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EFFECTS OF NATURAL SOLAR RADIATION ON MANIKIN HEAT EXCHANGE

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ABSTRACT

The main objective was to compare solar radiation to short wave radiation from Thorn lamp on clothing that were tested in lab on the manikins and on the subjects. In sun all manikin front zones get more or less evenly radiated but in the lab the radiated power reaches some zones more than others.

Tests were carried out on the thermal manikin Tore under clear sky in a building corner facing the sun. Basic tests without radiation were carried out in homogenous conditions in the climatic chamber. 4 sets of coveralls were tested with polypropylene underwear. Thermocouples were fixed at chest on underwear and outer layer inner and outer surfaces for textile surface temperature measurements.

From basic tests there were estimated the heat losses for particular outdoor conditions. The insulation values were corrected for air velocity according to EN 342 (1). The difference between the calculated heat losses for no sun and actual measured heat losses outdoors gave heat gain from sun for those particular conditions. There was a clear difference between black coverall and the other suits and reflective coverall and the other suits. The highest textile temperatures were recorded for black and lowest for reflective coverall. The curves followed the same pattern as observed from the material tests with solar lamps in the climatic chambers: underwear had often the highest temperatures.

1. INTRODUCTION

Several studies have evaluated the effect of solar radiation by means of tests on human subjects (2, 3, 4), manikins (2, 5) or other instruments (6). Various models (7) have been developed in order to consider human solar heat load both for exposure to cold and heat (5, 8). Also, several authors have looked on the effect of colour of the clothing (4, 9, 10) or skin (11) or animal fur (12). It was also shown that material (fur) tests do not need to match the results from living animals (12).

Within the THERMPROTECT project (13) tests on materials, manikins and subjects were carried out. Temperature curves in material tests were acquired at different power levels / lamp distances. The main objective of the present measurements was to gather data that allows comparing short wave radiation of Thorn lamp to solar radiation on our chosen garment ensembles. It was important to be able to compare different ensembles with each other, and look at general trends, e.g. if temperature curves followed the same pattern outdoors and in lab.
In common laboratory tests on manikin the radiation power was chosen in a way that did not increase the surface temperature over the set point, and thus allowed evaluating the changes in heat loss. Another difference between natural and lamp radiation was that in sun whole

Table 1. Experimental conditions.

Garment [1]	Date	Time	Solar angle (°) [2]	T_a (°C)	Vertical surf radiation (W/m^2) [3]			Plane Radiant Temp (°C) [4]			Air velocity (m/s)		Heat loss[5] (W/m^2)
					A (sun)	B (Tore)	A-background	A (sun)	B (Tore)	A-background	3 min mean	SD	
BN1a	22/03/2005	09:55	61.76	7.3	>900						1.10	0.55	65
BN1b	22/03/2005	10:05	60.87	7.3	>900						1.10	0.55	59
BN3a	01/04/2001	13:26	53.15	14.7	831	794	392	74.3	71.2	59.6	0.78	0.41	8
BN3b	01/04/2001	13:36	53.74	14.7	831	794	392	74.3	71.2	59.6	0.78	0.41	5
ON1a	22/03/2005	11:10	56.49	11.5	>900						0.69	0.49	47
ON1b	22/03/2005	11:20	56.06	11.5	>900						0.69	0.49	57
ON2a	31/03/2001	16:05	69.08	12.2	756	647	346				1.08	0.58	43
ON2b	31/03/2001	16:15	70.37	12.2	756	647	346				1.08	0.58	41
ON3a	01/04/2001	12:05	51.08	15.4	811	747	401				0.70	0.42	23
ON3b	01/04/2001	12:15	51.07	15.4	811	747	401				0.70	0.42	21
BL1a	22/03/2005	12:25	55.01	9.7	>900						1.02	0.65	35
BL1b	22/03/2005	12:35	55.13	9.7	>900						1.02	0.65	44
WC1a	22/03/2005	15:03	64.83	9.3	747						1.32	0.62	83
WC1b	22/03/2005	15:13	65.90	9.3	747						1.32	0.62	93
WC2a	31/03/2001	15:05	61.94	13							0.90	0.49	30
WC2b	31/03/2001	15:15	63.05	13							0.90	0.49	31
WC3a	01/04/2001	14:29	58.06	16.8	806	794	367	71.9	71.4	55.1	0.71	0.40	12
WC3b	01/04/2001	14:39	59.02	16.8	806	794	367	71.9	71.4	55.1	0.71	0.40	11
RN1a	22/03/2005	13:50	58.27	8.6	588						1.47	0.55	100
RN1b	22/03/2005	14:00	58.97	8.6	588						1.47	0.55	97
RN2a	31/03/2001	12:30	51.57	10.4	795	660	385				0.70	0.38	88
RN2b	31/03/2001	12:40	51.76	10.4	795	660	385				0.70	0.38	82
RN3a	04/04/2001	12:59	50.88	21.3	718	842	279	62.5	75.8	41.2	1.58	0.70	47
RN3b	04/04/2001	13:09	51.30	21.3	718	842	279	62.5	75.8	41.2	1.58	0.70	55

[1] In test codes (Garment) 1, 2 and 3 mean different tests, while a and b come from the same run with 10 minute difference in order to minimize environment dependent difference and for control.

[2] Solar angle from vertical surface in degrees.

[3] Radiation intensity on vertical surface: sensor standing between the sun and Tore with front side turned the sun [A (Sun)] and backside towards the manikin [B (Tore)]; A-background was measured between the manikin and the glass background behind him (reflection from wall).

[4] Plane radiant temperature corresponds to the radiation intensity: sensor standing between the sun and Tore with front side turned the sun [A (Sun)] and backside towards the manikin [B (Tore)]; A-background was measured between the manikin and the glass background behind him (reflection from wall).

[5] Heat loss excluding non-covered areas, i.e. head, hands and feet (area of covered body parts was 1.43 m^2).

manikin front got more or less evenly radiated but in lab the radiated power reached some zones, e.g. chest, more than others depending on the lamp position. Thus, an aim for the outdoor tests was to look on realistic temperatures in textiles and total heat loss reduction from manikin / gain from sun. Also, the outdoor data could serve as a link between material tests with high radiation power and manikin tests with relatively moderate power levels, but also in order to relate to subjects' data.

Figure 1. Tore outdoors and the Sun position at the end of each test

2. METHODS

Tests were carried out on the thermal manikin Tore under clear sky in a building corner facing the sun (Figure 1). The manikin was turned so that in the end of each trial the sun faced manikin front (Figure 1). All outdoor conditions are given in Table 1 and some parameters drawn in Figure 2. Tests without radiation in homogenous conditions were carried out in a climatic chamber.

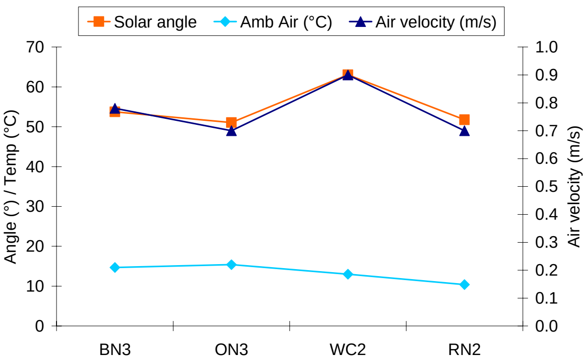

Figure 2. Ambient conditions for some tests.

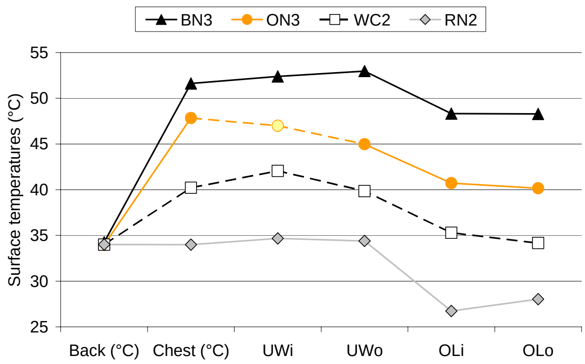

Figure 3. Manikin's back and chest, and textile surface temperatures at chest (underwear inner (UWi) and outer (UWo), and outer layer inner (OLi) and outer (OLo) surface) for some conditions. Point UWi for ON3 is estimated because of missing value due to sensor error.

After pre-tests 4 sets of clothing were chosen for further testing: black Nomex (BN, reflectivity 0.23), orange Nomex (ON, reflectivity 0.26), white cotton (WC) and reflective Nomex (RN, reflectivity 0.78). Black laminated Nomex (BL) was skipped due to close values to BN. Helly-Hansen underwear (super stretch, polypropylene) was used under all coveralls. Thermocouples were fixed at chest on underwear inner (UWi) and outer (UWo) surfaces and outer layer inner (OLi) and outer (OLo) surfaces for textile surface temperature measurements. Data was recorded each 10 seconds.

3. RESULTS AND DISCUSSION

Figure 3 shows manikin's back and chest surface temperatures, and textile surface temperatures at chest (facing the sun). As expected, the highest temperatures were recorded for BN and lowest for RN. Difference between ON and WC was present, too. The temperature curves followed the same pattern as observed from material and the manikin tests (13) with solar lamps in the climatic chambers: underwear surfaces just under outer layer had often the highest temperatures. Figure 4 illustrates heat losses from the whole manikin body and from the areas totally covered with the coveralls (head, hands and feet excluded). The figure confirms the results from surface temperatures (Figure 3). RN differed from others somewhat more due to lower air temperature (Figure 2), although, even at higher ambient temperature the difference would have anyway been considerable, e.g. RN3 at 21 °C with air velocity of 1.6 m/s (Table 1) had heat losses of 51 W/m^2 from covered parts. Vice versa, difference between ON and WC might have been slightly less if they have had the same air velocity and temperature.

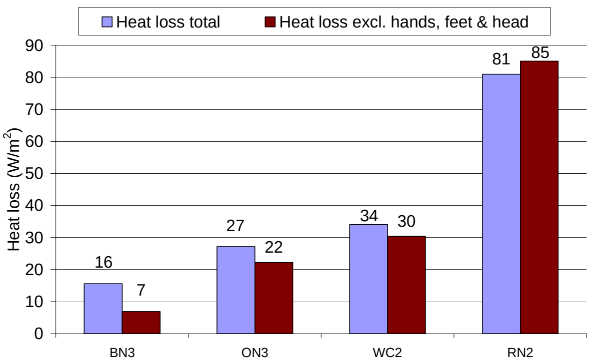

Figure 4. Heat loss for one particular test of each coverall. Test with each coverall was chosen to be carried out under as close environmental conditions as possible with others.

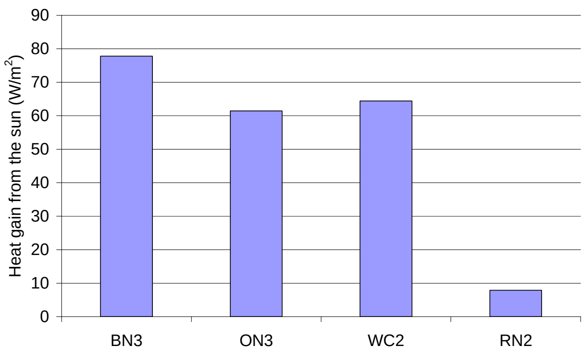

Figure 5. Relative heat gain from the sun for the specific conditions.

From homogenous chamber test results (insulation values) there were estimated the heat losses for particular outdoor conditions without solar load. Insulation values were corrected for air velocity according to Annex C, EN 342 (1):

$$I_{tr} / I_t = 0{,}54 \cdot e^{(-0{,}15v - 0{,}22w)} + 0{,}5 \quad (1)$$

for v = 0.4 m/s to 2.0 m/s. The difference between the calculated heat losses and actual measured heat losses outdoors gives us heat gain from sun for those particular conditions (Figure 5). These values for various colours lay in the same range as reported in earlier studies (3, 4, 5, 6). Also, the results from Thermprotect study (13) carried out on human subjects point towards the same direction. There is a clear difference between BN and the other suits, and RN and the other suits, however, ON and WC are quite similar. It might depend on solar load (not available for WC, Table 1) that in its own turn is related to solar angle (highest for WC, i.e. bigger surface radiated), and clearness of the sky (the test days were very clear with practically no clouds observed). In spite of higher relative heat gain values for WC, the surface temperatures of ON are higher in all layers (Figure 3). It might be related to that in actual conditions ON had somewhat higher temperature and lower wind speed than WC (Table 1 and Figure 2) but also on transmission through textiles.

Based on outdoor tests the following relationship (R^2=0.89) was acquired:

$$Q=177+26.85*r-5.18*T_a+16.21*v_a-0.11*P_i \qquad (2)$$

where Q is heat loss (W/m^2); r is reflectivity; T_a is air temperature (°C); v_a is air velocity (m/s); P_i is incident power (W/m^2).

Figure 6 shows linear relationship between manikin heat loss, ambient air temperature and incident power for reflective and black garment at air velocity of 0.8 m/s. The outdoor tests were relatively limited in count and in clearly defined conditions, e.g. varying air velocity at low level (0.4-1.5 m/s), commonly high incident power levels outdoors or low indoors (chamber tests), clothes with similar insulation only (0.22-0.26 m^2°C/W) and solar angle (from vertical from 50-70°, from horizon 20-40°), thus the relationship should be treated with care for only specified range. Obviously, more defined manikin tests in chamber can be the base for the better model, and then the outdoor tests may be used for validation. However, some manikin tests of Thermprotect (13) were not in agreement with this study. That may be due to that even high radiation level measured there (507 W/m^2) was lower than the lowest incident power measured up in this study and thus was outside the scope of the linear relationship given above.

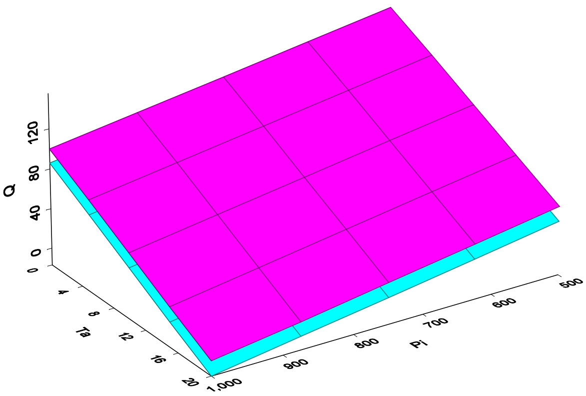

Figure 6. Linear relationship between manikin heat loss (W/m^2), ambient air temperature (°C) and incident power (W/m^2) for reflective (upper/red area) and black (lower/blue area) garment at air velocity of 0.8 m/s.

4. CONCLUSIONS

The temperature curves followed the same pattern as observed from the material and manikin tests in the climatic chambers: underwear had the highest temperatures. Thus, laboratory tests with solar lamp are representative for short wave radiation tests on garments and textiles on manikin. Heat losses depend on environmental conditions (air temperature and velocity). These are impossible to standardise outdoors. Thus, laboratory conditions are to be preferred for textile/garment testing on thermal manikins. Due to overheating of the zones facing the sun only (chest and stomach) it is not correct to use insulation values from outdoor tests for estimation of heat losses in order to compare manikin tests with solar lamps in the climatic chambers, where conditions were kept so that the heat losses stayed minimal even in the radiated zones, although, calculated heat gain was in the same range as in other studies. However, it might be possible to model outdoor conditions based on the chamber tests. In that case validation tests should be carried out.

5. ACKNOWLEDGEMENTS

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