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COOLED PLATE TESTS ON TEXTILE MATERIALS IN SIMULATED COCKPIT UNDER “SOLAR RADIATION”

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Abstract

This study investigated if clothing material with reflective properties has an effect on heat gain in pilot, specifically, under solar radiation. Two materials, conventional pilot suit material (Old) and material coated with coldblack® (New, Schoeller Technologies AG, Switzerland) were tested over variety of underwear layers and in a box simulating cockpit. A hot plate was used to measure textile combinations' insulation. Under the solar radiation simulation with a Thorn lamp (841 W/m²) a water cooled plate was utilized.

The insulation of New was slightly lower than in Old. New showed about 10 % lower heat transmission under solar radiation than Old. Textile surface temperature in New was several degrees lower than in Old. When placed in the box the heat transmission difference reduced to nothing. The new material has ability to reduce the heat load in the open space. In closed space the advantage disappears, i.e. the effect of the outer layer in cockpit scenario is marginal.

Keywords: Pilot clothing, outer layer, solar radiation, cockpit ventilation, heat transmission, water cooled plate

1 Introduction

In order to save energy for active systems under mission flights various solutions have been studied. Simultaneously, the solutions should not affect pilot performance negatively, e.g. through increased heat or cold stress. Therefore, improving pilot's thermal comfort by passive and/or less energy consuming means would allow saving energy for improving technical parameters for mission capacity. Some of the solutions could be using insulation paint for airplane surface, insulating inner surfaces of cockpit etc. One solution could be using heat-reflective coating on pilot clothing outer surface. The aims of this pilot study were to investigate the differences in two materials, conventional suit material (*Old*) and material coated with *coldblack*® (*New*, Schoeller Technologies AG, Switzerland), from insulation and material to skin heat transfer viewpoint.

2 Methods

Both hot and cool plates were used in the investigation. Insulation measurements of the materials and the layering systems were carried out on hot plate following ISO 11092 (1993). Total thermal resistance of the material and air layer package (R_t , m²K/W) measured with 0.41±0.08 m/s and with no solar simulation (Table 1). The textiles were always placed over the layer of the underwear shirt. All conditions were tested twice. The air temperature was kept at +20.2±0.1 °C for textile measurements and at +5.4±0.1 °C for condition *Air gap*. Textile material package insulation, R_{cl} was acquired by subtracting air layer insulation from total insulation.

Table 1 Test conditions on hot plate

Abbreviation	Description
AL	Air layer resistance of a hot plate only is the same for both materials
Textile	A textile layer on top of the layer of an underwear shirt
Plastic	A condition where a layer of bubble-plastic was included as an additional layer to simulate any other possible layers and air gaps of the clothing system
Air gap	A situation where the textile is located in average about 15 cm above the plate, and forming the walls around the plate, thus, reducing the influence of air velocity close to plate surface

While simulating the effect of solar radiation, however, the temperature of hot plate surface raised above +35 °C and the heat loss recordings for comparison were not possible. Even if the chamber temperature was lowered to +5 °C the plate surface stayed above +35 °C (around +45 °C for *coldblack*® and about +57 °C for conventional material).

Therefore, a water cooled cool plate was used under the solar load simulations to evaluate heat transmitted from radiation through textile package into the system. The method was developed at Lund University, the Thermal Environment Laboratory, and is described by Jögård (2004). Shortly, the system measures the inlet and outlet temperature of the water that is circulated at defined velocity in silicon tubing in/on an insulated material. Water tubing is covered by a thin aluminium plate for better heat distribution with a textile simulating human skin glued on it and avoiding reflection from the aluminium plate. As the textile or system insulation, and tubing and plate area are known, then transmission could be calculated based on the difference in water inlet and outlet temperatures. Water flow was created by a peristaltic pump (Gilson Minipulse, France). The average water flow was 0.158 ± 0.018 g/s, and it was checked for each individual condition. Solar load was simulated by a Thorn lamp. That was placed 2.5 meters away from the material surface creating a load of 841 W/m^2 on the plate area.

Tests were carried out in the air and in a box covered by glass simulating cockpit situation. Inside of the box was covered by the textile and the cooling plate was located under it in the bottom of the box. The box was positioned in a way that allowed lamp directly shining in it, and so that the sides were affected minimally. The box edges were covered by aluminium foilium to diminish the heat input from the box warming (Figure 1a). The chamber temperature stayed at $+19.7 \pm 0.1$ °C and air velocity 50 cm in front of the test setting was in average 0.47 ± 0.08 m/s.

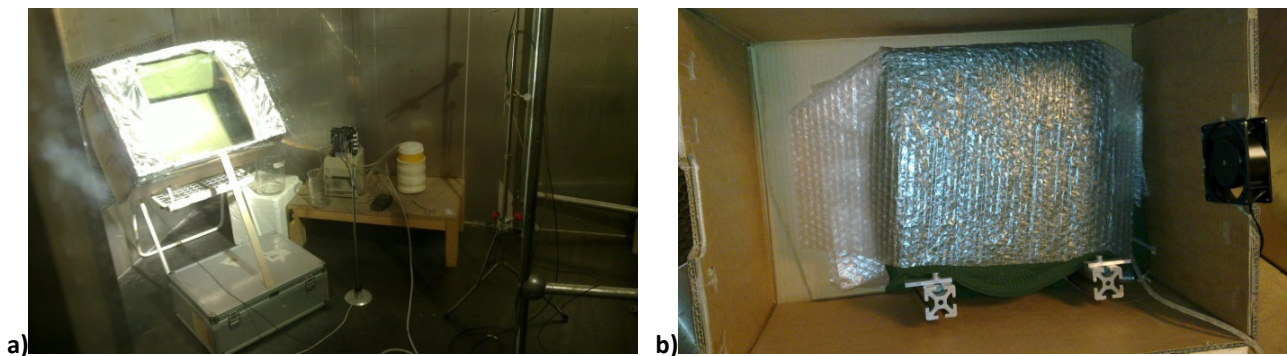


Figure 1 a) Box and equipment position in the chamber. Right from the box can be seen peristaltic pump and water reservoirs. b) Position of the cooling plate in the box modified for additional tests with bubble-plastic and fan. Textiles were placed on top of the plate.

After the measurement series and preliminary discussions a set of additional tests in the box was carried out. Due to time constraints only 1 test per additional condition was performed.

1. A layer of bubble-plastic was added between underwear shirt and the textile in order to simulate the other layers of the system (insulation was still lower than in full pilot clothing system (Kuklane and Holmér, 2012);
2. The same as above, however, a computer fan was added to the box to suck the air from the box (Figure 1b). Air inlet was located in the opposite wall to the fan, but also the openings in the box cover could allow some air flow in the box. The caption of tables should be above the table as shown below.

The equivalent temperature for textile comparison was calculated according to Nilsson (2004):

$$t_{eq} = t_s - \frac{q_T}{h_{teq}} \quad (1)$$

where t_{eq} is equivalent temperature of the uniform, homogenous environment (°C); t_s is plate surface temperature (°C); q_T is measured manikin heat loss during the actual conditions (W/m^2); and h_{teq} is dry heat transfer coefficient, including clothing, determined during calibration ($\text{W/m}^2\text{K}$).

3 Results and discussion

Figure 2 show the total and the clothing insulation of the material package. In the *Air gap* condition the higher insulation from new material could be related to a larger textile piece that allowed diminishing leakage better, but also to a possibly higher air penetration resistance (lower air permeability) than the conventional material (not measured within the limits of this study, but the data should be available from

the manufacturer of the textiles). Otherwise, the differences in new and old material insulation (new had somewhat lower thermal resistance) were consistently independent from the combination of other layers. The differences were small, and would probably stay unnoticed by the users.

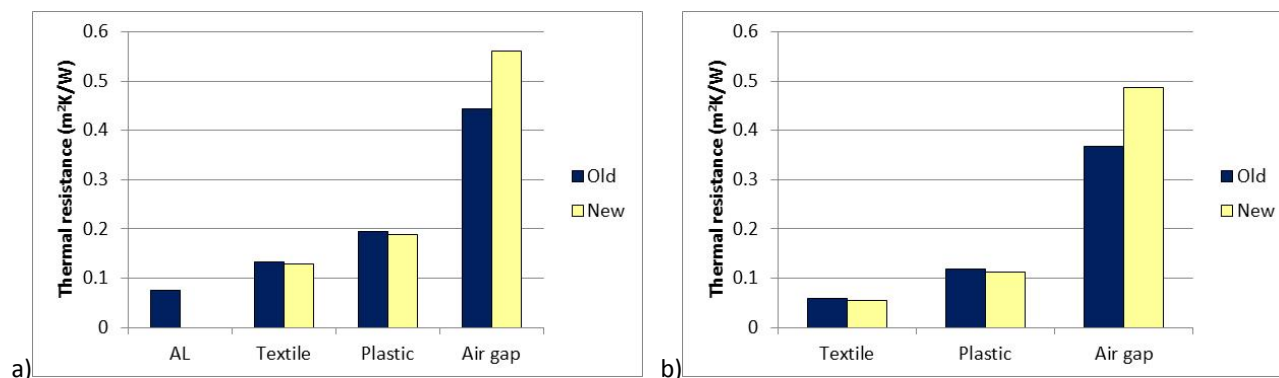


Figure 2 a) Total thermal resistance of the material and air layer package (R_t , m²K/W), and b) thermal resistance of clothing material package (R_{cl} , m²K/W) measured with 0.41 ± 0.08 m/s and no solar simulation. *Old* is the present material and *New* is material with *coldblack*® finish. *AL* is air layer resistance of a hot plate only and is the same for both. The *Textile* was always measured over a layer of underwear. *Plastic* is a condition where a layer of bubble-plastic was included as an additional layer to simulate any other possible layers and air gaps of the clothing system. *Air gap* is a situation where the textile is located in average about 15 cm above the plate, and forming the walls around the plate, thus, reducing the influence of air velocity close to plate surface

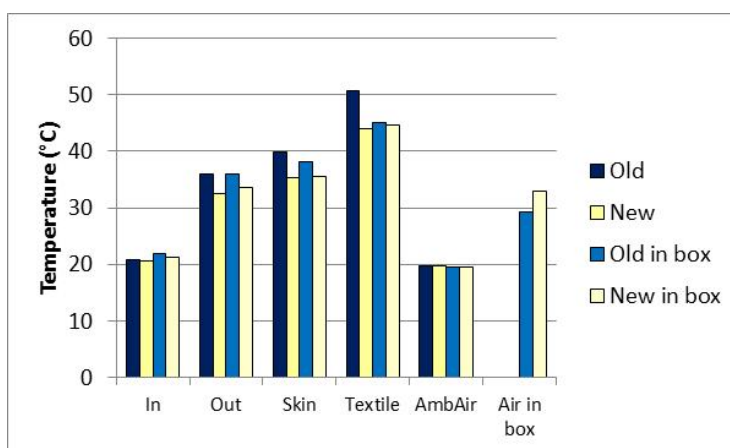


Figure 3 Temperatures (°C) at various points of the system. *In* – inlet temperature of water; *Out* – outlet temperature of water; *Skin* – temperature on textile skin in the centre of the plate under the tested material package; *Textile* – temperature on textile at the centre of the plate facing the solar lamp; *AmbAir* – air temperature in the chamber; *In box* – air temperature in the box.

Figure 3 shows 5 minute average stable state temperature values for each test condition. There seems to be no risk of skin injury due to heat with neither of the materials. As it can be seen then conventional textile absorbed more heat, however, in box the differences became less. In the open air where surrounding environment is minimally affected by the radiation there are significant differences between old and new textile reaching to over 70 W/m^2 , and indicating superiority of the new material (Figure 4). With new material the heat transmission to skin is over 8 % less (Figure 5). Thus, when a pilot would stay in open space in the sun, then the heat load would be considerably lower corresponding to equivalent temperature difference of 6.5 K. If to consider a relatively moderate activity level (body own heat production) of 90 W/m^2 then the difference was close to 7 K.

The situation in the box differed drastically. The difference in transmission was only 1.5 % leading to reduced heat gain from new material only to 13 W/m² (Figures 6 and 7). Relating this information to temperature data in the box (Figure 3) it may be expected that considerable amount of heat was trapped in the box and was not reflected out (greenhouse effect). This affected the air temperature increase in the box by almost 4 degrees and that most probably did increase the heat transport into the plate. Thus, the textile surface temperatures in the box were relatively similar, although, the effect on textile skin was still stronger under the old material (point measurement in the centre of the plate in the strongest radiation area). Converting these differences into differences of the equivalent temperature we can see that in passive system the new material is better by 0.4 K, and considering internal heat production of working pilot (90 W/m²) up to 0.9 K.

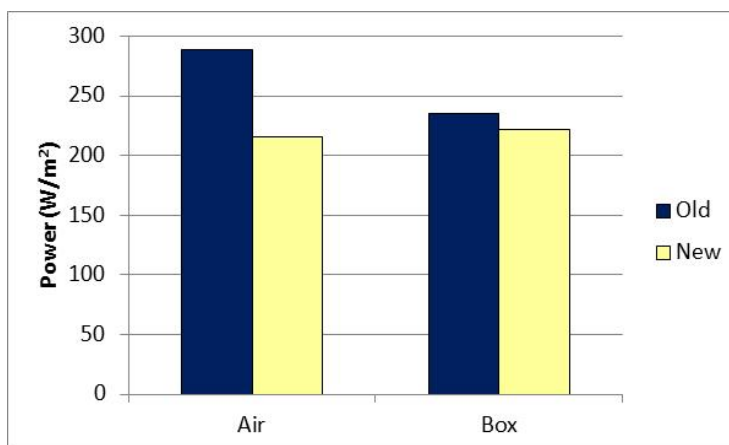


Figure 4 Absorbed and transported heat (W/m²) for *Old* (conventional) and *New* (coldblack®) textile in the air and in the box

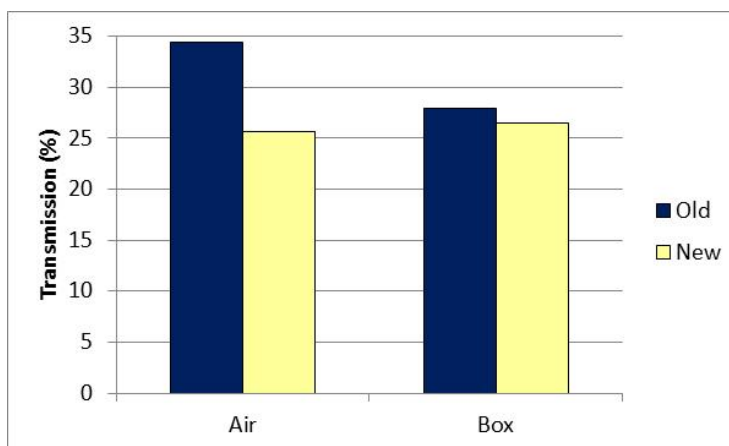


Figure 5 Transmission (%) of the simulated solar heat to the plate for *Old* (conventional) and *New* (coldblack®) textile in the air and in the box

Based on the results up to this point the new material would give a very significant effect under direct solar radiation, while in closed spaces the positive effect was diminished. This was expected to be diminished even more by additional insulation layers of other clothing pieces in pilot clothing ensembles, but counterbalanced with ventilation of the box space that would remove the stored heat. Therefore, additional tests were carried out with layer of bubble-plastic and ventilating the test box. The results can be seen in Figures 6-8.

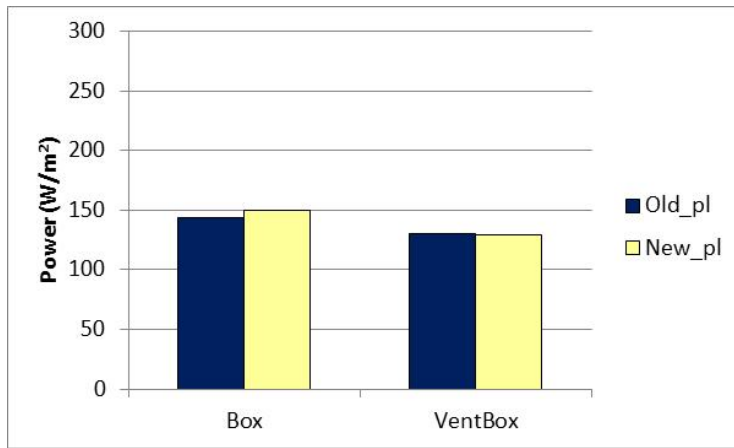


Figure 6 Absorbed and transported heat (W/m^2) for *Old_pl* (conventional) and *New_pl* (*coldblack*®) textile in the box with additional insulation (bubble-plastic) and with ventilation of the box

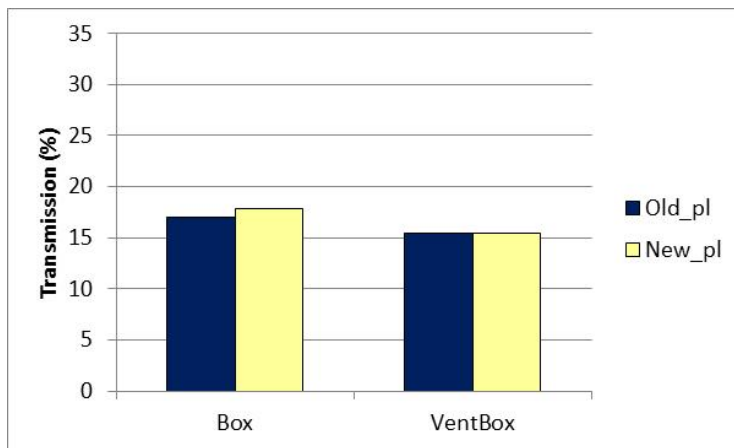


Figure 7 Transmission (%) of the simulated solar heat to the plate for *Old_pl* (conventional) and *New_pl* (*coldblack*®) textile in the box with additional insulation (bubble-plastic) and with ventilation of the box

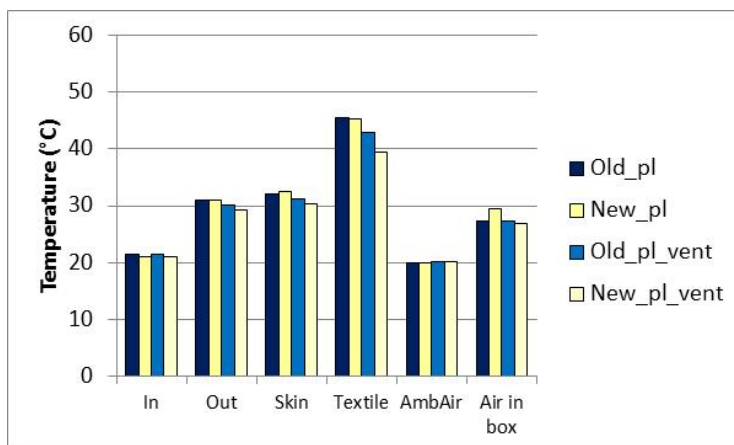


Figure 8 Temperatures ($^{\circ}C$) at various points of the system under additional measurements in the box with additional insulation (bubble-plastic) and with ventilation of the box. *In* – inlet temperature of water; *Out* – outlet temperature of water; *Skin* – temperature on textile skin in the centre of the plate under the tested material package; *Textile* – temperature on textile at the centre of the plate facing the solar lamp; *AmbAir* – air temperature in the chamber; *In box* – air temperature in the box.

Figure 6 shows that the heat transmitted through textile package to cooled plate was in the case of the new material somewhat ($7 W/m^2$) higher than in the old material. This does draw the attention to the insulation results observed with condition of air gap (Figure 2). It indicates that the differences observed there may be

related even to some more important factors than just more material available for surrounding the sample. Due to that the transmitted energy through textile package and skin (simulated by textile) into the tissues (simulated by water filled silicone tubing) was also higher for new material. In such conditions the equivalent temperatures of the new and the old materials did differ neither with nor without ventilation, although, ventilation considerably affected the textile surface temperature difference (Figure 8). I.e. the earlier expected effect of the ventilation was not observed here. A difference in new material's favour was observed in the equivalent temperatures if internal heat production was added. Somewhat lower insulation (= higher heat transfer coefficient) would allow the 0.6 K difference in equivalent temperature. If we do not account for any considerable measuring errors (only 1 test per additional condition) then it seems that the old material does not function worse than the new one in cockpit scenario.

4 Conclusions

The new material has an ability to reduce the heat load considerably in the open space that is exposed to solar radiation. In closed space the advantage is reduced to minimal or nothing, depending on the conditions. In this study the analysis was based on the whole surface exposure to the solar radiation. In reality the exposed surface is commonly less than half. This issue may diminish the observed effect.

In this study the material properties differed. If *coldblack*[®] is applied to the conventional material then the effect of insulation may not be observed at all. It has to be ensured that the finish will not increase the evaporative resistance of the outer layer, and thus, of the whole system. In hot conditions the major heat loss from human body takes place via evaporation and any positive effect of the reflective surface of the material may easily be cancelled by lower vapour permeability of that layer. Also, any ventilation system into the pilot suit would diminish the effect of the outer layer, as the cooling occurs closer to skin surface and anything happening on the outer layer has even smaller effect due to the insulation of the layers in between.

Considering that the reflective effect of the outer layer in heat under solar load would improve the situation, while it would be a disadvantage in the cold where heat gain from the sun would act as a considerable positive effect then possibly two different outer layers for warm respective cold conditions may be required. Based on this study, however, the effect of the outer layer for cockpit scenarios is marginal.

Acknowledgements

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References

- [1] International Organization for Standardization (ISO): *Textiles – Physiological effects – Measurement and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test)* (Standard No. ISO 11092:1993), Geneva, Switzerland, ISO, (1993)
- [2] Jögård, H.: *Solenergitransmission i textila material (Transmission of solar energy in textiles)*, in Swedish, Kandidatexamen vid institutionen Textilhögskolan, Högskolan i Borås, 2004:2:1, (2004)
- [3] Kuklane, K. & Holmér, I.: *Pilot clothing system with a CBRN protective underwear*, A report for Aeronautics, Saab AB. Thermal Environment Laboratory, Faculty of Engineering, Lund University, Lund, Sweden, (2012)
- [4] Nilsson, H. O.: *Comfort climate evaluation with thermal manikin methods and computer simulation models*, Doctoral thesis. Royal Institute of Technology, University of Gävle, National Institute for Working Life. Published in *Arbete och Hälsa* 2004:2, (2004)