Interaction effects of radiation and convection measured by a thermal manikin wearing protective clothing with different radiant properties

Interaction Effects of Radiation and Convection measured by a Thermal Manikin wearing Protective Clothing with Different Radiant Properties

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ABSTRACT

As part of the EU funded research project THERMPROTECT ("Thermal properties of protective clothing and their use") this paper deals with manikin experiments on the effects of heat radiation at different wind speeds, considering aspects related to the reflectivity of the clothing. A heated thermal manikin "Newton" was operated with a constant surface temperature of 34 °C standing in a climatic chamber. The manikin was placed in a wind tunnel, with fans sucking the air through the tunnel and the manikin facing the wind and the radiation. To ensure proper operation of the manikin's heating mechanism the experiments were carried out at a low air temperature (T_a) of 6 °C with 50% relative humidity. Four wind speeds (0.5m/s, 1.0m/s, 2.0m/s and 5.0m/s) were used. The manikin wore four different outer wears (Black Laminated Nomex, Black Nomex, Orange Nomex and Reflective Nomex). All clothing had equal design. Identical underwear was worn in all trials (Helly Hansen super bodywear). Two THORN compact high intensity floodlight for PAR64 sealed beam CSI lamps were used in the tests as the radiant source. Lamps were set at a distance of 1.5metres away from the manikin for high radiation level (±450 W/m2) and 2.0 meters for medium level (±325 W/m2). The results showed a decrease in whole body heat loss, i.e. heat gain for the conditions with radiant heat stress compared to the reference without radiation. With wind, the heat gain decreased. Except for the reflective suit, the influence of the material and colour of the outer garment on radiant heat gains was negligible. The reflective suit showed the lowest heat gain. Increased heat loss by wind compensated for the radiant heat gains, with an effect size similar for all suits up to 2 m/s wind. Above this speed the wind effect on the reflective suit was smaller than for the others. The data obtained can be used to predict heat gain of humans by radiation in the presence of air movement.

Key words: protective clothing, heat stress, thermal manikin, radiation, wind

1. INTRODUCTION

Clothing provides a thermal resistance between the human body and surrounding environment. A functional role of clothing is therefore to maintain the human body in an acceptable thermal state, in a variety of environments. However, there are considerable side effects to wearing protective clothing, and typically with increasing protection requirements the ergonomic problems increase. The main problem in this area is the added load on the body in terms of weight and that of heat stress due to the insulative nature of most personal protective clothing.

As part of the EU funded research project THERMPROTECT ("Thermal properties of protective clothing and their use") this paper deals with manikin experiments on the effects of heat radiation at different wind speeds, considering aspects related to the reflectivity of the clothing.

The question addressed is: how does thermal radiation affect the dry heat exchange in protective clothing, how does this relate to the reflectivity of the outer clothing layer, and finally, how this process is affected by air movement.

2. METHODS

A heated thermal manikin "Newton" was operated with a constant surface temperature of 34 °C standing in a climatic chamber. The manikin was placed in a wind tunnel, with fans sucking the air through the tunnel and the manikin facing the wind and the radiation.

To ensure proper operation of the manikin's heating mechanism (ensuring heat input was still required in the radiation conditions) the experiments were carried out at a low air temperature (T_a) of 6 °C with 50% relative humidity. Four wind speeds (0.5m/s, 1.0m/s, 2.0m/s and 5.0m/s) were used. The manikin wore four different outer wears (Black Laminated Nomex, Black Nomex, Orange Nomex and Reflective Nomex). All clothing had equal design. Identical underwear was worn in all trials (Helly Hansen super bodywear).

Two THORN compact high intensity floodlights for PAR64 sealed beam CSI lamps were used in the tests as radiant source. Lamps were set at a distance of 1.5metres away from the manikin for high radiation level (±450 W/m2) and 2.0 meters for medium level (±325 W/m2).

The manikin had 32 zones. Heat loss from the zones and insulation values were calculated using the parallel method (ISO 9920, ISO 15831, Havenith, 2005):

$$\frac{1}{I_T} = \frac{\sum \alpha_i . H_i}{\overline{t}_{sk} - t_a}$$

$$= \sum \alpha_i . \left(\frac{H_i}{\overline{t}_{sk} - t_a} \right) = \sum \alpha_i . \frac{1}{I_{T,i}}$$

3. RESULTS AND DISCUSSION

The results showed a decrease in whole body heat loss, i.e. heat gain for the conditions with radiant heat stress compared to the reference without radiation.
As expected the heat loss changed mainly in the front side of the manikin as illustrated in Fig. 1 and 2.

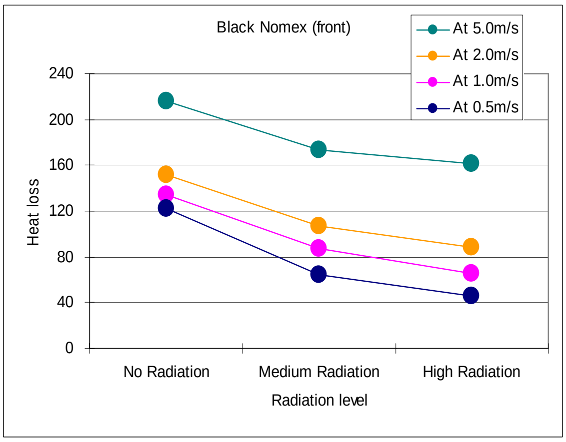

Fig. 1, heat loss from the frontal (radiated) side of the manikin for black Nomex ($W \cdot m^{-2}$)

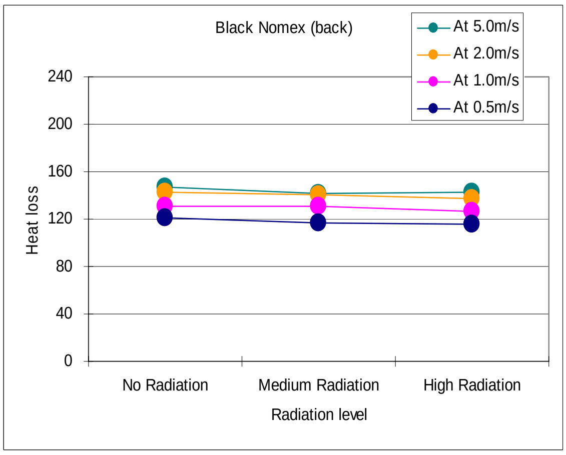

Fig. 2, heat loss from the back side of the manikin for black Nomex ($W \cdot m^{-2}$)

This difference was much less for the more reflective garments, as can be seen in Fig. 3 and 4.

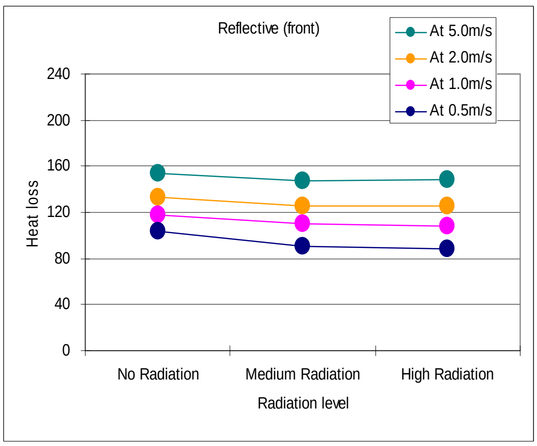

Fig. 3, heat loss from the frontal (radiated) side of the manikin for reflective Nomex ($W \cdot m^{-2}$)

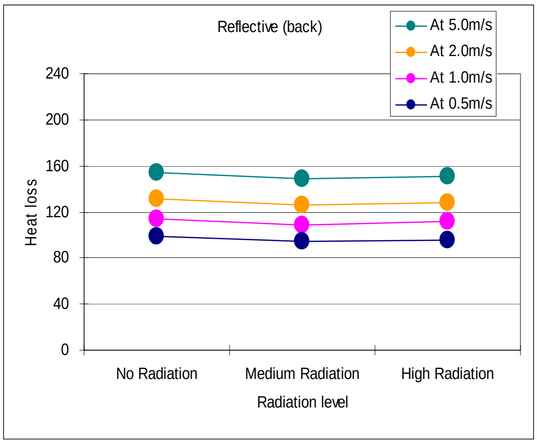

Fig. 4, heat loss from the back side of the manikin for reflective Nomex ($W \cdot m^{-2}$)

Heat loss from the manikin decreased with increasing radiation. With wind, the heat gain by radiation was reduced, and an interaction was present where the radiation effect was smaller at higher air speeds. From these heat losses an apparent insulation was calculated to allow an easy comparison of the conditions. This apparent insulation is determined as:

$$I_{T,\ apparent} = \frac{T_{skin} - T_{ambient}}{Manikin\ Heat\ Loss}$$

So, no account of the radiation was made in the calculation. This was the reason to call it 'apparent insulation'. These results are presented in Figures 5 and 6 for no radiation and the highest radiation.

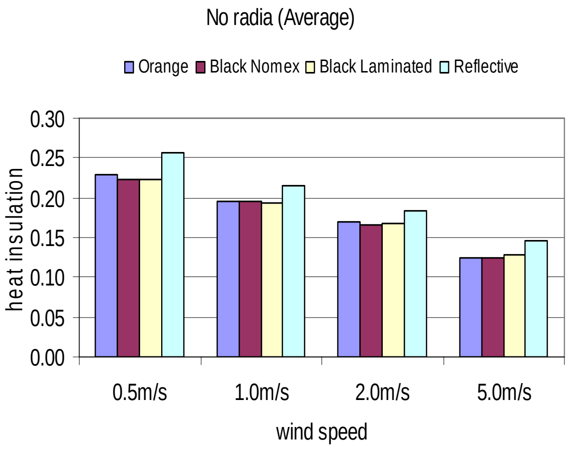

Fig. 5, (Apparent) Heat insulation ($m^2 \cdot °C \cdot W^{-1}$) at no radiation (all wind speeds)

Figure 5 shows the real insulation value (equal to the 'apparent insulation' for no radiation) for the different outer layers. It can be seen that colour has no significant effect, while the reflective suit has a higher insulation in all cases. Though all materials were planned to be similar, the reflective one had a different structure/stiffness due to the reflective coating. This resulted in a higher insulation for all wind conditions. The coated black material showed results very close to the uncoated black, showing that the black Nomex, though air permeable, was densely woven, allowing little air penetration. Only at the highest wind speed, the coating seems to have a small effect.

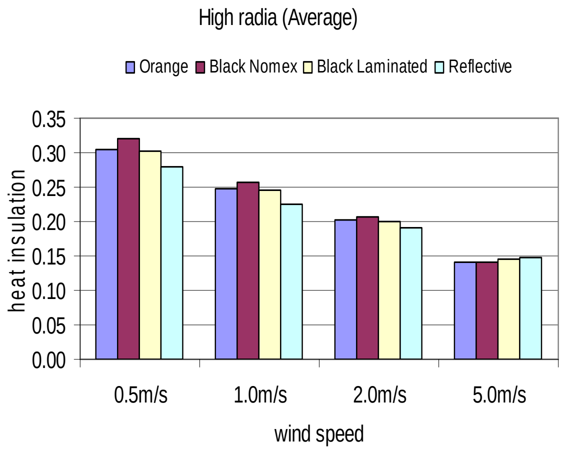

Fig. 6, (Apparent) Heat insulation ($m^2 \cdot °C \cdot W^{-1}$) at high radiation (all wind speeds)

At the high radiation condition (Fig. 6) and the lower wind speeds an effect of colour is present, with the orange suit receiving less radiant input than the black, showing a lower apparent insulation (the higher the radiant heat input, the lower the heat loss from the manikin and thus the higher the apparent insulation). Also a difference appears between the black and the black laminated oversuit. The lamination is performed on the back of the Nomex material, and is white. A possible cause therefore is that less radiation will penetrate the material for the black laminated suit as the laminate acts like a reflective layer underneath the surface layer. In earlier tests (Fukazawa 2005) a deep penetration of the radiation was suggested.

The apparent insulation of the reflective suit increases much less with increasing radiation than that of the other suits. Comparing figures 5 and 6, one can see very similar values for the reflective suit. This reflects the low radiation absorption by the reflective clothing.

Figure 1 shows that in the no wind condition the net absorption of radiation at the front of the manikin is around 80 W/m^2 for the black suit (comparing no radiation with high radiation at the lowest wind speed). This is substantially less than the absolute radiation input would suggest. The absolute radiation input at the surface of the clothing is 450 W/m^2 in the high radiation condition. Thus results suggest that less than 20% of the incident radiation is transferred to the body.

Comparing the apparent resistances of the reflective and black suits, they are only about 10% different in the high radiation condition, with lower heat absorption by the reflective suit. Thus wearing this suit has a limited advantage at these radiation levels and would require much higher radiation levels to obtain substantial advantages. It should also be noted that the reflective suit, due to the coating, has a much higher vapour resistance, which will hamper evaporative heat loss. Thus this has to be weighed against the radiative advantage. This potential conflict will be studied in a human subject experiment in the near future.

4. CONCLUSIONS

From the data we can conclude that in the visible light spectrum (solar radiation), clothing colour has a small effect, while reflective coatings have more substantial effects on radiation absorption. In windy conditions the differences between suits become less in terms of radiation absorption. It is hypothesized that the advantage of reflective coatings may be cancelled out by their reduced vapour resistance for radiation levels studied here.

5. REFERENCES

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6. ACKNOWLEDGEMENT:

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