INDOOR THERMAL COMFORT CONSIDERATIONS - HUMAN BODY RADIATIVE BALANCE IN THE PRESENCE OF CORNER WINDOW SYSTEMS

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ABSTRACT: Indoor thermal comfort is a key issue in building design. The most important component of the thermal comfort is considered the indoor air temperature. However, radiative exchange between human body and the surfaces of the enclosure can influence to a significant extent the thermal comfort conditions. This is especially important in the case of indoor spaces with large glazed areas, such as modern office buildings. In such cases, it is essential to understand the heat transfer mechanisms and their weights in the overall energy balance of the thermodynamic system consisting of the human body and the surfaces of the enclosure. The concept of mean radiant temperature was presented and discussed and its implications were interpreted. A procedure and a numerical algorithm were developed allowing quantification of radiative exchange between human body and surfaces of the enclosure for any indoor space configuration and any position of the human body.

Keywords: Indoor thermal comfort; Radiative exchange; Glazed area

INTRODUCTION

Modern human psychology includes studies concerning heat exchange (conduction, convection, evaporation and radiation), hyperthermia, hypothermia, mean body temperature, heat capacity and thermal steady state. Human body radiative loss is a complex phenomenon [1,5] governed by many physiologic factors. Thermal comfort is a concept involving interaction of many factors, based on First Law of Thermodynamics, Newton's Law of cooling and Stephan Boltzmann Law of radiation. Thermal comfort is regulated by occupational and safety health standards. Such acts include all possible factors that influence the welfare and health of human beings in living or working environments. Among such factors, radiative balance between human body and the surfaces of the enclosure are of utmost importance. Radiative balance is not connected directly and it is influenced to a small extent by indoor air temperature. The main influence is the mean radiant temperature, defined as arithmetic mean enclosure surfaces temperatures. Total absorbed radiation on the human body surface is the sum of absorbed solar radiation and net long wave radiation on the surface [2]. The wavelength component that contributes to the highest extent to the thermal comfort sensation ranges between 0.2 and 0.9 μm [3,4]. Radiative heat loss in enclosures with large glazed areas can have detrimental effects on thermal comfort even if all others conditions (indoor air temperature, evaporative loss). Large glazed areas are a modern trend in architecture, especially in office and administrative buildings. However, in temperate continental climate, there is an important potential for thermal discomfort during low exterior temperatures and thereby violation of health and safety standards.

Corner window (Fig. 1) is a modern and distinctive architectural element with seamless glass panels joining in the corner and creating a strong visual effect from both inside and outside. It is however essential to estimate the impact of such configuration upon thermal comfort since large cold surfaces increase significantly the radiative heat loss of the human body. No matter if high thermal performance butt glass window are used, the window surface will always be colder than the walls.

Fig. 1. Typical corner window during construction

ANALYSIS METHOD

Radiative exchange between two bodies (grey-diffuse surfaces) is governed by the Stephan Boltzmann equation [6]:

$$Q_{1-2} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1} + \frac{1}{A_1 F_{1-2}} + \frac{1-\varepsilon_2}{\varepsilon_2 A_2}} \qquad (1)$$

with the following notations:

σ - Stefan-Boltzmann constant: $\sigma = 5{,}67 \times 10^{-8} \frac{W}{m^2 K^4}$

T - absolute temperature [K]

ε - surface emissivity

A – surface area [m^2]

F – view factor

Radiative heat loss of the human body given by Eq. (1) can be calculated if temperature values of the surfaces, surface areas, surface emissivity values and relative position of the human body and surfaces are known. Relative position of the human body is a key factor that determines the overall radiative heat balance. Radiative heat loss of the human body in an enclosure consisting of *N* surfaces is given by:

$$Q = \sum_{j=1}^{N} Q_{HB-j} \tag{2}$$

In order to account for relative position of the human subject in the enclosure a numerical algorithm was developed that makes possible evaluation of radiative heat loss in each point of the enclosure. The algorithm models the human subject from a ratiative viewpoint, calculates the radiative heat loss and then repositions the subject in the next point of the computational grid and resumes the calculation. A schematic of the room under analysis and the computational grid are presented in Fig. 2. The reference case was that of a standard window system placed on the longest dimension of the room. For consistency, the surface area of the reference window and corner window were identical.

The algorithim developed in this paper has the following structure:

Human body is modelled as a system of plane surfaces (designated *model surfaces*) arranged in a rectangular prism with the dimensions 1.80x0.2x0.4 m. It is noteworthy that the radiative heat loss of the human body depends on the orientation of the surfaces. In order to account fo the worst case scenario, the orientation of the human body was chosen in such way that model surfaces were parallel to the enclosure surfaces.

For both model surfaces and enclosure surfaces rectangular meshe systems were generated and radiative heat flow given by Eq. (1) was calculated between surface elements. The algorithm operates based on the following data:

- Absolute position of the surface element, described by the following:

- Origin of the surface as a vector in the 3D Cartesian coordinate system

- Orientation of the surface, given by two vectors with the origin in the origin of the surface and aligned along the surfaces sides

- Distance between centres of the surface elements, given by:

$$s = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2}$$

- View factor between the surface elements dA_1 and dA_2 [7]:

$$F_{1-2} = \frac{\cos\theta_1 \cos\theta_2}{\pi s^2} dA_2$$

Surface emissivity values were considered as follows: walls 0.8, glazed areas 0.3, human subject 0.6 [6].

Commercial software package Matlab [8] was used for algorithm implementation. Details of the implementaion are beyond the scope of the paper.

Temperatures of the surfaces will be considered as follows: human body 32 °C; walls 20 °C; glazed area 8 °C

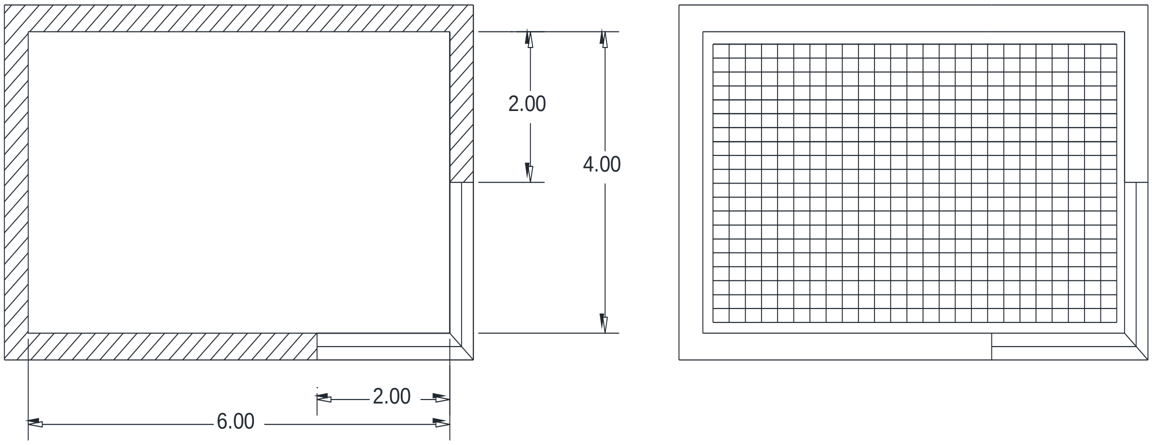

Fig. 2. Corner window and computational grid

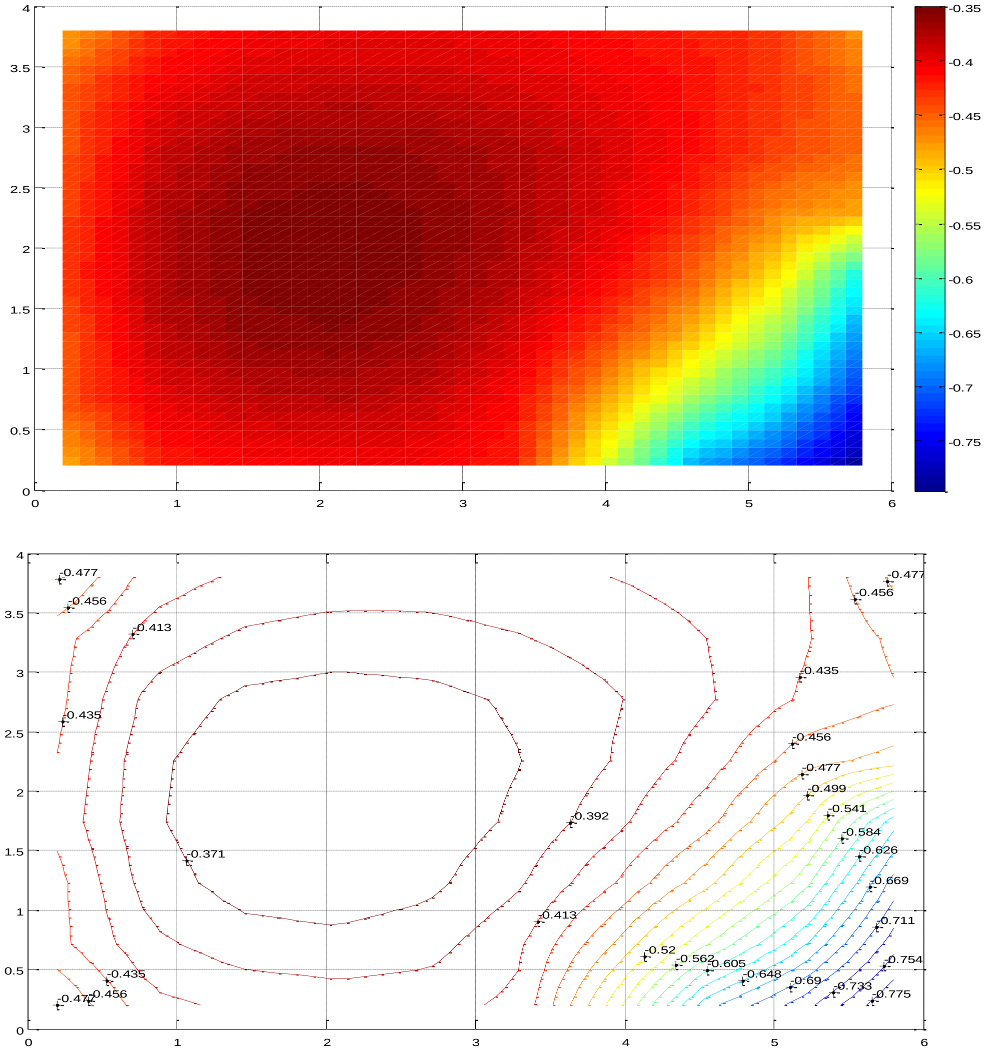

Fig. 3. Distribution of radiative heat loss in the case of standard window system

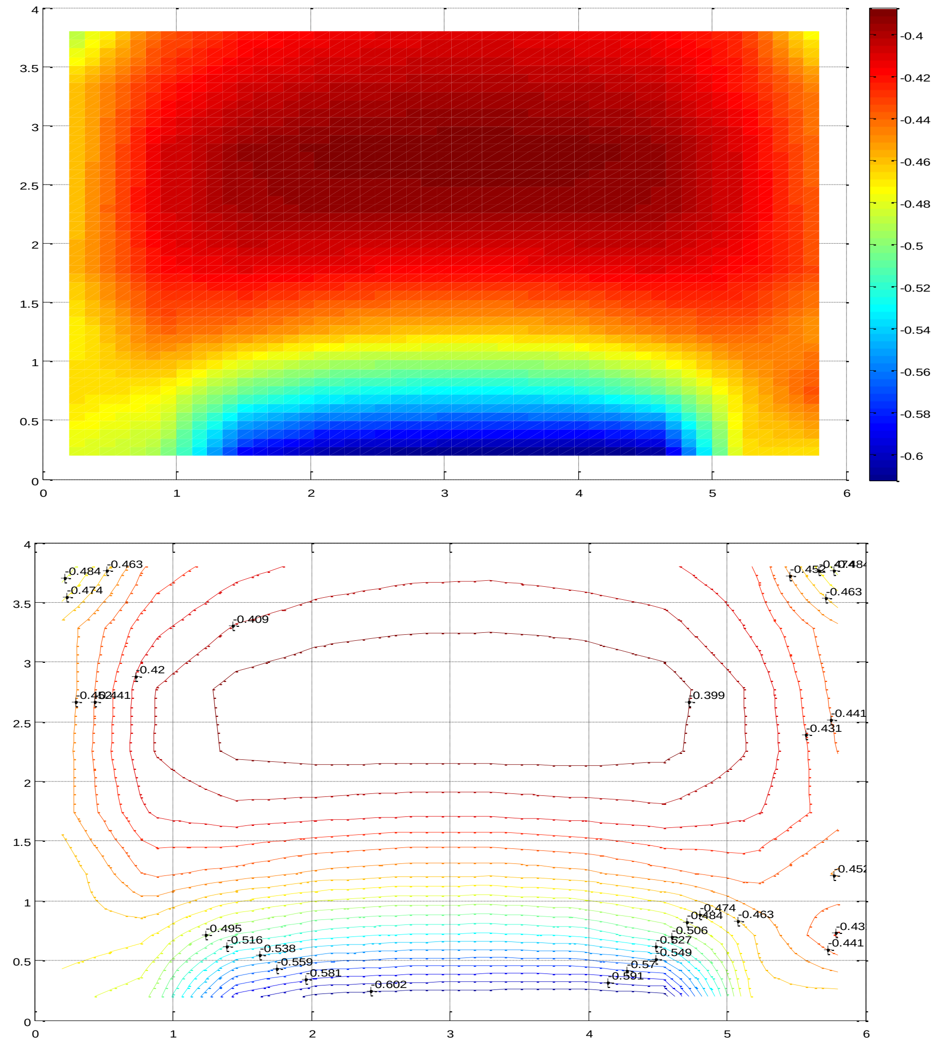

Fig. 4. Distribution of radiative heat loss in the case of corner window system

CONCLUSIONS

Radiative heat loss of the human being in an indoor environment consisting of standard walls and glazed areas in two configurations was analyzed. First, a standard window configuration was analyzed in order to develop a reference mode. Then a new type of window configuration – corner window – was considered under the same assumptions as the reference case. It was found that the corner window configuration diminishes radiative heat loss in the corners of the room opposite to the window compared to the reference model. Analyzing Figs. 3 and 4 it can be noticed that a larger area inside the room fails to provide the necessary thermal comfort conditions (see Fig. 5). It is very interesting to note that in the case of standard window the radiative heat body loss in areas closed to the room corner becomes higher than in the case of corner window.

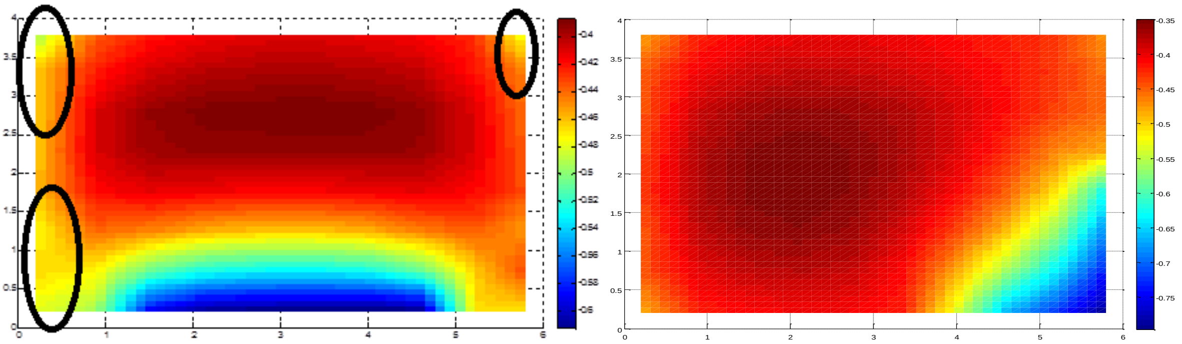

Fig. 5. Areas exhibiting higher values of the radiative heat body loss in the case of standard window configuration

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