Temperature Equivalent of Solar Radiation on Man

by

D. H. K. Lee* and I. A. Vaughan**

INTRODUCTION

The climatic elements which determine the net rate of heat loss from the human body, and thus the ease with which it can achieve a heat balance, are four in number: temperature, humidity, air movement, and radiation (Lee 1958, 1962, 1963, 1964).

Several methods for making a combined assessment of these four thermal factors have been put forward (Yaglou and Miller, 1925; Gagge, 1940; McArdle et al., 1947; Bedford, 1945; Robinson, Turrell and Gerking, 1945; Belding and Hatch, 1955; Carlson and Buettner, 1957). These either omit radiant heat exchange, or deal with industrial rather than open desert conditions.

Inclusion of radiation effects would be simplified if they could be expressed as the rise of air temperature which would produce the same physiological responses. This is possible, of course, only when the non-radiative conditions are such that bodily responses have been raised to levels where any additional stress produces a further response which is measurable with certainty and is quantitatively related to the stress increment.

Since summer conditions in the open desert are such as to raise the physiological processes of exercising men to these levels, it was decided to determine the increment of air temperature equivalent to the radiation load (ITER), by comparing the physiological reactions of subjects exposed to desert conditions with the reactions of the same subjects exposed to similar ambient conditions but without radiation, and at various higher air temperatures.

Attempts had been made to devise a mathematical formula by which the heat exchange through radiation between a man and his surroundings could be expressed in terms of an equivalent rise in air temperature. The formulation is fairly complicated, and involves certain assumptions. It is clearly desirable to make some direct comparisons between the net physiological effects of a rise in air temperature on the one hand, and the effects of added radiant heat on the other.

Information of this nature was gathered by Adolph and Molnar (1946) in the course of systematic studies of man's reactions to hot environment; but inasmuch as such measurements are always approximate and limited by the conditions under which they are made, it was decided to make a further assessment through a more controlled approach, using mobile chambers in which ambient conditions could be controlled. Simpler methods were first tried, but as these proved inadequate more complex methods were later adopted.

MATERIALS AND METHODS

TRANSPORTABLE SOLAR CHAMBER: The basic unit is a climatic chamber, Fig. 1, measuring 12 ft by 8 ft (3.66 m by 2.44 m) with 6 ft (1.83 m) lateral walls, and a ridged roof rising in the center line to 12 ft above the floor. The walls and roof are composed

*) Division of Occupational Health, U.S. Public Health Service, Cincinnati, Ohio.
**) Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Oklahoma, U.S.A. Studies were made while the authors were employed by the U.S. Army Quartermaster Research & Development Command, Natick, Mass.
Received 9 June 1964.
of panels, 24 in (0.61 m) wide, each consisting of a $\frac{1}{4}$ in (1.25 cm) metal frame, on which mylar film, 0.005 in (0.13 mm) thick, is stretched. Beneath the wooden floor an air-input duct runs along each side and discharges through six registers situated close to and directed up along the walls. The space between the two input ducts constitutes a single return-air duct, drawing through four floor grilles. The center section of the floor is removable for the insertion of a treadmill. Aluminum screens can be bolted into position over the walls and roof when it is desired to exclude radiation.

The input and return ducts are connected through flexible hose and metal fittings with a conditioning compartment at one end of a "machinery" trailer, Fig. 2. This conditioning compartment contains heating and cooling coils supplied by air-conditioning machinery, and a large centrifugal fan with adjustable baffles so arranged that the desired proportion of fresh air can be taken in, and the flow over heating and cooling coils controlled as required.

The power is supplied by a 50-kw V8 gasoline motor-generator. Connected to the radiator of the generator motor is a large water tank, from which a pump circulates the heated water as required through the heating coils of the conditioning compartment. Auxiliary electric heaters powered from the generator can be used to raise the temperature of the water still further if desired.

A 30-ton compressor, utilizing Freon 22, and powered from the generator, supplies refrigeration for the cooling coils of the conditioning compartment, through a two stage system. Heat is removed from the compressed refrigerant by an evaporative condenser through which a strong draft is maintained by three fans.

Two Brown recorder-controllers, actuated by dry- and wet-bulb thermocouple thermostats in the climatic chamber, regulate the flow of hot and cold solutions through the conditioning coils. The dry-bulb controller regulates the flow of hot solution through the heating coils, and also maintains the flow of cold solution through the cooling coils whenever that is required to balance heating. The wet-bulb controller regulates the humidifiers and also maintains the flow of cold solution through the cooling coils whenever that is required to lower the wet-bulb temperature, and thus the humidity. The controls operate through compressed air regulating valves in the hot and cold lines.

The treadmill and other ancillary apparatus also draw power from the generator. The component parts of the climatic chamber are stored in a second trailer when disassembled. This trailer also contains two Bristol 6-point thermocouple recorders, radiometric and thermometric equipment, and other basic laboratory necessities, and serves as a laboratory and work room when the components of the climatic chamber are removed.

EXPERIMENTAL PROCEDURES: Subjects walked for 2 hr at 94 m/min on a treadmill in the climatic chamber, with an air temperature of 37.8°C, a known vapor pressure and air movement. They subsequently repeated the experiment with radiation screened out by metal covers at different air temperatures. A second experiment with exposure to solar radiation was performed in each case to check on training and acclimatization changes. Insofar as weather conditions permitted, subjects performed daily until the series (12 to 21 experiments) was complete. During the series each subject was under the usual disciplinary regime.

Four combinations of air movement and clothing were employed, namely, low air movement (45 m/min ventilation turbulence) with desert uniform, low air movement with minimum underwear, high air movement (152 m/min direct fan stream over whole side) with desert uniform, and high air movement with minimum underwear. Subjects were permitted to drink cooled water each 15 min in multiples of 250 ml as desired.

The air temperatures used in experiments without radiation were 40.6, 43.3, 46.1, 48.9°C and the vapor pressure was controlled between 6 and 10 mm Hg. The times of the experiment were 09:07 to 11:07, 11:37 to 13:37, and 14:07 to 16:07 hr MST. (True solar noon was at 12:57 hr MST). Physiological measurements included nude body weight at the beginning and end; weight of clothes at the beginning and end; rectal temperature measured with a clinical thermometer at the beginning and every 30 min; pulse rate at the beginning and every 15 min.