EXPERIMENTAL AND NUMERICAL ANALYSIS OF INDOOR AIR QUALITY IN CLASSROOMS

Marcelo Luiz Pereira, marcelo.pereira@ifsc.edu.br
Federal Institute of Education, Science and Technology of Santa Catarina, Brazil

Rogério Vilain, vilain@ifsc.edu.br
Federal Institute of Education, Science and Technology of Santa Catarina, Brazil
University of São Paulo, Polytechnic School, Program of Post-Graduation in Mechanical Engineering, Brazil

Arlindo Tribess, tribess@usp.br
University of São Paulo, Polytechnic School, Department of Mechanical Engineering, Brazil

Abstract. *The issue of air quality in classrooms is important to highlight the main sources of contamination and the risk of acquiring illnesses. This study investigated the movement, distribution and concentration of contaminants in a school room ventilated with split system using experimental measuring and computational fluid dynamics techniques (CFD). The measurements were carried out during indoor activity and the results showed that in all cases analyzed the air change rates (ACH) were far below the recommended for classrooms. This is due to the fact that the split system only recirculates the indoor air, without a fresh supply outdoor air. It will favor the increasing of the air contamination inside of the room representing a risk to the occupants. The CFD analysis showed that due to the equipment flow pattern in a densely occupied room the risk of contamination is much increased and should be of concern to the director board. Finally, it is important to highlight that although the methodology proposed utilizing experimental measuring and computational fluid dynamics techniques showed to be very effective, continued studies in schools are needed to fully assess both the exposure levels and the clinical significance to atopic children allergic to these contaminants*

Keywords*: IAQ, CFD, Classrooms, occupational health.*

1. INTRODUCTION

The spread of influenza H1N1 and H5N5 over the last years increases significantly the concern about airborne infection transmission control. Since bacteria are usually carried by particles or spread via water droplets (Kowalski, 2006; Apte 2000) one of the fundamentals techniques to diminish this spread is controlling the number of particles inside a room.

Classrooms and other school spaces must be ventilated to remove odors and other pollutants. Infections can be transmitted in various ways, particularly through physical contact or through the air. Schools play a major role in spreading viral infections through the population. The likelihood of respiratory infections such as influenza being spread via schools is partly determined by the concentration of pathogens in classrooms air. However, no suitable study has been conducted on the link between ventilation and the prevention of infections caused by pathogens in schools.

Various European studies on the air in classrooms found concentrations of particle in excess of the exposure limit for outdoor air. This mainly applied to the coarser fraction of particulate matter, which enters air through the activities of pupils. This particulate matter could plausibly exacerbate respiratory symptoms, especially in the case of the asthmatic pupils, but no research has been conducted into this (HCN, 2010).

Most schools in Brazil have natural ventilation in classroom and most of the schools with air conditioning have split system. A Split system normally includes an evaporator, a condenser, a compressor and interconnecting refrigerant hoses, fittings, and electrical harnesses and controls. The evaporator is located inside of the room while the condenser and compressor are located outside.

Normally this type of system only recirculates the air inside the room without filtration and the appropriate quantity of outside air. Besides, this kind of equipment produces an enormous turbulence inside the room. Air movement can create draughts, a sensation of an unwanted local cooling of the skin. It is also important to highlight that, although split system ventilation is often used, there are few published studies that examines the impact of the split system on indoor contamination concentration and distribution in classrooms and other school spaces.

The use of particle counters and CO_2 measurements help to define the basic air quality inside conditioned spaces (Jones, 2008), along with them, the use of a CFD approach has helped understanding the movement and concentration distribution of particles inside a room. The CFD approach is used here and showed very interesting results in a densely occupied classroom providing information about the use of split systems, so common today, indicating points of concern to improve IAQ in this particular site, a classroom.

In this context, this study investigates the distribution of the airborne particles in a classroom ventilated with split system using experimental measuring and computational fluid dynamics techniques (CFD). The measurements and simulation were accomplished at a Brazilian school located in Florianópolis-SC.

2. ROOM GEOMETRY AND AIR CONDITIONING EQUIPMENT

The classroom has dimensions of 9x6x3m (figure 1) and 31 people are inside this classroom. Windows are positioned in one side of the room and are kept closed, while the door is located in the opposite side and is kept closed as well. The chalkboard has 5.0x1.3m dimensions, 0.9m above the floor.

The air conditioning equipment has a 36,000BTU/h cooling capacity with an air flow of 2,200m^3/h (corresponding to the maximum value, without swing mode).

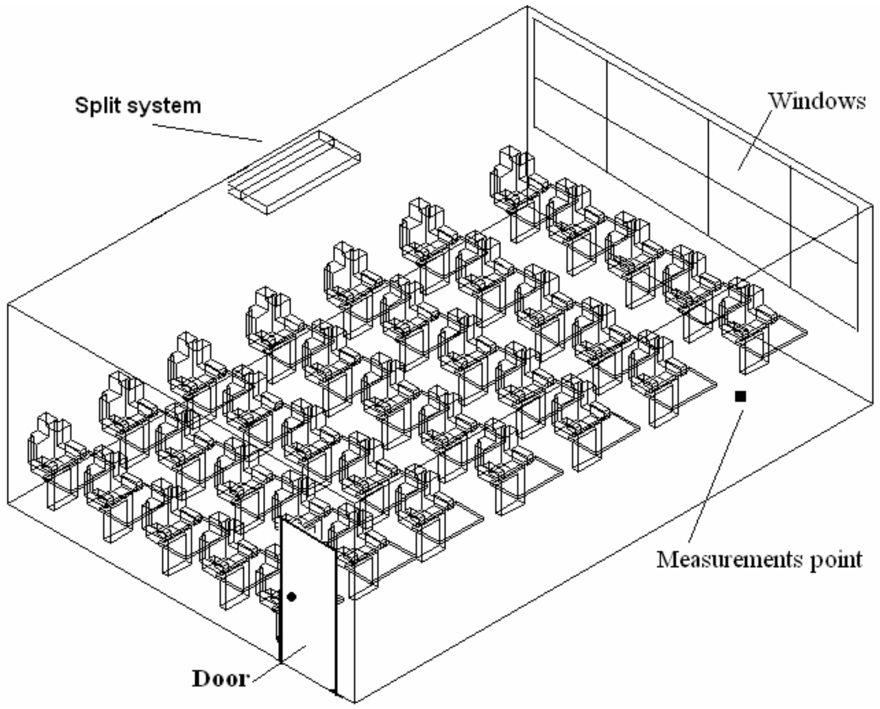

Figure 1. Classroom geometry

3. PARTICLES COUNTING

The number and size distribution of airborne particles on the classroom was recorded using a particle counter, calibrated by the manufacturer (MET ONE). The equipment was programmed to run continuously during all class and recorded the particle count every 5min for six size distributions, 0.3 µm to 0.5 µm, 0.5 µm to 1.0 µm,1.0 µm to 3.0 µm, 3.0 µm to 5.0 µm, 5.0 µm to 10.0 µm, and >10 µm, with a flow of 0.1 cfm (2.83 L/min). The particle counter was placed approximately at 1 m high (Figure 1).

The activities performed within the classroom also were recorded every 5 minutes, so as to obtain a relation between the particles generated and the activities performed.

4. CFD ANALYSIS

In order to study the flow pattern a CFD analysis of the classroom was carried out using the fluent commercial software (Fluent, 2005) The discretization of the domain was done using a tetrahedral mesh with refinements in the region of the air conditioning equipment, both outlet and inlet.

4.1. Boundary conditions

To simulate the air flow it was used a fixed split outlet velocity of 3.0m/s (total amount of air of 2,200m^3/h) and all the flow returning to the inlet positioned at the bottom of the split. All the walls, including floor and ceiling are set to trap the particles with no rebound and no resuspention for simplification. If the particle reaches the inlet it is considered out of the room, escaped. The ambient was considered isothermal without air changes. The solution of the problem used a standard k-ε model to solve the viscous turbulent flow. The mean turbulent trajectories are used to represent the particle trajectories. People and desks are modeled as simplified solids. As the ACH was too low (0.75), as shown in item 4.1, and for simplification no outside air is considered in the model. Most of the turbulence is generated by the free jet coming from the outlet of the air conditioning equipment.

4.2 Flow solution

The Euler-Lagrange approach was used to solve the air flow and the pollutant dispersion inside the room. In this model the general conservation law equation for the variable Ø (eq.1, Versteeg and Malalasakera, 1995) along with a turbulence model is used to solve the air flow. A discrete phase model (Fluent, 2005) is used to track the particles. The interaction between the particles and the air is calculated by the drag force exerted on the particle (Kowalski, 2006; Lu, 1996).

$$\frac{\partial(\rho\phi)}{\partial t} + div\left(\rho\phi\vec{u}\right) = div(\Gamma grad\phi) + S_\phi \quad (1)$$

where:
ϕ = mass, momentum or energy
$\vec{u}$ = velocity vector
S_ϕ = source term
ρ = density
Γ = diffusion coefficient for the variable ϕ

$$F_d = \frac{18\mu}{\rho_p d_p^2}\frac{Cd\,\mathrm{Re}}{24} \quad (2)$$

where:
F_d = drag force
μ = air viscosity
ρ_p = density of the particle
d_p = diameter of the particle
C_d = drag coefficient
Re = Reynolds number

To model the particles, inert spherical water droplets are used. They will be injected from the outlet of the air conditioning and from the people that are considered infected. They are treated as a bacteria carrying particle (BCP) that is responsible for disease spread. As shown in item 6, from the split outlet 20 particles (1µm diameter) will be tracked (dpm model) and from a student in the front line 2 particles (1µm and 10µm) will be tracked too. The results will then be represented by their trajectories (Figs. 4 to 7).

Besides its aerodynamic diameter, if the real particle is not spherical, it is necessary to consider the density of the particles (equation 3, Kowalski, 2006). If we consider the particles or microbes spherical then we will have the equivalent diameter of water droplets that are represented in the simulation:

$$Da = D_p\sqrt{\frac{\rho_p}{\rho_w}} \quad (3)$$

where:
Da = equivalent aerodynamic diameter
Dp = diameter of the particle
ρ_p = density of the real particle
ρ_w = density of the water (1,000kg/m^3)

5. EXPERIMENTAL RESULTS

5.1 CO_2 concentration

Figure 2 illustrates the temporal variations of CO_2 in the classroom studied with 31 occupants in comparison with the ASHRAE recommendations (ASHRAE Standard 62.1, 2004). It can be seen that the CO_2 concentration increases continuously during the measurement. Healthy thresholds are exceeded within a matter of minutes after students arrival at 7:30 a.m. The amount of outside air was previously estimated with the use of a CO_2 indicator resulting in an ACH (air changes per hour) of 0.75 (Awbi, 2003), which is very low compared to the ASHRAE guidelines for classrooms with ACH of 5.51 (8 l/s per person of outside air).

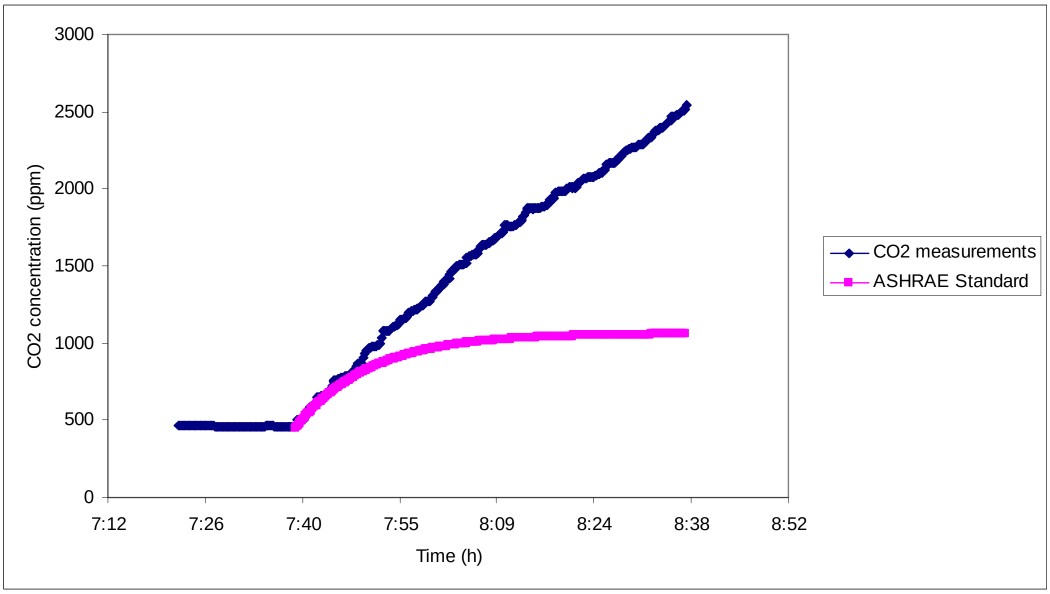

Figure 2. Fluctuation of CO_2 concentration in the classroom compared with AHSRAE recommendation.

5.2 Particle concentration

Figure 3 shows the temporal variations of particle concentrations in the room. It can be seen that before the students arrival, the concentration of particles was low. With the students entrance the concentration increases until it reaches stability as they remained seated. At the end of the class the movement of the students increases the concentration again.

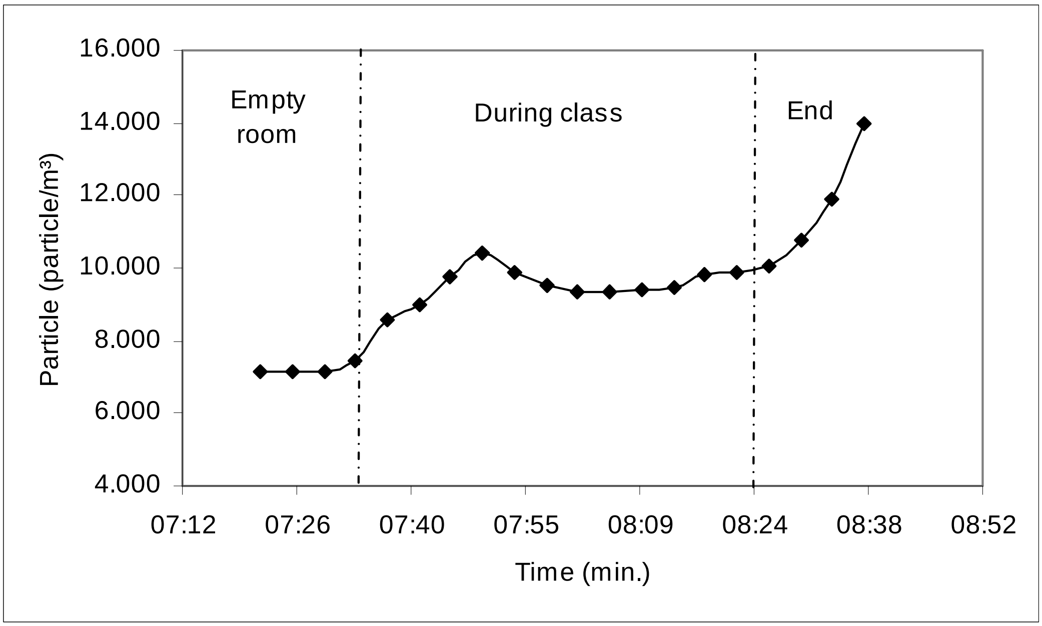

Figure 3. Particle concentration inside the classroom

6. CFD RESULTS

The simulations show the results of particle trajectories released from a person located in the first line in the middle of the room, for 1 and 10 µm diameter size. As well it was simulated the release of particles (1 µm) from the outlet of the split system.

In the results, each particle trajectory can be incomplete, trapped or escaped according to the total particle time step defined previously in the simulation.

Figure 4 shows the trajectory of a 1µm diameter particle released by an infected person positioned in the center of the classroom in the first row,. It begins at the breathing height of 1.2m and then is carried by the flow passing near the split, but it is not caught by the return of the split, recirculating again in the room, i.e., its fate is incomplete.

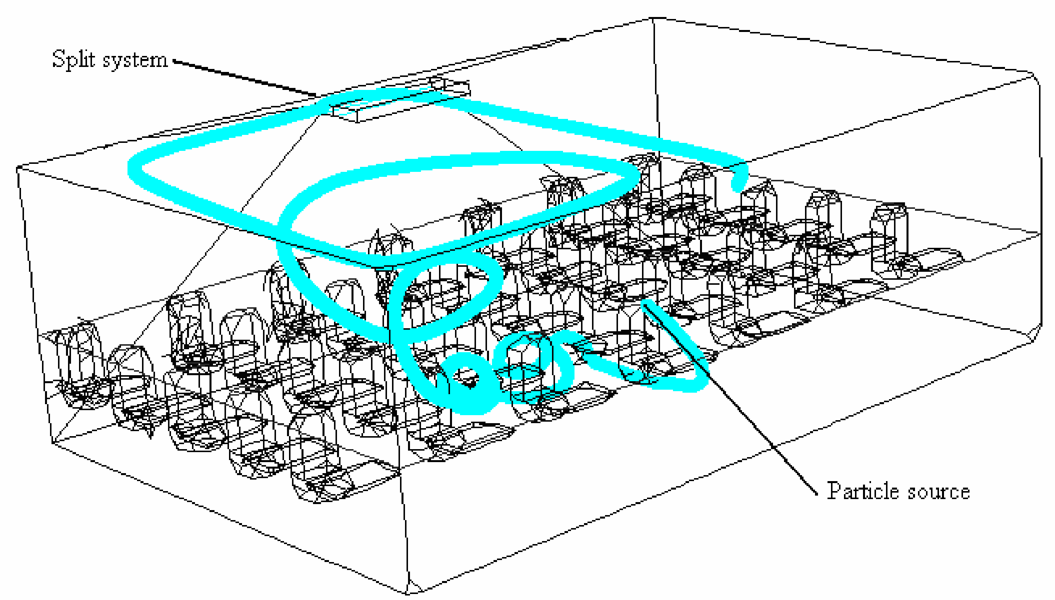

Figure 4. Particle trajectory (1 µm).

Figure 5 shows a 10µm particle released at the same point, center of the classroom, but now as its weight is greater, 1,000 times heavier than the 1 um particle of figure 1, it will remains longer at the breathing height. As contrary to our expectation it will fluctuate more than the lighter ones at the breathing height. It was shown as incomplete fate too.

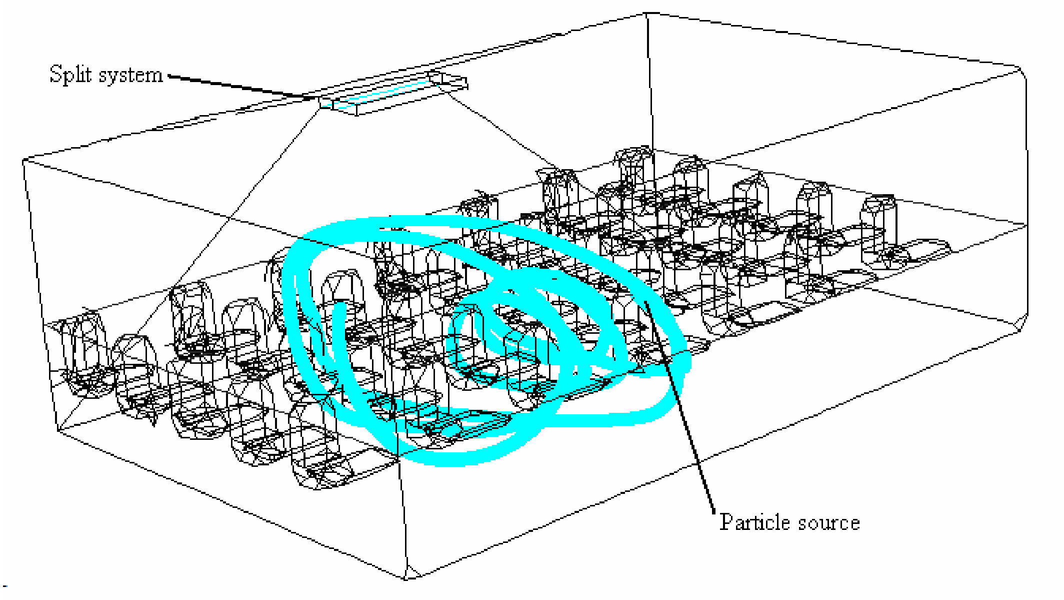

Figure 5. Particle trajectory (10 µm)

Figure 6 shows that the trajectory of the particle released at the same place can have a totally different direction. In other words, in figures 4 and 5 the particles released went to the left side of the room. In figure 6 both particles go to the right side showing the random characteristic of the model used. The initial trajectories are roughly the same as in figures 4 and 5, but then one of the particles is trapped and the other remains incomplete.

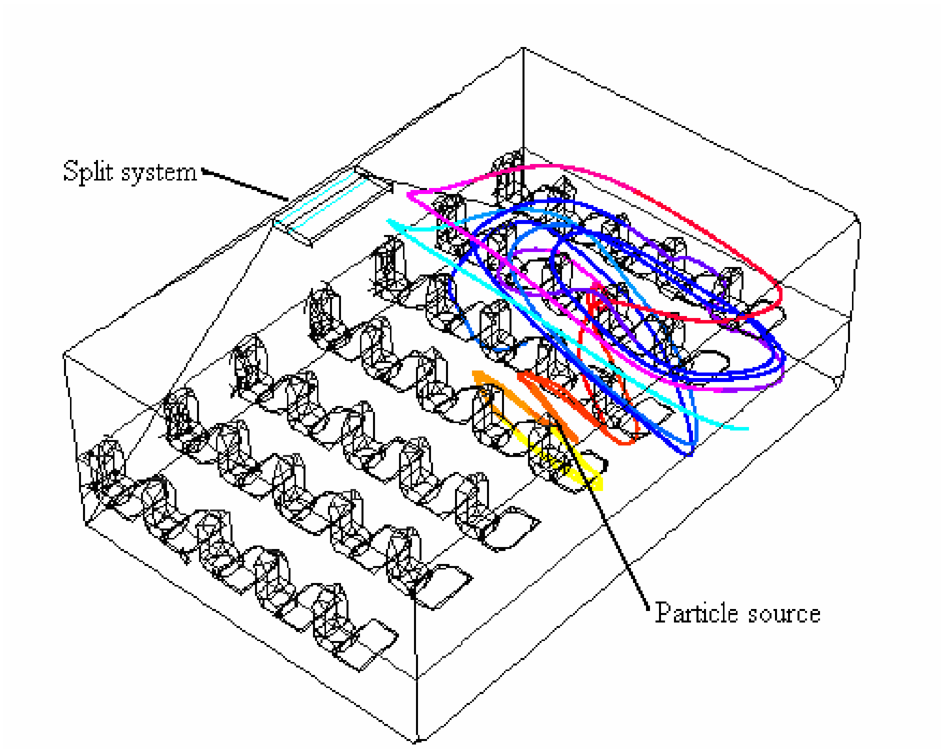

Figure 6. Particle trajectories (1 and 10 µm)

Figure 7 shows the resulting trajectories of 1µm diameter particles released from the outlet of the split. Twenty particles are tracked from the outlet, resulting for this particular trajectory length, that five particles are trapped in the walls, five escaped to the split inlet and 10 particles (50%) have their fate incomplete resulting in a great recirculation of particles over the room and low contaminant removal efficiency. It is important to remember that the split can accumulate dust or throw the particles back to the room due to filtering deficiency. That is why it is important to consider the pollutant coming from the split system.

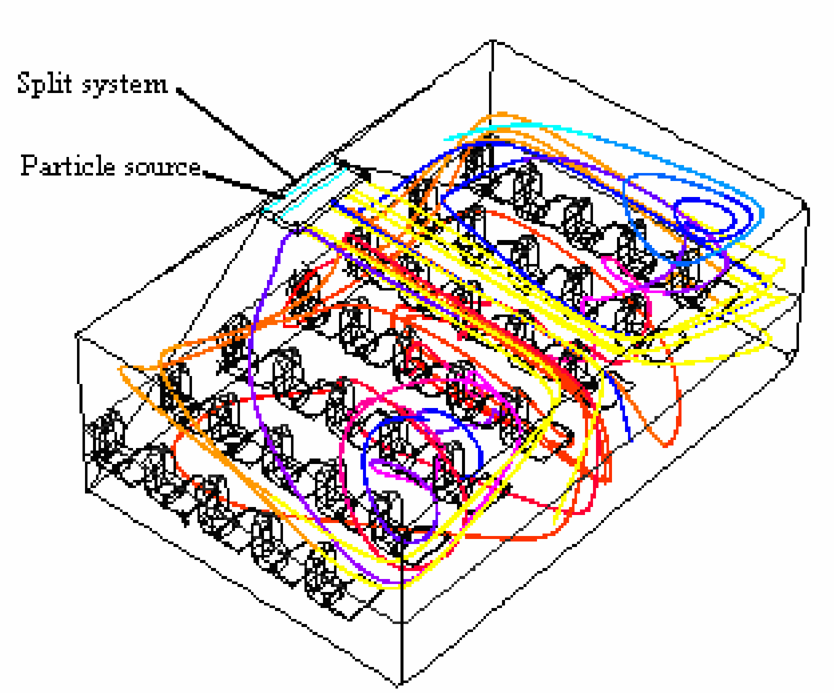

Figure 7. Particle trajectories (1 µm) for particles released from the outlet of the equipment

Figure 8 shows the particle concentration in the entire room. It can be seen from this figure that the pollutants will be concentrated in the stagnant areas. The concentrations showed in figure 8 are not representative of the real concentration values as showed in figure 3, but it was created for visualization interest.

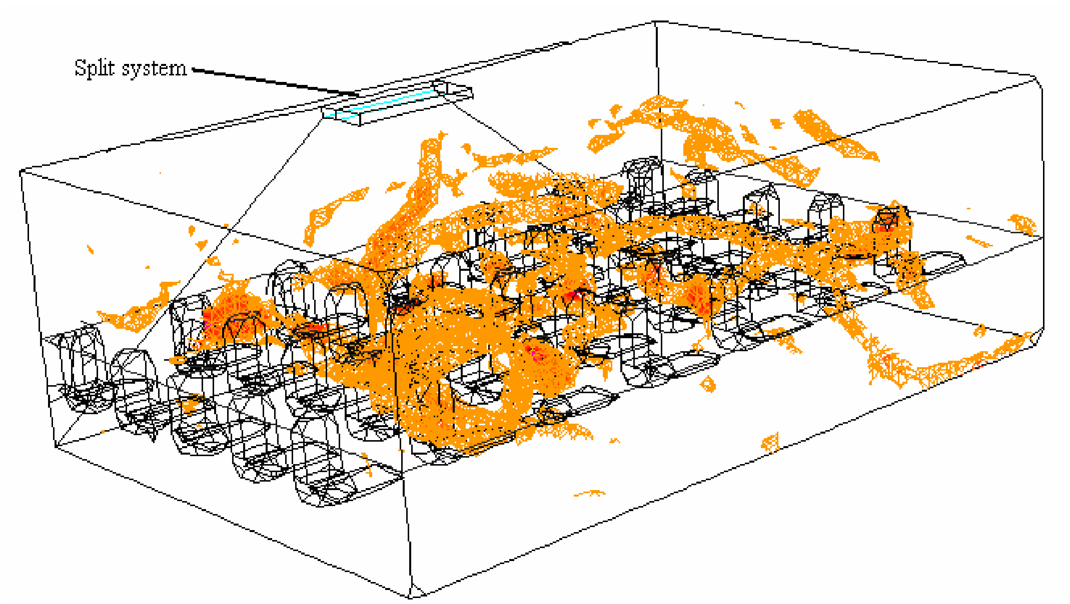

Figure 8. Particle concentration

7. CONCLUSIONS

As a result of the poor outside ventilation the particle concentration build up from approximately 7,000 to 9,000 particles/cm^3 and the CO_2 concentration followed an increasing tendency, from 500 to 2,500 ppm, no reaching a steady value.

According to particle concentration the numerical results showed that the concentration was high and uneven distributed in the interior of the room as a result of the flow pattern generated by the split system.

The experimental results were obtained using only one measuring point, owing this fact the experimental results may not represent the behavior of particles in the whole room.

The heavier particles (10µm) tend to stay fluctuating longer at the breathing height, and the lighter ones (1µm) are easier to be carried by the flow, and can escape, be trapped or recirculate again. A recirculating pattern flow is created in both sides of the room on the right and left of the split outlet.

Once more it was evidenced that the use of a split air conditioner, with poor filtering, and a low outside air intake increases the risk of contamination to the people exposed to the contaminants, the students.

General conclusion was that the methodology proposed utilizing experimental measuring and computational fluid dynamics techniques shown to be very effective. Computational fluid dynamics (CFD) models have been developed to help to understand the transport and dispersion of these particles in indoor environments and the experimental data were used to understand the temporal variation of particle concentrations.

It is also important to highlight that continued studies in schools are needed to fully assess both the exposure levels and the clinical significance to atopic children allergic to these contaminants.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

Awbi, H.B., Ventilation of buildings, 2nd edition, 2003. Spon Press, London, pp.74.

ASHRAE Standard 62.1 (2004) Ventilation for acceptable indoor air quality, American Society of Heating, Refrigeration and Air Conditioning, Atlanta, GA.

Apte, M.G., W.J. Fisk, and J.M. Daisey, Associations between Indoor CO2 Concentrations and Sick Building Syndrome Symptoms in U.S. Office Buildings: An Analysis of the 1994-1996 BASE Study Data. Indoor Air, 2000. 10(4): 246-257.

Fluent Full Manual, 2005. Fluent Inc. Lebanon, NH.

HCN - Health Council of the Netherlands. 2010. Indoor air quality in primary schools. Publication no. 2010/06E. ISBN 978-90-5549-808-6.

Kowalski, W.J., 2006, “Aerobiological Engineering Handbook”, McGraw-Hill. US.

Lu, W., Howarth, A. Adam, N. and Riffat. S. 1996. Modeling and measurement of airflow and aerosol particle distribution in a ventilated two-zone chamber. *Building and Environment* 31: 417–423.

Jones,B.M., Kirby, R., Kolokotroni, M. Payne, T.. Air quality measured in a classroom served by roof mounted natural ventilation windcatchers. Proceedings of the 2008 Conference for the Engineering Doctorate in Environmental Technology. UK.

Schell, M., Int-Hout, Dan. Demand Control Ventilation Using CO2. ASHRAE Journal. Febuery 2001.

Seppänen, O., Fisk, W.J. Association of ventilation system type with SBS symptoms in office workers. Indoor Air, 2002. 12(2): 98-112.

Seppänen, O., Fisk, W.J., Q.H. Lei, Ventilation and performance in office work. Indoor Air, 2006. 16(1): 28-36.

Pereira, M.L., Vilain, R. and Tribess, A. 2009. Modeling and measurement of air contaminant distribution in a operating room ventilated with split system. 9th International Conference on Industrial Ventilation 2009.

Versteeg, H.K. and Malalasekera, W. 1995. An introduction to computational fluid dynamics - The finite volume method. Longman Group Ltd. England.

10. RESPONSIBILITY NOTICE

The authors Marcelo Luiz Pereira, Rogério Vilain and Arlindo Tribess are the only responsible for the printed material included in this paper.