Infiltration Characteristics of Entrance Doors

New Tests Determine Heat Load in Air Conditioning of Buildings—Broad Conclusions Cited

By Arthur M. Simpson

WE have enough coefficients and factors to enable an engineer to make a fairly accurate estimate of air conditioning loads—wall and glass areas, their construction, exposure and the like, electric lights and appliances, hot plates and gas burners, body radiation and all the rest. The books also cover what has been found out as to the kind of windows, their construction and the use of coefficients of crack infiltration.

When it comes to the entrance door, however, it has been another matter. The engineer may perhaps assume that since he has a plenum job air can only move out through the door at a slow velocity as determined by his plenum pressure. Or again he will assume that the wind does not blow at all under maximum wet bulb design conditions, so that he can neglect the entrance. Or he will say, "I guess that entrance ought to be equivalent to 200 or 300 c.f.m." Up to this time he has not had any accepted coefficients for entrance infiltration for different kinds of entrances and traffic.

Most air conditioning coefficients have come out of laboratory experiments, but entrance infiltration was one factor in the calculation which was not adaptable to such tests. There are too many factors to be duplicated. There are the varying directions and velocities of the wind and eddy currents in the city streets; the varying flow of traffic, the speed with which the traffic moves, the density and the frequency of the traffic, and the varying operation of different types of doorways.

Our interest in studying entrance infiltration, therefore, carried us into the field in order to make our tests and measurements, and the information which we have to present here was secured as the result of tests run on more than 600 entrances in cities up and down the Atlantic seaboard from Washington, D. C., to Boston, Mass., and as far west as Chicago, Ill.

The study of entrance infiltration divides itself into three phases:

a. Entrance infiltration caused by combinations of wind pressure, chimney effect of heated buildings, and exhaust fan ventilation in the heating season.

b. Infiltration and exfiltration caused by wind pressure acting on two or more entrances in different outside walls around a given area in which temperature and low humidity are to be maintained in the comfort zone during the hot weather season.

c. Infiltration and exfiltration where we have a single entrance to an air conditioned area.

Since there is no measurable chimney action in buildings in the summer season the first phase is one having to do purely with the question of heating and ventilation, and not with air conditioning or refrigeration, and will therefore be neglected in this discussion.

Our second and third phases are the real problems, as far as air conditioning is concerned. The more serious of these is the case of entrances on two walls providing a chance for the wind to blow directly through an area, or more commonly, where the action of wind currents builds up a positive pressure at one entrance and a negative pressure at the other, causing a surprisingly large volume of air to flow in and out of the building. The third phase, where we have a single entrance or entrances in one wall only, while a much less serious problem, still presents factors and possible losses which should be taken into account by any engineer estimating an air conditioning installation on the basis of refrigeration capacity.

Wind Blows on Hot, Muggy Days

THERE is a more or less general assumption on the part of engineers in the air conditioning industry to the effect that the wind does not blow on hot, muggy days. In other words, that high wet bulb temperatures and bright sunlight are not ordinarily accompanied by normal wind velocities. While some of our data books caution us that the effect of wind pressure on infiltration may be extremely large we have all seen examples and instruction sheets that contained statements to the effect that additional infiltration from wind may usually be neglected in summer. Our investigation shows clearly that velocity, eddy currents, and pressure areas built up by summer winds are the very cause of the entrance infiltration problem in air conditioning.

In order to find out what wind velocities could be expected during periods of high wet bulb readings a study was made of meteorological data prepared by

Table 1. Typical Meteorological Data on Relation of Wet Bulb Temperature to Wind Velocity

(New York, N. Y. 1934)

Date	June 6		June 29		July 7		July 25	
Hour	Wet bulb, °F.	Wind, m.p.h.	Wet bulb, °F.	Wind, m.p.h.	Wet bulb, °F.	Wind, m.p.h.	Wet bulb, °F.	Wind, m.p.h.
9 a.m.	72	12	79	11	81	10	68	13
11 a.m.	73	12	80	10	79	10	72	9
1 p.m.	74	12	82	10	76	12	76	10
3 p.m.	74	12	79	13	76	11	80	9
5 p.m.	73	15	75	10	76	9	78	11

the New York City Meteorological Station in Central Park. Table 1 gives the hourly wet bulb temperature and wind velocity on a number of typical days in 1934 during which the wet bulb temperature was 75° F. or higher. It is important to note that the average wind velocity during these periods was approximately 10 m.p.h., while the average wind velocity throughout the four months during which these figures were taken was approximately 9 m.p.h. In other words, the records of the Weather Bureau show that we can expect a greater than average wind velocity during high wet bulb periods.

Another interesting fact developed in connection with wind velocity is that there seems to be no reliable relationship between the *direction* of the wind, and the *direction* of infiltration under typical city conditions. The obstructions of buildings of various sizes and shapes cause such unexpected pressure areas and eddy currents that there are virtually no protected entrances. Where an entrance faces an unobstructed area such as a park we can naturally expect the direction of the entrance infiltration or exfiltration to be the same as the direction of the wind. However, if it is a typical store entrance in a built up business section, one will be almost certain to find an exfiltration or infiltration in the entrance on any day when there is a normal or nearly normal wind velocity—regardless of the direction in which the wind is blowing.

Measuring Velocities in Entrances

THE only way to measure entrance infiltration is to run tests under actual conditions in the field. The conduct of these tests seemed, at first, to be a difficult problem under the usual summer conditions. With the wide variation in velocity for short periods of time, the variations running from 10 to 500 ft./min. or even higher, anemometers were out of the question. The Kata thermometer is a laboratory instrument and requires too many auxiliaries for use in a busy entrance. After considerable experimentation it was determined that the measurement of the velocity by a smoke puff test was the best solution to the problem. But such a test had to be conducted in a manner which would not be objectionable to the public and which would not interfere with traffic in a busy entrance. This problem was overcome by the development of a simple little device which could give convenient, quick puffs of cigarette smoke by means of a rubber bulb.

In checking these velocities, entrances were selected wherever possible having relatively deep and narrow approaches between the show windows, so we could measure the flow in a channel of approximately uniform cross section. In a great many cases the measurement was taken through vestibules which gave us very accurate results, but in many instances where a single door opened into a large room distances of five or six feet were measured from the inside of the opening and five or six feet from the outside of the opening and lines were marked on the floor at these distances. One man standing at the doorway could reach out with the smoke puffer and make a traverse of the entrance with eight to ten puffs of smoke and the other men in the party stationed at the line to the interior and exterior of the opening would time with an accumulative reading stop watch the total elapsed time for the travel of the smoke from the doorway to the line, which had already been marked on the floor.

Approximately 200 tests in entrances to areas having doors in more than one outside wall showed en-

Table 2. Summer Entrance Draft Velocities in Multiple Entrance Buildings (Typical Cases).

Case No.	Direction doors face	Velocity, ft./min.	Temp. d.b.	Wet bulb, °F.	Wind direction	Wind vel., m.p.h.
1	N.	+361	85	70	S.W.	12
	S.	—350				
2	N.	—480	83.4	66	S.W.	18
	S.W.	+370				
3	S.	+500	83.4	66	S.W.	18
	N.	—280				
4	E.	+300	77	66	S.	25
	S.	—246				
5	W.	+120	77	66	S.	25
6	W.	—226	82	62	W.	8
	N.	+327				
	S.	+287	82	62	W.	8
	N.	—321				
7	S.W.	+120	88	70	S.W.	12
		+264				
8	N.	—210	89	71	S.W.	12
	W.	+102				
9	S.W.	+384	89	71	S.W.	12
	W.	—140				
	N.	+128				
	S.	—140				
	N.	—144				
	S.	—148				
10	N.	—169	85	69	S.	8
	W	+188				
	N.	+190				
	W.	—102				

trance infiltration velocities varying from a minimum of 104 ft./min. to a maximum of 350 ft./min., with a mean of 256 ft./min. With a double doorway five feet wide left wide open, an infiltration velocity of 256 ft./min. would represent a total infiltration of 9,000 c.f.m.

Typical readings in multiple entrance buildings with doors in more than one outside wall are given in Table 2. It is very interesting to note in studying this table that the infiltration, which is represented by a plus sign, is very often in a direction opposite to the direction of the wind and the same is also true in the case of exfiltration, which is indicated by a minus sign. These are cases where entrances face on typical streets in down town areas. The eddy currents and pressure areas built up by obstructing buildings cause a flow of air on lower levels opposite to the direction of the wind.

Table 3. Entrance Draft Velocities in Single Entrance Buildings (Summer)

Case No.	*Direction doors face*	*Velocity, ft./min.*	*Temp. d.b.*	*Wet bulb, °F.*	*Wind direction*	*Wind vel., m.p.h.*
1	E.	+72	88	70	S.W.	12
2	W.	+120	88	70	S.W.	12
3	W.	+378	88	70	S.W.	12
4	W.	+84	88	70	S.W.	12
5	S.	+144	88	70	S.W.	12
6	N.	—135	88	70	S.W.	12
7	N.	+200	88	70	S.W.	12
8	N.E.	+104	88	70	S.W.	12
9	S.E.	+180	88	70	S.W.	12
10	E.	+240	88	71	S.W.	12
11	S.	—120	90	75	S.E.	8
12	N.	—120	86	69	S.W.	12
13	E.	+100	86	69	S.W.	12

Another series of tests on approximately 250 entrances to areas having entrance doors in only one outside wall showed entrance infiltration velocities varying from 75 to 250 ft./min. with a mean of 165. Under this condition a double doorway wide open would permit an infiltration or exfiltration flow of 5,800 c.f.m. Typical readings in buildings of this type are shown in Table 3.

Effective Door Openings, Hinged Doors

WHILE the above velocities give us a measurement of entrance infiltration in open doorways, it is necessary for us to get additional data in order to determine the amount of infiltration occurring in hinged door entrances where the doors, normally in the closed position, are opened and closed as people pass through the entrance. This is also a condition where accurate information can only be secured from actual tests in the field under typical traffic conditions and typical door operation. Such tests have been conducted in more than 150 entrances.

First it was necessary to determine a method of measuring the time that a door was open. A very

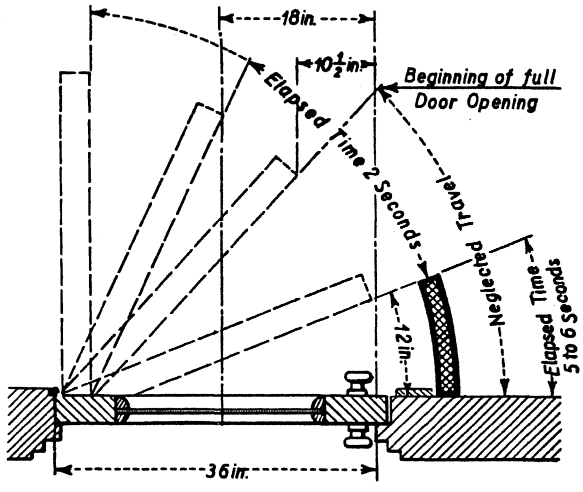

FIG. 1. DIAGRAM SHOWING MEASUREMENT OF EFFECTIVE DOOR OPENING.

thorough study was made of this problem with results as shown in Fig. 1. The average swing door requires two seconds to open and six seconds to close with a door check. Approximately two seconds of this time is spent from the time the door is opened one foot until it returns to within one foot of the jamb. The balance of the time spent is in the slower movement as it approaches the jamb. If we consider this 12-in. distance alone, with an average duration of six seconds for an average opening of 6 in., it is of course equivalent to a 3-ft. opening for one second. The result of our tests and study in the laboratory and in the field was that a measurement of the time spent from the time the door was opened one foot until it reached to within one foot of the jamb, would give a very close approximation of the effective full opening of the door when the door was used by one person. Of course, in actual practice in the field a number of people will pass through a door in one opening, in which case the measurement of the elapsed time the door was open in the above manner as compared to the number of people passing through greatly reduces any possibility of error.

The 150 tests on single doorways showed that the average effective door opening for a single door entrance was two seconds for each person passing through. In looking for an answer to the infiltration problem the vestibule presents itself as the most obvious solution. A similar study of vestibule entrances in more than 200 instances, however, gave us rather surprising results.

In making tests on the vestibule entrances a similar procedure was followed as in the case of tests on single swing doors. The traffic passing through the entrance was clocked in and out and with a stop watch the time was secured of the through draft opening occurring while at least one inner and one outer door was open more than 12 in. The watch was stopped when either the inner or outer set of doors was closed to within 12 in. of the jamb. It was determined that in the usual busy entrance the effective duration of a through draft opening in a vestibule was one and one half seconds for each person passing through the entrance. This means that a vestibule gives only 25% better protection than a single swing door. The failure of the vestibule to give better protection comes from the fact that the flow of traffic is such that the repeated simultaneous opening of the inner and outer doors nullifies the expected protection.

The consideration of the data on the velocity of entrance infiltration together with that on door operation enables us to arrive at definite values for the volume of infiltration to be expected. Let us consider first the case of a building or area having doors on more than one outside wall. As we have determined before, with a double doorway standing open we can expect, under median conditions, an infiltration of 9,000 c.f.m. or approximately 4,500 c.f.m. for each door standing open.

Where the doors are open only while people pass in and out of the area a single doorway open two seconds with an average infiltration velocity of 256 ft./min. would produce an infiltration volume of 165 ft.^{3} for each person passing through the entrance. Likewise a vestibule under similar conditions with an effective door opening of 1.5 seconds per person would permit an infiltration of 128 ft.^{3} for each person passing through the entrance.

We can also summarize the data on areas having an entrance in only one outside wall. As pointed out before, under this condition the infiltration to be expected, under median conditions, with a double open doorway is 5,800 c.f.m. or approximately 3,000 c.f.m. for each door. Where the door is opened only to permit people to enter and leave the building an effective opening of two seconds, together with an average infiltration velocity of 165 ft./min., would show an infiltration volume of 110 ft.^{3} per person passing through the entrance.

With a vestibule under these conditions and effective door opening of 1.5 seconds per person this infiltration would amount to 82 ft.^{3} per person passing through the entrance.

Methods of Measuring Infiltration at Revolving Doors

THE other common type of entrance to modern buildings is the revolving door. This has been used extensively to prevent entrance infiltration under winter heating conditions where there is a marked chimney effect that creates positive suction pressure. However, no definite values as to its effectiveness had been worked out until recently and there has been a wide variation in opinion as to the effect of this type of entrance on summer air conditioning. It is evident that a revolving door must displace some air as it rotates. There is, however, no positive displacement as in the case of a pump or in the case of a blower with a scroll housing. A revolving door is merely a paddle wheel set inside of a circular enclosure which moves the air around. The question was, how much air was discharged at the interior and exterior as the door rotated.

The factors which govern the displacement of air by a revolving door are:

a. Speed of rotation of the revolving door.

b. Scavaging effect of air currents directed towards the compartments of the door when they are exposed at the interior and exterior of the entrance.

c. Difference in temperature between the interior and exterior which would set up a vertical circulation of the air in each compartment as it was exposed to the interior and exterior.

Since the revolving door seals the entrance against any free flow of air, the size of the room, the height of the building and the difference in pressure between the inside and outside would have no measurable or practical effect on the displacement of air by a revolving door.

The measurement of the effectiveness of the revolving door was merely a question of measuring the efficiency of the device as a means for displacing air, and this brought us back to the laboratory where a test booth installation was built as shown in Fig. 2.

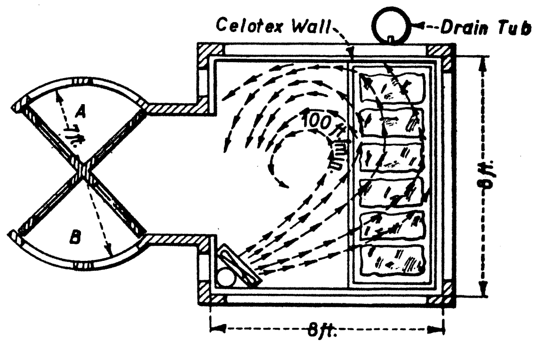

FIG. 2. PLAN OF REVOLVING DOOR TEST BOOTH.

The booth was built of Celotex, 8 ft. square and 8 ft. high. The revolving door was mounted at the entrance to the booth. A fan was located in one corner as shown in order to provide a scavaging velocity of 100 ft./min. to cause a displacement of the air in the section of the door exposed to the booth. The test was equipped with eleven thermometers, six inside of the booth and five outside. Wet bulb readings were taken with a sling psychrometer at frequent intervals during the test.

With this equipment three types of tests were conducted to determine the amount of displacement caused by the rotation of the revolving doors. During these tests the revolving door was rotated by having people pass through at normal speeds, entering and leaving the booth by the revolving door. In another test the door was rotated mechanically to give more uniform speeds of rotation, and in all cases the average r.p.m. was determined accurately.

The first test was a cooling test in which we checked the actual displacement of air by the revolving door by measuring the heat loss caused by this displacement. The bunker in the booth was loaded with ice. First a test was conducted with the fan operating but with the revolving door standing still, in order to

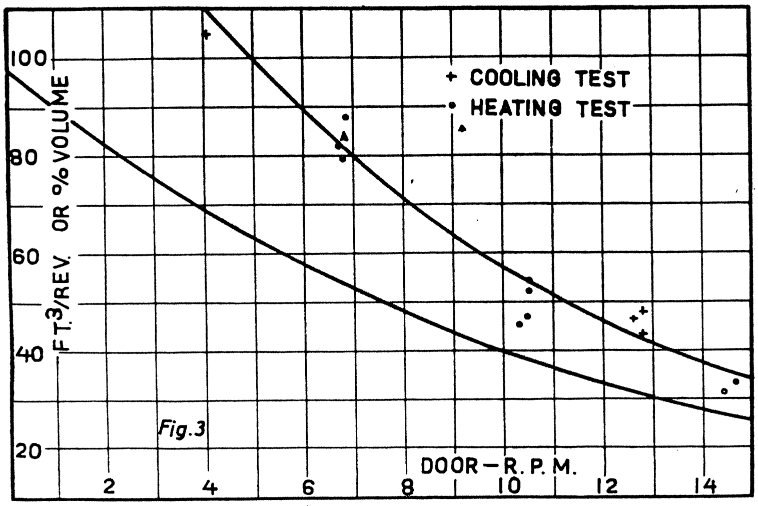

FIG. 3. DOOR FILTRATION IN TERMS OF DOOR REVOLUTIONS.

Upper curve: Displacement of air by revolving door at booth entrance, ft.³ revolution. Lower curve: Diminution of original atmosphere of smoke filled booth due to displacement by revolving door where smoke density was measured by electric eye.

check calculation of the transmission factor for the booth. Dry bulb and wet bulb readings were taken inside and outside of the booth at frequent intervals and the run-off water gave us the measure of the heat transmission loss.

The test was then repeated many times with the revolving door rotating at various speeds; with the door driven mechanically; with it operated by persons passing in and out of the booth as in actual service. Accurate and detailed dry bulb and wet bulb readings were taken inside and outside. The run-off water was measured and the relative difference in the heat loss gave the means to determine the displacement caused by the rotation of the revolving door. The points shown for cooling tests on Fig. 3 are typical of the results secured under these conditions.

It was evident that the extreme delicacy of the wet bulb readings and the possibility of wide variations in results from slight accuracies in wet bulb temperatures might leave some question as to the reliability of results secured by the cooling test as described above. In order to secure a check on this method and a simpler test and calculation, a steam radiator was substituted for the ice bunker and the whole series of tests was repeated, checking the temperatures and the condensate. The result of these tests are also shown by the points plotted for heating tests on Fig. 3.

As an additional and final check on these two methods a test was made by means of an electric eye—the Hazegage—made by the Ess Instrument Company. This proved to be a very accurate and consistent method. This sensitive electric eye was located across the booth from front to back and from side to side. With the revolving door rotating and the fan running a smoke candle was set off in the booth and after a stable condition was reached readings were taken on the Hazegage for each revolution of the revolving door as a measurement of the dilution of the smoke caused by the rotation of the revolving door. The results of typical tests and the formula involved are shown on the lower curve of Fig. 3.

Since the normal operating speed of the revolving door is between 12 and 14 r. p. m., which is determined by a normal rate of walking, and since the normal speed of a revolving door is never less than 10 r. p. m., it is evident from the curves of Fig. 3 that the displacement of this particular revolving door at normal speeds averaged 46 ft.³ per revolution. Since the volume of this revolving door, which was 7 ft. in

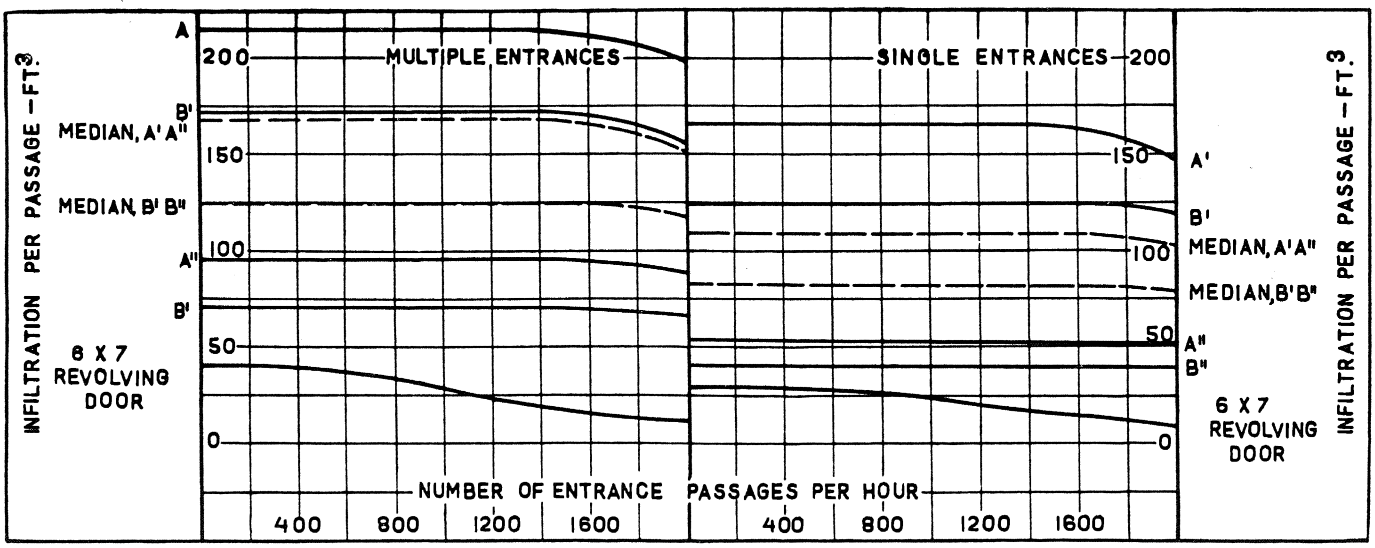

FIG. 4. COOLING LOAD LOSSES DUE TO DOOR FILTRATION IN MULTIPLE AND SINGLE ENTRANCE BUILDINGS.

Range for single swing doors in A′ to A″ where A′ is for exposed position and wind velocity more than 10 m.p.h.; A″ is for sheltered position and wind velocity less than 5 m.p.h. Range for swing door vestibules is B′ to B″ where similar notation holds.

diameter by 7 ft. high, was 270 ft.,[3] the revolving door is shown with an efficiency of 17% as a displacement medium, or metering device.

One other factor affects the infiltration of a revolving door—the number of revolutions for each person passing through. This factor was determined by clocking over 100 revolving door installations, counting the traffic through the door and the number of revolutions at the same time. These tests showed that a revolving door in fairly good condition of maintenance rotates on an average of .4 revolutions per person passing through.

With 46 ft.[3] of displacement per revolution and .4 revolutions per person a revolving door 7 ft. in diameter and 7 ft. high causes an infiltration of 18.5 ft.[3] per person passing through. With this size door this infiltration is the same summer or winter, as heating or cooling provides approximately the same scavaging velocity directed toward the entrance.

Summary

IN order to summarize and consolidate the data secured as the result of this investigation we have consolidated the information in the curves of Fig. 4 and the data of Table 4. Fig. 4 gives the infiltration characteristics for entrances to areas which have entrances on more than one outside wall, as well as for areas having entrances on only one outside wall. Both are for summer cooling conditions only.

Table 4. Occupancy of Buildings Related to Door Openings

Entrance passages per hr.	*200*	*600*	*1000*	*1400*	*1800*
Banks	25	75	125	175	225
Barber shops	50	—	—	—	—
Broker's offices	25	75	125	—	—
Candy and soda	33	100	166	233	300
Cigar stores	8	25	42	50	75
Department stores	75	75	125	175	225
Five and ten	17	50	84	116	150
Dress shop	66	200	—	—	—
Drug stores	25	75	175	175	225
Furriers	66	—	—	—	—
Lunch rooms	33	100	166	200	300
Men's shops	50	150	—	—	—
Office bldgs.	100	300	500	700	900
Public bldgs.	66	200	333	466	600
Restaurants	66	200	333	466	600
Shoe stores	50	150	—	—	—

Table 4 gives the occupancy for various types of business. The top line gives the number of entrance passages per hour to be expected for the corresponding occupancy, for each type of business. These entrance passages per hour are based on one count for each movement through the entrance. One person entering and leaving a store would cause two entrance passages.

On the upper portion of the chart there has been shown the range of the readings taken in single entrance doorways. Directly below this and partly superimposed upon this above area are the range of the readings in swing door vestibule doorways. The median value for each of these areas is shown by the broken lines. Below these is shown a curve giving values of revolving door infiltration for a 6 ft. x 7 ft. revolving door. In lower volumes of traffic up to 800 passages per hour, the curve was determined by assuming that traffic passed through the revolving door two at a time at a normal rate of speed and the revolving door came to rest between the movement of each two persons and the exposed quarter section was completely scavenged during the time the doors came to rest. Values above 800 passages per hour for the revolving doors were determined by assuming that from this point on the revolving door rotated at a uniform speed sufficient to handle the traffic passing through.

New Publication Surveys Progress in Domestic Electric Refrigeration

The sustained effort to insure more efficient electric refrigeration at reduced cost to the consumer is today's outstanding achievement in the field of domestic electric refrigeration, according to Dr. Warren M. Persons, former professor of economics at Harvard University and a member of the advisory committee of Kelvinator's Temperature Research Foundation.

In a study recently conducted four principal advances in household refrigeration during the past few years are cited by Dr. Persons as of importance to the American housewife; lower initial cost, increased perfection of insulation, increased perfection of temperature control, lower energy consumption. These findings have been published in a booklet entitled, "An Economist's Appraisal of Domestic Electric Refrigeration."

"The past five years," Dr. Persons said, "have witnessed the successful commercialization of electric refrigeration." So rapid, in fact, has been the growth of the industry that refrigerators now top all other electric appliances in aggregate value of sales.

A corresponding rise in consumption of electric current by refrigerators, he maintained, was the chief reason why domestic consumption of current did not fall during the depression. "In spite of lower energy consumption by the newer models, increased total consumption by electric refrigerators may be expected to continue," he declared.

To support this prediction, Dr. Persons quoted statistics, asserting: "One family in every three homes wired for electricity has an electric refrigerator. Great technical progress toward perfecting refrigerating machinery in insulation, in temperature control, and in energy cost of operation has been made in the past year or two. Meanwhile, prices of refrigerators today are about one-half of those six or eight years ago and the cost of current per kilowatt hour for electric energy in different localities is less by a fourth, a third, or a half that of 1929.

"Further, the improvements in domestic refrigerators in recent years have made the earlier models obsolete. Economy is often served by turning in old models as part payments against new models or even by scrapping old models."