Energy and Thermal Comfort Management in a Kindergarten School Building in the South of Portugal in Winter Conditions

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Abstract: - In this work a numerical model, which simulates the buildings thermal response and evaluates the indoor environment comfort, in transient conditions, is used in the energy and thermal comfort management in a kindergarten school building in the South of Portugal in Winter conditions. After it's validation, this numerical model is applied in the evaluation of the building thermal behavior, using the indoor temperature field, and the occupants thermal comfort levels, using the PMV and PPD indexes.
In the numerical model validation, experimental data and numerical values, for the indoor air temperature, are compared. In the experimental tests, for a typical Winter day, the outdoor and indoor environmental variables are measured. In the numerical simulation of the kindergarten school building, the 25 compartments, the 498 building main bodies and the 42 windows glasses, as well as all surrounding main buildings, are considered.
The viability to build an indoor greenhouse, used to heat the cooled spaces, and the evolution of indoor thermal comfort level are analyzed.

Key-Words: - Kindergarten school building, Numerical simulation, Experimental tests, Building thermal behavior, Energy, Indoor greenhouse, Thermal comfort.

1 Introduction

In the Algarve region, in the South of Portugal, it is very important to develop kindergarten school buildings, adapted to this region, that can promote the increase of the occupants comfort conditions, namely the thermal and air quality, as well as to promote the reduction of energy consumption levels for the buildings.
In Winter conditions renewable resources, like direct solar radiation, in order to increase the indoor air temperature level, are used. The energy management in this kind of situation, in order to obtain a better thermal comfort field inside a building environment, is frequently analyzed using building thermal behavior numerical models.
In [1], as example, a school building thermal response, located in the South of Portugal, in a Winter typical day using a numerical model that simulates the thermal behavior of a building with complex topology and evaluates the indoor air quality, in transient condition, was made. The idea of the study is to reduce the buildings energy consumption and increase the occupants' thermal comfort levels, using the high solar radiation levels disposable in this region. In the first phase the uncomfortable rooms were identified, in the second phase the electric air heating systems with PMV index control were numerically installed and, in the third phase, three air collectors located above the roof area to heat the air to be injected in the uncomfortable rooms were numerically analyzed. In the first phase were verified that, in general, the rooms with windows turned North, the compartments with windows subjected to shading devices and the indoor spaces without windows with low occupation level, presented the highest uncomfortable thermal conditions. The installation of electric air heating systems in uncomfortable spaces promoted good thermal comfort levels. It was verified that using the PMV index control is possible to guarantee high comfort levels with lower energy consumption levels in the heating process. The highest consumption level was verified in the first hours of the day, mainly in compartments with main occupation time verified during break times. In the third phase was verified that the solar air collectors promoted, in the afternoon, acceptable thermal and air quality levels in the considered spaces. In this phase, in order to

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promote simultaneously thermal and air quality good levels, was verified that the uncomfortable occupied spaces are ventilated and heated using warm air from the collector, the comfortable or lightly comfortable spaces are ventilated and heated using lightly warm air from the corridor and the small comfortable occupied spaces are ventilated using clean air coming directly from the outdoor environment.

In order to evaluate the thermal comfort level in moderate environments equipped with air-conditioning systems, either in cold or in warm climates, during Winter or Summer, the PMV (Predicted Mean Vote) and the PPD (Predicted Percentage of Dissatisfied) indexes are used in [2], [3] and [4]. For acceptable thermal comfort conditions, the [4] defines three comfort categories (A, B and C), establishing limits for PMV and PPD indexes. This classification allows the selection a priori of one thermal environment according to the required demands.

In this work a numerical model, that simulates the buildings thermal response and evaluates the indoor environment comfort, in transient conditions, is used in the energy and thermal comfort management in a kindergarten school building in the South of Portugal in Winter conditions. The work is divided in three parts: in the first one the numerical values are compared with the experimental measured data, in the second one the indoor temperature field are used to identify potential spaces used as indoor greenhouse with capacity to use the solar radiation in the indoor air heating, finally, in the third one the indoor thermal comfort level, using the PMV and PPD index, that occupants are subjected, is evaluated.

2 Numerical Model

The multi-nodal buildings thermal behavior model, which operates in transient conditions, is based in energy and mass balance integral equations (see [5], [6] and [7]). The energy balance integral equations are developed for:

- the air (inside the several compartments and ducts system);
- the different windows glasses;
- the interior bodies (located inside the several spaces);
- the different layers of buildings main bodies and ducts system.

The mass balance integral equations are developed for:

- the water vapor (inside the several spaces, ducts system and in the interior surfaces);
- the air contaminants (inside the several spaces and ducts system).

In the resolution of this equations system the Runge-Kutta-Fehlberg method with error control is used. The model considers the conductive, convective, radiative and mass transfer phenomena:

- the conduction is verified in the building main bodies (doors, ceiling, ground, walls, etc.) and ducts system (fluid transport) layers;
- in convection the natural, forced and mixed phenomena are considered;
- in the radiation, verified inside and outside the building, the short-wave (the real distribution of direct solar radiation in external and internal surfaces) and long-wave (heat exchanges between the buildings external surfaces and the surrounding surfaces as well as among the internal surfaces of each space) phenomena are considered. In radiative calculus the shading effect caused by the surrounding surfaces and by the internal surfaces is considered.

The input data in the software are:

- the buildings geometry (introduced in a three-dimensional design software);
- the boundary conditions;
- the materials thermal proprieties and other conditions (like the outdoor environmental and geographical conditions, the initial conditions, the several heat and mass load, the occupation cycle, the occupant's clothing and activity levels and the air ventilation topologies).

3 Building Simplified Geometry

In the analyzed kindergarten school building (see Figure 1), divided in 24 compartments (see identification in figure 2), 498 building main bodies and 42 windows glasses are considered. This building, located in Olhão, has three classrooms, for 3, 4 and 5 years old children, and other spaces for offices, administrative, WC, teachers and non-teachers staff and meeting room.

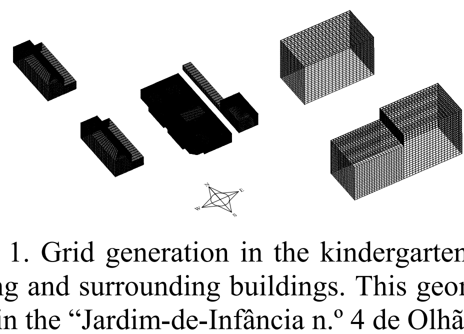

Figure 1. Grid generation in the kindergarten school building and surrounding buildings. This geometry is based in the "Jardim-de-Infância n.º 4 de Olhão".

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In Figures 1 the grid generation used in the numerical simulation of the kindergarten school building is presented. This numerical grid, used in the internal and external direct solar radiation determination, was spaced 30 cm in both directions.

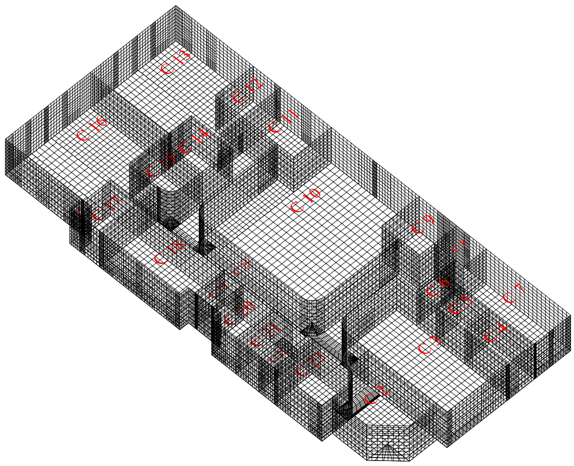

Figure 2. Identification of the indoor compartment of the kindergarten school building.

4 Results

In this study the software that simulates the buildings thermal response, with complex topology, in transient conditions, and evaluates the indoor thermal comfort and indoor air quality levels, is used. This software was validated in Winter [6] and Summer [7] conditions, in school buildings with complex topology. Nevertheless, in this work, before the evaluation of building thermal response and occupants thermal comfort conditions, the software is also validated considering the surrounding buildings.

In this numerical model validation the doors and windows were closed, the internal curtains were open, the air-conditioning systems were off, the occupation is not considered and the internal radiative heat exchanges were also not considered. The air mean renovation values inside each compartment by infiltration were experimentally obtained, in several compartments, using the tracer gas concentration method. In the school buildings numerical simulation, in order to evaluate the real building thermal inertia, the previous 5 days were also simulated. The experimental test, used in the validation phase, was made in a day without external wind.

4.1 Validation tests

The experimental data used in the numerical model as inputs of the outdoor environmental variables (the outdoor air temperature and relative humidity) and in the validation of the indoor air temperatures for three occupied strategic rooms: numbers 3, 10 and 16 (figure 2) were measured in the typical Winter, the 27th January 2007. All measured data were stored in four dataloggers during 24 hours with an acquisition rate of 1 sample per minute.

In figures 3, 4 and 5 the evolution of the measured and calculated indoor air temperature, are presented. The figures 3 are associated to compartment number 3, the figure 4 are associated to compartment number 10 and figure 5 are associated to compartment number 16. In these figures the points are associated to experimental data, while the lines are associated to numerical values.

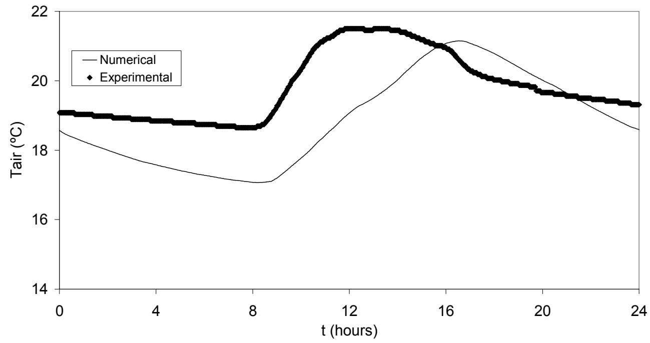

Figure 3. Evolution of air temperature, measured and calculated, inside the compartment number 3.

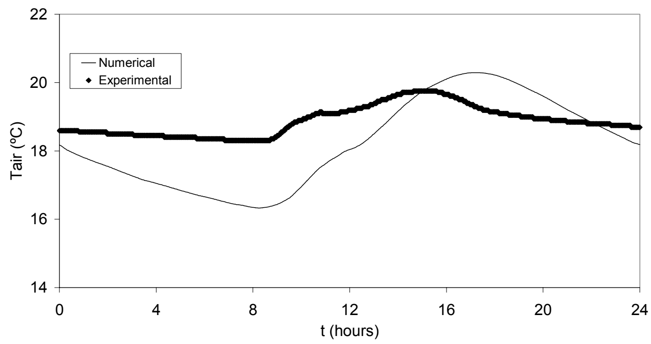

Figure 4. Evolution of air temperature, measured and calculated, inside the compartment number 10.

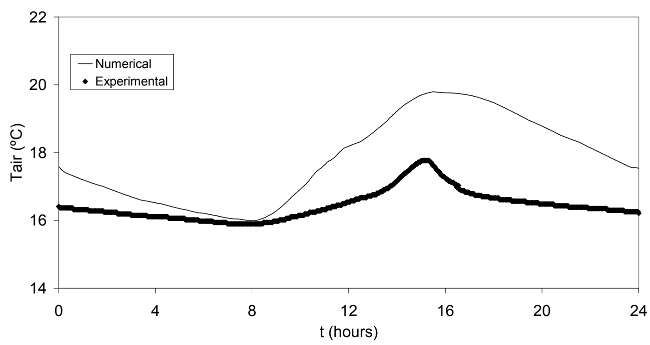

Figure 5. Evolution of air temperature, measured and calculated, inside the compartment number 16.

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Classroom number 3 is equipped with windows turned South, the playground number 10 is equipped with windows turned to East and classroom number 16 is equipped with windows turned West and North.

In accordance to the obtained results, in the previous figures, it is possible to conclude that the numerical model reproduces the experimental indoor air temperatures behavior. In general, the difference between numerical and experimental indoor air temperature values is lower than 2.5 ºC.

Some discrepancies verified between the numerical values and the experimental results, are associated to:

- the North classroom windows curtains, that were partially closed during the experimental data assessment, creating an obstacle to the radiative exchanges, verified in the numerical over-dimensioned values for this classrooms (compartments 16);
- the mean value for the air renovation rate experimentally obtained in some spaces, presents local differences;
- the building interior bodies, that can influence the building thermal inertia, were not considered;
- the ceiling, in contact with the outdoor environment, presents a great solar load. Thus, small discrepancies in the identification of the material are reflected in the indoor air temperature calculation;
- the small differences in the evaluation of the surrounding buildings external geometry, are reflected in the kindergarten school building external surfaces solar radiation;
- the grid generation is spaced 30 cm in both directions. The reduction of this distance, with consequently increase of the calculation time, allows better shading effects and solar radiation calculations;
- the numerical model used to determine the external solar radiation, with and without cloudy sky. In this simulation the best model for the analyzed day was used, nevertheless, these kinds of models may cause some errors in solar radiation calculations;
- the outdoor environmental variables, used as input data, measured in the outdoor environment, due to the building dimensions and complexity.

4.2 Building thermal behavior

The evolution of indoor air temperature for the hall, corridors and playground area (compartments 2, 10 and 25), the classrooms (compartments 3, 13 and 16) and the offices (compartments 7, 11 and 23) are presented, respectively, in figure 6, 7 and 8.

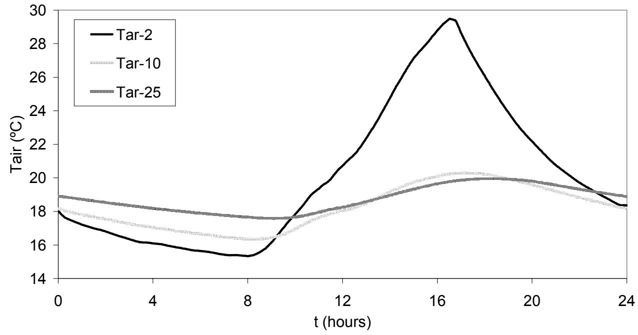

Figure 6. Evolution of air temperature calculated inside compartments number 2, 10 and 25.

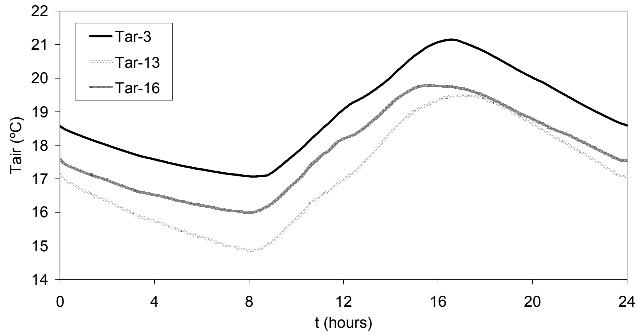

Figure 7. Evolution of air temperature calculated inside compartments number 3, 13 and 16.

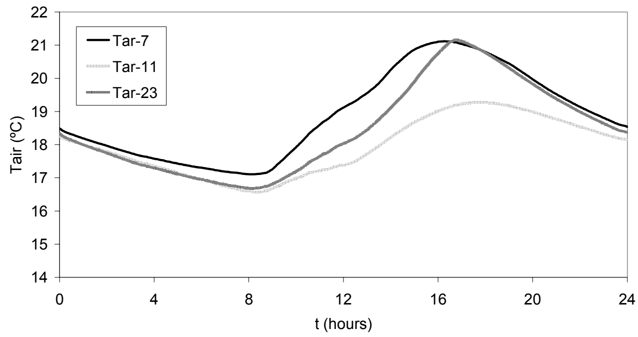

Figure 8. Evolution of air temperature calculated inside compartments number 7, 11 and 23.

In accordance to the figures 6, 7 and 8, it’s possible to conclude that:

- the classrooms with windows turned to North (compartments 13 and 16) had the lowest indoor air temperature values, while the hall (compartment 2) presented the highest indoor air temperature values;
- the hall, with high window area turned South and West, in accordance to the highest indoor air temperature verified, can be used as indoor greenhouse. The warm air can be used to heat the indoor air temperature of the classroom with windows turned North (compartments 13 and 16).

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4.3 Occupants thermal comfort

The evolution of thermal comfort levels for the hall, corridors and playground area (compartments 2, 10 and 25), the classrooms (compartments 3, 13 and 16) and the offices (compartments 7, 11 and 23) are presented in figures 9 to 14. In figures 9, 11 and 13 the PPD evaluation is presented, while in figures 10, 12 and 14 the PMV evaluation is presented.

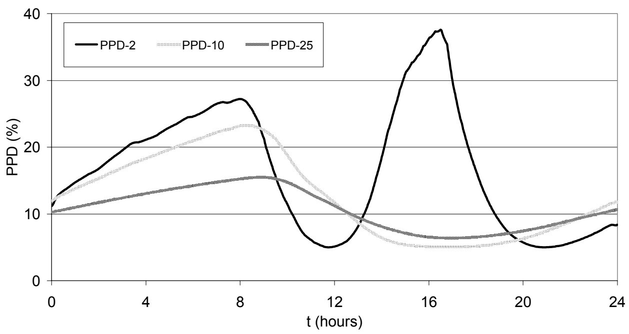

Figure 9. Evolution of PPD index calculated inside compartments numbers 2, 10 and 25.

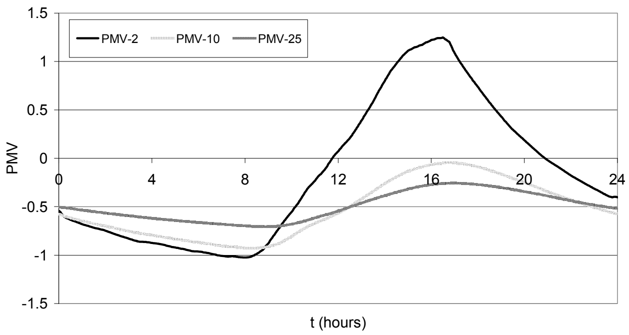

Figure 10. Evolution of PMV index calculated inside compartments numbers 2, 10 and 25.

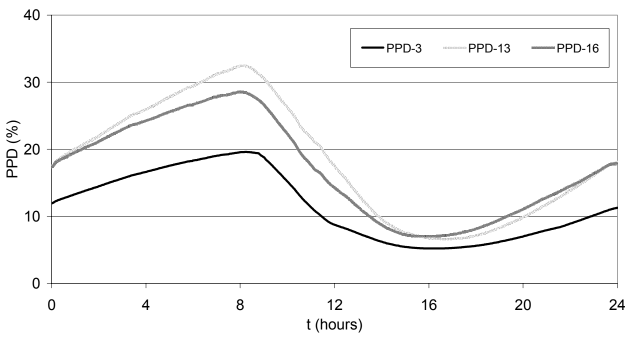

Figure 11. Evolution of PPD index calculated inside compartments numbers 3, 13 and 16.

The PMV index is calculated, by the software, for each space, using the numerical values of the indoor air temperature, air velocity (obtained through the air renovation and recycled air mass flow), air relative humidity and mean radiant temperature (obtained through the mean value of the compartments surrounding surfaces temperatures), for a pre-defined clothing and activity level. In this calculus the Fanger model [2] is used. The PPD index is correlated with the PMV index using the Fanger model [2].

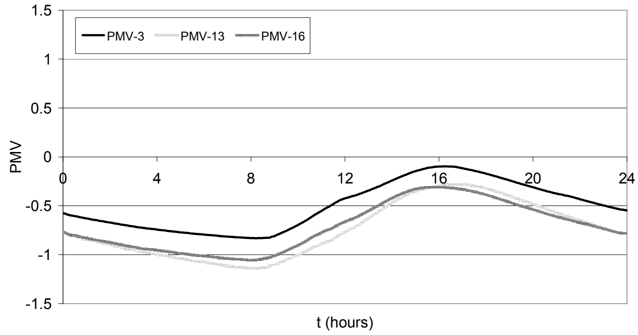

Figure 12. Evolution of PMV index calculated inside compartments numbers 3, 13 and 16.

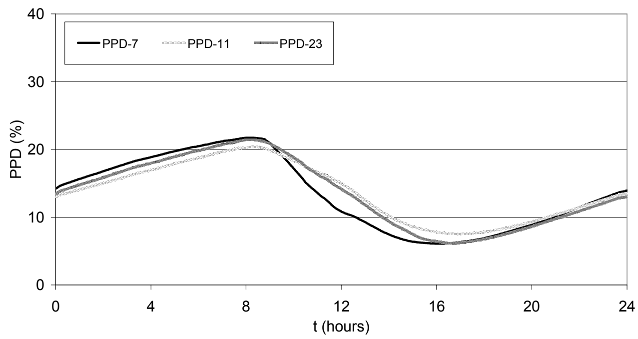

Figure 13. Evolution of PPD index calculated inside compartments numbers 2, 10 and 25.

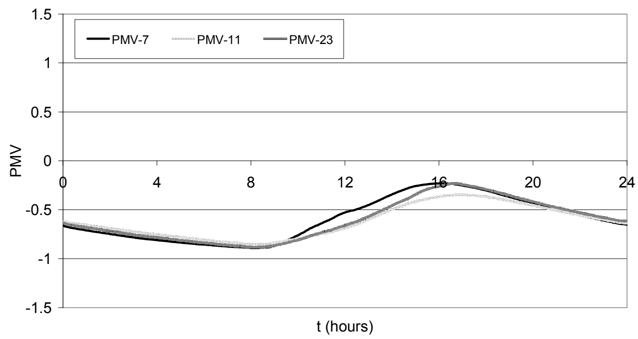

Figure 14. Evolution of PMV index calculated inside compartments numbers 2, 10 and 25.

In accordance to the figures 9 to 14, it's possible to conclude that:

- the hall is thermally uncomfortable, by positive PMV values and the corridor and the playground are thermally comfortable in the afternoon;
- the classrooms with window turned North are most uncomfortable than the classroom with windows turned to South;
- the offices are thermally comfortable in the afternoon, nevertheless their occupation during the day isn't continuous.

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5 Conclusion

In this work a numerical model, that simulates the buildings thermal response and evaluates the indoor thermal comfort and air quality, in transient conditions, is used in the energy and thermal comfort management in a kindergarten school building in the South of Portugal in Winter conditions.

The work is divided in three parts: in the first one the numerical values are compared to the experimental measured data, in the second one the indoor temperature field is used to identify potential spaces used as indoor greenhouse and in the third one the indoor thermal comfort level, using the PMV and PPD indexes, that occupants are subjected, is evaluated.

The validation of the numerical model, being considered the kindergarten school building and the surrounding buildings, shows good agreement between the numerical values and the experimental data. The higher difference, in general, doesn't exceed the 2.5 ºC.

It was verified that the classrooms with window turned North present the lowest indoor air temperature values, while the hall, with significant area of glasses windows turned South and West, the highest indoor air temperature values. Thus, is suggested to consider the hall as greenhouse used to warm the air to be used in the classrooms with window turned North. It is suggested to use a horizontal duct or the corridor, to transport this warm air from the greenhouse to the classrooms with windows turned North. It is also suggested to analyze, in future simulations, this topic.

The classrooms with windows turned North are thermally uncomfortable, nevertheless the comfort level in the afternoon in the classroom with windows turned South are in accord to the standards.

It is suggested to consider the presence of occupants and the introduction of ventilation in future simulations. The first will increase the indoor air temperature, while the second, if the air came from the outdoor environment without heated, will decrease the indoor air temperature.

6 Acknowledgement

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