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Report No. 24

DEVELOPMENT OF THE SECTIONALIZED HAND CALORIMETER

by

HERMAN MADNICK

Approved: Theodore L. Bailey, Chief
Clothing Branch

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FOREWORD

This report describes an apparatus which has been developed to obtain accurate measurements of the distribution of insulation over the hand, in particular that provided by cold weather handwear. This sectionalized hand calorimeter was developed by Dunn Engineering Corporation under Contract No. DA19-129-QM-1568 during the period of March 1960 thru September 1961.

The Technical Supervisor of the program was Project Officer, Herman Madnick (QM R&E Command). Mr. J. R. Breckenridge, U. S. Army Research Institute of Environmental Medicine, furnished additional technical guidance and conducted the experimental test runs of the hand.

ABSTRACT

A sectionalized hand with its surface divided into 23 separate sections, each individually heated, has been constructed. This calorimeter is hinged at each finger joint to permit them to be set at any position from extended to "ready to work." This apparatus may be used in two separate ways; (1) operated at a uniform temperature in a cool environment to provide information on the sectional insulation of handwear and (2) as a means of studying heat transfer from the human hand under various conditions.

Several types of handwear have been studied on the calorimeter to evaluate various techniques for insulating handwear. The instrument has proven capable of measuring and distinguishing the effects of changes in insulating materials and handwear design, and of changes in distribution of insulation on the hand. Results for three of the combinations studies are given.

I. INTRODUCTION

The essential Military Characteristics for cold-dry handwear requires that the handwear shall conform to the shape of the hand at rest and shall provide protection for as long as eight (8) hours at temperatures as low as -65°F and yet allow the wearer to operate all types of arms and equipment and perform other duties.

The present method of insulating the hand does not provide adequate environmental protection at the lower limits. Due to the bulk of insulation acquired at these limits, satisfactory manual dexterity to meet the required Military Characteristics is extremely difficult to obtain. Studies[1], primarily in terms of manual performance, were conducted wherein the relative merits of experimental handwear ensembles designed for use under arctic conditions were conducted. One of the items tested indicated the redistribution of insulation principle, wherein greater insulation is placed over the back of the hand than on the palmar side, was sound and should be improved. However, the addition of insulation also causes extreneous enlargement of the handwear making it too cumbersome to wear when performing normal duties.

The present methods of evaluating handwear for environmental protection, wherein a straight fingered continuous surface copper hand (Figure 1) is used, cannot indicate where the greatest heat loss occurs, but merely provides an overall value. Thus, significant developments on environmental protective handwear seemed unlikely until a suitable means of determining sectional insulating value with the hand in its normal, flexible, relaxed position became available.

Accordingly, a contract was awarded (Dunn Engineering, Corporation, Cambridge, Mass., Contract No. DA19-129-QM-1568) for a complete laboratory instrument to measure the effective heat loss occuring in various types of handwear with the hand in a relaxed or curved state, and the relationship of such heat loss to that with the hand in varying working positions. In effect, the results of testing handwear on an instrument of this type would indicate which areas of a particular type of handwear being tested should be redesigned to include additional insulation.

A design suggested to the contractor for such instrumentation is listed as follows:

1. Hinged hand, made of wood or other non-conductive material, conforming to the hand at rest, and in a straight position, the surface of which shall be divided into a number of appropriately distributed zones. Each zone will be provided with a temperature sensing device and electrical heating elements and will be covered by a metal equalizing plate. The test zones will be guarded by the zones adjacent to its perimeter. The uppermost zone in the wrist area will function as a guard ring to prevent edge losses from the testzones.

2. Power input feeders for heaters of the sectioned hand.

3. Temperature measuring circuitry to measure temperature of the hand zones.

4. Suggested Zones--fingertips (front and back), palm, back of hand, thumb (front and back), wrist.

5. It was required that the sectionalized hand form and electrical circuits be compatible with a Weston Multiple 24 Point Recorder Model 6702.

II. DEVELOPMENT OF THE SECTIONALIZED HAND CALORIMETER AND CONTROL UNIT

The guarded hot plate method of measurement of heat conductivity is a well known and accepted technique for use with materials in flat sheet form. The Sectionalized Hand Calorimeter is essentially a number of guarded hot plates in the shape of a hand. Each individual section is a separate conductivity measuring apparatus guarded by the sections adjacent to it. The calorimeter is intended to be used to determine for each section the insulating value of the materials covering it. With this instrument the insulation values over the hand can be mapped for any given design of handwear so that any weakness may be noted.

GENERAL DESCRIPTION:

Sectionalized Hand--The hand consists of a form of epoxy resin in the shape of a hand. The fingers are separated at each joint and hinged so that they can be moved into a variety of positions to simulate the various hand positions. The hinges at the base of the index, ring, and small fingers are so fabricated that the fingers can also be spread sideways to facilitate dressing the hand. The individual sections of the hand are covered with thin copper sheet heated with uniformly spaced nichrome wire in close contact with the underside. The leads for each heater and for a copper constantan thermocouple soldered to the copper surface are brought down through holes drilled in the sections, except for those associated with the palm and back of hand which are brought directly to the base. This hand is supported vertically with the fingers upward on a non-conducting plate and chassis base which also supports the connectors for the thermocouple and heating circuits. (See Figure 2.)

Twelve Sections of the hand (positions 1-12) are designated as test sections while the other eleven areas (positions I-XI) are designated as guard sections. (See Figure 3.) However, all but one guard zone can be used as test zones to determine insulation, (in the same way as the designated test zones are used) since each guard zone is in turn guarded by the two adjacent zones. The twelve test sections are located as follows: Two each per first joint of each finger; a circular section approximately one inch in diameter in the center of the palm; and a like section on the back of the hand approximately 1-1/2 inch in diameter.

The test zones on the tips of the thumb, index, and little finger are separated side from side while the other two fingers are separated front from back. The epoxy is in one piece for each fingertip but the metal covering is applied in two individually heated sections separated by approximately 1/16inch. These metal sections are held in place by small screws countersunk flush with the metal.

The guard zones include the remainder of the finger sections (one thumb section and two sections per each finger), a section made up of the bulk of the hand, which acts as a guard for the two circular test sections, and a forearm guard extending from the wrist to the base.

The heaters for the various sections were designed for a total power dissipation (maximum) of 15 Watts. The resistance requirement for each section was obtained assuming a uniform distribution of insulation over the hand, i.e., that the power required was proportional to surface area. This basis of design was necessary for lack of information on the variation of handwear insulation from zone to zone but has proved satisfactory with the handwear already studied. Future experience may indicate the need for some changes in this power relationship for the sections, but this can be accomplished by changing the control rheostats in the operating console. (See Figure 4.)

Control Unit--The temperature of each hand section is set by adjustment of the current to the heating element. These adjustments are made by varying rheostats supplied from a common regulated constant voltage source. This source is adjustable between 0 and 6V to permit raising or lowering the operating temperature of the entire hand A constant voltage transformer provides 115V output, which is stepped down to 6V with a filament transformer, and then further adjusted by means of an auto-transformer controlled by the operator. The control unit also includes a voltmeter for reading the potential on each circuit, and a selector switch for connecting either the test zone thermocouples or the guard zone thermocouples to a recorder. This switching arrangement was necessary to make the calorimeter compatible with an already existing sectionalized foot calorimeter[2] which employs 12 points of the recorder for temperature measurement. The two calorimeters must be used separately since the thermocouple circuits for the hand calorimeter are connected to the recorder through the connectors used for the foot calorimeter.

III. METHOD OF OPERATION

There are two different ways in which the calorimeter can be operated. The first, uniform temperature operation, is used to measure the insulating value over each section. The second, in which the temperature pattern over the surface is non-uniform, may be used to study the actual heat losses from various sections of the hand for a particular environmental condition. The value of the second method will depend on several factors, namely, (1) the degree of thermal similarity of the calorimeter and human hand, and (2) the ability to determine and reproduce the temperature patterns found on the human hand. No experience with this second method of operation has yet been obtained as the information is not yet available and the discussion will be confined to the first (uniform temperature) method.

For insulation measurements, the hand is operated at a temperature between 60°F - 90°F depending on the environmental temperature and the insulating characteristics of the handwear. This choice of operating temperature is permissible because of the direct proportionality between heat loss and temperature difference from zone to air (Fourier's Law). The hand is placed in a constant temperature room in the handwear under test with its fingers positioned as desired. Initially, the auto-transformer is set at mid-range or where indicated by experience. The rheostats on each zone are left undisturbed until the temperature of the respective sections provides information on the direction of adjustment needed. This indication does not occur until the central mass of epoxy has been warmed, which requires a waiting period of as much as two hours. In particular, the temperature of the palm/back section must be at or near the desired operating temperature before all but gross adjustments on the other sections can be made. Because of this, it is convenient not to preselect an exact operating temperature but to select it during the experiment on the basis of least adjustment to the individual rheostats. To illustrate: Some section temperatures will be higher initially than others and the easiest method of obtaining a uniform temperature is to raise the temperatures on some zones and lower the temperatures on others (bearing in mind the operating temperature of the palm/back zone.) Adjustment of the individual rheostats is continued until all sections are within $\pm$ .2°F of the palm/back section and show no change after a wait of approximately one hour. The experiment is concluded by observing and recording the section temperatures, air temperature, and the section voltages.

Calculation--The heat transfer coefficients for each section are calculated as follows: The wattage dissipated by the section is taken as voltage square divided by the difference between surface and air temperatures and by the area of the section and converted to give a coefficient in kilogram calories per hour per degree F per square meter of area. The value can be readily converted into Clo units by dividing into 3.09 (3.09 ÷ Kg. Cal./Hr/°F/m^2).

IV. TEST RUNS

Preliminary test measurements of heat loss of several experimental types of handwear were made. These included insulated construction as compared to the same design less the insulation.

To illustrate the capability of the calorimeter with respect to affect of design and insulation, three curves of heat transfer, coefficients vs zones, were plotted (Figure 5) to compare the Standard U. S. Army Glove Shell Leather, M-1949, against two experimental handwear designs. These are: (1) A Glove Shell Leather with lightweight insulation added to the back of the hand, fingers, and thumb, worn over a U. S. Army Standard Glove Insert, Wool, M-1949, and (2) A Mitten Shell Leather, 3/finger with lightweight insulation added to the back of the hand, fingers, and thumb, worn over an experimental 3/finger Mitten Insert, wool, equal in material quality to the U. S. Army Standard Wool Glove Insert.

Several observations can be made from Figure 5. By the collection of several fingers in one grouping (3/finger Mitten Shell) results in lower coefficients, whereas separating each finger increases the heat loss per section.

Adding insulation on the back of the hand made the experimental glove somewhat better than the Standard Glove, except for the fingertips. However, fingertips are most susceptible and this attempt to improve handwear protection has not been beneficial in this respect.

V. REFERENCES

1. Environmental Protection Research Division, QM R&E Command, Research Study Report entitled, "Evaluation of Experimental Arctic Handwear in Terms of Manual Performance," dated May 1956, prepared by Wm. C. Roehrig.

2. Textile, Clothing & Footwear Division, QM R&E Command, Clothing Branch Series Report No. 16, Research Study Report entitled, "Areas of Effective Insulation in Cold Climate Footwear and Development of the Sectionalized Foot Calorimeter," dated 31 March 1960, prepared by Philip A. Crispino, Research Group Leader and Norman D. Marcus.

FIGURE 1.
STRAIGHT FINGERED CONTINUOUS SURFACE COPPER HAND

FIGURE 2.

SECTIONALIZED HAND CALORIMETER

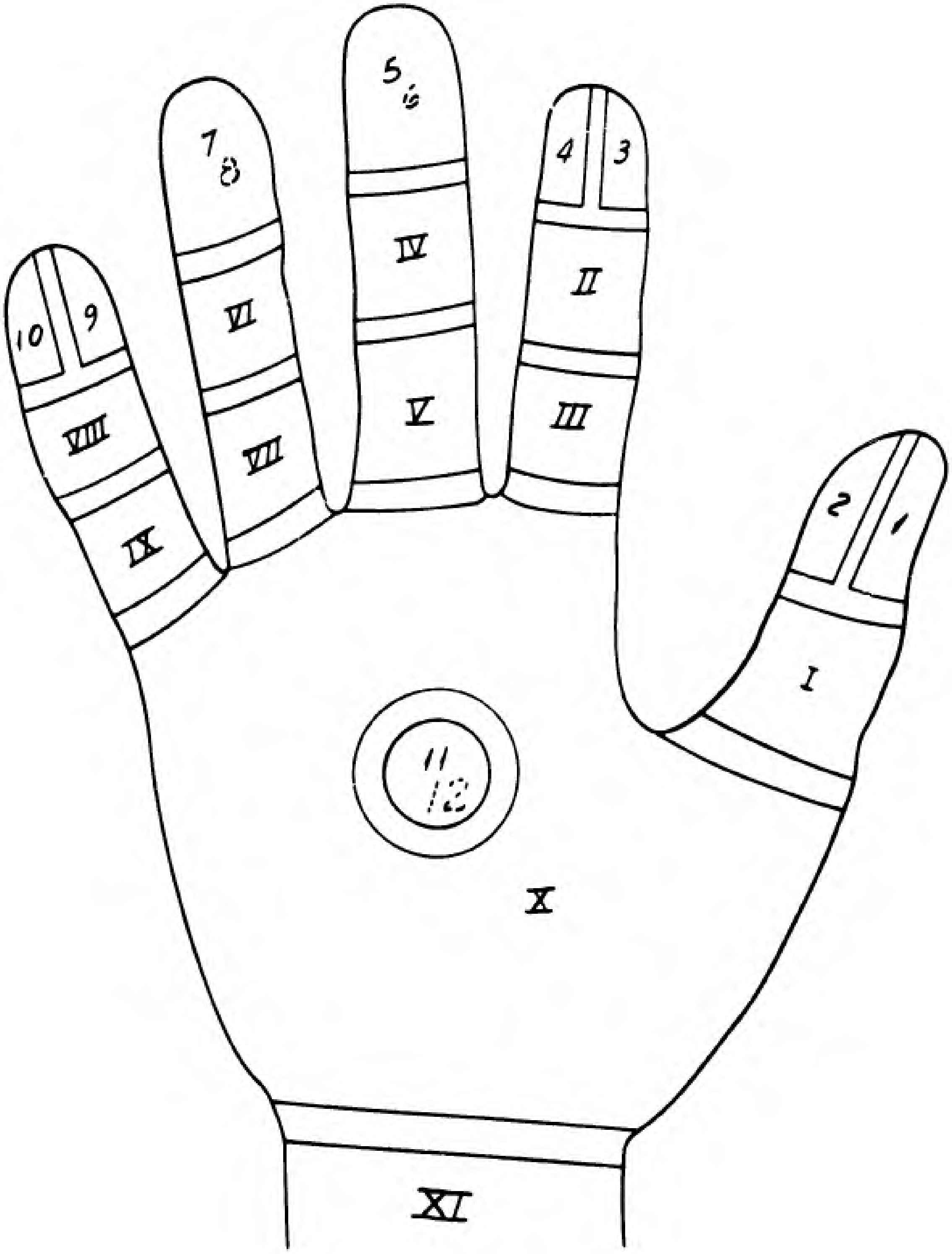

FIGURE 3.

DRAWING OF HAND SECTION

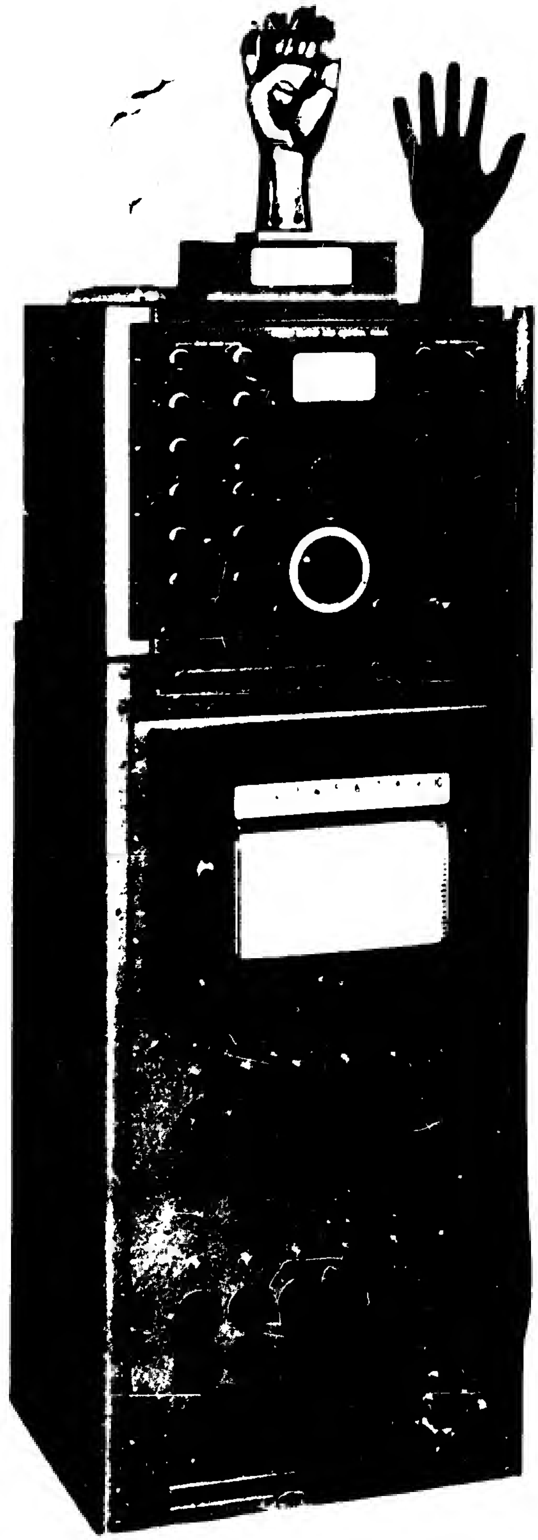

FIGURE 4.

CONTROL UNIT WITH HAND

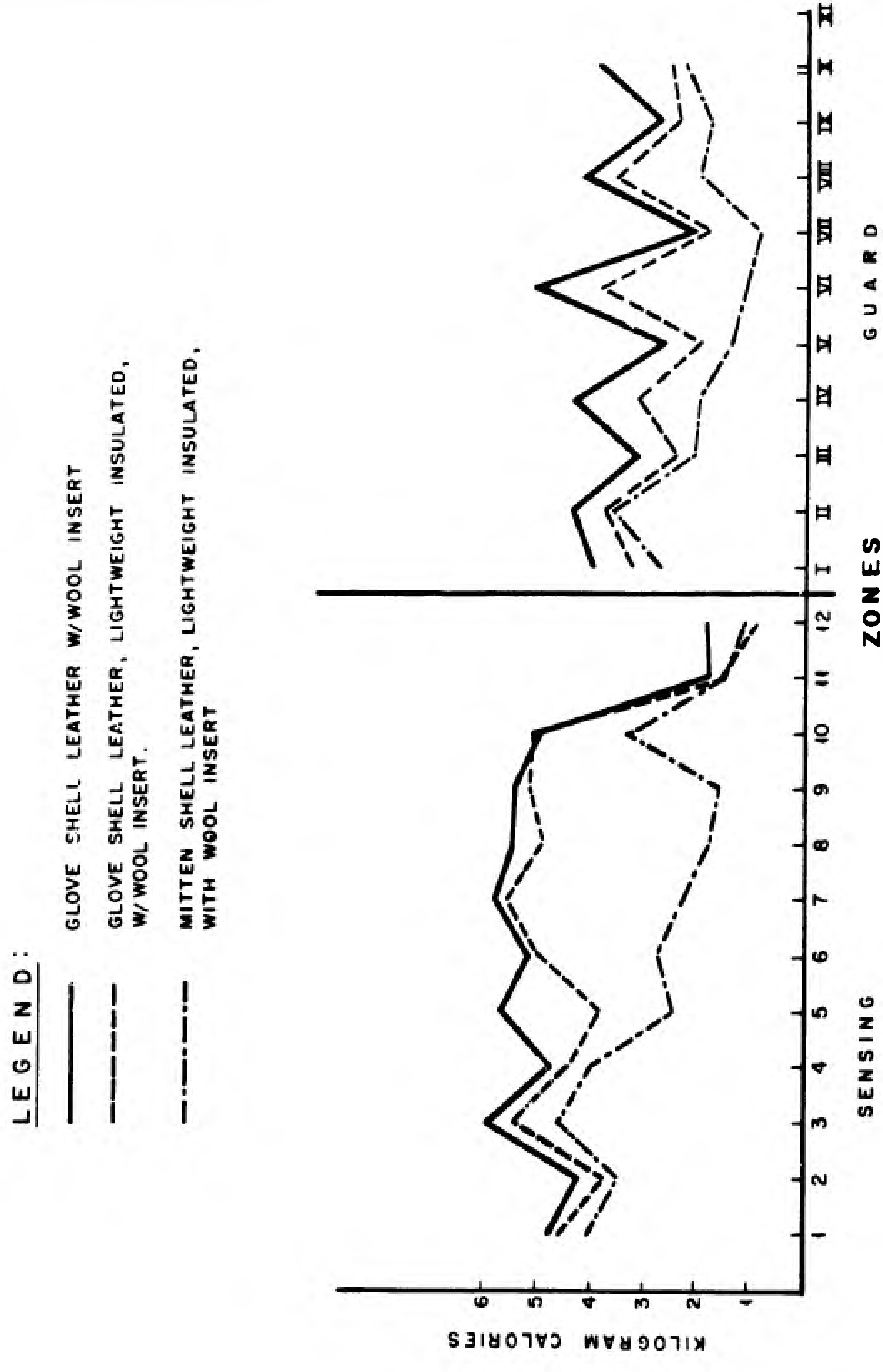

FIGURE 5.

HEAT TRANSFER CURVES

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