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Design and Radiative heat transfer in a fireman in wildfire environment

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Abstract

This work presents the design and radiative heat transfer in a fireman in wildfire environment. The fireman body model, used in this work, is divided into 35 elements. Each element is subdivided into several layers, constituted by fat, muscle, core and skin, and can be protected from the outside environment by several clothing layers. The geometry of the fireman and the fire front are developed using numerical models. Fireman thermal systems consider energy and mass balance integral equations. The energy balance integral equations consider the conduction, convection, evaporation and radiation, amount other phenomena, while the mass balance integral equations consider the convection and diffusion, amount other phenomena. The fireman has subjected two vertical fire fronts. The fireman and the fire front geometry was developed and are used to evaluate the view factors that each fireman section is subjected. The view factors are used to evaluate separately the influence of the two fire front and the Mean Radiant Temperature are used to evaluate integrated the influence of both fire front.

1. Introduction

In this study the influence of two fire fronts in the fireman are analysed. The view factors are used to evaluate separately the influence of each one in the fireman, while the Mean Radiant Temperature (see (ISO, 2005), (Fanger, 1970), (ASHRAE, 2017)) is used to evaluate integratelly the influence of the two fire front in the fireman. However, in order to evaluate the view factors and the Mean Radiant Temperature the fireman and fire front geometry are important to generate in detail.

The numerical model used in this study considers the fireman geometry and the fireman thermal response. In the fireman thermal response special attention is made in the radiative phenomenon.

The human body geometry considers 34 cylindrical elements and 1 sphere element (see (Conceição and Lúcio, 2001), (Conceição et al., 2018) and (Conceição and Awbi, 2021)). In the cylindrical elements are considered the neck, chest, upper abdomen, lower abdomen, right upper shoulder, right lower shoulder, right upper arm, right lower arm, right hand, left upper shoulder, left lower shoulder, left upper arm, left lower arm, left hand, right upper thigh, right lower thigh, right upper leg, right lower leg, right foot, left upper thigh, left lower thigh, left upper leg, left lower leg, left foot and 10 fingers. In the sphere element the head is considered.

In the fireman thermal response, it is important to consider the radiative heat exchanges to evaluate the thermal interaction between the surrounding surfaces and the fireman body surfaces. In this study the shading devices is also considered. See this methodology applied in plan surfaces in (Conceição et al., 2010), (Conceição, Gomes and Awbi, 2019) and (Conceição and Lúcio, 2010). The numerical model considers also the convective heat exchanges between the body surface and the surrounding airflow, the heat conduction through the bodies' tissues, water heat loss by evaporation from the skin surface and clothing of the fireman. In the numerical model the energy and mass balance integral equations is used.

In the radiative heat exchange the view factors between the fire front and the fireman should be evaluated. The view factors, among others works, can be analysed in (Jiang et al., 2017), (Vorre, Jensen and Le Dréau, 2015) and (Lai, Maing and Ng, 2017).

2. Numerical model

The fireman thermal response is based on the energy balance integral equations for the body tissues and clothing and the mass balance integral equation for the water in the body tissues and clothing.

The energy balance integral equations consider the following phenomena:

- The conduction phenomenon appears between the various layers of each body element and between the various layers of clothing.
- The convection phenomenon appear between the bodies external surface (skin and clothing) and the surrounding air environment.
- The evaporation phenomena appear between the bodies external surface (skin and clothing), subjected to water vapour, and the surrounding air environment.
- The radiation phenomenon appears between the bodies external surface and the fire front, whose modelling uses the Mean Radiant Temperature values. Between the clothing levels and between the skin and the clothing the radiation phenomenon are also verified.

The mass balance integral equations consider the following phenomena:

- The water vapour convection appear between the bodies external surface (skin and clothing) and the surrounding air environment.
- The diffusion phenomenon appears between the clothing bodies and between the skin and the clothing surfaces.

The systems of equations defined above are solved by the Runge-Kutta-Fehlberg algorithm with error control.

3. Numerical methodology

The fireman model has a height of 1.8 m and consists of 35 elements. It is equipped with three layers of clothing, the outer layer corresponding to the typical equipment (including the helmet) of a fireman fighting a forest fire.

In this study two fire front, being static in the numerical simulation, are considered:

- The fire front number 1 has 10 m wide and 1 m high and is located in front to the fireman;
- The fire front number 2 has 8 m wide and 1 m high and is located in the side to the fireman.

The fireman distance between each fire front is:

- 5 m from the fireman to the fire front number 1;
- 6.5 m from the fireman to the fire front number 2.

The fireman is placed at a distance of 5 m perpendicular to the central zone of the fire front, as shown, respectively, in Figure 1 and Figure 2.

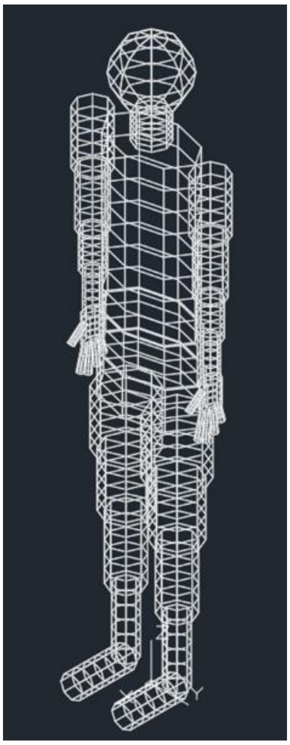

Figure 1- Fireman three-dimensional model

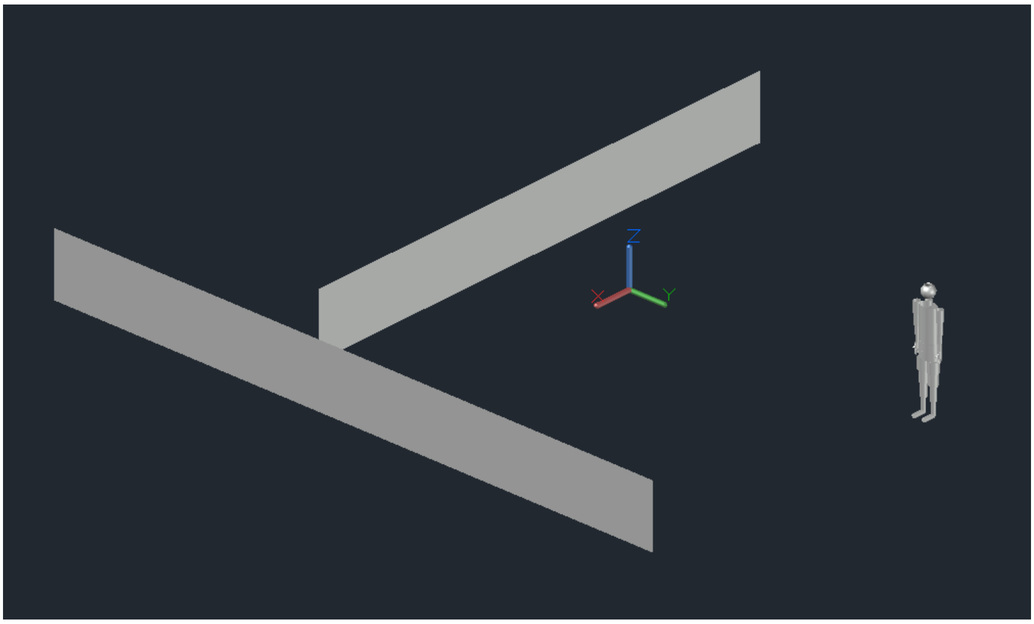

Figure 2- Location of the fireman in relation to the fire front number 1 and number 2

4. Results

This section presents the results obtained in the view factors for the fire front number 1 (see figure 3) and the view factors for the fire front number 2 (see figure 4). The Mean Radiant Temperature distribution, that is influence of the two fire front is presented in Figure 5.

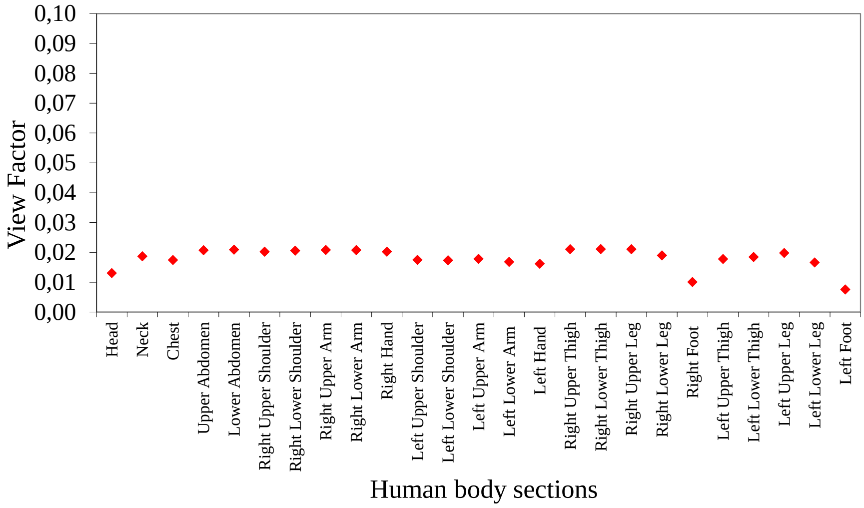

Figure 3. View factor that the fireman are subjected in the fire front number 1.

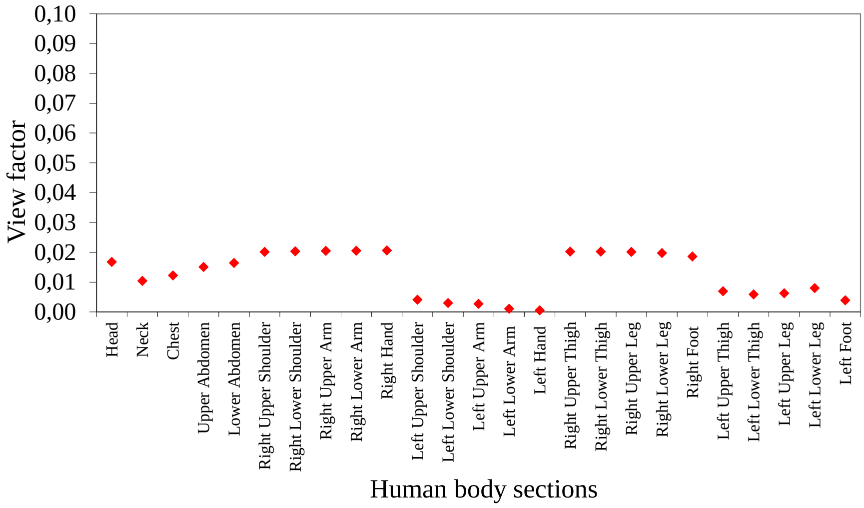

Figure 4. View factor that the fireman are subjected in the fire front number 2.

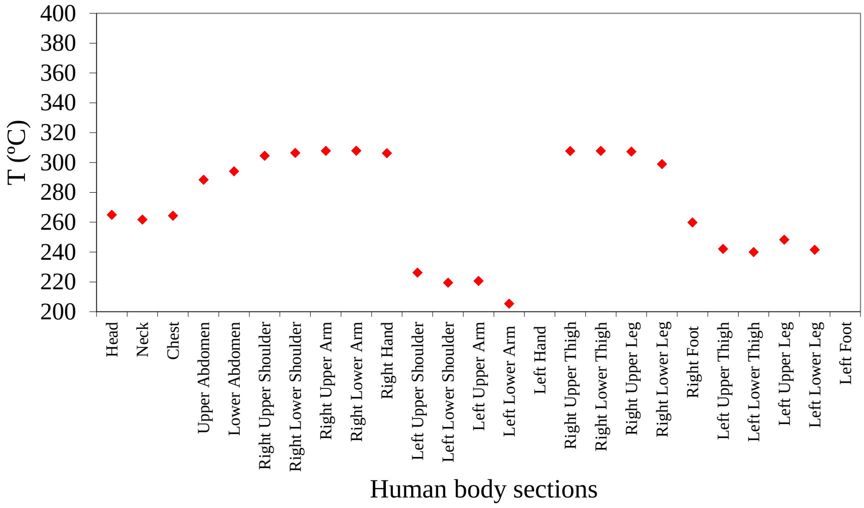

Figure 5. Mean Radiant Temperature distribution in the fireman.

In accordance with the obtained results the fire front located in front to the fireman present similar distribution of the view factor in the human body. In general, the view factor value is similar, however the head and the feet's presents slight low values.

When the fire front is localized in the lateral area to the fireman, the left upper and the left lower member, mainly the upper arm, present lower view factor values. Thus, these human body sections are protected from the radiation flux of the fire front number 2.

Finally, the Mean Radiant Temperature present the contribution of the radiant heat flux come from the two fire fronts, calculated trough the view factors. In the present study, namely in the fire front number 2, the protection promoted by the trunk is verified in the left arm. The low view facts verified also in the foot and hear are also verified in the Mean Radiant Temperature.

Thus, this kind of situation, namely when the occupant are subjected simultaneous to several fire front, this methodology consider simultaneously the real radiative effect that the fireman are subjected.

5. Conclusions

In this paper a design and radiative heat transfer in a fireman in wildfire environment is evaluated. In accordance with the obtained results, the fireman and the fire front geometry is very important in the calculation of the view factors and the Mean Radiant Temperature used to evaluate the heat exchanges that the fireman is subjected.

The human body geometry considers 35 human body elements. The grid generation refinement considered in cylinders and sphere is important in the view factors calculus. In the fire front geometry, considered as a plan vertical surface, the grid generation refinement is also an important factor in the view factors calculus.

The Mean Radiant Temperature is calculated based in the view factors obtained individually in each fire front.

This methodology is important to evaluate individual the effect that each fire front promoted in the fireman, using the view factor concept, and is important to evaluate simultaneously the integral effect that all fire front promoted in the fireman, using the Mean Radiant Temperature.

6. Acknowledgments

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7. References

ASHRAE (2017) 'ANSI/ASHRAE Standard 55-2017 : Thermal Environmental Conditions for Human Occupancy', ASHRAE Inc.

Conceição, E. and Awbi, H. (2021) 'Evaluation of integral effect of thermal comfort, air quality and draught risk for desks equipped with personalized ventilation systems', Energies. doi: 10.3390/en14113235.

Conceição, E., Gomes, J. and Awbi, H. (2019) 'Influence of the airflow in a solar passive building on the indoor air quality and thermal comfort levels', Atmosphere, 10(12). doi: 10.3390/ATMOS10120766.

Conceição, E. Z. E. et al. (2010) 'Application of a school building thermal response numerical model in the evolution of the adaptive thermal comfort level in the Mediterranean environment', International Journal of Ventilation, 9(3). doi: 10.1080/14733315.2010.11683887.

Conceição, E. Z. E. et al. (2018) 'Predicting the air quality, thermal comfort and draught risk for a virtual classroom with desk-type personalized ventilation systems', Buildings, 8(2). doi: 10.3390/buildings8020035.

Conceição, E. Z. E. and Lúcio, M. (2001) 'Numerical and subjective responses of human thermal sensation', Proceedings of the BioEng.

Conceição, E. Z. E. and Lúcio, M. M. J. R. (2010) 'Numerical study of the influence of opaque external trees with pyramidal shape on the thermal behaviour of a school building in summer conditions', Indoor and Built Environment, 19(6). doi: 10.1177/1420326X10377546.

Fanger, P. O. (1970) Thermal comfort. Analysis and applications in environmental engineering., Copenhagen: Danish Technical Press. Danish Technical Press.

ISO (2005) 'ISO 7730: Ergonomics of the thermal environment Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria', Management. doi: 10.1016/j.soildyn.2004.11.005.

Jiang, F. et al. (2017) 'Accuracy analysis and improvement of the Blind Enclosure Model to calculate the longwave radiative heat transfer for a façade with louver blinds', Energy and Buildings. doi: 10.1016/j.enbuild.2017.01.065.

Lai, A., Maing, M. and Ng, E. (2017) 'Observational studies of mean radiant temperature across different outdoor spaces under shaded conditions in densely built environment', Building and Environment. doi: 10.1016/j.buildenv.2016.12.034.

Vorre, M. H., Jensen, R. L. and Le Dréau, J. (2015) 'Radiation exchange between persons and surfaces for building energy simulations', Energy and Buildings. doi: 10.1016/j.enbuild.2015.05.005.