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ENERGY PERFORMANCE OF A SOLAR GREENHOUSE USED AS HEAT SOURCE IN VENTILATION SYSTEMS

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Abstract. This paper presents a numerical study on the energy performance of a solar greenhouse used as a heat source in a ventilation system applied in a virtual house. This work, developed in winter conditions, uses a greenhouse and a ventilation system as heating ventilation system. The greenhouse, used to heating the air, is built with a group of glasses turned to East, South and West, placed above the roof, and the ventilation system, built with two groups of ducts, one used to transport the warm air to spaces turned to north and other used to free cooling to spaces turned south. This numerical simulation uses a software, developed by the authors, that simulates the Building Thermal Modelling and evaluates the building internal environment variables, building bodies temperatures, building contaminants concentrations, thermal comfort, energy consumptions, among others. The study, with and without the greenhouse, evaluates the energy production and transport, the internal temperature and thermal comfort to which the occupants are exposed, in transient conditions, during all day. Without the greenhouse system, in spaces with south-facing windows, the thermal conditions are uncomfortable by positive PMV (Predicted Mean Votes) index values, while in spaces with north-facing windows the thermal conditions are uncomfortable due to positive values of the PMV index. Using the greenhouse and the ventilation strategies, all spaces during the occupation are thermal comfortable.

1 Introduction

The study on the energy performance in a solar greenhouse used as a heat source in a ventilation system is applied numerically in a family house house.

The greenhouse is used as passive solar strategy for heating the interior spaces of buildings. This kind of natural ventilation strategy is used to heat the internal air and to reduce the building energy consumption [1, 2]. The application of a solar passive greenhouse in ventilation systems promotes energy gains, as verified by Ignjatovic et al. [3] and Ulpiani et al. [4].

The work presented in this study considers the numerical application of a Building Thermal Modelling model. This model, developed by the authors, considering the radiative and convective phenomena, was applied in school buildings with complex topology [5, 6]. In Conceição et al. [5], it is presented a group of separated buildings. In Conceição and Lúcio [6], it is presented a group of three buildings arranged in a U configuration. In both buildings, the shading devices and the solar radiation are considered: either on opaque surfaces, considering absorption and reflection, or on transparent surfaces, considering radiosity. The convection heat transfer was analysed in the study of Conceição et al. [7].

Building Thermal Modelling numerical model considers energy and mass balance integral equations, integrated in transient conditions. The energy balance integral equations are used to evaluate the opaque bodies, transparent bodies, internal bodies and internal air temperature distributions. The mass balance integral equations are used to evaluate the water and contaminants mass distribution inside the spaces.

In thermal comfort evaluation, the Building Thermal Modelling numerical model uses Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD) indexes (see Fanger [9]), and presented in ISO 7730 [10]. In the Building Thermal Modelling numerical model, the thermal comfort is evaluated in school spaces (see Conceição et al. [11]), based on the human thermal physiology.

The Building Thermal Modelling numerical model uses the carbon dioxide concentration, as indicator of the indoor air quality (see ASHRAE 62.1 [12]) and the airflow rate to promote the indoor air quality. The evolution of carbon dioxide concentration was analysed in buildings occupied spaces [13], and the airflow rate was applied in vehicles [14].

The Building Thermal Modelling numerical model, namely the building geometry and temperature distribution, is used as input by the coupling of CFD and

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Human Thermal Modelling in order to evaluate the comfort [8].

The Building Thermal Modelling numerical model was validated in winter and in summer conditions, with different conditions, for school buildings and other spaces.

The main objective of this numerical work is to evaluate the energy performance in a solar greenhouse used as a heat source of a ventilation system applied in a virtual house, located in the roof turned to south direction. The solar greenhouse is connected by a duct system to all occupied spaces. The study is done for winter conditions in an environment of Mediterranean-type.

2 Numerical Model

The Building Thermal Modelling numerical model is used to simulate the building thermal response, energy consumption, photovoltaic production, thermal comfort, indoor air quality and others.

In the building thermal response, the software, the geometry, the equations, the inputs and the mass and temperatures are developed and calculated:

- The geometry is developed using the CAD system. All building bodies are represented;
- The CAD system is used to generate the energy and mass balance integral equations. In this calculus the boundary conditions are also considered;
- As inputs, the buildings materials, the external conditions, the geographic conditions, the occupation cycle, the ventilation topologies, and other details, are considered;
- The resolution of the equation system is used to calculate the mass temperature.

The thermal comfort is evaluated using the human thermophysiology, namely using the PMV and the PPD indexes. These indexes depending on the internal air temperature, air velocity, Mean Radiant Temperature, air relative humidity, clothing level and activity level.

The indoor air quality is evaluated by the carbon dioxide concentration release in the respiration process. This calculus depending on the air renovation, the occupation and the room volume.

The energy integral equations system considers the following phenomena:

- The heat transfers by conduction, in the opaque bodies, between the different layers;
- The heat transfers by natural, forced and mixed convection, in the opaque, transparent and indoor bodies, evaluated using dimensionless coefficients and used in the opaque and glazed surfaces;
- The considered radiative heat exchanges are the incident solar radiation, the absorbed solar radiation by transparent bodies (glasses) and opaque bodies and the transmitted solar radiation through the transparent (glasses) bodies. The radiation phenomenon considers all shading devices;
- In the radiative process, the heat exchange by radiation, in each space, is also considered. In these calculus the radiosity equations and the Mean Radiant Temperature concepts are used.

The mass integral equations system considers the convection, diffusion, adsorption and desorption phenomena.

The energy and mass balance integral equations are solved by the Runge-Kutta-Felberg method with error control.

The energy balance integral equations calculate the opaque temperature (door, walls, floor and ceiling) bodies, transparent (glasses) temperature bodies, indoor (seats, desks and others) bodies and internal air of the spaces of the virtual buildings.

The mass balance integral equations calculate the mass concentration of the water vapour and the mass concentration of the contaminants inside the building indoor spaces.

3 Numerical Methodology

The study takes into account a virtual house prototype (Fig. 1) provided by South, West and East facing greenhouse systems, connected to the occupied spaces. The virtual building considers five spaces in the first floor and two spaces (loft and greenhouse) in the second floor.

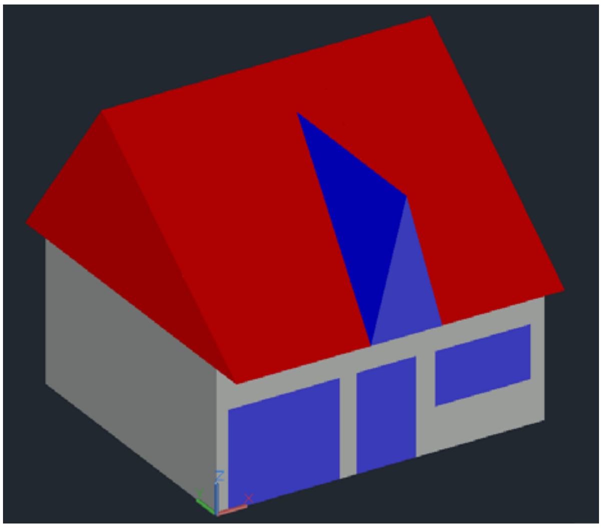

Fig. 1. Virtual building equipped with a greenhouse located in the roof.

The numerical simulation considers one external space (space number 1), five internal spaces (spaces number 2 to 6), a loft and a greenhouse (space number 7), namely:

- Space 1 – external space. The external environmental variables are used as input data;
- Space 2 – non-permanent occupation space. This space is equipped with a glass door facing south;
- Space 3 – occupied space with two persons between 19 to 24 hours. This space is equipped with a window facing south;
- Space 4 – occupied space with two persons between 12 to 14 hours and one occupant between 18 to 19 hours. This space is equipped with a window facing north;

- Space 5 – occupied space with two persons between 0 to 8 hours. This space is equipped with a window facing east;
- Space 6 – occupied space with two persons between 18 to 19 hours. This space is equipped with a window facing south;
- Space 7 – non-permanent occupation space. This space is used to regulate the temperature in the building.

This work is divided as follows:

- Without greenhouse system: the heating process is made using only direct solar radiation;
- With greenhouse system: the heating process is made using direct solar radiation and heat transported by ducts from the greenhouse, placed in the roof area, to the uncomfortable cold spaces placed in the north-facing area of the house;
- With greenhouse system: air renovation with the external environment, in order to control the internal temperature.

Without greenhouse system, the airflow rate is proportional to the occupation level: 35 m^3/h per occupant. In this case the air renovation is exchanged with the external environment.

With greenhouse systems, the following airflow rates are considered:

- An airflow rate of 0.03 m^3/s, between the spaces numbers 2, 3 and 6 and the external environment, during 24 hours;
- An airflow rate of 0,00375 m^3/s, between the greenhouse and the spaces numbers 4 and 5, during 24 hours.

4 Results

In Fig. 2, the solar radiation to which the glasses of the solar greenhouse are subjected is shown. The external and internal air temperatures in the occupied spaces and the greenhouse space are presented: when the greenhouse is not considered the results are presented in Fig. 3, while when the greenhouse is considered the results are presented in Fig. 4. Finally, in Fig. 5 is presented the evolution of PMV index in the occupied spaces, when the greenhouse is considered.

In accordance with the radiation transmitted in the glasses surfaces of the greenhouse, it is possible to conclude that in the beginning of the day, during the day and in the end of the day the greenhouse is subjected to solar radiation. The transmitted solar radiation is higher in the beginning of the day (East glass) and in the end of the day (West glass) than during the day (South glass).

In accordance with the obtained results, without greenhouse, the spaces with windows turned to north present lower air temperature than the spaces with windows turned to south. Thus, the thermal comfort level is uncomfortable in spaces with windows turned to north due to negative PMV values and in spaces with windows turned to south due to positive PMV values.

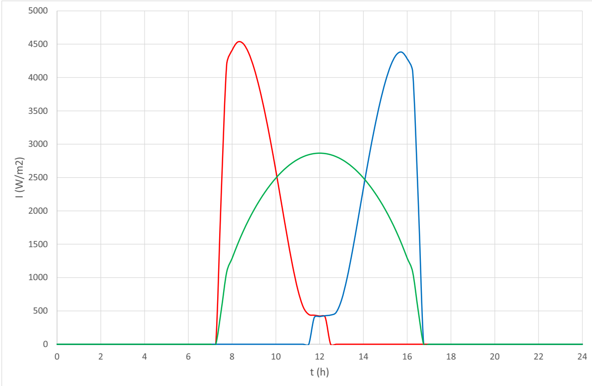

Fig. 2. Solar radiation that the glasses of the solar greenhouse are subjected. Red line is associated to a glass surface turned to East, green line is associated to a glass surface turned to south and blue line is associated to a glass surface turned to west.

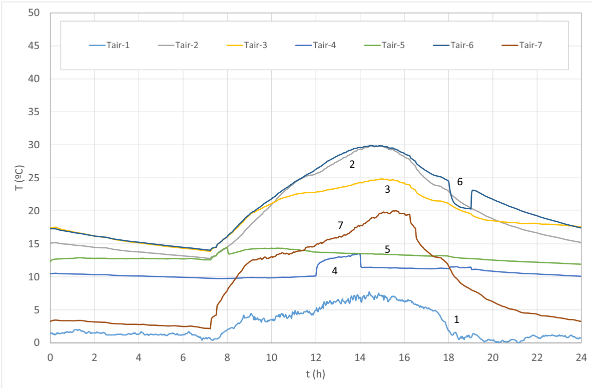

Fig. 3. Evolution of external (Tair-1) and internal air temperatures in the occupied spaces (Tair-2 to Tair-6) and the greenhouse space (Tair-7), when the solar greenhouse is not considered.

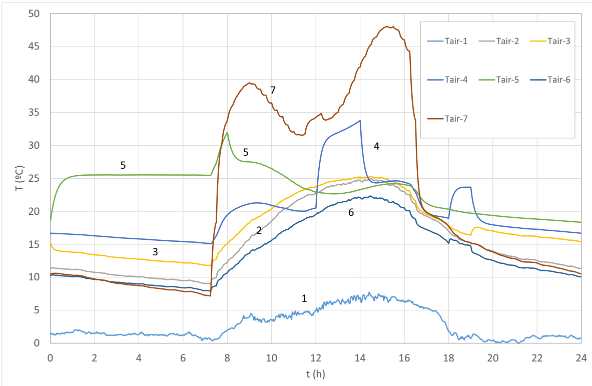

Fig. 4. Evolution of external (Tair-1) and internal air temperatures in the occupied spaces (Tair-2 to Tair-6) and the greenhouse space (Tair-7), when the solar greenhouse is considered.

When is considered the greenhouse, the warm air increases the internal air temperature in spaces turned to north and the air recirculation with the external environment decreases the internal air temperature in spaces turned to south. Thus, the greenhouse improves the thermal comfort level, mainly in spaces with windows turned to north and the thermal comfort level is acceptable, mainly when the spaces are occupied.

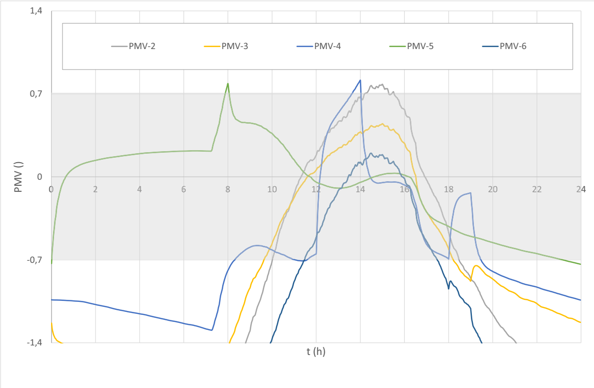

Fig. 5. Evolution of PMV index in the occupied spaces, when the greenhouse is considered. The shaded area represents the comfort zone according to Category C [10].

5 Conclusions

In this study the influence of a solar greenhouse used as a heat source in a ventilation system applied in a virtual house was evaluated. The study was made for winter conditions in a Mediterranean-type environment.

The greenhouse geometry, developed in this study, guarantees incident solar radiation not only during the day, but also specially with high intensity in the morning and in the afternoon.

Without greenhouse, the spaces with windows turned to north are uncomfortable by negative PMV values, while the spaces with windows turned to south are uncomfortable by positive PMV values. The combination of greenhouse with air renovation promotes acceptable thermal comfort levels, mainly, when the occupation is verified.

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