Fresh air fans supply outside air at the rate of 80,000 cu. ft./min. (2,265 cu. m/min.) and exhaust fans discharge 50,000 cu. ft./min. (1,416 cu. m./min.). The building has a vestibule-type entrance having four 3 by 7 ft. (0·91 by 2·13 m.) doors and the inside temperature is maintained at 75°F (23·9°C). Find infiltration rate through the entrance at a time when the traffic rate is 2,000 persons per hour.

Solution:

From Fig. 5A, the theoretical draft for a 350 ft. (106·68 m.) building height and a 75°F (41·7°C) inside-outside temperature differential is 0·88 in. (2·24 cm.) of water. The net air supply rate is 80,000 – 5,000 = 30,000 cu. ft./min. (849·5 cu. m./min.). This is 30,000 by 60/4,200,000 or 0·43 air change per hour. From Fig. 5B the corrected or effective draft for 0·43 net supply air change is 0·462 in. (1·17 cm.) of water.

The traffic rate per door is 2,000/4 = 500 persons per hour. From Fig. 5C the vestibule entrance co-efficient is 0·08.

From 5D for an effective pressure differential of 0·46 inch (1·17 cm.) of water, and an entrance co-efficient of 0·08, the infiltration rate per door is 4,500 cu. ft./min. (127·4 cu. m./min.). Infiltration through the 4-door entrance = 4 by 4,500 = 18,000 cu. ft./min. (509·7 cu. m./min.).

For details, reference No. 1 should be consulted.

(*C*) *Summer Cooling Conditions*

Laboratory tests indicate that the entrance co-efficients under summer cooling conditions are essentially the same as those under winter heating conditions.[6]

The pressure differential across entrance due to combined temperature difference and fan operation under summer cooling conditions is not available. In the absence of research data, it may be logical and safe to assume a complete inversion of pressure difference under winter heating conditions for that under summer cooling conditions.[6] To be more specific, it means that the negative pressure differential (inside pressure is greater than outside pressure at the entrance due to heavier inside air) can be determined by Fig. 5B in the similar fashion.

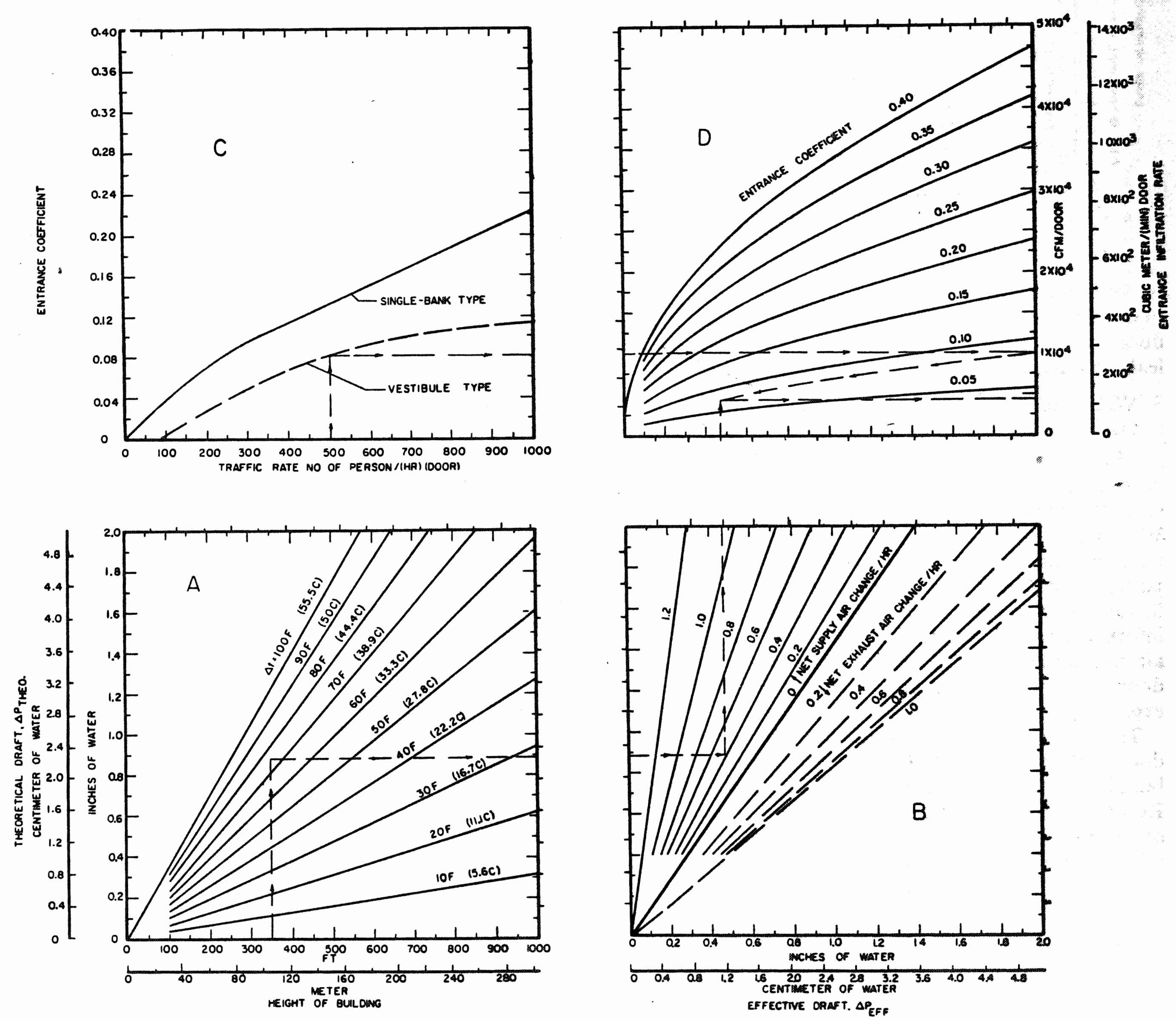


Fig. 5 Design chart for evaluating air infiltration rate through swinging door entrances under winter heating conditions

Attention should be given to the use of Fig. 5B in determining the effective pressure differential. Under winter heating conditions, exhaust fans in the building tend to raise the pressure differential at the entrance; while in the summer cooling conditions, they tend to decrease the negative pressure differential and so decrease the exfiltration. In other words, the curve for net supply under winter heating conditions in Fig. 5B becomes the curve for net exhaust under summer cooling conditions. The rate of entrance exfiltration can then be evaluated by Fig. 5C and 5D.

(D) Leakage Through Door Cracks

The leakage through door cracks can be evaluated by Fig. 6, once the pressure differential across the entrance

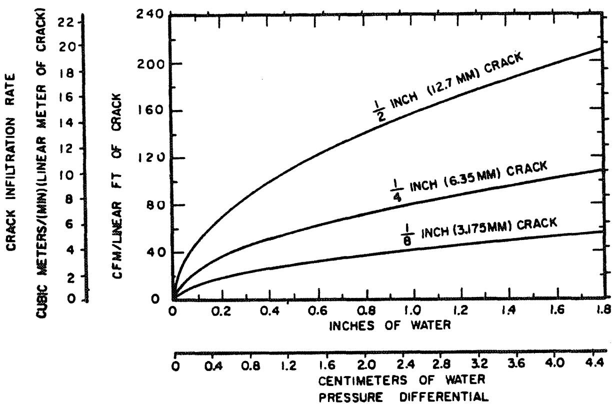


Fig. 6 Infiltration rate through swinging-door cracks

is determined. It should be noted, however, that the infiltration or exfiltration through cracks around the doors becomes an appreciable part of the total entrance leakage only during periods of very low traffic rate.

REVOLVING DOOR

(A) Additional Parameters Affecting Infiltration Rate

Air infiltration through revolving doors is composed of two parts, one influenced by the air leakage past the door seals and the other related to the revolving of the door. With manually operated doors, the temperature and wind pressure between indoors and outdoors, and traffic pattern and traffic rate were recognised[2] as significant factors. For motor-driven revolving doors, additional information on door speed was needed. The amount of air turbulence inside and outside, and the condition of the door seals would also affect infiltration to a certain extent.

The magnitude of air leakage through the seals of the door is the result of the pressure differential across the building entrance and the size of the openings at the seal. Revolving the door causes an exchange of indoor and outdoor air of approximately equal volume. The amount of this air exchange depends upon the door speed, the temperature differential, and somewhat upon the wind and indoor air velocities.

(B) Design Chart

A design chart for evaluating infiltration through manually operated and power-operated revolving doors is presented in Fig. 7. The chart was based on a very recent report by L. F. Schutrum and his associate.[2] Fig. 7C was taken for worn door seal, which, although worn, still provided good contact with adjacent surfaces. If seals deteriorate to the point that good contact is not maintained, leakage past the seals would be expected to increase greatly.

Fig. 7, a flow chart, is illustrated by the following example.

Given: A conventional building 350 ft. (106·68 m.) high has a net cubage of 4,200,000 cu. ft. (118,930 cu.m.). Fresh air fans supply outside air at the rate of 80,000 cu. ft./min. (2,265 cu. m./min.) and exhaust fans discharge 50,000 cu. ft./min. (1,416 cu. m./min.). The building has two manually operated revolving doors, and the inside temperature is maintained at 75°F (23·9°C). Find the entrance infiltration when the traffic rate is 1,000 persons per hour per door, and the outside temperature is zero°F. (−17·8°C.).

Solution: From Fig. 7A and 7B the effective pressure differential is 0·46 in. (1·17 cm.) of water. The procedure is identical with that in Fig. 5A and 5B of the previous example. The infiltration through door seals due to the effective pressure differential is 250 cu. ft./min. (7·08 cu. m./min.) from Fig. 7C for two wings and worn seals. The infiltration rate due to temperature difference of 75°F (41·7°C) and traffic rate of 1,000 persons/h. (door) is 750 cu. ft./min (21·2 cu. m./min.) from Fig. 7D.

As shown in Fig. 7F, the total entrance infiltration per door is 1,000 cu. ft./min. (28·3 cu. m./min.) or 2,000 cu. ft./min. (56·6 cu. m./min.) for two doors. If the doors are motor driven and operate at a constant speed of 10 r.p.m. instead of manually operated, then the infiltration due to revolving of door is 1,040 cu. ft./min. (29·45 cu. m./min.) from 7E. Thus making the total infiltration from Fig. 7F 1,290 cu. ft./min. (36·5 cu. m./min.) per door or 2,590 cu. ft./min. (73 cu. m./min.) for two doors.

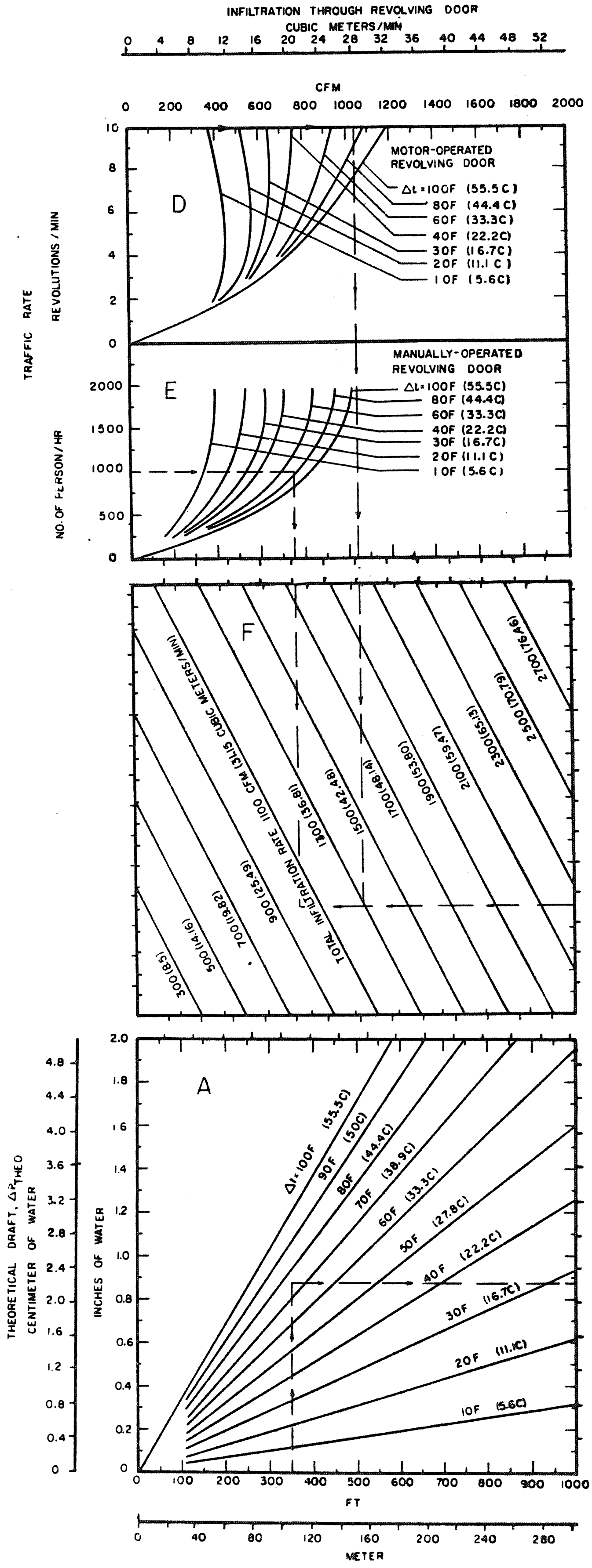
METHOD OF CONTROLLING ENTRANCE INFILTRATION AND BASIC REQUIREMENT OF AN ENTRANCE

Since entrance traffic rate, height of building, and temperature difference between inside and outside cannot be controlled, the principle of reducing entrance infiltration can only be accomplished by one or a combination of the following methods:

1. Reducing the pressure differential across the entrance by sealing or tightening other parts of the building envelope.
2. Reducing the pressure differential across the entrance by pressurising the structure with outside ventilation air.
3. Sealing the entrance by using proper type of entrance doors.

As was mentioned[6, 8] there should be no infiltration across entrances in buildings no matter how tall they are so long as their envelopes are 100 per cent tight or seal-proof. Apparently, most of the conventional buildings are not 100 per cent tight and have a natural draught factor of 0·7.[1] It was also observed that a presumably tighter-than-average building[1, 9] has a lower draught factor.

The building tested was of metal curtain wall construction and had windows which were tightly sealed by



inflated gaskets. The lower natural draught factor was probably due to the tightly sealed windows rather than to the curtain-wall construction as such.[9] Unfortunately, data is far from enough for quantitative correlation. Also the criteria of tightness of the envelope of buildings have not been established.

As shown in Fig. 7B, the net supply air from the outside will reduce the pressure differential across entrances, and thus decrease infiltration rate. However, air in excess of ventilation requirements, if allowed to enter, is a needless heating load. It is not economically feasible to use excessive ventilation air merely for pressurising tall buildings and eliminating the infiltration problems.

The last method is to employ a proper type of entrance which allows traffic but seals flow of air. This appears to be practical and effective. From Fig. 7D and 7E, it was indicated that the infiltration through a revolving door (except a small portion past the door seals) is almost unaffected by the height of the building, the difference in pressure between the inside and outside, and fan operation.

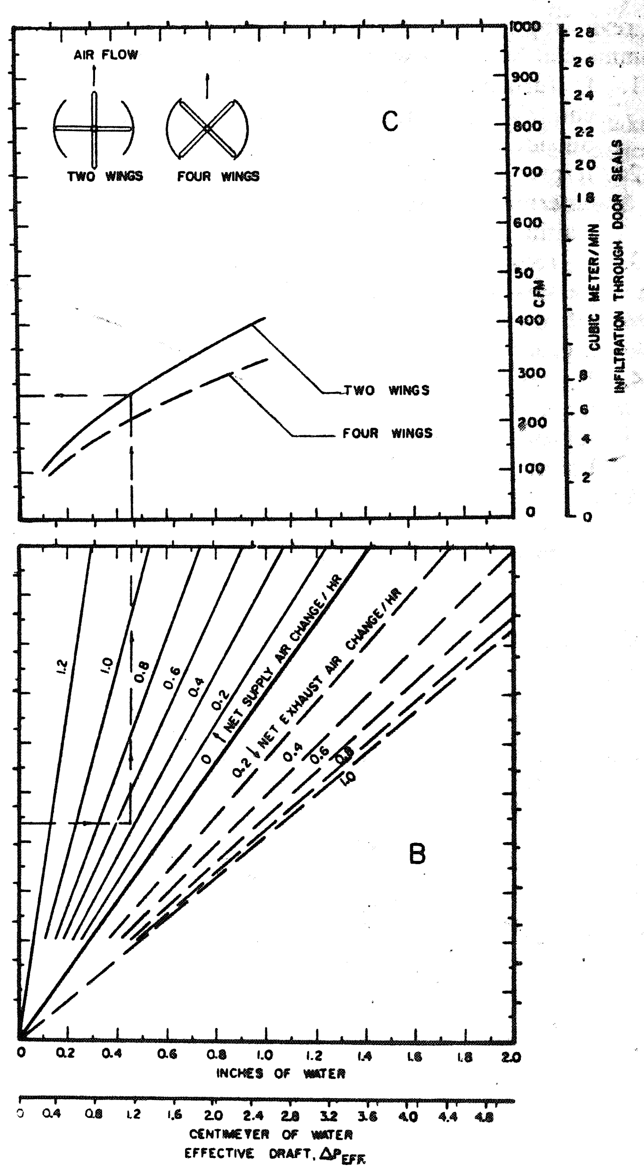


Fig. 7 Design chart for evaluating air infiltration rate through revolving doors

From the typical examples for swinging door and revolving door, aforementioned, it may be of interest to note that the infiltration rate through a swinging door is about 900 cu. ft. (25·5 cu. m.) per person for a single-bank entrance, and 550 cu. ft. (15·6 cu. m.) per person for a vestibule-type entrance.

Under the same conditions, the infiltration is about 60 cu. ft. (1·7 cu. m.) per person for a manually revolving door and 32 cu. ft. (0·91 cu. m.) per person for a motor-driven type. In other words, the revolving door is essentially a good air lock. The infiltration rate is primarily the amount of the displacement of air produced by the revolving of the doors.

However, it has been observed during field tests of some 23 tall commercial buildings in Cleveland and Pittsburgh, and a few other buildings in New York and Chicago, that the revolving door has many drawbacks which offset the service of handling the large volume of entrance traffic provided by the swinging doors.

BASIC REQUIREMENTS OF AN ENTRANCE

In reviewing the basic requirement of an entrance in tall commercial buildings we may arrive at the following:

1. It furnishes entrance and exit for customers, employees, merchandise, and equipment from outside to inside (and *vice-versa*) of the building.
2. It provides facilities for rapid transportation for entering and leaving the building with the least waiting period at peak load of traffic.
3. It requires the least attention and effort for passers-by of all ages (children, adults, elders) when passing through entrances individually or in a group.
4. It does not restrict passers-by who may be carrying large packages during the busy Christmas shopping season, as well as supermarket shoppers, those holding luggage, infants, etc. at air, rail, bus, subway terminals, and hotels; it also provides convenience for those riding in wheel chairs, or pushing a hand cart.
5. It provides adequate illumination and temperature.
6. It employs all safety features, fire protection and other emergency measures.
7. It eliminates entrance infiltration, draught, dirt, dust, and noise from the streets.

While both the swinging door and revolving door fulfil some of the above-mentioned requirements, neither satisfies all the requirements.

TRAVELLING ENTRANCE-WAY

This leads to the introduction of a unique entrance design, namely the travelling entrance-way, or gliding entrance-way, more simply "Glidoor", which meets all the requirements of an entrance. The Sketch of the conceptual design is shown in Fig. 8. It has the following features:

1. The "gliding conveyor-track", handrails, and doors travel at exactly the same speed (say 120 ft./min. i.e., 31·1 m./min.) to ensure steadiness and balance on horizontal travel and to aid naturally in stepping in and off the combplates.
2. There will always be at least a pair of moving doors to block infiltration due to pressure differential across the entrance.
3. The "gliding track" is large and steady, and its levelling with combplates insures against slipping and tripping as one enters or leaves the glidoor.
4. It eliminates the co-ordination of the pace, path, rate of walking and door movement.
5. The "gliding track" is wide enough to permit a large volume of passengers or merchandise to enter at a time.
6. It is furnished with controls for reversible operation in and out as desired, merely by pressing a

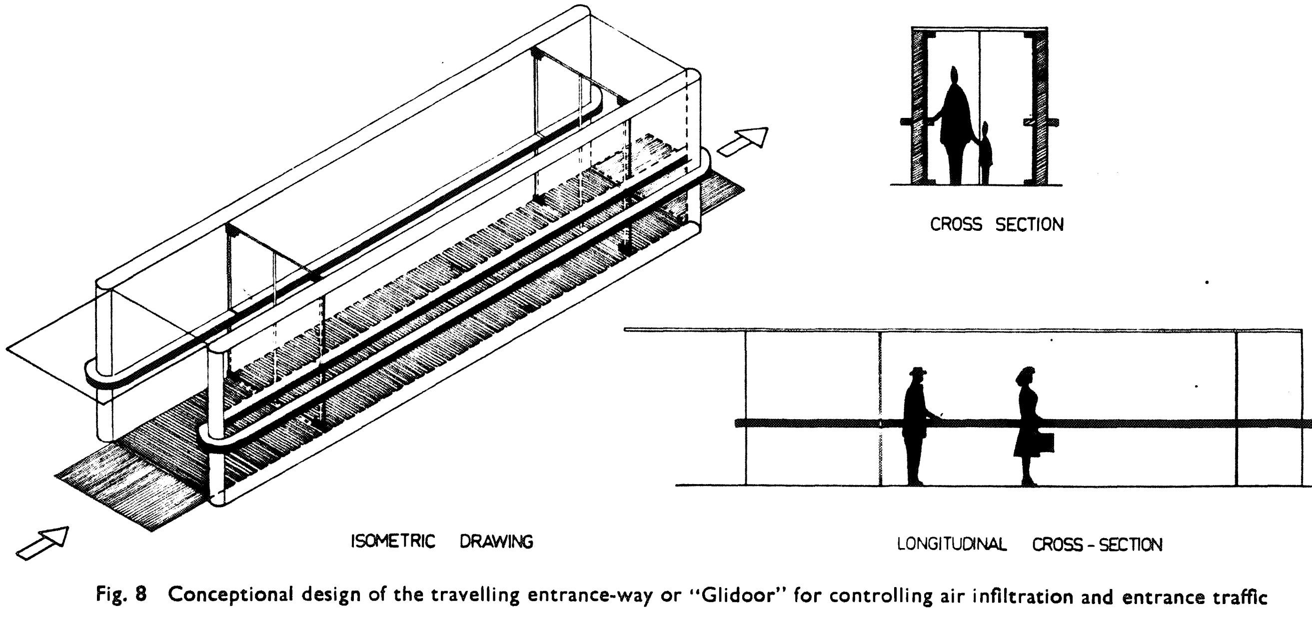


Fig. 8 Conceptional design of the travelling entrance-way or "Glidoor" for controlling air infiltration and entrance traffic

control button. This provides for one-way movement of large groups of people in either direction, such as during the opening or closing time of large stores.

7. Automatic controls of a service brake bring the entrance-way to a smooth stop if electric power or mechanical parts should fail. Passengers would then walk the conveyor-track as they would any stationary entrance-way of swinging doors.
8. In case of overspeed or underspeed an automatic governor shuts down the moving entrance-way.
9. An emergency stop switch is located near the combplate for one to shut down the entrance-way if by some accident it is caused to reverse its direction.
10. Last, but not least, the "glidoor" is always in motion and inviting passengers to "take a ride"—enough justification for commercial purposes.

Data for determining the infiltration through the "glidoor" is not available. However, the cubage of infiltration per person passing through the entrance may be approximated simply by the equation:

$$Q = V/N \quad (1)$$

where:

Q = the cubage of infiltration per passers-by
V = cubage per cycle
N = number of passengers per cycle.

For a revolving door of 6·5 ft. (1·98 m.) diameter, 7 ft. (2·1 m.) high, and 4 passers-by cycle the infiltration calculated by equation (1) is 58 cu. ft./person (1·64 cu. m./person). This rough estimation agrees with the order of magnitude of infiltration illustrated in the example by the use of Fig. 7. Therefore, equation (1) may be used as a first approximation of infiltration.

In the case of a gliding entrance-way of 7 ft. (2·1 m.) wide, 24 ft. (7·3 m.) long and 7 ft. (2·1 m.) high accommodating 25 passengers per cycle, the infiltration calculated by equation (1) is 47 cu. ft./person (1·3 cu. m./person).

Hence, infiltration-wise, the "glidoor" is compatible, if not better than an entrance with the revolving doors.

Traffic-wise, each "glidoor" may convey as much as 10,000 persons/h. whereas a revolving door accommodates about 2,000 persons/h.

In addition, the "glidoor" removes the annoyance and frustration that one feels he is being pushed, either by someone behind or by the revolving door, particularly at peak load. It also eliminates the time lost by passenger interferences in getting in or out of the revolving doors.

It excludes the installation of both revolving and swinging doors required by the ordinance of most cities. It is particularly suitable for commercial buildings such as department stores, hotels and supermarkets; air, rail, bus and subway terminals; office buildings connected with underground tunnels where not only the adult customers and employees, but also infants, children, elders, packages, bags, luggage, shopping carts, hand-carts, strollers, merchandise, and equipment are moving in and out all the time.

Entrances have not had any renovation for more than a quarter of a century. From the viewpoint of technology, serviceability, and economy, the need of a new entrance in tall commercial buildings for controlling infiltration and traffic cannot be over-emphasised.

It is highly possible that "glidoor" will become a reality within the next decade.

ACKNOWLEDGEMENT

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9. "Discussion of Winter Infiltration Through Swinging Door Entrances in Multi-Storey Buildings", by H. T. Gilkey, *Transactions of the American Society of Heating and Air Conditioning Engineers*, Vol. 64, 1958, pp. 440-442.

DISCUSSION

E. Harrison: I found Professor Min's paper interesting though somewhat frustrating. The frustration arises from my failure to understand exactly how the charts in his paper, which enable one to calculate the infiltration through various types of entrance, accord with what he calls the natural draught factor of a building. In the first place, may I ask why his paper is restricted in its title to commercial buildings? Surely as long as they are tall and people go in and out through the entrance doors, the purpose of the building does not matter unless 'commercial' refers to a particular pattern of subdivision inside the building? If so, the important thing is not the purpose to which the building is devoted but the pattern of this subdivision and a broad description of this would be more useful than merely describing it as 'commercial'.

In the second place, I should like to ask Professor Min whether the natural draught factor which he describes in his paper as being of the order of 0·7, is a characteristic of the kind of building that he has described as 'commercial' or whether it is something general, applicable to any building. As I understand Professor Min, he has defined the natural draught factor as that fraction of the theoretical pressure difference at the bottom of the building which is found by measuring pressure difference across the entrance of that building. It is described in the paper as the 'natural' draught factor of the building, but surely if it is measured across the entrance of the building it is more correctly described as the natural draught factor for the entrance door of that building.

If one takes a building, an empty shell with no communication to the outside, except one entrance door at the bottom and another similar exit door at the top, its natural draught factor in Professor Min's terms would be 0·5 or 50%. Half the pressure difference across the building exists across the entrance at the bottom and the other half across the exit at the top. A natural draught factor of 0·7 implies that the building has an exit at the top which is half the resistance of the entrance at the bottom, or thereabouts. Conversely, if you have greater resistance to the exit at the top than to the entrance at the bottom—for instance, if the resistance at the top is twice the resistance at the bottom, the natural draught factor would be one-third. Plainly it depends not on absolute values of the resistances of the inlet and exit to the building to air, but their relative values, that is to say, if you have in a particular case a natural draught factor measured across the entrance of a building of 0·7 , you can alter that in two ways. You can alter it by altering the sealing of the rest of the building, or by altering the sealing of the door. If my interpretation is correct, and the natural draught factor across an entrance door in a building is dependent on the relative magnitude of the resistances of (*a*) the entrance and (*b*) the combination of other openings which provide the exit for the air, then it is surely incorrect first to assume its constancy, regardless of the type of entrance, and then to modify the rate of air infiltration *according to the type of entrance*. But this (unless I am mistaken) is precisely what is done in Professor Min's design charts, Figs. 5 and 7. It is this strange contradiction between Professor Min's definition of the natural draught factor and his application of it in practice which I find so baffling.

That brings me back to my question: how far is a natural draught factor of 0·7 true for what are described as 'commercial' buildings? What kind of buildings are they of which this is true? We are interested in this country in the question of infiltration by natural means into buildings, not only the infiltration which can take place through an entrance into a building, but infiltration which takes place through windows at different levels of the building. I am aware that Professor Min has not attempted to deal with this general problem, but I hoped that his paper would throw some more light on this, because it seems to me that if the natural draught factor of 0·7 which, in his case, should refer only to the entrance of the building, is also applicable to the windows in the lower floors of the building, then there is a very real problem of infiltration in the United States. I am certain that in buildings in this country the natural draught factor is much lower than that for the windows of the lower floors.

F. L. G. Hartgroves: When we are trying to control air within tight limits we need very accurate measuring devices which are reliable. I have tried without success to motorize a frost point hygrometer, but I can confirm that the electrolytic type of meter is reliable.

With regard to the control of humidity at very low values, I should like to know whether the authors have in fact had much difficulty with stratification and pressure gradients of moisture content in enclosed spaces. I had occasion recently to lower the moisture content of a very large laboratory building down to 0·7 grains/cu ft and I am sure I discovered that there was a much higher level of humidity near the walls than in the actual place where the work was being done. The scientist was satisfied that his environment was right, but I was not satisfied that we had achieved control throughout the building.

If you are dealing with compressed air and you have to cool it after compression and then dry it, it is most important to keep your temperatures above dewpoint temperature otherwise the adsorber beds do not appear to be capable of controlling the precipitated moisture particles. They will control water vapour but I have detected water trickling through and being re-absorbed by the dry air. Can the authors confirm that this is correct?

On the absolute control of atmospheres, I have been asked to eliminate trace elements in atmospheres but I did not know of a ready method of measuring them.

Finally, the question of environments in the case of space vehicles is not so far fetched. It is probably not well known that the background count from radiation from particles in the atmosphere is often higher than from the thing being measured. I have considered making artificial air for laboratories where such measurements are made. It has been very complicated and from what I learn from colleagues at the Admiralty it is quite impossibly expensive at the moment. But it is something we have to consider in the future, and see whether we cannot bring it down to an economic possibility.

P. A. Coles: I was interested in the comments made by Mr. Gregory and Mr. Hackett regarding the question of sound level measurement and control. It is my view, also, that a great deal of further work is needed in this direction. I feel we must not lose sight of the question of sound level which is part of the comfort environment which we, as heating, ventilating and air conditioning engineers, are striving to achieve.

I was also interested in their comments regarding the question of bacteria and in their comments on total air treatment. I was surprised that there was no mention of the use of electronic air cleaners or electrostatic filters for the collection of bacteria or cigarette smoke particles.

On the question of ionising level, I was interested in their sensible appreciation of the possible dangers of creating a fad or fashion and the necessity for detailed investigation before we rush too quickly into the possible effects of variations in natural level of ionization in the atmosphere.

S. A. Gregory (*in reply*): I should like to thank Mr. Hartgroves for the points he has raised.

The first point dealt with the measurement of moisture content and also with stratification of moisture. I do not think that I need follow up on the question of the measurement of moisture content. It is because the electrolytic type of moisture measuring device is already proved to be much simpler than any of the motorized frost point methods.

I am very interested in the question of stratification. There is a fallacy which is quite popular, and it deals not only with moisture content, but with things such as oxygen and CO_2—a fallacy which says that if you have a positive pressure in a room you cannot get an in-leak. This is untrue. If you have a partial pressure difference from the outside of the room to the inside of the room it is possible for moisture to travel through the structural material into the dry room although the total pressure inside the room is greater than the total pressure outside. We have observed this, amongst other things, with oxygen in metallurgical furnaces. Sometimes it can have quite catastrophic effects. I agree with Mr. Hartgroves that you can get stratification by the wall due to this in-leak.

A further point dealt with the passage of droplets of water through an adsorbent dryer. It is advisable when you are using an adsorbent type of dryer to use a mechanical separator in advance of the dryer. The amount of droplets passing through will depend on the particle size of the droplet and the way in which the separation is arranged. The large droplets will be separated easily by centrifugal effect. It is possible, however, for sub-micron droplets to pass into the adsorbent bed because they are not easily separated by the centrifugal effect. Water droplets place a heavy load on the adsorbent and thereby reduces its capacity for water vapour. In addition, the thermal stresses set up (due to the heat of adsorption) may be sufficient to cause a mechanical breakdown in the desiccant itself. With high quantities of liquid water carried over, re-adsorption by the dry air, as suggested by Mr. Hartgroves, is quite conceivable. Therefore, I reiterate the need for taking out the mechanical moisture in advance of using the adsorbent system.

The final question dealt with the elimination of trace elements. This is an interesting problem. The first part of our work is bound up with the ascertainment of the extent of trace elements. I think, as stated there, that spectrographic processes are called for. If they can detect the material, I am confident that some means can be devised for taking the unwanted elements out.

I was interested in the final remark concerning artificial environment. Where you can lead off unwanted by-products, I think it is not too expensive. The really expensive artificial environment is where you have to have complete control of all the elements in the system; the sort where you have to re-cycle carbon monoxide or carbon dioxide back to carbon and oxygen. This is expensive, and difficult, although theoretically quite possible.

Professor T. C. Min (*in reply*): As to the title of the paper, I agree with Mr. Harrison that the word 'Public' is somewhat more general than the word 'Commercial'. However, the very fact of the value of 0·7 of the natural draft factor for the entrance was arrived at after the field study of some twenty-one commercial buildings and two public buildings. The commercial buildings tested consist of mostly office buildings, some department stores, and one railroad terminal building. The two public buildings are university buildings. The natural draft factor, as pointed out in the paper and in more detail in reference 1, may be influenced by many parameters. By and large, the 0·7 is a typical value for the buildings investigated under normal daily activities with the mechanical supply and exhaust fan not in operation. Neither the height which ranges from 15 storeys to 45 storeys, the structures, the numbers of entrances, the types of entrances, nor the degree of freedom of air communication between rooms and storeys, the relative area and resistance of opening for in-flow and out-flow, the rates and patterns of traffic, the business activities, and the outdoor conditions are identical from one building to another. It turned out amazingly that the draft factors are essentially the same. Reference should be again made to reference 1 for further information.

Regarding to the distribution of the pressure differential and window infiltration at various height of the building, the Technical Committee on Heating and Air Conditioning Loads of the American Society of Heating, Refrigerating, and Air Conditioning Engineers has been interested for some time; and I am certainly pleased to learn that Mr. Harrison shares our interest. We would like to see that investigation on the distribution of pressure differential at various height across the building be encouraged and carried out.

In conclusion, I wish to thank Mr. Harrison for the constructive discussion. I would also like to express my appreciation to the National Science Foundation for an International Travel Grant and to Dean Fred H. Pumphrey for his encouragement which made this presentation possible.

P. A. Coles, Vice-Chairman for the meeting, propoed a vote of thanks to the authors and contributors, which was carried by acclamation, and the meeting terminated.