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CONTINUOUS REGISTRATION OF BODY WEIGHT

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FOREWORD

The experimental work reported herein was conducted in the Department of Physiology, Saint Louis University School of Medicine, Saint Louis, Missouri, in partial fulfillment of Contract AF 33(657)-11551, administered by the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. Mr. John F. Hall, Jr., Chief, Biothermal Branch, Physiology Division, served as the contract monitor for the Biomedical Laboratory. The work was performed under Project No. 7164, "Biomedical Criteria for Aerospace Flight," Task No. 716409, "Human Thermal Stress." Alrick B. Hertzman, Director of the Department of Physiology, was the Principal Investigator of this research project. The development of the device as described in this report occurred during the period, May 1963 through September 1964.

Part of the cost of this research was covered by grants H-4939 and HE-07070 from the United States Public Health Service.

This technical report has been reviewed and is approved.

WAYNE H. McCANDLESS
Technical Director
Biomedical Laboratory

ABSTRACT

This report describes a device for continuous recording of the weight of a human subject. The frame on which the subject may either sit or lie is carried by three load cells mounted as a tripod. The electrical signals from the strain-gauges permit detection of a weight change of one gram. Insulation and heating of the load cells to a constant temperature $\pm 0.1°C$ permit use of the system in the presence of rapid changes in environmental temperatures. Circuits are described for automatic regulation of load cell temperature.

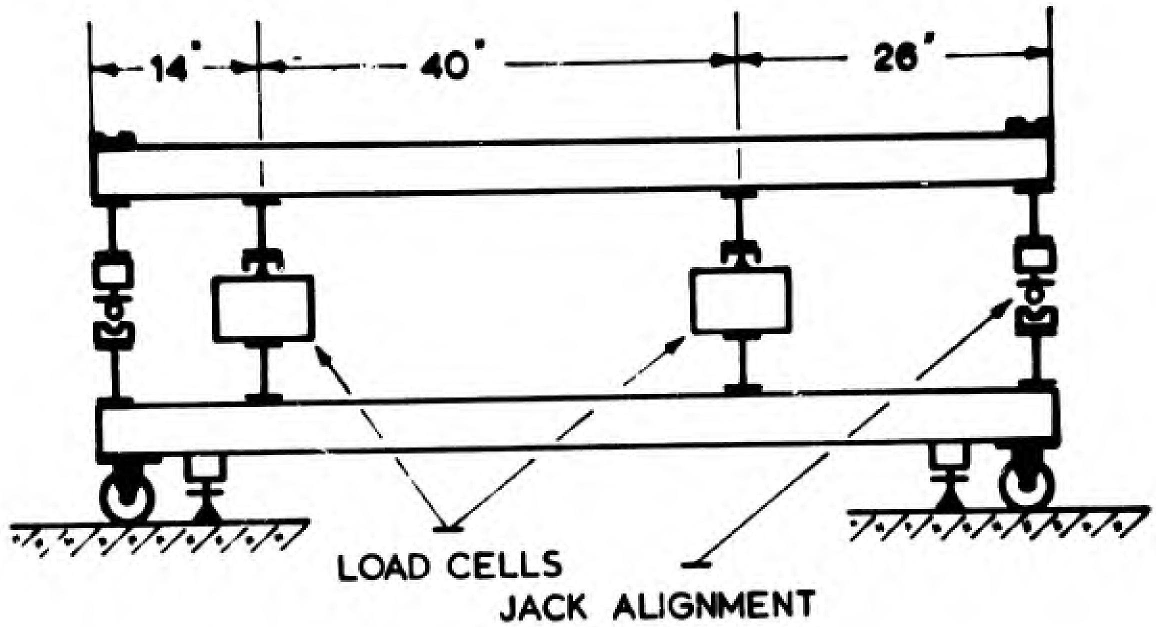

Figure 1. Arrangement for continuous recording of subject's weight. The lower frame may rest on either casters or jacks. The upper frame may rest on either the jacks or the load cells. Drawn to scale.

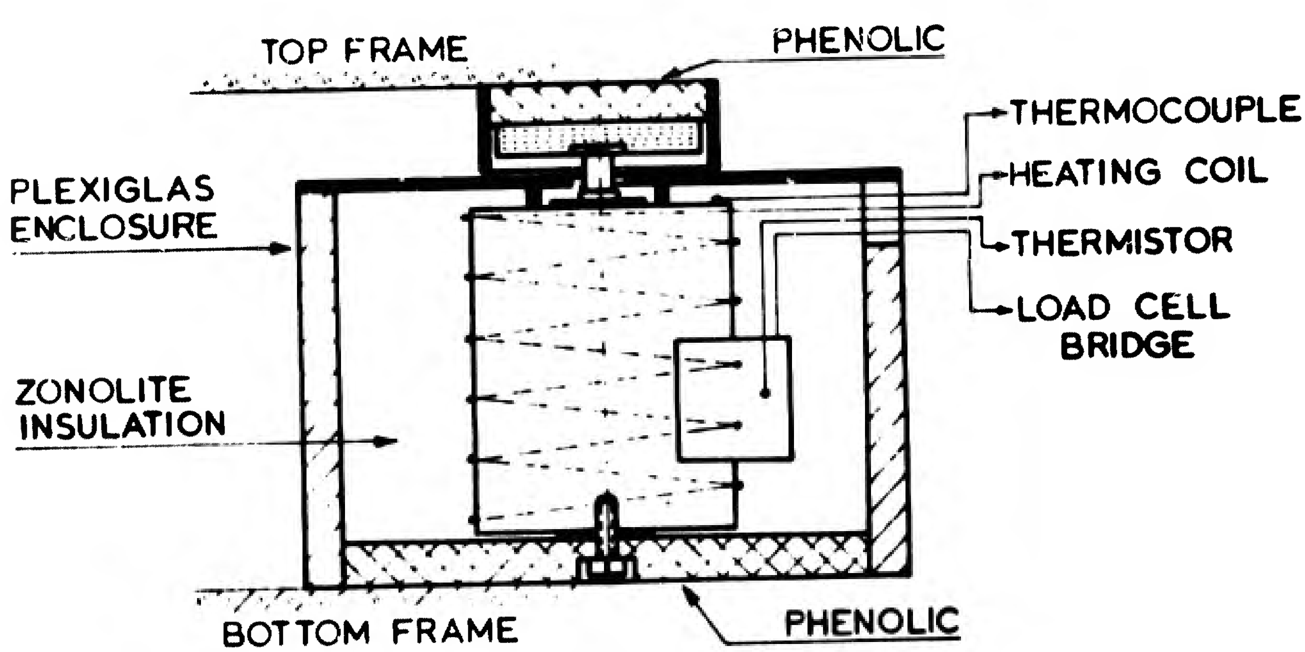

Figure 2. Details of the load cell assembly.

SECTION I

INTRODUCTION

Continuous recording of the weight of a human subject is often useful in studies of the influence of the environment on the human. The required resolution is determined by the objectives of the measurements but may be as great as one gram. Observations in this laboratory on the sweating responses to heat indicated that a resolution of 10 grams would be satisfactory in many of our experiments, particularly if a higher sensitivity were available for brief periods.

In examining various arrangements which might be used, spring and lever devices were rejected because of lack of flexibility in mounting these, or because of thermal sensitivity. The "load cell" which incorporates a strain gauge for sensing the force, offered the advantages of a compact system permitting mobility of the final assembly combined with high sensitivity and an electrical signal which could be recorded and calibrated easily. It was also obvious that thermal effects on the sensor could be eliminated by designing a constant thermal environment for the load cell which would still permit mobility of the mechanical arrangement and use in a climate chamber. This report describes the system which was designed to meet the requirements of sensitivity and linearity in response, continuous recording, use with other recording sensors, constant temperature of the sensor and mobility.

SECTION II

MECHANICAL DESIGN

The mechanical assembly is illustrated in figure 1. The top frame on which may be mounted a hospital type bed or other support for the subject, rests on three load cells which in turn are placed on supporting cross bars. The load cells are the three points of a tripod suspension designed to provide very nearly equal pressures on each cell. Two of the load cells carry the weight of the head, neck, arms and most of the trunk while one unit carries the weight of the lower extremity. (With this arrangement, each load cell provides approximately the same signal.)

The details of the load cell assembly are shown in figure 2. The cell is enclosed in a plexiglass tube from which it is thermally insulated. The cell is protected against thermal metal contacts with the upper and lower frames by the construction of the upper button nest and the lower frame rest from phenolic fiber of low thermal conductivity. A heating wire is wrapped around the load cell to maintain its temperature at the pre-selected level which is monitored by a thermocouple and thermistor, the latter serving to control the heating circuit.

The load cells are protected when the device is not in use by four jacks which are placed at the two ends of the assembly. During use the upper frame is slowly lowered to the load cell buttons by releasing the support of the jacks. Alignment is assured by the design of the jacks as shown in figure 3. The load cell buttons fit into nests illustrated in figures 2 and 4. The entire assembly rests during use on the lower jacks which are adjusted to provide a level position of the frames as indicated by spirit levels mounted on them. Casters on the lower frame permit mobility when desired.

SECTION III

ELECTRICAL CIRCUITS

The load cell which is used in the Type U-3 Gl (Baldwin-Lima-Hamilton) having a bridge resistance of about 350 ohms, a load capacity of 91 Kg/load cell and an output signal of 0.033/V/Kg. The circuit is shown in figure 5. An excitation voltage of about 13.1 V was supplied to each cell from its individual power supply (Harrison Laboratories, Model 6346A). Final regulations of the excitation voltage was adjusted so that the sum of the output signals was 0.4 mv/Kg. The weight could be placed anywhere on the upper frame without an appreciable change in the total output signal. A balancing circuit was included to permit use of the null point method in measuring the weight of the subject and of the deflection method in following changes in weight. The balancing sections of the circuit as well as the sensitivity control were mounted in a steel housing acting as an electrical and magnetic shield and insulated with 2-inch styrofoam to avoid thermal drifts. A recorder* with a deflection of 100 mm/0.4 mv was used for recording. This provided a legibility of 1 mm/10 grams. Greater resolution could be obtained with a suitable preamplifier. Noise due to building vibrations, ballistic effects of the heart beat, breathing and other movements of the subject was damped by electrical filtering.

Although temperature compensation is provided in the bridge circuit of the load cell, this proved to be inadequate in several applications of the weighing device, particularly during changes in the temperature of a climate chamber. Temperature gradients in the load cell significantly affected its output signal at constant load. Reference has been made recently to this performance of strain-gauge transducers during steep temperature gradients and the inadequate correction by temperature compensating resistors located in the transducer housing (1). Two circuits, as illustrated in the block diagram of figure 6, were designed to maintain load cell temperature at a selected level which should not exceed 50°C. The circuit for manual control is shown in figure 7. Coarse adjustment of heater current was provided in a variable auto transformer and fine adjustment by means of a variable resistance. A thermistor mounted on the load cell (figure 8) monitored the cell's temperature which was inscribed continuously on a servoriter. Load cell temperatures were inscribed also by thermocouples on a Brown recorder. The thermistor probe shown in figure 7 controlled a relay switch which protected the load cell against overheating. Load cell temperature was regulated within $\pm$ 0.05°C with these arrangements.

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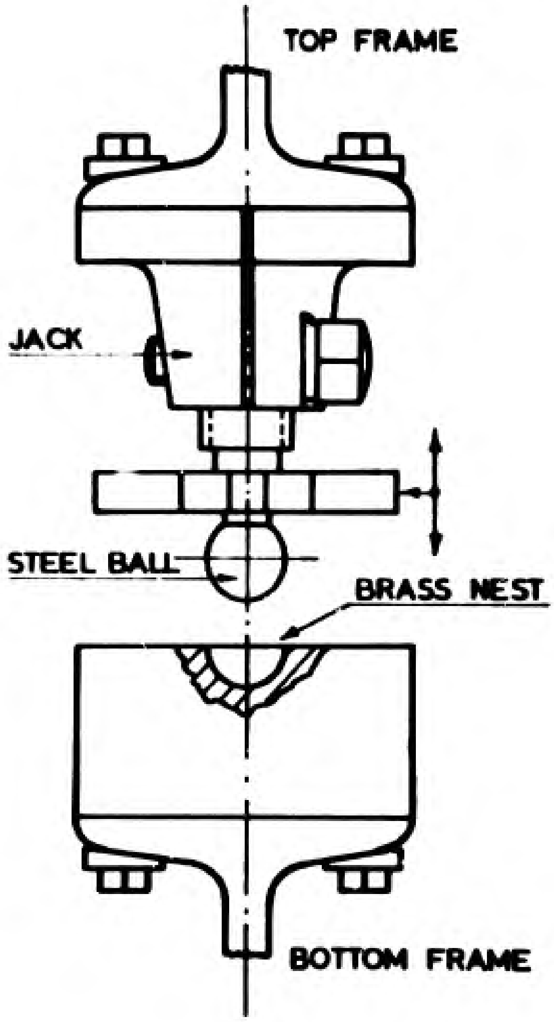
* Servoriter



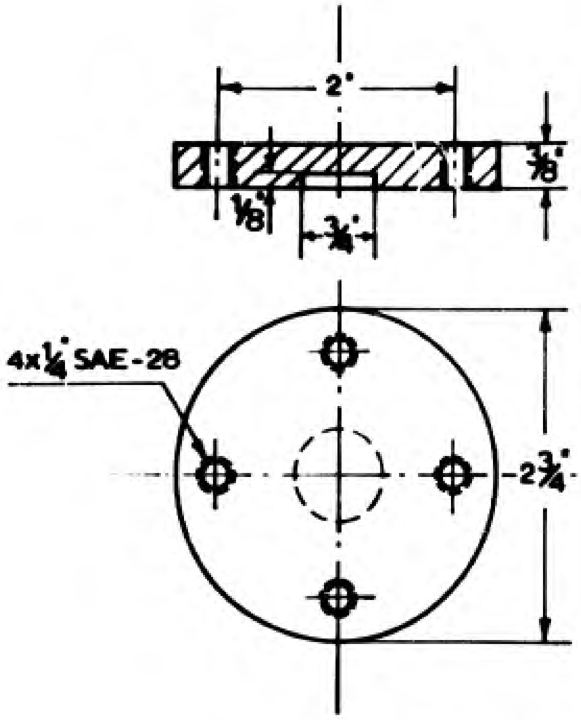


Figure 3. Details of jacks used in aligning upper and lower frames when the upper frame is lowered to the three load cells.

Figure 4. Details of the nest for the load cell button. This nest is shown in position in figure 3.

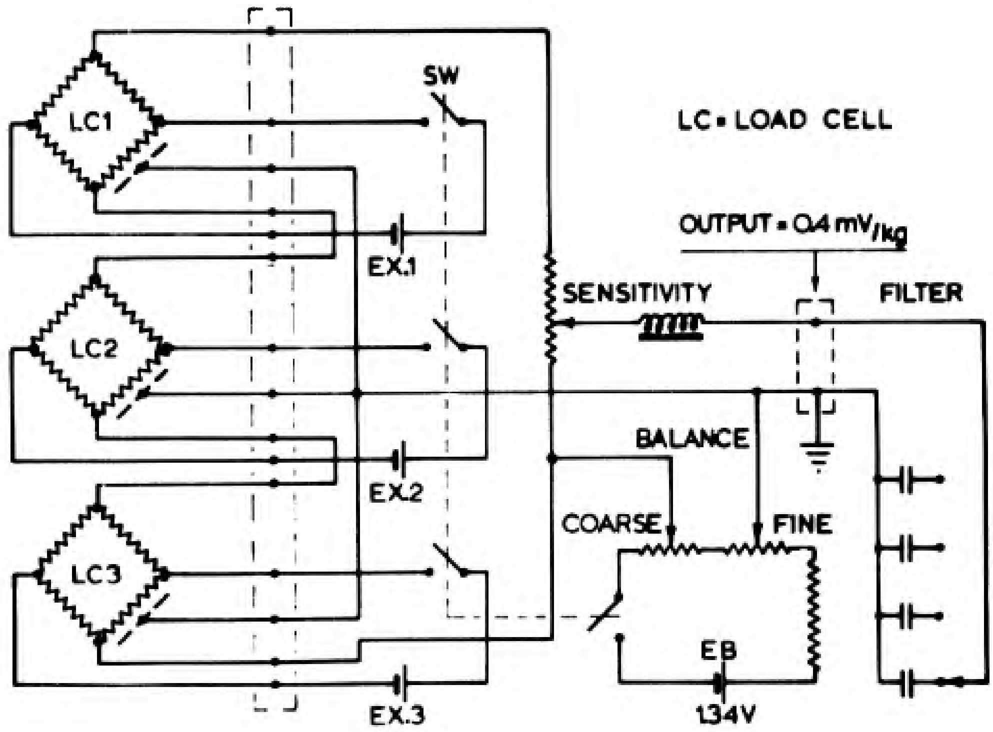


Figure 5. Circuit for summing output potentials from the individual load cells.

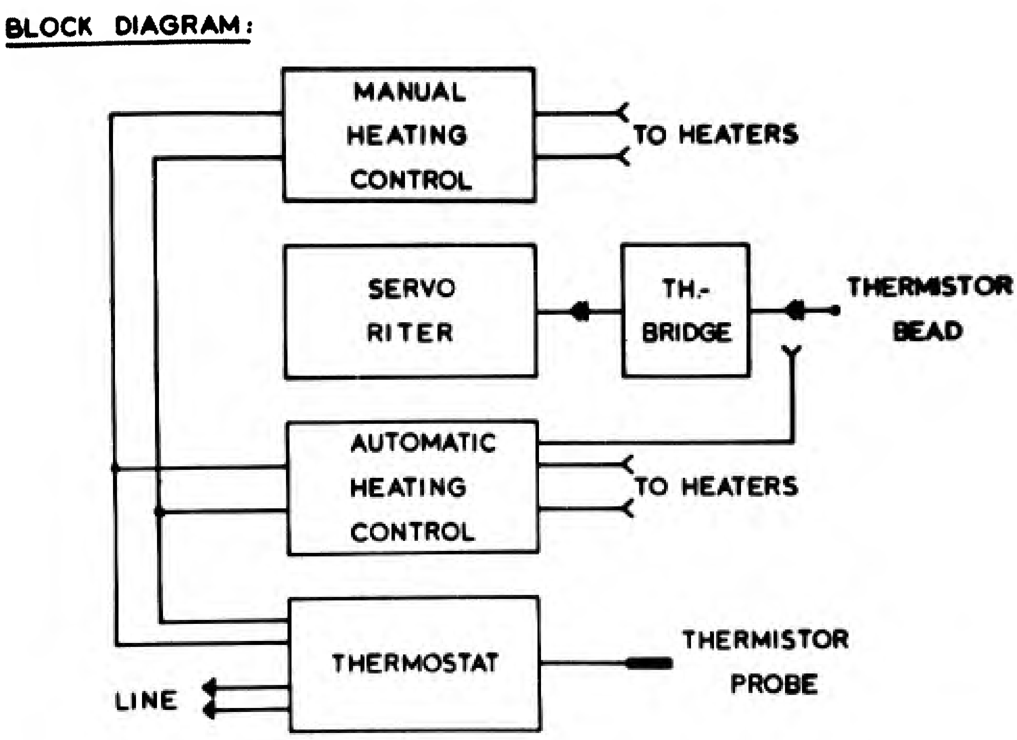


Figure 6. Block diagram of arrangements for controlling the temperature of the load cells.

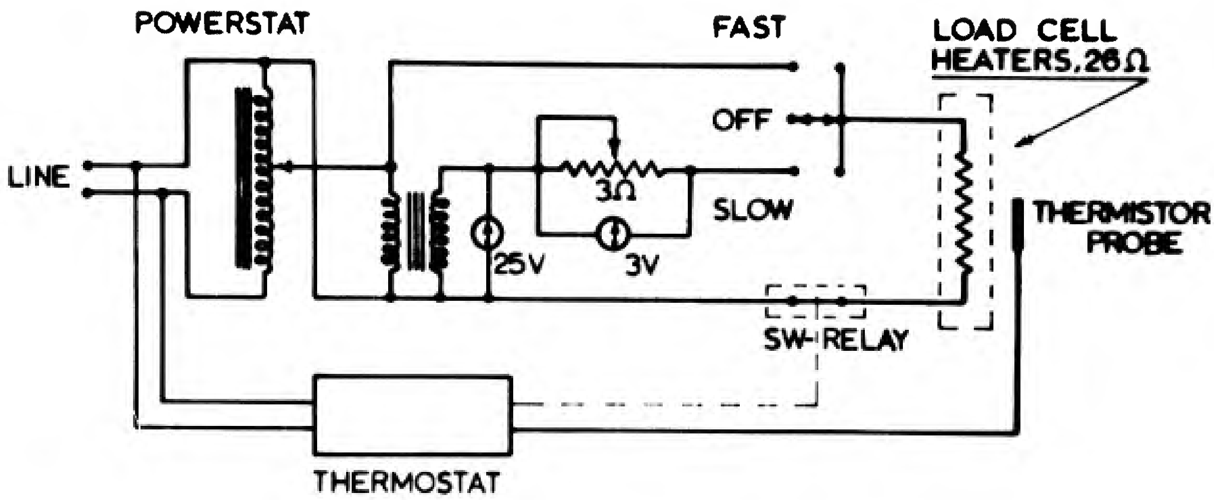


Figure 7. Circuit for manual control of load cell temperature. The thermistor thermostat section provided protection against over-heating of the load cell.

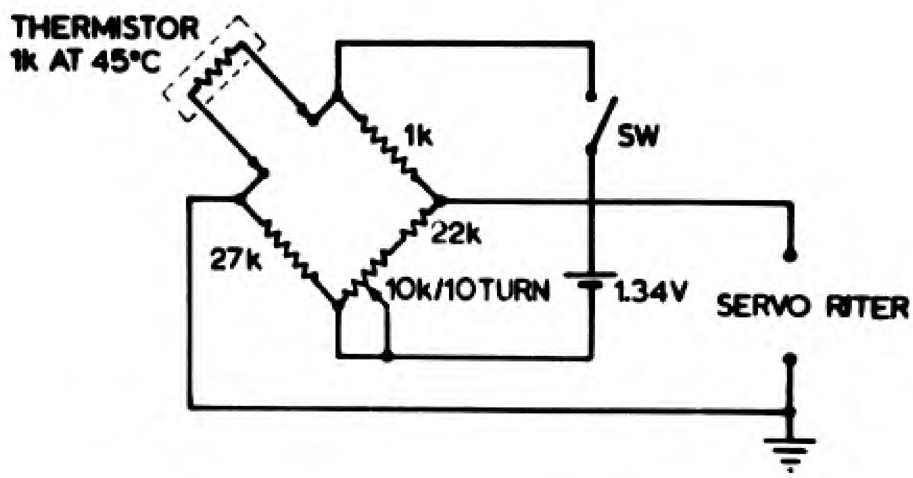


Figure 8. Circuit for inscription of variations in load cell temperature during either manual or automatic control.

Since manual control of the temperature of the load cell requires continuous attention, the circuit shown in figure 9 was designed to substitute for manual control. The thermistor forming one arm of the bridge circuit in the upper section of the figure is mounted on the load cell. Bridge imbalance through control of the amplifier section changes the output to the heaters located on the load cells. Bridge imbalance may be adjusted by a variable arm to obtain the desired temperature of the load cells. As this temperature rises towards the selected level the changing bridge imbalance correspondingly reduces the heating current until thermal equilibrium is attained. This process is continuous but we have found manual control by an experienced operator to be superior because his foresight permits anticipation of a swing in load cell temperature. A somewhat similar but less sensitive circuit has been described recently (2). In practice, we use the automatic control to maintain the temperature of the load cells at the desired level between experiments and resort to manual control during an experiment.

SECTION IV

HYSTERESIS

When the upper frame is lowered on the three unloaded load cells, several hours are required for their outputs to stabilize. Once this initial hysteresis has disappeared, the change in electrical output of the load cells during an increment or decrement in load is abrupt and complete within the response time of the recording system. It has been our practice to load the cells the day before an experiment. When the subject was then placed on the device, his weight could be read at once from the balancing potentiometer of figure 5.

SECTION V

PERFORMANCE OF THE WEIGHING DEVICE

Figure 10 illustrates the use of this device in following the rate of weight loss of a subject prior to and during an exposure to heat. With chamber temperature at 30°C, the rate of weight loss was 60 gm/hr or 30 gm/M^2/hr. An increase in this rate was first noted approximately 20 minutes after the beginning of the rise in chamber temperature when this had increased to 43°C.

Evaporative rates attained a steady value of 280 gm/hr about ten minutes after T_A had been stabilized at 43°C. The original record clearly showed the moment of increase in the rate of weight loss and its attainment of a steady value. A low chamber humidity permitted evaporation of sweat as it appeared on the skin surface. It is obvious that the use of this device for following total sweating is aided by a low humidity.

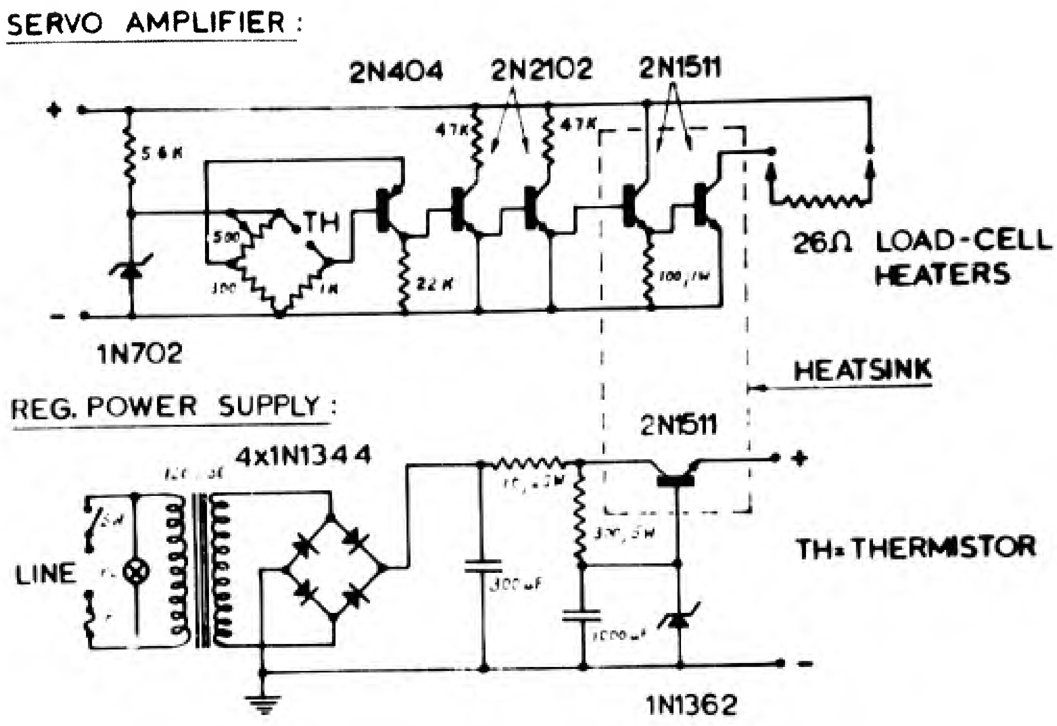


Figure 9. Circuit for continuous automatic control of load cell temperature.

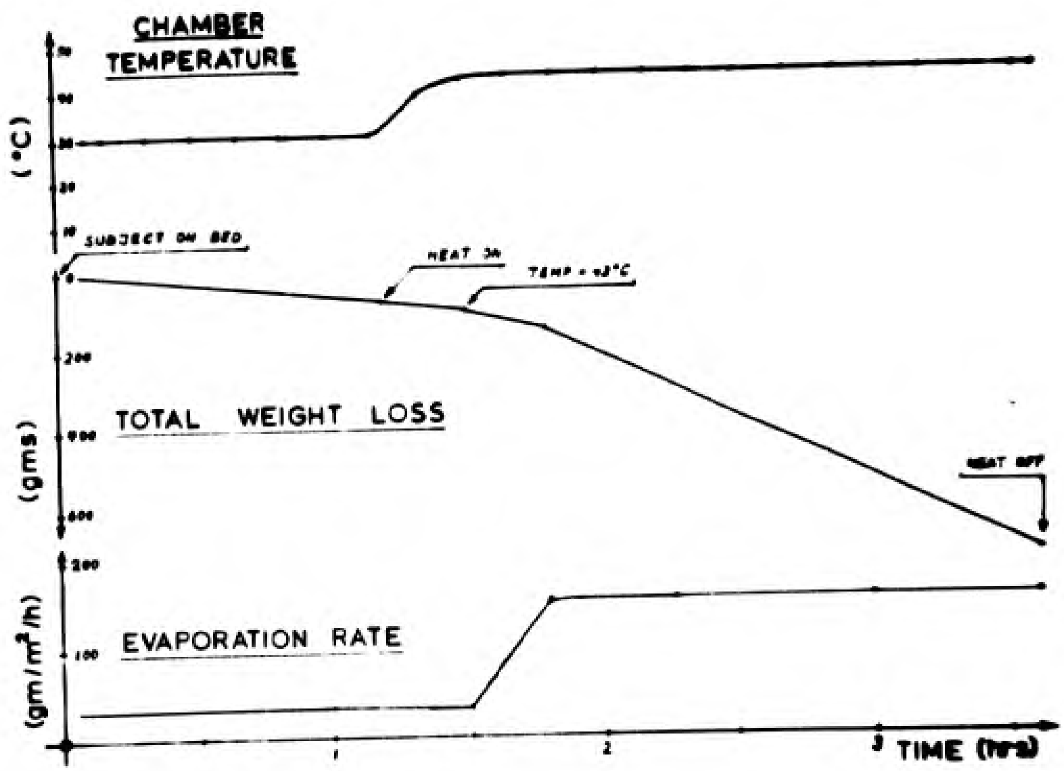


Figure 10. Changes in weight of a nude subject during exposure to a chamber temperature of 30°C and its subsequent rise to 43°C.

This weighing procedure may be employed when units for recording regional sweating (3) are attached to various skin surfaces. The water evaporated into such capsules is measured by the weighing device as it escapes from the body surface. Tared desiccating capsules are more difficult to use. Other recording devices such as thermocouples, photoelectric plethysmographs and impedance electrodes for measuring respiration or cardiac output may be employed so long as the weights of these attachments and cables remain constant.

A somewhat similar method of weighing the subject by means of proving rings was described (4) after the preparation of this report. However, the design requires a constant environmental temperature and does not appear to be suitable in its present form for climate chamber studies.

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3. A.B. Hertzman and F. Flath. "The continuous simultaneous registration of sweating and blood flow in a small skin area". Aerospace Med., 34:710-713, 1963.

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