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PERFORMANCE OF KATHAROMETER FOR AIR INFILTRATION MEASUREMENT

by

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PREFACE

It is often important to be able to determine the air changes in any occupied space in a building which result from natural or induced air leakage. The direct measurement of this infiltration rate is difficult. The most acceptable method at present involves the use of helium as a tracer gas and measurement of helium concentrations using a katharometer. Some experiments on the techniques and instrumentation are now reported.

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The tracer gas technique is a useful method for determining the ventilation rate of an enclosure whose boundary contains a number of openings that are not well defined. For this reason several investigators have used this technique to determine the ventilation characteristics of houses where air infiltration takes place through cracks and interstices formed by the doors and windows located in the outside walls. This technique involves the use of some tracer gas such as helium, hydrogen or carbon dioxide whose thermal conductivity differs substantially from that of air. Tracer gas is introduced inside an enclosure and allowed to decay with the natural ventilation of the enclosure. The decay is measured with a katharometer which is sensitive to the changes in the thermal conductivity of the tracer gas-air mixture. The katharometer usually contains two heated elements, one exposed to the tracer gas sample and the other enclosed in a standard gas and forms a part of a Wheatstone bridge circuit.

The relationship between the concentration of the tracer gas and the ventilation rate may be expressed by:

$$-Vdc = Kcdt.$$

Integration of this equation gives

$$\frac{K}{V} = \frac{\ln C_1/C_2}{t_2 - t_1} \tag{1}$$

where K = infiltration rate
V = volume of an enclosure
C = tracer gas concentration
t = time
$\frac{K}{V}$ = air change rate.

In the above equation it is assumed that the tracer gas concentration is uniform over the whole volume of the enclosure at all times, and that the air and the tracer gas leave the boundary in the same manner. Since the equation involves the ratio of the tracer gas concentration, any quantities proportional to the tracer gas concentration may be used to determine the ventilation rate. Therefore the calibration of these quantities with the absolute tracer gas concentration is not required. With the use of the katharometer for infiltration measurement, it is essential that the output from its bridge circuit be proportional to the tracer gas concentration.

With helium as the tracer and with the katharometer designed by Coblentz et al of the National Bureau of Standards (1), a series of calibration tests was conducted in the laboratory to check the validity of the above assumptions and to assess the performance of the katharometer. A design modification was made on the katharometer which will be described later in this report. The katharometer was calibrated by introducing a known quantity of air into a large box and determining the ventilation rate using the tracer gas technique. The result of this investigation is herein reported.

PRINCIPLE OF KATHAROMETER

A katharometer consists of two elements mounted in two separate cells in a metal block to maintain equal temperatures in the two cells. One element is exposed to the gas mixture to be measured and the other is enclosed in a standard gas. With the addition of two fixed resistors, a Wheatstone bridge circuit is formed and the potential difference across the bridge is measured to determine any changes in the conductivity of the gas surrounding the sensing element. If the heated elements are perfectly matched and the gases surrounding the elements are similar, the potential difference across the bridge remains constant with changes in the input current or the temperature of the block.

The temperature, and hence the resistance of the heated element is dependent on the heat transfer that takes place within a cell. A katharometer is designed so that the heat transfer from the element occurs mainly by conduction. This is achieved by locating the heated element vertically and co-axially in a tube with the tube diameter made small enough (less than 1 cm) to restrict the convection currents within it. Daynes (2) refers to the work by Langmuir, Lenher and Taylor which demonstrated the existence of a stationary layer of air surrounding the heated wire. Because the gas pressure does not affect thermal conductivity but affects natural convection, the resistance change of the heated element with a change in pressure would indicate that the heat loss by natural convection may be a significant part of the total heat loss. Treating the case of the heated wire in a tube, it is shown by Daynes that the temperature rise of the element is inversely proportional to the conductivity when the rise is small. For a heated element with a negative temperature coefficient of resistance, the resistance change of the element would then be directly proportional to the conductivity.

It is also shown that for a small change in the resistance of the sensing element, the potential difference output from the bridge is proportional to this change. Therefore, with a low tracer gas concentration, the change in the concentration is proportional to the bridge output.

DESCRIPTION OF APPARATUS

The katharometer designed by the National Bureau of Standards (1) consists of two matched thermistors located in the two cylindrical cavities of a brass block. The size of the cavity is 1 3/4 by 5/8 in. in diameter. One thermistor (standard) is completely enclosed and the other thermistor (sensing) is located inside the cavity with four 1/32-in. diameter holes in the brass block, two at the top and two at the bottom of the cavity, to permit access of the sample gas by convection and diffusion. The two thermistors together with two 15 K ohm resistors are installed in parallel to form a Wheatstone bridge circuit. The imbalance produced by the sensing thermistor with changes in the helium concentration is recorded on a single-point millivolt recorder.

Because it was observed that the performance of the katharometer was affected by changes in the barometric pressure, its design was modified to ensure a constant difference between the pressures in the two cavities containing the thermistors (Fig. 1). The standard thermistor was enclosed in a glass envelope with a small open tube at the bottom end. This tube was filled with light oil to obtain a movable seal. By means of this seal, the pressure difference represented by the column of oil is kept at a constant value with changes in the barometric pressure.

Although the two thermistors are carefully matched, the deviation in their characteristics cannot be entirely avoided; it was found necessary to control the katharometer temperature and the current input. A simple temperature control box was devised to obtain a constant temperature over a short period of time. This box whose dimensions are 12 by 12 by 14 in. was fabricated from copper sheet metal and covered with 2-in. foam insulation. The box was filled with water to act as a constant temperature medium. The katharometer was secured to the side of the box ensuring good thermal contact. By means of a small diaphragm pump, the sample gas was passed through a copper tube inside the water-filled container to a cavity formed by the katharometer and its plastic cover. The cover was provided with a hole to permit the gas to escape into the surrounding air. To control the input current to the thermistors, two fixed resistors of 200 ohms and 15 K ohms were added in parallel to the Wheatstone bridge circuit (see Fig. 2 for complete circuit). The balance across the circuits containing the standard thermistor and the 200-ohm resistor was monitored with the vacuum tube voltmeter. Any unbalance caused by the resistance change in the standard thermistor due to the drift in the current input was corrected by adjusting the dc voltage supply.

To eliminate possible error due to the variation in humidity, the sample gas was passed through a drying bottle containing calcium chloride before being pumped to the katharometer.

A large box designed for window air leakage measurements was adapted to serve as an enclosure in which the ventilation rates were determined. This box, with an internal dimension of 4 by 8 by 8 ft, is made in two halves supported on castors with two access doors and two observation windows. A measured quantity of air is piped to an opening in the box from a service line to obtain a predetermined ventilation rate in the enclosure. The pressure developed by this air input causes the air to exfiltrate through the interstices formed by the mating surfaces of the box and the access doors, and through other extraneous cracks.

PERFORMANCE TESTS

In order to develop a reliable apparatus and technique for determining ventilation rates, a series of tests was conducted to investigate (i) the effect of the variation in the ambient air temperature and pressure and, also, of the variation in the current on the stability of zero, (ii) the accuracy of the ventilation rates indicated by the katharometer as employed in the tracer gas method.

The katharometer was operated with 300 dc volts applied across the bridge with a current of approximately 22 ma for each thermistor. The unbalance between the circuit arms of the standard thermistor and the 200-ohm resistor was kept within $\pm$ 0.2 mv. Approximately one hr was required for the katharometer to approach a thermal steady-state condition so that the zero position could be established on the millivolt recorder. To establish a steady zero position approximately 2 1/2 hr of warm-up time was required.

The amount of helium required to obtain a maximum of 70 to 80 per cent full-scale reading (10 mv) on the recorder was 1 to 2 per cent by volume depending on the rate of air change in the box. The quantity of helium released inside the enclosure was measured with a wet test gas meter. For equal maximum readings on the recorder, a larger volume of helium was required at higher ventilation rate.

AMBIENT AIR TEMPERATURE EFFECT

With the katharometer circuit as shown in Fig. 2 and without any temperature control, the zero position on the recorder fluctuated with changes in the ambient air temperature. For a 1-deg change in the ambient air temperature, the zero position drifted approximately 3/4 of a millivolt. Even with ambient air temperature fluctuations within a narrow range, the zero position is erratic and difficult to ascertain. To overcome this effect, the katharometer was mounted on a temperature control box as previously described. With this arrangement the surface temperature of the katharometer was recorded with a thermocouple. Over a 2 1/2-hr period the katharometer temperature varied 0.1°F with 1°F variation in the ambient air temperature. This resulted in much improved stability of the zero position. It can be expected that during a normal test period the katharometer temperature will remain constant within this range.

CURRENT EFFECT

With the temperature-controlled katharometer, the katharometer circuits with and without current control were tested to determine their effectiveness on maintaining the zero stability. Without any current control the zero position drifted 0.8 mv during 1 1/4 hr. By maintaining a balance within $\pm$ 0.2 mv between the circuit arms containing the standard thermistor and the 200-ohm resistor to obtain constant input current, the drift in the zero position was reduced to 0.12 mv. The katharometer circuit was also checked with the standard thermistor replaced with a 200-ohm resistor, and without any current control. During a 1/2-hr period the zero position drifted by 1.3 mv. It can be seen that the change in the zero position due to the variation in the input current is reduced with matched thermistors in the bridge circuit; this is further reduced with careful control of the input current.

PRESSURE EFFECT

To check the barometric pressure effect, the katharometer was subjected to various pressures and a change in the zero position was noted. With the cavity of the standard thermistor sealed with plasticine in the open tube, the katharometer was placed inside the calibration box and the pressure inside the box was brought up to 10 mm of water with increments of 2 mm of water. At 10 mm of water, the zero position drifted 0.2 mv, and after the pressure was released, the original zero position was restored. The test was repeated with oil in the open tube of the katharometer. No change in the zero position was indicated. This demonstrated the effectiveness of the oil seal to counter the effect of the change in the barometric pressure on the zero position. The pressure tests have also indicated that the resistance and, hence, the temperature of the thermistor is sensitive to changes in the gas pressure and, therefore, the heat transfer in the cavities of the katharometer is due in part to natural convection. With the standard thermistor enclosed in a glass envelope, the heat transfer coefficients in the two cavities are somewhat different. This would have the same effect as a mismatch in the temperature sensitivity of the two thermistors.

CALIBRATION TESTS

To determine the accuracy of the katharometer as employed in the tracer gas technique, the ventilation tests were conducted on the large box previously described. By introducing a constant rate of air flow measured with a variable area flowmeter, a known ventilation rate of the box was obtained. The helium gas at a pressure of 10 psi was injected into the box through a plastic tube. With a small diaphragm pump, a continuous sample of helium-air mixture was drawn through a tube to the drying bottle and then to the katharometer located outside the calibration box. The unbalance of the bridge circuit caused by the changes in the helium concentration was recorded on the millivolt recorder. From the helium decay curve, the ventilation rate was computed and compared with the ventilation rate calculated from the rate of air input.

Since the sample gas flow rate may affect the performance of the katharometer, the flow rate was varied from 460 to 2300 ccm. This did not alter the zero position on the recorder. There was no marked difference in the results of ventilation tests run with sample gas flow rates of 1050 and 2300 ccm. The majority of the ventilation tests were run with a sample gas flow rate of 2300 ccm which gave approximately 200 air changes per hr inside the cover of the katharometer. At ventilation rates of 8 and 10 air changes per hr in the calibration box, readings were recorded with the katharometer inside the calibration box and exposed directly to the helium-air mixture; the ventilation rates obtained were the same as those obtained with the sample gas pumped to the katharometer. It can be concluded that with the sample gas flow rate used for the calibration test, the helium decay characteristics in the calibration box and in the vicinity of the katharometer are the same.

Because helium is much lighter than air, it was thought that due to stratification, the helium-air mixture in the box might not be homogeneous. Four sampling points were located near the corners 4 ft above the floor level and the helium-air mixture was circulated with a table fan. Later tests conducted without the table fan and with a single sampling point located near the floor level gave similar ventilation rates. This indicated that due to the high diffusion rate of helium, the helium-air mixture was essentially homogeneous in the calibration box as it was assumed in the derivation of the equation for computing the ventilation rate. To determine the house ventilation rate, it is probably necessary to circulate the air mechanically to ensure a homogeneous mixture.

Ventilation tests were conducted with air flow rates of 1/2 to 10 air changes per hr. The results of these tests are shown in Fig. 3; a typical helium decay curve is shown in Fig. 4. Good agreement is obtained with the air change rate up to 4 air changes per hr. Above this rate, the air change rate determined with the katharometer is much lower than the actual rate. This discrepancy is probably caused by the lag of the katharometer which is dependent on the volume of the cell and the rate of interchange of gas inside and outside the cell through the four small holes. This interchange of gas takes place by diffusion and by stack effect due to the difference between the cell air and the outside air temperature. It would appear that below 4 air changes per hr, the helium decay rate is low enough that the helium concentration of the sample gas inside the cell is essentially the same as that inside the calibration box. Above 4 air changes per hr, however, due to the lag of the katharometer, the sample gas inside the cell is no longer representative of the gas inside the box; this condition is aggravated at a higher air change rate. It is likely that this would also be true for the case of similar rates of increase of helium concentration. Rapid increase in the helium concentration occurs immediately after helium is injected, reaches a peak and then begins to decay due to the ventilation in the enclosure. Because of the high rate of change, it is probable that the katharometer detects helium concentration lower than the actual concentration during this period.

FIELD VENTILATION TEST

To determine the house ventilation rate and to investigate the relevant factors that affect the ventilation rate, a series of tests was conducted in the field with the katharometer. By injecting the helium in the supply air duct of the forced air heating system, the helium was circulated throughout the house. With the circulation fan operating continuously, a sample helium-air mixture was drawn from the return air duct to the katharometer and the subsequent helium decay characteristics were recorded.

The ventilation rates of the two bungalows investigated during the winter and summer trials were found to be well under 1 air change per hr. At these rates, the time for the helium to decay completely took several hours so that the test was terminated before the final zero position was obtained. Although precautions are taken to obtain a stable zero position prior to the test, it is possible for the zero position to drift during the test causing an error in the ventilation rate measured. By drawing outside air to the katharometer, the zero position at the end of the test may be obtained and a linear zero drift during the test may be assumed. Care must be taken to ensure that the temperature and the background carbon dioxide content of the sample outside air are not substantially different from that of the room air.

In the calculation of the air change rate it is assumed that the helium leaves the boundary through cracks and interstices around a house in the same manner as the exfiltration air. It is quite probable that part of the helium leaving the boundary is due to diffusion through the exterior walls and ceiling. Although the amount of diffusion of helium to outdoors is relatively small, it may be significant at a low ventilation rate. The decay of helium concentration may also be partly due to diffusion of helium into furniture, cupboards, closets and walls of the house. Ventilation tests conducted by Bahnfleth et al (3) with cupboards and closet doors opened and closed indicated no change in the ventilation rates. Because of the interchange of helium in a room and enclosed spaces, the effect of furniture, closets, interior wall panels, etc. on the decay rate is probably negligible.

CONCLUSION

Because the katharometer is sensitive to changes in the ambient air temperature, humidity, barometric pressure and current input, provision should be made to maintain constant operating condition. As indicated by the sensitivity of the katharometer to changes in pressure, heat transfer by convection takes place in the cavity enclosing the thermistor. Because the diameter of the cylindrical cavity is well over 1 cm, the heat transfer in the cavity probably occurs mainly by natural convection. The calibration tests have shown that the katharometer as used in the tracer gas technique gives reliable results for ventilation rates from 1/2 to 4 air changes per hr. This would imply that the bridge output is proportional to the helium concentration and, hence, proportional to the thermal conductivity of the helium-air mixture. Above 4 air changes per hr, due to the lag of the katharometer, the katharometer records ventilation rates lower than the actual values.

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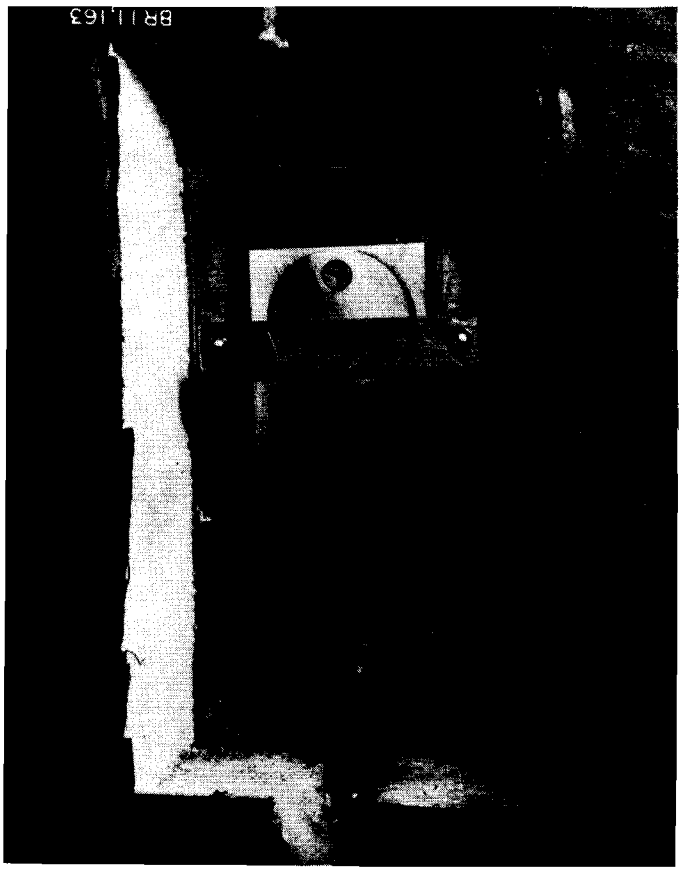
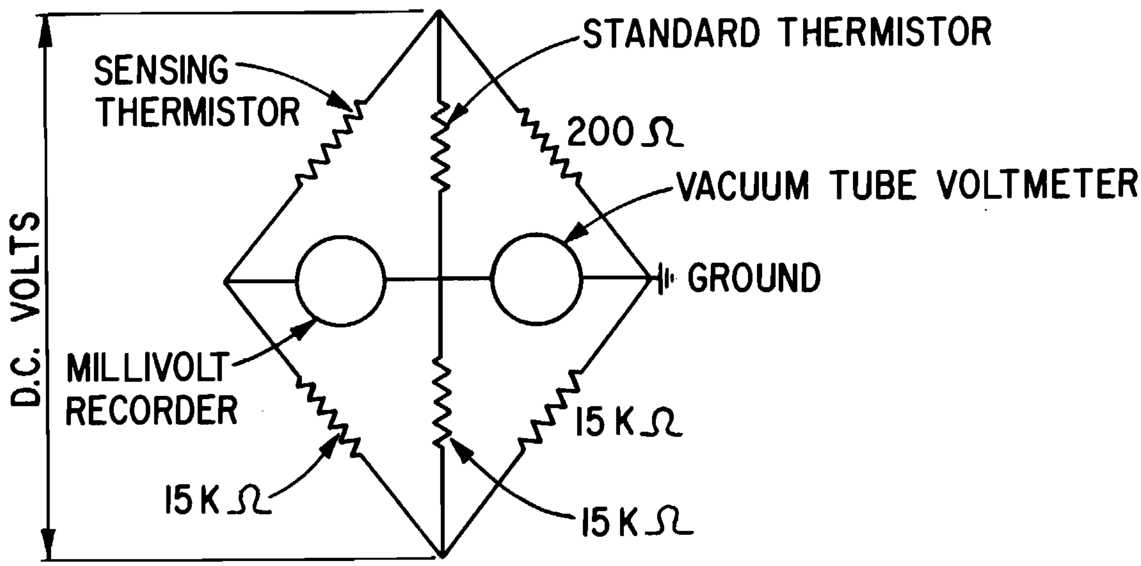


Figure 1

View of the Katharometer Attached to the Temperature Control Box



NOTE:

KATHAROMETER LEADS SHIELDED

FIGURE 2

KATHAROMETER CIRCUIT DIAGRAM

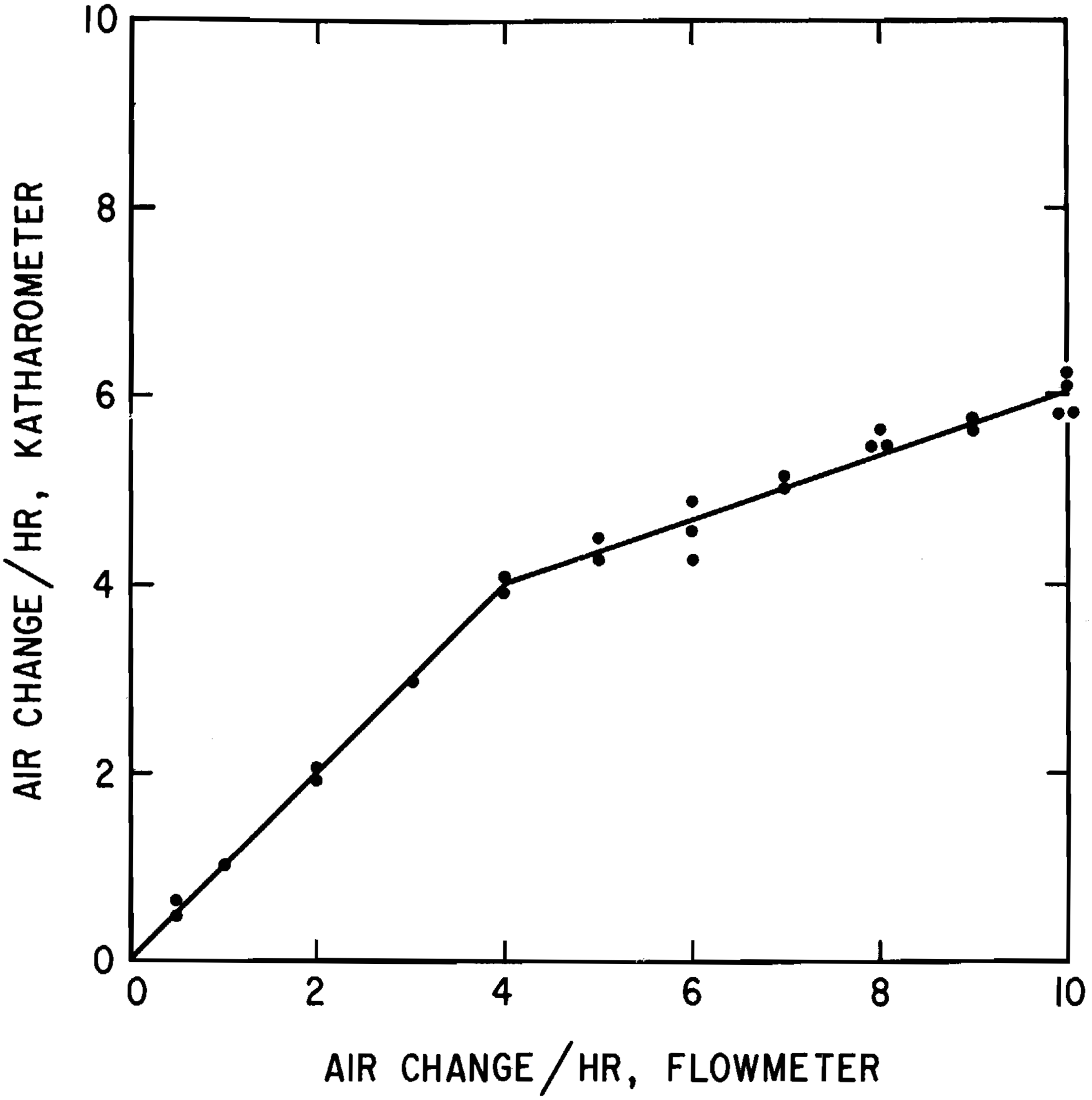


FIGURE 3
CALIBRATION TESTS ON KATHAROMETER

BR. 2698-2

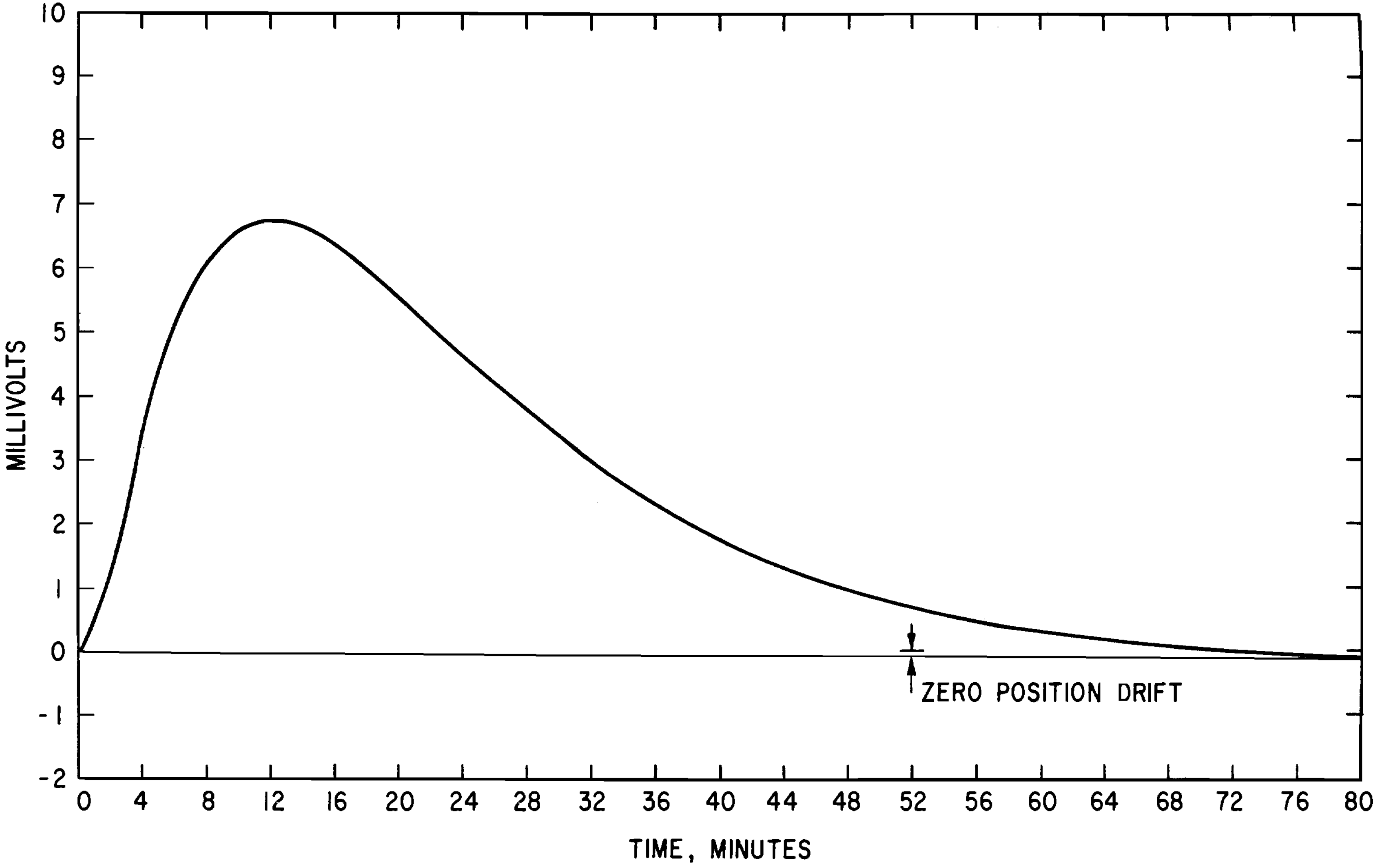


FIGURE 4
HELUIM DECAY CURVE REPRESENTING FOUR AIR CHANGES PER HOUR

BR 2698-3