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# MODELING THERMAL CLOTHING COMFORT INDEX

**Amine HADJ TAIEB [*], Abir BAKLOUTI, Dhouha MAROINI, Slah MSAHLI**
Laboratory of Genie Textile of ISET of Ksar Hellal, 5070, Ksar Hellal,Tunisia
ISAMS

## ABSTRACT

One of the fundamental functions of clothing is to keep the human body in an appropriate thermal environment in which it can maintain its thermal balance and thermal comfort.

This paper investigates the process of thermal perceptions of clothing and to develop a modelling method for predicting thermal clothing comfort performance from fabric physical properties. We try to represent objectively the thermal comfort to simulate the consumer comfort perception by using desirability function.

The conceived index can help fabric's producer, fashion or textile designer, to tune affine the textile product for the whished application according to the index's value

**KEYWORDS**: Modelling, Thermal comfort, comfort index, desirability functions.

## INTRODUCTION

Today clothing comfort is considered as fundamental property when a textile product is valued [1]. It is a subjective notion and a multicriteria phenomenon that requires the simultaneous satisfaction of several properties; that's why it is difficult to find an efficient method permitting to optimize this perception in spite of attempts of some researchers [2, 3]. In fact, the textile industry lacks objective approaches for determining the level of comfort. In this context, some researches were done to optimize some properties of the textile material but a very few of them optimise a set of properties in the same time [4, 5]. Besides, it is generally easier to determine the different properties that affect the comfort separately. These measured properties separately don't give a lot of information to the consumer when using the textile product, from where the necessity of comfort indexes by measuring different properties affecting textile comfort perception [6].
According to the literature [7, 8] the textile comfort can be divided into three groups: psychological, tactile and thermal comfort.
In this survey, we will focus on developing a model for predicting the thermal clothing comfort levels of fabrics according to physical fabric properties.

## MATERIALS AND METHODS

In this study, we will use mathematical function based on the desirability functions for evaluating the subjective thermal clothing comfort from the objective measurement of physical properties of fabric. Thermal comfort index will be conceived for a set of properties affecting thermal clothing comfort to optimise the thermal comfort perception. This index takes into account the consumer requirements and the importance of each selected property affecting the thermal comfort.

### The selected physical properties affecting thermal comfort

In this survey, the studied physical aspects of thermal comfort are thermal insulation, air permeability and water resistance.

#### *The thermal insulation*

Clothing has a large part to play in the maintenance of heat balance as it modifies the heat loss from the skin surface and at the same time has the secondary effect of altering the moisture loss from the skin. However, no one clothing system is suitable for all occasions. A clothing system which is suitable for one climate may not be suitable for another climate [9].

Good thermal insulation properties are needed in clothing and textiles used in cold climates. The thermal insulation depends on a number of factors, thickness and number of layers, drape, fibre density, flexibility of layers and adequacy of closures [10].

***Air permeability***

Air permeability describes the property of fabric to let through air. In outdoor clothing it is important that air permeability is as low as possible because it should function as a wind protection. Air permeability of a fabric is a measure of how well it allows the passage of air through it. The ease or otherwise of passage of air is of importance for a number of fabric end uses such as industrial filters, tents, sail cloths, parachutes, raincoat materials, shirting, and airbags [11].

Generally, the air permeability of a fabric can influence its comfort behaviour in several ways. In the first case, a material that is permeable to air is in general, likely to be permeable to water, in either the vapour or the liquid phase. Thus, the moisture-vapour permeability and the liquid-moisture transmission are normally closed related to air permeability. In the second case, the thermal resistance of a fabric is strongly dependent on the enclosed still air, and this factor is in turn influenced by the fabric structure.

***Water resistance***

Water resistance is needed in outdoor clothing for protection against rain and is a requirement for furniture and bed covering to protect against liquid excretions. Textile and clothing can be water resistance treated with finishing agents or they can be made totally water resistant with coating or laminated membranes. Liquid water transmission is an important feature of diapers. It is the ability to absorb and capture liquid inside the fibres but not letting it escape. If sweat condenses to liquid it must be able to be transmitted away from the skin surface.

**The selected thermal comfort modelling method: the Desirability Function**

In this survey, we will use a new approach for evaluating the thermal comfort from physical properties of fabric. Thermal comfort was calculated by using the desirability functions.

The desirability function is a simple process to combine the values of several responses in a simple quantitative measure, representative of the quality of the compromise. This method is composed of three stages:

- Response Modelling: Yj = fj (X1,…., Xk)
- Transformation of every model according to the objective dj = Tj (Yj, objective)
- Creation of a desirability function characterizing the compromise D = g (d1,…, dm)

Every transformation ″dj″ is the satisfaction percentage according to the criteria calculated by the model, in relation to the objectives fixed on these criteria.

Harrington in 1965 is the first that formulated a diagram of optimization in term of desirability function. Then Gatza and Mila in 1972 and finally Derringter and Swich in 1980 [12] brought some improvements to the calculations of the desirability function.

The ″dj″ values are combined by using the geometric mean calculated according the formula (1).

$$D = (d1 \times \ldots \times dm)1/2 \quad (1)$$

Where:

D is the global desirability function to optimize.

This composite desirability is a measure of how the solution has satisfied the combined goals for all the responses. Composite desirability has a range of zero to one. One represents the ideal case; zero indicates that one or more responses are outside their acceptable limits. Composite desirability is the weighted geometric mean of the individual desirability for the responses.

In the case where it is possible to create a hierarchy between the properties affecting the comfort perception, we affect to every property an importance degree. By using the Derringen and Suich desirability function and by according relative importance for each individual desirability we calculated the global desirability function as follows [12]:

$$d = (d_1^{w_1} \times d_2^{w_2} \times \ldots \times d_m^{w_m})^{1/w} \quad (2)$$

Where:
di is the individual desirability function of the property Yi affecting the thermal comfort perception.
wi is the weight of the property "Yi" in the global desirability function "d".

$w = \sum_{1}^{m} w_i$ , and m is the number of properties.

Some mathematical transformations permit to transform every response to an individual desirability function.
These desirability functions "di" can be classified into two main types: desirability function to minimize and to maximize.
For example, when we want to maximize a property "Yi", such as the air permeability, we use the desirability function to maximize. Below the lower bound the response desirability is zero; above the target it is one.
In this desirability function we take into account the target "Ytarget", the different acceptance intervals [Ymin, Ymax] and the requirement level.

Where di is calculated as follows:

$$d_i = \begin{cases} 0 \quad \text{if } Y_i \le Y_{min} \\ \left( \dfrac{Y_i - Y_{min}}{Y_{target} - Y_{min}} \right)^s \quad \text{if } Y_{min} \le Y_i \le Y_{target} \\ 1 \quad \text{if } Y_i \ge Y_{target} \end{cases} \quad (3)$$

The weight "s" in the formula (3) defines the shape of the desirability function for each property. We can select a weight (from 0.1 to 10) to emphasize or de-emphasize the target.
This weight "s" can be also interpreted like the consumer's requirement: the "s" value increase is proportional to the requirement increase.
If "s =1" it places equal importance on the target and the bounds. The desirability for a response increases linearly and the consumer requirement is medium.
If "s >> 1"it places more emphasis on the target. A response value must be very close to the target to have a high desirability we estimate that the consumer requirement is too high.
If "s << 1" it places less emphasis on the target. A response value far from the target may have a high desirability. We can consider that the consumer requirement is too low.

When we want to minimize a property "Yi", we use the desirability function to minimize, for example the thermal insulation in summer clothing end uses. Below the target the response desirability is one; above the upper bound it is zero.
Where di is calculated as follows:

$$d_i = \begin{cases} 1 \text{ if } Y_i \le Y_{target} \\ \left( \dfrac{Y_i - Y_{max}}{Y_{target} - Y_{max}} \right)^t \text{ if } Y_{target} \le Y_i \le Y_{max} \\ 0 \text{ if } Y_i \ge Y_{max} \end{cases} \quad (4)$$

In this case, the consumer's requirement is represented by the "t" value.
To define the desirability function, we have to fix the objective of every property affecting the thermal comfort perception.
The desirable level fabric performance comfort is defined in terms of the intended end use and, ultimately, by the user. It is generally difficult to describe what is meant by term "performance, comfort". The requirement, or the specific performance comfort level for each characteristic, is more difficult to establish. Manufacturers' experience with consumers and suppliers is often a factor in establishing the minimum performance comfort level and in establishing standard performance is to match the consumers' expectations for the product [12].
In this study, table 1 represents the target values and the limits of the selected thermal comfort properties.

***Table 1. The target values and the limits of the selected thermal comfort properties.***

| Properties | Reference method | Objectives | Lower limit | Upper limit |
|---|---|---|---|---|
| Thermal insulation | NF G 07-108 | Maximize | 19 | 21 |
| Air perméability (ml/cm²/sec) | BS 5636 | Maximize | 5 | 10 |
| Water resistance (mm of water pressure) | ISO 811:1981 | Maximize | 45 | 70 |

## RESULTS AND DISCUSSION

**Measured comfort properties**

Different physical properties affecting thermal perception (thermal insulation, water resistance and air permeability) are measured according to reference test method represented in table 1.
The construction features of studied fabric are represented in table 2.

***Table 2. Construction features of studied fabric.***

| Properties | | Fabric 1 | Fabric 2 | Fabric 3 | Fabric 4 | Fabric 5 |
|---|---|---|---|---|---|---|
| Weft yarn density (yarns/cm) | | 22 | 27 | 25 | 23 | 21 |
| Warp yarn density (yarns /cm) | | 17 | 22 | 20 | 19 | 18 |
| Yarn thickness (Tex) | Weft | 42 | 48 | 45 | 50 | 47 |
| | Warp | 55 | 60 | 57 | 63 | 65 |
| Twisting coefficient | Weft | 105 | 115 | 108 | 106 | 114 |
| | Warp | 95 | 102 | 101 | 95 | 101 |
| Thickness (mm) | | 0,85 | 0,95 | 0,98 | 0,87 | 0,98 |
| Fabric weight (g/m²) | | 268 | 313 | 307,5 | 277,8 | 300 |

For the five studied denim sample fabrics, the selected physical properties are represented in the table 3.

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***Table 3. Characteristics of thermal comfort properties of studied fabrics.***

| Properties | Reference method | Fabric 1 | Fabric 2 | Fabric 3 | Fabric 4 | Fabric 5 |
|---|---|---|---|---|---|---|
| Thermal insulation | NF G 07-108 | 17,25 | 18,42 | 19,81 | 17,44 | 20,24 |
| Air perméability (ml/cm²/sec) | BS 5636 | 13 | 10,5 | 12 | 7 | 10,86 |
| Water resistance (mm of water pressure) | ISO 811:1981 | 36 | 47 | 50 | 41 | 64 |

**Individual desirability functions**

For the measured properties, we will study the thermal comfort performances of the five different denim fabrics by using the desirability functions as described in the formula (3) and (4) according to the objective of each properties.

For the studied fabrics, we obtained the individual desirability of the selected physical comfort properties as shown in table 4 (the consumer's requirements were: s = 1).

***Table 4. Individual desirability functions of thermal comfort properties of studied fabrics.***

| Properties | Fabric 1 | Fabric 2 | Fabric 3 | Fabric 4 | Fabric 5 |
|---|---|---|---|---|---|
| Thermal insulation | 0 | 0 | 0.4 | 0 | 0.62 |
| Air permeability (ml/cm²/sec) | 1 | 1 | 1 | 0.4 | 1 |
| Water resistance (mm of water pressure) | 0 | 0.08 | 0.2 | 0 | 0.36 |

**Thermal comfort indexes**

After calculating individual desirability ($d_i$) for different properties affecting thermal comfort, we have combined them to provide a measure of the composite, or overall, desirability of the thermal comfort. This measure of composite desirability is the weighted geometric mean of the individual desirability for the comfort properties. The optimal solution for a better thermal comfort for a specified application can then be determined by maximizing the composite desirability. They can be used as comfort indexes for the thermal component.
The table 5 summarizes the thermal comfort indexes for the five studied fabrics.

***Table 5. Thermal comfort indexes of the studied fabrics***

| | Fabric 1 | Fabric 2 | Fabric 3 | Fabric 4 | Fabric 5 |
|---|---|---|---|---|---|
| Thermal Comfort Index | 0 | 0 | 0.28 | 0 | 0.47 |

From the table 5, we can notice that the fabric n°5 and n°3, give the first and the second better thermal comfort index, this can be due to the high thickness fabric compared to the others studied denim fabrics,
Consequently, for the studied fabrics, we can estimate the Thermal Clothing Comfort Index, according to the consumer requirements and the importance degree assigned to every selected fabric property. The desirability values depend on the objective of every property, on the acceptance intervals and on the requirement of the consumer. This desirability value can be used as thermal clothing comfort index of consumer’s comfort perception of denim fabric. This method can be also used for other kind of fabrics to foresee the Thermal Clothing Comfort Index according to the end user needs.

## CONCLUSION

The importance of this study appears in the attempt to represent, objectively, thermal clothing comfort of fabrics which is multicriteria phenomenon. This approach takes into account the fabric end uses, different consumer requirement and the contribution of every property in thermal clothing comfort perception.
This method is achieved by mathematical functions which are the desirability functions. It is applied to different denim fabrics.

We anticipate that this study will provide a tool using mathematical function to assess the contribution of physical fabric properties affecting thermal clothing comfort by developing a model for predicting the level of thermal comfort.

By this thermal clothing comfort modelling, on one hand, the producer will have a tool that allows him, according to the targeted consumer, to adjust his product in order to reach the wished thermal comfort. On the other hand, consumer can be informed by the thermal comfort indexes, to help him when buying a textile product.

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