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Human Design, Comfort and Discomfort Evaluation

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ABSTRACT

In this work the human design, the thermal comfort and the local thermal discomfort are evaluated. In the design the human geometry is developed for a standard seating occupant. In the thermal comfort the PMV and the PPD indexes are calculated. In the local thermal discomfort, the Draught Risk is evaluated. The study, that considers the Human Thermal Modelling, calculates the evolution of the temperature in the body, namely in the skin and cold and warm thermo-receptors. The thermal comfort is dependent of the heat exchange between the body and the environment and the draught risk is dependent of the air temperature, air velocity and air turbulence intensity. The Human Thermal Modelling, that works in steady state and 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. In the thermal comfort, a mean air velocity is considered in steady state conditions, while in the Draught Risk two different air velocities Root Mean Square are considered in transient conditions.

Keywords: Local thermal discomfort, Static and dynamic responses, Thermo-receptors, Draught risk

INTRODUCTION

The human body thermal response, subjected to a mean air velocity field in steady state conditions and a turbulent air velocity field in transient conditions inside a ventilated space, is evaluated in this work. The human body can be used to assess the thermal comfort, Draught Risk and other human body variables.

The Human Thermal Modelling numerical model considers the human body divided in cylinders and spheres and the Computational Fluid Dynamics numerical model considers the human body divided in boxes.

The Human Thermal Modelling numerical model evaluates the temperature distribution in the human body and in the clothing. The Human Thermal

Modelling uses as input of the Computational Fluid Dynamics numerical model. This software is used to evaluate the thermal comfort and the Draught Risk level of each occupant. The Human Thermal Modelling numerical model considers energy balance integral equation (Conceição et al. 2000) and mass balance integral equation, based in natural, forced or mixed convection between the skin and the environment and between the clothing and the environment, the conduction between skin and the clothing and between the clothing and the seats, evaporation between the skin and the clothing and between the clothing and the environment, radiation between the skin and the clothing and between the skin and the surrounding surfaces, and the respiration between the body and the environment. Examples of the application of this numerical model can be seen in the works of (Conceição and Lúcio 2001) in an experimental and numerical methodology in an experimental data were used as input data and (Conceição et al. 2010) in the application of the adaptive comfort concepts.

Other studies about Human Thermal Modelling numerical models can be analyzed in (Ferreira and Yanagihara 2009), (Zhang et al. 2010), (Tanabe et al. 2002), and others.

The Computational Fluid Dynamics numerical model calculates the environmental variables around the occupants and the parameters that the occupants are subjected. As variables, the numerical model evaluates the air velocity, air temperature, carbon dioxide concentration, as example, and as parameters the numerical model evaluate the as airflow rate, air exchange rate and Draught Risk, as example. The Computational Fluid Dynamics numerical model considers differential equations, as Navier-stokes, energy and others. The Computational Fluid Dynamics numerical model uses as input of the Human Thermal Modelling numerical model. Examples of the application of this numerical model can be seen in the works of (Conceição, Vicente, and Lúcio 2008) in the calculation of the airflow inside the spaces and (Conceição and Lúcio 2010) in the airflow around the occupants.

Other examples of the application of the Computational Fluid Dynamics numerical model can be analyzed in (Xing, Hatton, and Awbi 2001), (Awbi 1998) and (Aslam Bhutta et al. 2012).

The Computational Fluid Dynamics numerical model and the Human Thermal Modelling numerical model work as a coupling methodology. Both numerical models use as input the values calculated in the Building Thermal Modelling numerical model. This numerical model calculate the airflow rate exchanged between spaces and between spaces and the external environment (Conceiçäo, Silva, and Viegas 1997) and the spaces Heating, Ventilating and Air Conditioning (HVAC) system.

The thermal comfort level depends on the environmental variables, as air temperature, air relative humidity, air velocity and Mean Radiant Temperature, and the personal variables, as clothing level and activity level. The thermal comfort used the PMV (Predicted Mean Vote) and the PPD (Predicted Percentage of Dissatisfied people) (see (Ole Fanger 1970), (ISO 2005) and (ASHRAE-55 2017)). Measurements in laboratory conditions around the occupants, in order to evaluate the air velocity around the occupants can be analyzed in (Conceição, Silva, and Viegas 1997).

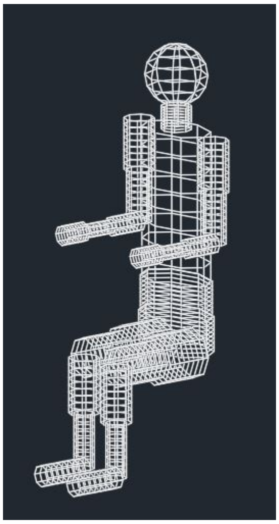

Figure 1: Human body geometry considered in this work.

The Draught Risk level depends on the air velocity, air temperature and turbulence air temperature around the occupants (see (ISO 2005)). More details can be seen in (Fanger et al. 1988).

NUMERICAL METHODOLOGY

In the thermal comfort a mean air velocity is considered in steady state conditions, while in the Draught Risk two different air velocities Root Mean Square is considered in transient conditions, mainly in the neck.

The study is made in winter conditions, using a winter typical personal levels, namely:

- The clothing level is 1 Clo;
- The activity level 1 Met.

Figure 1 show the human body geometry considered in this study.

The environmental variables that the occupant is subjected, in steady state conditions, are the following:

- Mean air temperature is 20°C;
- Mean air relative humidity is 50 %;
- Mean air velocity is 0.2 m/s;
- Mean Radiant Temperature is 20 °C.

In transient conditions, for a mean air velocity is 0.2 m/s, the following air velocity Root Mean Square (RMS) are considered:

- In the Case A the RMS is 0.011 m/s;
- In the Case B the RMS is 0,022 m/s.

In the first part, steady-state conditions, is simulated the human thermal response subjected to a mean airflow. In the second part, transient conditions, is simulated the human thermal response subjected to a random airflow.

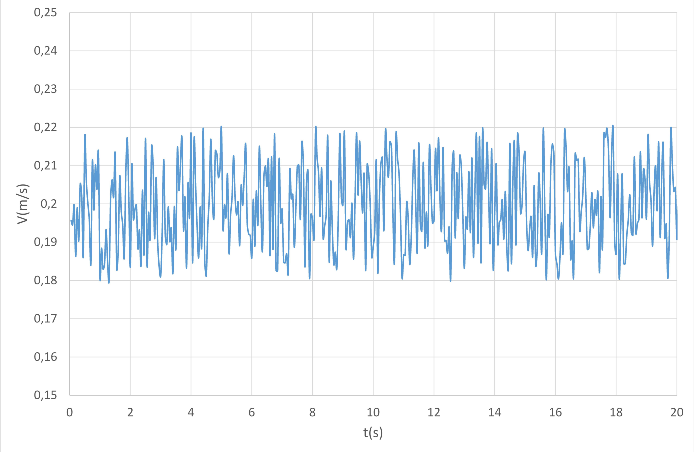

Figure 2: Air velocity random signal used in the human thermal response numerical simulation in the Case A.

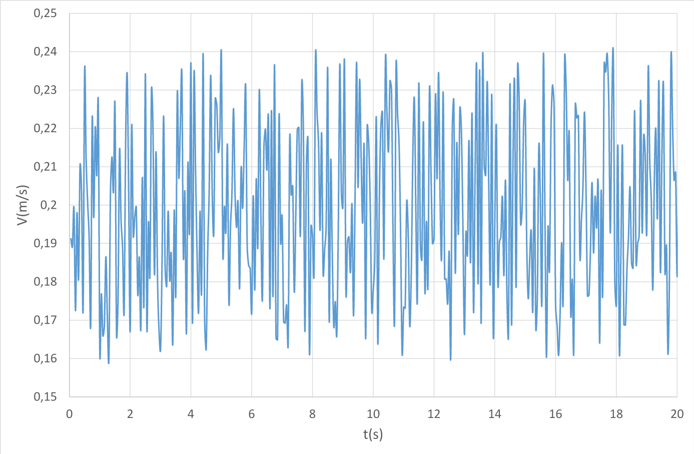

Figure 3: Air velocity random signal used in the human thermal response numerical simulation in the Case B.

The airflow fluctuation is characterized by a random signal is presented in the figure 2, for the Case A, and in the figure 3, for the Case B. The numerical simulation was performed for 20 s.

RESULTS AND DISCUSSION

In this section, the results obtained in steady state and transient regime are presented, for the human thermal response.

In table 1 the thermal comfort level values are presented, when the steady state regime is considered.

In accordance with the results, the occupant, in the present thermal conditions, are thermal comfortable, in accordance with the category C of the international standards, by negative PMV values.

Table 1. Thermal comfort, PMV and PPD level values, when the steady state regime is considered.

	Values
PMV	−0.66
PPD (%)	13.97

Table 2. Draught Risk values, when the transient regime is considered (neck).

T (°C)	V (m/s)	RMS (m/s)	TI (%)	PD (static) (%)	PD (dynamic) (%)	PD (%)
20	0,2	0,011	5,567	13,480	1,760	15,240
20	0,2	0,022	11,167	13,488	3,511	16,959

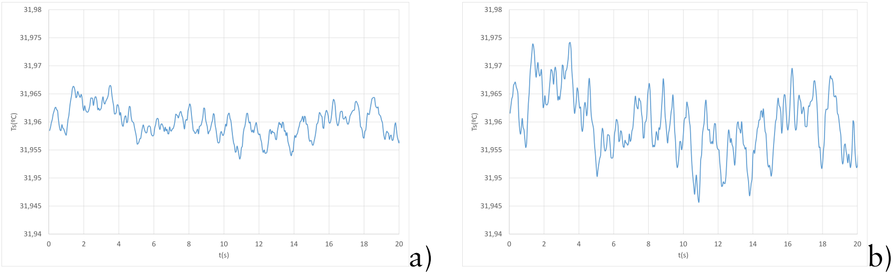

Figure 4: Evolution of the temperatures of the skin surface (Ts), for an air velocity random in the occupant's neck area. Figure a) is associated to the Case A and figure b) is associated with the Case B.

In table 2 the local thermal discomfort level values, namely the Draught Risk, are presented, when the transient regime is considered. In this study only the neck results are presented. In this table the T, V, RMS and TI are associated, respectively, with the air temperature, air velocity, Root Mean Square and air turbulence intensity, while the PD (static), PD (dynamic) and PD are associated, respectively, the static Draught Risk, dynamic Draught Risk and Draught Risk.

The Draught Risk, in accordance with the obtained results, are in accordance with the Category A of the international standards. The static Draught Risk, in the Case A and B present similar values, however, the dynamic Draught Risk present higher values in the Case A than in the Case B. The air turbulence intensity is higher in the Case A than in the Case B.

Figure 4, 5 and 6 shows, respectively, the evolution of temperatures verified on the skin surface (Ts), on the cold (Tc) thermoreceptor and on the heat (Tw) thermoreceptor obtained for an airflow random occurred in the neck area of a seated person.

In accordance with the skin temperature evolution is verify that the fluctuation verified in the Case A is lower than the Case B. The evolution of temperature fluctuations of the cold and warm thermoreceptors are in accordance with the results obtained in the skin temperature. However, the fluctuations verified in the skin temperature are highest and the fluctuations verified in the warm temperature are lowest.

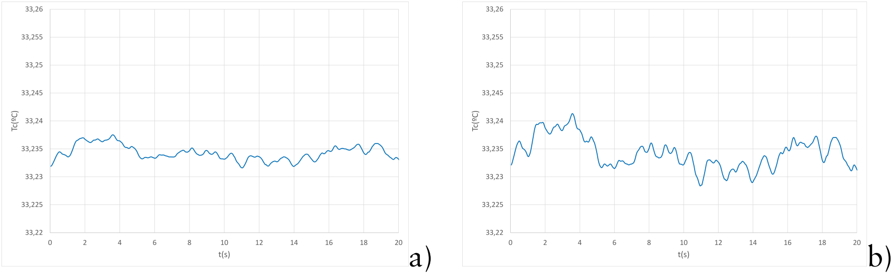

Figure 5: Evolution of the temperatures of the cold thermoreceptor (Tc), for an air velocity random in the occupant's neck area. Figure a) is associated to the Case A and figure b) is associated with the Case B.

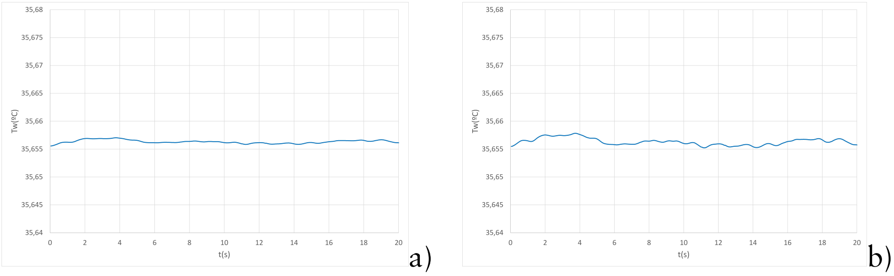

Figure 6: Evolution of the temperatures of the warm thermoreceptor (Tw), for an air velocity random in the occupant's neck area. Figure a) is associated to the Case A and figure b) is associated with the Case B.

CONCLUSION

In this work the human design, the thermal comfort and the local thermal discomfort are evaluated.

The design, used in this work, present a posture of a typical occupant. The grid generation, in accordance with the previous results, guarantee acceptable view factors and acceptable radiant heat exchanges between the occupant and the surrounding environments.

The thermal comfort are acceptable in accordance with the category C, by negative PMV values, of the international standards.

Finally, the Draught Risk, for the Cases A and B, in the neck, are acceptable in accordance with the category A for the international standards. When the RMS increase the fluctuation of the temperature in the skin, cold termoreceptor and warm termoreceptor increase. However, the fluctuations in the Skin are higher than the fluctuation in the warm termoreceptors.

Im future works the response of the cold and warm termoreceptores will be evaluated and the obtained results correlated with the Draught Risk values will also be evaluated.

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