THERMAL COMFORT CONDITIONS IN A ROOM VENTILATED WITH SPLIT SYSTEM – NUMERICAL AND EXPERIMENTAL ANALYSIS

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Abstract. *The ISO 7730 Standard defines thermal comfort as the mental condition that expresses satisfaction with the thermal environment. The evaluation of thermal comfort in indoor environments is usually performed by the measurement of air temperature, global temperature (mean radiant temperature), velocity and relative humidity. In recent years, however, there has been an increasing use of CFD software for numerical solution of flow and exchange of heat and mass for calculation of the environmental parameters. Therefore, in this work the conditions of thermal comfort based on* PPD and PMV *assessment in a classroom with a split system are analyzed using experimental and numerical results. The air temperature and velocity were measured and compared with the numerical results. The measurements and numerical results showed a reasonable agreement and the analyses allowed the identification of the thermal characteristics of the environment as well as comfort conditions. It was found that the measured and predicted air temperatures were within the limits of thermal comfort standards. However, the air velocity showed a significant variation in some points in the room, which revealed great difficulty in obtaining uniform conditions for thermal comfort in the classroom air-conditioned with split system. The position in front of the blackboard where the flow inlet hits directly showed to have the most thermal dissatisfaction, caused by the air motion that can lead to draught sensation.*

Keywords: Thermal comfort, classroom , CFD, *numerical solution*.

1. INTRODUCTION

Indoor environments of rooms are needed to be more thermally comfortable and healthy as the residence time in the building has been gradually increased and the wellbeing concepts to upgrade the quality of life have dominated our society (Noh et al, 2007; ISO, 2005; ASHRAE Standard 55, 2005).

The main objective of heating, ventilation and air conditioning is to provide comfort to the occupants removing or adding heat and humidity of the occupied space (Orosa, 2009).

Most schools in Brazil have natural ventilation in classrooms and those with air conditioning have split systems. A Split System normally includes an Evaporator, a Condenser, a Compressor and interconnecting refrigerant hoses, fittings, and electrical harness and controls. The evaporator is located inside the room while the condenser and compressor are located outside.

Normally this type of system only recirculates the air inside the room without the appropriate filtration and quantity of outside air. Besides, this kind of equipment produces an enormous turbulence inside the room due to the cold inlet jet and its high velocity (3.0 m/s). Air movement can create draughts, a sensation of unwanted local cooling of the skin. It is also important to highlight that, although split systems are often used, there are few published studies that examines the impact of this equipment on indoor thermal comfort conditions in classrooms and other school spaces. That is, the existing information or academic performance on thermal comfort in schools that use this type of equipment are especially limited and those have been studied separately by some researchers (Pereira, 2009).

The assessment of thermal comfort in interior buildings is generally done with the measurement of air temperature, air globe temperature (radiant temperature), air velocity and humidity calculating the PMV and PPD indices (ISO 7730, 2005; ASHRAE Standard 55, 2005).

In this context, this work evaluated the thermal comfort conditions so as to identify the comfort and localized discomfort conditions during lesson hours in the classroom air-conditioned with a Split System using thermal comfort parameters measurement and CFD analysis.

2. METHOD

2.1. Experimental Method

The classroom chosen for the study has 162 m^3 volume (9x6x3m, see figure 1) with one 36,000 BTU/h air-conditioning unit, responsible for the recirculation of the air, with no qualified filter.

The evaluation of thermal comfort conditions in the environment was based on local measurements of comfort variables. Measurements were made at 7 points previously determined, covering the whole room area. Figure 2 shows the location inside the room where the comfort variables were measured. At each location, the transducers were placed at five heights above the floor (0.10, 0.60, 1.10, 1.60 and 2.50 m).

The experimental equipment used in the measurements included a hot wire anemometer (Airflow TA-35), a humidity sensor (Ahlborn – Almemo 2290-8), an infrared thermometer (Raytek Raynger MX) and a data acquisition system (Yokogawa Datum-Y).

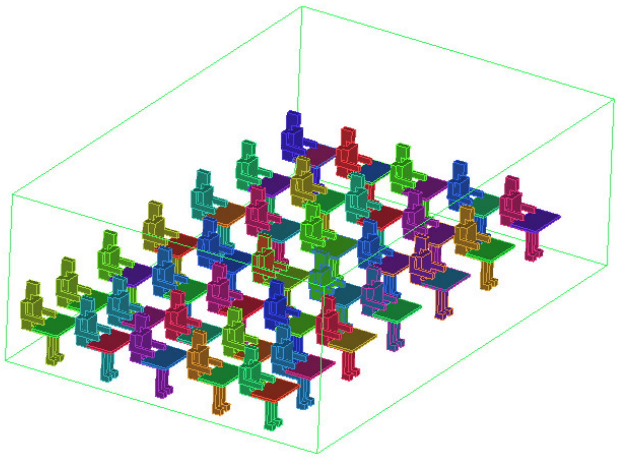

Figure 1. classroom geometry

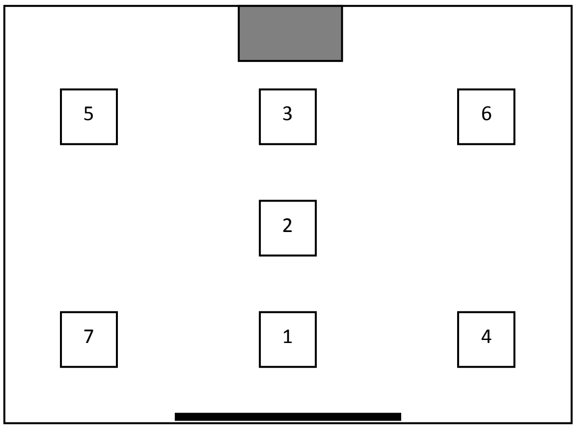

Figure 2. Location of measuring points

2.2 Numerical Method

In order to study the flow pattern a CFD analysis of the classroom was carried out using the Fluent Commercial Software.

The simulated model has the same geometrical configuration as the room. The approach was to build a basic geometry of the room and to generate a relatively coarse grid so as to procure a solution to confirm the modeling assumptions. Details such as furniture and heat sources were then inserted into the geometry. This was followed by grid refinement to improve resolution and accuracy.

As boundary conditions to simulate the flow, a fixed velocity inlet of 3.0 m/s was used (total amount of air of 2,200 m^3/h) and all the flow returning to the outlet that is positioned below the split. The discretization of the domain was done using a tetrahedral mesh with refinements in the region of the air conditioning equipment, both inlet and outlet. Also for boundary conditions, it was considered a fixed temperature both for people and walls, without air changes. The solution of the problem used a standard k-ε model to solve the viscous turbulent flow. (Fluent Full Manual, 2005).

For the assessment of PPD and PMV, some adjustments were necessary in the model to use the measured data, so for the supply temperature it was used an average temperature of 15°C, with superficial temperature of the people models of 30°C, the walls temperature according to the measurements using the infrared thermometer were set to 23.5°C and for the furniture no heat flux. The temperatures of the air in the simulation were a little below those of the measurements showing that the numeric model in steady state condition was more sensitive to the supply temperature.

3. RESULTS

3.1 Temperatures and velocities field

The environment's thermal conditions were analyzed based on thermal comfort variables measured and simulated, such as air temperature and velocity. The experimental results are represented in the form of graphs in Figures 3 and 4.

For seated people, the vertical differences of the values measured between levels 0.10 m and 1.10 m did not exceed 0.9°C and it can also be seen that the temperature in the whole room area was very close. This phenomenon occurred mainly because the main heat sources from people are situated below 0.6 m level and because of mixing ventilation produced by the split system.

At foot level it was verified that the minimum temperature in the whole room area was 21°C at position 1.

For the standing position, the minimum temperature values in the whole room area were 21°C also at position 1. It is important to highlight that this point was located in front of the blackboard where the cold jet flow inlet hits directly.

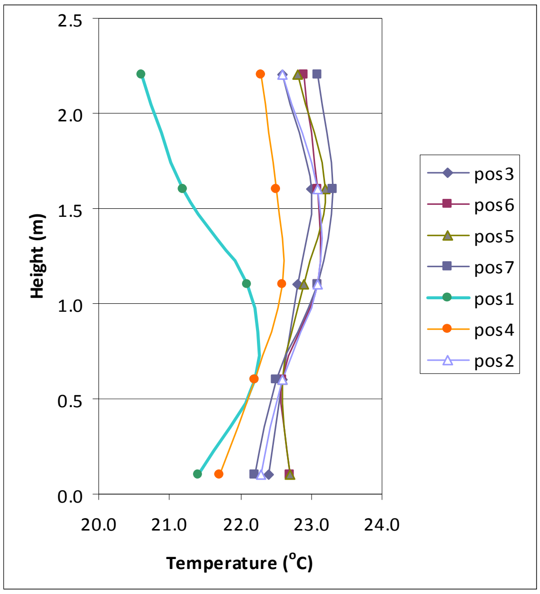

Figure 3. Air temperature profiles – experimental measurements

Concerning air velocity, the profiles acquired from these measurements, indicated a significant variation in velocity in some locations of the room area. At all measured locations, the highest value found at occupation zone was 0.50 m/s, mostly remaining around 0,10 and 0,25 m/s.

It can be seen that the highest vertical variation occurred at positions 1 and 2. That is, at position 1 the air velocity increased constantly with height, the values measured varied between 0,10 m/s and 0,7 m/s. It is also important to remember that the positions 1 and 2 were located in front of the flow inlet jet.

The lowest vertical variation occurred at positions 5 and 6, both located at the back of the room and in both cases the variation was 0.1 m/s.

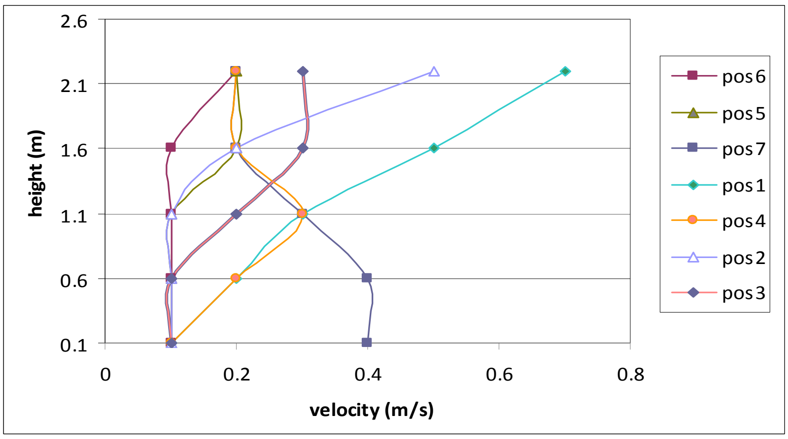

Figure 4. Air velocity profiles – experimental measurements

Figure 5 shows the pathlines of the flow inside the room and figure 6 the velocity contours, both coming from the numerical analysis. It can be seen that in this split system model the air return is below the equipment on top of the room, the flow inlet hits the opposite wall where the blackboard is located and then circulates on the periphery of the room until it reaches the outlet.

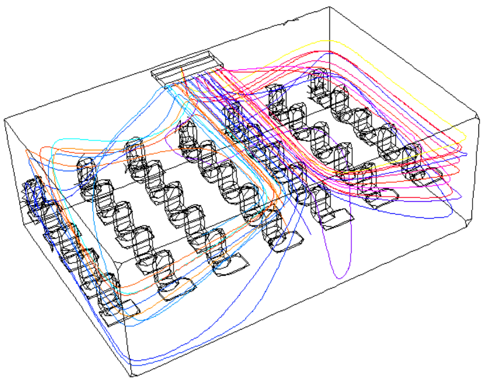

Figure 5 – Pathlines inside the room

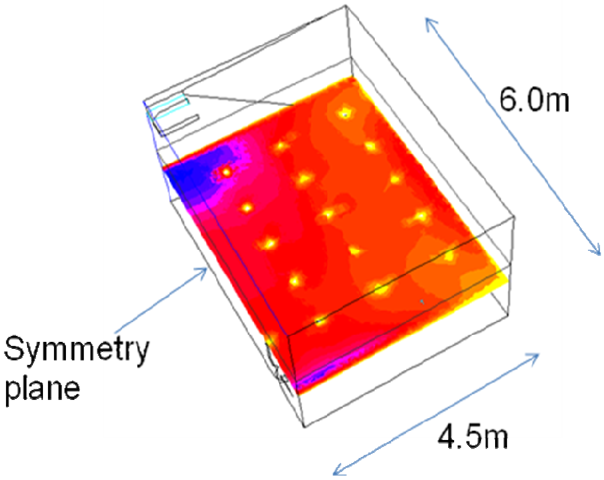

Figure 6 – Top view with velocity contours (h=1.10m), simulation

Figures 7 and 8 shows the numerics results for the temperature and velocity field in a horizontal plane view used to calculate the PMV and PPD values.

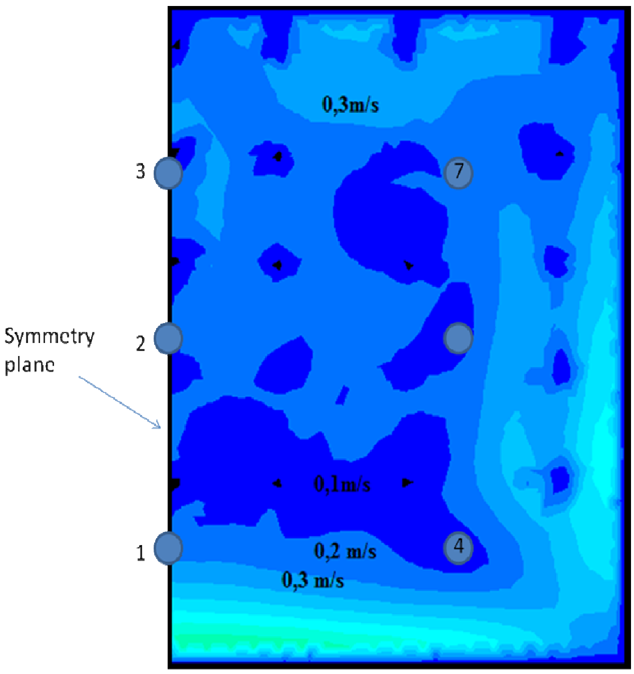

Figure 7 – Plane view of velocity contours (h=1.10m), simulation

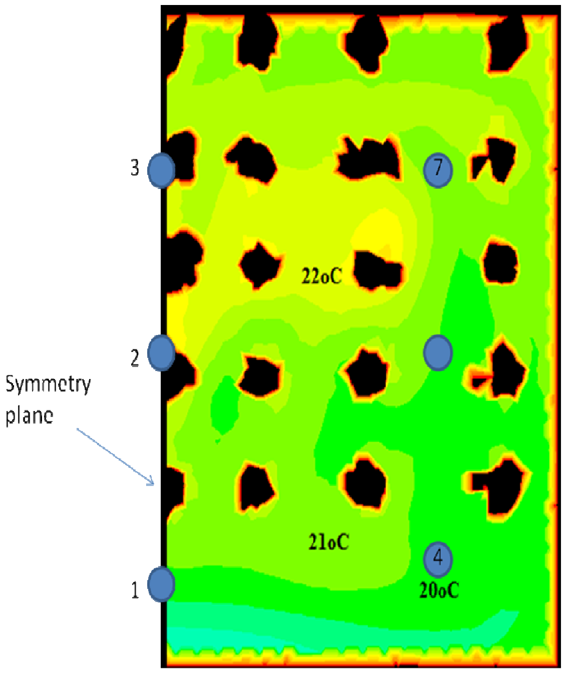

Figure 8 – Plane view of temperature contours (h=1.10m), simulation

3.2 Return and supply temperature

The return temperature controls the on/off cycle of the Split system and was set to 23.0°C during the measurements. Figure 9 shows the supply and return temperature profile during the experiment, for the CFD modeling and the experimental assessment of PMV and PPD an average value of the supply temperature was used.

Due to short-circuiting between supply and return of the split, small changes in temperature supply does not affect the temperature in the 1.10m height plane (breathing plane), thus it is possible to analyze the overall comfort assessment even with a steady state approach, at least for this case when the measured data of the room are already collected for comparison. So a 15°C up to 17°C supply temperature will result in quite the same PMV and PPD responses for the tested points. This is not true when you allow this temperature to reach a 10°C supply temperature, which will cause a major thermal discomfort to the subjects.

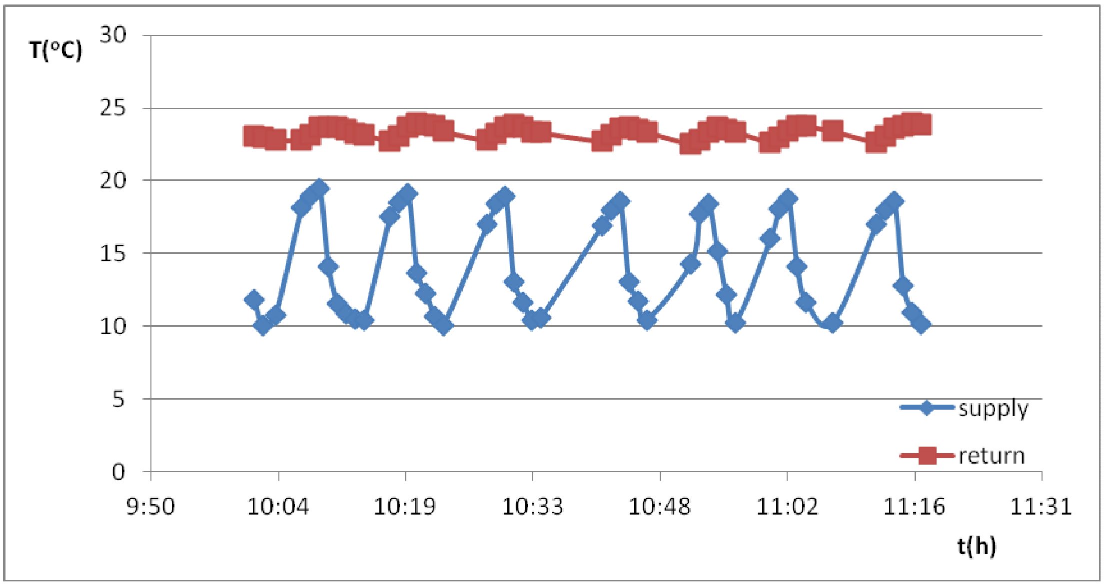

Figure 9 – Supply and return temperature cycle.

3.3 Assessment of PMV and PPD

The ISO 7730 standard provides equations for the assessment of thermal comfort conditions, according to these equations the PMV and PPD were calculated for each point measured inside the room, the results are indicated in figure 10 showing a good symmetry for the results, points 5 and 6 and points 4 and 7 have quite the same PMV and PPD. For these locations the temperature are slight different and the velocities too, which led to a slight variation in PMV and PPD.

Also it was necessary to define according to the standard and in site measurements, the metabolic rate as 50W/m^2, the radiant temperature as 23.5°C, partial air pressure as 1.466 kPa (50% humidity), and clothing insulation as 0.5clo,

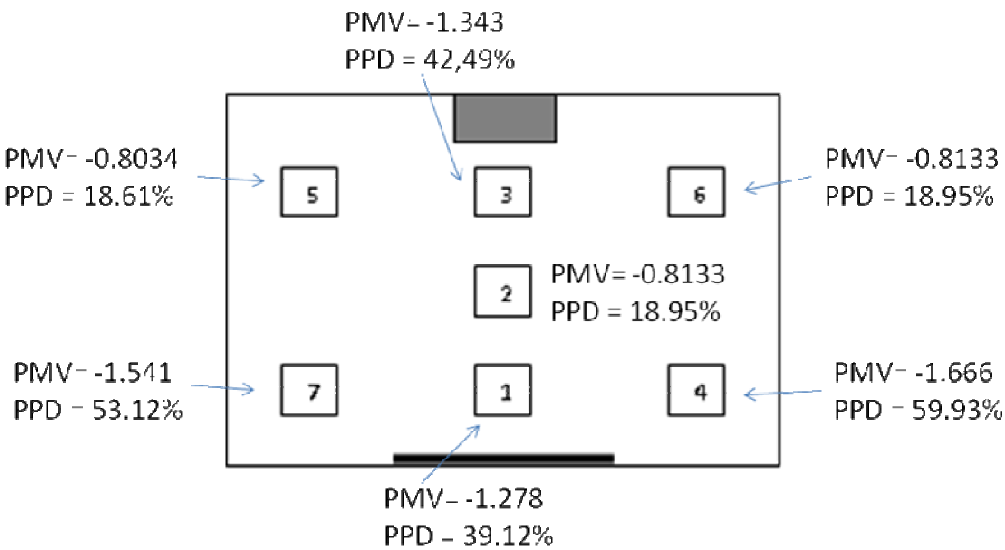

Figure 10 – Results for PMV and PPD for breathing height (1.10m), experimental results.

Figure 11 show the numerical results for the PMV and PPD (1.10m height). Except for point 1, it can be seen a good agreement with experimental results. That is, the points 5 and 6, and points 4 and 7 have quite the same PMV and PPD values.

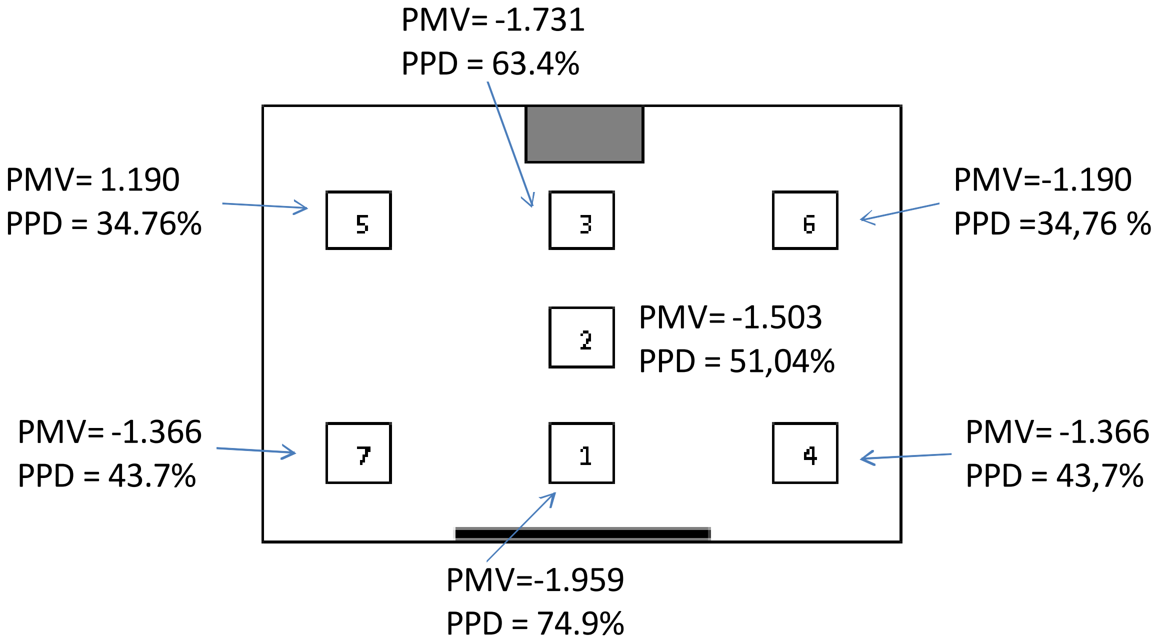

Figure 11 – Numerical results for the PMV and PPD (1.10m height)

4. CONCLUSIONS AND CONSIDERATIONS

It is important to highlight that, in this work it was used in the simulations a supply temperature of 15 ^{o}C, but during the measurements it was observed that the supply temperature varied between 10 and 19 ^{o}C. The supply temperatures of 15 up to 17^{o}C when used in the simulations, lead to the same PMV and PPD values and agrees with the measured data. However, when the split works with a 10^{o}C supply temperature the thermal discomfort reaches its maximum value.

This paper evaluates the current thermal comfort conditions of a classroom conditioned with a Split system using experimental measurements and computational fluid dynamics modeling. A CFD tool was used to simulate the indoor comfort parameters, such as air temperature and velocity. Corroboration between results from the field measurements and predicted values were conducted.

From the results one can see that the overall agreement between the measured and predicted (CFD) velocities and temperatures were good when the model boundary conditions is adjusted with the measured temperatures. Then, the general conclusions were that the methodology proposed utilizing experimental measuring and computational fluid dynamics techniques showed to be very effective. Computational fluid dynamics models have been developed to help understand the spatial distribution of airflow pattern and temperature gradients in the classroom environment and the experimental data was used to understand the temporal variation of these parameters.

At breathing level (1.10m height) it could be seen that the temperature in the whole room area was very uniform. It suggests that for the situation analyzed the Split system did not cause problems for thermal gradients.

Concerning air velocity, the results showed a significant variation in the air velocity in the whole room, which showed great difficulty in obtaining uniform conditions for thermal comfort in the classroom air-conditioned with this type of split system. The position in front of the blackboard where the cold flow inlet hits directly showed to have the greatest thermal dissatisfaction, caused by the air motion that can lead to draught sensation. So it is recommended that the discharge angle for this type of split system should be controlled.

5. ACKNOWLEDGEMENTS

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