# Numerical investigation of the radiant asymmetry in a non- uniform thermal environment

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***Numerical investigation of the radiant asymmetry in a non-uniform thermal environment:*** *aims at predicting the plane radiant temperature distribution over the body of a subject occupying a thermally non-uniform environment with respect to the temperature of the surrounding surfaces. Another important goal of the study is to demonstrate the possibility for improving the uneven and potentially causing radiant asymmetry plane radiant temperature distribution over the body of the occupant caused by a cold window through introducing hot spots on the room walls.*

***Key words:*** *Plane Radiant Temperature, Radiant Temperature Asymmetry, Local Thermal Discomfort*

## INTRODUCTION

There are two groups of parameters that predetermine the occupant's thermal comfort, namely personal parameters and parameters of the physical environment. According to the current practice to the first group belong the occupant's metabolic rate and the thermal resistance of his/her clothing ensemble. To the second group belong all parameters that have impact on the heat exchange between the indoor environment and the occupant's body, i.e. air temperature and humidity, instantaneous relative air velocity with respect to the occupant's body, characterized by both its mean value and turbulence intensity, as well as the temperature of all indoor surfaces surrounding the occupant, characterized by the plane radiant temperatures measured in six directions at the occupant's body center of gravity and the mean radiant temperature. Those parameters are used by the PMV/PPD model to calculate the whole body thermal comfort of the occupants as well as to characterize the local thermal discomfort.

Currently available standards mostly use the PMV/PPD model to assess thermal comfort indoors. It was developed under uniform, steady–state conditions, [1], [3], [9]. However, in reality the above mentioned factors might not be uniformly distributed over the occupant's body. For this reason, it might be difficult to define the comfort range with the use of a whole body thermal sensation model, [9], [8], [4]. The local thermal discomfort parameters act locally on a specific body part and affect the overall comfort of an occupant. Those parameters are: draught, radiant temperature asymmetry, vertical air temperature difference and warm/cold floor [1]. The local thermal discomfort parameters might be manifested separately or simultaneously in a given indoor environment.

The thermal environment, generated by the modern heating or cooling systems, is non-uniform, [6], [9]. Non- uniform environments are difficult to be evaluated due to the fact that there is no unique temperature value that can be used to describe the complexity of the generated temperature fields indoors, [7]. The acceptability of such environments cannot be accurately predicted by a simple whole body thermal sensation model, because the radiant asymmetry might affect only portion of the body and cause discomfort even though the whole body thermal sensation is neutral, [6], [10], [11].

If radiant temperature asymmetry is present the occupants might experience local discomfort of different parts of their bodies as they would be simultaneously exposed to high or low plane radiant temperature. According to the current standards the radiant temperature asymmetry is calculated from the plane radiant temperature, measured in six directions at the occupant's body center of gravity, [1]. This means that the radiant temperature discomfort is evaluated, based on measurements at a single point. Since local thermal discomfort parameters may affect different parts of the occupant's body and cause dissatisfaction, measuring the plane radiant temperature at a single point might not be enough to estimate the effect of radiant temperature distribution on the occupant's body.

Local thermal state is essential for the overall sensation of comfort. Human exposure to asymmetric radiation might cause discomfort, but it is also documented that higher level of thermal comfort might be achieved in asymmetric compared to uniform environments. For this reason investigating the effect of the non-uniformity of the environment on the thermal comfort is important.

The main goal of this study is to predict the plane radiant temperature (PRT) distribution over a human body in a thermally non-uniform environment with respect to the temperature of the surfaces surrounding the occupant. Another important goal of the study is to demonstrate the possibility for improving an uneven and potentially causing radiant asymmetry plane radiant temperature distribution over the body of an occupant caused by a cold window pane through introducing hot spots on the room walls.

**METHODS**

For prediction of the plane radiant temperature distribution in a thermally non-uniform environment with respect to the temperature of the surfaces surrounding the occupant is used the procedure developed by the authors and presented elsewhere, [5]. This procedure was developed within the MATLAB environment. The accuracy of the predictions by this procedure was examined and the results obtained verify that it can be used as a precise tool for evaluating the radiant temperature distribution over the body of an arbitrary occupant of the indoor environment, [5].

The procedure is based on the prescriptions of the ISO 7726:1998 standard for calculation of the plane radiant temperature ( $T_p$ ) at the center of a small plane element (p)

$$T_p^4 = \sum_{i=1}^{N} T_i^4 F_{i \to p} \tag{1}$$

where: $T_i$, in K, is the temperature of the surface i surrounding the small plane element p and $F_{i \to p}$ is the view factor between the surface **i** and the small plane element **p**.

During the winter period the temperature of the inner surfaces in a typical room of a student's dormitory vary in a wide range. Hence, for the purpose of the study the thermally non-uniform environment is computationally established in a typical room of a student's dormitory which has dimensions of 4.6 m x 2.9 m x 2.4 m (length x width x height). The walls of the room are at different surface temperature. For improving the plane radiant temperature distribution over the body of a female occupant over the walls of the room are introduced hot spots. Information about the size of the room, the location of the window and the door, the heater and the hot spots is presented on Figure 1 and in Table 1.

The room air temperature was assumed to be 22$^{o}$C.

A series of 13012 small plane elements **p**, representing the surface of the body of a standard Scandinavian woman (height of 168 cm, size of 38), is used for investigation of the plane radiant temperature distribution over the body of an imaginary female subject occupying the thermally non-uniform environment with respect to the surface temperature. The body center of gravity of the manikin has coordinates X=92.5 cm, Y=226.5 cm and Z=60 cm (Figure 1). The angle of rotation of the local coordinate system (attached to the body center of gravity of the manikin) with respect to the global coordinate system (attached to the left low corner of the room) is $\alpha$=90$^{o}$.

Each of the surfaces surrounding the occupant was divided into square cells of equal size of 1 cm on an edge, i.e. the surfaces in the investigated room are divided into 626800 square cells. For prediction of the plane radiant temperature distribution over the body of the occupant for each case are calculated 8.1559216E+09 view factors.

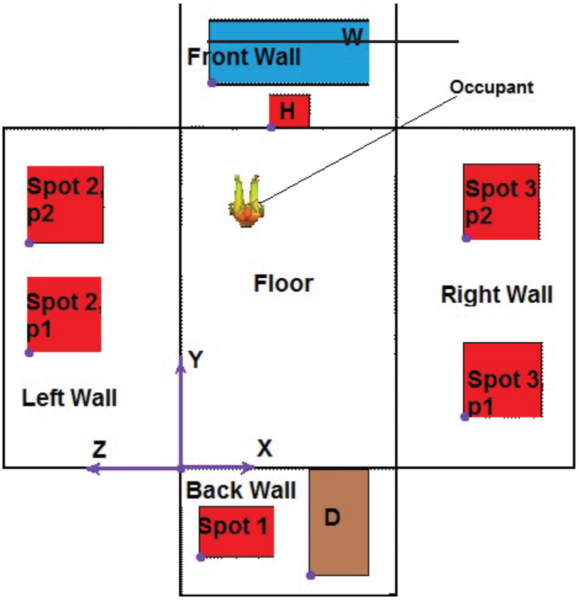



*Figure 1 Location of the heat sources and the position of the occupant in the room*

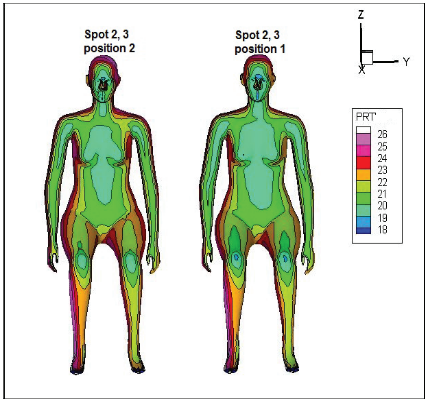
*Table 1 Thermal spots dimensions and temperatures and walls temperatures*

| Walls | | Elements | | | | | |
|---|---|---|---|---|---|---|---|
| Label | t | Label | Size | X* | Y* | Z* | t |
| | $^{o}C$ | | cm x cm | cm | cm | cm | $^{o}C$ |
| Back | 19 | Door (D) | 70x200 | 145 | 0 | 200 | 20 |
| Left | 22 | Window (W) | 210x125 | 55 | 460 | 60 | 8 |
| Right | 22 | Heater (H) | 45x45 | 112 | 460 | 0 | 45 |
| Front | 14 | Spot 1 | 100x100 | 30 | 0 | 160 | 30 |
| Floor | 22 | Spot 2-p1 | 100x100 | 0 | 165 | 115 | 30 |
| Ceiling | 22 | Spot 2-p2 | 100x100 | 0 | 220 | 115 | 30 |
| | | Spot 3-p1 | 100x100 | 290 | 150 | 10 | 30 |
| | | Spot 3-p2 | 100x100 | 290 | 220 | 10 | 30 |
| * X,Y,Z are the coordinates of the blue points (lower left corner of the elements) on the flat plane view of the investigated room presented on Figure 1 | | | | | | | |

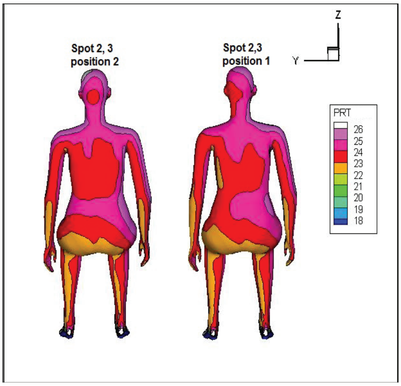
On Figure 2 are presented results from the simulated PRT distribution over the front (Figure 2a), back (Figure 2b) side of the occupant. On Figure 3 is shown the PRT distribution over the left (Figure 3a) and right (Figure 3b) side of the occupant.

Changing the position of the thermal spots with respect to the seated occupant (Spot 2 and Spot 3 from position 1 to position 2) changed the PRT distribution over the occupant's body. When Spot 2 and Spot 3 were at position 1 the effect of the cold window on the front side of the occupant was more prominent compared to the case when Spot 2 and Spot 3 were at position 2 (Figure 2a). When the spots were located closer to the occupant, the PRT over the front side of the occupant increased and the area of the body with PRT below 19oC was smaller. Comparing the PRT distribution over the left and the right side of the occupant (Figure 3a and 3b) it could be observed that although the manikin was seated closer to the left wall of the room the PRT over the left side was lower compared to the right side. This result could be explained with the influence of the heater, located under the window. The heater with surface temperature of 45oC could be “seen” from the right side of the manikin and it caused the PRT of the right side to be higher compared to the left.

The average difference between the PRT over the left and the right side of the occupant was 2oC, while the average difference between the PRT over the front and the back side of the occupant was 6oC.

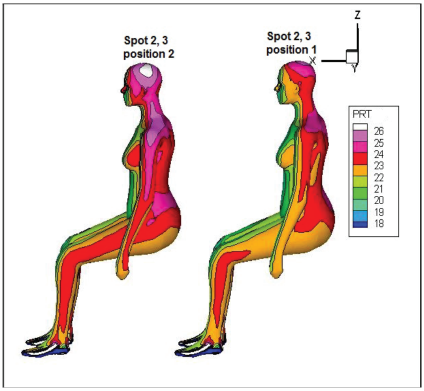



*a) PRT distribution over the front side*

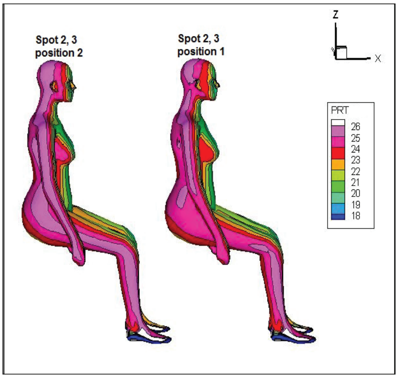



*b) PRT distribution over the back side*

*Figure 2 PRT distribution over the front and back side of the manikin*




*a) PRT distribution over the left side*




*b) PRT distribution over the right side*

*Figure 3 PRT distribution over the left and the right side of the manikin*

## CONCLUSIONS

The results from the simulated cases showed that the distribution of PRT over the body of the occupant, even in a geometrically simple environment, was non-uniform and that there was a significant difference between the PRT obtained at the different segments of the body of the occupant. For this reason it could be difficult to evaluate the influence of the thermal environment on the comfort of the occupant based on measurements at single point only. The thermal comfort of the occupants indoors can be influenced by changing the position and the temperature of the heat sources in the occupied space.

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**This paper has been reviewed.**