603418

A METHOD FOR THE MEASUREMENT OF PHYSIOLOGIC EVAPORATIVE WATER LOSS

THOMAS ADAMS
Chief, Thermal Section
Environmental Physiology Branch

GORDON E. FUNKHOUSER
Environmental Physiology Branch

WARREN W. KENDALL
Department of Zoology
University of Oklahoma

18p $1.00 hc
$0.50 mf

63-25

FEDERAL AVIATION AGENCY
CIVIL AEROMEDICAL RESEARCH INSTITUTE
AERONAUTICAL CENTER
OKLAHOMA CITY, OKLAHOMA
OCTOBER 1963

FOREWORD

This instrument and method provides a system for the quantification of evaporative water loss from the skin. Since humans have been demonstrated to increase palmar sweating with emotional stress, this system can serve as an adjunct to an accurate estimation of central nervous system activity, paralleling other less precise observations of behavioral performance in providing a measurement of anxiety in chronic and acute stress testing. This procedure also allows for an accurate determination of heat loss by evaporation of sweat during thermal stress. Since sweating is the only avenue of heat loss operating under conditions in which environmental temperature is greater than skin temperature, a quantitative measurement of sweating is essential to the completion of a thermoregulatory balance sheet in protection against hyperthermia.

A METHOD FOR THE MEASUREMENT OF PHYSIOLOGIC EVAPORATIVE WATER LOSS

Thomas Adams, Ph.D.
Gordon E. Funkhouser
Warren W. Kendall

ABSTRACT

The precise measurement of evaporative water loss is essential to an accurate evaluation of this avenue of heat loss in acute and chronic exposures to heat. In psychological studies, the quantitative measurement of palmar sweating plays an equally important role in establishing an index of emotional stress and anxiety. This report describes a technique for measuring local sweat response which is relatively inexpensive, highly stable and accurate. Basically, the system uses a thermal conductivity cell for the detection of water vapor in an air stream passing over the skin. A method for calibration of the unit and examples of its application in physiological and psychological testing are described.

A number of techniques have been used to measure sweat gland activity in thermoregulatory and exercise physiology, and in experimental psychology (palmar sweating). The most direct method, measurements of body weight changes in time, lacks the precision demanded in most studies, and is applicable only under conditions of sizable sweat production (1-3). Infra-red analyzers (4,5), resistance hygrometric elements (6,7) and "coulometric cells" (8) supply the desired sensitivity, but are too expensive or cumbersome for most applications. Limited experiments by the present authors have indicated that resistance hygrometric systems are adequately sensitive in response to small changes in water vapor, but are too difficult to calibrate due to a large time constant associated with the desorbtion of water from the hygroscopic mass. The characteristics of the hysteresis loops occurring in the calibration curves depended on the calibration procedures.

This paper describes a sensitive, inexpensive system for the measurement of evaporative water loss. The technique is based upon the varying thermal conductivity due to density changes caused by fluctuations in the water vapor content of air flowing through a thermal conductivity cell.

Stability of the measuring system is critically dependent upon a controlled flow of air through the cell. Monitoring air flow with a rotametric type flow meter, controlled by a precision needle valve (B4M, Nupro-fine valve with micrometer handle) and a differential flow controller (Moore) in series in the air circuit, allowed for measured baseline stability for several hours of determinations. An air flow of 200 cc/min, although in excess of the flow rates recommended by the manufacturer, was found to be convenient for control and sensitivity of the unit, and met the requirements of the physiologic tests (see below).

The bridge circuit driving the cell and indicating resistance imbalance in the housed thermistor elements, is shown in Figure 1. This circuit is basically that suggested by the thermal conductivity cell manufacturer (GOW-MAC); slight modifications (as shown) were necessary to meet the specific recording scheme. The circuit providing control for the remainder of the unit is shown in Figure 2. Figure 3 shows the circuit used to indicate temperature in the cell enclosure.

Two methods for directing air flow through the unit have been used: one, in which the dry carrier air is drawn through the temperature controlled housing by a small pump, is shown in Figure 4; another, using a compressed air tank to supply the kinetic energy required to maintain air flow, is shown in Figure 5. Both systems provided *stable cell responses with* essentially the same calibration characteristics; the specific arrangement chosen should be dictated by the application of the system. In both arrangements, the thermal conductivity cell (model 9677, GOW-MAC Instrument Co., New Jersey) was housed in an insulated container with a small fan and a temperature control system to maintain the unit at 50°C (see Figure 11). The drying units shown in Figures 4 and 5 were tubes filled with "Drierite".

Reproducible calibration is a difficulty common to all relative humidity or water vapor pressure sensing elements, arising in part from the detection characteristics of the individual unit, but largely related to difficulties in obtaining stable, predictable, low levels of water vapor. Calibration of the unit described here required first, stability in air flow through, and temperature of, the thermal conductivity cell, and second, stability and reproducibility of characteristics in the circuit driving the cell. An additional problem was to provide a stable source for different rates of water vapor production.

The first problem was overcome by the designs shown in Figures 4 and 5 discussed above. The second, by monitoring both voltage across and current flow through the thermal conductivity cell, as shown in Figure 1. The problem of obtaining stable and controlled rates of evaporative water loss for calibration was met by using the device described in Figure 6. It was possible to obtain extremely stable rates of water vapor production over the required calibration range by adjusting the surface area of the water (filling one or more of the concentric holes in the brass block) and/or water temperature (bringing the block to a desired temperature with the electric heater).

Calibration procedures consisted of running dry air through the brass block shown in Figure 6, and into the thermal conductivity cell circuit. As shown in Figure 1, one side of the cell is exposed to the air sample and the balancing thermistor continuously responds to dry air. For calibration, a carefully weighed, small (approx. 50 gms) bottle filled with "Drierite" was connected *into the circuit at points* A *and* B *in* Figure 4, temporarily replacing the drying unit interposed between the two sides of the cell, or attached as indicated in Figure 5. A change in weight of the calibration sample bottle in a prescribed time interval reflected the amount of water passing through the unit at a steady rate.

Imbalance in the bridge circuit (mV), plotted as a function of the steady state rate of water vapor traversing the unit, provided the calibration curve shown in Figure 7. Since the system is shown to respond to very small rates of water vapor production, it is of course, important that fresh "Drierite" be used in each drying cylinder. Calibration bottles were weighed to the nearest 0.1 mgm. No changes in the calibration curve were noted on successive days of measurement, a characteristic not shared by an infrared analyzer technique (5).

Latency and time constant of response of the unit depends on the size of the sampling capsule, the length and diameter of the tubing connecting to the cell, and the air flow rate through the system. Using a 2 cm. (diameter) by 1.5 cm. plastic capsule for sampling and approximately 60 cm of PE 240 tubing with an air flow rate of 200 cc/min, resulted in a response latency and time constant in the order of 2 seconds and 10 seconds respectively; using the smaller capsules shown in Figure 8 shortened these characteristics considerably. In any combination of these factors, these characteristics can be determined empirically and records appropriately interpreted.

The design of two capsules used for the assessment of physiologic sweating are shown in Figure 8; A., for the measurement from 1 cm^2 skin surface and B., *for air circulation over* a smaller skin area.

Two physiologic applications of the technique are reported in Figure 9. In A., the plastic capsule was sealed to the lateral surface of the forearm during a brief bout of exercise ("running in place"); in B., the capsule was sealed to the palmar surface of the hand. Three types of information are obtainable from these records: 1. instantaneous rate (ordinate), 2. acceleration (slope of tracing at any part of the curve), of water vapor production, and 3. total amount of water produced (area under curve for any time interval). A rate of air flow of 200 cc/min was adequate to keep the skin free of accumulated sweat during both of these measurements. Drying room air (or air from the compressed air tank) before it is presented to the skin provides a reproducible sample for the reference side of the cell and further insures complete evaporation of sweat by providing a steep vapor pressure gradient.

Photographs of the control panel, cell housing, and the unit in operation are shown in Figures 10, 11 and 12 respectively.

This report has presented a method for the measurement of evaporative water loss from small skin areas. The same detection system could be readily applied to measurements involving larger skin areas, including whole body, by drawing an aliquot through the thermal conductivity cell from a faster flowing air stream directed through a container enclosing a larger body area. In this application, the measurement of the amount of water passing through the main air stream, plus the amount extracted by the sampling circuit, would provide the required calibration units as a function of cell imbalance. Since other gas species are detectable by this system, it is important that respiratory gases not be allowed to mix with air used for evaporative water measurements.

This method provides an indirect measurement of evaporative water loss with a stable reference and adequate precision for most tests. The attachment of the sampling capsule need not interfere with the free movements of the subject and could be worn for extended periods of time during most performance tests. Using dry air as a carrier gas, the difficulties associated with using other gases or gas mixtures is avoided (8). Although the calibration procedures require meticulously precise techniques, the actual operation of the system is relatively simple.

BIBLIOGRAPHY

1. Rodahl, K. and D. W. Rennie. Comparative Sweat Rates of Eskimoes and Caucasians under Controlled Conditions. Proj. No. 8-7951, Rep. No. 7, AAL, Ladd AFB, Alaska, 1957.
2. Belding, H. S. and B. A. Hertig. Sweating and Body Temperatures Following Abrupt Changes in Environmental Temperature. J. Appl. Physiol., 17:103-106, 1962.
3. Webb, P., L. N. Garlington and M. J. Schwarz. Insensible Weight Loss at High Skin Temperatures. J. Appl. Physiol., 11:41-44, 1957.
4. Brebner, D. F. and D. McKerslake. The Effect of Cyclical Heating of the Front of the Trunk on Forearm Sweat Rate. J. Physiol. (Lond.) 158:144-153, 1961.
5. Palmes, E. D. An Apparatus and Method for the Continuous Measurement of Evaporative Water Loss from Human Subjects. Rev. Sci. Instr., 19:711-717, 1948.
6. Bullard, R. W. Continuous Recording of Sweating Rate by Resistance Hygrometry. J. Appl. Physiol., 17:745-757, 1962.
7. Custance, A. C. Cycling of Sweat Gland Activity Recorded by a New Technique. J. Appl. Physiol., 17:741-742, 1962.
8. Wilcott, R. C. The Continuous Measurement of Palmar Sweating. Am. J. Psychol., 74: 619-624, 1961.
9. Ratcliffe, J. S. A Thermistor Temperature Controller with Increased Sensitivity, J. Chem. Education, 39:637, 1962.

Parts List for Thermal Conductivity Cell Circuit and Accessory Components:

1. Model AEL 9677 Thermistor Thermal Conductivity Cell, GOW-MAC Instrument Co., 100 Kings Road, Madison, New Jersey. (1)
2. 0-10 (with alternate 0-1.0) mv, DC recorder (type used: Varian, graphic model G-14) (1)
3. Variable transformer (type used: "Adjust-a-Volt", type 100 BU, Standard Electric Products Co., Dayton, Ohio) (1)
4. Small air cirbulating fan (recomm. 4" blade, 110v AC) (1)
5. Thermoregulator (type used: Cat. No. 55260, thermoregulator with set point at 50.0°C (specify), Chicago Apparatus Co., 1827 McGee Street, Kansas City 8, Missouri) (1)
6. Thermoregulator Relay (type used: Cat. No. 55275 thermoregulator Buffer relay, Chicago Apparatus Co., see above address) (1)
7. 12 V DC supply (recomm. N. - Cd, wet cell or other suitable, rechargeable battery) (1)
8. Rotametric type air flowmeter, 0-300 cc/min range (1)
9. Compressed air tank with two stage pressure regulator and indicating air pressure gauges (1) (if air flow is maintained by drawing the air through the cell circuit, require suitable pump and vacuum gauge)
10. 0-15 V DC panel meter (1)
11. 0-10 MADC panel meter (1)
12. 0-50 MICROAMPS, DC panel meter (1)
13. Flow Controller (type used: Differential Flow Controller, (Moore), Cat. No. PC-103-6 for 1609, with needle valve) (1)
14. Three position stopcocks (3)
15. NE 51 panel lights with mounts (5)
16. 1 amp. fuse with holder (1)
17. 10 MA fuse with holder (1)
18. DPDT switch (4)
19. 150 ohm flexible heater wire (1)
20. 500 ohm, 2 watt pot. (3)
21. 2K, 2 watt pot. (1)
22. 5K, ten turn pot. (1)
23. 100 ohm, ten turn pot. (1)
24. 1½ v (nom.) Hg. battery (2)
25. 3 deck, 3 pos. switch (1)
26. 1/2 watt resistors:
    a. 50 ohm w. w. (2)
    b. 150 ohm (1)
    c. 1.5 meg. (1)
    d. 220 k (1)
    e. 3.3 k (3)
    f. 250 ohm (1)
    g. 2.2 k (2)
    h. 2.7 k (1)
27. Drierite Containers (type used: Cat. No. 20885, Drying Tower, Drierite, Chicago Apparatus Co. (see above address) (2).
28. Shielded, single connector, stranded wire
29. Shielded, double connector, stranded wire
30. Mounting cabinet and panel for meters and controls (1)
31. Insulated box (5) for constant temp. container for TCC.
32. MISC.:
    a. Solder, "hook-up" wire, banana plugs and jacks, multiple terminal cable connectors, grommets, terminal strips and connectors, misc. hardware.
    b. P. E. tubing with connectors
    c. Tygon tubing
    d. 2.5K (nom.) thermistor probe.

ACKNOWLEDGEMENT

The authors would like to express their appreciation to Mr. J. Hildebrandt, Department of Physiology and Biophysics, University of Washington, School of Medicine, Seattle 5, Washington, who suggested the thermal conductivity cell as a possible humidity sensor.

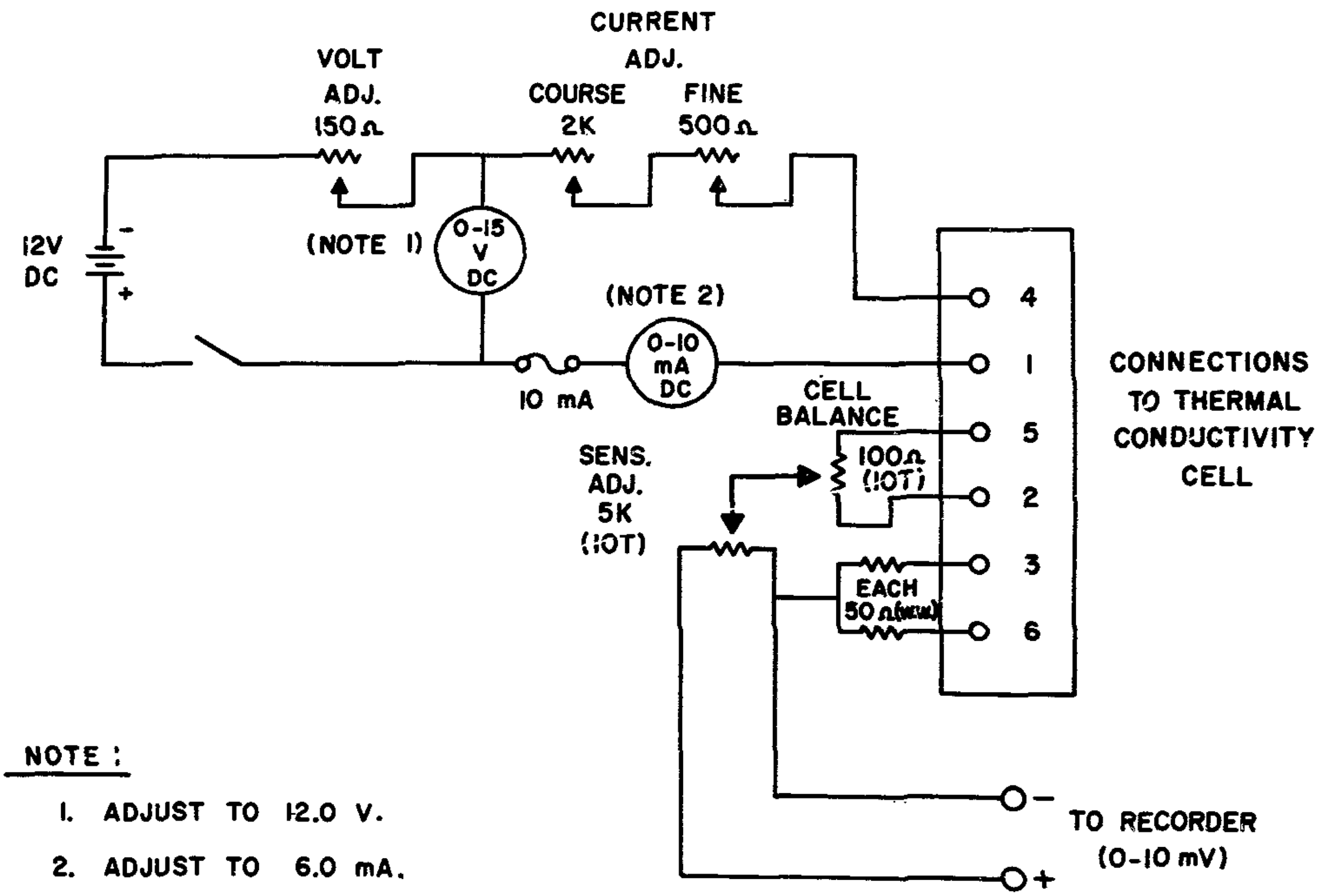

FIGURE 1. This circuit is a slightly modified form of the bridge suggested by the manufacturer of the thermal conductivity cell. The numbered connections to the cell are specific to the model. The mV. recorder used in these tests was a Varian, graphic recorder, model G-14. A 12 V. wet cell battery was used as a DC voltage source in initial studies. Two 6 V Ni-Cd batteries were used in later experiments; these units provided a more stable, smaller voltage source. All electrical connections to the thermal conductivity cell should be shielded throughout the circuit.

732-436 O-64--2

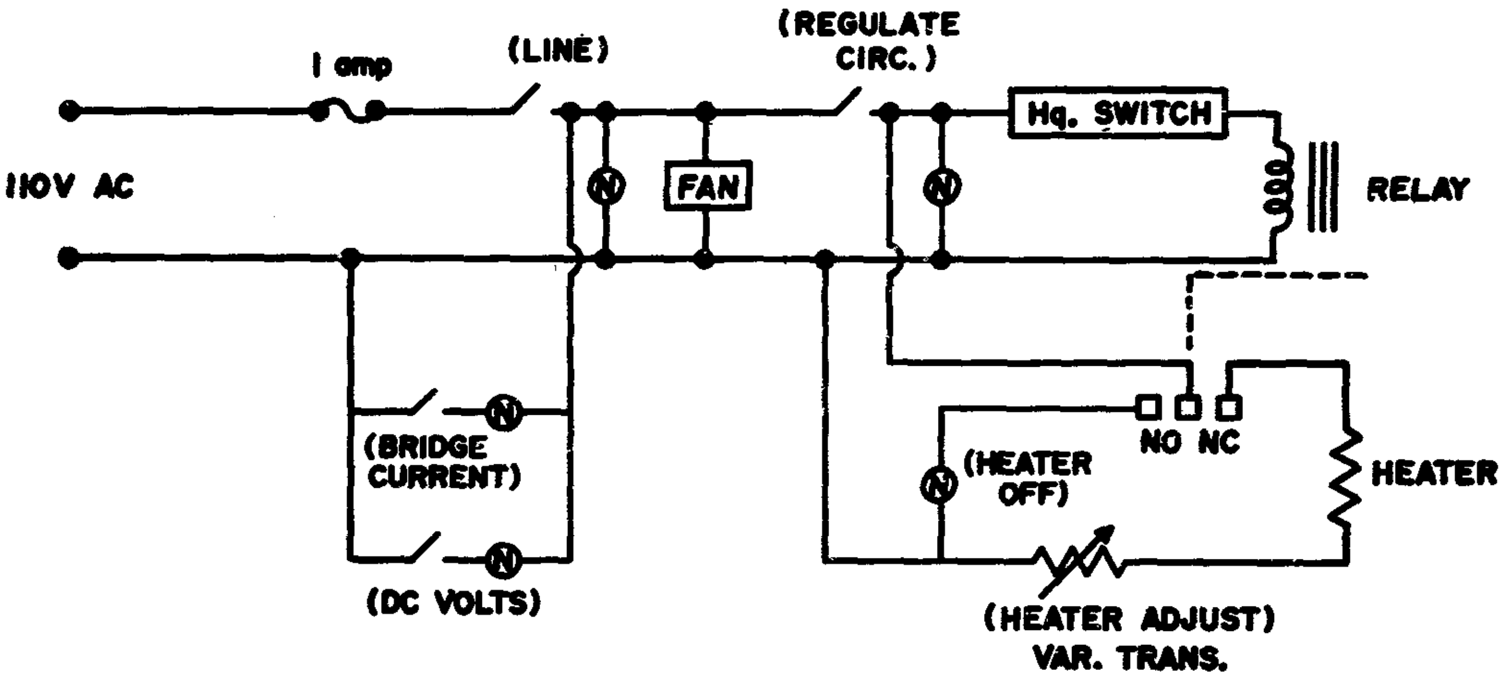

FIGURE 2. This diagram indicates the arrangement of the controls for the temperature stable enclosure for the thermal conductivity cell and the remainder of the unit. The mercury thermostat and regulator (see appendix A) may be replaced by a thermistor driven relay similar to that suggested by Ratcliffe (9). Rapid heating of the cell enclosure at the beginning of a test period may be obtained by applying a large voltage to the heater; better temperature control is attained with the heater operating at a lower wattage after the enclosure and components have reached thermal stability at 50°C. A warm-up period of approximately 30 minutes is required with the described design.

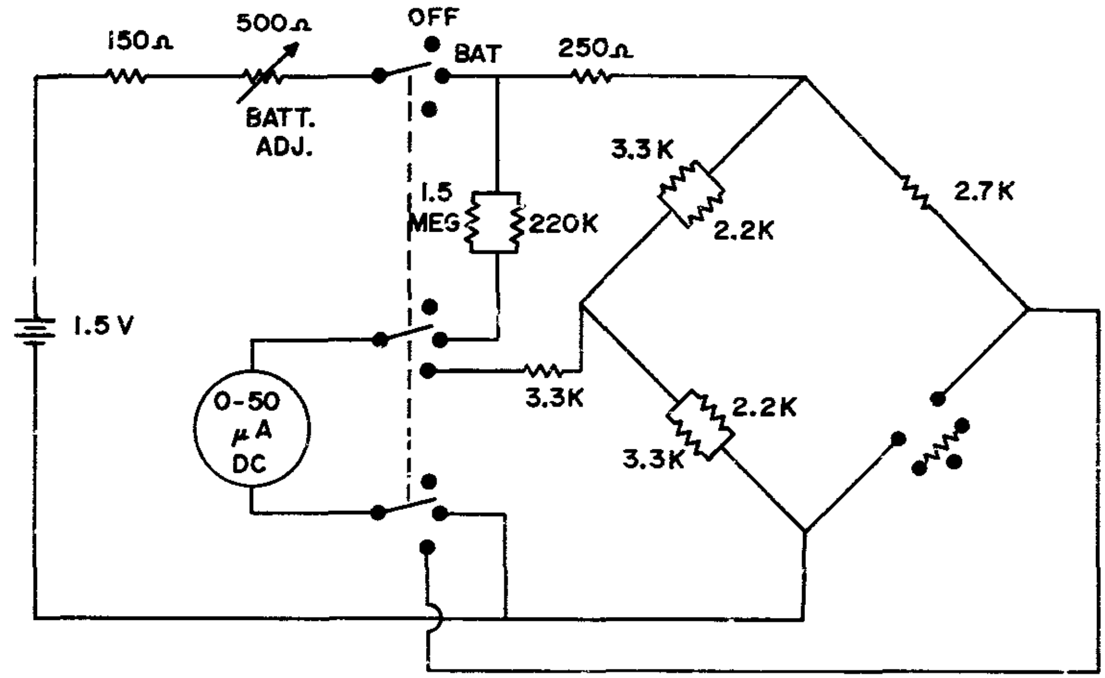

FIGURE 3. A separate indication of the temperature in the thermal conductivity cell housing was provided with this circuit. Although this measurement of temperature was not precise enough to provide an indication of cell temperature changes during operation (heater control cycling), it served as a valuable aid in adjusting heater voltage during cell warm-up.

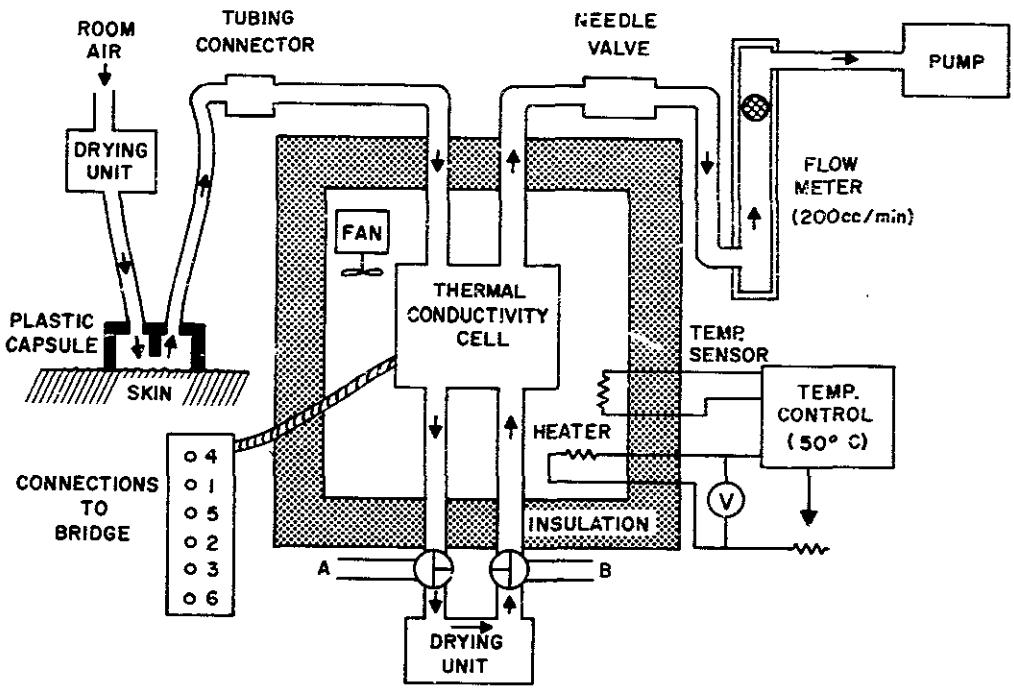

FIGURE 4. The numbered connections to the bridge circuit are supplied with the cell. Pulsatile variations in bridge output due to pressure and flow changes caused by pump action can be damped by interposing a large air capacitance in series with the pump, without adversely affecting the operating characteristics of the system.

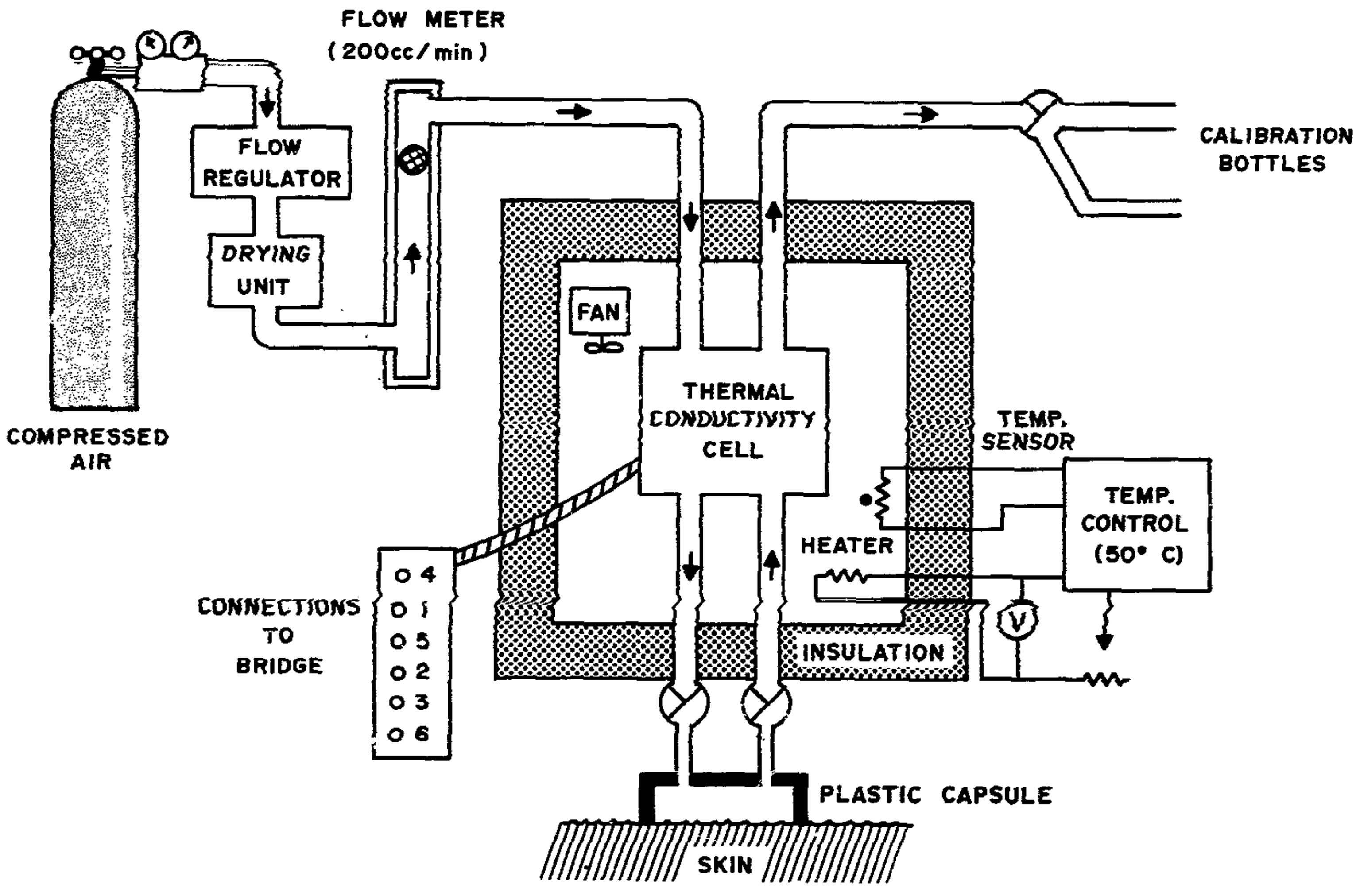

FIGURE 5. This design differs from that shown in Figure 4 in that a tank of compressed air is used to maintain air flow through the system. Operating the differential pressure-flow regulator at an inlet pressure of 12 psi was adequate to establish a uniformly controlled air flow of 200 cc/min. The flow regulator was housed in the control panel cabinet.

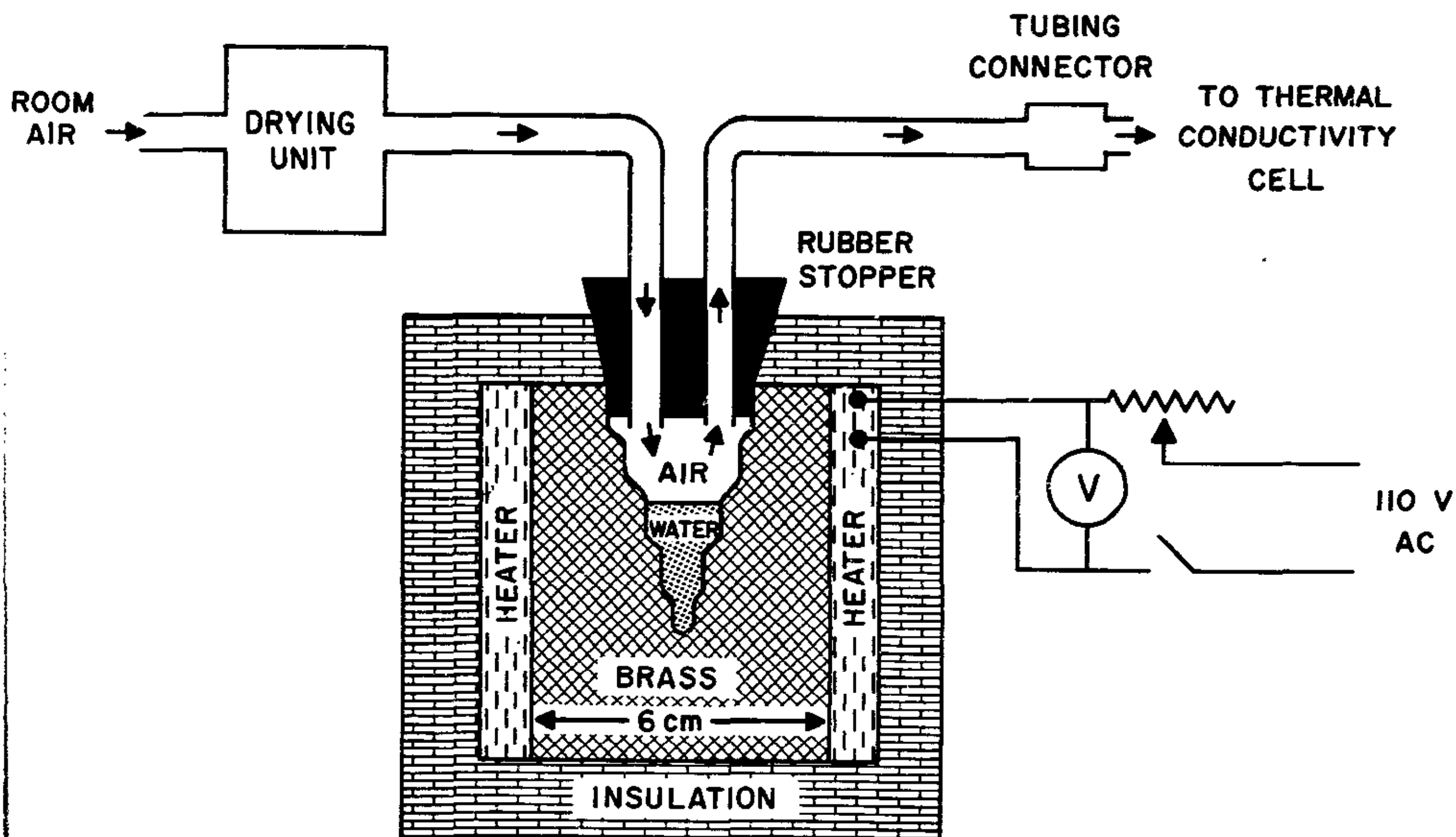

FIGURE 6. A cross section of the device required to obtain steady rates of water vapor production for calibration. During calibration, the tubing connector joined the air flow circuits as shown in Figures 4 and 5 at the points indicated, replacing the plastic capsule. An electrically insulated heater should be used which will allow a controlled change in block temperature.

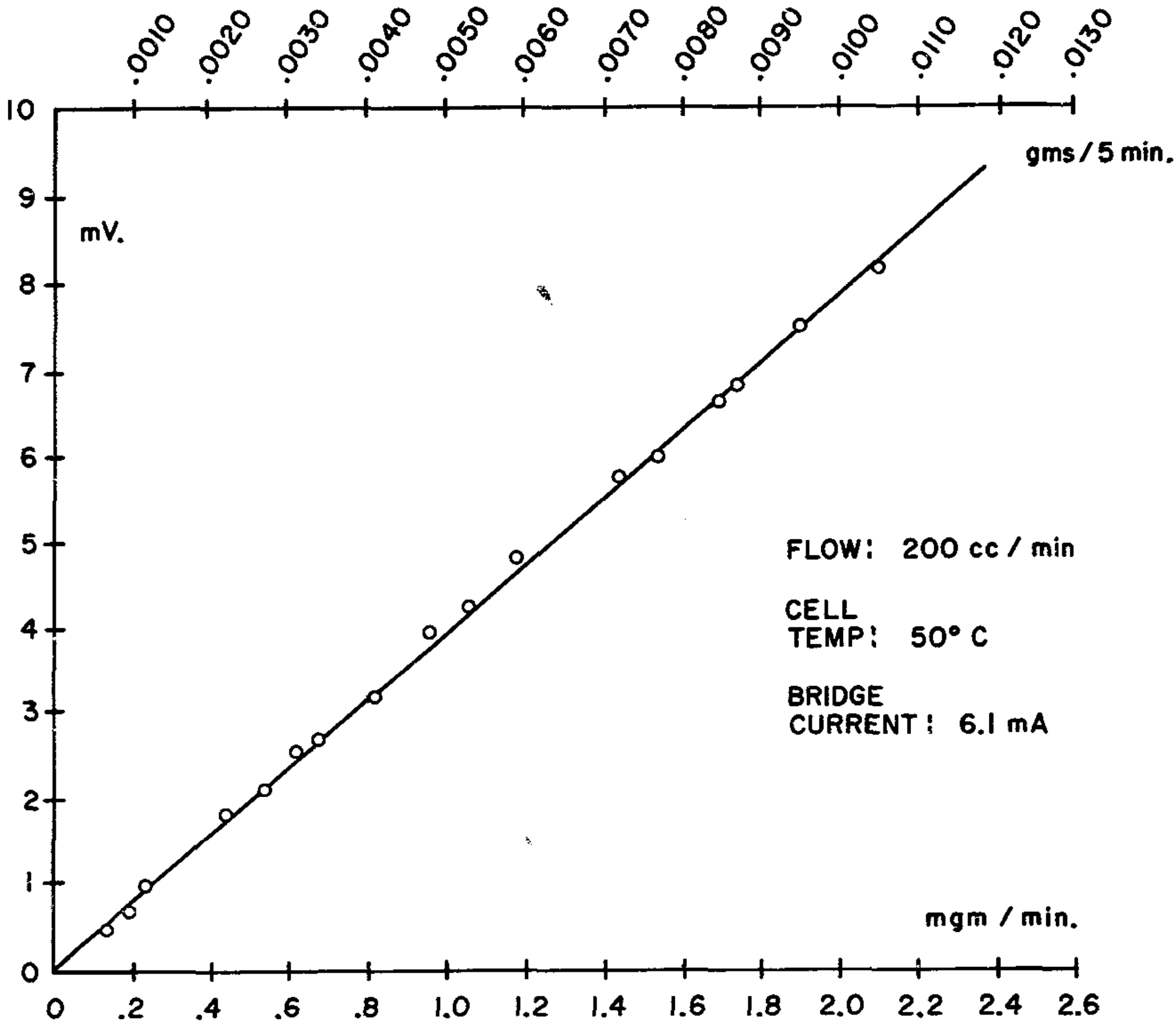

FIGURE 7. Bridge imbalance is shown as a function of the rate of water vapor production at a *bridge sensitivity setting of 4500 ohms. Increased or decreased cell sensitivity* would allow for measurements of other ranges of rates of water vapor production, with the upper limit being defined by the saturation of air at the ambient temperature in which the unit is operated. The calibration points for this curve were obtained on different days, reproducing operating values of the system at each different test.

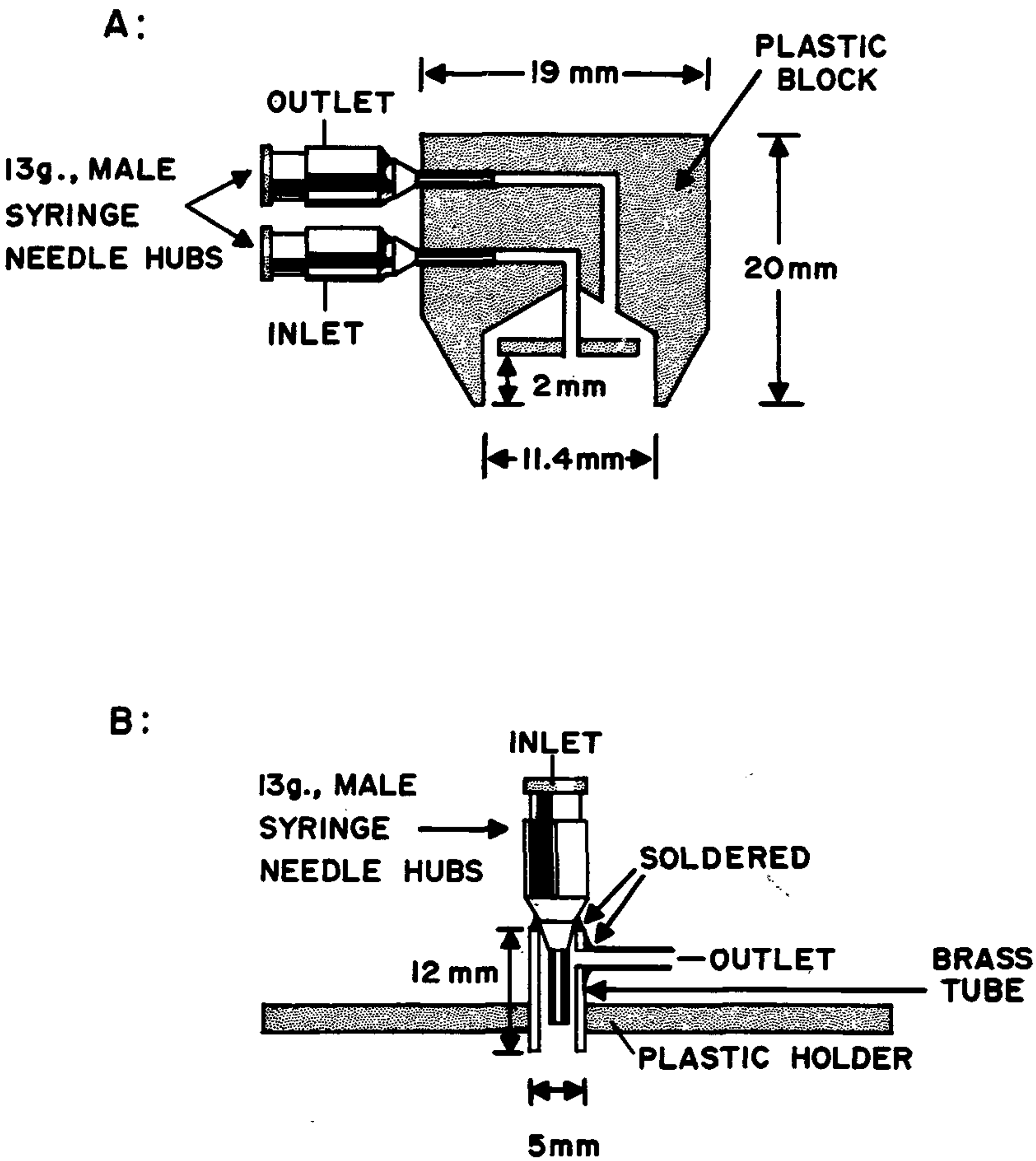

FIGURE 8. A. This capsule was used in most tests, sampling from a skin surface area of 1 cm^2. The needle hubs were press-fitted into holes drilled into the plastic block. The plastic shield at the end of the inlet tube inside the capsule insured uniform dry air distribution over the skin surface.
B. For measurements of sweating activity from smaller skin areas this capsule was attached to the skin with tape over the plastic holder.

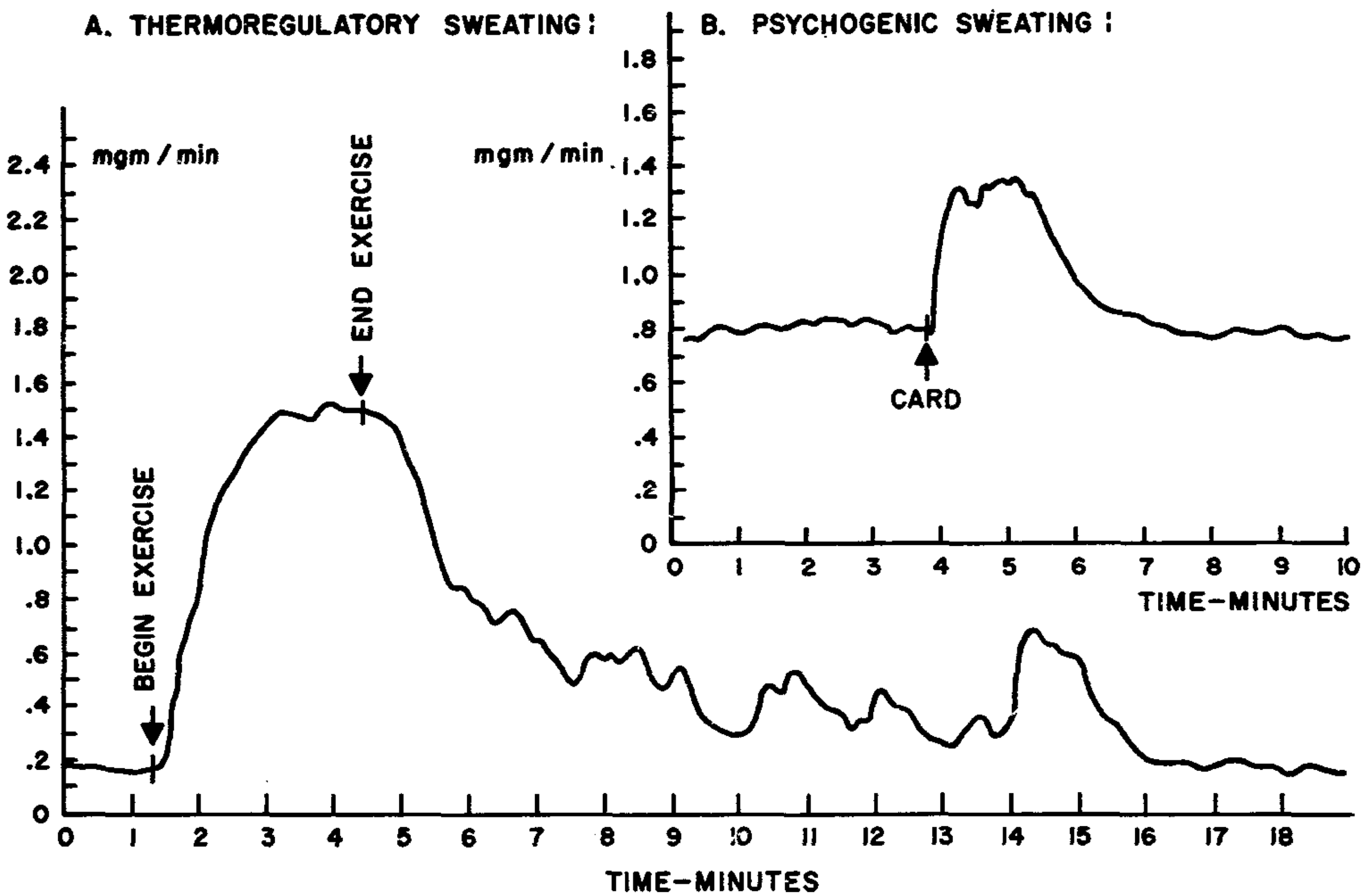

FIGURE 9. These tracings represent recorded changes in evaporative water loss in A: from *the forearm during a brief period of exercise, and B: from the palm of the hand* when the subject was shown a card on which was printed a profane word.

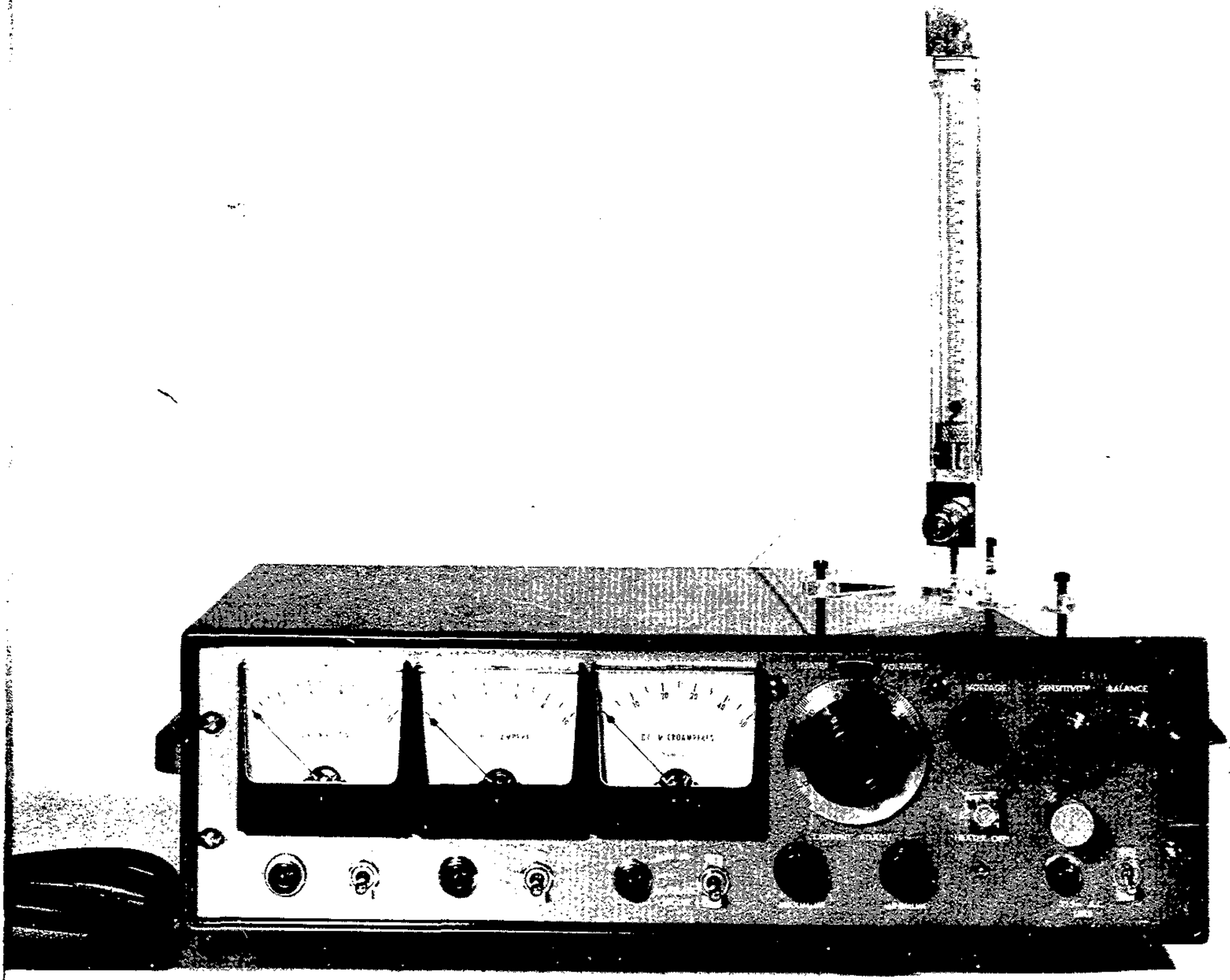

FIGURE 10. This photograph shows the front of the panel used to control the unit. The three meters (left to right) indicate DC voltage and current (DC mA) in the thermal conductivity cell circuit, and temperature (calibrated in DC uA) within the cell housing, respectively. The rotametric flow meter is shown on top of the panel cabinet. The cable connecting the control panel and the cell enclosure, the 12 V DC source and air connections were attached at the rear of the cabinet.

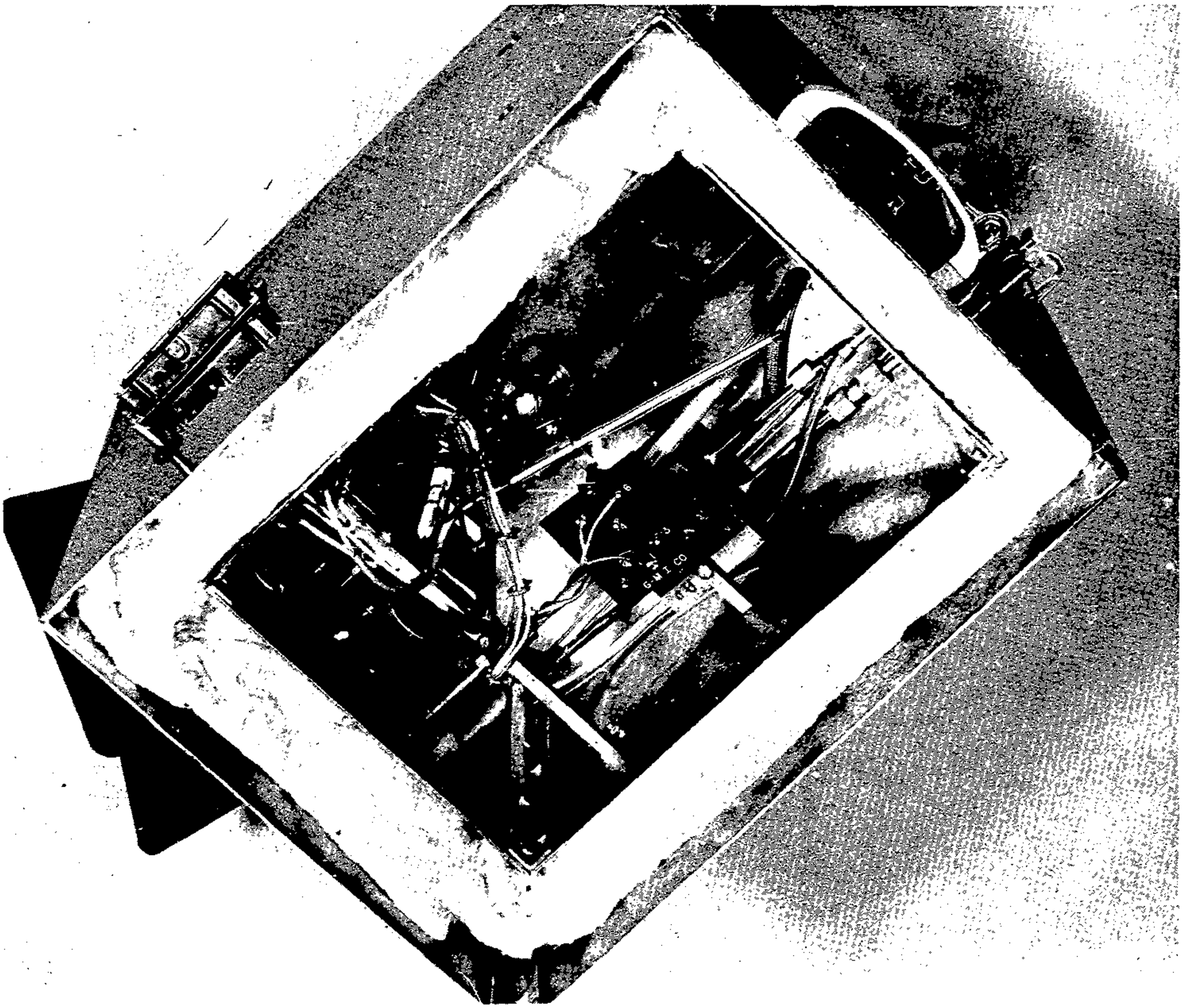

FIGURE 11. The covers for the inner and outer metal boxes and the intervening top layer of insulation have been removed to show the arrangement of components in the constant temperature enclosure. The mercury switch, heater and thermistor for indicating cell temperature are arranged immediately in *front of the fan*. The *thermal conductivity* cell and its connections are on the left. The cable connection to the control panel is shown on the right of the outer box. The connections on the facing panel are for the attachment of the skin capsule.

FIGURE 12. This photograph indicates the general arrangement of the unit during operation. The compressed air tank is shown on the left. A 10 foot cable connects the control panel to the cell enclosure. The recorder is shown to the left of the control panel.

U.S. GOVERNMENT PRINTING OFFICE : 1964 O—732-436