CORNER WINDOW SYSTEMS REVISITED. A HOLISTIC MODELING APPROACH OF RADIATIVE EXCHANGE

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ABSTRACT: Indoor thermal comfort is a key issue in building design. The key issue of thermal comfort is considered the indoor air temperature. However, radiative exchange between corner window elements, especially glazed area, 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.

KEY WORDS: Corner window; Indoor thermal comfort; Radiative exchange;

1.INTRODUCTION

Thermal comfort is a fundamental 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. Radiative exchange between human body and enclosure surfaces contributes with approximately 40 % in the overall thermal energy balance under normal metabolic conditions. The presence of cold surfaces can increase significantly this value even if the indoor air temperature and humidity are maintained at the design values. Even the most energy-efficient glazing systems have usually temperatures lower than walls due to the higher value of overall heat transfer coefficient and lower thermal inertia. Unlike walls, glazing areas respond promptly to outdoor temperature or solar irradiation variations. Thermal comfort fluctuations are therefore possible especially in locations close to the glazing areas.

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.

2.PROBLEM FORMULATION

Stephan Boltzmann equation [6] governs radiative exchange between two bodies (grey-diffuse surfaces):

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

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 test body given by Eq. (1) can be calculated if temperature values of the surfaces, surface areas, surface emissivity values and relative position of the test body and surfaces are known. Relative position of the test 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:

$$Q = \sum_{j=1}^{N} Q_{HB-j} \quad (2)$$

In order to account for relative position of the test body 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 test 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:

Test body is modelled as a system of plane surfaces (designated *model surfaces*) arranged in a rectangular prism with the dimensions 1.00x0.15x0.5 m. It is noteworthy that the radiative heat loss of the test body depends on the orientation of the surfaces. In order to account fo the worst case scenario, the orientation of the test body was chosen in such way that model surfaces were parallel to the enclosure surfaces.

For both model surfaces and enclosure surfaces rectangular mesh 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 0.9, glazed areas 0.35, test body 0.6 [6].

Commercial software package Matlab [8] was used for algorithm implementation. Details of the implementaion are extremely complex and will not be presented here.

Temperatures of the surfaces will be considered as follows: test body 30 °C; walls 20 °C; glazed area 8 °C

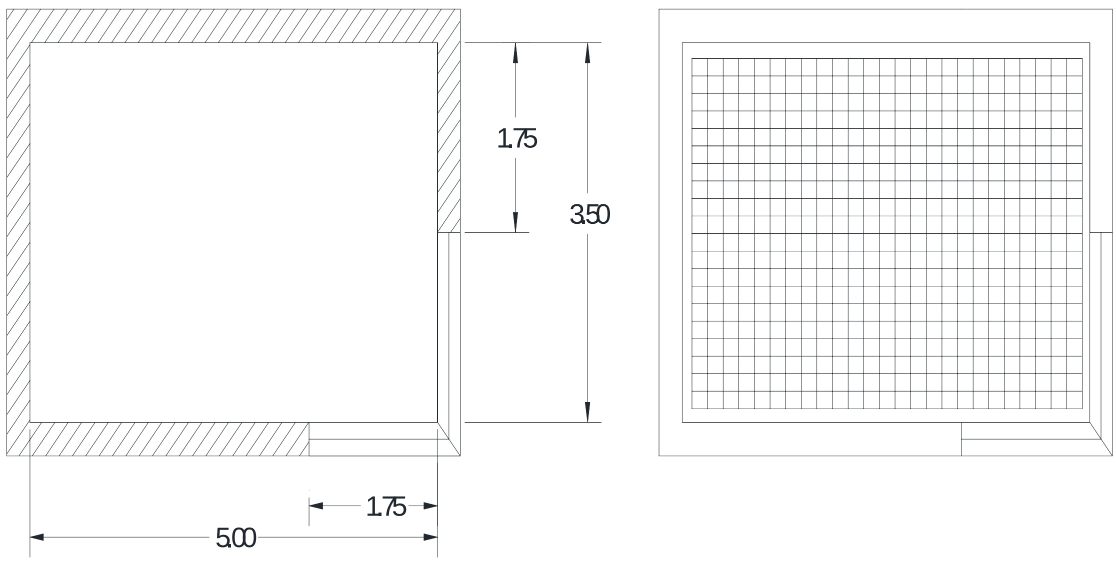

Fig. 2. Corner window and computational grid

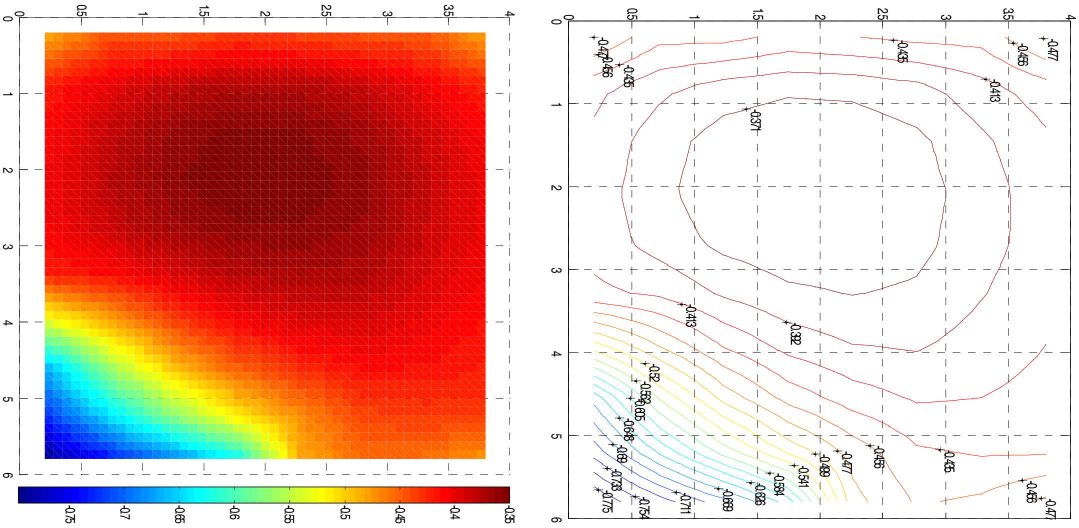

Fig. 3. Distribution of radiative heat loss in the case of standard window system

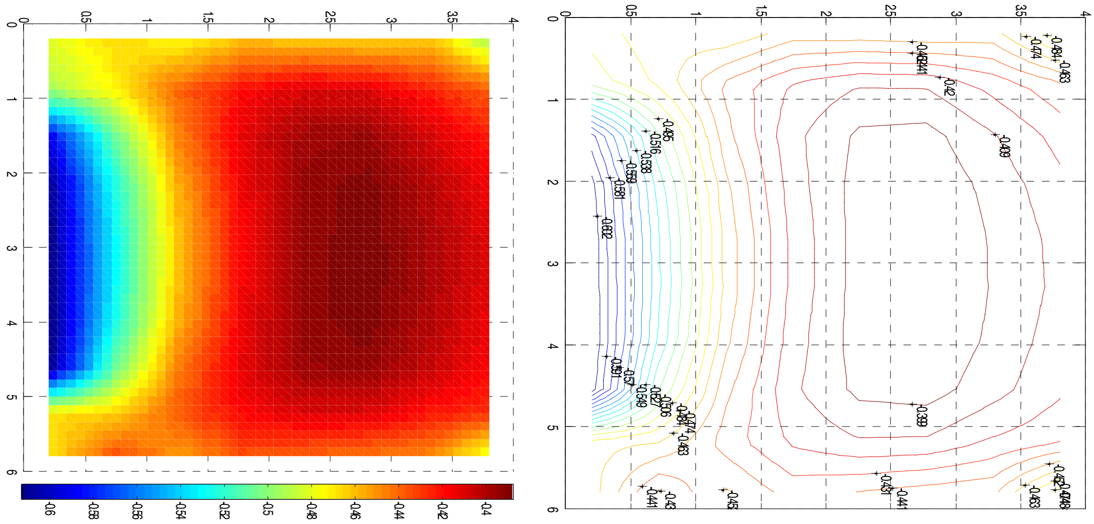

Fig. 4. Distribution of radiative heat loss in the case of corner window system

3.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.

The holistic approach proposed in this paper accurately models the radiative exchange due to its unique features that account for all physical parameters of the system. A sensitivity analysis using a MLA was carried out in order to investigate possible deviations caused by the random choice of the first iteration parameters. It was shown that the start-up parameters do not influence the final results:

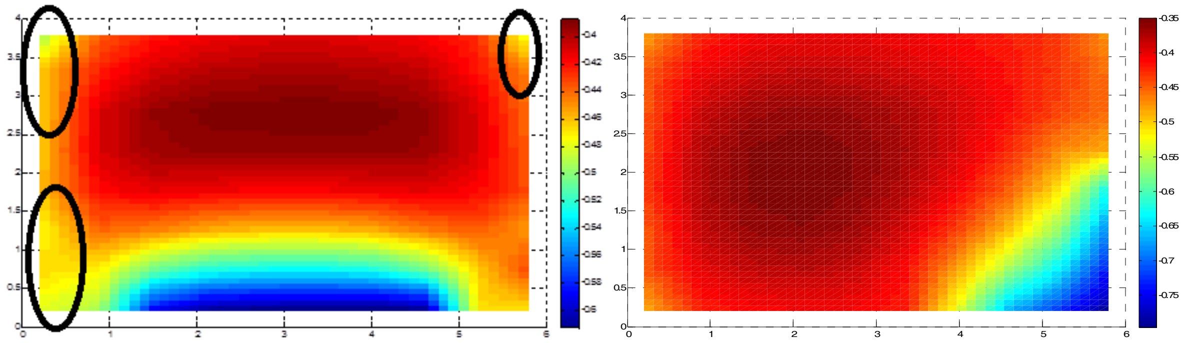

Fig. 5. Areas exhibiting higher values of the radiative heat body loss in the case of standard window configuration

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