THERMAL COMFORT OF TEXTILES FOR TENT APPLICATION

Gooijer Henk[1], Velan Manicka[2], Esen Irfan[1], Kamphuis Sven[1], Groeneveld Richard[1], Agrawal Pramod[1] and Brinks Ger[1]

[1]*Chair Smart Functional Materials, Research Centre Design and Technology, Saxion University of Applied Sciences, Enschede, The Netherlands.*

[2]*Department of Textile Design, National Institute of Technology, Ahemedabad, India,*

Email: h.gooijer@saxion.nl

ABSTRACT

The aim was to establish the influence of the tent fabric properties on the indoor tent climate. The first step was to thoroughly characterize a series of representative tent fabrics. The chosen route to quantify the influence of the tent fabric on comfort was first to establish the definition of thermal comfort and the related physical parameters. Comfort is connected to thermal comfort and the occurrence of condensation at the tent surface. Secondly, models for the influence of the fabric properties on those physical parameters were set-up. Finally the results of the fabric characterization were included in the model.

Key Words: Thermal comfort, Modelling, Tent fabrics,

1. INTRODUCTION

Comfort (or being comfortable) is a sense of physical or psychological ease, often characterized as a lack of hardship. Persons who are lacking in comfort are uncomfortable or experiencing discomfort. Within the scope of this research, we concentrate upon thermal comfort of people in the tent and on the occurrence of drop formation (condensation) on the inner tent surfaec. Parameters affecting thermal comfort are temperature, humidity, ventilation/breathability and radiation. A systematic approach has been adopted. A series of seven different tent fabrics was characterised. Mathamatical modelling was done to identify the influence of the tent fabric on heat transfer and water vapour transport, which were shown to define internal air temperature and relative humidity. Furthermore, the influence of the tent fabric on the occurrence of condensation at the inner tent surface was studied.

2. MATERIALS AND METHODS

2.1 Materials

Seven tent fabric were kindly supplied by Ten Cate Outdoor Fabrics BV, Nijverdal, the Netherlands. All fabrics were light brown coloured (except G, which is a dark brown coloured fabric). The table 1, below gives the code and composition of these fabrics.

Table 1. Seven selected tent fabric samples and their composition

Sample	Application	Composition
A	Caravan fabric	100 % PET, coated
B	Caravan fabric	PET/PVA (70/30), coated
C	Consumer tent (breathable)	100% cotton
D	Consumer tent (breathable)	Cotton/PET, 50/50
E	Rental tent	Cotton/PET 50/50
F	Rental tent/FR	Quatroblend (Modacrylic, viscose, PVA, PVA FR)
G	Rental tent/FR	Quatroblend (Modacrylic, viscose, PVA, PVA FR), dyed

2.2 Methods

A series of seven representative fabrics (table 1) was characterized and properties were measured. The following table (table 2) gives the information about the fabric properties, equipment used and appropriate related standards.

Table 2. Characterisation methods and properties evaluated for seven selected tent fabrics.

Fabric properties	**Equipment**	**ISO/AATCC standard**
Fabric weight	Weight balance	
Fabric thickness	Thickness meter	ISO 5084
Air permeability (mm/s)	Textest AG FX3300 Air Permeability Tester	ISO 9237:1995
Water vapour permeability (P)	Mesdan Lab Vapour Tester 3395	ISO 14268:2010
Heat transfer (λ/d)	SDL ATLAS Fabric Touch tester M293	

The air permeability of the fabrics was measured using a conditioned fabric in a conditioned lab as defined by the standard. All other analyses were done using non conditioned fabrics. The room temperature and humidity are expected to have especially a significant influence on the results of the water vapour permeability measurement. However, all samples were measured in the same batch. So, it was assumed that the results can be used for comparison, as measuring conditions (temperature and air humidity) were identical for all fabrics.

3. RESULTS AND DISCUSSION

3.1 Fabric properties

The properties of the seven selected tent fabric samples were measured. Those relevant data such as fabric density m, fabric thickness d, water vapour permeability (P) and heat transfer per unit of thickness (λ/d) for the seven fabrics are given in table 3.

Table 3. Selection of the fabric characterization results.

Fabric	m in g/m^2	d in mm	P in mg/cm^2.hr	λ/d in W/m^2 .K
A	193	0,35	0,8	115
B	155	0,30	1,0	120
C	316	0,44	16,7	115
D	280	0,43	15,6	113
E	407	0,66	12,5	96
F	424	0,62	10,6	97
G	424	0,62	8,1	97

From the table it is clear, that the fabric properties show significant differences depending on the type of end application. The three rental tent fabric (E, F and G) have the highest density and thickness, followed by the consumer tent fabrics C and D. It is clear from the table that coated fabrics (A and B) have the highest thermal conductance per unit of thickness. Overall ranking in water vapour permeability is coated caravan fabric < rental tent fabric < breathable fabric, which is to be expected.

3.2 Definition of comfort

Comfort within the tent is kept limited to thermal comfort and the occurrence of condensation at the tent surface. Condensation is defined as the occurrence of water drops at the inner tent surface and should be prevented. A literature search was conducted to investigate how internal thermal comfort can be defined. The problem is that thermal comfort is an individual perception. Two standards were found in literature defining indoor comfort. The Fanger Model used in ISO 7730 **[1]** and the ASHRAE 55-2013 **[2]**, both defining internal comfort as the situation in which less than 20% of the people has a feeling of discomfort. The most important parameters defining thermal comfort according ISO 7730 and ASHRAE 55-2013 are:

1. Temperature of the air,
2. Indoor air speed (wind, drought),
3. Relative humidity of the air,
4. Radiation
5. Metabolism of the persons present,
6. Isolation of clothing,

Both standards predict series of combinations of those conditions, in which less than 20% of the people perceive thermal discomfort **[1,2]**. As an example, in figure 1, the area in which less than 10% (dark grey) or less than 20% (light grey) of the people has feeling of thermal discomfort is shown as a function of indoor and outdoor temperature according ASHRAE 55-2013 **[2]**.

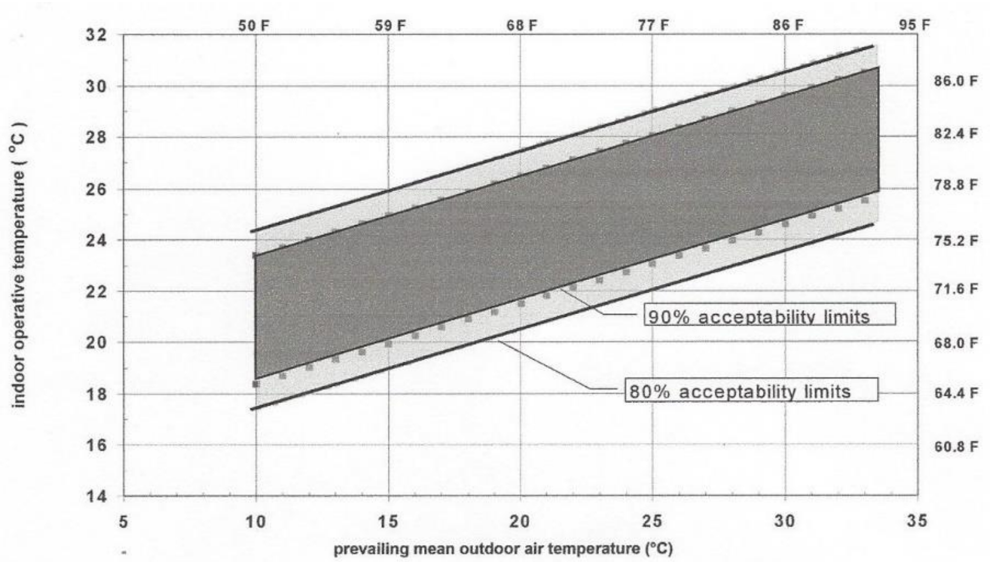

Figure 1. Influence of indoor and outdoor air temperature on thermal comfort (ASHRAE 55-2013) [2]

The ISO 77300 standard is designed for airconditioned spaces and less fit for spaces with natural ventilation, therefore the ASHRAE 55-2013 standard seems the most appropriate for defining thermal comfort in tents, although they both models overestimate the feeling of discomfort **[3,4,5]**. The biggest difference between the two models is that the ASHRAE 55-2012 takes the influence of the outdoor temperature into account **[2].**
The parameters 5 and 6, mentioned above, can of course not be influenced by the tent cloth and 2 is mainly defined by tent architecture. From **[2]** it was concluded that the relative humidity and the air temperature are the most important parameters defining thermal comfort, therefore this research further focussed on those two parameters for the modelling.

3.3 Modelling

Modelling was done to identify the influence of the tent fabric on heat transfer and water vapour transport between the inside and the outside of the tent. These two physical processes were assumed to define the internal air temperature and relative humidity. In a second part of the research, the influence of the tent fabric on the occurrence of condensation was studied.

3.3.1 Heat transfer

A model for heat transfer was set-up based on the general equation for the heat transfer coefficient U, as presented in equation 1.

$$1/U = 1/\alpha_{indoor} + d/\lambda + 1/\alpha_{outdoor} \qquad (1)$$

In which:
U = the overall coefficient for heat transfer ($W/m^2.K$)
α_{indoor} = coefficient for heat transfer of the air in tent ($W/m^2.K$)
λ = heat conductivity tent fabric ($W/m^3.K$)

d = thickness tent fabric (m)
$\alpha_{outdoor}$ = coefficient for heat transfer of the air outside tent ($W/m^2 .K$)

This equation shows that the total overall heat transfer coefficient U is not only partly a function of the fabric properties (λ/d), but that it is also determined by the air conditions in and outside of the tent (α_{indoor} and $\alpha_{outdoor}$) The heat transfer coefficient for the air outside the tent is assumed to be a strong function of the air velocity, e.g. the occurrence of wind, as moving air promotes heat transfer. Using the measured heat transfer of the selected fabrics, the heat transfer was calculated as a function of fabric type and the occurrence of wind. The air inside the tent was assumed to be not moving. The heat transfer was calculated for different levels of in and outdoor temperature. An example of results is shown in figure 2.

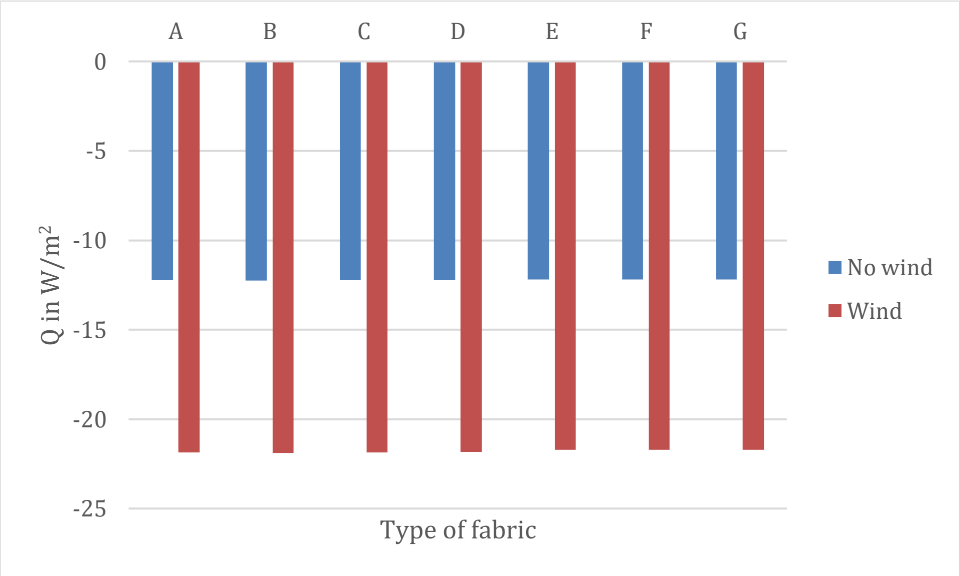

Figure 2. Heat transfer as a function of fabric type and wind.

From the figure, it appears that the type of fabric has no influence on the heat transfer and that wind does improve heat transfer. The heat transfer appears to be independent of the nature of the tested fabrics. This means that the heat transfer is mainly determined by the air conditions and that the resistance for heat transfer of the fabric can be neglected compared to the resistance for heat transfer of the air layers surrounding the fabric.

3.3.2 Water vapour transport

A model for water vapour transport was also set-up, using the general equation for mass transport, equation 2.

$$\Phi = D/RT * (p_{H20,outside} - p_{H20, inside})/d * 1/R_{fabric} \quad \textbf{(2)}$$

In which:
Φ = water vapour flow in $mol/m^2.s$
D = diffusion coefficient of water vapour in air in m^2/s
R = gas constant = 8,31 J/mol.K
T = temperature in K
P_{H2O} = water vapour partial pressure in Pa
d = thickness fabric in m
R_{fabric} = resistance mass transfer fabric ($s.m^2/mol$)

The R_{fabric} was deducted from the measured water vapour permeability P using equation 2. Due the measuring conditions in the Lab Vapour Tester, the mass transfer resistance for the fabric cannot be determined independently from the air conditions. So, the resistance to mass transport of the surrounding air in the measuring set-up is included in R_{fabric}. The water vapour transport was calculated for different temperatures and humidity levels.
An example of the results for the water vapour transport Φ, as a function of fabric type is presented in figure 3.

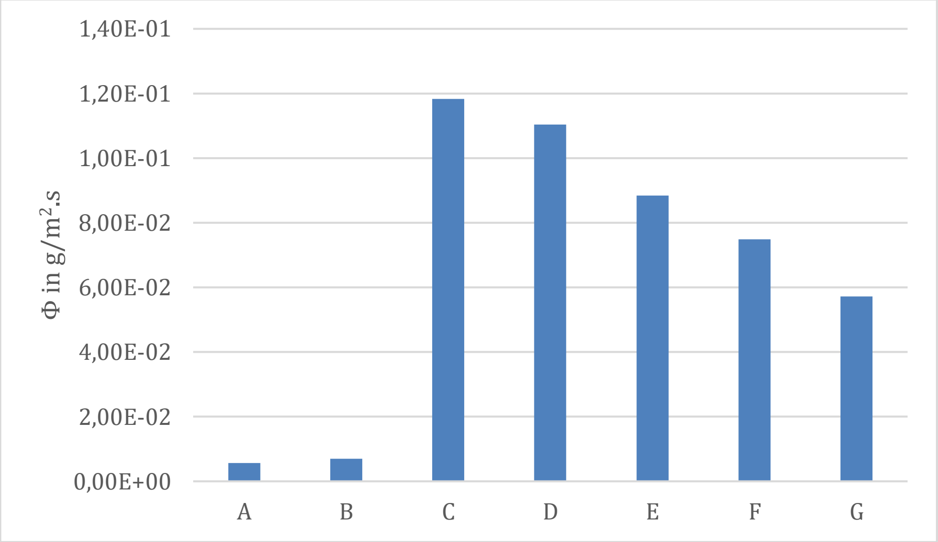

Figure 3. Water vapour transport as a function of fabric type.

Contrary, to the heat transfer, the mass transfer is strongly influenced by the type of fabric. From the figure it appears that the water vapour transport is much lower for the coated fabrics (A and B). Furthermore, the heavier fabrics for rental tents (E, F and G) show a lower water vapour transport capacity than the lighter fabrics for consumer tents (C and D).

3.3.3 Condensation

It was assumed that condensation occurs if the temperature of the tent fabric is lower than the temperature of the indoor air and the air inside the tent has a high relative air humidity. As shown in 3,3, the heat transfer is not influenced by the type of fabric and therefore also the fabric temperature is not influenced by the type of fabric. Calculations, using equation 1, however showed that in the presence of wind outside the tent, the temperature of the tent fabric is close to that of the outdoor atmosphere. An example is shown in figure 4, for a tent with an indoor temperature of 20 °C.

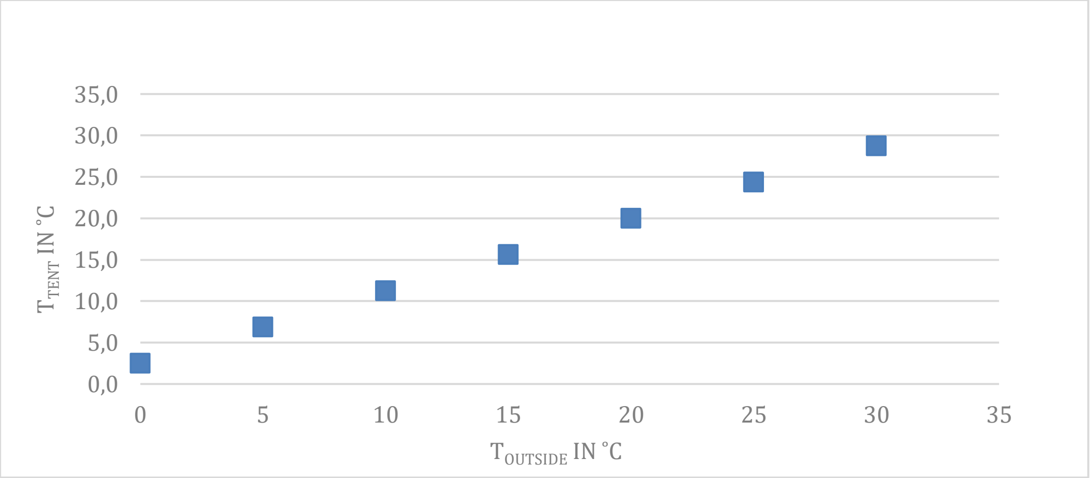

Figure 4. Temperature inner tent surface T_{tent} as a function of outside air temperature $T_{outside}$

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So, it was concluded that the occurrence of condensation cannot be influenced by the type of fabric. However, if the fabric is able to absorb the condensed water, no water drops will be visible at the surface of the tent fabric. So, by choosing the right fabric properties, the appearance of condensation cannot be prevented, but the visible results of condensation, the drops at the tent surface, can be prevented.

4. CONCLUSIONS

The models for thermal comfort conclude that the feeling of thermal comfort in the tent is mainly determined by the air temperature and humidity. An area with specific combinations of air temperature and humidity levels can be defined in which less than 20% of the people have a feeling of thermal discomfort.

A model has been set-up to model the heat transfer through a tent fabric as a function of the resistance to heat transfer of the fabric and the conditions of the surrounding air. The modelling showed that the different types of fabric have no influence on the heat transport through the fabric, but that this is solely defined by the air conditions in and outside the tent.

Furthermore, a model has been set up for the water vapour transport as a function of tent fabric and air conditions. The modelling showed that water vapour transport (P) is strongly influenced by the type of fabric. The heavier and especially the coated fabrics show a higher resistance to water vapour transport.

The model for heat transfer also showed that the occurrence of condensation cannot be prevented, as this is mainly cause by difference in air temperature and humidity in and outside the tent.

The developed models can be used as a tool in product development and in the product placement for different climate conditions.

5. REFERENCES

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