ENERGY AND THERMAL COMFORT EVALUATION FOR DIFFERENT PASSIVE SOLUTIONS IN A KINDERGARTEN IN SUMMER CONDITIONS

Eusébio. Z. E. Conceição[1], Margarida C. Lopes[1] and Mª. Manuela J. R. Lúcio[2]
[1]FCT, Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal
email: econcei@ualg.pt
[2]Agrupamento Vertical Professor Paula Nogueira, R. Comunidade Lusíada,
8700-000 Olhão, Portugal

ABSTRACT

In this work a numerical model, which simulates the buildings thermal response with complex topology and evaluates the indoor environment comfort, in transient conditions, is used in the energy and thermal comfort evaluation for different passive solutions in a kindergarten, in Summer conditions. After the validation phase, this numerical model is applied in the evaluation of the building thermal behaviour, using the indoor temperature field, and the occupants' thermal comfort levels, using the PMV and PPD indexes.

The introduction of a roof placed in the top of the kindergarten, horizontal shading devices placed above the windows level facing South and external pyramidal opaque trees placed in front to the windows facing West and East, used to reduce the indoor temperature level and to increase the indoor thermal comfort level, in Summer conditions, are analyzed.

INTRODUCTION

The external air temperature and solar radiation values in the South of Portugal, in an environment with Mediterranean characteristics, in Summer conditions, are very high. In this season adequate shading devices, to reduce this direct solar radiation, as example, are used. This situation requires a detailed study of the building thermal behaviour, considering the buildings structural details and the surrounding buildings.

The use of shading devices in school buildings is an efficient tool in order to reduce the internal air temperature, with low energy consumption level. Nevertheless, in particular situations, an additional ventilating and air-conditioning systems should be used.

In this region, with a particular climate, is very important to develop adapted kindergartens, that can promote the occupants comfort conditions, namely the thermal and air quality levels, as well as to promote the reduction of buildings energy consumption levels.

In this study, in order to develop shading devices adapted to particular kindergartens, a numerical model that simulates the buildings thermal response with complex topology and evaluates the indoor environment comfort, in transient conditions, is used. The numerical model, developed by the authors in the last years, considers 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, the water vapour (inside the several spaces, ducts system and in the interior surfaces) and the air contaminants (inside the several spaces and ducts system). In the evaluation of the indoor environment comfort, that an occupant feels in the different spaces, is important to evaluate the air temperature, air velocity, air relative humidity, mean radiant temperature, metabolic rate and clothing level (Fanger, 1970). The Predicted Mean Vote (PMV) and the Percentage of People Dissatisfied (PPD) indexes, used to evaluate the thermal comfort in steady state conditions, is usually used to integrate the environmental and personal parameters**.**

The present numerical model was used not only in studies of comparison between numerical and experimental data in Summer conditions (see Conceição *et al,* 2008a) and in Winter conditions (see Conceição *et al,* 2008b), but also in particular numerical applications as, for example, in the study of the influence of surrounding buildings (see Conceição *et al,* 2007) and in the use of a greenhouse, in Winter conditions, to increase the internal air temperature and the occupants' comfort levels (see Conceição *et al,* 2008c). In the present work, made in Summer conditions, the implementation of some shading devices, like the roof placed in the top of the kindergarten, horizontal shading devices placed above the windows level facing South and external pyramidal opaque trees placed in front to the windows facing West and East is studied.

This kind of numerical model, used in the building thermal analysis, has been developed in the last years by several authors. In the numerical study of buildings thermal behaviour, for example, Ozeki *et al.* (1992), Cammarata *et al.* (1994), Mendes and Santos (2001) and Strand *et al.* (2001), present some studies applied to similar complex situations than the one here presented in this paper.

NUMERICAL MODEL

This code, presented and used in this study, was developed and validated in the last years by the authors of this study (Conceição, 2003, Conceição *et al.*, 2004, Conceição and Lúcio, 2006, Conceição *et al.,* 2007 and Conceição *et al.,* 2008a,b,c). The present numerical program calculates the internal air temperature (inside the several compartments and ducts system), the different windows glasses temperature, the interior bodies temperature (located inside the several spaces), the different layers of buildings main bodies temperature, the water vapour concentration (inside the several spaces, ducts system and in the interior surfaces), the air contaminants concentration (inside the several spaces and ducts system) and the global thermal comfort conditions, using the PMV and PPD indexes, that the occupants are subjected.

The input data in the software are the building geometry (introduced in a three-dimensional design software), the boundary conditions, the materials thermal proprieties and other conditions (like the external 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).

More details about this numerical model can be seen, for example, in Conceição (2003), Conceição *et al.* (2004), Conceição and Lúcio (2006), Conceição *et al.* (2007) and Conceição *et al.* (2008a,b,c).

Balance integral equations

The multi-nodal buildings thermal behaviour model, which operates in transient conditions, is based in energy and mass balance integral equations. 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) and the different layers of buildings main bodies. The mass balance integral equations are developed for the water vapour (inside the several spaces, ducts system and in the interior surfaces) and the air contaminants (inside the several spaces and ducts system).

In the resolution of these integral equations system the Runge-Kutta-Fehlberg method with error control is used.

Heat exchanges with the environment

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.) layers, in convection the natural, forced and mixed phenomena are considered; in 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.

Building simplified model

In the numerical simulation of the kindergarten the 25 compartments, the 498 building main bodies, the 15 trees (90 surfaces), the roof (4 surfaces), the 4 shading devices and the 42 windows glasses, as well as two schools and three residential surrounding main buildings, are considered. In the building main bodies double brick, in the external walls, simple brick, in the internal walls, coverage of cement, in the ceiling, several meters of ground, in the floor, and interior and exterior doors, that include several wood layers, are used. In the pyramidal opaque trees only the external surfaces are considered. These trees, with falling foliage, guarantee a large passage of solar radiation in Winter (not considered in this work) and no passage of solar radiation in Summer conditions (considered in this work). The roof bodies consider the tiles and a thickness of coverage of cement. Finally, the horizontal shading devices placed above the windows level, facing South, are dimensioned in order to guarantee a lower direct solar radiation in Summer conditions and a higher direct solar radiation in Winter conditions.

This existing kindergarten, used in this study, located in Olhão (South of Portugal), has 10 spaces with higher occupation and 15 spaces with lower occupation. The idea is, in a first phase, to evaluate the actual buildings thermal behaviour and improve thermal comfort conditions that the occupants are subjected, using passive systems, which will be implemented in a second phase.

As spaces with higher occupation are considered the classrooms (numbers 3, 13 and 16), for 3, 4 and 5 years old children, playground (number 10), office (number 23), kitchen (number 18), teachers' room (number 7), non-teacher's staff room (number 11), corridors (numbers 19 and 25), while in the spaces with lower occupation are considered the hall (number 2), storage rooms (numbers 5, 6, 8, 12, 17 and 20), WC (numbers 4, 9, 14, 15, 21, 22 and 24) and garret (26).

In Figure 1 the grid generation used in the numerical simulation of the kindergarten and considered surrounding buildings is presented. This numerical grid, used in the indoor and outdoor direct solar radiation determination, was spaced 30 cm in both directions.

The detailed grid generation used in the numerical simulation of the kindergarten and the space numeration are presented in figure 2.

Finally, in figure 3 are presented the considered passive systems, namely the roof, the pyramidal opaque trees and the horizontal shading devices.

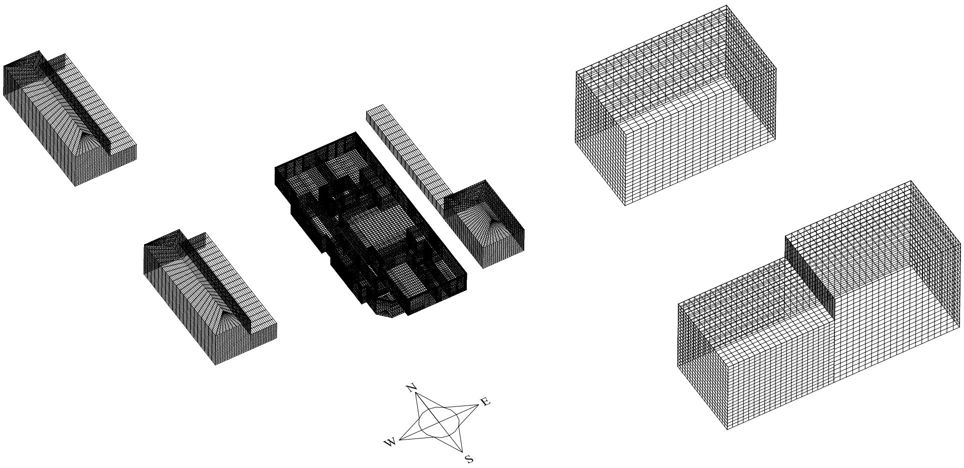

Figure 1 Grid generation in the kindergarten and surrounding buildings. This geometry is based in the "Kindergarten number 4 in Olhão".

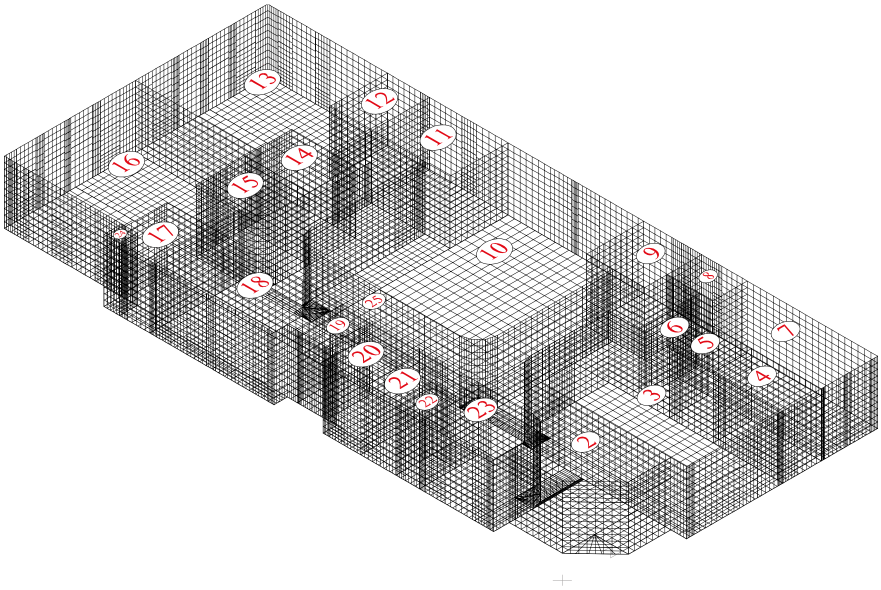

Figure 2 Identification of the indoor compartment of the kindergarten.

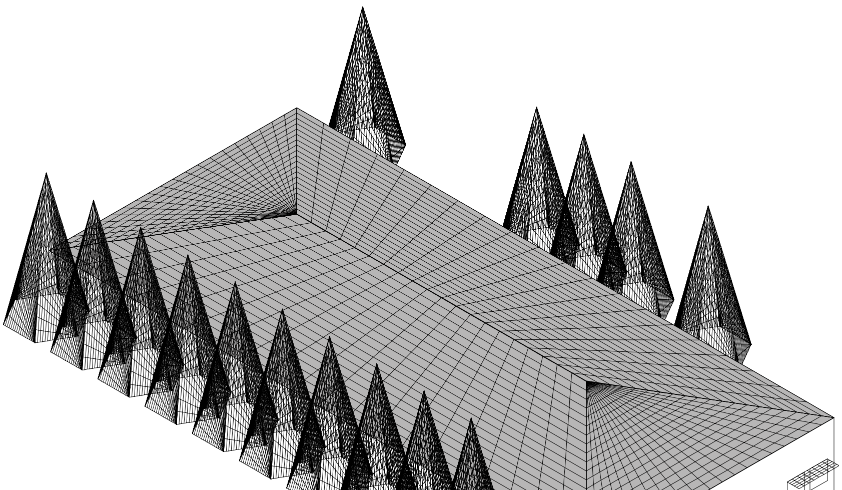

Figure 2 Scheme of the considered passive systems, namely the roof, the pyramidal opaque trees and the horizontal shading devices, in the kindergarten.

In this work typical pyramidal opaque trees, with similar dimensions and configurations, placed in accord to the windows positions, are used. These 15 trees, placed side by side, with pyramidal shape with six triangular plane surfaces (see figure 3), are characterized by the trees total height, the trees diameter and the trees main trunk height. In the present study trees with a total height of 8 m, a diameter of 4 m and a trunk height of 2 m were used.

Comfort model

In order to evaluate the thermal comfort level in moderate environments equipped with heating and air-conditioning systems, either in cold or in warm climates, during Winter or Summer conditions, the PMV (Predicted Mean Vote) and the PPD (Predicted Percentage of Dissatisfied) indexes are used (Fanger, 1970 or ISO 7730, 2005). For acceptable thermal comfort conditions the ISO 7730 (2005) defines three comfort categories (A, B and C), establishing limits for PMV and PPD indexes. In the category C, the limits of the suggested PMV values change between 0.7 and -0.7 (PPD=15 %). This classification allows the selection a priori of one thermal environment according to the required demands.

Fanger and Toftum (2002), for non-air-conditioned buildings in warm climates, present an extension of the PMV model. This extension, that combines the "static" PMV model and the adaptive model, uses the traditional PMV model (Fanger, 1970) and the expected verified in the adaptive model (de Dear et al., 1997).

The PMV index is calculated, by the software, for each space, using the numerical values of the indoor air temperature, indoor air velocity (obtained through the renovation and recycled airflow), indoor air relative humidity and indoor mean radiant temperature (obtained through the mean value of the compartment surrounding surfaces temperatures), for a pre-defined clothing and activity levels. In this calculus the Fanger (1970) model with the Fanger and Toftum (2002) extension are used. The PPD index is correlated with the PMV index using the Fanger (1970) model.

NUMERICAL SIMULATIONS

In these simulations the doors and windows are closed, the indoor curtains are open, the air-conditioning systems were not considered, the occupation is not considered and the indoor radiative heat exchanges are also not considered. The airflow renovation rate values, considered in these numerical simulations, inside each compartment by infiltration, were experimentally obtained, using the tracer gas concentration method. In the school buildings numerical simulations, in order to evaluate the real building's thermal inertia, the previous 5 days are also simulated.

In these simulations, made in this work in Summer conditions, external environmental information about 28th July 2007 are used. In figure 4 the evolution of external air temperature and relative humidity is presented. This day was selected as a typical day of Summer conditions in the Algarve (South Portugal). The considered clothing and the activity level are, respectively, 0.5 Clo. and 1.2 Met.

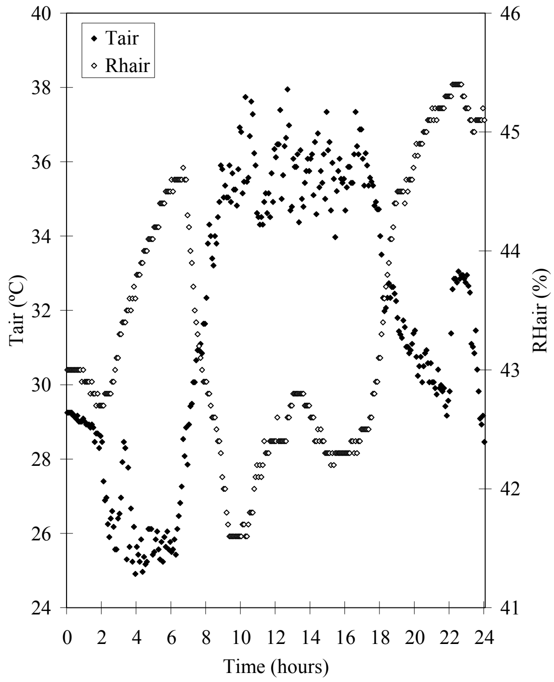

Figure 4 Evolution of external air temperature (Tair) and relative humidity (RHair) used in the numerical model as input.

In these simulations the kindergarten and the surrounding buildings are considered. In accord to Conceição *et al.* (2007) the surrounding buildings should be considered in the numerical simulation, because the shading devices verified are very important in the kindergarten behaviour.

In this study three kinds of numerical simulations were made:

- In the first one the existing kindergarten and the surrounding buildings, without particular shading devices are considered. This simulation, in accord to the previous validation tests, represent the actual kindergarten behaviour status;
- In the second one the kindergarten, the surrounding buildings, the horizontal shading devices placed above the windows level facing South and the external pyramidal opaque trees placed in front to the windows facing West and East are considered;
- In the third one the kindergarten, the surrounding buildings, the horizontal

shading devices placed above the windows level, facing South, and the roof, with four sides, placed above the kindergarten are considered.

RESULTS AND DISCUSSION

In this study, the developed numerical software that simulates the building 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 not only in school buildings with complex topology without surrounding buildings in Winter conditions (Conceição et al., 2004) and Summer conditions (Conceição and Lúcio, 2006), but also in kindergartens, with surrounding buildings presence, in Winter conditions (Conceição et al., 2008b) and Summer conditions (Conceição and Lúcio, 2008a)

From figures 5 to 9 the evolution of the calculated indoor air temperature, respectively, for the compartment 3 (classroom equipped with windows facing South), 10 (playground equipped with windows facing East), 13 (classroom equipped with windows facing North and East), 16 (classroom equipped with windows facing North and West) and 18 (kitchen equipped with windows facing West) is presented. In these figures the obtained results are shown without passive system (1), with horizontal shading devices (placed above the windows level facing South) and pyramidal opaque trees (placed in front to the windows facing East and West) (2) and with horizontal shading devices (placed above the windows levels facing South) and roof (placed above the kindergarten) (3). In all simulations the surrounding buildings are considered.

The evolution of the calculated PMV are presented from figures 10 to 12, respectively, for spaces occupied mainly by children (1), for spaces occupied mainly by teachers and non-teachers staff (2) and for transition spaces (corridors) (3). In these figures the kindergarten, the surrounding buildings, the horizontal shading devices placed above the windows level, facing South, and the roof, with four sides, placed in the top of the kindergarten are considered.

In accordance with the obtained results is possible to conclude that the shading devices placed above the windows level, facing South, reduces more than 0.5 ºC the air temperature inside the associated shaded space. Nevertheless, the pyramidal opaque trees presence, located in front to the windows facing East and West is not very efficient in the air temperature reduction inside the associated shaded space, because in the beginning of the morning and in the end of the afternoon, when the pyramidal opaque trees can shade the windows, the surrounding buildings, placed in East and West, also promote shading effect in the kindergarten.

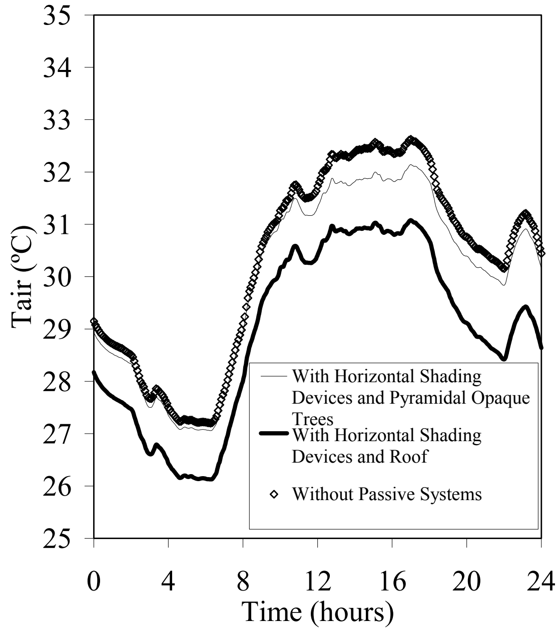

Figure 5 Evolution of air temperature (Tair) calculated in the space number 3 (with windows facing South).

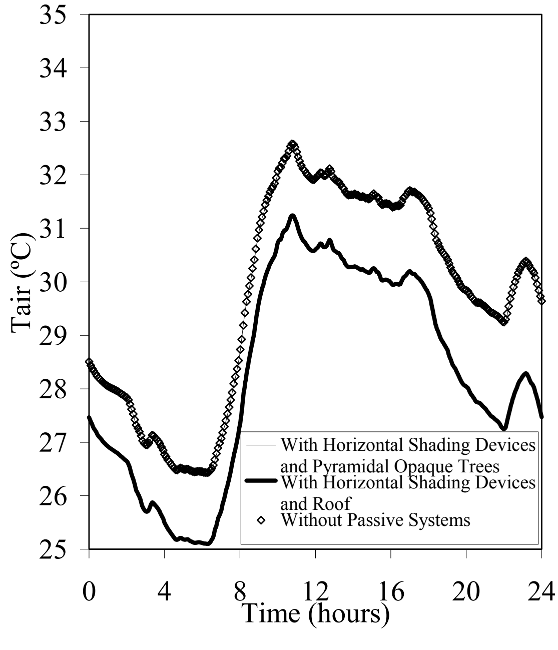

Figure 6 Evolution of air temperature (Tair) calculated, in the space number 10 (with windows facing East).

The introduction of the roof (see figure 3) reduces, in general, more than 1 ºC in all spaces. Nevertheless, in spaces also influenced by horizontal shading devices located above the windows level, facing South, the air temperature reduction is, in general, more than 1.5 ºC.

With passive systems the internal air temperature results, in general, is lower than without passive systems. These results, in transient conditions, that also consider the five previous days, are associated to the considered building thermal mass (namely, indoor and outdoor main building bodies, ceiling coverage of cement and tiles, floor with ground, roof and others bodies) and the low airflow renovation rate.

The internal air temperature, mainly in the playground (number 10) and in the classroom (number 13), present a peak around 11 a.m. These values are associated to the inlet solar radiation through the windows facing East and simultaneously to the external air temperature peak. Nevertheless, due to the external air temperature peak the other internal air temperatures also show a little peak.

In accordance with the previous results is possible to conclude that the thermal comfort level, in accord to Fanger (1970) and Fanger and Toftum (2002), in spaces occupied by children, are acceptable, in accord to the Category C of ISO 7730 (2005), during the afternoon in the playground (when the children are having lunch) and in the North classroom (when the children are in lessons).

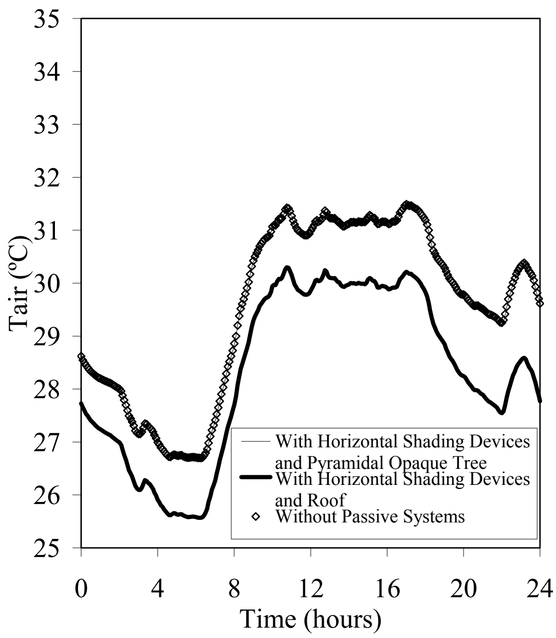

Figure 7 Evolution of air temperature (Tair) calculated in the space number 13 (with windows facing North and East).

In the South classroom, the internal thermal comfort conditions are not acceptable, nevertheless these thermal conditions are near the acceptable conditions in accordance with the category C of ISO 7730 (2005).

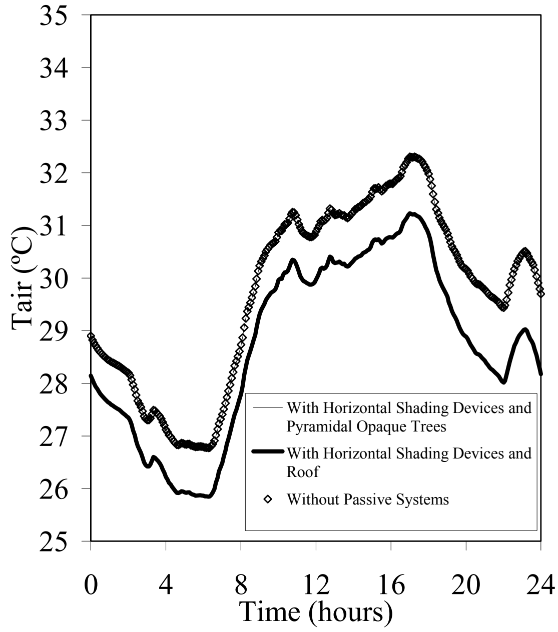

Figure 8 Evolution of air temperature (Tair) calculated in the space number 16 (with windows facing North and West).

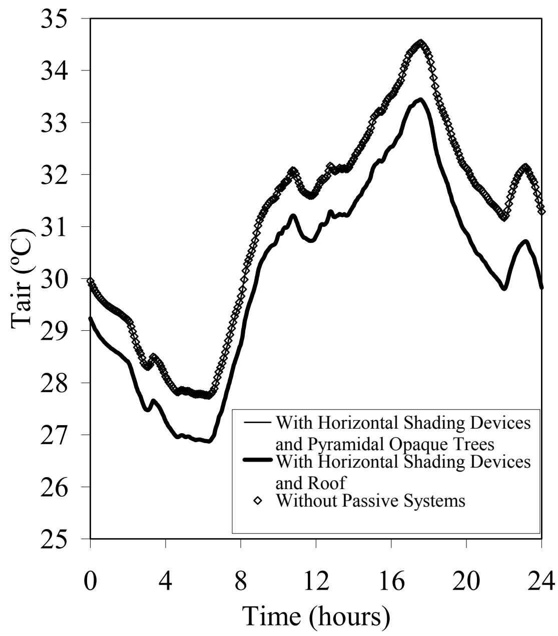

Figure 9 Evolution of air temperature (Tair) calculated in the space number 18 (with windows facing West).

The spaces occupied by the teacher and non-teacher staff, during all day, are generally thermally comfortable and the kitchen in the morning (when is occupied) is also comfortable in accordance with the category C of the ISO 7730 (2005). The office, with window facing West, is thermally uncomfortable mainly in the afternoon.

Finally, the main corridor (number 25), that the occupants use during all day, is also thermally comfortable. Nevertheless the corridor (number 19) is thermally uncomfortable during the main occupation time.

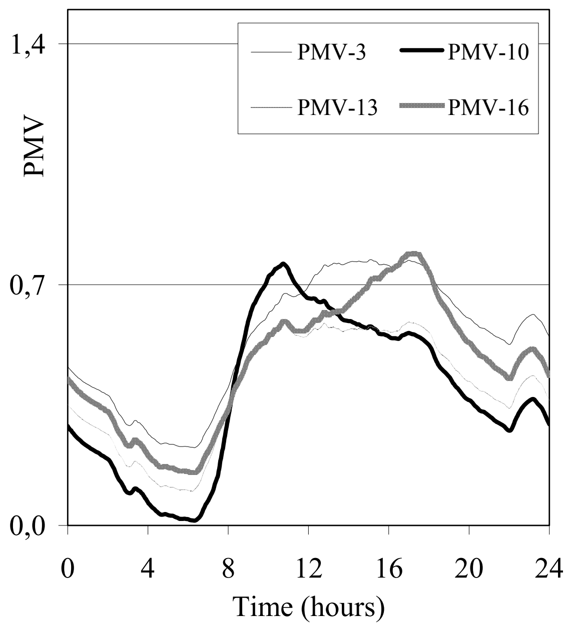

Figure 10 Evolution of PMV calculated inside the spaces (numbers 3, 10, 13 and 16) occupied by children.

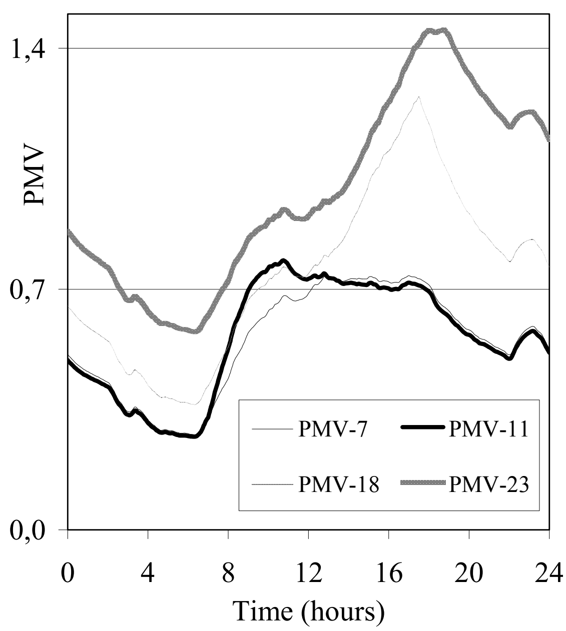

Figure 10 Evolution of PMV calculated inside the spaces occupied mainly by teachers and non-teachers (numbers 7, 11, 18 and 23).

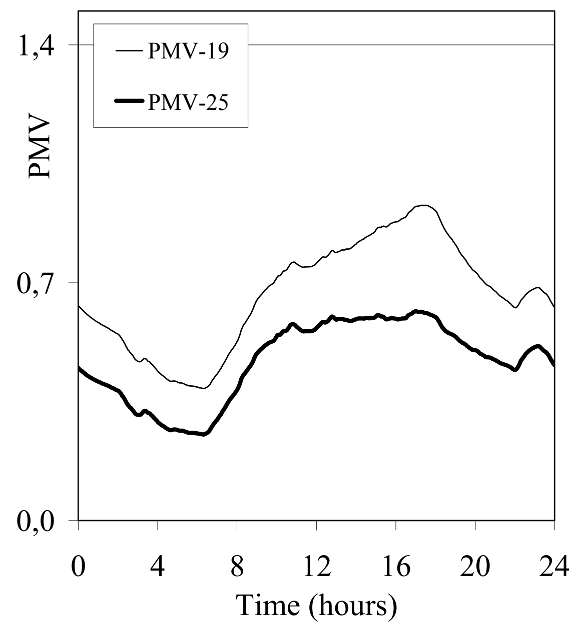

Figure 11 Evolution of PMV calculated inside the transition spaces (numbers 19 and 25) occupied by all occupants.

CONCLUSION

In this study, the numerical software that simulates the building thermal response, with complex topology, in transient conditions, and evaluates the indoor thermal comfort and indoor air quality levels, is used in the energy and thermal comfort evaluation for different passive solutions, in a kindergarten, in Summer conditions.

The introduction of a new roof in the top of the kindergarten, horizontal shading devices placed above the windows level, facing South, and external pyramidal opaque trees placed in front to the windows facing West and East, are numerically analysed. In accord to the obtained results, the new roof and the horizontal shading devices are thermally efficient, nevertheless the external pyramidal opaque trees are not thermally efficient due to the surrounding buildings presence.

When the kindergarten, the surrounding buildings, the horizontal shading devices and the roof are considered the thermal comfort level, in general, is acceptable in accord to the Category C of the ISO 7730 (2005). However, in some spaces, like South classroom, complementary corridor, office room, for example, the comfort level can be improved, for PMV values lower than 0.7. Is suggested, for example, the introduction of forced ventilation.

In the future this numerical model will be used in the implementation of other thermal solutions in the actual kindergarten, in order to improve the occupant's thermal comfort level and the energy savings. This kindergarten geometry will also be analysed in other geographical locations. Special attention will be given in the new local geographical location, in the new external conditions, in the new external surrounding buildings and bodies and in the new kindergarten orientation.

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