Design of virtual manikins in spaces with complex topology and high density of occupation

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Abstract. This work presents a software developed to design virtual manikins in spaces with complex topology and high density of occupation. The software is used to design 330 typical seated occupants in a Roman theatre or in an adapted auditorium. These virtual manikins are used by a numerical software in the evaluation of the occupants' thermal comfort level. This software simulates the human body and clothing thermal responses and analyses simultaneously several persons inside a space. The human body will be divided into 1 spherical and 34 cylindrical elements. These elements are designed considering the height and the weight of the occupants and have dimensions and angles similar to the human body. They are placed spatially in order to define the human posture in different positions and connected through articulations. In the theatre and auditorium, all fundamental elements will be considered.

Keywords: 3D Design · Numerical Software · Roman Theatre ·Thermal Comfort · Virtual Manikin

1 Introduction

Greek and Roman theatres are public buildings of great importance in the history of Western culture. Many of these spaces are still used today for their original function with minor adaptations or none at all. The exceptional achievement of the former designers to provide such robust and outstanding stage spaces has attracted architects and, in this framework, acoustics and other facilities plays an essential role [1].

In every building, the existence of a good level of thermal comfort contributes to the improvement of the performance of their occupants in the work they develop, in terms of their learning or in terms of the enjoyment of a musical or theatrical performance. In this sense, it is also justified to develop a study that analyzes the level of thermal comfort of Roman and Greek theatre occupants. Although classic antiquity theatres are open buildings, it is possible to numerically assess their level of thermal comfort taking into account parameters such as solar radiation, air temperature, mean radiant temperature, air velocity and air relative humidity.

According to Fanger [2], the level of thermal comfort that occupants of an enclosure ~~building~~ are subjected to depends, among other factors, on the levels of physical activity and clothing and on the heat exchange between the human body and the surrounding environment. The thermal comfort model, presented in [2] and [3], is based only on the body's thermal equilibrium (mass and heat exchanges) with the surrounding environment, and the body internal temperature is maintained through some physiological responses. In order to evaluate the level of thermal comfort, the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD) indexes, developed by Fanger in 1970 [2] and presented in ISO 7730 [3], are used.

The radiative exchanges may be done between the sections of the same body, between sections of different bodies and between the sections of the bodies and the surrounding surfaces of the building interior. These radiative heat exchanges are obtained from the resolution of the system of radiosity equations [4], and depend on the shape factors, temperatures and emissivity of the body and the building surfaces.

The heat flux from the solar radiation, which enters through the glass openings and that affects the bodies of the occupants, depends on the intensity of the solar radiation and how it affects the occupants. To do this calculation, the parallel ray method is used (please, see details in [5]).

The calculations of the above radiations depend strongly on the position of the human body and its location in the occupied space. In this calculation, the shadings of the different sections of the human body and of the surrounding surfaces in the occupied compartment are also considered. It is therefore necessary to have a three-dimensional mesh defining the limits of the outer surfaces of the occupant bodies and the interior surfaces of the compartment (please, see details in [6]).

This work presents a software developed to design virtual manikins in spaces with complex topology and high density of occupation. The software is used to design 330 typical seated occupants in a Roman theatre or in an adapted auditorium. These virtual manikins are used a numerical software in the evaluation of the occupants' thermal comfort level.

2 Numerical models

In this study, a coupling between a building thermal behavior (BTB) numerical model and a human thermal response (HTR) numerical model is used. The BTB model estimates the opaque and transparent surfaces temperatures, the indoor air temperatures, the average thermal comfort and indoor air quality (IAQ) [7]. This information is used by the HTR model to calculate, simultaneously, each occupant body and clothing temperatures and thermal comfort level [8]. In order to obtain these values, it is necessary to have detailed virtual manikins with thermal and thermoregulatory systems well defined.

The human body model (please, see Fig. 1) is divided into 35 elements (34 cylindrical and 1 spherical): head, neck, chest, abdomen (upper and lower areas), arms (upper and lower areas), forearms (upper and lower areas), hands, fingers, thighs (upper and lower areas), legs (upper and lower areas) and feet. The arms and legs are made up of 4 cylinders, the neck, hands, fingers and feet are made up of 1 cylinder and the trunk is made up of 3 cylinders. In turn, each element is sub-divided into 64 infinitesimal areas. That is, the outer surface of each person has a total of 2240 infinitesimal areas, which are used in the incident radiation calculus. In the thermal comfort determination, each element is sub-divided into 12 cylindrical (or spherical) slices.

Fig. 1. Virtual manikin (human body model).

In the calculation of the radiation level that each person element receives, trigonometric relations between the incident solar radiation and the person are used.

In the thermal comfort level evaluation, it is used the PMV index [2]. The PMV index depends on air temperature, air relative humidity, mean radiant temperature, air velocity, activity level and clothing level. In the IAQ evaluation, it is used the dioxide carbon concentration.

3 Numerical methodology

The virtual Roman theatre used in the simulations, presented in Fig. 2, is constituted by 718 opaque surfaces. In turn, each surface is sub-divided into several infinitesimal areas with 20×20 cm dimensions. The virtual adapted auditorium, presented in Fig. 3, is obtained from the Roman theatre enveloping it by 58 transparent surfaces (in a total of 776 surfaces).

In the numerical simulations, it is considered that Roman theatre and the adapted auditorium are occupied by 330 persons equally distributed by 15 rows and 22 columns. Each occupant is numbered from the bottom to the top of the column; the first column is located on the far right side of the theatre. Each occupant is considered to have a height of 1.7 m, a weight of 70 kg and an activity level of 1.2 met.

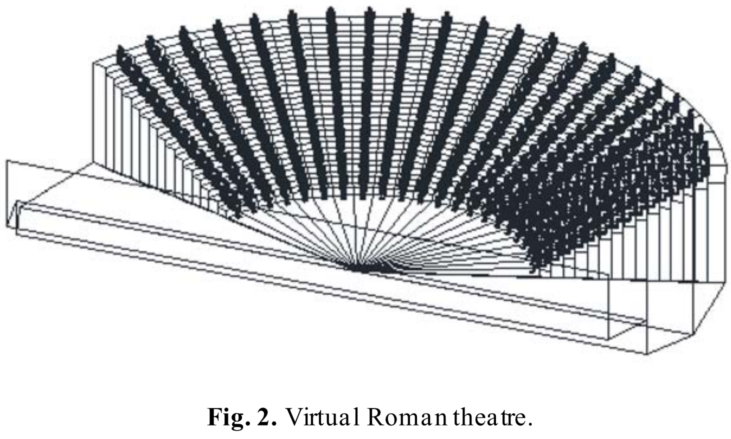

Fig. 2. Virtual Roman theatre.

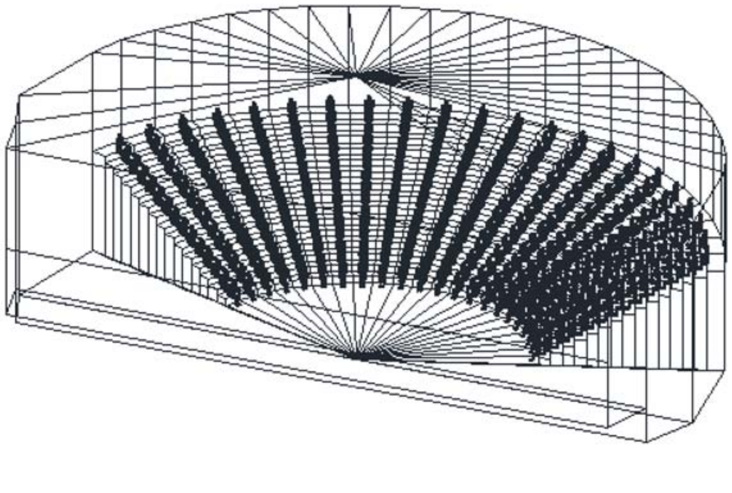

Fig. 3. Virtual adapted auditorium.

In this work, it is numerically calculated, by the BTB software, the carbon dioxide concentration, air temperature, PMV and solar radiation, for a winter typical day. The clothing level is considered to be 1.5 clo inside the auditorium and 1.5 or 3.0 clo inside the theatre. The PMV distribution and solar radiation level, to which each person is subjected at 12 hours, are calculated by the HTR software.

4 Results and discussion

In this section, for a typical winter day conditions, the carbon dioxide concentration results, the air temperature evolution (Fig. 4a) and the auditorium and theatre PMV evolution (Fig. 4b), given by the BTB are presented. The detailed results obtain at 12 hours for the solar radiation flux on each human body sections (Fig. 5a) and PMV distribution (Fig. 5b) to which each person is subject, given by the HTC, are presented. In Fig. 4b), the clothing level is identified by the number attached to the name of the space.

The carbon dioxide concentration obtained results show that its values, during all day, are below the standard value of 1800 mg/m^3 [9], meaning that the adapted auditorium has good IAQ. The results show that the auditorium air temperatures are between 20 and 22ºC around noon and in the beginning of the afternoon. This is achieved only by solar radiation. In the auditorium, the persons are comfortable around noon and in the beginning of the afternoon, by negative PMV values, according to category C [3], at least. In the theatre, the persons are comfortable by PMV values within category C [3], at least, but only dressed with a high clothing level of 3.0 clo.

The results of the solar radiant flux on the occupants' body sections show that its level depends on the occupant localization inside the auditorium and it is affected by the shading that occurs between them. As an example, in Fig. 5b, the solar radiation levels on the occupants' body sections of the column 11 are presented. It can be seen that occupants with numbers 158 to 165 receive no solar radiation, and, for example, occupants with numbers 151 to 155 receive high values of solar radiation, mainly in the head and trunk. Only those that are not subjected to solar radiation are thermally comfortable, by negative PMV values, according to category C [3].

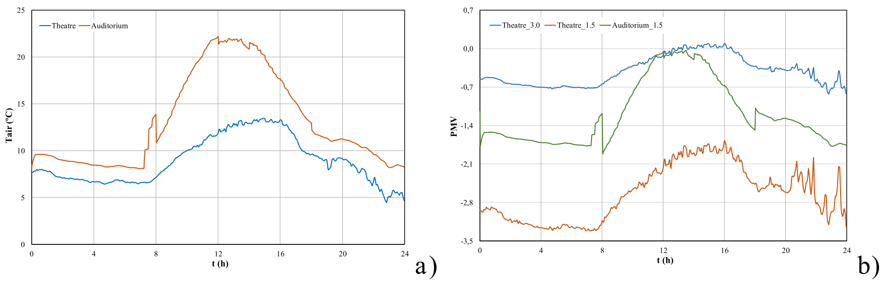

Fig. 4. BTB results for the theatre and auditorium: a) air temperature and b) PMV. The clothing level is identified by the number attached to the name of the space.

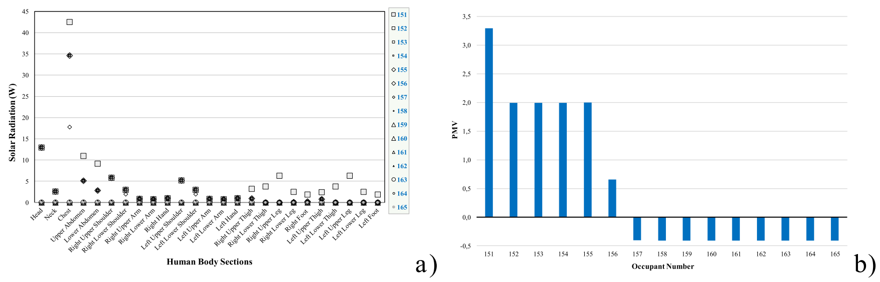

Fig. 5. HTR results in the auditorium: a) solar radiation values on the human body sections of 15 occupants; b) PMV index distribution for each selected occupant.

5 Conclusions

In this work, a software developed to design virtual manikins in spaces with complex topology and high density of occupation is presented. These virtual manikins are used by a numerical software to evaluate each occupant thermal comfort level.

The numerical results, for a typical winter day, show that the adapted auditorium presents good IAQ and good thermal comfort levels during the period of greatest sun exposure. The Roman theatre occupants are only comfortable when highly dressed. The individual occupant thermal comfort level is acceptable and is near the space average thermal comfort, but only for those not subjected to solar radiation. The occupants which are subjected to solar radiation have unacceptable thermal comfort levels.

These results reveal the importance of using virtual manikins in this kind of study, because allow it to identify the problems and to suggest some improvements. In this case, it is suggested to introduce an opaque roof or trees surrounding the auditorium. As future work, it is proposed to evaluate the importance of this shading elements on the thermal comfort levels of the auditorium occupants.

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