APPLICATION OF THE THERMAL MANIKIN AND NUMERICAL PHYSIOLOGY IN THE EVALUATION OF LOCAL THERMAL DISCOMFORT IN PERSONALIZED VENTILATION

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Summary: In this study the evaluation of local thermal discomfort in personalized ventilation, using a higro-thermal manikin and a numerical modelling of the static and dynamic responses of cold and warm thermo-receptors located in the skin, is made. One hygro-thermal manikin, one ventilated desk, a multi-nodal human thermal comfort model and two indoors climate analyzers, are used. The local thermal discomfort level, using the draught risk level, in an unclothed and in a clothed human body section, namely, in the head and in the chest, is evaluated.

Keywords: Hygro-thermal manikin, Numerical model, Personalized ventilation, Warm and cold thermo-receptors, Local thermal discomfort, Adaptation.

Category: Thermal manikin application including aerospace, automotive, clothing, commercial, industrial and military.

Introduction

The draught risk, caused by air movement, associated to the unwanted local cooling of the human body, is the most frequent cause of complaint in ventilated spaces.

These problems, verified when the skin is subjected to temperature fluctuations, in transient conditions, are detected through the static and dynamic responses of the warm and cold thermo-receptors, located below the human body skin surface. To know these responses is necessary to calculate the evolution of skin depth tissue temperature. In the calculus of these temperatures a model that simulates the human and clothing thermal systems (see [1]) is used.

In the local thermal discomfort level, evaluated by empirical models, the Draught Risk (DR) and the uncomfortable air velocity fluctuation frequencies are used. The first ones, presented for example in [2] and [3], depends on the local air temperature, velocity and turbulence intensity, defined in three categories (A with DR<10 %, B with DR<20 % and C with DR<30 %), while in the second one, presented in [4], the local discomfort sensations associated to the uncomfortable air velocity fluctuations frequency are verified in frequencies between 0.3 and 0.5 Hz. Nevertheless, in according recent studies made by [5] and [6], was verified that uncomfortable air velocity fluctuations equivalent frequencies are obtained in equivalent frequencies between 0.2 and 0.6 Hz.

The objective of this study is to evaluate the local thermal discomfort level that a student is subjected in an unclothed and in a clothed human body section. In this work is analysed, in detail, the head, as example of an unclothed human body section, and the chest, as example of a clothed human body section. The influence of the air mean temperature, velocity, turbulence intensity and the air velocity and temperature fluctuations frequencies in the local thermal discomfort level, are also analyzed.

Numerical Model

The numerical model, that evaluates the local thermal discomfort level, is built by human body and clothing thermal systems. The human body thermal system, that works in transient conditions, is based not only on the energy balance integral equations for the human body tissue, arterial and venous blood, but also on mass balance integral equations for the blood and transpired water in the skin surface. The clothing thermal system is based not only on the energy balance integral equations for the clothing, but also on mass balance integral equations for the transpired water in the clothing.

The human body is divided in 25 (cylindrical or spherical) elements. Each element is divided in 4 parts (core, muscle, fat and skin). In the present study are considered the core with 1 layer, the muscle with 2 layers, the fat with 2 layers and the skin with 15 layers (epidermis with 2 layers, dermis with 6 layers and sub-cutaneous tissue with 7 layers). The cold thermo-receptors are located between the epidermis and dermis, while the warm thermo-receptors are located in the dermis.

Each human body element could be still protected from the external environment through some clothing layers. In this work is considered a Summer typical clothing.

More details can be analysed, for example, in [1].
Cold and warm thermo-receptors

The cold and warm thermo-receptors, in accord to [7], are located below the skin surface at 0.2 and 0.5 mm, respectively. The thermo-receptors signals, analyzed in the central nervous system, that depend on skin depth tissues temperature can be static (that depends on the mean temperature value) or dynamic (that depends on the temperature changes).

In this work the thermo-receptors responses will be analyzed (see [8]), when the skin temperature is subjected to sinusoidal stimuli, caused by the airflow fluctuations. These responses will be used to evaluate the local thermal discomfort, that an occupant feels when is subjected to a turbulent airflow.

This discomfort level, evaluated by the percentage of dissatisfied people due to draft, was developed in accordance with the empirical models presented in [2] and [9]. The static part of the model is developed using the empirical model presented in [2] and [9], while the dynamic part of the model is developed using the empirical model presented in [9].

In the development of the draught risk numerical model a great number of different air velocities fluctuations was used, for different environmental conditions (air mean temperature, radiant mean temperature and air mean relative humidity), measured and generated in indoor ventilated spaces. The draught risk, evaluated by the percentage of dissatisfied people due to draft, for each unclothed human body section, is calculated in function of the PSI (Psychosensory intensity) value, which depends on the static and dynamic response of the thermo-receptors.

The idea is to subject an unclothed neck section by different air flow velocities, in several thermal conditions, and to calculate the associated PSI value. This value, for different experimental tests, is compared to the draught risk value obtained in subjective responses in real tests, done by empirical models, for the same interval conditions. The obtained correlations between the draught risk value and the PSI value is used, in the numerical model, to evaluate the local thermal discomfort for other situations.

The firsts draught risk values are plotted 20 seconds after the test beginning. This is the time required by the central nervous system to process the thermo-receptors responses.

Experimental Setup

In this study, made in a wood experimental chamber, a hygro-thermal manikin, able to simulate a seated occupant, a ventilated desk, equipped with two air terminal devices located above (in front to the trunk area, incident in the head area) and below (in front to the legs area, incident in the knees area) the desk writing area and two indoors climate analyzers (using sensors from SENSOR and from LSI), able to measure the environmental variables around the occupant, are used.

The air temperatures and velocities surrounding the manikin were measured with three omni-directional probes, from Sensor, during 10 minutes at a rate of 6 samples per second. These environmental variables, around the manikin, were measured in front to 15 human body sections (head, chest, abdomen, right shoulder, right arm, right hand, left shoulder, left arm, left hand, right thigh, right leg, right foot, left thigh, left leg, left foot), distanced 0.02 m from the skin or clothes. The indoor climate analyzer, multi-data logger with 11 inputs (Babuc-A) of LSI, was used to measure the mean environmental variables inside the experimental chamber.

In the experimental tests a wood desk, to be used in the schools compartments, is used. The experimental desk is equipped with two air terminal devices made in plastic material, with an exit area around of 48 cm²: one located above and other below the writing area of the desk. The air flow from the terminal devices, which came directly from a compartment not subjected to solar radiation, is controlled by two ventilators: a smaller ventilator placed after the exit air terminal device (used to help the air distribution in the air terminal device and protected by a spaced grid) and a main ventilator placed before the desk ducts system.

In Table 1 is possible to show the mean value of the air velocity (V) and temperature (T) measured in the upper and lower air terminal devices exit.

<table>
<thead>
<tr>
<th>V (m/s)</th>
<th>T (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>Lower</td>
</tr>
<tr>
<td>0,59</td>
<td>28,04</td>
</tr>
<tr>
<td>0,90</td>
<td>28,17</td>
</tr>
</tbody>
</table>

In this study, in order to evaluate the local thermal discomfort level, using the draught risk, only an unclothed (head area) and a clothed (chest area) human body section are analysed in detail.

In Fig. 1 and 2 the air mean velocity evolution measured, respectively, in the head and chest sections are presented, while in Fig. 3 and 4 the air mean temperature evolution measured respectively, in the head and chest are shown.

![Fig. 1. Air mean velocity evolution measured in the head section.](image-url)
Results and Discussion

The objective of this work is to evaluate numerically the local thermal discomfort level, that a seated occupant is subjected to a turbulent air flow field, experimentally obtained, in different manikin body section, during 10 minutes. In the numerical simulation is also possible to analyze the influence of the adaptation that the human body is subjected in the different sections.

In Fig. 5 and 6 are presented the skin temperature evolution calculated, in the surface and in the cold and warm thermo-receptors, respectively, for the head and chest section.

The air velocity fluctuations frequencies verified in the head and chest sections are presented, respectively, in Fig. 7 and 8. The two vertical lines, represented in the figures, are associated to the uncomfortable air velocities frequencies limit, presented in [4].
The draught risk evolution calculated in the chest (clothed section) human body section is presented in Fig. 9 and 10.

In Table 2 is presented the measured air mean velocity and temperature and the calculated air mean turbulence intensity and equivalent frequency, while in Table 3 the draught risk obtained in the numerical model is compared to the Fanger model. The mean numerical draught risk is obtained in the last 8 minutes.

In accord to the previous results is possible to conclude that:

− When a human section is subjected to a turbulent airflow the skin temperature of an unclothed section decreases more than a clothed section;

− In both analysed head and trunk sections the uncomfortable air velocity fluctuations frequencies, calculated in [4], and the uncomfortable air velocity fluctuations equivalent frequencies, calculated using [5] and [6], are not very important;

− The local thermal discomfort level, that the student feels when is subjected to an instantaneous turbulent airflow, is higher in an unclothed section, than a clothed section;

− The initial step, verified in the draught risk, is higher in an unclothed section than in a clothed section. This step time for an unclothed section is around 2 minutes, nevertheless, for a clothed section this time is lower;

− The prevision made by the numerical model for an unclothed sections, is in accord to the presented empirical model. Nevertheless, as it would be expected, the prevision of the local thermal discomfort level, made by the numerical model, in a human body section protected by the clothing is lower that in a human body section not protected by the clothing;

− The draught risk, calculated by the numerical model, is in accord to the Category B.

Conclusions

In this work is presented and applied a numerical model, which evaluates the local thermal discomfort level in an unclothed and in a clothed section, in indoor ventilated spaces. The numerical local thermal discomfort levels is dependent not only of the air mean temperature, velocity and turbulence intensity and the air velocity and temperature fluctuations frequencies, but also on the radiant mean temperature, relative humidity and solar radiation.

It was verified that the human body section not protected by the clothing, in general, is subjected in the first two minutes to an initial step, nevertheless, in clothed sections, in general, this step is only verified during the first minute. In unclothed human body sections the draught risk level, calculated by the numerical model after the initial step, is similar to the values obtained in [2], nevertheless, in clothed sections the numerical values calculated by the numerical model are lower than the empirical models presented in the bibliography.

In future is suggested to use more empirical data to improve even more the numerical draught risk effectiveness.
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References


