Radiant Heating and Cooling Systems Combined with Displacement Ventilation in Schools; Strategies to Improve IAQ

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ABSTRACT

The new schools in Canada are designed to improve indoor environment quality while achieving a much better energy performance than the code compliance requirements.
The IAQ and thermal comfort of a radiant heating and cooling floor combined with displacement ventilation was monitored in a recently built primary school in Québec, Canada. Despite a good thermal stratification, the air quality measured in the occupied zone was above CO2 acceptable level. In order to improve IAQ, it was proposed to do some tests such as the position of the classroom door opened or closed and the addition of a mechanical assisted exhaust fan. The classroom door, when opened combined with mechanical exhaust fan did have a positive impact on air quality. Results are presented during heating mode condition

KEYWORDS

Thermal comfort, Air quality, School

1 INTRODUCTION

Nowadays, new primary schools in Québec are designed to achieve many goals such as consuming less energy, reducing greenhouse gas while providing a very good indoor environment which contribute to a better academic performance of the students. Gregory Kats 'Greening America's Schools 2006'says 'Greening school design provides an extraordinary cost-effective way to enhance student learning'. A pro-active schoolboard in Québec approached us to monitor the IEQ of two classrooms of one of their new school design. This paper will overview the limitations of the HVAC design and the strategy proposed to improve indoor air quality.

2 STUDY BUILDING

The field measurement was performed in a primary school located in Terrebonne , Québec. A new section framed in Figure 1, was built in 2017.

Figure 1 Marie-Soleil Tougas school

Each classroom of this new section is designed with a radiant floor providing warm or cool water depending of the outdoor temperature. The new classroom is ventilated with displacement diffuser. To avoid the cost of installing two new ventilation units and enlarge the existing mechanical room, the schoolboard chose to replace and upgrade the existing ventilation unit to satisfy the airflow rate requirement. Two classrooms located on the second floor were selected for indoor air quality assessment. Classroom (231) facing north-east and classroom 202 facing south-west. During the contruction, the two classrooms were equiped with different sensors all connected to the building automation system. Table 1 outlines the different sensors installed in the two classrooms.The purpose of those permanent sensors is to allow researchers to get data remotely at any time during the year. The figure 2 shows the air distribution in classroom 202 and the location of the four corner diffusers and the return ventilation grilles.

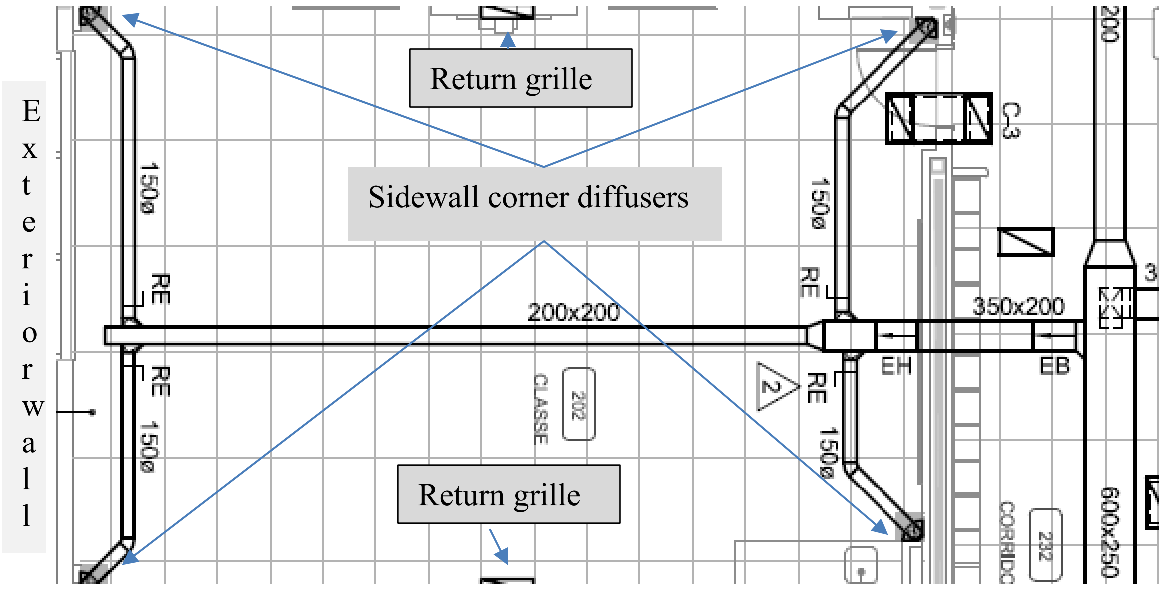

Figure 2 Air distribution in classroom 202

Table 1 list of sensors for continuous monitoring

Type of sensor	Quantity	location
CO2	2	Air diffuser & return duct
Humidity	1	Air diffuser
Air temperature	2	Air diffuser & return duct
Airflow rate	1	Air diffuser
Slab temperature	23	Concrete slab
Operative temperature	1	Classroom wall
BTU meter	1	Radiant manifold

In addition to the sensors listed in table 1, the schoolboard have installed their own sensors to control classroom and floor temperature, and to monitor CO2 in the breathing zone.

2.1 HVAC systems

The HVAC system is designed with a series of geothermal heat pumps providing heating or cooling to the building. The heat pumps are assisted with a thermal accumulator and a back-up electric boiler to maintain geothermal supply water temperature to a minimum of 0 ºC. The radiant slab temperature will vary between 18 and 22 ºC during summer and 18 and 26 ºC during winter.
A central ventilation system is supplying air to all classrooms. The set point temperature of the supply fan can vary between 17 ºC and 21 ºC. The central ventilation system is supplying fresh and recirculated air to the building. The amount of fresh air will vary with respect to the concentration of CO_2 set to maintain 700 ppm in the return duct. A heat recovery device is also installed as part of the ventilation system.

2.2 Air distribution

The air is distributed in each classroom through a ducting network located below the ceiling. Older classrooms are supplying air through ceiling diffusers and new classrooms have displacement diffusers. The air temperature supplied to the diffusers can increase up to 2 ºC between the mechanical room and the classroom located at the farthest distance from the mechanical room.

2.3 Measurement procedure

2.3.1 Measurement location

The performance assessment of the DV system consisted of a monitoring period at three different locations in classroom 202[1]. Figure 3 illustrates the three locations where monitoring was carried out. A picture of the main pole used at the different locations in the classroom is also shown. Location A is close to the exterior wall and slightly outside the occupied zone marked by the dotted line. Location B is within the occupied zone and location C is at the centre of the classroom. In addition to the main pole, a return and reference poles were installed in the classroom, the former to monitor return temperature and CO_2 concentration and the latter to monitor the fluctuation of the temperature of the classroom near the thermostat.

[1] Classroom 202 was selected by the schoolboard to test the effect of mechanical exhaust fan assistance.

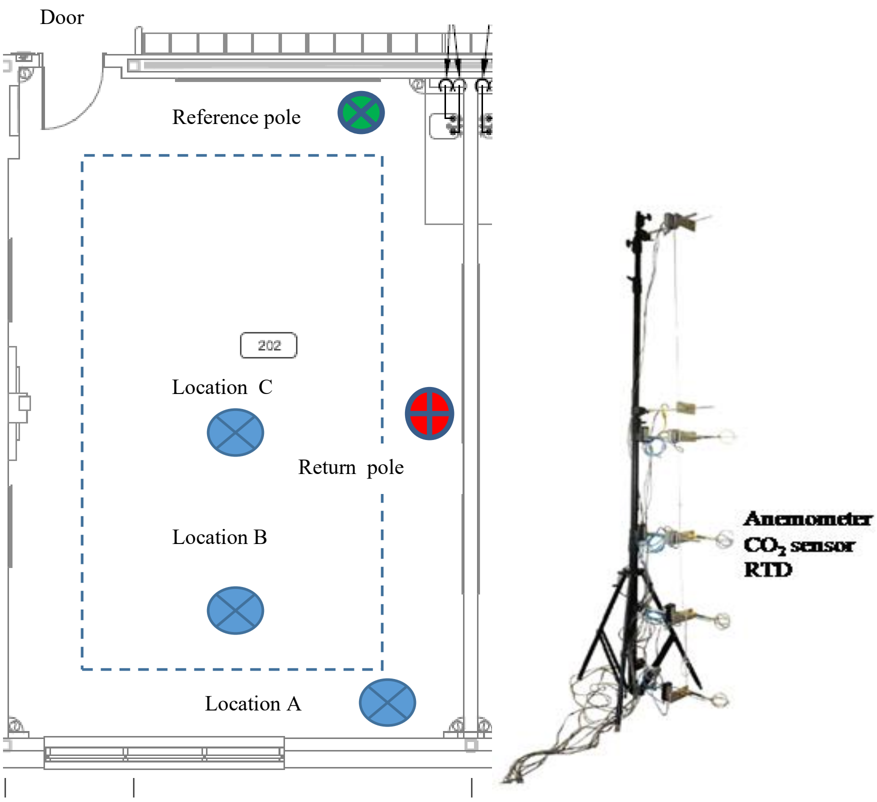

Figure 3 location of the sensors in classroom

2.3.2 Time schedule of measurement

The detailed schedule of measurement is outlined in table 2.

Table 2 Time schedule of the measurement in classroom 202

Location	Start at	Stop at	Door state	Exhaust fan
A	08h00	08h30	open	On
A	08h30	08h55	close	On
break	08h56	09h09	Not monitored	On
A	09h10	09h55	open	On
A	09h56	10h15	close	On
Change of location	10h16	10h19	Not monitored	On
B	10h20	10h45	open	On
B	10h46	11h15	close	On
Lunch time	11h16	12h31	Not monitored	On
C	12h32	12h59	open	On
C	13h00	13h30	close	On
C	13h31	13h44	close	Off
C	13h45	14h15	open	Off

2.3.3 Observations on classroom, ventilation system and climatic conditions

The monitoring session was scheduled on February 26 2019, a winter day in Québec. Table 3 is providing some architectural and ventilation information. Occupancy during the monitoring is also reported. The climatic conditions during that day were as follow:

From 08h00-11h00, the outside temperature was of -14 °C,with sunny sky.
From13h00-15h00, the outside temperature was of -13 °C with sunny sky.

The figure 4 shows the temperature and solar radiation profiles obtained from a weather station installed on the roof of the school.

Table 3 Obsevations on classroom

Monitoring date	February 26, 2019
Classroom	202
Orientation	West South West
Floor area (m2)	68.7
Fenestration area (m2)	7.12
Ceiling height (m)	2,77
Number of students	24 +1 teacher
Student age	12
Monitoring period	07h30-14h30
Number & type diffuseurs	4 Corner displacement diffusers
Air flow supplied to the classroom	213 l/s
Air flow exhaust fan	187 l/s[2]

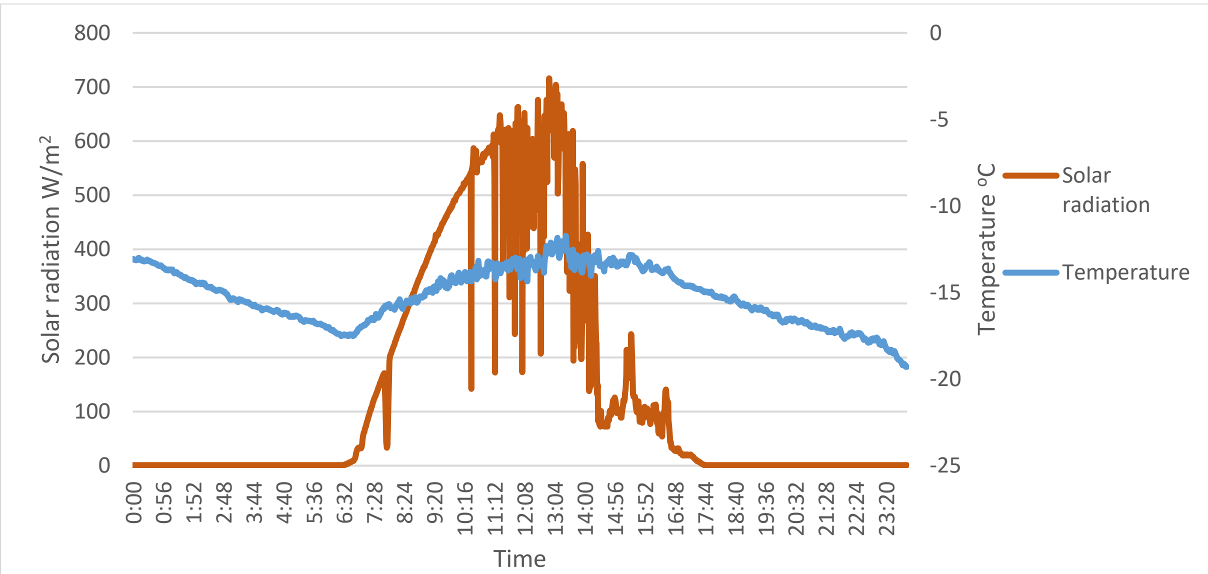

Figure 4 Temperature and solar radiation from a weather station on the roof of Marie-Soleil Tougas school

[2] The exhaust airflow was set to keep the classroom pressure slightly poisitive

This monitoring session was the third one carried out at Marie-Soleil Tougas school. The two previous monitoring sessions were held on March 14 2018, winter condition and September 19 2018, summer condition. During those monitoring sessions, we found that the ventilation airflow and the temperature supplied to the diffusers were not meeting the design specifications. Rebalancing of the ventilation system was then carried out in order to meet the design requirements. Moreover, based on the risk of downdraft observed during the September monitoring session, it was recommended to install a local mechanical exhaust fan ducted to one of the classroom return grille. The schoolboard was highly preoccupied by the high level of CO_2 in the breathing zone and opted for this mechanical assistance to help removing CO_2 from the breathing zone.

2.4 Results

Figure 5 shows the floor temperature, diffuser outlet temperature and operative temperature at 1.1m along the day.

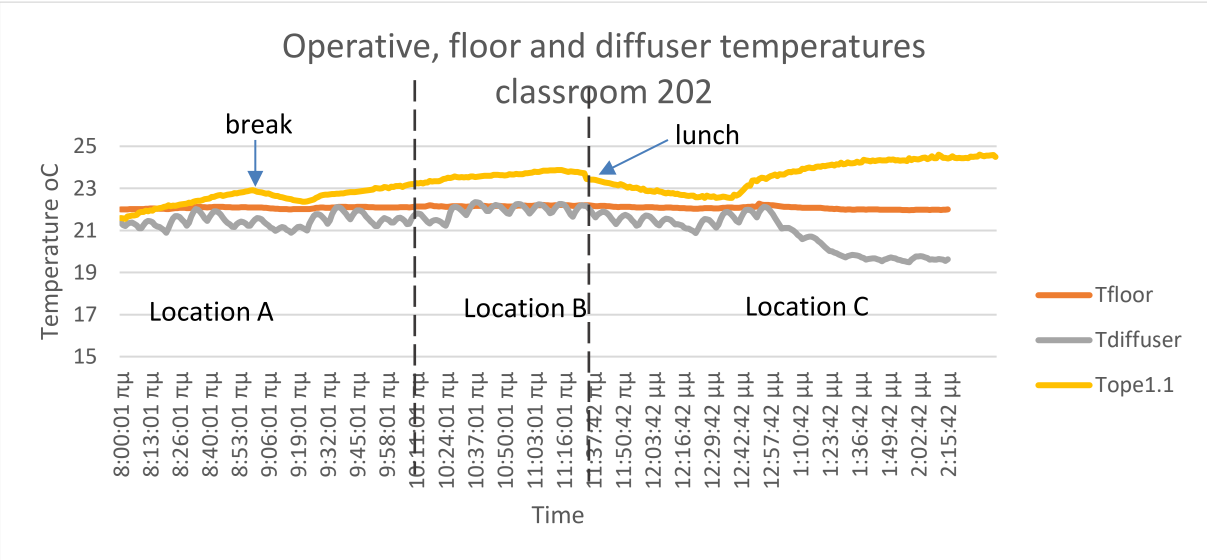

Figure 5 Floor temperature, diffuser outlet temperature and operative temperature at 1.1m

The operative temperature increased from 21.5°C at the beginning of the monitoring (08h00) up to 24.5°C at the end of the monitoring (14h15). If we exclude the morning and the lunch breaks where we can observe a temperature drop (empty classroom), the operative temperature profile was constantly increasing specially after lunch when solar radiation reached a peak of 700 W/m^2. This profile is an indication that the classroom was overheated. The temperature of the floor remained constant at 22 °C and the diffuser temperature fluctuated between 21°C and 22°C except for the last hour where we can observe a significant temperature drop.

In figure 6, the average temperature ratio is showing a good stratification for the three locations when the exhaust fan is on. Measurement done with the exhaust fan off (EFO) at location C indicates that mixing ventilation starts to occur at a height of 1.1 m (see rectangle). In figure 7, the average temperature profiles are plotted for the three locations A,B and C with the classroom door opened (DO) or closed (DC). The door position is clearly showing a difference, with a net advantage for the door open position. With the exhaust fan off, the temperature profiles (dotted curves) does not show any significant differences with respect to the door position. However, there is a significant temperature increase when we compare the temperature profiles, door open and fan on (DO_ABC) with door open and fan off (DO_C-EFO[3]).

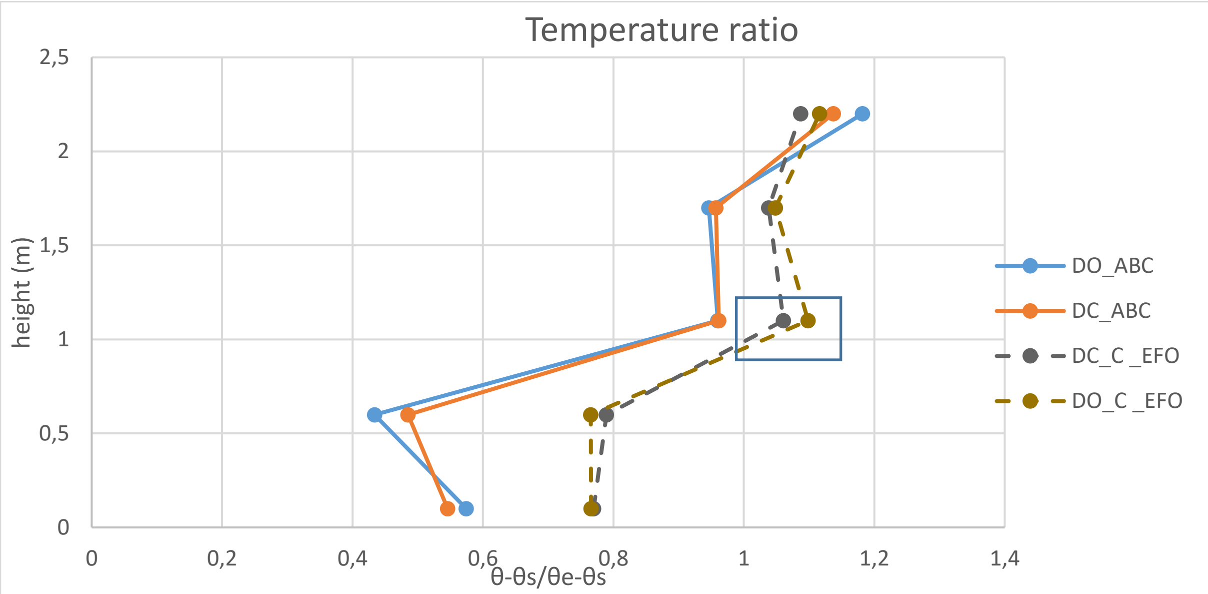

Figure 6 temperature ratio

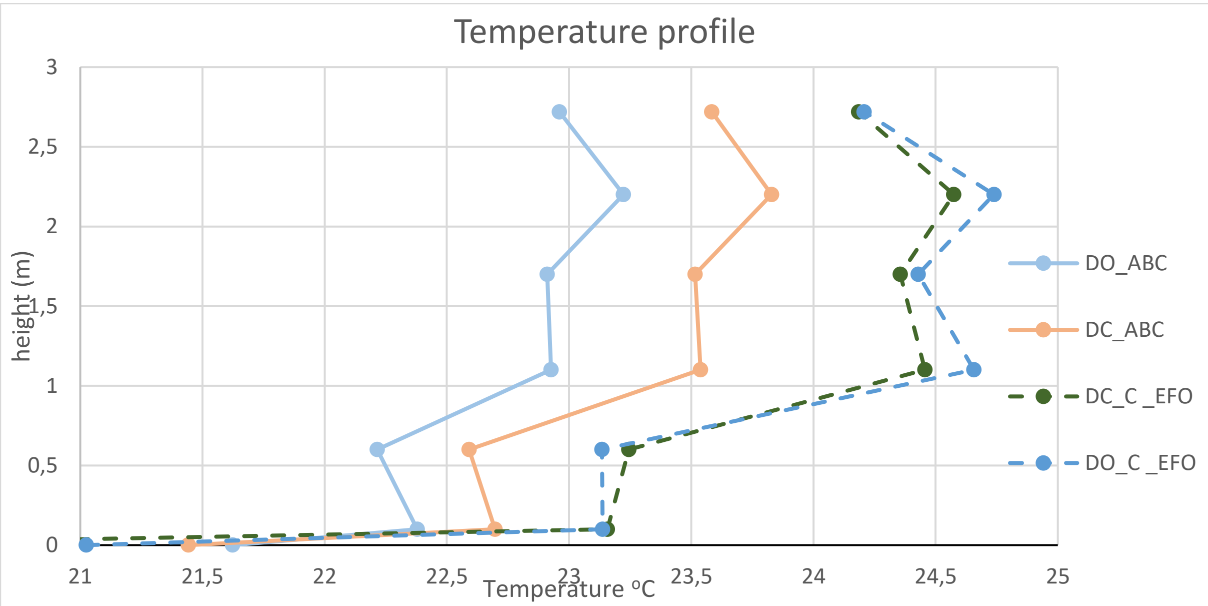

Figure 7 temperature profiles

On figure 8, the average CO_2 profile for the three locations indicates a lower vertical CO_2 concentration when the classroom door is open and exhaust fan switched on. With the exhaust

[3] Due to time restrictions the Exhaust Fan Off (EFO) test was only done at location C

fan switched off, the CO_2 profiles with respect to the door position coincides and are slightly less than the door close profile with the fan on.

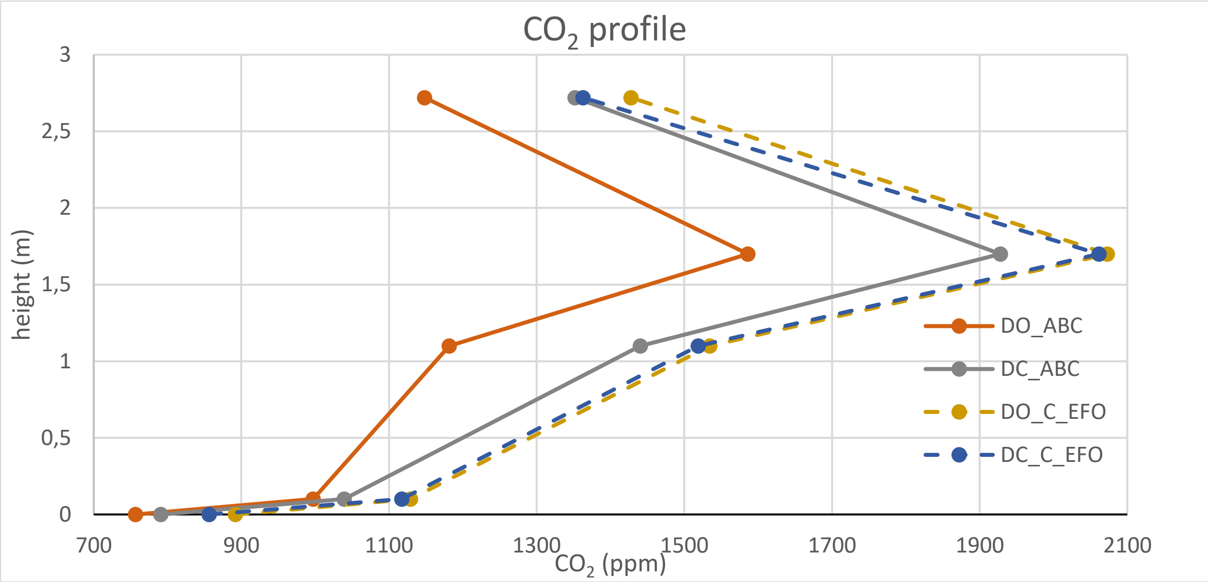

Figure 8 CO_2 profile locations A,B,C

2.5 Discussion

The objective of the monitoring results presented in the previous section was to determine if there was a solution to improve the air quality and thermal comfort of this new section of the Marie-Soleil Tougas School. The assistance of a mechanical exhaust fan have had a positive impact as shown on the temperature and CO_2 profiles (Figures 7 and 8). At 1.1 meters corresponding to the breathing height of seating students, the temperature difference between a classroom door open condition with the assistance of mechanical exhaust fan and a classroom door open condition without the fan assistance was of 1.5°C. Similarly, the CO_2 concentration difference at the same height was of 337ppm. The classroom door position is also beneficial when opened, but this solution cannot be applicable at all time because of potential acoustic issues. The previous results are taking into account the supply air temperature increase of 3 °C and CO_2 concentration increase of 280 ppm along the day.The overall indoor environmental quality could be even better if the supply air temperature at the diffuser is, adjusted to offset the heating loads and if the CO_2 concentration at the diffuser is limited to 700ppm or even lower, as per the building automation control strategy.

3 CONCLUSIONS

Thermal comfort and air quality for primary school students are key parameters to maintain the student's attention throughout the day. Floor heating and displacement ventilation are well suited to provide thermal comfort, good air quality and significant energy savings. However, the specific design of Marie-Soleil Tougas School was found to be more challenging for maintaining a good indoor environment quality. Simple solutions such as the classroom door position and the addition of a local mechanical exhaust fan were tested and the monitoring results showed the positive impact of those strategies. In order to validate this simple solution approach at any time, the monitoring protocol will be applied again in a summer condition.

4 ACKNOWLEDGEMENTS

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