A HEAT FLUX MANNEQUIN INSTRUMENTED WITH 28 THERMAL GUARDED CALORIMETERS

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INTRODUCTION

Bair Hugger® forced-air warming therapy utilizes both convective and radiative heat transfer to transport energy to a patient's cutaneous layer. Bair Hugger® therapy consists of a plastic canopy carefully positioned over the patient, the lower canopy surface being permeable by virtue of more than 2000 discrete, small-diameter holes. The holes cause air jets to be directed onto the patient while, simultaneously, the canopy emits infrared radiation which impinges on the patient. Traditionally, heat flux transducers are used as a tool to quantitatively measure the heat flux delivered by warming therapies such as the Bair Hugger® system. Despite the cost effectiveness of these transducers, questions have been raised regarding their accuracy. An underestimation of 29-35 percent of the measured heat flux is incurred when using heat flux transducers on vasodilated warm patients [1]. To avoid these errors, it was determined that a thermal mannequin be used to measure the delivered heat flux.

In appraising thermal mannequins that have been designed and fabricated over the last 50 years, two insufficiencies are apparent. Most importantly, the existing mannequins produce surface-averaged heat transfer rates over each of their sections [2]. Secondarily, all but two mannequins had no more than 16-19 measurement sites. Data from the two with more sites were usually combined into 16-19 sections for reporting purposes.

The mannequin developed here was designed to provide highly localized heat flux data at as many as 28 distinct surface locations. The heat flux gauging system built into the mannequin enables separate identification of the convective and radiative components of the heat flux. Each gauge is a guard-heated, insulated calorimeter. Different surface finishes of the face of the calorimeter facilitate radiation-convection separation. The mannequin is built to accommodate 28 individual gauges.

METHODS

The essential components of each gauge include a disk-shaped calorimeter, a guard-heating system to prevent extraneous heat losses or gains at the back face of the calorimeter disk, and suitable insulation to minimize heat losses/gains at the lateral faces of the disk. The front face of the calorimeter disk is flush with the surface of the mannequin. Convective and radiative interactions between the calorimeter and its surroundings occur at the front face.

Two types of calorimeters are used. Calorimeters with polished front faces will measure the convective heat flux, and black-faced calorimeters will measure the combined convective and radiative heat flux. The respective finishes are respectively achieved by hand polishing and by black anodizing atop of sand-blasting. Each disk is made of aluminum, 1.0 inch in diameter and 0.13 inches thick.

To determine the heat fluxes which occur during warming therapy, the timewise temperature variations of a calorimeter disk are measured using a 0.005 inch diameter, type E thermocouple imbedded in the back face of the calorimeter disk. The thermocouple signals are processed using a National Instruments SCXI multiplexer, a MIO analog board and a LabVIEW® package. The back face of the calorimeter is equipped with a wire-wound heater (0.003 inch diameter Chromega™ resistance wire).

The guard heater assembly is situated immediately adjacent to the back face of the calorimeter disk. A closed-loop electronic control system regulates and energizes each guard heater whenever a 0.010 inch diameter, type E differential thermopile installed in each assembly senses an axial temperature difference across a thermal resistance. This regulation produces a pseudo-adiabatic boundary condition at the back. face of each calorimeter. With the measured timewise disk temperatures and with the known power input at the calorimeter heater, combined convective-radiative heat transfer rates or pure convection heat transfer can be backed out, respectively for the black-faced and polished-face disks. Here, the analysis tool is an energy balance. It is necessary to deduce the radiation heat transfer coefficient in an indirect manner. Since both the convective and radiative heat transfer modalities act in parallel, the measured beat transfer coefficient for the polished calorimeter assembly is subtracted from the measured heat transfer coefficient for the blackened calorimeter assembly.

In order to measure the electrical power input to the calorimeter disk, the voltage across the calorimeter heater and the current flowing through it are measured. With a 0.010 inch diameter Chromega™ wire soldered across the heater input leads, the heater voltage is measured and processed using a National Instrument SCXI multiplexer. To measure the current through the heater, a 1.0 ohm, temperature-insensitive shunt resistor is placed in series with the heater. Once the voltage across the shunt resistor is measured, the current can be calculated using Ohm's Law. To reduce the cost of purchasing additional boards for the card cage in the SCXI multiplexer, Cpole AC relays will be used to multiplex the signal voltages from both the heater and shunt circuits. The 28 sites at which the calorimeters are installed in the mannequin are shown in Figure 1.

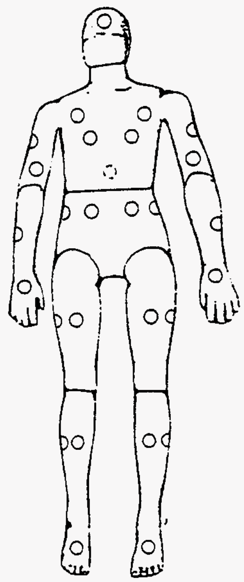

FIG. 1 MANNEQUIN CALORIMETER SITES

RESULTS

Preliminary experiments have been carried out to determine the relative magnitudes of the convective and radiative heat transfers associated with Bair Hugger® warming therapy. These results show that convection is the dominant mode.

CONCLUSIONS

The capability of the newly devised mannequin to measure local heat transfer rates to high accuracy makes it an especially valuable tool to guide the development of focal warming systems. The extensive number of available measurement sites further enhances its capability for local resolution. Also of great value is the special feature of separating the individual convective and radiative heat transfers. In a continuing study, the heat transfer rates provided by Bair Hugger® convective therapy and its competitive convective therapies are to be assessed.

REFERENCES

1. Ducharme, M. B., et. al. 1990, Errors in heat flux measurements due to the thermal resistance of heat flux disks, DCIEM Report No. 90-P-27.

2. Wyon, D. P. 1989, Use of thermal manikins in environmental ergonomics, *Scand J. Work Environ. Health* 15(suppl. 1), 84-94.