would be more pronounced for houses in more exposed locations than that of the Research Home.

In answer to Mr. Min's first question, the abscissa of Fig. 4 is indoor-outdoor static pressure difference measured at the first-story floor level. Thus, it would seem that at an indoor-outdoor pressure difference of 0.000 in. of water the neutral plane should be at 0 in. above the floor of the first story. Fig. 5 shows that an indoor-outdoor pressure difference of 0.000 in. of water represents a day having a low indoor-outdoor temperature difference and low wind velocity. Therefore, it would be expected that the pressure difference between different elevations in the house would be zero also, and the neutral plane could be assumed at any level.

Mr. Min is correct that there should be a minus sign in the equation $Vdc = nV\,dt$. While the minus sign was omitted in this equation, it apparently was considered in the solution of the equation.

Mr. Parsons expresses the opinion that the infiltration rates shown in Table 4, page 245 of the ASHAE GUIDE should be reduced. The authors feel that results obtained in only 2 houses are not sufficient to warrant changes in the material now published in THE GUIDE. They do agree that additional tests of this type are desirable and should be encouraged.

No. 1616

DESIGN AND PERFORMANCE OF A PORTABLE INFILTRATION METER

By CARL W. COBLENTZ* AND PAUL R. ACHENBACH**, WASHINGTON, D. C.

CALCULATION of the heating or cooling load of a structure usually includes a component for the load caused by the infiltration of outside air into the building. The computation of this portion of the heating or cooling load may be based on the length of the cracks around the doors and windows, an estimate of the workmanship involved, the design wind velocity, the degree of exposure to the wind, and the inside-outside temperature difference; or it may be based on a more general estimate of the number of air changes under design conditions. These methods are known to provide only approximations of the true air leakage, but they have been found useful in the absence of an acceptable method for direct measurement of air leakage. A portable infiltration meter was designed and constructed which utilizes the tracer-gas technique to determine the air change rate in different rooms or at different places in a building.

The air change rate of an enclosure is usually defined as the ratio of the hourly rate at which the air enters (or leaves) the enclosure to the volume of the enclosure. The rate of change in concentration of a tracer gas caused by infiltration of outside air can be expressed by the formula:

$$-V\,(dc/dt) = Kc \qquad (1)$$

where

V = volume of the enclosure.
c = concentration of tracer gas at time t.
K = average volume of air infiltration per unit time for the time interval.

When $c = c_0$ at $t = 0$, the solution of Equation 1 is as follows:

$$c = c_0\, e^{-Kt/V} \qquad (2)$$

or

$$Kt/V = \log_e (c_0/c) \qquad (3)$$

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Equation 3 shows that the number of air changes occurring during the time t is equal to the natural logarithm of the ratio of the tracer-gas concentrations at the beginning and at the end of this time interval.

One of the methods for measuring changes in concentration of a tracer gas is to observe the change of thermal conductivity of the mixture of air and the tracer gas. Since the thermal conductivity of helium is about 6 times that of air, small concentrations of helium in air cause a change in the thermal conductivity of the mixture that can readily be measured by means of a thermal conductivity meter. This technique was probably first used by Marley[1] in England for measuring air infiltration of buildings. Other tracer gases and other means of measuring change of concentration of these tracers have been proposed and some are in practical use. Some of these alternate tracer-gas techniques use the following gases and detecting instruments:

1. Ethane gas with an interferometer.
2. Radioactive tracer gas with a sensitive electrometer.
3. Hydrocarbon gas with an infrared gas analyzer.
4. Halogenated hydrocarbon gas with a photometer.
5. Hydrocarbon gas with a sensitive hygrometer to sense changes in the moisture content of samples after combustion of the hydrocarbon.

In designing the portable thermal conductivity meter (Fig. 1), or katharometer, simplification in the apparatus and procedure for making infiltration measurements by the tracer-gas method was sought by applying the following principles:

1. The sensing elements were located in the spaces where the infiltration rate was to be measured, and natural convection moved the mixture of tracer gas and air through them, thus all sensing elements had the same lag in response. The sensing elements were connected to the measuring console with cables.
2. The change in tracer-gas concentration was observed rather than the absolute value since only the change in concentration is required to determine infiltration rate.
3. A saturater was not required for the gas sample since the change of humidity at a given station during a 1-hour infiltration test would usually be small and because absolute values were not being measured.

Although the thermal conductivity of hydrogen is about 7 times that of air, whereas that of helium is only 6 times as high as air, the use of helium is preferable for infiltration measurements because of the explosion hazard of hydrogen. However, when helium is not available, the use of a hydrogen concentration of 0.4 percent does not introduce an acute danger, as the minimum explosive concentration of hydrogen is about 4.1 percent. Hydrogen should not be used when the house is heated with a hot air furnace, since the hydrogen would be slowly oxidized as the hydrogen-laden air was recirculated between the furnace and the living space, and thus introduce a false indication of decay.

DESIGN OF THE SENSING ELEMENTS

The thermal conductivity cells consist of brass blocks $1 \times 1\frac{3}{4} \times 3\frac{1}{4}$ in. with two $\frac{5}{8}$-in. ID cylindrical cavities, symmetrically arranged. Carefully matched thermistors, of the bead type on a glass probe, are cemented in the cavities with

[1] The Measurement of the Rate of Air Change, by W. G. Marley (*Journal of the Institution of Heating and Ventilating Engineers*, Vol. 2, 1935).

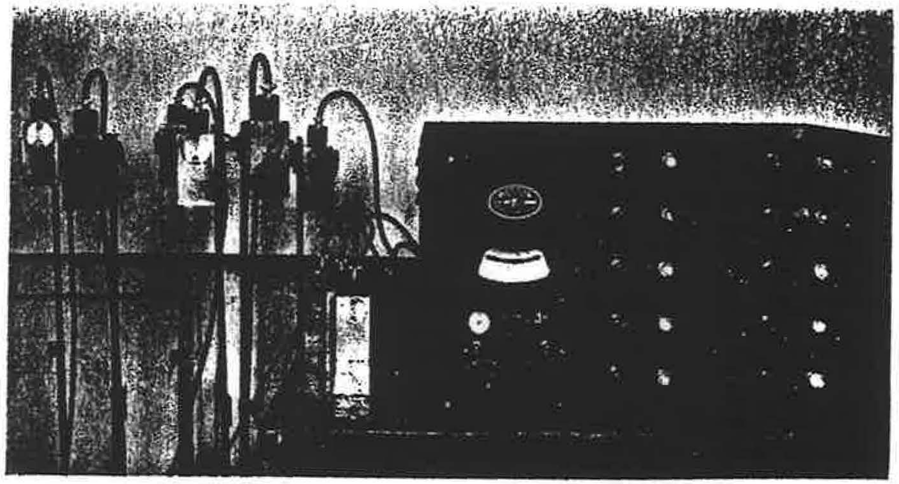

FIG. 1—VIEW OF THE NEWLY DESIGNED PORTABLE INFILTRATION METER

epoxy-type cement. One cavity is hermetically sealed and the other one contains two $\frac{3}{64}$-in. holes each at the top and at the bottom of the cavity to permit natural convection air movement, induced by the heated thermistor. The 2 thermistors are connected in series and are heated with 120 milliwatts to approximately 200 F. This heat input produces a rise in temperature of the brass blocks of less than 1 deg above room temperature. The time constant for the response of the sensing elements was found to be about 76 sec.

Both cavities provide equivalent heat absorbing surfaces. The coefficients of heat transfer by radiation and convection are the same for both cavities, whereas the coefficient of heat transfer by conduction is higher in the cavity which contains the helium-air mixture. Therefore, the thermistor in this cavity will be slightly cooler than the one in the sealed cavity. Small changes in the temperature of the thermistor produce a considerable change of its resistance, such that a change of helium concentration can be determined by observing the difference of the resistance of the 2 thermistors. By installing the 2 thermistors in a Wheatstone bridge circuit, the unbalance produced by presence of helium in 1 cavity can be used as a measure of helium concentration.

DESIGN OF THE MEASURING APPARATUS

The control cabinet housed the bridge circuits and control equipment for 10 sensing elements and was designed for 115-volt a-c operation. Each probe had a polarized outlet and was connected with the cabinet by means of a 3-conductor shielded cable. A schematic wiring diagram of the apparatus showing the power supply and metering circuit and one of the 10 probe circuits is shown in Fig. 2. Two 200-ohm resistors, R_3 and R_5, formed the fixed legs of the Wheatstone bridge for each test probe. Each bridge circuit was balanced with two 10-ohm variable resistors, R_4 and R_6, connected in parallel. One of them, R_4, was connected in series with the fixed 10-ohm resistor, R_7, to provide a coarse and fine adjustment over a rather wide range.

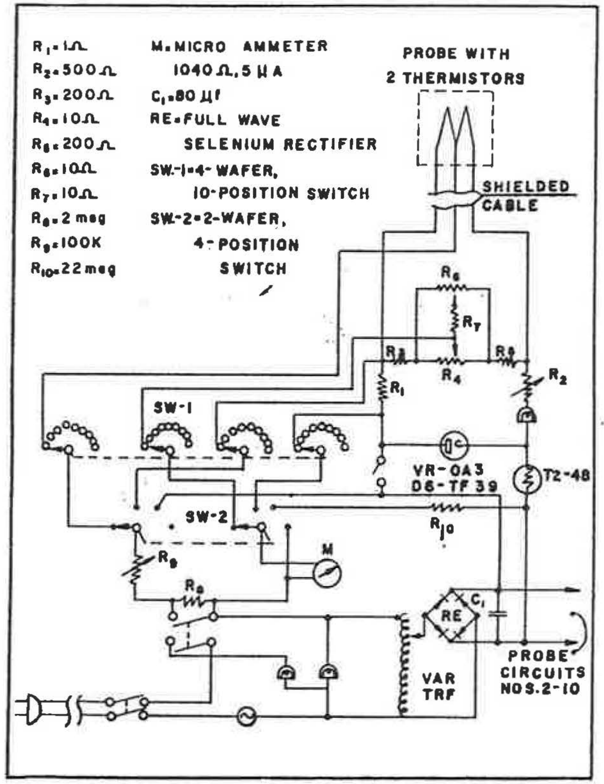

FIG. 2—SCHEMATIC WIRING DIAGRAM OF POWER SUPPLY, THE METERING CIRCUIT AND ONE OF THE PROBE CIRCUITS

The thermistors in each probe were selected to have a minimum difference in resistance over a current range from 12 MA to 22 MA. However, it was found that due to the aging of the thermistors and resistors, and to the accumulation of certain gases produced by the setting of the cement in the sealed cavity, an appreciable balancing range was necessary for the bridge circuit.

A filtered 105-volt direct current supply for each probe circuit was obtained by installing a variable transformer in series with the a-c side of a full-wave selenium rectifier. This variable transformer also compensates for aging of the rectifier and for changes in the output voltage caused by using different numbers of probes.

A constant-wattage network is required for supplying the thermistors. Line voltage fluctuations were reduced by means of a voltage regulator tube, VR-OA3, with a variable resistance tube D6-FT39, as the voltage-dropping resistor. With a proper variable resistor, R_2, and a switchboard bulb, T2-48, operating as pilot light as well as a voltage-dropping resistor, as shown in Fig. 2, fluctuations of the a-c supply voltage of ±25 percent produce a change in the bridge heater current of less than 0.4 percent. The individual current control for each bridge circuit is necessary because the thermistors require a higher initial voltage to bring them up to temperature.

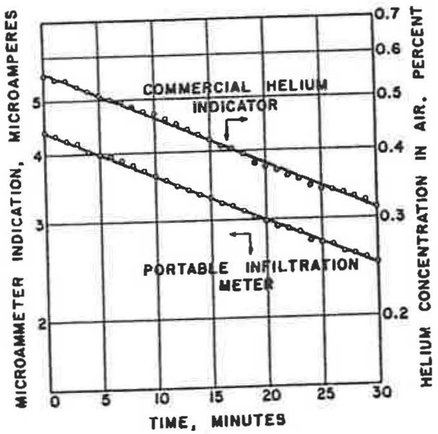

FIG. 3—DECAY CURVES OF PORTABLE INFILTRATION METER AND COMMERCIAL HELIUM INDICATOR

A 1040-ohm microammeter, M, with full scale deflection at 5 micro-ampere current is used as an indicator. Two series-connected selector switches and the necessary shunt and voltage-dropping resistors permit the measurement of the progressive unbalance of the Wheatstone bridge circuit of each probe, the heating current of each probe, the d-c output voltage of the rectifier, and allow shunting of the meter when not in operation. A green pilot light indicates that the line voltage is supplied to the variable transformer and a red pilot light shows that the 2-megohm safety resistor, R_8, in series with the indicating meter, has been shunted.

PERFORMANCE

When air infiltrates into a room at a steady rate, the tracer-gas concentration decreases along a logarithmic curve as shown by Equation 3. Plotted on semi-logarithmic paper the decay curve, then, must be a straight line. A test was made under controlled conditions in the Test Bungalow at the National Bureau of Standards where the outside air movement and inside and outside temperatures were maintained constant. Under such steady conditions the forces producing infiltration should be constant and the rate of air leakage should also be constant. Observations were made on both the portable infiltration meter described herein and a larger commercial helium indicator which employed a sampling system and a pump. The inlet of the sampling line of the commercial instrument was installed adjacent to the probe of the portable meter and the first readings of both instruments were taken at the same time. The observed readings for both instruments are plotted in Fig. 3. The straight lines shown are those best fitted to the observed data based on the least mean squares of the deviations. The straight lines show that both instruments were indicating a logarithmic decay in the helium concentration. The infiltration rate indicated in Fig. 3 by the commercial instrument is 3.23 air changes per hour, whereas that indicated by the portable infiltration meter is 3.19 air changes per hour.

The effect of a change in relative humidity around the sensing probe was determined by measuring the change in the microammeter indication for a known change in relative humidity. For this purpose a probe was allowed to come to steady-state conditions with no helium in the air for an ambient relative humidity of 28 percent. The probe was then placed in a sealed can into which an ample amount of calcium chloride crystals had been placed to reduce the relative humidity to approximately 0.5 percent. The microammeter showed a change in deflection of 0.20 microamperes, indicating a higher infiltration rate than the true value. It subsequently returned to its original position after removing the desiccant and admitting room air into the can.

On the basis of this test, the error in the computed air-change rate caused by a 1 percent change in relative humidity during a 1-hr test period when the apparent infiltration rate was 1 air change per hr and the initial helium concentration caused a 5.0 microampere scale deflection would be 0.4 percent. The error in computed infiltration rate caused by a unit change in relative humidity should increase with temperature and with decreasing infiltration rate, but would probably be very little affected by the relative humidity level.

A change in the room temperature during the test period would have no effect on the meter reading, if the 2 thermistors in a probe were perfectly matched with respect to their temperature-resistance characteristics over the range of temperature used. Moderate care, but not the ultimate possible, was used in matching the thermistors for the prototype instrument. A test of one of the sensing probes showed that a deflection of 0.35 μA was caused on the indicating meter by a temperature change of 35 deg, *i.e.*, the sensitivity to temperature was 0.01 μA/F.

Under the same test conditions cited for the investigation of sensitivity to relative humidity, the error caused by a 1 deg temperature change would be 0.3 percent. Logically, a standard for matching the thermistors would have to be established if the prototype infiltration meter were put into commercial production.

OPERATIONAL PROCEDURE

For infiltration measurements, the console is placed at a central location in the building and a probe is mounted on a tripod near the middle of each room about 3 ft above the floor. After adjusting the heating current for each probe, at least a ½-hr period should be allowed for all components to warm up to a steady state condition. The bridge circuits are then balanced by adjusting the balancing resistors so that the meter reads zero for each probe used in the test. Helium in the amount of approximately ½ of 1 percent of the total volume of the space is then introduced either directly into the rooms and thoroughly mixed with the room air by using desk-type fans or, where a forced air heating system is in use, the helium is fed into the blower intake and distributed into the rooms through the duct system.

Under some conditions of usage of the infiltration meter, the corrections required to account for changing ambient humidity and temperature during a test could be determined by observing the drift of the microammeter during a rating period preceding the introduction of helium into the space. This method would probably be useful only when the changes in humidity and temperature followed a steady trend during the rating period and the test period.

The apparatus described can be used to study air movement between the different enclosed spaces in a house, such as basement and living quarters, first floor and second floor, living quarters and attic, or between outdoors and any of these spaces. It is sufficiently portable to use in field studies of infiltration in different types of building construction without great inconvenience to the occupants of the building.

No. 1617

PERFORMANCE TESTING OF ROOF VENTILATORS

By J. J. WANNENBURG*, PRETORIA, SOUTH AFRICA

APPLICATION of natural draft roof ventilators to industrial buildings has made apparent the necessity of developing a method whereby the performance of these ventilators may be conveniently tested. The purpose of such tests would be to obtain data to serve (*a*) as a basis for the comparative rating of ventilators, and (*b*) for the prediction of ventilator performance under practical conditions. The investigations, of which the results and conclusions are given here, were directed towards development of a test method which could be applied with expedience to the routine testing of ventilators.

Essentially, 3 factors contribute to the movement of air through a natural draft roof ventilator, viz:

1. Acceleration of air in the vicinity of the ventilator head causes a depression which results in the extraction of air from the building. This is the ***aspiration effect***. Its magnitude is a function of ventilator shape, and of windspeed and wind direction at the ventilator.

2. If the outside air is cooler than air inside, the warmer air will move through the ventilator to the cooler outdoor environment. This is the ***chimney*** or ***stack effect***.

3. Generally, in the case of a building exposed to wind, a positive pressure exists over the windward walls, and a negative pressure over the roof and leeward walls[1]. If there are openings in the roof and walls, movement of air results, inward through the windward openings and outward through the leeward and roof openings[2]. Thus there is an additional extraction of air through a roof ventilator, and this flow does not depend upon ventilator shape, but upon wind condition, the resistance to flow of the ventilator, and its position on the roof. In addition, the pressure causing the flow depends on the number and size of other ventilating openings.

This effect is here referred to as the ***forced draft effect***, and it must be noted that it is not present during the testing of a ventilator in an open jet wind tunnel, the static

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[1] Exponent numerals refer to References.

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