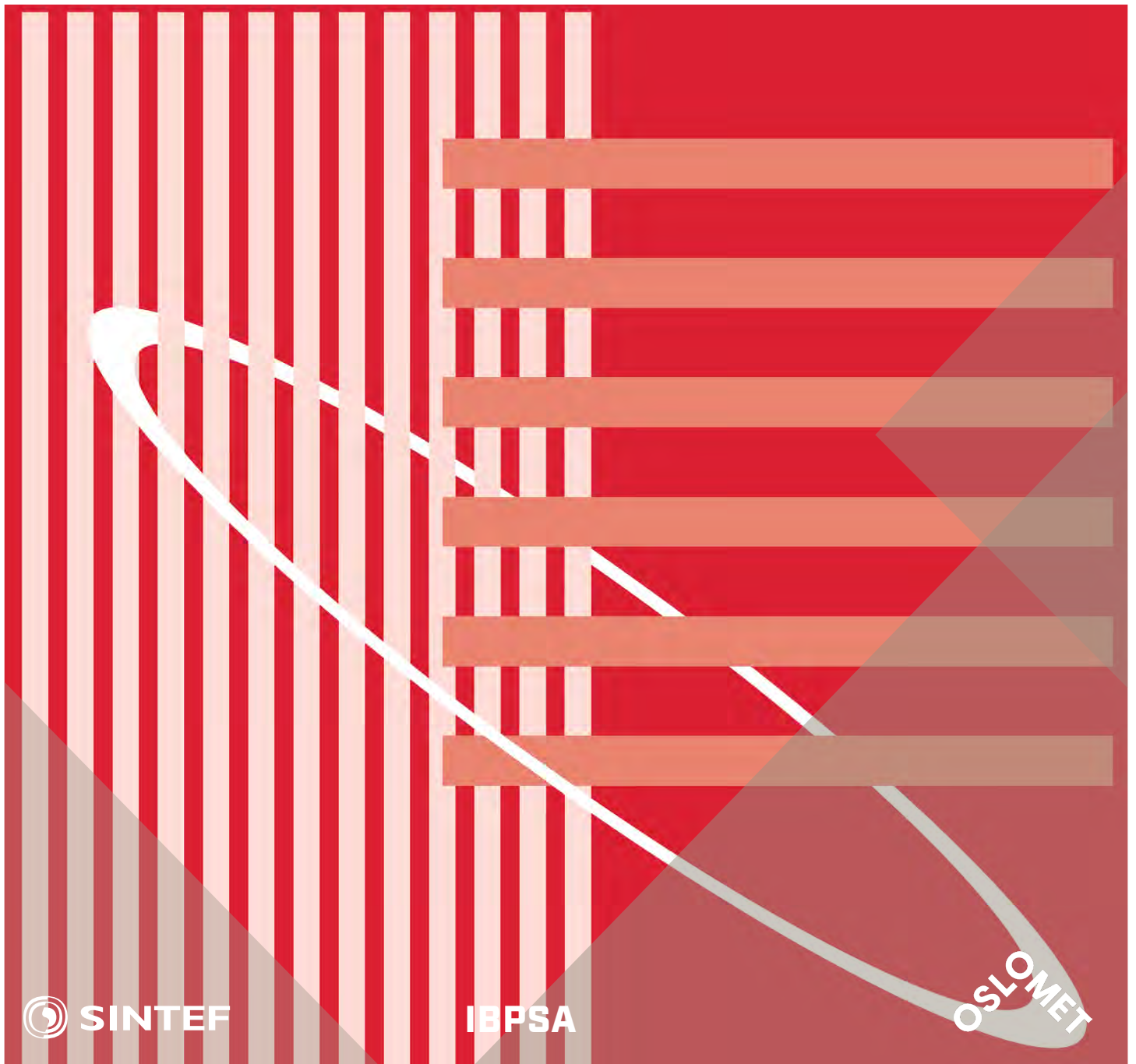


International Conference Organised by
IBPSA-Nordic, 13th-14th October 2020,
OsloMet

BuildSIM-Nordic 2020

Selected papers



SINTEF Proceedings

Editors:

Laurent Georges, Matthias Haase, Vojislav Novakovic and Peter G. Schild

BuildSIM-Nordic 2020

Selected papers

International Conference Organised by IBPSA-Nordic,
13th–14th October 2020, OsloMet

SINTEF Academic Press

SINTEF Proceedings no 5

Editors:

Laurent Georges, Matthias Haase, Vojislav Novakovic and Peter G. Schild

BuildSIM-Nordic 2020

Selected papers

International Conference Organised by IBPSA-Nordic,

13th–14th October 2020, OsloMet

Keywords:

Building acoustics, Building Information Modelling (BIM), Building physics, CFD and air flow, Commissioning and control, Daylighting and lighting, Developments in simulation, Education in building performance simulation, Energy storage, Heating, Ventilation and Air Conditioning (HVAC), Human behavior in simulation, Indoor Environmental Quality (IEQ), New software developments, Optimization, Simulation at urban scale, Simulation to support regulations, Simulation vs reality, Solar energy systems, Validation, calibration and uncertainty, Weather data & Climate adaptation, Fenestration (windows & shading), Zero Energy Buildings (ZEB), Emissions and Life Cycle Analysis

Cover illustration: IBPSA-logo

ISSN 2387-4295 (online)

ISBN 978-82-536-1679-7 (pdf)



© The authors

Published by SINTEF Academic Press 2020

This is an open access publication under the CC BY-NC-ND license

(<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

SINTEF Academic Press

Address: Børrestuveien 3

PO Box 124 Blindern

N-0314 OSLO

Tel: +47 40 00 51 00

www.sintef.no/community

www.sintefbok.no

SINTEF Proceedings

SINTEF Proceedings is a serial publication for peer-reviewed conference proceedings on a variety of scientific topics.

The processes of peer-reviewing of papers published in SINTEF Proceedings are administered by the conference organizers and proceedings editors. Detailed procedures will vary according to custom and practice in each scientific community.

Application of Coupling of CFD and Human and Clothing Thermal Response in Ceiling Mounted Localized Air Distribution Systems in Winter Conditions

Eusébio Z. E. Conceição^{1*}, M^a Inês L. Conceição², M^a Manuela J. R. Lúcio¹
and Hazim B. Awbi³

¹FCT - University of Algarve, Campus de Gambelas, 8005-139 Faro, Portugal

²Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

³School of Construction Management & Engineering, University of Reading, Reading, RG6, 6AW, United Kingdom

* corresponding author: econcei@ualg.pt

Abstract

This work presents and applies a numerical model, developed by the authors in the last years, that considers the coupling of the CFD (Computational Fluids Dynamics) and HCTR (Human and Clothing Thermal Response). The coupling system, itself, generates the external occupants' surfaces and the surrounding surfaces and transfers the inputs/outputs between the CFD and HCTS numerical models.

The input of the compartment, using the CAD (Computational Aid Design), the location of the occupants and the external environmental variables are introduced in the software, while the occupants' geometry is generated by empirical equations, based in height and weight.

The study is made in a virtual chamber occupied by twelve virtual manikins, six desks and twelve seats and equipped with a new ceiling mounted localized air distribution system. The ventilated system is equipped with an inlet system, built with two horizontal ducts, and an extraction system, built with six ducts. The inlet horizontal ducts consider twelve jets located above the head and in front to the occupants' level and twelve jets located above the desk area.

In the present study the thermal comfort level, the air quality level and the ADI (Air Distribution Index) are calculated, for an inlet air velocity of 1, 3 and 5 m/s, in winter conditions. The ADI index is highest for highest inlet air velocities.

Introduction

This work is a continuation of ceiling mounted localized air distribution systems presented in Conceição *et al.* (2017). In this work the inlet is made above the head level and the extraction is placed in the ceiling level. Similar works about the ceiling mounted were developed by other authors, such as Yang *et al.* (2010) and Yang *et al.* (2009). To develop a HVAC (Heating, Ventilating and Air-Conditioning) system, a numerical software is used to

calculate the thermal comfort, the DR (Draught Risk) and the indoor air quality levels. However, in order to evaluate the performance of the HVAC system, namely the effectiveness for heat removal and the effectiveness for contaminant removal, it is also important to evaluate the ADI.

The DR, that considers the air temperature, air velocity and air turbulence intensity, was developed in Fanger *et al.* (1988). Some applications can be seen, as example, in Conceição *et al.* (2008).

The detailed presentation of the ADI can be seen in the works of Awbi (2004) and Conceição *et al.* (2013), respectively, for uniform and non-uniform environments.

In the HCTR numerical model the PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied people) indexes, are applied in the thermal comfort level determination in a conditioned space. These indexes were developed by Fanger (1970) and adopted by international standards like ISO (2005). This standard defines three comfort categories accordingly to the occupied spaces thermal comfort requirements.

To evaluate the indoor air quality, using the CFD numerical model, the indoor carbon dioxide (CO₂) concentrations are used. ASHRAE (2016) presents values which can be considered to guarantee acceptable indoor air quality (CO₂ concentration below 1800 mg/m³). Some applications, using the airflow rate, can be seen in Conceição *et al.* (1997).

The numerical software, developed by the authors, and applied in this work, considers the coupling of CFD and HCTR numerical models. Some application of the coupling methodology were presented in Conceição and Lúcio (2011) and Conceição and Lúcio (2010a).

The surrounding surfaces, used by the coupling software, used a third software that evaluates the Building Dynamic Software. This numerical model, is used to evaluate the temperature, concentration and energy in a building or vehicles. See as example, Conceição *et al.* (2000), Conceição *et al.* (2008) and Conceição *et al.* (2000).

These numerical software develop a new HVAC system based in a ceiling mounted localized air distribution systems. The study is made in winter typical day conditions. The thermal comfort, the indoor air quality, the DR, the effectiveness for heat removal, the effectiveness for contaminant removal and the ADI are evaluated.

The motivation of this work is to develop a new ceiling mounted localized air distribution systems with the objective to guarantee best indoor air quality and thermal comfort levels. The main idea of the system is to consider an inlet system, placed above the head level and in the occupation area, and an extraction system, also placed above the head level but in the not occupied area. The two systems are placed in the same level to facilitate the extraction of the CO₂ concentration. The inlet system considers one jet located above the head level and another jet located above the desk level, while the extraction considers six vertical ducts. The jet located above the desk level is used to improve the airflow around the occupant seated in this table and the occupant seated in front.

Numerical Model

The Human and Clothing Thermal Response numerical model (Conceição 2000), (Conceição 1999), (Conceição and Lúcio 2001) and (Conceição et al. 2010), is built by sub-models of:

- human body thermal system;
- thermoregulatory system;
- clothing system;
- thermal comfort.

This software, that simulates simultaneously a group of people, in the human body thermal system and in thermoregulatory system, evaluates:

- Human body temperature;
- Blood flow in the human body;
- Water transpiration flow;
- Blood (arterial and venous) temperature.

The HCTR numerical model works in transient conditions and in steady-state conditions. In this work, for each CFD thermal condition, the steady-state conditions were obtained.

The clothing system calculates:

- Temperature of the clothing;
- Water flow through the clothing.

Finally, the thermal comfort sub-model, that uses the PPD and PMV indexes, developed by Fanger (1970), is used to evaluate the thermal comfort level, considering all heat fluxes verified in the human body.

More details about the validation of the HCTR numerical model can be seen in Conceição (1999), in the study of

evaluation of thermal comfort and simulation of HCTR numerical model and in Conceição and Lúcio (2001), in a numerical and subjective responses of human thermal sensation.

The CFD numerical model presented in Conceição *et al.* (2008) that works in steady-state conditions, evaluates the:

- air temperature;
- air velocity;
- carbon dioxide (CO₂) concentration;
- turbulent kinetic energy;
- turbulent energy dissipation;
- indoor air quality level;
- DR level.

In the partial differential equations discretization, used in the CFD numerical model developed by the authors and applied in this work, the finite volume method is used. The hybrid scheme is used in the convective/diffusive fluxes. The SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) algorithm is used in the velocity and pressure equations. The non-uniform methodology is used in the grid generation. The iterative TDMA (Tri-Diagonal Matrix Algorithm) method is used in the equations system resolution. The RNG turbulence model, for high Reynolds number, is used in the turbulence simulation. In the wall boundary the surface proximity is used.

The CFD numerical model simulates:

- isothermal thermal conditions (Conceição *et al.*, 2008);
- non-isothermal thermal conditions (Conceição and Lúcio, 2016) using the k-epsilon turbulence model and (Conceição and Lúcio, 2016) using the RNG turbulence model.

The development and validation were made in Conceição *et al.* (2008), in a study of airflow inside office compartments with moderate environments.

In the validation, of the coupling software with the Building Dynamic model (Conceição and Lúcio, 2016), the experimental and numerical values of the chamber surface temperature, the air temperature, the air velocity, the air turbulence intensity and the DR around the occupants are compared.

The Building Dynamic numerical model (Conceição and Lúcio, 2010b), used in the study in the evaluation of surrounding surfaces, was validated in Conceição *et al.* (2004), in winter condition, and Conceição and Lúcio (2006), in summer conditions.

The ADI, developed in Awbi (2004) for uniform environments and adapted in Conceição *et al.* (2013) to non-uniform environments, uses the thermal comfort number and the air quality number. The first one considers the effectiveness for heat removal and the PPD, while the second one considers the effectiveness for

contaminant removal and the percentage of dissatisfied associated to the indoor air quality.

Numerical Methodology

The new ceiling mounted localized air distribution systems consider an inlet system, placed above the head level and in the occupation area, and an extraction system, also placed above the head level but in the not occupied area. This not occupied area, is located between the two occupation areas.

The inlet system considers one jet located above the head level and another jet located above the desk level, while the extraction considers six vertical ducts. This numerical study is made in a virtual chamber. The chamber is occupied by twelve occupants and equipped with six desks and twelve seats.

The virtual chamber, equal to an existing experimental chamber, which simulates a virtual office, with $4.5 \times 2.55 \times 2.5 \text{ m}^3$. The real experimental chamber is built by a wood structure equipped with an isolation material with a thickness of 3 cm.

The ventilated system is equipped with:

- an inlet system built with two horizontal rectangular ducts. Each inlet horizontal rectangular duct considers twelve jets located above the head level and in front to the occupants and twelve jets located above the desk area (see figures 1 to 4);
- an extraction system, built with six vertical extraction ducts. Each extraction duct is divided in a vertical duct, connected to a horizontal duct (see figures 1 to 4).

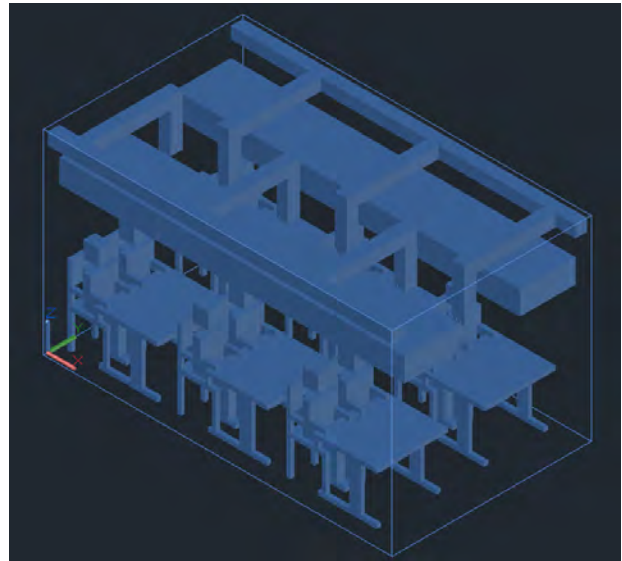
In the numerical simulation, made in winter conditions, the inlet air velocity is 1 ($0.064 \text{ m}^3/\text{s}$), 3 ($0.19 \text{ m}^3/\text{s}$) and 5 ($0.32 \text{ m}^3/\text{s}$) m/s.

In figure 1 is presented the scheme of the virtual chamber, equipped with ceiling mounted localized air distribution systems, using in the CFD. The figure a) represents the occupants, desks, seats and ventilation system, while b) represents only the occupants, desks and seats.

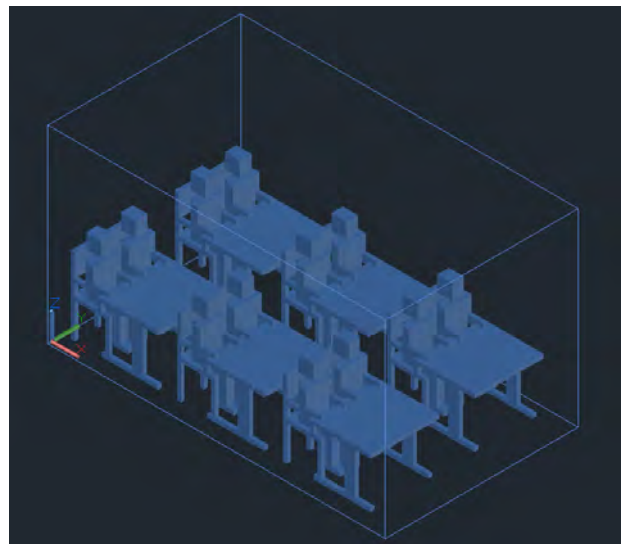
The scheme of the virtual chamber, equipped with ceiling mounted localized air distribution system, used in the HCTR is depicted in Figure 2. The Figure a) represents the occupants, desks, seats and ventilated system, while b) represents only the occupants, desks and seats. The Figure a) also includes the surrounding surfaces. The grid presented in these Figures is used in the calculation of the heat exchanges by radiation (1) between the occupants and (2) between the occupants and the surrounding surfaces of the desk and ventilation system. This Figure is used by the HCTR numerical model, but is generated in the CFD numerical model.

Figure 3 shows the location of the occupants and the identification of the number of the occupants seated in the experimental chamber.

This numerical work, that simulates a small classroom, considers four rows of students, namely, two located in the corridor side and two located in the window or wall side.



a) occupants, desks, seats and ventilated system.

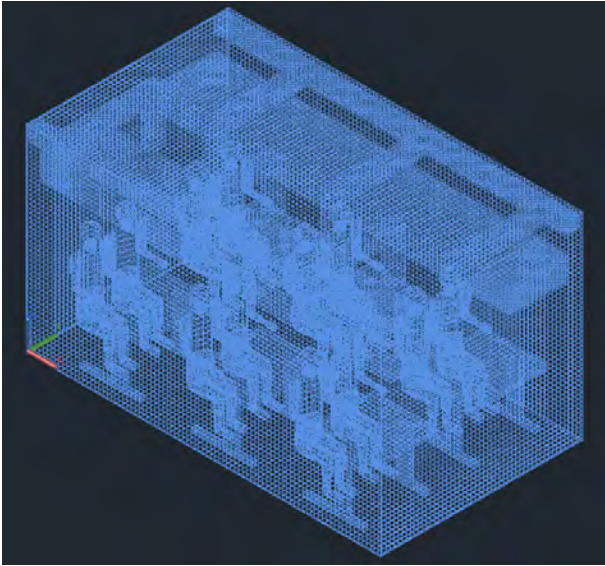


b) only the occupants, desks, seats.

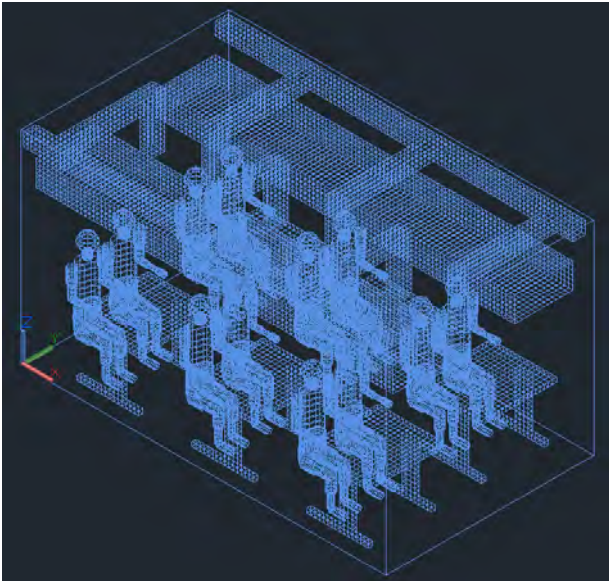
Figure 1. Scheme of the virtual chamber, equipped with ceiling mounted localized air distribution systems, used in the CFD.

The students 1, 2, 7 and 8 are located in the beginning of the rows, while the students 5, 6, 11 and 12 are located in the end of the rows. In the beginning of the rows the students are only subjected to a jet located in front to the occupant, while the students located in the middle or in the final of the rows are subjected to a jet located in front and another jet located behind them.

The inlet airflow location used in the CFD numerical simulation is depicted in Figure 4. The inlet and also the outlet, are located 1.8 m above the floor level.



a) occupants, desks, seats and ventilated system.



b) only the occupants, desks, seats.

Figure 2. Scheme of the virtual chamber, equipped with ceiling mounted localized air distribution systems, used in the HCTR.

The occupants' clothing level, used in the HCTR numerical model, in winter conditions, is 1 clo and the activity level is 1.2 met. The clothing level, considered in this work is formed by long sleeved shirt, dust, pants, shoes and normal underwear.

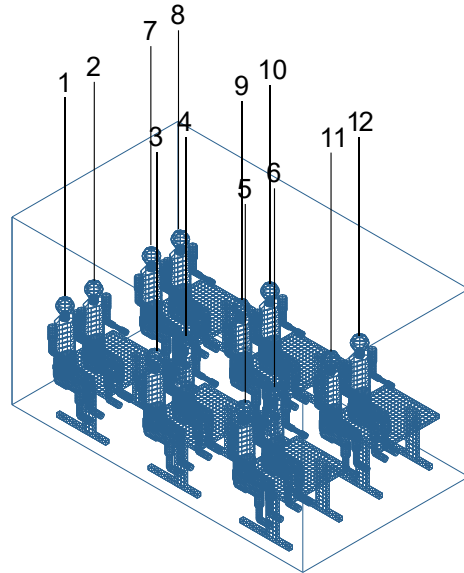
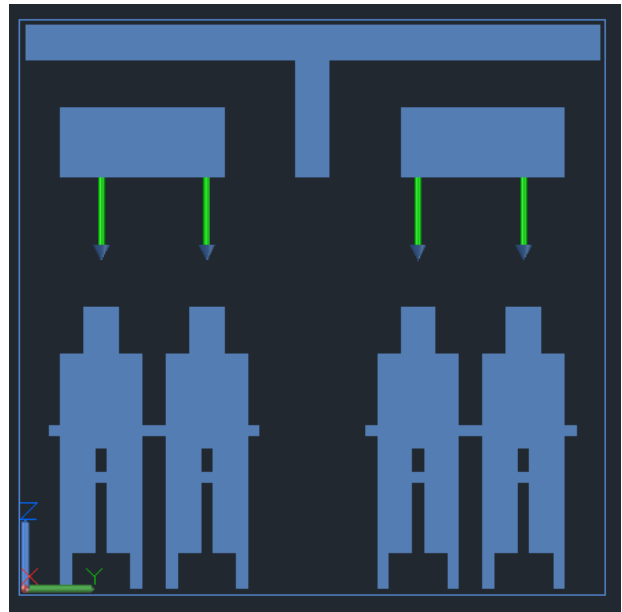
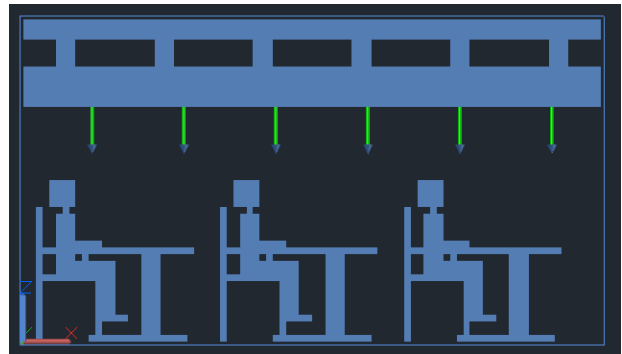


Figure 3. Location of the occupants and identification of the number of the occupants.



a)



b)

Figure 4. Inlet airflow location used in the numerical simulation. a) front and b) side view.

Results and Discussions

In this section the air velocity, the air temperature, the DR and the ADI are presented.

Figures 5, 6 and 7 show, respectively, the air velocity, air temperature and DR around the occupants. Figures (a), (b) and (c) are associated to, respectively, inlet air velocity of 1, 3 and 5 m/s.

The mean values of air velocity, air temperature and DR are calculated using all values around each of the 25 occupants' sections.

The air velocity around the occupant section increases when the inlet air velocity increases and the air velocity around the occupant is relatively uniform. However, the occupants located in the corridor side, present a highest air velocity in the upper member located in the corridor side.

The air temperature around the occupants' section decreases when the inlet air velocity increases and the air temperature around the occupant sections are relatively uniform. However, the air temperature around the hands presents the lowest value, mainly when the inlet air velocity is 3 and 5 m/s.

The DR around the occupant section increases when the inlet air velocity increases. In general, the DR around the occupant is uniform. However, the occupants located in the corridor side, present a highest DR in the upper member located in the corridor side. This highest DR values are associated to highest air velocities values. The DR level is acceptable in accordance with the category C (30% of dissatisfied people) of the ISO (2005).

The obtained ADI value is showed in Tables 1, 2 and 3, respectively, when the inlet air velocity is 1, 3 and 5 m/s. In these Tables are also presented the values of effectiveness for heat removal, thermal comfort level, thermal comfort number, CO₂ concentration in the respiration area, effectiveness for contaminant removal and air quality number.

The effectiveness for heat removal decreases when the inlet air velocity increases. The effectiveness for heat removal is relatively uniform for all occupants.

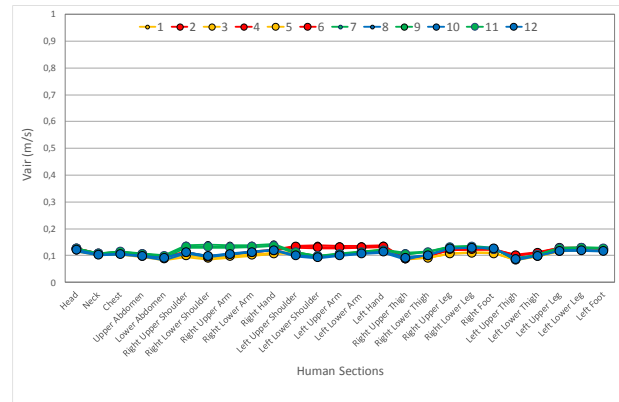
The thermal comfort level, evaluated by the PPD index, increases when the inlet air velocity increases. For an inlet air velocity of 5 m/s the thermal comfort level is acceptable in accordance with the international standards ISO (2005). The thermal comfort level, mainly for higher inlet air velocities, is better for occupants seated in the corridor side.

The thermal comfort number is evaluated by the quotient of the effectiveness for heat removal and the PPD index. The thermal comfort number increases when the inlet air velocity increases. This parameter, mainly for higher inlet air velocities, is better for occupants seated in the corridor side.

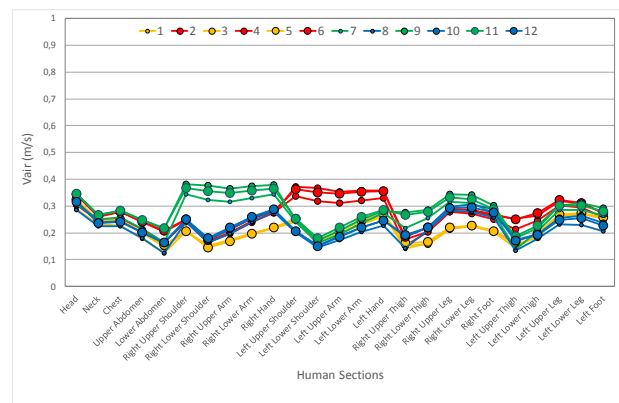
The CO₂ concentration in the respiration area, decreases when the inlet air velocity increases. In accord to the

international standards (ASHRAE, 2016), the internal air quality is acceptable in all simulations. However, the air quality level is better for higher inlet air velocities, than for lower inlet air velocities.

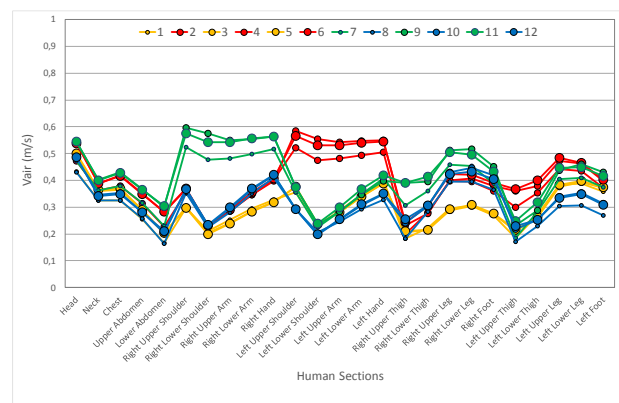
The effectiveness for contaminant removal decreases slightly, when the inlet air velocity increases and is relatively lower for occupants located in the beginning of the row (subjected only to one air jet) than the others.



a)



b)

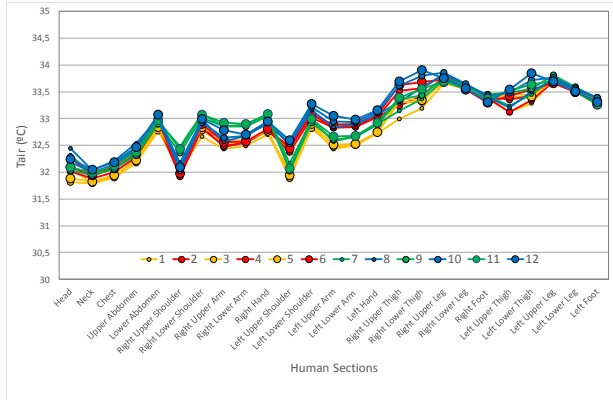


c)

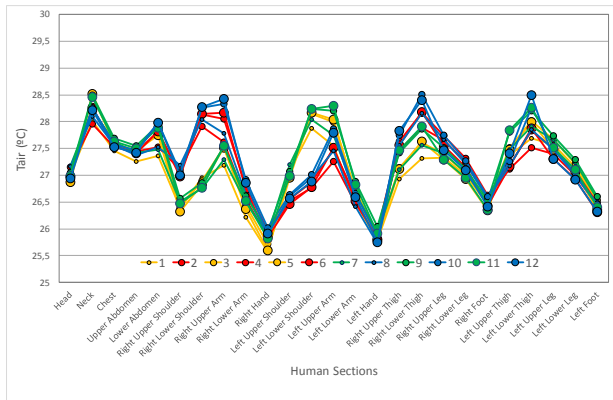
Figure 5. Air velocity around the occupants, when the inlet air velocity is 1 (a), 3 (b) and 5 (c) m/s.

The air quality number increases when the inlet air velocity increases and is relatively lower for occupant located in the beginning of the row.

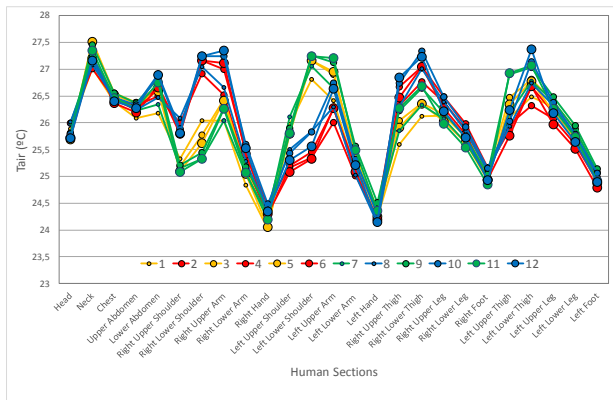
Finally, the ADI increases when the inlet air velocity increases. The ADI, in general, is higher when the occupants are subjected simultaneously to jets located in front and behind them than when the occupants are subjected only to jets located in front and is higher when the occupants are located in the corridor side than the occupants are located in the wall side.



a)

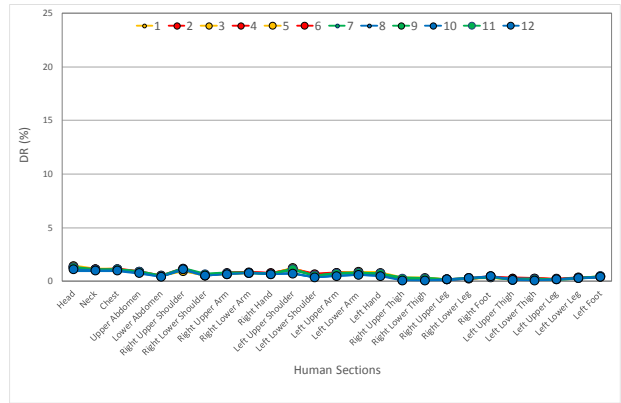


b)

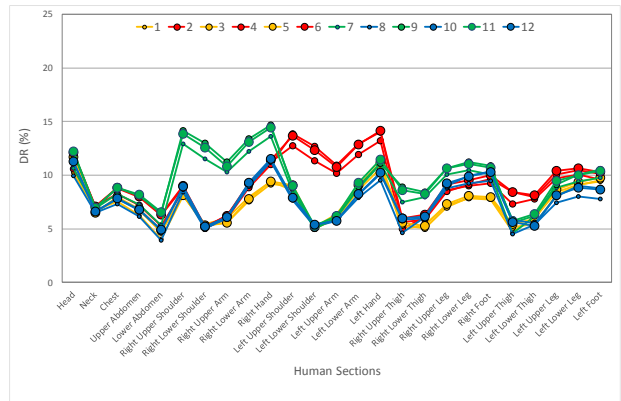


c)

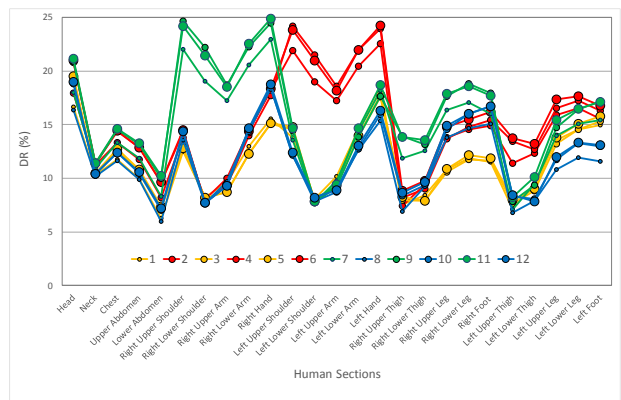
Figure 6. Air temperature around the occupants, when the inlet air velocity is 1 (a), 3 (b) and 5 (c) m/s.



a)



b)



c)

Figure 7. Draught Risk around the occupants, when the inlet air velocity is 1 (a), 3 (b) and 5 (c) m/s.

Table 1. Obtained ADI values, when the inlet air velocity is 1 m/s.

Occupant number	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Inlet Temperature (°C)	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0
Outlet Temperature (°C)	32,4	32,4	32,4	32,4	32,4	32,4	32,4	32,4	32,4	32,4	32,4	32,4	32,4
Body Mean Temperature (°C)	32,6	32,7	32,6	32,7	32,6	32,8	32,8	32,8	32,7	32,8	32,8	32,9	32,7
Effectiveness For Heat Removal (%)	98,6	97,4	98,4	97,6	98,2	97,3	97,1	96,7	97,4	96,7	97,1	96,4	97,4
PPD (%)	67,4	68,2	67,9	68,0	67,9	68,2	68,3	68,5	68,1	68,5	68,2	68,6	68,1
Thermal Comfort Number	1,5	1,4	1,5	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4
Inlet CO2 Concentration (mg/m3)	500	500	500	500	500	500	500	500	500	500	500	500	500
Outlet CO2 Concentration (mg/m3)	1210	1210	1210	1210	1210	1210	1210	1210	1210	1210	1210	1210	1210
CO2 in the Respiration Area (mg/m3)	1569	1652	1504	1569	1425	1501	1659	1851	1582	1805	1503	1708	1611
Effectiveness Contaminant Removal (%)	66,4	61,7	70,7	66,4	76,8	71,0	61,3	52,6	65,6	54,4	70,8	58,8	64,7
Ventilating Rate (l/s/Olf)	5,3	5,3	5,3	5,3	5,3	5,3	5,3	5,3	5,3	5,3	5,3	5,3	5,3
PD with Indoor Air Quality (%)	24,5	24,5	24,5	24,5	24,5	24,5	24,5	24,5	24,5	24,5	24,5	24,5	24,5
Air Quality Number	2,7	2,5	2,9	2,7	3,1	2,9	2,5	2,1	2,7	2,2	2,9	2,4	2,6
Air Distribution Index(ADI)	2,0	1,9	2,0	2,0	2,1	2,0	1,9	1,7	2,0	1,8	2,0	1,8	1,9

Table 2. Obtained ADI values, when the inlet air velocity is 3 m/s.

Occupant number	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Inlet Temperature (°C)	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0
Outlet Temperature (°C)	24,9	24,9	24,9	24,9	24,9	24,9	24,9	24,9	24,9	24,9	24,9	24,9	24,9
Body Mean Temperature (°C)	27,2	27,3	27,4	27,4	27,3	27,3	27,3	27,4	27,5	27,5	27,4	27,4	27,4
Effectiveness For Heat Removal (%)	67,7	66,8	66,4	66,0	66,7	66,5	66,4	66,3	65,2	65,3	65,8	65,7	66,2
PPD (%)	18,3	17,7	18,5	17,5	18,2	17,1	17,8	19,0	17,5	18,7	17,3	18,5	18,0
Thermal Comfort Number	3,7	3,8	3,6	3,8	3,7	3,9	3,7	3,5	3,7	3,5	3,8	3,5	3,7
Inlet CO2 Concentration (mg/m3)	500	500	500	500	500	500	500	500	500	500	500	500	500
Outlet CO2 Concentration (mg/m3)	733	733	733	733	733	733	733	733	733	733	733	733	733
CO2 in the Respiration Area (mg/m3)	892	902	844	858	819	837	903	962	863	927	840	896	879
Effectiveness Contaminant Removal (%)	59,5	57,9	67,8	65,1	73,0	69,1	57,8	50,4	64,1	54,5	68,5	58,8	62,2
Ventilating Rate (l/s/Off)	16,0	16,0	16,0	16,0	16,0	16,0	16,0	16,0	16,0	16,0	16,0	16,0	16,0
PD with Indoor Air Quality (%)	10,2	10,2	10,2	10,2	10,2	10,2	10,2	10,2	10,2	10,2	10,2	10,2	10,2
Air Quality Number	5,8	5,7	6,7	6,4	7,2	6,8	5,7	5,0	6,3	5,4	6,7	5,8	6,1
Air Distribution Index(ADI)	4,7	4,6	4,9	4,9	5,1	5,1	4,6	4,2	4,8	4,3	5,1	4,5	4,7

Table 3. Obtained ADI values, when the inlet air velocity is 5 m/s.

Occupant number	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Inlet Temperature (°C)	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0
Outlet Temperature (°C)	23,2	23,2	23,2	23,2	23,2	23,2	23,2	23,2	23,2	23,2	23,2	23,2	23,2
Body Mean Temperature (°C)	26,0	26,1	26,2	26,2	26,1	26,1	26,2	26,3	26,3	26,2	26,2	26,2	26,2
Effectiveness For Heat Removal (%)	53,4	52,6	51,9	52,1	52,6	52,8	52,6	52,0	51,4	51,1	52,1	51,7	52,2
PPD (%)	7,7	7,2	7,7	6,9	7,5	6,7	7,2	8,1	6,9	7,9	6,7	7,7	7,4
Thermal Comfort Number	6,9	7,3	6,7	7,5	7,0	7,9	7,4	6,4	7,4	6,5	7,7	6,7	7,1
Inlet CO2 Concentration (mg/m3)	500	500	500	500	500	500	500	500	500	500	500	500	500
Outlet CO2 Concentration (mg/m3)	646	646	646	646	646	646	646	646	646	646	646	646	646
CO2 in the Respiration Area (mg/m3)	749	759	714	724	699	713	756	789	726	766	712	747	738
Effectiveness Contaminant Removal (%)	58,5	56,3	68,0	64,9	73,1	68,5	56,8	50,4	64,5	54,7	68,6	58,9	61,9
Ventilating Rate (l/s/Off)	26,6	26,6	26,6	26,6	26,6	26,6	26,6	26,6	26,6	26,6	26,6	26,6	26,6
PD with Indoor Air Quality (%)	6,2	6,2	6,2	6,2	6,2	6,2	6,2	6,2	6,2	6,2	6,2	6,2	6,2
Air Quality Number	9,5	9,1	11,0	10,5	11,8	11,1	9,2	8,1	10,4	8,8	11,1	9,5	10,0
Air Distribution Index(ADI)	8,1	8,2	8,6	8,9	9,1	9,3	8,2	7,2	8,8	7,6	9,3	8,0	8,4

Conclusions

This numerical study develops a HVAC system based in a ceiling mounted localized air distribution systems. The study is made in winter typical day conditions. The thermal comfort, the indoor air quality, the DR, the effectiveness for heat removal, the effectiveness for contaminant removal and the ADI, are evaluated.

When the inlet air velocity increases the DR around the occupants increases. The DR is acceptable in accordance to the international standards.

The thermal comfort level increases when the inlet air velocity increases and is acceptable for highest inlet air velocities in accordance with the international standards.

The indoor air quality level increases when the inlet air velocity increases and is acceptable, in accordance with the international standards for all simulations.

Finally, the ADI increases when the inlet airflow increases. The ADI is highest when the occupants are subjected simultaneously to jets located in front and behind and is highest for occupants located in the corridor side.

Acknowledgement

The authors would like to acknowledge to the project (SAICT-ALG/39586/2018) from Algarve Regional Operational Program (CRESC Algarve 2020), under the PORTUGAL 2020 Partnership Agreement, through the European Regional Development Fund (ERDF) and the National Science and Technology Foundation (FCT).

References

- ASHRAE. 2016. "Ventilation for Acceptable Indoor Air Quality." *Journal of Physics A: Mathematical and Theoretical*.
- Awbi, H. B. 2004. *Ventilation of Buildings*.
- Conceição, E., A. Silva, and Lúcio M. M. J. R. 2004. "Numerical Study of Thermal Response of School Buildings in Winter Conditions." Pp. 5–8 in *Proceedings of the 9th Conference on Air Distribution in Rooms (Roomvent 2004), Coimbra, Portugal*.
- Conceição, E. Z. E. 1999. "Avaliação de Condições de Conforto Térmico: Simulação Numérica Do Sistema Térmico Do Corpo Humano e Do Vestuário." *Proceedings of the CIAR*.
- Conceição, E. Z. E. 2000. "Evaluation of Thermal Comfort and Local Discomfort Conditions Using the Numerical Modelling of the Human and Clothing Thermal System." Pp. 131–36 in *RoomVent'2000-7th International Conference on Air Distribution in Rooms*.
- Conceição, E. Z. E. and Lúcio, M. M. J. R. 2006. "Numerical Study of Thermal Response of School Buildings in Summer Conditions." in *HB 2006 - Healthy Buildings: Creating a Healthy Indoor Environment for People, Proceedings*. Vol. 3.
- Conceição, E. Z. E., and Lúcio, M. M. J. R.. 2010a. "Evaluation of Thermal Comfort Conditions in a Localized Radiant System Placed in Front and behind Two Students Seated Nearby Warmed Curtains." *Building and Environment* 45(10).
- Conceição, E. Z. E., and Lúcio, M. M. J. R.. 2010b. "Numerical Simulation of Passive and Active Solar Strategies in Buildings with Complex Topology." *Building Simulation* 3(3).
- Conceição, E. Z. E., and Lúcio, M. M. J. R. 2011. "Evaluation of Thermal Comfort Conditions in a Classroom Equipped with Radiant Cooling Systems and Subjected to Uniform Convective Environment." *Applied Mathematical Modelling* 35(3).
- Conceição, E. Z. E., and Lúcio, M. M. J. R. 2016. "Numerical Simulation of the Application of Solar Radiant Systems, Internal Airflow and Occupants' Presence in the Improvement of Comfort in Winter Conditions." *Buildings* 6(3).
- Conceição, E. Z. E., Lúcio, M. M. J. R., and H. B. Awbi. 2013. "Comfort and Airflow Evaluation in Spaces Equipped with Mixing Ventilation and Cold Radiant Floor." *Building Simulation* 6(1).
- Conceição, E. Z. E., Lúcio, M. M. J. R., and M. C. Lopes. 2008. "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* 4(8).
- Conceição, E. Z. E., Lúcio M. M. J. R., V. D. S. R. Vicente, and V. C. T. Rosão. 2008. "Evaluation of Local Thermal Discomfort in a Classroom Equipped with Cross Flow Ventilation." *International Journal of Ventilation* 7(3).
- Conceição, E. Z. E., and Lúcio, M. M. J. R. 2001. "Numerical and Subjective Responses of Human Thermal Sensation." *Proceedings of the BioEng.*
- Conceição, E. Z. E., Rosa, S. P., Custódio, A. L. V., Andrade, R. L., Meira, M. J. P. A. and Lúcio, M. M. J. R.. 2010. "Study of Airflow around Occupants Seated in Desks Equipped with Upper and Lower Air Terminal Devices for Slightly Warm Environments." *HVAC and R Research* 16(4).
- Conceição, E. Z. E., Santiago, C. I. M., and Awbi, H. B.. 2017. "Numerical Study of Different Ceiling-Mounted Air Distribution Systems for a Virtual Classroom Environment." *Indoor and Built Environment* 26(10).
- Conceicao, E. Z. E., Silva, M. C. G., Andre, J. C. S. and Viega, D. X. 2000. "Thermal Behaviour Simulation of the Passenger Compartment of Vehicles." *International Journal of Vehicle Design* 24(4):372–87.
- Conceição, E. Z. E., Silva, M. C. G. and Viegas, D. X.. 1997. "Air Quality inside the Passenger Compartment of a Bus." *Journal of Exposure Analysis and Environmental Epidemiology* 7(4).
- Conceição, E. Z. E., Vicente, V. D. S. R. and Lúcio M. M. J. R. 2008. "Airflow inside School Building Office Compartments with Moderate Environments." *HVAC and R Research* 14(2).
- Fanger, P. O., A. K. Melikov, H. Hanzawa, and J. Ring. 1988. "Air Turbulence and Sensation of Draught." *Energy and Buildings.*
- Fanger, P. O. P. 1970. "Thermal Comfort. Analysis and Applications in Environmental Engineering." *Copenhagen: Danish Technical Press.*
- ISO. 2005. "ISO 7730: Ergonomics of the Thermal Environment Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria." *Management.*
- Yang, Bin, Arsen Melikov, and Chandra Sekhar. 2009. "Performance Evaluation of Ceiling Mounted Personalized Ventilation System." in *ASHRAE Transactions.*
- Yang, Bin, Chandra Sekhar, and Arsen K. Melikov. 2010. "Ceiling Mounted Personalized Ventilation System in Hot and Humid Climate - An Energy Analysis." *Energy and Buildings.*