Influence of External Environmental Conditions in the occupants thermal comfort level in University Building in the South of Portugal

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Abstract**—**In this work a numerical model is used to simulate the influence of external environmental conditions in the occupant thermal comfort, in transient conditions, of an university building in the south of Portugal. The study, developed with and without occupation, is made in summer and winter conditions.

The experimental external environmental conditions are the air temperature, air relative humidity, air velocity and wind direction. The solar radiation, considered in this study, that each building main bodies and windows glasses bodies are subjected to, is calculated numerically.

The building surfaces temperature, namely the building main bodies and the windows glasses bodies, and the indoor environmental conditions are calculated. The occupants thermal comfort level are evaluated in accordance with the internal air mean temperature, air mean relative humidity, air mean velocity and mean radiant temperature, for a clothing and activity level.

In the numerical simulation of the university building the 344 compartments, the 2904 building main bodies and the 404 windows glasses are considered. In the natural internal ventilation one renovation, made by infiltrations, is considered.

Keywords**—** University building, Numerical simulation, Building thermal behavior, External environmental conditions, Indoor air temperature, Human thermal comfort.

I. Introduction

In the Algarve region, in the South of Portugal, it is very important to develop university buildings, adapted to this region, that can promotes 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. In summer conditions renewable resources, like the introduction of shadings devices located in between the solar trajectory and the window glass surface, are used. The energy management in both situations, in order to obtain a better thermal comfort levels inside the building environment, is frequently analyzed using building thermal behavior numerical models.

In moderate environments, in cold (during winter conditions) or in warm (during summer conditions) climates, the PMV (Predicted Mean Vote) and the PPD (Predicted Percentage of Dissatisfied) indexes are used (see [1] and [2]). For acceptable thermal comfort conditions, the [2] defines three comfort categories (A, B and C), establishing limits for PMV and PPD indexes: for the category C, used in this study, the PMV change between -0,7 and 0.7 and PPD is less than 15%.

An application of an indoor greenhouse in the energy and thermal comfort performance in a kindergarten school building in the south of Portugal in winter conditions is presented in [3]. The life quality, the energy management and the human health has been also an important issue analyzed in the last years. The increases of quality of life in the modern city, for example in [4], the energy consumption and exhaust emissions reduction, for example in [5] and [6], and the atmosphere air quality, for example in [7], are some practical examples of this issue. In the last issue, related to the human health, special interest are being shown in the development of efficient buildings, which proportionate highest comfort levels, with low energy consumption level.

The need to increase the buildings energy efficiency and at the same time providing good indoor air quality has become an important factor in the building sector. To successfully manage indoor air quality and low energy consumption it is necessary have the best, as possible, knowledge of building behavior (before and after is built). In [8], a study of indoor climate and energy consumption in residential buildings is made where it is concluded that indoor climate of residential buildings is greatly affected by the arrangement of air change which in its turn is influenced by country external climate. In [9] the same authors extended their study to educational buildings and introduced also the influence of the new domestic water on the building heating. It is showed that problem of indoor climate seriously concerns educational buildings. It is presented some results of carbon dioxide concentration and indoor temperature in classroom with natural ventilation and with balanced ventilation that is carried in several classrooms of different schools.

II. Numerical Model

The multi-nodal buildings thermal behavior model, which operates in transient conditions, is based in energy and mass balance integral equations (see [10], [11] and [12]). The energy balance integral equations are developed for (see equation (1) as example):

- 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.

$$mCp\frac{dT}{dt}=\sum_i \dot{Q}_i \qquad (1)$$

The main symbols m, Cp, T, t and $\dot{Q}_i$ are associated to the mass, specific heat to the constant pressure, temperature, time and heat flux. The equation left member is associated to the accumulated sensible heat, while in the equation right member the terms represent, respectively, the heat flux due to the conduction, convection, radiation, evaporations and others.

The mass balance integral equations are developed for (see equation (2) as example):

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

$$\frac{dm}{dt}=\sum_i \dot{m}_i \qquad (2)$$

The main symbol m, t and $\dot{m}_i$ are associated to the mass, time and mass flux. The equation left member is associated to the accumulated mass, while in the equation right member the terms represent, respectively, the mass flux due to the convection, diffusion and others.

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.

The input data in the software are:

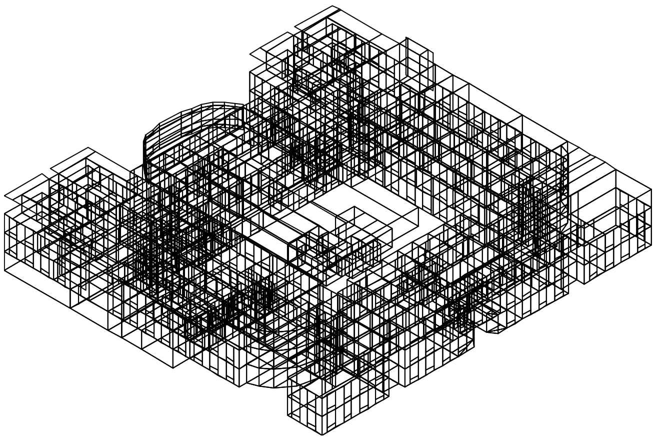
- the buildings geometry (introduced in a three-dimensional design software);
- the boundary conditions;
- the materials thermal proprieties and other conditions (like the outdoor environmental and geographical conditions, the initial conditions, the several heat and mass load, the occupation cycle,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

III. Building Simplified Geometry

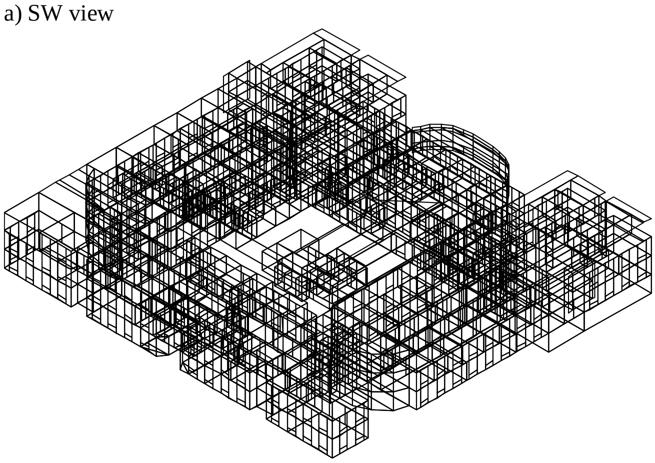
In figure 1 the university building scheme is presented.

In the analyzed university building, 344 compartments, 2904 building main bodies and 404 windows glasses are considered.

The numerical grid, used in the internal and external direct solar radiation determination, was spaced 30 cm in both directions for the opaque surfaces and spaced 5 cm in both directions for the transparent surfaces.

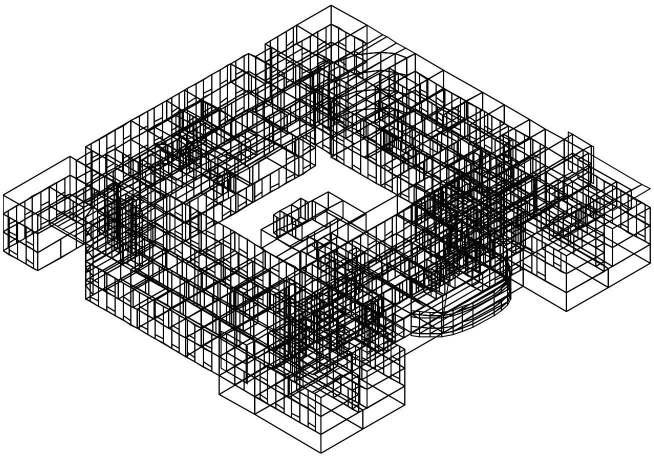


a) SW view

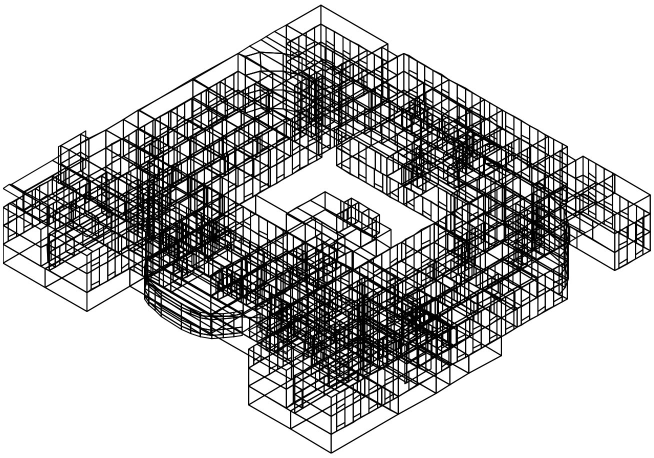


b) SE view

Fig.1 – University building scheme. a) SW view, b) SE view, c) NW view and d) NE view.



c) NW view



d) NE view

Fig.1 – University building scheme. a) SW view, b) SE view, c) NW view and d) NE view.

IV. NUMERICAL VALIDATION

In this study the software that simulates the buildings thermal response, with complex topology, in transient conditions, is used. This software was validated in winter [11] and summer [12] conditions, in school buildings with complex topology.

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.

V. INPUT DATA

In the numerical simulation, as input data, the external meteorological data (namely the air temperature, air relative humidity, air velocity and wind direction), occupation cycle and the air ventilation are considered.

The measured external conditions, namely, air temperature, air relative humidity, air velocity and wind direction, used in the numerical simulation, are obtained from a weather station installed in the study university building. The measured external conditions are obtained for a typical summer day, 21st June 2011, and for a typical winter day, 21st December 2011. In figures 2 and 3 the measured external conditions for a typical summer day are presented, while in figures 4 and 5 the measured external conditions for a typical winter day are presented.

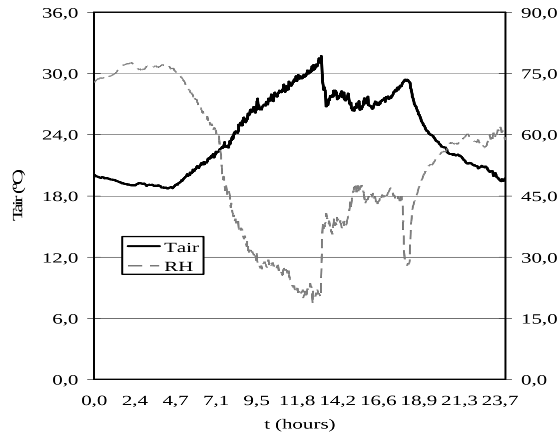


Fig.2 – Measured outdoor air temperature (Tair) and air relative humidity (RH) for a typical summer day.

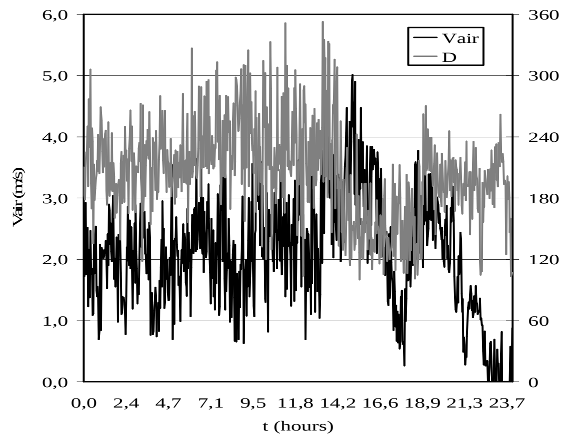


Fig.3 – Measured outdoor air velocity (Vair) and wind direction (D) for a typical summer day.

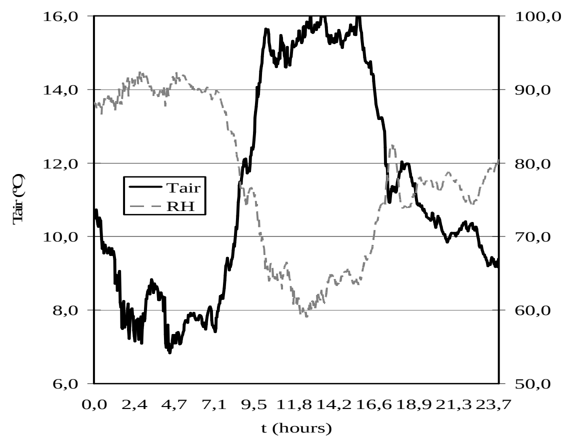


Fig.4 – Measured outdoor air temperature (Tair) and air relative humidity (RH) for a typical winter day.

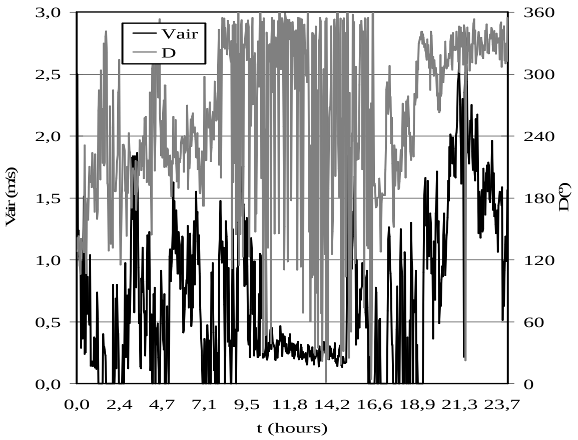


Fig.5 – Measured outdoor air velocity (Vair) and wind direction (D) for a typical winter day.

In table I and II the occupation cycle, respectively, for the laboratories and office, is presented.

In the air ventilation one air renovation rate is considered in all compartments.

Table I – Occupation cycle used in the laboratories.

Time (hours)	0 to 8:30	8:30 to 10	10 to 10:15	10:15 to 11:45	11:45 to 12	12 to 13:30	13:30 to 13:45	13:45 to 15:15	15:15 to 15:30	15:30 to 17	17 to 17:15	17:15 to 18:45	18:45 to 19	19 to 20:30	20:30 to 24
Spaces															
56	0	8	0	8	0	8	0	8	0	8	0	8	0	8	0
68	0	10	0	10	0	10	0	10	0	10	0	10	0	10	0
96	0	8	0	8	0	8	0	8	0	8	0	8	0	8	0
107	0	8	0	8	0	8	0	8	0	8	0	8	0	8	0

Table II – Occupation cycle used in the office.

Time (hours)	0 to 8:30	8:30 to 10	10 to 10:15	10:15 to 11:45	11:45 to 12	12 to 13:30	13:30 to 13:45	13:45 to 15:15	15:15 to 15:30	15:30 to 17	17 to 17:15	17:15 to 18:45	18:45 to 19	19 to 20:30	20:30 to 24
Spaces															
151	0	2	2	2	2	2	2	2	2	2	2	2	2	2	0
178	0	2	2	2	2	2	2	2	2	2	2	2	2	2	0
183	0	2	2	2	2	2	2	2	2	2	2	2	2	2	0
229	0	2	2	2	2	2	2	2	2	2	2	2	2	2	0

VI. Results

In this work a numerical model, which simulates the building thermal response and evaluates the indoor environment comfort, in transient conditions, is used in the study of the influence of external environmental conditions in the occupant thermal comfort of a university building in the south of Portugal.

The study, developed with and without occupation, is made in summer and winter conditions. In both situations the thermal comfort level, using the Predicted Mean Vote (PMV), is presented for several selected spaces.

In the university building numerical simulation, in order to evaluate the real building thermal inertia, the previous 5 days were also simulated.

As example, the results are referred to compartments turned to north (96 and 178), south (107 and 183), east (68 and 151) and west (56 and 229) directions, which areas are presented in table III. All compartments, used as example, are associated with the first floor.

Table III – Compartments' area used, as example, in this study.

Space	56	68	96	107	151	178	183	229
Area (m^2)	92,3	131,7	85,1	176,4	40,9	21,3	24,7	37,0

PMV index without Occupation

From figure 6 to figure 9 is showed the numerical PMV index, calculated in summer conditions, in compartments turned to north, south, east and west directions.

From figure 10 to figure 13 is showed the numerical PMV index, calculated in winter conditions, in compartments turned to north, south, east and west directions.

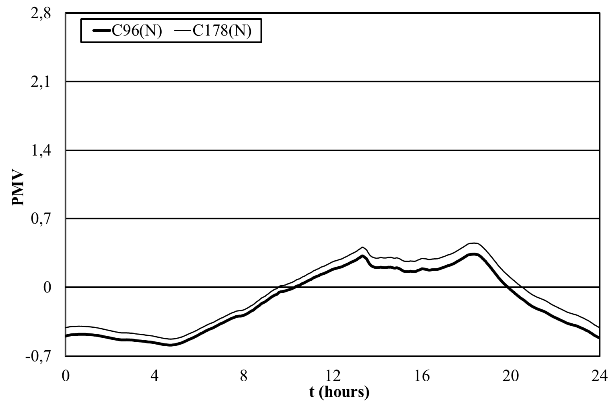


Fig.6 – Numerical PMV index obtained in two compartments turned to north, for a typical summer day.

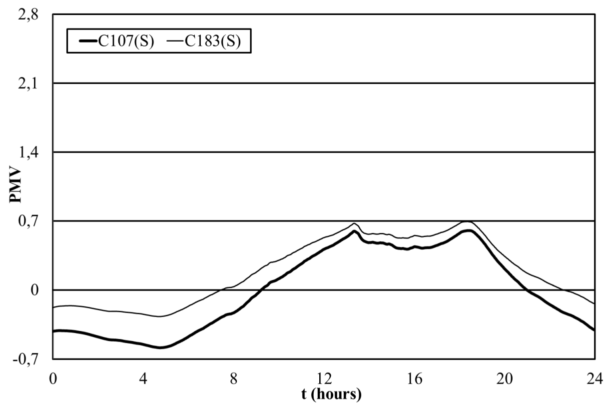


Fig.7 – Numerical PMV index obtained in two compartments turned to south, for a typical summer day.

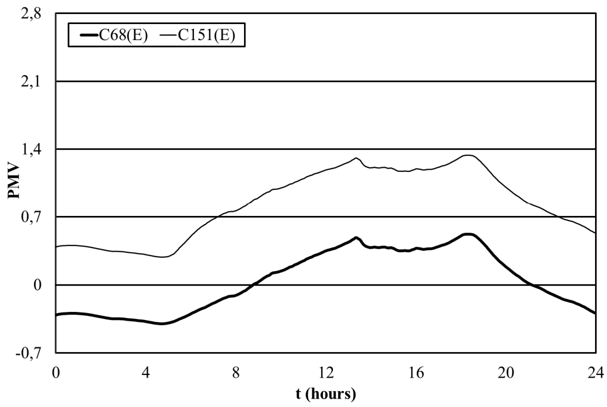


Fig.8 – Numerical PMV index obtained in two compartments turned to east, for a typical summer day.

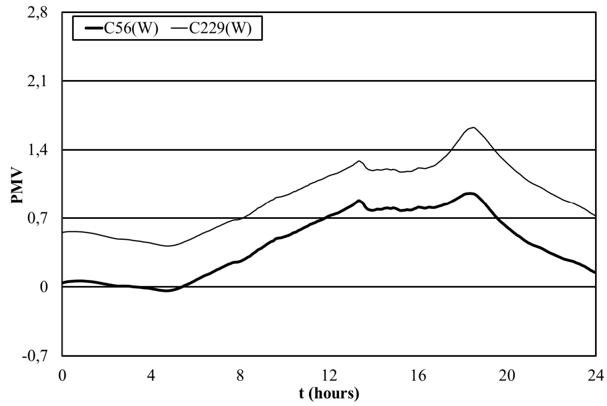


Fig.9 – Numerical PMV index obtained in two compartments turned to west, for a typical summer day.

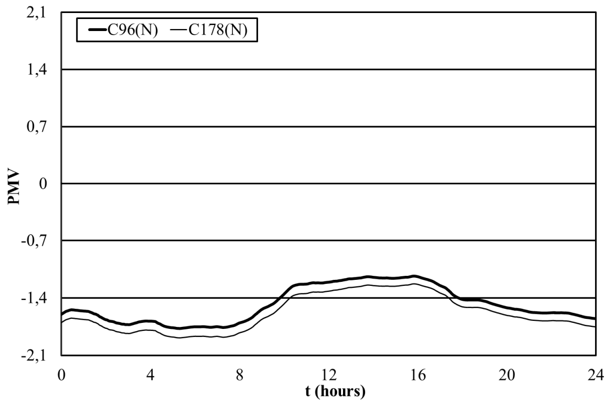


Fig.10 – Numerical PMV index obtained in two compartments turned to north, for a typical winter day.

In accordance with the obtained results, in summer conditions, without occupation, is possible to conclude that:

- in general, the compartments turned to north and south directions are comfortable with positive PMV values;
- the laboratories compartments' turned to east direction are comfortable with positive PMV values;
- the offices compartments' turned to east direction are uncomfortable;
- the compartments turned to west direction are also uncomfortable.

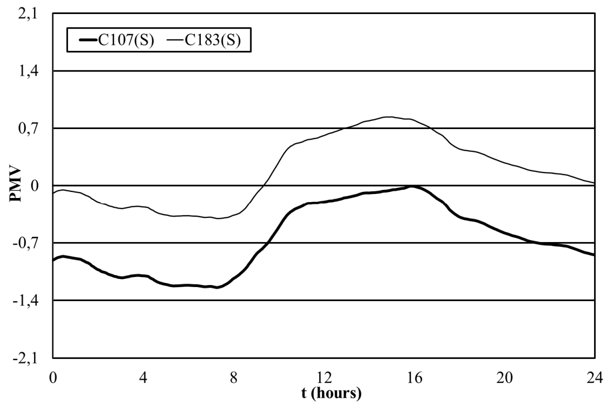


Fig.11 – Numerical PMV index obtained in two compartments turned to south, for a typical winter day.

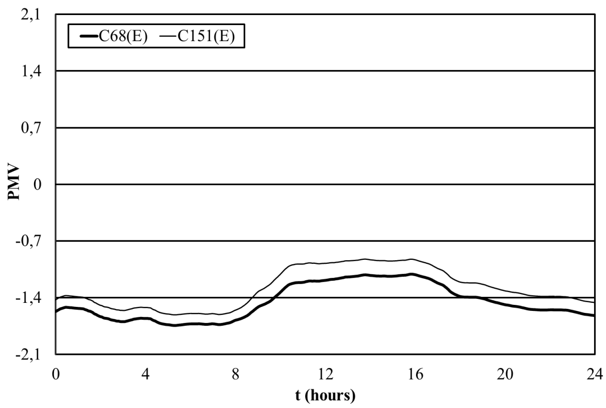


Fig.12 – Numerical PMV index obtained in two compartments turned to east, for a typical winter day.

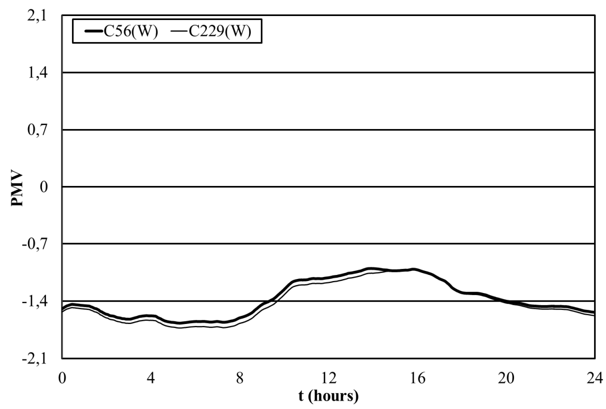


Fig.13 – Numerical PMV index obtained in two compartments turned to west, for a typical winter day.

In winter conditions, in accordance with the obtained results, without occupation, is possible to conclude that:

- in general, the laboratories compartments' turned to south direction are comfortable with negative PMV values;

- the office compartments' turned to south direction are comfortable with positive PMV values;
- however, in general, the compartments turned to west, east and north directions are uncomfortable.

PMV index with Occupation

From figure 14 to figure 17 is showed the numerical PMV index, calculated in summer conditions, in compartments turned to north, south, east and west directions.

From figure 18 to figure 21 is showed the numerical PMV index, calculated in winter conditions, in compartments turned to north, south, east and west directions.

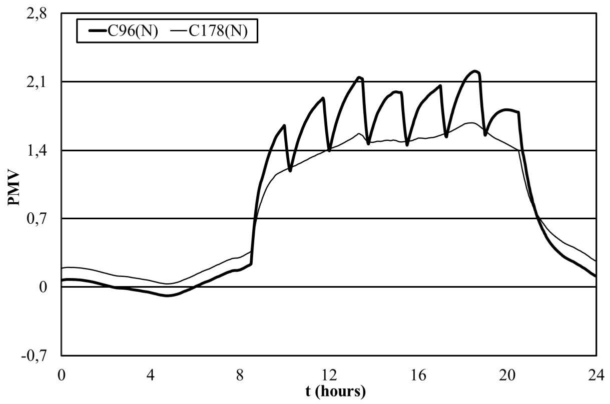


Fig.14 – Numerical PMV index obtained in two compartments turned to north, for a typical summer day.

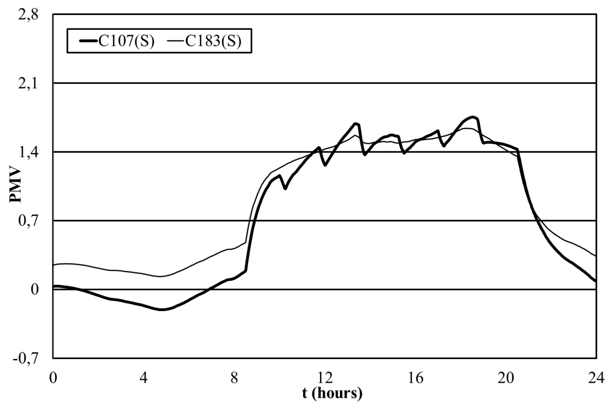


Fig.15 – Numerical PMV index obtained in two compartments turned to south, for a typical summer day.

In accordance with the obtained results, in summer conditions, with occupation, is possible to conclude that:

- in general, all compartments are uncomfortable;
- the compartments turned to east and west direction are more uncomfortable than the compartments turned to north and south direction.

In winter conditions, in accordance with the obtained results, with occupation, is possible to conclude that:

- in general, the compartments turned to north direction are comfortable with negative PMV values;
- the compartments turned to west and east directions are comfortable by negative PMV values (offices) and comfortable by optimal PMV values (laboratories);
- the laboratories compartments turned to south direction, in general, are comfortable by positive PMV values,
- the office compartments' turned to south direction are uncomfortable.

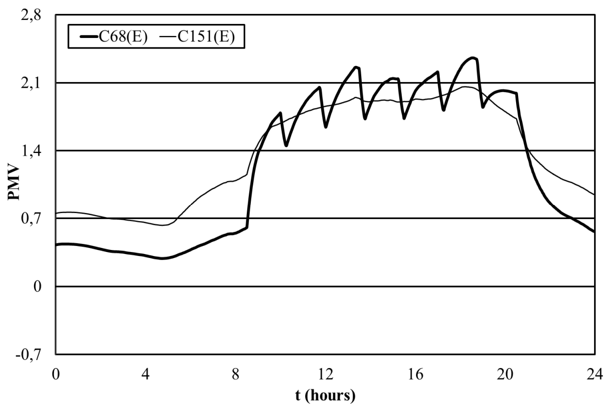


Fig.16 – Numerical PMV index obtained in two compartments turned to east, for a typical summer day.

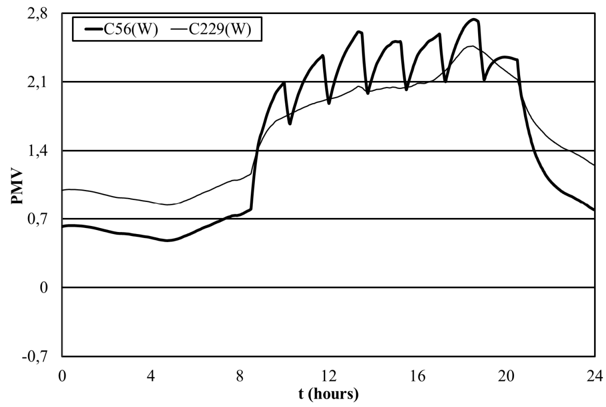


Fig.17 – Numerical PMV index obtained in two compartments turned to west, for a typical summer day.

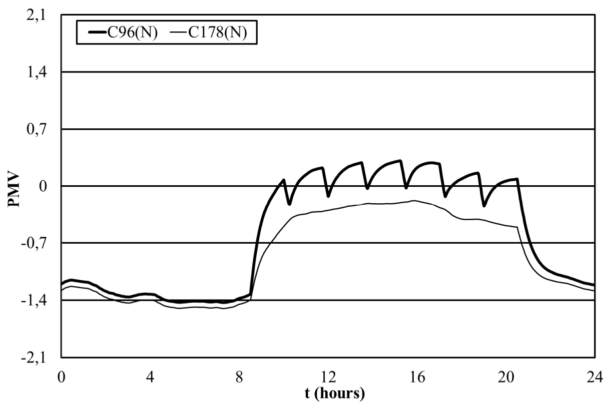


Fig.18 – Numerical PMV index obtained in two compartments turned to north, for a typical winter day.

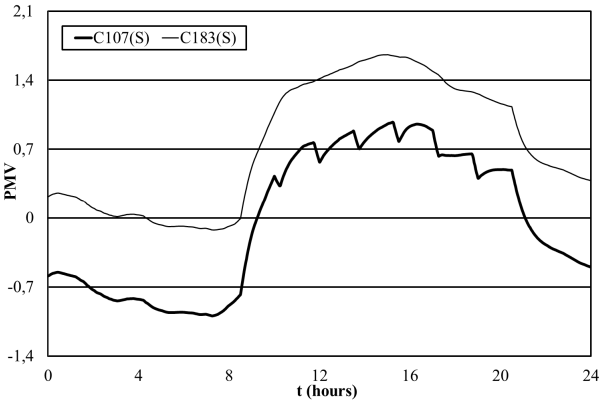


Fig.19 – Numerical PMV index obtained in two compartments turned to south, for a typical winter day.

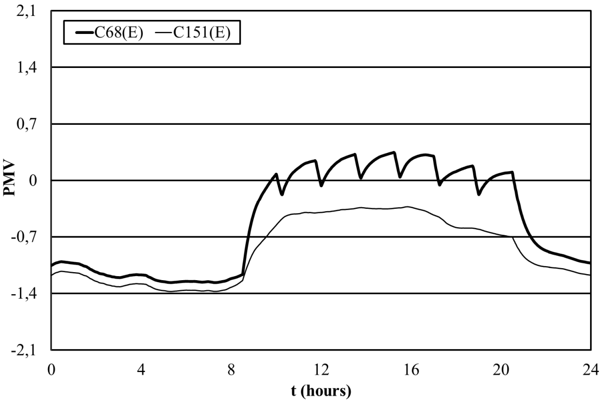


Fig.20 – Numerical PMV index obtained in two compartments turned to east, for a typical winter day.

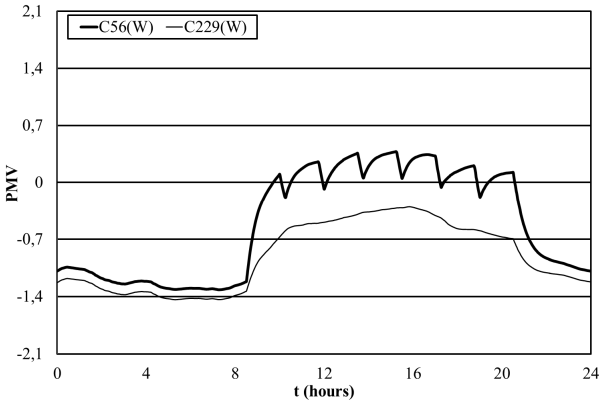


Fig.21 – Numerical PMV index obtained in two compartments turned to west, for a typical winter day.

PPD index results without Occupation

From figure 22 to figure 25 is showed the PPD index, numerically obtained in summer conditions, in compartments turned to north, south, east and west directions.

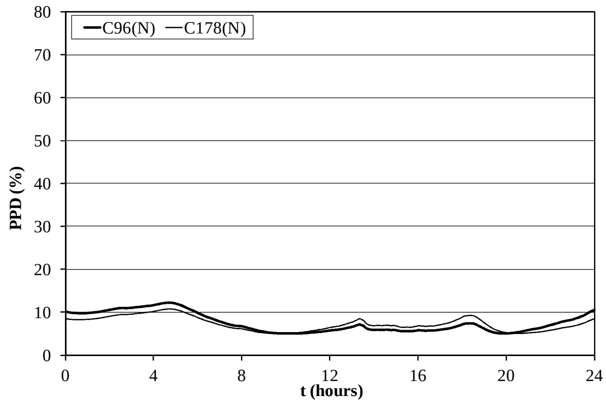


Fig.22 – PPD index numerically obtained in two compartments turned to north, for a typical summer day.

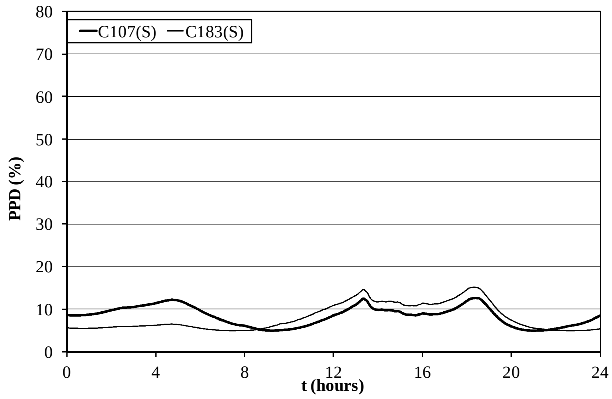


Fig.23 – PPD index numerically obtained in two compartments turned to south, for a typical summer day.

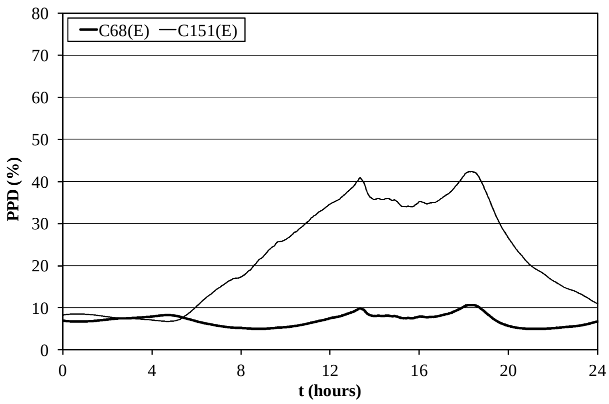


Fig.24 – PPD index numerically obtained in two compartments turned to east, for a typical summer day.

From figure 26 to figure 29 is showed the PPD index, numerically obtained in winter conditions, in compartments turned to north, south, east and west directions.

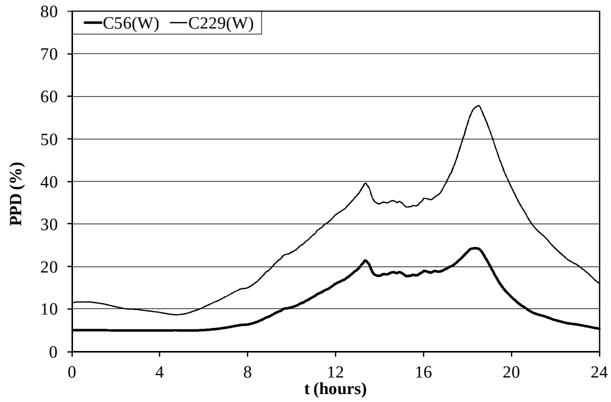


Fig.25 – PPD index numerically obtained in two compartments turned to west, for a typical summer day.

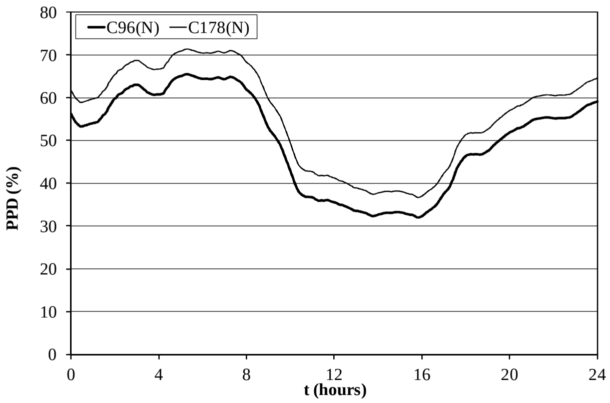


Fig.26 – PPD index numerically obtained in two compartments turned to north, for a typical winter day.

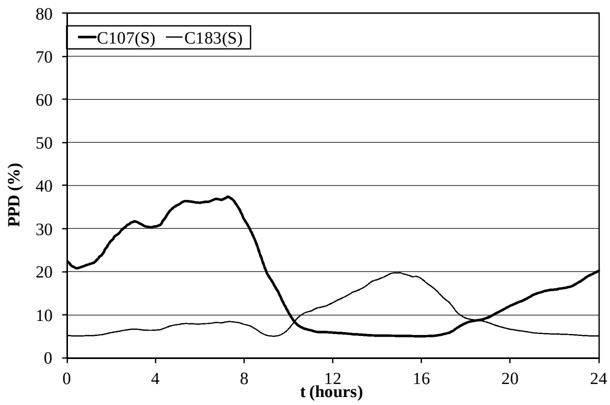


Fig.27 – PPD index numerically obtained in two compartments turned to south, for a typical winter day.

In accordance with the obtained results, in summer conditions, without occupation, is possible to conclude that:

- in general, the PPD index along the day is highest in the compartments facing west;
- the PPD index along the day is lowest in the compartments facing north.

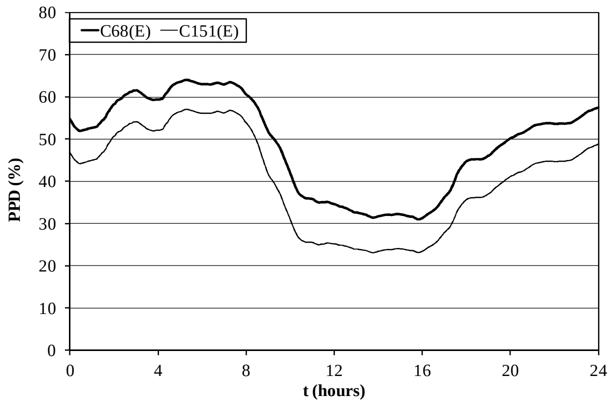


Fig.28 – PPD index numerically obtained in two compartments turned to east, for a typical winter day.

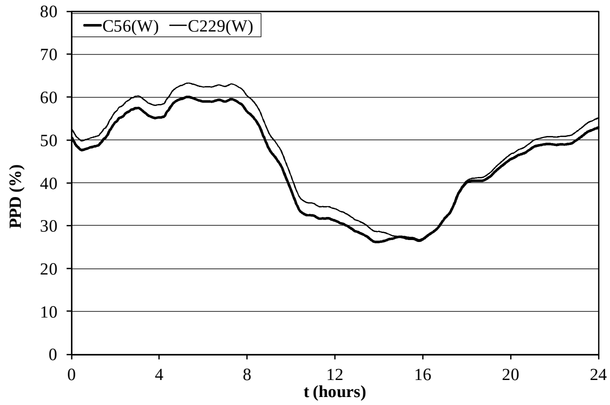


Fig.29 – PPD index numerically obtained in two compartments turned to west, for a typical winter day.

In winter conditions, in accordance with the obtained results, without occupation, is possible to conclude that:

- in general, the PPD index along the day, as expected, is highest in the compartments facing north;
- the difference along the day between PPD index of compartments facing east and PPD index of compartments facing west is slight.

PPD index results with Occupation

From figure 30 to figure 33 is showed the PPD index, numerically obtained in summer conditions, in compartments turned to north, south, east and west directions.

From figure 34 to figure 37 is showed the PPD index, numerically obtained in winter conditions, in compartments turned to north, south, east and west directions.

In accordance with the obtained results, in summer conditions, with occupation, is possible to conclude that:

- in general, the PPD index along the day is highest in the compartments facing west and east;
- the PPD index along the day is lowest in the compartments facing north and south.

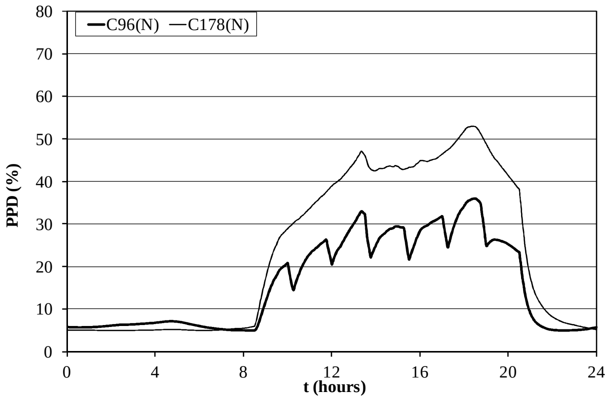


Fig.30 – PPD index numerically obtained in two compartments turned to north, for a typical summer day.

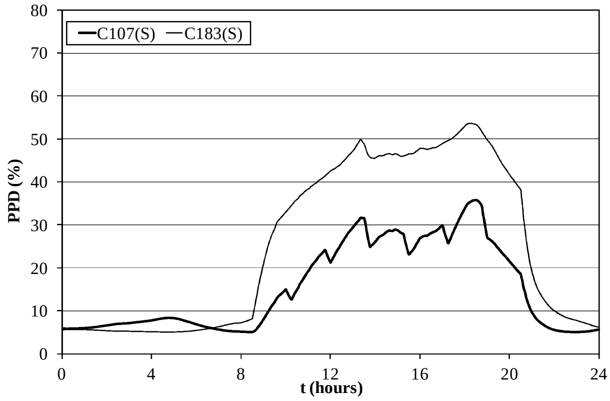


Fig.31 – PPD index numerically obtained in two compartments turned to south, for a typical summer day.

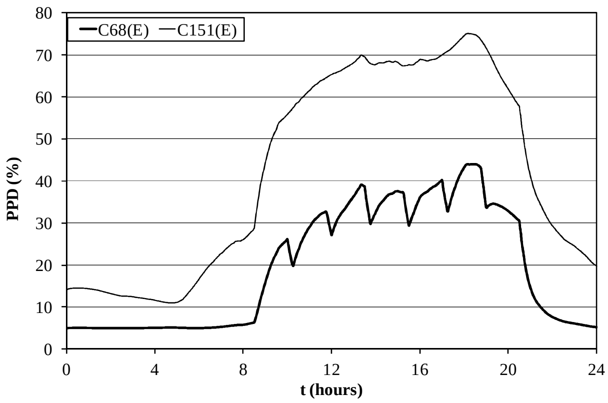


Fig.32 – PPD index numerically obtained in two compartments turned to east, for a typical summer day.

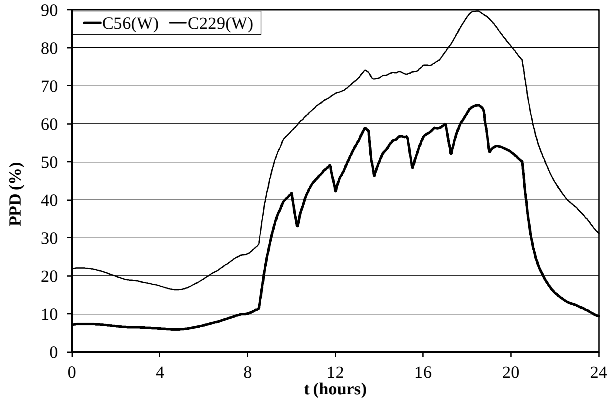


Fig.33 – PPD index numerically obtained in two compartments turned to west, for a typical summer day.

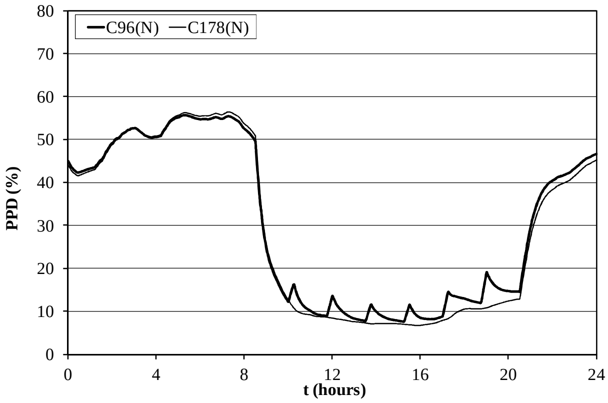


Fig.34 – PPD index numerically obtained in two compartments turned to north, for a typical winter day.

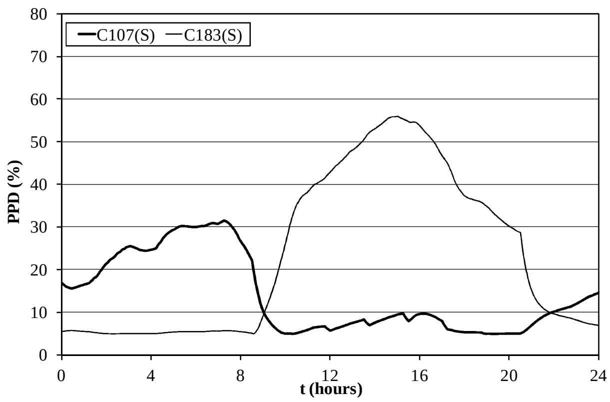


Fig.35 – PPD index numerically obtained in two compartments turned to south, for a typical winter day.

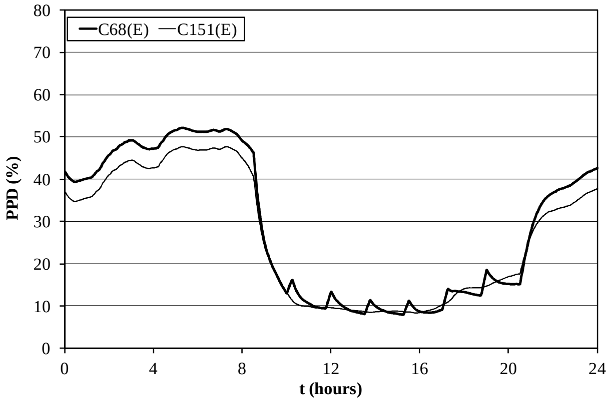


Fig.36 – PPD index numerically obtained in two compartments turned to east, for a typical winter day.

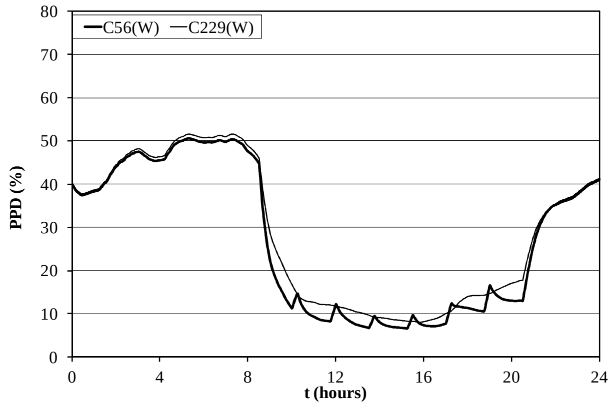


Fig.37 – PPD index numerically obtained in two compartments turned to west, for a typical winter day.

In winter conditions, in accordance with the obtained results, with occupation, is possible to conclude that:

- the PPD index along the day is highest in the compartments facing south;
- the difference along the day between PPD index of compartments facing east and PPD index of compartments facing west is slight.

VII. Conclusions

In this work a numerical model used to simulate the influence of external environmental conditions in the human thermal comfort level, in transient conditions, in summer and winter conditions is applied. The study is made in a University building located in a south of Portugal. The input external environmental conditions are the air temperature, air relative humidity, air velocity and wind direction. The solar radiation field and the indoor environmental conditions are calculated.

In accordance with the obtained results is possible to conclude that, in summer conditions, in general, the compartments without occupation are comfortable. However, the compartments with occupation are uncomfortable. In order to improve the thermal comfort conditions, that the occupants are subjected to, the implementation of an air renovation forced system or an air conditioning system is suggested.

In winter conditions, in general, the compartments without occupation are uncomfortable, by negative PMV values. However, with occupation, the thermal comfort conditions are obtained.

Acknowledgment

The authors grateful the collaboration of the Environmental Engineering Degree students, of the University of Algarve, in the building implementation.

References

[1] P. O. Fanger, “Thermal comfort”, Danish Technical Press, 1970.
[2] ISO 7730. “Ergonomics of the thermal environments – Analytical Determination and Interpretation of Thermal Comfort using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria”. International Standard. Switzerland. 2005.
[3] E. Z. E. Conceição, Mª M. J. R. Lúcio and M. C. Lopes, “Application of an indoor greenhouse in the energy and thermal comfort performance in a kindergarten school building in the south of portugal in winter conditions", WSEAS Transactions on Environment and Development, Issue 8, vol. 4, August 2008, pp. 644-654.
[4] L. Loures, L. Santos and T. Panagopoulos, “Urban parks and sustainable city planning - the case of Portimão”, Portugal, WSEAS Transactions on Environment and Development, Issue 10, vol. 3, October 2007, pp. 171-180.
[5] H. E. Yong-xiu, L. I. De-zhi and L. I Yan, “Research on the cointegration relationship of energy consumption and economy growth in Beijing”, WSEAS Transactions on Environment and Development, Issue 9, vol. 3, September 2007, pp. 165-170.
[6] Z. Ye, Z. Li and H. Mohamadian, “Engine performance improvement on fuel economy and exhaust emissions using lean burn control technologies”, WSEAS Transactions on Environment and Development, Issue 4, vol. 3, April 2007, pp. 65-71.
[7] C. Vongmahadlek and B. Satayopas, “Applicability of RAMS for a simulation to provide inputs to an air quality model: modeling evaluation and sensitivity test”, WSEAS Transactions On Environment And Development, Issue 8, vol. 3, August 2007, pp. 129-138.
[8] T-A. Koiv, H. Voll, A. Mikola, K. Kuusk and M. Maivel, “Indoor climate and energy consumption in residential buildings in estonian climatic conditions”, WSEAS Transactions on Environment and Development, vol. 6, pp. 235-244, 2010.
[9] T-A. Koiv, K. Kuusk, M. Maivel and A. Mikola, “Energy efficiency and indoor climate of apartment and educational buildings in Estonia”, WSEAS Transactions on Environment and Development, vol. 6, pp. 804-814, 2010.
[10] E. Z. E. Conceição, “Numerical simulation of buildings thermal behaviour and human thermal comfort multi-node models”, In Proceedings of the 8th International IBPSA Conference - Building Simulation 2003. Eindhoven, vol. 1, pp. 227-234.
[11] E. Z. E. Conceição, A. Silva and M. M. J. R. Lúcio, “Numerical study of thermal response of school buildings in winter conditions”, In Proceedings of the 9th Conference on Air Distribution in Rooms - Roomvent 2004, Coimbra.
[12] E. Z. E. Conceição and M. M. J. R. Lúcio, “Numerical study of thermal response of school buildings in summer conditions”, In Proceedings of the Healthy Buildings, 2006, Lisbon, vol. 3, pp. 195-200.