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EFFECT OF A GAS FURNACE CHIMNEY ON THE AIR LEAKAGE CHARACTERISTIC OF A TWO-STOREY DETACHED HOUSE

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ABSTRACT

An experimental assessment was made of the effect of a chimney on the air leakage characteristic of an unoccupied, two-storey detached house, as heated by either gas or electric furnace. Measurements were taken of air tightness values and air infiltration rates with the chimney capped and uncapped. Infiltration rates were also measured during operation of the electric furnace.

The over-all air infiltration rate was greater with the gas furnace than with the electric furnace under the same weather conditions, and the difference was smaller than the air flow rate through the chimney. When the gas furnace was in operation, stack action was the dominant driving potential for air infiltration, with wind speeds up to 7 m/s (16 mph) and with inside-to-outside temperature differences greater than 20 K (36 R).

INTRODUCTION

Because of the rising cost of heating fuel and the attractive subsidy from the federal government for off-oil conversion, more and more Canadian homeowners are switching to natural gas for heating. As a conventional gas-fired furnace has a chimney for venting combustion products and there is usually a draft diverter located near the exit of the combustion chamber, a vertical leakage path extending from basement to roof exists in most gas-heated houses. Consequently, inside air moves upward continuously through the chimney during the heating season. As a result, air infiltration is controlled not only by stack action and wind but also by air movement in the gas furnace chimney.

Although air leakage studies on gas-heated houses have been carried out,[1,2] the effect of chimneys on air infiltration is still not fully understood. A project was therefore undertaken during the heating season of 1980-81 to study the air leakage characteristic of a two-storey house as heated by either a gas-fired furnace or an electric furnace. The main objectives were to determine:

1. the influence of a gas furnace chimney on air tightness and air infiltration,
2. the influence of various operating modes of a gas furnace on air infiltration, and
3. the combined influence of weather and a gas chimney on air infiltration.

TEST HOUSE

The house under consideration (Figure 1) is one of four houses involved in the HUDAC/NRC Mark XI energy research project.[3] It is a two-storey dwelling with a basement, located in a developed residential area in Gloucester, Ontario. It already had an electric forced-air furnace, and for this study a gas furnace was installed in parallel with it. Two diverting dampers, one in the supply and the other in the return air duct, were added to minimize cross air flow between the two furnaces. A Class C insulated chimney, 12.7 cm (5 in.) diameter, was installed for the gas furnace. The flue pipe connecting the furnace to the chimney was 10 cm (4 in.) diameter. Whenever the electric furnace was in operation, the flue pipe was disconnected from the chimney and a metal cap sealed into the chimney opening. The house was unoccupied when the study was conducted.

TEST METHODS

Air Tightness Values

Air tightness values were measured with and without the chimney capped, using the fan pressurization method. The apparatus[4] consisted of a centrifugal fan with a maximum capacity of 380 L/s (800 cfm) and a laminar-flow air flow meter (MERIAN LFE Element, accurate to 3% of the measured flow rate). A pair of total-pressure-averaging tubes and a thermocouple were installed in the flue pipe to measure the air flow rate through the chimney and the flue gas temperature, respectively. To facilitate comparison with house infiltration rates, the measured chimney flow rates were corrected to room temperature.

Air Infiltration Rates under Controlled Gas Furnace Operation

Air infiltration rates for the house and air flow rates through the chimney were measured with the gas furnace operating under the following conditions: 1) burner on continuously; 2) burner off; and 3) burner cycling under thermostatic control.

An automated SF_6 constant-concentration tracer gas apparatus[5] was used for infiltration rate measurements. The SF_6 detector for the apparatus was a pulsed-mode electron-capture detector. To cross-check the results of the SF_6 apparatus, infiltration rates were also measured simultaneously by the decay method,[5] using CO_2 and CH_4 as the tracer gases. Concentrations of CO_2 and CH_4 were measured with infrared and flame-ionization gas analyzers, respectively.

All three detectors were located in the living room on the ground floor of the house (Figure 1). The tracer gases were injected into the supply duct and samples collected from the return duct through individual injection and sampling tubes. Only one furnace fan was used to mix the tracer gases with the inside air.

Air Infiltration Rates under Normal Furnace Operating Modes

Air infiltration rates were measured continuously for three days with the electric furnace in operation and the chimney capped. For comparison, similar measurements were also taken with the gas furnace in operation. In both instances the furnace was under thermostatic control. The infiltration rates were measured with the automated constant-concentration tracer gas apparatus[5] only.

Neutral Pressure Level

Neutral pressure levels were measured on a calm day with the burner both on and off. When the burner was off, readings were taken with the chimney capped as well as uncapped. The neutral pressure level was determined by drawing a straight line through two simultaneously measured pressure differentials, one across the bottom of an entrance door and the other across the top of a second-floor window directly above the door.

RESULTS AND DISCUSSION

Figure 2 shows the air leakage rates of the house with the chimney both capped and uncapped. These results were fitted to Equation (1) to obtain the flow coefficients and the exponents for both cases:

$$Q = C\ A\ (\Delta P)^n \quad (1)$$

where

Q = over-all air leakage rate, L/s (cfm)
C = flow coefficient, $L/s \cdot m^2 \cdot Pa^n$ (cfm/ft^2 (in. of water)^n)
A = area of building envelope, area of exterior wall above grade and ceiling area of the top floor, 228 m^2 (2454 ft^2)
ΔP = pressure difference across exterior wall, Pa (in. of water)
n = flow exponent.

The flow exponent is 0.71 for both cases and the corresponding flow coefficients are 0.107 $L/s \cdot m^2 \cdot Pa^{0.71}$ (1.06 $cfm/ft^2 \cdot$ in. of water$^{0.71}$) with the chimney uncapped and 0.098 (0.97) with it capped.

The difference between the two air leakage rates is, in theory, the air flow rate through the chimney. As shown in Figure 2, the chimney flow rate obtained by this method is smaller than that measured directly. The disagreement is attributable to the error of the indirect method, which uses the difference between two large air leakage rates to obtain the much smaller value for the chimney. Figure 2 indicates that for this house the air leakage rate through the chimney constitutes about 9% of the over-all air leakage rate.

The air infiltration rates under various modes of furnace operation were measured simultaneously, using three different tracer gases. Figure 3 compares CO_2 and CH_4 decay results with the SF_6 constant-concentration air change rates. As shown, the three results agreed closely with one another for air infiltration rates greater than 0.2 air changes per hour. Below this rate the SF_6 results appeared to be smaller than the corresponding decay results. The difference, however, was just slightly above the experimental error, which was estimated to be about ±10% of the measured value.[6]

Figure 4 shows the mean values for the three simultaneously obtained tracer gas results for the gas burner operating continuously and not operating. The results indicate that the infiltration rates with the burner on were, on average, 10% greater than those with it off. The difference decreased as the inside-outside temperature difference increased.

These infiltration data are compared in Figure 5 with those measured separately under normal operating conditions of either the gas or the electric furnace. The results indicate that for similar weather conditions the infiltration rates with the burner cycling were almost identical to those with it shut down. When the electric furnace was in operation (chimney capped), however, there was a noticeable reduction in infiltration.

Air flow rates through the uncapped chimney were measured during these tests. As shown in Figure 6, air flow through the chimney during operation of the gas burner varied from 22 to 26 L/s (47 to 55 cfm) as inside-outside temperature difference increased from 22 to 42 K (39.6 to 75.6°R). Figure 6 also indicates that when the burner was off, the chimney flow varied from 18 to 23 L/s (38 to 49 cfm). The average flow rate with the burner cycling was about 20 L/s (42 cfm). About 60% of the air exfiltration occurred through the chimney (Figure 5); the remaining 40% was mainly through the ceiling.

The air infiltration rates of the house with the chimney capped (Figure 5) were, on average, 11 L/s (23 cfm) smaller than those with it uncapped. The difference, which was much smaller than the average 20 L/s (42 cfm) of air flow through the chimney, was due to increased exfiltration resulting from the lowered level of the neutral pressure plane.

Figure 7 shows that with an inside-outside temperature difference of 28 K (50 R) the neutral pressure level changed from 3.6 to 4.8 m (11.8 to 15.7 ft), an increase of 1.33 times. This caused a flow reversal from exfiltration to infiltration at the exterior wall between the two neutral pressure levels: it increased the infiltration through the lower and middle walls and reduced the exfiltration through the upper portion of the house. The slope of the pressure differential profile for the electric furnace was assumed to be the same as that for the gas furnace because the slope is not dependent on the presence or absence of a chimney. Because of lower wind speed, the scatter in the data for the gas furnace was smaller than that for the electric furnace.

Figure 8 shows that when the electric furnace operated normally, the measured air infiltration rates for wind speeds lower than 3.5 m/s (8 mph) agreed closely with the rates predicted by Equation (2) (this equation was derived previously for two houses without chimneys, included in the Mark XI project).[7]

$$I = 0.32\ (A/v)\ C_e\ (\Delta t)^n \quad \text{for } w < 3.5 \text{ m/s} \tag{2}$$

where

- I = infiltration rate, air changes per hour (ac/h)
- A = area of building envelope, m^2 (ft^2)
- v = volume of house, m^3 (ft^3) (386 m^3 (13 634 ft^3) for this house)
- C_e = flow coefficient with chimney capped, $L/s \cdot m^2 \cdot Pa^n$ (cfm/ft^2 (in. of water)^n)
- Δt = inside-to-outside temperature difference, K (R)
- n = flow exponent (0.71 for this house).

For comparison, Figure 8 also shows the infiltration rates for the gas furnace under low wind conditions. Again, the data were fitted to an expression similar to Equation (2):

$$I = 0.43(A/v)\ C_g\ (\Delta t)^n \quad \text{for } w < 3.5 \text{ m/s} \qquad (3)$$

where C_g is the flow coefficient with the chimney uncapped and n is 0.71. Figure 8 indicates that the air infiltration for this house with the gas-fired furnace operating is about 1.5 times greater than that with an electric furnace. The ratio of the constants in Equations (2) and (3) is approximately equal to the ratio of the two neutral pressure levels. As earlier studies also indicate that air infiltration due to stack action is directly proportional to the neutral pressure level,[8,9] a general expression for Equations (2) and (3) would be:

$$I = 0.32(A/v)\ r\ C\ (\Delta t)^n \quad \text{for } w < 3.5 \text{ m/s} \qquad (4)$$
$$r = H_g/H_e$$

where H_g and H_e are the neutral pressure levels with and without a chimney, respectively. The value of r is 1 for houses without chimneys, but can vary from 1 to 2 for houses with chimneys. For this house, r is approximately 1.33. C and n in Equation (4) are measured by means of the fan pressurization method with chimneys, if existing, uncapped.

Figure 9 shows the temperature-induced air leakage and pressure differential patterns for this house with chimney capped and uncapped. The air leakage rates were obtained from Figure 8 for an inside-outside temperature difference of 28 K (50 R). The chimney flow rate was assumed to be 60% of the over-all exfiltration rate (Figure 6). As noted previously, the infiltration rate with chimney uncapped was 50% greater than that with chimney capped (32 L/s versus 21 L/s). Although over-all exfiltration also was greater when the chimney was uncapped, the amount of inside air leaving the house through the walls and ceiling was smaller. These results suggest two reasons why houses without chimneys have more problems with condensation than those with chimneys:

1) for the same internal moisture generation rate, houses without chimneys have higher relative humidity than those with chimneys because there is less infiltration for dilution;

2) because there is no chimney venting of the inside air chimneyless houses have more humid air flowing through the cold parts of the upper walls and ceiling; they are therefore more susceptible to condensation problems.

Unlike electrically heated houses,[7] air infiltration rates in the gas heated dwelling were influenced by stack action for wind speeds as high as 7 m/s (16 mph). This suggests that for tight houses the strength of stack action is reinforced by the presence of a chimney. Unless, therefore, wind strength also increases proportionately, stack action remains the dominant driving potential for infiltration. Measured air infiltration rates under this condition, as shown in Figure 10, can also be approximately expressed by Equation (4).

SUMMARY

The effect of a gas furnace with a Class C circular chimney 12.7 cm (5 in.) in diameter on the air leakage of a two-storey house is as follows:

1. The air leakage value of the house with chimney uncapped is about 9% greater than that with chimney capped.

2. The air infiltration rate with the burner on continuously is 10% greater, on average, than it is with the burner cycling or off.

3. About 60% of inside air leaves the house through the chimney and the remaining 40% exfiltrates through the upper portion of the house envelope.

4. Switching from an electric furnace to a gas furnace results in a 50% increase in air infiltration with wind speeds lower than 3.5 m/s.

5. Stack action reinforced by the exhaust air through the chimney remains the dominant driving potential for infiltration with wind speeds up to 7 m/s and inside-to-outside temperature differences greater than 20 K.

REFERENCES

1. Malik, N. Field studies of dependence of air infiltration on outside temperature and wind. Energy and Buildings. 1 (3) 1977/1978.

2. Elkins, R.H. and Wensman, C.E. Natural ventilation of modern tightly constructed homes. Presented at the American Gas Association Institute of Gas Technology Conference on Natural Gas Research and Technology, Chicago, Ill., 1971.

3. Quirouette, R.L. The Mark XI research project - Design and construction. National Research Council of Canada, Division of Building Research, Building Research Note No. 131, 1978.

4. Shaw, C.Y. and Tamura, G.T. Mark XI energy research project - Air tightness and air infiltration measurements. National Research Council of Canada, Division of Building Research, Building Research Note No. 162, 1980.

5. Kumar, R., Ireson, A.D. and Orr, H.W. An automated air infiltration measuring system using SF_6 tracer gas in constant concentration and decay methods. ASHRAE Transactions, 85 part 2, 1979, pp. 385-395.

6. Bassett, M.R., Shaw, C.Y. and Evans, R.G. An appraisal of the sulphur hexafluoride decay technique for measuring air infiltration rates in buildings. ASHRAE Transactions, 87 part 2, 1981.

7. Shaw, C.Y. A correlation between air infiltration and air tightness for houses in a developed residential area. ASHRAE Transactions, 87, part 2, 1981.

8. Shaw, C.Y. and Tamura, G.T. The calculation of air infiltration rates caused by wind and stack action for tall buildings. ASHRAE Transactions, 83 part 2, 1977, pp. 145-158.

9. Tamura, G.T. The calculation of house infiltration rates. ASHRAE Transactions, 85 part 1, 1979, pp. 58-71.

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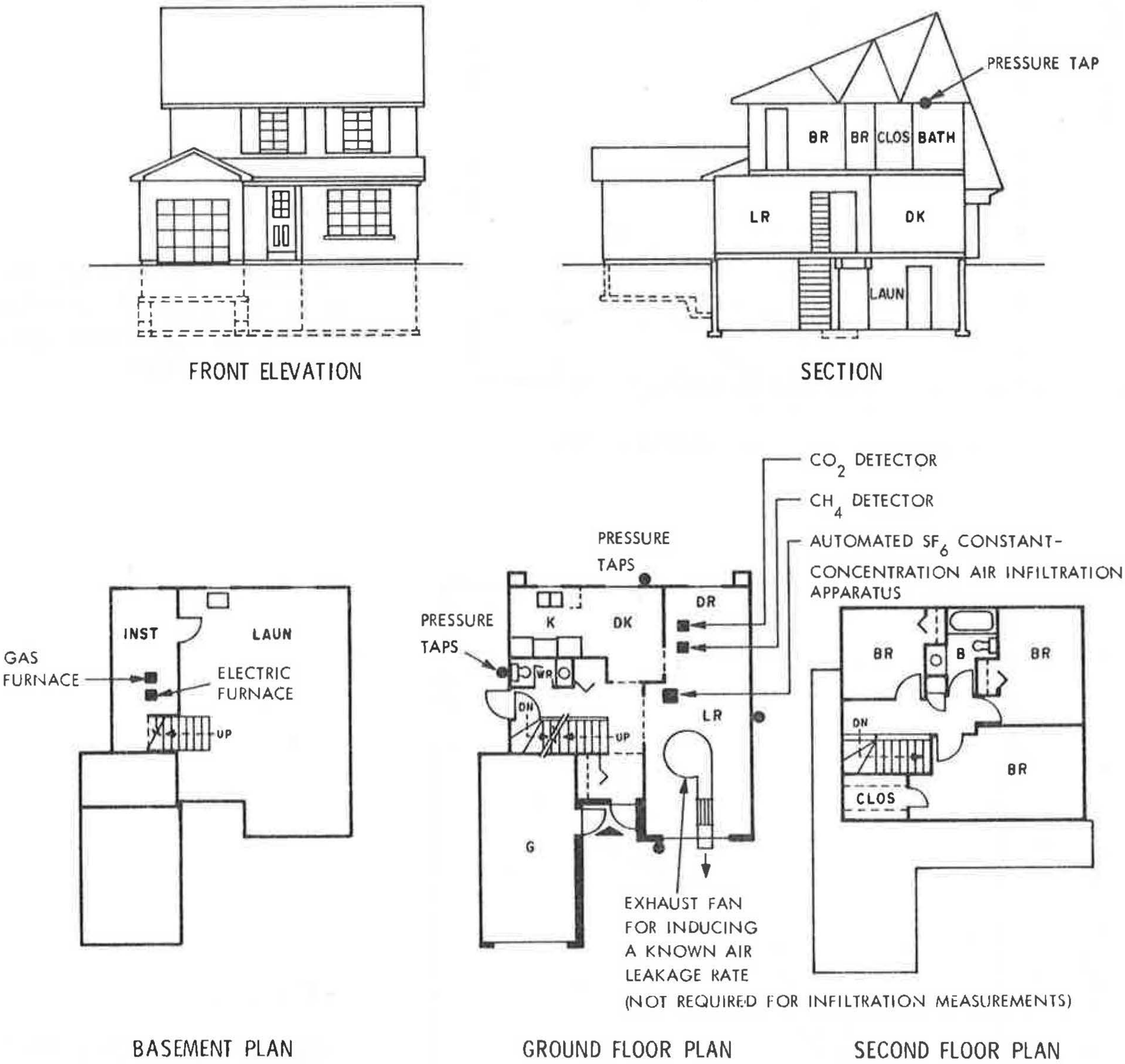

FIGURE 1

TEST HOUSE

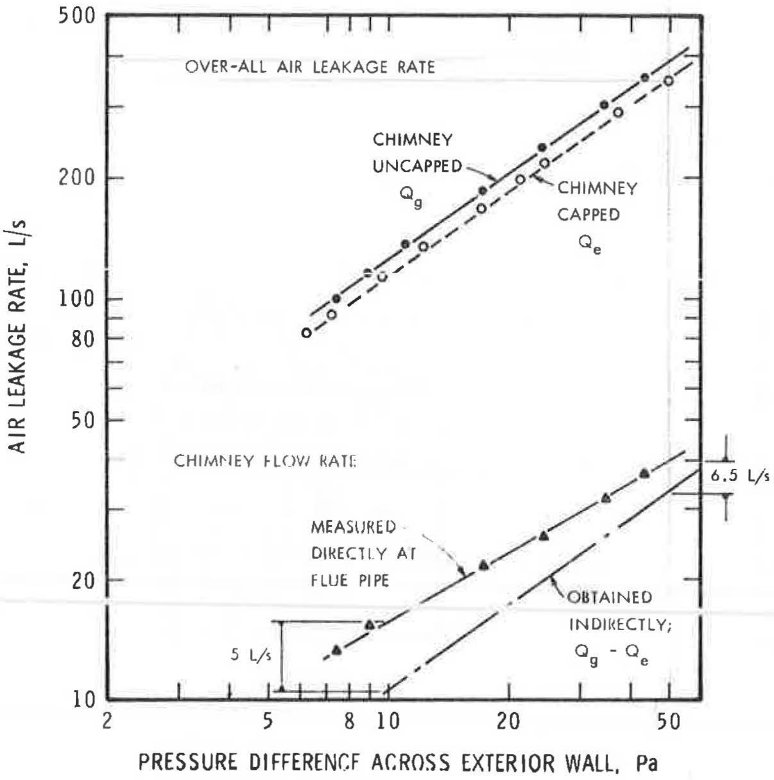

FIGURE 2

OVER-ALL AIR LEAKAGE RATES WITH AND WITHOUT CHIMNEY CAPPED AND AIR FLOW RATE THROUGH CHIMNEY

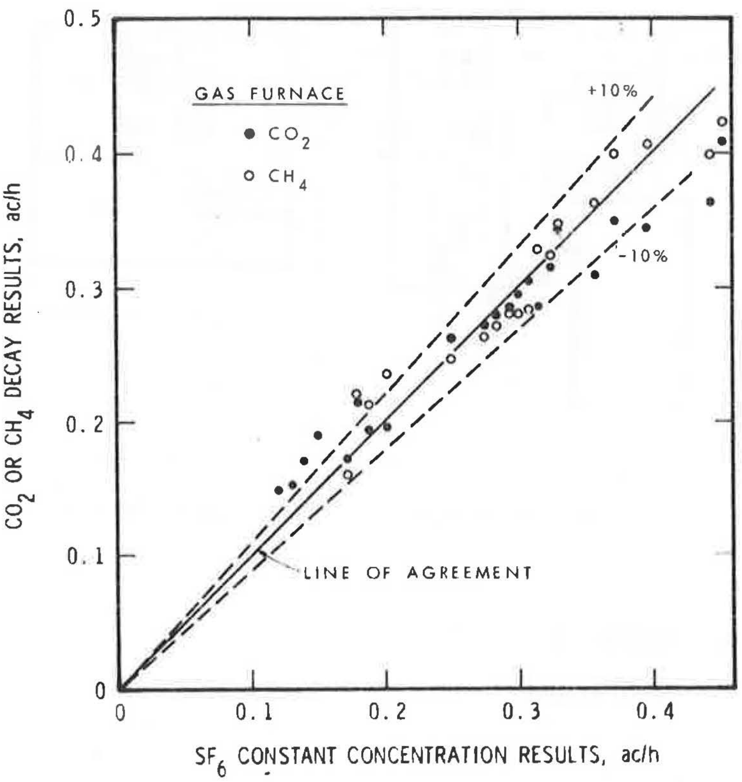

FIGURE 3

COMPARISON OF AIR INFILTRATION RATE BETWEEN SF_6 CONSTANT CONCENTRATION AND CO_2 OR CH_4 DECAY METHODS

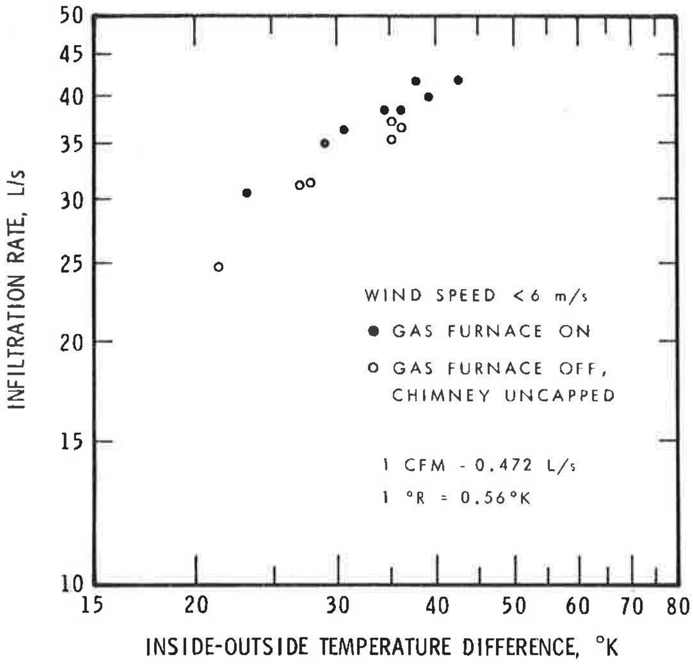

FIGURE 4

AIR INFILTRATION RATES UNDER VARIOUS MODES OF FURNACE OPERATION

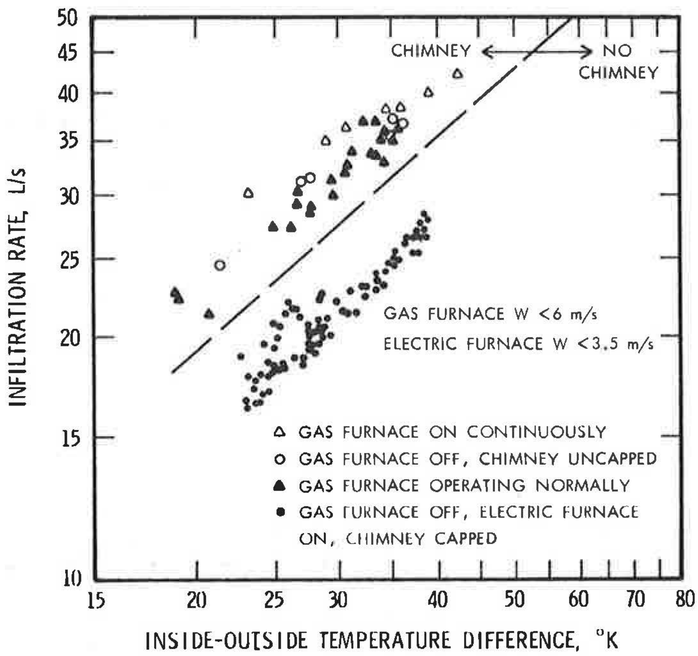

FIGURE 5

INFILTRATION RATES UNDER CONTROLLED AND NORMAL FURNACE OPERATION

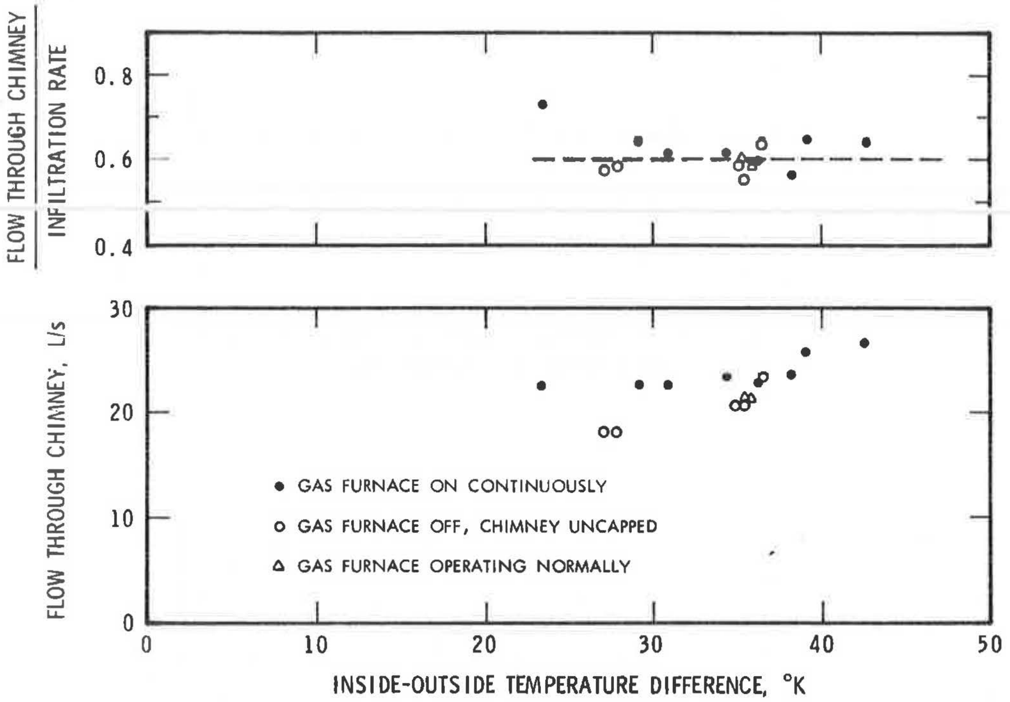

FIGURE 6

AIR FLOW RATE THROUGH CHIMNEY UNDER NATURAL CONDITIONS AND RATIO BETWEEN CHIMNEY EXHAUST RATE AND INFILTRATION RATE OF HOUSE

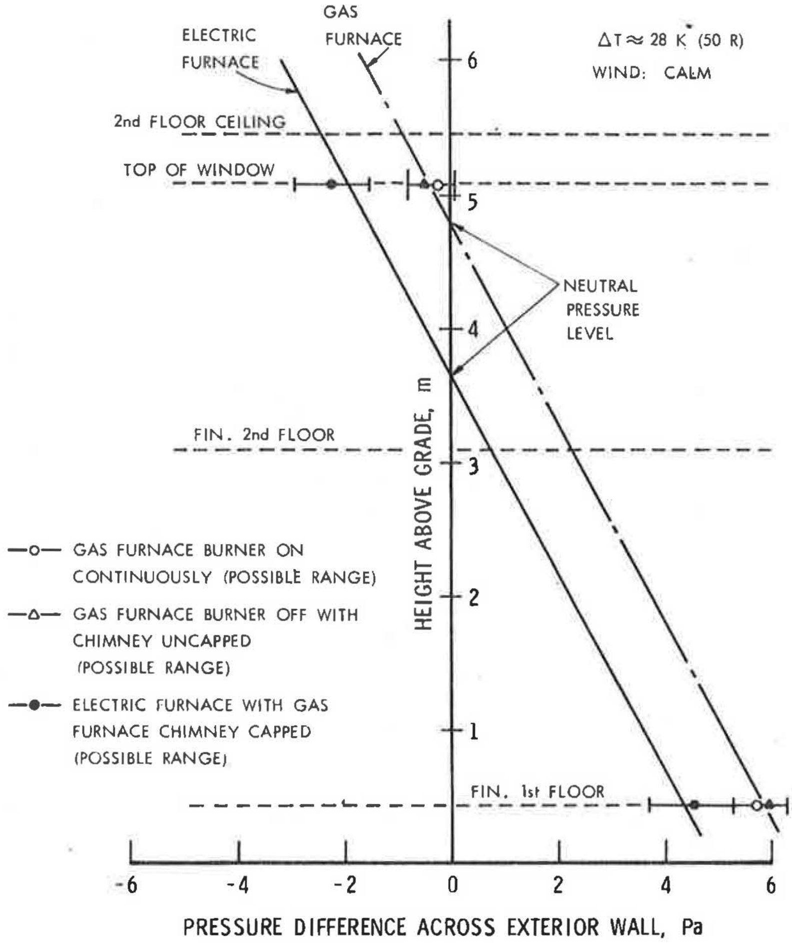

FIGURE 7

NEUTRAL PRESSURE LEVELS UNDER OPERATION OF GAS OR ELECTRIC FURNACE

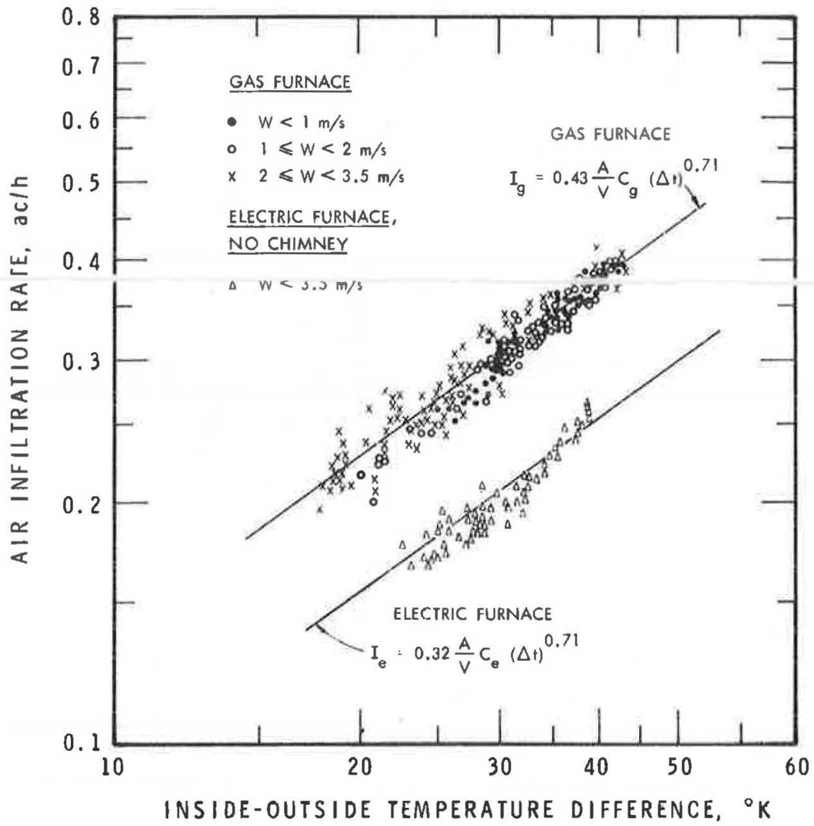

FIGURE 8

AIR INFILTRATION RATES FOR ELECTRIC AND GAS FURNACES UNDER LOW WIND

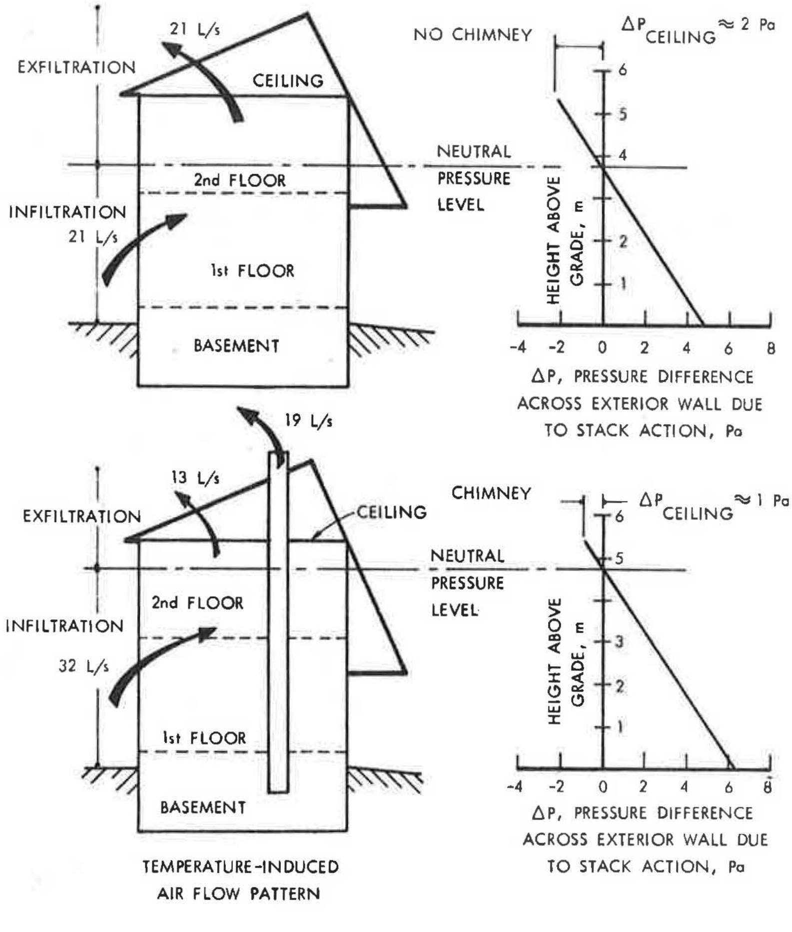

FIGURE 9

TEMPERATURE-INDUCED PRESSURE AND AIR FLOW PATTERNS UNDER OPERATION OF ELECTRIC OR GAS FURNACE FOR Δt = 28 K

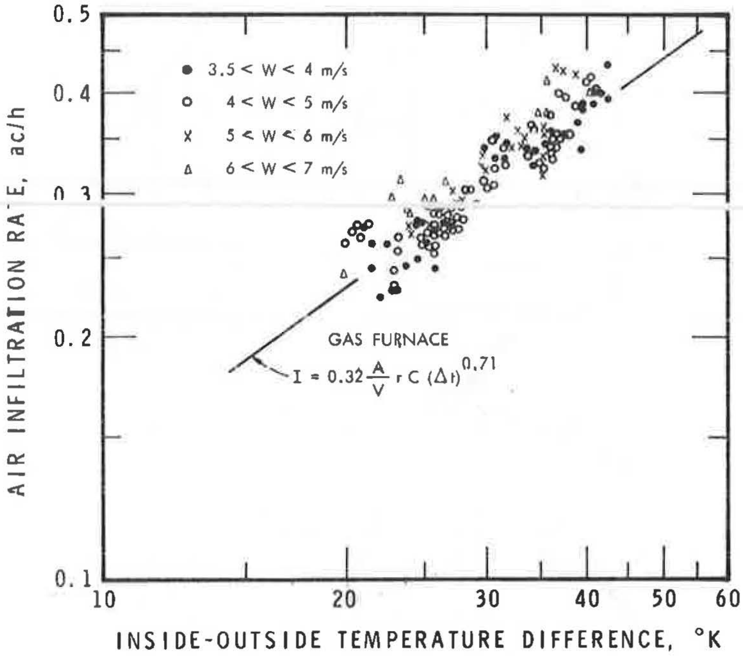

FIGURE 10

INFILTRATION RATES FOR GAS FURNACE UNDER MODERATE WIND