Indoor comfort and air quality in spaces equipped with eco-ventilation systems

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Abstract

In this numerical work the developing of a heating, ventilation and air conditioning system (HVAC), more environmentally friendly and healthy, for seniors, is made. This HVAC system is based on vertical jets located between the compartments walls surfaces. This system allows creating a comfortable environment with high levels of thermal comfort, high levels of air quality, low levels of Draught Risks and low levels of energy consumption. The vertical jets, with inlet temperature equal to external air environment, promote a renewal of the air in the space.

The coupling multi-nodal human thermal comfort integral numerical model and the computational fluid dynamics differential numerical model are used in this work. The environmental variables, calculated around the occupants by the computational fluid dynamics, are used as input data in the multi-nodal human thermal comfort numerical model. The human body temperature and clothing surfaces temperature, surrounding temperatures and the inlet airflow conditions, are used as boundary conditions in the computational fluid dynamics numerical model.

1. Introduction

The study of the quality of life of a senior occupies an important place in our society due to the demographic changes in developed countries. Over the years has been and it will continue to be an increase in the population with more than 60 years. Consequently, the number of adapted homes and nursing homes increased in the last years.

Some studies say that the elderly population spends 19 to 20 h/day in closed environments and, considering their weak immune systems, their breathing problems and chronic diseases, this population can become more vulnerable to health complications associated, mainly, to the concentration of pollutants of the indoor air that can be 10 to 20 times higher than outdoors.

The exposure to high concentrations of pollutants may influence the frequency of visits to doctors and the use of medication or, in more extreme cases, admissions in hospitals and premature deaths.

Beyond the importance of air quality, in closed spaces, in the health of seniors, the thermal environment is, also, a key factor that influences thermal comfort, the health and the well-being of people.

Now, and given the importance of thermal comfort of individuals in closed spaces, rises the need to project HVAC systems with high levels of comfort and with low energy consumption (Conceição *et al*., 2014).

Relatively to the determination of thermal comfort level of the occupants, it’s made through PMV (*Predicted Mean Vote*) and PPD (*Predicted Percentage of Dissatisfied people*) indexes. PMV index corresponds to a Predicted Mean Vote of a panel of evaluators, about conditions of comfort of a given moderate thermal environment. The PPD index shows the Predicted Percentage of Dissatisfied people face to the same thermal environment (see Fanger, 1970; ISO 7730, 2005; ANSI/ASHRAE, 2004).

These indexes are determined through an integral numerical model which simulates the human thermal response and are affected by environmental parameters: air temperature, air velocity, air relative humidity and mean radiant temperature around all sections of the human body, and the personal parameters (clothing level and physical activity). The application of this model can be found at Conceição et al. (2006), Conceição et al. (2010a) and Conceição et al. (2010b).

Relatively to the local thermal discomfort, this is measured by DR (Draught Risk) index. This index was developed by Fanger et al. (1988) and it depends on air temperature, air velocity and air turbulence intensity. This index was applied in works as Fanger and Christensen (1986) and Melikov et al. (1990).

To evaluate the air quality, the differential numerical model that simulates internal flows with heat and mass transfer in turbulent regime is used, and it will consider the concentration of carbon dioxide released from occupants. The acceptable values of this concentration, in a closed space, can be consulted in ANSI/ASHRAE Standard 62.1, (2004) and, also, in Decreto-Lei nº 79/2006 de 4 de Abril (Portuguese Regulations).

Applications of this indicator to evaluate indoor air quality can be seen in Papakonstantinou *et al*. (2002), Nagy and Senitkova (2007), Bulinska (2007) and Levine (1993).

2. Numerical models

The coupling multi-nodal human thermal comfort integral numerical model and the computational fluid dynamics differential numerical model are used in this work. The multi-nodal human thermal comfort integral numerical model is used to evaluate not only the human body temperature, the clothing temperature and the water vapor fields, but also the thermal comfort level. The computational fluid dynamics differential numerical model is used to evaluate not only the airflow around the occupants (air temperature, air velocity, air turbulence intensity and Draught Risk), but also the air quality level (using the carbon dioxide concentration).

The environmental variables, calculated around the occupants by the computational fluid dynamics, are used as input data in the multi-nodal human thermal comfort numerical model. The human body temperature and clothing surfaces temperature, surrounding temperatures (room surfaces and desk surface) and the inlet airflow conditions (air velocity, air temperature and air turbulence intensity), are used as input data in the computational fluid dynamics numerical model.

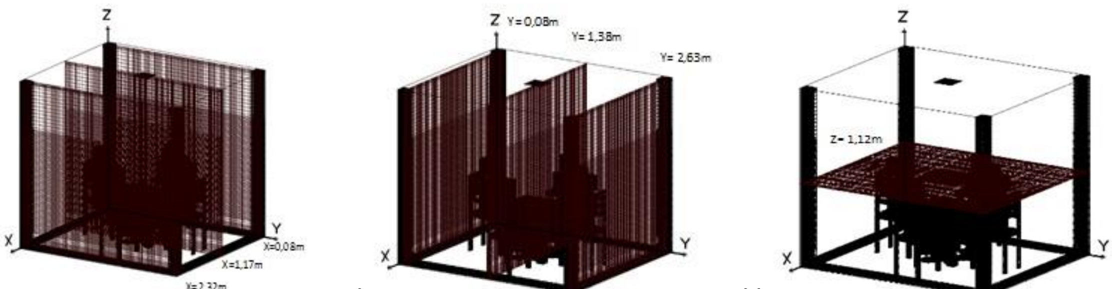
3. Numerical methodology

In this numerical work the developing of a heating, ventilating and air conditioning system (HVAC), more environmentally friendly and healthy, for seniors in winter, spring/autumn and summer season's situation, is made. The virtual space includes a central virtual desk, four virtual occupants, four virtual chairs, four virtual vertical ducts, located between walls in the compartment corners, and a virtual exhaust, located in the ceiling central area. The definition of parameters used in simulations is show in table 1.

Table 1- Definition of parameters used in simulations.

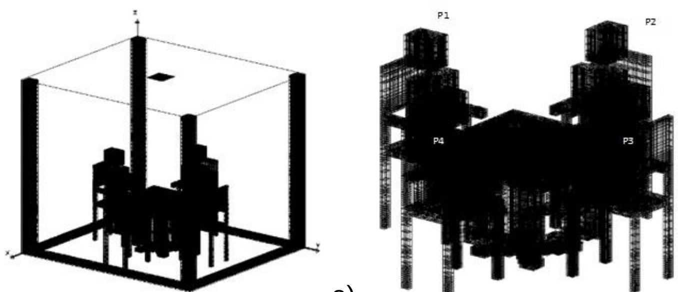
	Inlet Air Temperature (outlet conditions)(ºC)	**Inlet Air Velocity (m/s)**
Winter Situation	8	2 and 3
Spring and Autumn Situation	18	2 and 3
Summer situation	28	2 and 3

In the numerical simulations the differential (internal flow with heat and mass transfer in turbulent regime) and integral (human thermal response) numerical models are used. In the differential model a non-uniform mesh with 155 × 164 × 146 is shown in the figures 1 and 2, while the integral numerical model considers the virtual occupants with 1,70 meters tall, 70 kg of weight and 1 clo for winter situation, 0,8 clo for spring and 0,3 clo for summer (figure 3).



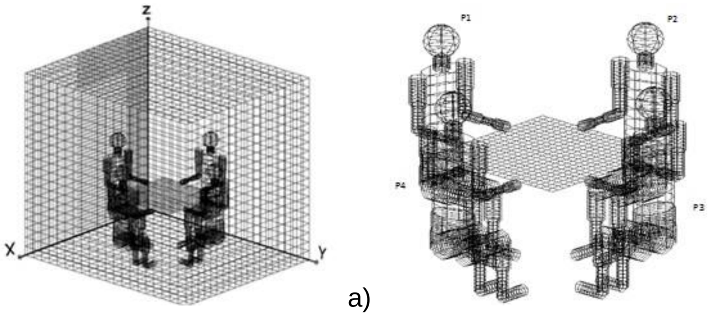
a) b) c)

Fig. 1- Mesh generation through differential numerical model that simulates internal flows with heat and mass transfer in turbulent flow. Representation of a) plans in the X-axis, b) plans in the Y-axis, c) plans in the Z-axis.



a) b)

Fig. 2- a) Mesh generation through differential numerical model that simulates internal flows with heat and mass transfer in turbulent flow. b) Representation and identification of the occupants.



a) b)

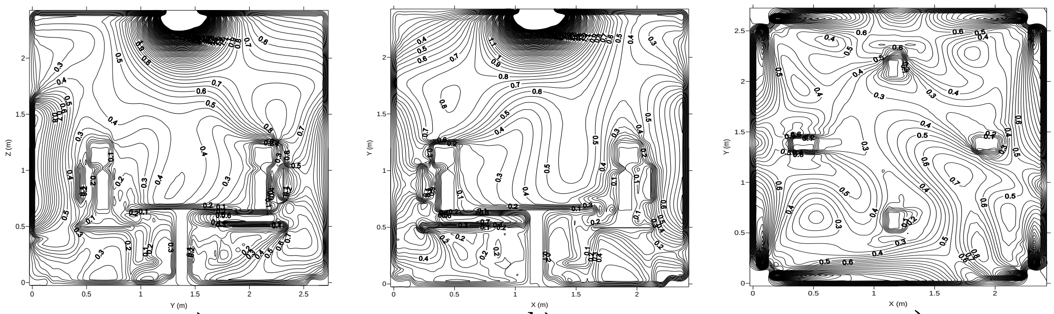
Fig. 3- a) Mesh generation through the integral numerical model which simulates the human thermal response. b) Representation and identification of the occupants.

4. Results and discussion

This chapter presents the results about the airflow around the occupants, the thermal comfort level, the local discomfort and the indoor air quality.

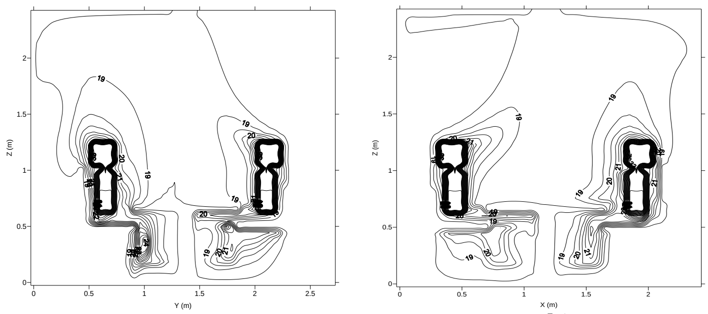
4.1 Airflow around the occupants

In figures 4 and 5 are shown, respectively, the air velocity and the air temperature around the occupants for spring and autumn situations. The figure a) shows the plan X= 1,17 m while the figure b) shows the plan Y= 1,38 m and the figure c) shows de plan Z= 1,12 m.



a) b) c)

Fig. 4- Representation of air velocity field around the occupants in the plans a) X = 1,17 m, b) Y = 1,38 m and c) Z = 1,12 m. Spring and autumn situations at a temperature of 18 °C and an air velocity of 2 m/s.



a) b)

Fig. 5- Representation of air temperature field around the occupants in the plans a) X = 1,17 m and b) Y = 1,38 m. Spring and autumn situations at a temperature of 18 °C and an air velocity of 2 m/s.

In the air velocity field are not presented many variations through the different seasons. In general, the airflow topology is uniform around the occupants and inside the virtual spaces.

In the air temperature field the higher value is verified around the occupants. Inside of the compartment the temperature field is higher in the summer and lower in the winter conditions.

4.2 Thermal comfort level

Figure 6 shows the air velocity and air temperature values around the 25 human body sections, for a spring and autumn situations.

In tables 2, 3 and 4 the PMV values are compared, according to the season of winter, spring/autumn, and summer to air inlet velocities of 2 and 3 m/s.

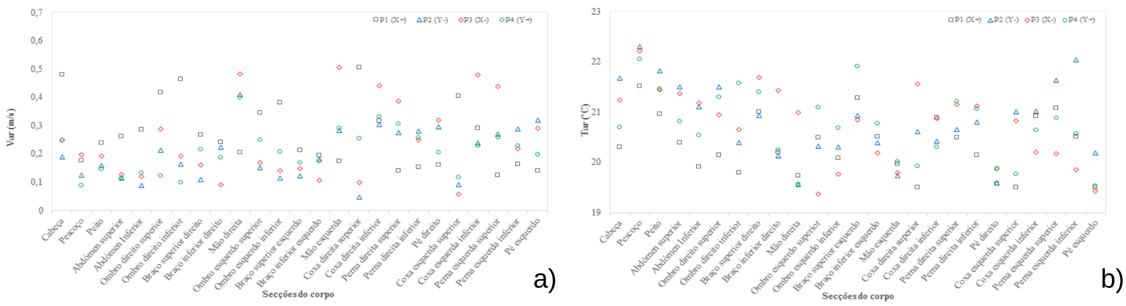


Fig. 6- a) Air velocity and b) air temperature fields around the body sections of four subjects, in the spring and autumn situations at a temperature of 18 °C and an air velocity of 2 m/s.

Table 2- Thermal comfort level in winter situation for an outdoor air temperature of 8 ºC and an inlet air velocity of 2 and 3 m/s.

	P1	P2	P3	P4	Average
PMV(V=2)	-2,60	-1,97	-2,18	-1,98	-2,18
PMV(V=3)	-2,94	-2,24	-2,44	-2,30	-2,48

Table 3- Thermal comfort level in spring/autumn situation for an outdoor air temperature of 18 ºC and an inlet air velocity of 2 and 3 m/s.

	P1	P2	P3	P4	Average
PMV(V=2)	-0,90	-0,39	-0,54	-0,39	-0,56
PMV(V=3)	-1,66	-0,86	-1,01	-0,89	-1,11

Table 4- Thermal comfort level in summer situation for an outdoor air temperature of 28 ºC and an inlet air velocity of 2 and 3 m/s.

	P1	P2	P3	P4	Average
PMV(V=2)	0,85	1,00	0,92	1,02	0,95
PMV(V=3)	0,78	0,88	0,83	0,89	0,85

The air velocity field around the occupants is uniform and the air velocity value is lower. Thus, it can consider this ventilation system as good for seniors.

The air temperature around the occupants' sections is higher in the summer than in the winter conditions, is highest around the occupants and, on the other hand, the dispersion of values around the occupants is higher in winter and spring and lower in the summer.

In accordance with the obtained results, the thermal comfort in winter conditions is not acceptable and worsens when the air velocity increases. In the spring/autumn the thermal comfort level is acceptable for lower inlet air velocity. The thermal comfort level for the summer is acceptable and slightly improves when the air velocity increases.

4.3 Local thermal discomfort

Figure 7 shows the DR for winter, spring/autumn and summer.

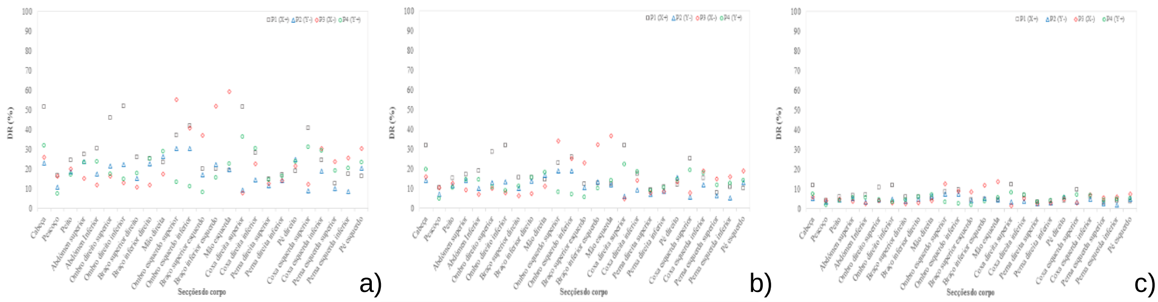


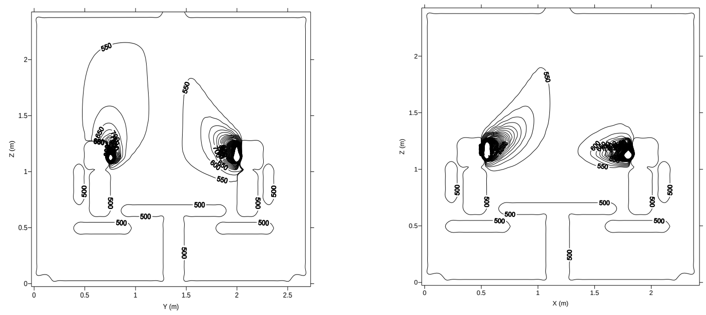
Fig. 7- Draught risk around body sections of four subjects in winter a), spring/autumn b) and summer c) *and an air velocity of 2 m/s.*

The draught risk is slightly higher in winter conditions. However, it is not given much importance to this risk on areas that are protected by clothing. When the air temperature increases this index decreases and when the air velocity increases this index increases.

4.4 Indoor air quality

The carbon dioxide concentrations in the breathing area of the senior occupants, is presented in figure 8 for spring/autumn condition.

In tables 5, 6 and 7 are presented the values of the carbon dioxide concentration in the breathing area of the occupant, for winter, spring/autumn and summer conditions, to air inlet velocities of 2 and 3 m/s.



a) b)

Fig. 8- Representation of the carbon dioxide concentration field in the breathing area of the occupants in the plans a) X = 1,17 m and b) Y = 1,38 m. Spring situation at a temperature of 18 °C and an air velocity of 2 m/s.

Table 5- Carbon dioxide concentration in the breathing area of the occupants. Winter situation, with an air temperature of 8 °C and an air inlet speed of 2 and 3 m/s.

	P1	**P2**	**P3**	**P4**	**Average**
CO_2 (mg/m^3)(V=2)	6 900	1 500	1 500	4 800	3 675
CO_2 (mg/m^3)(V=3)	4 520	1 070	1 227	3 514	2 583

Table 6- Carbon dioxide concentration in the breathing area of the occupants. Spring situation, with an air temperature of 18 °C and an air inlet speed of 2 and 3 m/s.

	P1	**P2**	**P3**	**P4**	**Average**
CO_2 (mg/m^3)(V=2)	6 763	1 480	1 511	5 053	3 702
CO_2 (mg/m^3)(V=3)	4 402	1 070	1 307	3 512	2 573

Table 7- Carbon dioxide concentration in the breathing area of the occupants. Summer situation, with an air temperature of 28 °C and an air inlet speed of 2 and 3 m/s.

	P1	**P2**	**P3**	**P4**	**Average**
CO_2 (mg/m^3)(V=2)	6 383	1 432	1 700	4 902	3 604
CO_2 (mg/m^3)(V=3)	4 387	1 070	1 311	3 511	2 570

In accordance with the obtained results, the carbon dioxide concentration is not influenced by the inlet air temperature and this concentration moves towards the ceiling, where the exhaust is located.

Increasing the inlet air velocity reduces the carbon dioxide concentration, however, the levels are slightly above the threshold values suggested by the ANSI/ASHRAE Standard 62-2001.

5. Conclusion

In this paper was carried out a study on the development of an HVAC system based on healthy eco-ventilation for seniors. The ventilation system developed is based on vertical jets at low air velocity, placed in the corners of a room and with the exhaust located in the center of the room ceiling

The present ventilation system guarantees a uniform distribution of air velocity field around the occupants. The air temperature is highest around the occupant's body and increases when the outside air temperature increases.

The thermal comfort in winter conditions is not acceptable and decreases when the velocity increases. In the spring/autumn the thermal comfort level is acceptable for lower inlet air velocity. The thermal comfort level for the summer is acceptable and slightly improves when the inlet air velocity increases.

The Draught Risk cover categories A, B and C according to ISO 7730, (2005). The risk in areas covered by clothing is not considered important because these areas are protected.

The carbon dioxide concentration is not influenced by the inlet air temperature and this concentration moves towards the ceiling, where the exhaust is located.

In future work, in accordance with the obtained results, the radiating surfaces (placed on floor, walls and/or ceiling) will be combined with the vertical jets (located between the compartments walls surfaces) analyzed in this work. The combination of these two systems allows creating a comfortable environment with high levels of thermal comfort, high levels of air quality, low levels of Draught Risks and low levels of energy consumption. The radiant surfaces will be heated by solar collectors during the winter and cooled by geothermal energy in summer conditions.

6. Acknowledgment

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7. References

ANSI/ASHRAE Standard 62.1. 2004. ASHRAE Standard – Ventilation for acceptable indoor air quality, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Bulinska, A. 2007. Determination of Airflow Pattern in a Residential Building Using Metabolic Carbon Dioxide Concentration Measurements. RoomVent'2007, Tenth International Conference on Air Distribution in Rooms, Helsinki, Finland, 13-15 June 2007.

Conceição E. Z. E., Lúcio Mª M. J. R., Capela T. L. and Brito A. I. P. V. 2006. Evaluation of thermal comfort in slightly warm ventilated spaces in non-uniform environments. International Journal of Heating, Ventilating, Air-Conditioning and Refrigerating Research, ASHRAE, Vol. 12, N. 3, pp. 451-458.

Conceição E. Z. E., Rosa S. P., Custódio A. L. V., Andrade R. L., Meira Mª J. P. A. and Lúcio Mª M. J. R. 2010a. Study of Airflow Around Occupants Seated in Desks Equipped With Upper and Lower Air Terminal Devices for Slightly Warm Environments, International Journal on Heating Air Conditioning and Refrigerating Research, ASHRAE, Vol. 16, N. 4, July 2010, pp. 401-412.

Conceição, E. Z. E., Lúcio, Mª M. J. R. Rosa, S. P. Custódio, A. L. V. Andrade, R. L. and Meira Mª J. P. A. 2010b, Evaluation of comfort level in desks equipped with two personalized ventilation systems in slightly warm environments, Building and Environment, Volume 45, Issue 3, March 2010b, pp. 601-609.

Conceição, E. Z. E., Manuela, M., Lúcio, J. R, Gomes, M. 2014, Numerical Simulation in a Topology Building Using HVAC Systems Equipped with PMV Control, International Journal of Advanced Engineering Applications, Volume 7, Issue.4, 2014, pp.53-63.

Decreto-Lei nº 79/2006. Regulamento dos sistemas energéticos de climatização em edifícios (RSECE), Diário da República, I Série- A, N. 67, 4 de Abril.

Fanger P.O. 1970. Thermal comfort. Copenhagen: Danish Technical Press.

Fanger, P. O. and Christensen, N. K. 1986. Prediction of Draught in Ventilated Spaces, Ergonomics, V. 29, pp. 215-235.

Fanger, P. O. 1988. Introduction of the olf and the decipol units to quantify air pollution perceived by humans indoors and outdoors. Energy and Buildings, Volume 12, Issue 1, 1988, pp 1-6.

ISO 7730, 2005. 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.

Levine, K. B., Sterling, E. M. and Collet, C. W. 1993. Estimation of Outdoor Air Ventilation Rates Using CO2 Concentration. ASHRAE Transactions, Part 1, pp. 1554-1559.

Melikov, A. K., Langkilde, G. and Derbiszewsbi, B. 1990. Airflow Characteristics in the Occupied Zone of Rooms with Displacement Ventilation, ASHRAE Transactions, V. 96, Part. 1, pp. 555-563.

Nagy, R. and Senitkova, K. 2007. IAQ and Distribution Systems in School Buildings. RoomVent'2007, Tenth International Conference on Air Distribution in Rooms, Helsinki, Finland, 13-15 June 2007.

Papakonstantinou, K. A., Kiranoudis, C. T. and Markatos N. C. 2002. Numerical Simulation of CO2 dispersion in a auditorium. Energy and Buildings. Vol. 34, pp. 245-250.