# Prototype Heat Attenuation Vest

Uwe Reischl[1], Ravindra Goonetilleke[2], Budimir Mijovic[3], Zenun Skenderi[3]

[1]College of Health Sciences, Boise State University, Boise, Idaho, USA
[2]Department of Industrial Engineering and Logistics Management, Hong Kong University of Science and Technology, Hong Kong
[3]Faculty of Textile Technology, University of Zagreb, Zagreb, Croatia

**Abstract:**

Solar heat radiation can impose significant heat stress on persons working outdoors. A prototype light-weight vest was developed which can offer protection to agricultural workers and constructions workers exposed to high levels of solar radiation. The prototype vest was tested using a laboratory based thermal manikin which was exposed to controlled heat radiation intensity levels. The tests showed that a vest including 3.2 cm spacers can reduce heat gain by 30% without imposing a significant corresponding insulation heat gain. The thermal cross-over point for such a vest was lowest in comparison to others tested. Commercial development of such a vest for use by agricultural workers and construction workers in hot solar environments is encouraged.

**Key Words:** Heat Stress, Infrared Radiation, Heat Attenuation Vest, Thermal Manikin

**Sazetak:** To be translated into Croatian

**Kljucne rijeci:** To be translated into Croatian

## 1. Introduction

Solar infrared heat radiation can impose a significant heat load on workers who are engage in outdoor occupational activities. Agricultural workers and construction workers are known to have a high risk of heat stress especially in arid climates where high ambient air temperatures are often associated with intense daytime sunshine. These conditions present occupational environments that may lead to serious heat illnesses. Use of tents, hats, and other protective equipment are frequently employed to help reduce solar heat exposure. However, such measures may be impractical in work settings where the workers are engaged in complex manual tasks, must interact with multiple tools and equipment, and are required to change body posture and location. Requiring employees to use protective clothing in such environments may also be counter-productive because such garments impose heat stress on the body by adding insulation and reducing air flow over the skin which subsequently reduces sweat evaporation.

Physiologically, the human body is a metabolic heat generating system that maintains a balance between heat loss and heat gain. This mechanism allows the body to observe a narrow range of internal temperatures which is required by the body. Many environmental factors such as air temperature, air velocity, heat radiation, and humidity can affect this balance (1 -4). Clothing material and garment design can also impact the heat balance body by promoting or reducing heat exchange through sweat evaporation, convection, conduction, and heat radiation. The radiant protective performance of fabrics is related to the chemical and physical structure of the fabric material being used including thickness and weight. Woven textile materials generally do not offer a good barrier against infrared radiation. However, the greater the thickness and greater the weight of the fabric, the better the radiant protective performance (5).

The development of a light-weight vest was undertaken to offer an alternative protection strategy for agricultural workers and constructions workers exposed to high levels of solar radiation. Two prototype vests were assembled and tested using a thermal manikin which was placed in a controlled environment. Data were obtained that identified optimal design features of a solar reflector vest capable of reducing outdoor heat stress.

## 2. Methods and Procedures

Two vests were assembled for testing. The vests consisted of thin (1.0 mm) flexible CB material which was cut into a pattern that offered a simple vest design which included a front panel and a back panel as illustrated in Figure 1. One vest had a plastic reflective surface (Berry Plastics) while the other did not. Both vests included flexible ring-spacers that maintained a gap between the vest and the skin of the manikin. The spacers were distributed uniformly over the front and back panels of the vest. The spacers maintained a separation between the vest and the manikin skin at distances of 1.6 cm and 3.2 cm.

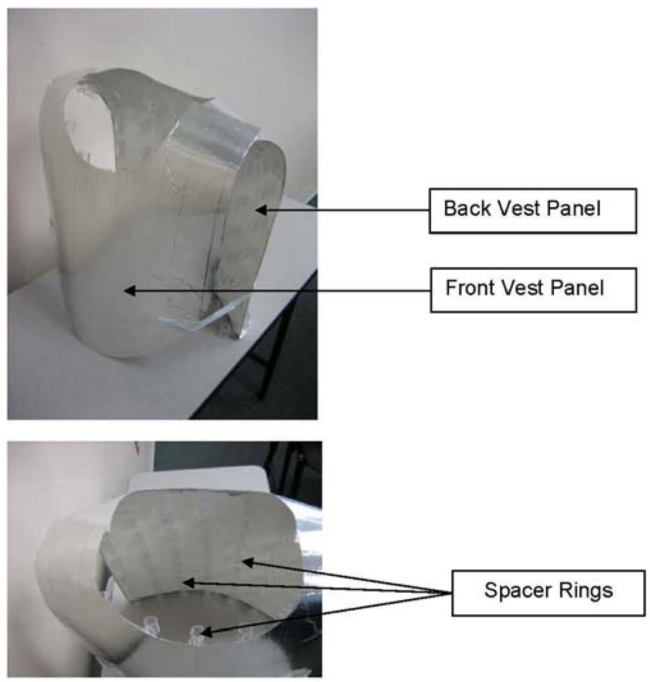


Figure 1. Prototype vest develop to reduce exposure to outdoor heat stress. The vest consists of a front and a back panel connected to each other over the shoulders. Inside both panels are equally spaced flexible plastic rings that can be adjusted to provide 1.6 cm and 3.2 cm separations between the vest and the manikin skin.

The thermal manikin tests were conducted using the protocol described by Mijovic, Reischl, et.al. (6-8). All experiments were preceded by a reference (control) run using a semi-nude manikin configuration as illustrated in Figure 2. Environmental air temperature conditions were maintained between 22.5$^{0}$C and

23.5$^0$C, relative humidity was maintained between 40% and 45%, and no heat radiation exposure sources were present.

Each of the two vests was evaluated for conditions with no heat radiation exposure as well as with heat radiation exposure. Heat radiation was produced using four 250 watt IR lamps directed at the chest of the manikin. The reflective vest was tested with both the 1.6 cm spacers and the 3.2 cm spacers. The non-reflective vest was tested with the 3.2 cm spacers only. For comparison purposes, a lightweight fabric jacket (2.0 mm thickness) was also evaluated under both non-radiation conditions as well as for radiation conditions. There were no spacers placed into the jacket. The manikin heat radiation exposure set-up is illustrated in Figure 3.

Figure 2. Inflatable thermal manikin used for assessing the effectiveness of the prototype vests. The photograph illustrates a semi-nude (control) manikin configuration

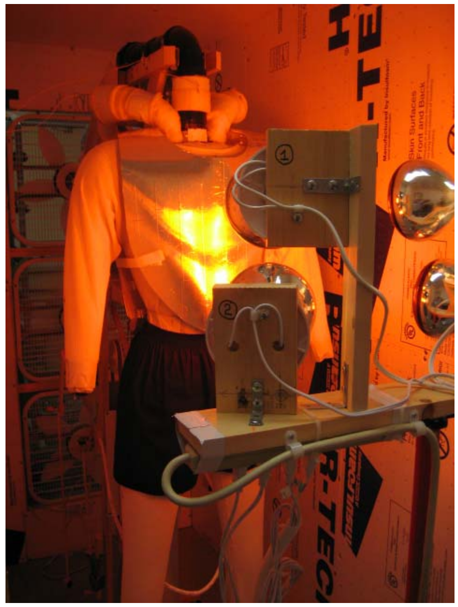

Figure 3. Illustration of inflatable thermal manikin exposed to infrared heat radiation while wearing prototype vest. The heat radiation produced by the four IR lamps was directed onto the chest of the manikin.

## 3. Results

Total manikin body heat gain was used as the measure for heat stress. Total body heat gain was also used to evaluate the insulation imposed on the manikin by the garments. The test results are summarized in Table 1.

Heat gain for both the control condition (semi-nude / unprotected) and the jacket condition was 61.2 watts each. The Non-reflective vest exhibited a heat gain of 38.5 watts, while the aluminized vest with 3.2 cm spacers exhibited a heat gain of 42.7 watts. The aluminized vest with 1.6 cm spacers exhibited a heat gain of 47.0 watts.

Table 1. Summary of manikin heat gain with exposure to infrared heat radiation for the control condition (semi-nude), for the two prototype vests, and for the comparison jacket

| Garment Design | Ventilation Space between garment and skin | Measured insulation heat gain without IR exposure | Measured heat gain for IR radiation exposure |
|---|---|---|---|
| | | | |
| Manikin semi-nude (Control) | N/A | N/A | 61.2 watts |
| Non- reflective Vest (CB) | 3.2 cm | 1.5 watts | 38.5 watts |
| Aluminized Vest (AL) | 3.2 cm | 4.3 watts | 42.7 watts |
| Aluminized Vest (AL) | 1.6 cm | 8.6 watts | 47.0 watts |
| Jacket | 0 cm | 17.1 watts | 61.2 watts |
| | | | |

## 4. **Analysis**

Table 1 shows that the reflector vest with 3.2 cm spacers exhibited the highest IR heat reduction. The difference between the aluminized reflective surface and the non-reflective surface was less substantial. All configurations contributed to heat gain due to the individual insulation characteristics of each garment.

The relationship between the four vest designs, jacket, and the semi-nude control configuration of the manikin is illustrated in Figure 4. It can be seen that all of the garment configurations provided a beneficial shielding. However, the beneficial effects generally increased with increasing heat radiation levels. The degree of protection offered by a garment is defined by the temperature cross-over point. This point identifies the infrared heat radiation level above which the garment reduces heat stress on the body compared to a semi-nude configuration. Below this cross-over point, the garment imposes “unnecessary” thermal insulation. Figure 4 also shows that the non-reflective (CB) vest configuration exhibited the lowest cross-over point. This is also seen in Table 1 with a insulation heat gain of only 1.5 watts. The highest temperature cross-over point (and the highest baseline insulation heat gain value of 17.1 watts) was exhibited by the jacket.

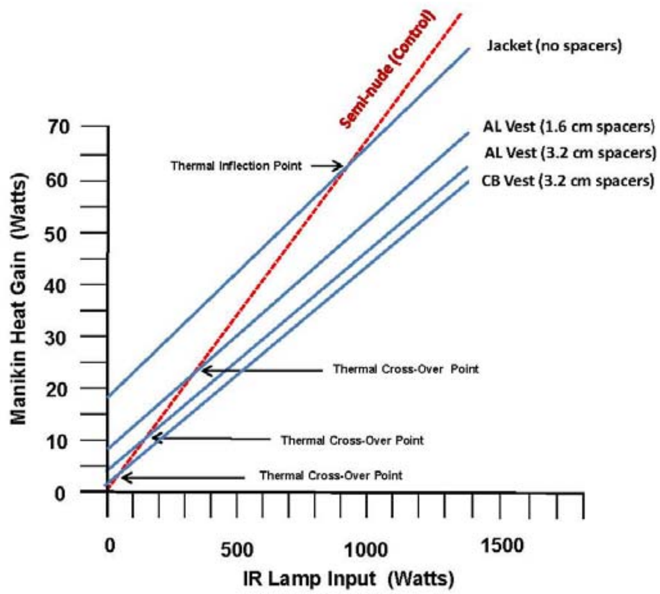


Figure 4. Relationship between IR exposure and manikin heat gain observed for the manikin semi-nude control configuration, for the three vest configurations, and for the jacket configuration. The graph is based on data obtained for the “0” IR exposure level and the 900 watt IR lamp power input level.

## 5. Conclusions

Our data suggest that use of solar reflector vests can reduce heat stress for employees engaged in outdoor work during exposure to high solar heat conditions. The laboratory data showed that a vest with 3.2 cm spacers can reduce IR heat gain substantially without imposing a concomitant insulation heat gain. Use of aluminized reflecting surfaces did not measurably increase the infrared reflection efficiency of the vest. The Thermal Inflection Point (TIP) for the vests with 3.2 cm spacers was much lower than for any of the other configurations. Development of a reflector vest for use by agricultural workers and construction workers exposed to high intensity sunlight environments is recommended.

**References:**


1. Bishop, P., Smith, G., Ray, P., Beaird, J., and Smith, J., Empirical Prediction of Physiological Response to Prolonged Work in Encapsulating Protective Clothing, Ergonomics 37 (9), 1503-1540 (1994)

2. Holmer, I., Protective Clothing and Heat Stress, Ergonomics 38 (1), 166-182 (1995).

3. Montain, S.J. , Sawka, M.N., Cadarette . B.S. Quigley, M.D., and Mckay, J.M., Physiological Tolerance to Uncompensable Heat Stress: Effects of Exercise Intensity, Protective Clothing, and Climate, J. Appl. Physiol. 77 (1), 216-222 (1994).

4. Reischl, U. , and Stransky, A., Assessment of Ventilation Characteristics of Standard and Prototype Firefighter Protective Clothing, Textile Res. J. 50 (3), 193-201 ( 1980).

5. Sun, G.,Yoo, HS, Zhang, XS, Pan, N.  Radiant Protective and Transport Properties of fabrics used by Wildland firefighters. Textile Research Journal July 2000 vol. 70 no. 7 567-573

6. B. Mijovic, Z.  Skenderi,  J. Camara, U. Reischl, C. Colby and A. Mermerian. "Inflatable Mannequin for Testing Thermal Properties of Clothing". Proceedings of the 17th World Congress on Ergonomics, Beijing, China, August 9-14, 2009.

7. U. Reischl and C. Colby: "PNEUMOTECH: A New Tool for Evaluating the Thermal Characteristics of Clothing Systems" Proceedings of the 4th International Ergonomics Conference, Budimir Mijovic, Editor. Stubicke Toplice, Zagreb, Croatia, pp. 29-36, June 30 – July 3, 2010.

8. U. Reischl, B. Mijovic, Z. Skenderi, I. Cubic: "Heat Transfer Dynamics in Clothing Exposed to Infrared Radiation" Proceedings of the 3rd International Conference on Applied Human Factors and Ergonomics, Miami, Florida, USA, pp. 589-598, July 17-20, 2010.