Impact of Environmental Changes on Thermal Behaviour of Textile Materials

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Thermal Comfort of *Textile Materials and Its Assessment was discussed in the previous and the first article* of *this series. Environmental conditions and changes do affect the insulation properties* of *textiles. Hence variations are noticed in the thermal behaviors* of *these materials. Most* of *the times, the assessment* of *thermal behaviors is done in stable/Non Variable environmental conditions, which may lead* us *to the wrong selection* of *textile materials. Researches reveal that testing in Non variable environment results in over estimation* of *the desired properties but in actual use textile material fails to serve* as *per requirement and may cause disasters. The article discusses outcomes* of *various studies conducted in variable environmental conditions and advocates the importance* of *real thermal behavior assessment* of *textile materials. The next paper* of *this series will discuss about different global standards used for thermal comfort assessment and usage* of *thermal manikins.*

Measuring or assessment of thermal properties of the clothing in static mode/state is one traditional way, which involves easier process and procedures with cost effectiveness, but its unable to give the realistic capabilities to perform as many of the important factors are not taken in the consideration while performing the test. So the latest researches have been shifted to the dynamic state testing, which is nothing but the simulation of actual conditions of wear, activity and environmental conditions.

There are lot of efforts have been done on evaluating the thermal properties in the dynamic state or in other words variable environment with simulation of human body. It leads to more realistic results and gives a clear picture of the thermal performance of the clothing.

Before moving forward, it's important to understand the key terms used in measuring thermal behaviour.

Basic Terminology

The main properties important for maintaining thermal comfort/thermal behaviour are-

Insulation: Human body can be in comfort around 28-29° C with out wearing any cloth, if the surrounding temperature is lower than this, human body will start loosing heat, to prevent it one may need clothing with some insulation, so in simple words insulation is nothing but a kind of resistance to the heat flow.[8]

The heat flow through a fabric is due to combination of conduction and radiation. The conduction loss is determined by the thickness of the fabric and its thermal conductivity. The thermal conductivity itself a combination of air k_A and that of fibre k,

Fabric conductivity $k = (1-f)\, k_A + f\, k_F$

Where f is the fraction of the volume of the fabric taken up by the fibre. The insulation value of the clothing when its is worn is not just dependent on the insulation value of individual garment but the air pockets or air gaps present in between the layers also add to the insulation value.

CLo Value:

This is one of the most widely used Unit in Thermal Transmission in Textiles as a measure of Thermal insulation or Thermal Resistance.

1 CLo=R Value X 1.136

1 CLo means, the insulation required to maintain temperature 21 *DC* at 50% RH and a wind speed of 0.01 m/Sec
Lowest clo value is 0 (naked body)
Highest practical clo value = 4 clo (complete body coverage- aerogel coat and gloves, etc.)
Summer clothing ~ 0.6 clo
Winter clothing ~1 clo

The insulation value (Clo) of a fabric is mainly dependent on thickness of the fabric and can be expressed as below

Clo = 1.6 X thickness in cm.

THERMAL CONDUCTIVITY is an intensive property of a material that measures its capacity to sustain heat flow. The units of thermal conductivity are often provided in metric values of Watts/meter-degree Kelvin or W/m-K. The symbol used to denote thermal conductivity is k (or lambda, λ).

THERMAL RESISTANCE (R VALUE) is the capacity of a material to resist the heat flow from a given area and at a given temperature.

- The units of thermal resistance are provided in m-K/W (or $ft^2hr^\circ F/BTU$)
- Thickness/k value = R value
- Resistances of insulators in series can be added
- R-value can be for whole thickness or normalized (e.g. R-value is 12 per inches or 24 for 2 inches of R-12 per inch material)
- R/in = 144/k (in mW/m-K) -> 12 mW/m-K = 12 per inch R value
- The reciprocal of thermal resistance is thermal conductance (also known as the heat transfer coefficient), with units of W/m^2K. This value is frequently measured in systems as the overall heat transfer coefficient (OHTC).
- Thermal resistance values are often used in the building and construction markets as a relative measure of thermal insulation performance for materials and systems.

HEAT TRANSFER COEFFICIENT (U VALUE) is a measure of thermal conductance, an indicator of the heat flow per unit area and temperature (W/m^2K) change through a material or system.

- U-value is heat transfer coefficient
- Low U values mean good insulation values (very similar to thermal conductivity k)
- OHTC -> Overall heat transfer coefficient; frequently used to measure the thermal conductance of systems

Tog Value: This is another unit of thermal insulation given by Peirce and Rees, I Tog is equal to 0.1 m^2 - K/W.

TIV: Thermal Insulation Value is one another unit to measure the thermal insulation of fabrics and can be mathematically expressed as below

TIV= [1- Hc/Hv] X 100

Where Hc is the heat loss from the covered body and Hv is the heat loss from the uncovered body. The units Clo, Tog and TIV are used to quantify the thermal insulation of fabric for thermal comfort related measurements.

Thermal Behaviour testing Dynamic state Vs. Static state

Sincere efforts have been put on understanding the thermal behaviour of textile materials in variable environments as simulation of actual working conditions.

Some major researches have been done by Dr. Mark G. M. Richards and Niklaus G. Mattie from EMPA, Swiss Federal Laboratories for Materials Testing and Research, Switzerland while developing a Sweating Agile Thermal Manikin (SAM). Thermal behaviors testing under dynamic conditions were conducted and it was observed that protective clothing for long periods of time which is subjected to heavy workloads looses the thermal insulation properties. Thermal Protection against wind, rain, certain liquids, heat, flame, thorns, rocks, shrapnel, and nuclear, biological and chemical weapons (NBC) tend to make the clothing impermeably to water vapour. In this situation the body moisture can not escape properly to the surrounding environment. After a long exposure to this type of environment the moisture content builds up and results in reducing overall thermal insulation.

Body movements too reduce the thermal insulation of clothing as hear transmission between the clothing layers (microclimate) and the external environment increases. The thermal insulation is also drastically affected with walking speed as well as the wind speed.

It can be observed from the below figure (Fig. 1) that an increase of wind speed from 1 to 13 m/s can reduce the effective thermal resistance by up to 80% for fleece materials. [1]

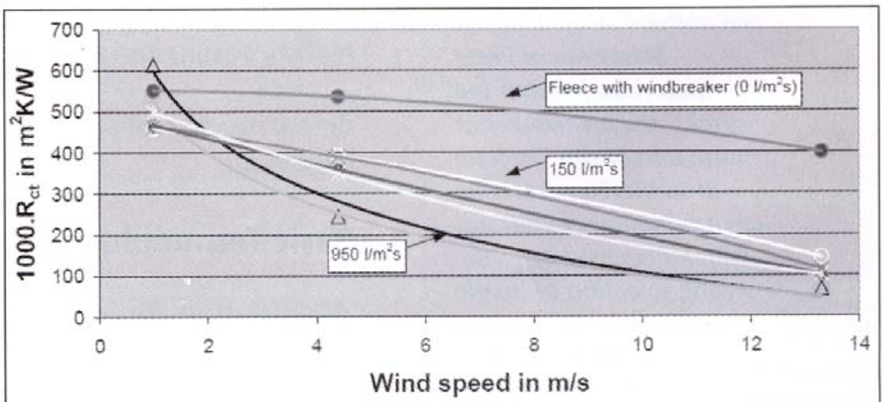


Figure 1 : Reduction of thermal resistance with wind speed for various fleece materials measured on the sweating arm[1]

Some researches have been conducted by Hans Wigö and Hakan o Nilsson, University of Gavle, Centre for Built Environment, Gavle, Sweden. Various tests were conducted on thermal manikins to measure the thermal properties under different environmental conditions by varying the air flow speed and changing the room temperature from 20˚C to 24˚C. It was observed that when the manikin was exposed to a high air flow, there was 10% more heat loss from the body, and the heat loss from the exposed areas (hands and face) increased by 20 % as compared to the heat loss in no air flow condition. It was also observed that after 80 minutes testing period, the total energy loss was 2% higher in variable velocity conditions than that of a constant air floe condition.[2]

Effect of moisture on thermal properties of fire fighting clothing is studied extensively by R. L. Barker, C. Guerth Schacher, R. V. Grimes and H. Hamouda at Center for Research on Textile Protection and Comfort College of Textiles, North Carolina State University and it was observed that the addition of moisture affects adversely on the predicted burn protection to the highest level when the moisture is added at a low level of around 15% of turnout composite weight. As the moisture level increases beyond this limit, burn times increase to approach values measured for dry composites.[3]

The below figure (Fig. 2) depicts the same phenomena observed by above mentioned researchers,

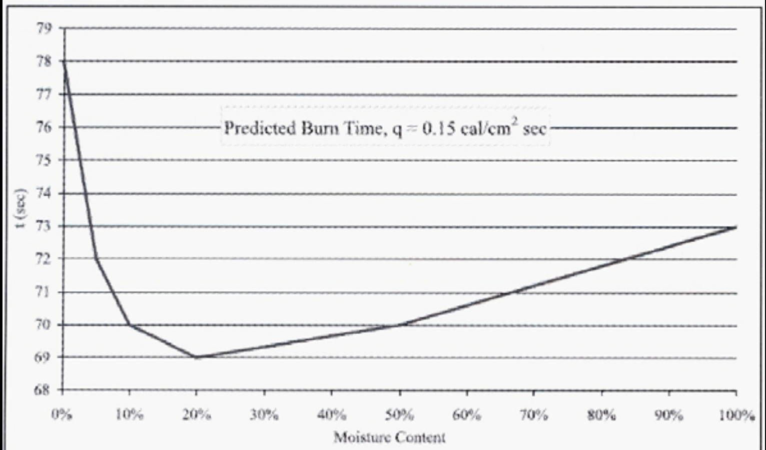
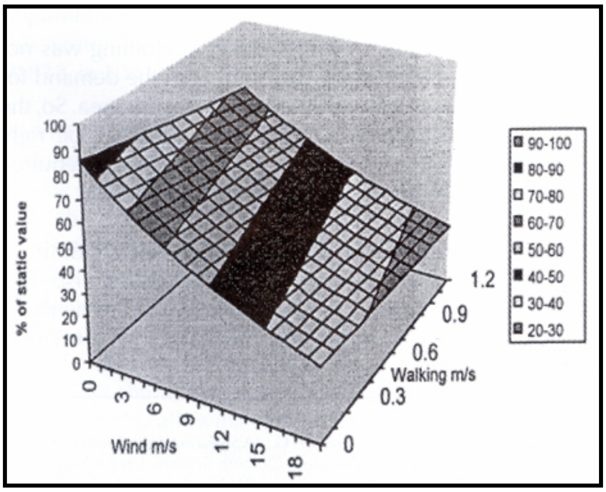


Figure 2 : Relationship between second-degree burn time and turnout moisture content[2]

Some interesting researches have been done by Ingvar Holmear at Department of Occupational Medicine, National Institute for Working Life, Solna, Sweden, the tests were conducted in different environmental conditions by changing the wind speed with variable walking speed and the thermal insulation of the clothing was tested. It was observed that values obtained under dynamic conditions are 10±30% lower than static values. The changes in the thermal insulation of the clothing with change in Wind speed and Walking speed of the wearer is shown in the below figure-3.[4]



Adding to above there is a significant change in the heat loss with change in the air velocity as shown in below figure-4.

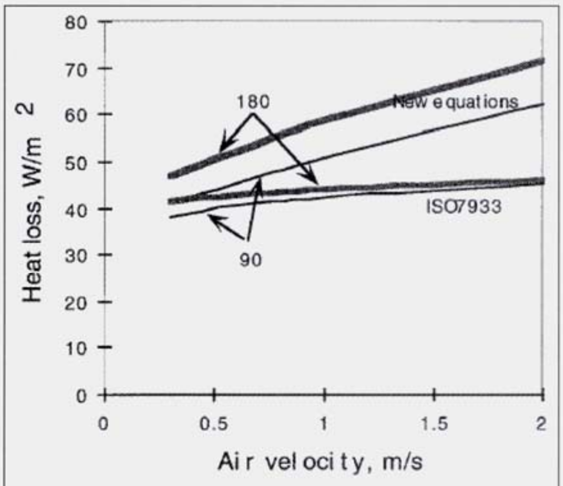


Figure 4 : Change in the heat loss with change in the air velocity[4]

The tests were conducted to calculated values for convective and radioactive heat loss in W/m² for two conditions using the ISO 7933 and the new correction procedures. Calculations refer to a basic clothing value of 1.0 clo and a metabolic rate of 90 and 180 W/m², respectively. Skin and air temperatures were 34 and 258°C, respectively.[5]

Based on the researched done by Elizabeth A. McCullough and Chil Soon Kim from Institute for Environmental Research, Kansas State University, USA, where static (standing) and dynamic (walking) clothing insulation values were studied it was observed that the total static insulation values for cold weather clothing ensembles ranged from 1.54 clo to 4.12 clo and at the same time total dynamic insulation values ranged from 0.85 clo to 3.54 clo, and a decrease in total insulation due to walking at 90 steps/min was found varied from 14 to 46 %.[6]

Studies conducted on effect of walking speed and wind velocity on thermal insulation of clothing under researches done at Institute of Textiles and Clothing, The Hong Kong Polytechnic University by Xiaoming Qian and Jintu Fan, it was observed that with the increase in wind velocity and walking speed, there is decrease in the thermal insulation of the clothing, the results were analyzed by using correlation between wind speed and reduction in thermal insulation, and a correlation coefficient of 0.97-0.99 was achieved as result of the analysis, it proves that both are highly positively correlated.[7]

Influence of body moisture on thermal properties on sleeping bags was studied by EMPA, Swiss Federal Laboratories for Materials Testing and Research and TNO, Netherlands Organization for Applied Scientific Research and Human Factors Research Institute, under theses researches influence of body moisture on the insulation properties was studied 10 different sleeping bags used in extreme conditions below – 30 °C.

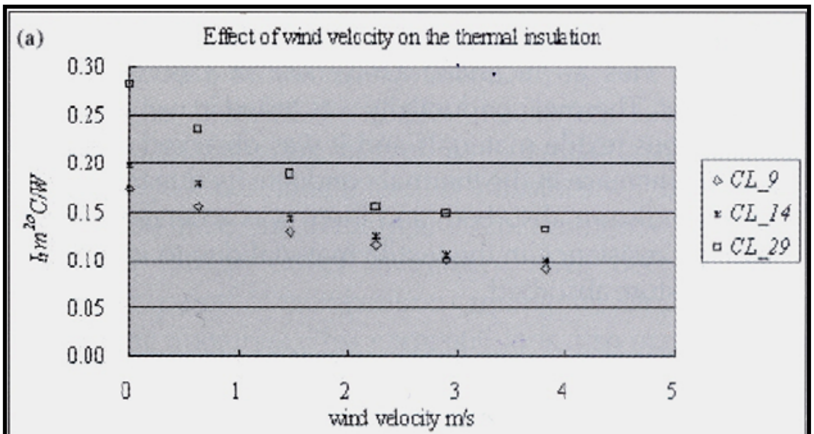


Figure 5 : Effect of wind velocity on the Thermal Insulation[7]

It was observed that in the extreme climates up to 80% of the moisture released by the human body condenses inside the sleeping bag itself and it results in reduction of the thermal insulation.

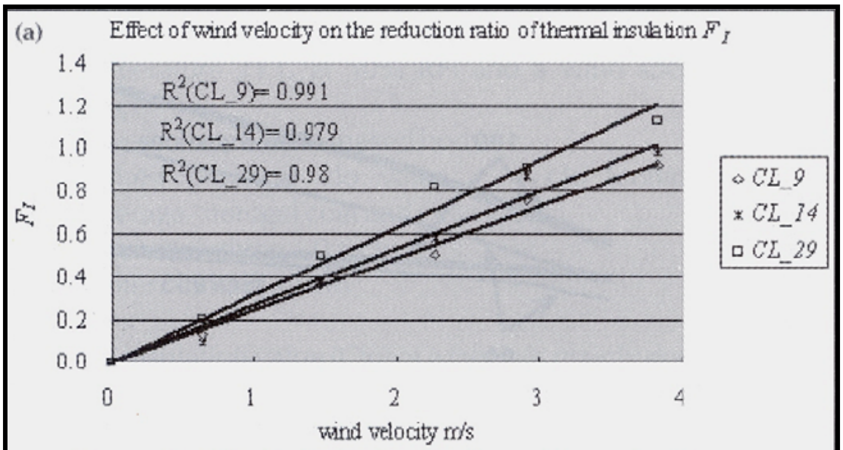


Figure 6 : Effect of wind velocity on the reduction ration of Thermal Insulation[7]

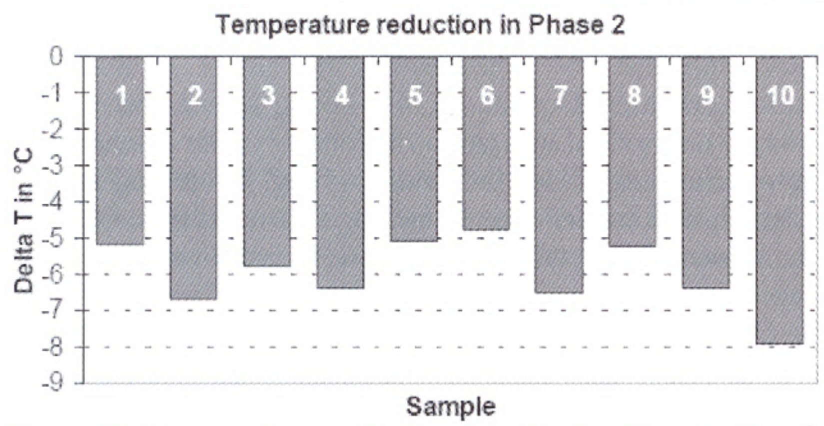


Figure 7 : Temperature reduction in side the sleeping bags[8]

A drastic change in the temperature inside the sleep bag was observed, and it was due to the reduction in the thermal insulation due to moisture accumulation. Thermal Comfort properties of textile material as studied by Prof. L. Hes at Technical University of Liberec, Czech Republic, Thermal conductivity was tested in wet condition for various textile materials and it was observed that there was an increase in the thermal conductivity due to increase in the moisture absorbed, and there was a decrease in the thermal resistance in the textile material due to increase in the moisture absorbed.

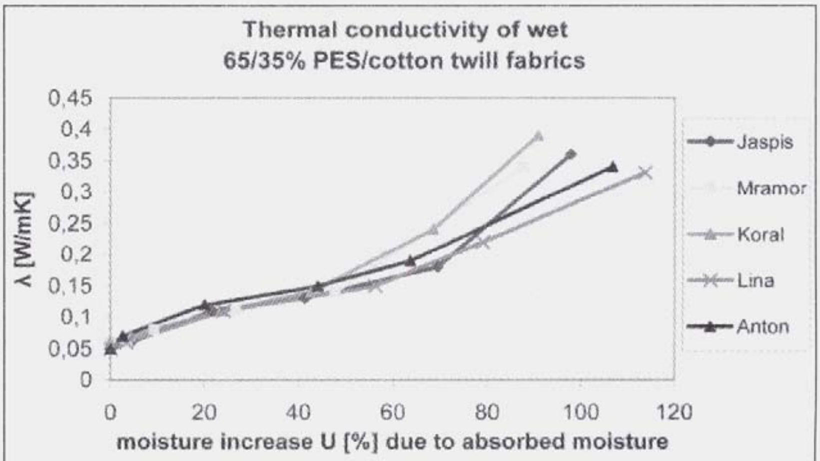


Figure 8 : Thermal conductivity changes with moisture for different working cloth fabrics

The observations are represented in the below charts (Fig. 8 and Fig. 9).[9]

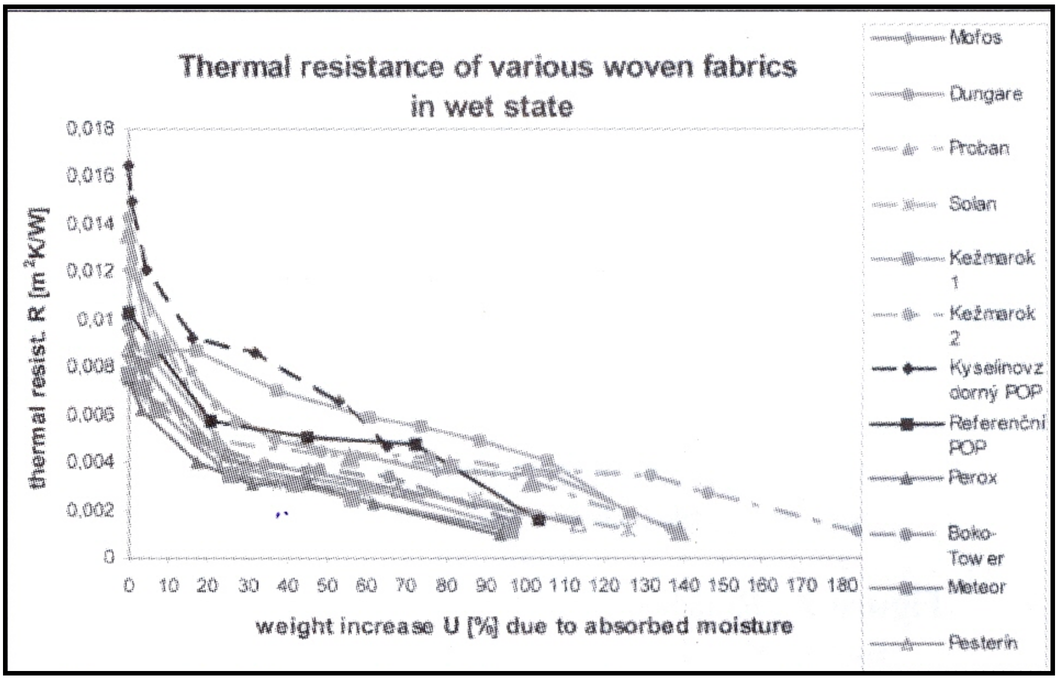


Figure 9: Thermal resistance changes with moisture for different working cloth fabrics

The studies and researches discussed in this article prove that there is a drastic change in the thermal behaviour of textile material white they are tested under dynamic conditions; hence it leads to more realistic assessment of the performance of the clothing.

Conclusion

Thermal properties of clothing plays vital role in providing comfort to the human body. Wrong assessment of performance level of clothing may cause some serious problems on psychological as well as physiological ground. Many researches have shown that sense of uncomforted decreases the efficiency level of work also and it results in energy loss.

The importance of achieving comfort in clothing was not given importance in earlier times but with the demand for better performance has increased interest in this area. So, the correct analysis, understanding and selection of right material that serves the requirement and meet the required performance standards is need of the hours.

The correct measurement of thermal behaviour of clothing is very crucial for risk assessment in extreme climate also, This deals with ergonomic properties and requirements of clothing, making it more user friendly with providing protection.

References

1. Richards Mark G. M., Mattie Niklaus G.; "A Sweating Agile Thermal Manikin (SAM) Developed to Test Complete Clothing Systems Under Normal and Extreme Conditions", EMPA, Swiss Federal Laboratories for Materials Testing and Research, accessed on' 4-12-2009

2. Wigo Hans and Nilsson Hakan o; "Application of a Thermal Manikin to Evaluate Heat Loss Rates from People caused by Variations in Air Velocity and Air

Temperature", Centre for 8uilt Environment, University of Gavle, Sweden, accessed from www.ijovent.org.uk. on 24-03-2010

3. Barker R. L. , Schacher C. Guerth, Grimes R. V. , and Hamouda H.; "Effects of Moisture on the Thermal Protective Performance of Firefighter Protective Clothing in Low-level Radiant Heat Exposures", Textile Research Journal 2006; 76; 27, Accesed from http://trj.sagepub.com/cgi/content/abstract/ *76/1/27* on 21-03-2010

4. Holmear Ingvar; "The Role of Performance Tests, Manikins and Test Houses in Defining Clothing Characteristics Relevant to Risk Assessment, Department of Occupational Medicine", National Institute for Working Life, Solna, Sweden, accessed from http://annhyg.oxfordjournals.orgon 11-03-2010

5. Holmear I, Nillson H., Havenith G., Parsons K.; "Clothing Convective Heat Exchange-Proposal for Improved Prediction in Standards and Models", accessed from http://annhyg.oxfordjournals.orgon 21-03-2010

6. McCullough Elizabeth A. and Kim Chil Soon; "Insulation values for cold weather clothing under static and dynamic conditions", accessed from http://www.lboro.ac.uk/departments/hu/groups/EEC/ICEE/textsearch/96articles/McCullough1996.pdf, on 21-03-2010

7. Qian Xiaoming and Fan Jintu; "Prediction of Clothing Thermal Insulation and Moisture Vapour Resistance of the Clothed Body Walking in Wind", Ann. Occup. Hyg., Vol. SO, No.8, pp. 833-842, 2006, Published by Oxford University Press, accessed from http://annhyg.oxford journals.org! cgi/content/abstract/SO/8/833 on 18-02-2010

8. Camenzind M., Weder M. and Hartog E. Den; "Influence of Body Moisture on the Thermal Insulation of Sleeping Bags", Paper presented at the RTO HFM Symposium on "Blowing Hot and Cold: Protecting Against Climatic Extremes", held in Dresden, Germany, 8-10 October 2001, and published in RTO-MP-076, accessed from http://ftp.rta.nato.int/public//PubFuIIText/RTO/MP/RTO-MP-0761I1MP-076-0S.pdf on 24-03-2010

9. Hes L.; "Thermal Comfort Properties of Textile Fabrics in Wet State", Accessed from http://www.teknikfuarcilik.com/Makale/ bbur_master_islak_kumasjng.pdfon 26-12-2010

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