INFLUENCE OF STACK EFFECT ON THE HEAT LOSS IN TALL BUILDINGS

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THE purpose of this paper is to present the results of investigations made in the Penobscot Building, Detroit, Mich., to determine the influence of stack effect on the heat loss from a tall building. The tests conducted in this building are the first in a series to be made in investigating this subject, and the results should not be interpreted as applying to any building until additional tests with other buildings have shown similar agreement between the calculated heat loss and the heat input as determined by test. The investigations are to be carried on during the next heating season at Detroit, and it is hoped when these tests are completed that the influence of stack effect on heat losses in tall buildings may be properly accounted for.

By *stack effect*, as applied to tall buildings, is meant the pressure difference existing between the inside and outside of a building due to the temperature difference. This pressure difference tends to increase the inflow of air on the lower floors of a building by adding to the wind effect and opposes the effect of the wind at the upper floors. For any given inside and outside temperature, the pressure difference at any elevation is theoretically proportional to the distance this place is from the neutral zone.[1]

The work is being done in cooperation with the Technical Advisory Committee on Heat Losses from Buildings of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS. It was made possible through the courtesy of the owners of the Penobscot Building and the building engineer, Mr. G. M. Lewis, who made available space for the study and assisted in every manner possible; and the Detroit Edison Co. who installed all the test equipment, made all the arrangements, and collected the test data.

THE BUILDING

The Penobscot Building, Fig. 1, is a modern 47-story office building located at the corner of Griswold and Fort Streets, Detroit, Mich. It is 565 ft from street level to roof, has a volume of 6,858,360 cu ft, and contains 73,940 sq ft of direct radiation and 19,250 sq ft of equivalent radiation in fan coils.

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[1] The Neutral Zone in Ventilating, by J. E. Emswiler, A. S. H. V. E. TRANSACTIONS, Vol. 32, 26.

Presented at the Semi-Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, June, 1934, Buck Hill Falls, Pa., by J. H. Walker.

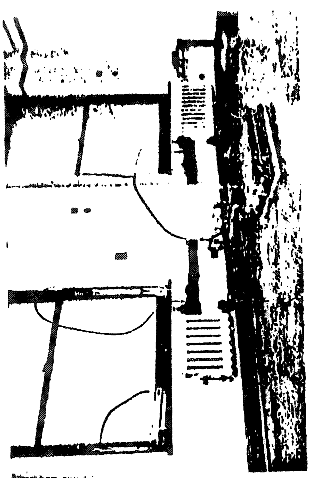

Fig. 4. Test Room on 21st Floor

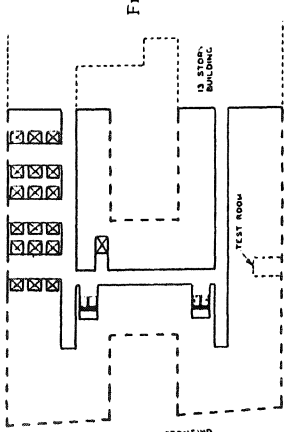

Fig. 3. Cross-section of Building at 8th Floor

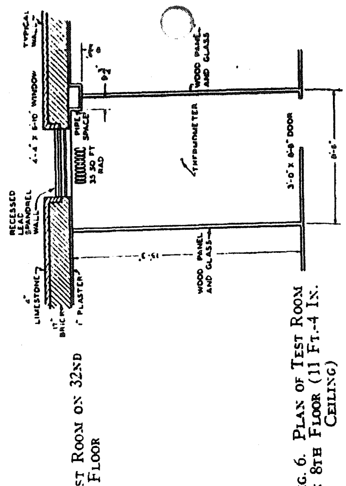

Fig. 6. Plan of Test Room on 8th Floor (11 Ft.-4 In. Ceiling)

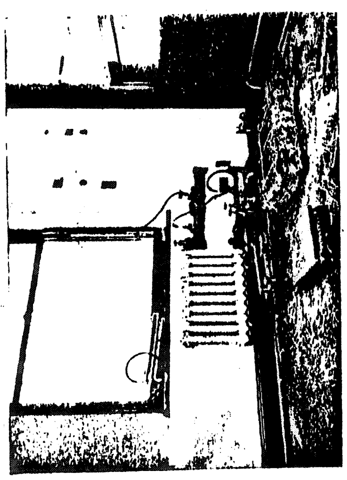

Fig. 5. Test Room on 32nd Floor

The wind velocity and direction, the per cent of possible sunshine, the barometric pressure, and the outside temperature were obtained from the local weather bureau, which is located at the Majestic Building about three blocks away. The outside temperature obtained by thermometers suspended outside the windows at the various floors and 6 in. away from the wall surface were used in calculating the heat loss. These temperatures were practically identical with the temperatures reported by the weather bureau.

An attempt was made to measure the amount of infiltration or exfiltration from the test room by replacing the transom over the door with a tight fitting board that had a one square foot opening, and measuring the velocity at this place with an anemometer. The velocities in all cases were too low to move the anemometer wheel. The infiltration figures used in the calculations were based on the results of, Air Leakage Studies on Metal Windows, by Houghten and O'Connell [2] corresponding to the actual pressure drops measured across the windows. The pressure difference was measured with an inclined draft gage connected to copper tubing that extended through a hole drilled in the window sash.

Results

The principal results are presented in Table 2. Column 5 gives the heat input in Btu per hour from the steam to maintain the test rooms at the temperatures indicated in Column 3 for the various outside temperatures listed in Column 14. The figures in Column 5 include the necessary corrections for any heat loss or gain from or to the surrounding rooms.

Column 6 is the heat input from steam corrected to a common inside temperature of 72.6 F. Column 6 is obtained by multiplying the values in Column 5 by the ratio of 72.6 F minus the outside temperature over the actual temperature difference between inside and outside. The temperature 72.6 F is the average room temperature for all tests.

Column 7 shows the amount of heat which would be necessary to maintain the test rooms on the various floors at 72.6 F, if the exposed wall and glass areas were the same as the 8th floor test room.

The calculated transmission loss, Column 8, is the sum of the quantities obtained by multiplying the area in square feet of exposed wall and that of glass by their respective transmission coefficient (U) and by the temperature difference between the air inside and outside. The temperature difference is 72.6 F minus the outside temperature.

The transmission coefficient (U) is

$$U = \frac{1}{\frac{1}{f_i} + \frac{1}{f_o} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3}}$$

in which

f_i and f_o = Surface coefficients.
k_1, k_2, etc. = The conductivity of the respective material.
x_1, x_2, etc. = The thickness of the various materials in inches.

The outside wall of the 8th floor test room has 38.1 sq ft of stone veneered wall and 19.5 sq ft of a recessed lead spandrel construction. The stone

[2] A. S. H. V. E. Transactions, Vol. 34, 1928, p. 321.

veneered wall is composed of the following material: 1 in. plaster, 17 in. brick, and 4 in. of cut limestone; and the recessed lead spandrel section is made up of 1 in. plaster, 8 in. brick, and a 2½ in. lead spandrel. The glass area for

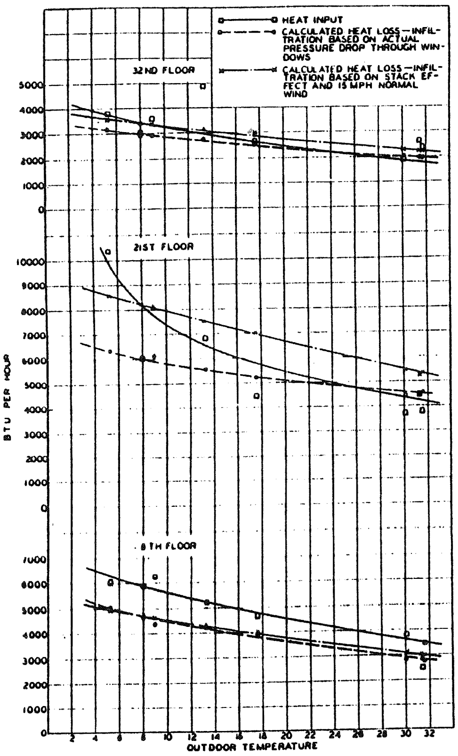

Fig. 7. Comparison of Calculated Heat Loss and Actual Heat Input to Maintain Test Rooms at 72.6 F

the 8th floor room is 29.6 sq ft. The transmission coefficient for the stone veneered section, using values from The Guide 1934 is

$$U = \frac{1}{\frac{1}{1.65} + \frac{1}{6.0} + \frac{1}{3.3} + \frac{17}{5} + \frac{4}{12.5}} = 0.208 \text{ Btu per hour per sq ft per deg.}$$

and for the recessed spandrel wall

$$U = \frac{1}{\frac{1}{1.65} + \frac{1}{6.0} + \frac{1}{3.3} + \frac{8}{5} + \frac{2.5}{111}} = 0.370 \text{ Btu per hour per sq ft per deg.}$$

The total transmission loss in Btu per hour per degree temperature difference for the exposed wall and glass of the 8th floor test room is equal to

$$38.1 \times 0.208 + 19.5 \times 0.370 + 29.6 \times 1.13 = 48.53$$

To obtain the total transmission loss for any given temperature difference for the 8th floor room, 48.53 is multiplied by the temperature difference.

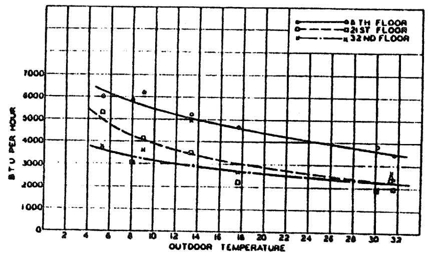

Fig. 8. Btu Required to Maintain Test Rooms at 72.6 F Reduced to 8th Floor Exposure as a Base for the Purpose of Comparison

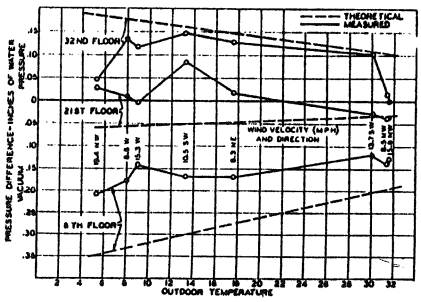

Fig. 9. Comparison of Measured Pressure Difference Across Windows with Theoretical Difference Due to Stack Effect

The method employed in calculating the transmission loss for the 8th floor test room was also used in calculating the transmission loss for the 21st and

The reason for the large difference in the two curves portraying the calculated heat loss is due to the two different methods used in calculating the infiltration loss. As has already been pointed out, actual pressure drops across the window show the 21st floor to be at about the neutral zone, while THE GUIDE method assumes the neutral zone to be at mid-height or 29 ft higher than the 21st floor. This 29 ft, plus the 15 mile normal wind used in THE GUIDE method of determining the infiltration loss, is responsible for the difference in the two curves.

The curves in Fig. 7 showing the heat supply and the calculated heat loss for the 32nd floor agree remarkably well with the exception of the 13.3 F test point. There is no known reason for this discrepancy.

Fig. 8 shows the amount of heat which would be required to maintain the test rooms on the various floors at 72.6 F if the exposed wall and glass areas were the same as the 8th floor test room. It is evident from Fig. 8 that it requires more heat to maintain a temperature of 72.6 F in the 8th floor test room than it would to maintain this same temperature in a room on the 21st or 32nd floor having the same exposure.

Fig. 9 shows the actual pressure difference across the windows for the three test rooms plotted against the outside temperature with the wind velocity and direction indicated for each test point. For the purpose of comparison, the theoretical pressure difference due to temperature difference for each test room is also plotted. In obtaining the values for the theoretical curve, the effective head was measured from the mid-height of the building. The theoretical pressure difference does not include any wind effect and represents the maximum pressure difference that could exist with zero flow.

CONCLUSIONS

It is evident from the curves of heat supply in Fig. 8 that it requires more heat to maintain the same room temperature on the lower floors of this building, for a given exposure, than it does on the upper floors. The difference in the amount of heat necessary to heat the 32nd floor test room is approximately 40 per cent less than that required to heat the 8th floor room, when expressed on the same amount of exposed wall and glass.

THE GUIDE 1934 method of calculating the heat loss for the 8th floor, which is below the neutral zone, does not give values of heat quantities that compared with those obtained by these tests. The portion of this difference that is due to infiltration cannot be definitely stated at this time, but it is hoped that the future tests being planned will answer this question.