Demand controlled ventilation in practice: Case study

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ABSTRACT

Demand controlled ventilation (DCV) can reduce the energy use significantly compared to a constant air volume (CAV) system. However, there is still a large uncertainty about the real energy savings and the ventilation efficiency. Furthermore, control and operation of the system are more complex. To formulate answers to these questions, measurements on a DCV system in a university building in Ghent, Belgium provide insight in the system operation and performance and the air distribution in the classrooms. Monitoring is carried out in March and May 2015.

During the measurements the VAV operation related to the set points was analysed. The active power demand for the fan and the thermal power demand for the heating coil was monitored. Furthermore, the CO_2 concentration was measured at five positions in the classroom to determine the ventilation efficiency at maximum and reduced air flow rate.
The results for the operation of the air handling unit (AHU) show that DCV is able to control the indoor set points for both CO_2 concentration and room temperature. When there is no occupancy in the classroom the DCV system operates at 32% of the time at a minimum air flow rate during operating hours, which decrease the active power demand for the fan.

The CO_2 concentration was measured at five positions in the classroom to characterise the ventilation efficiency. The measurements show that at a high air flow rate the lowest concentrations were found for the position in the middle of the classroom. Comparing a high and low air flow it was found that during a low air flow the difference in CO_2 concentrations for the five positions is at maximum 150 ppm. For a high air flow the position in the middle of the classroom has a maximum difference of 500 ppm lower compared to the front and back of the classroom. Furthermore, it was found that the room sensor did not deliver representative results especially in case of low air flow rates.

KEYWORDS

Demand Controlled Ventilation, Energy savings, Ventilation efficiency, Measurement, Air handling unit

1 INTRODUCTION

Demand controlled ventilation (DCV) is a ventilation system that automatically controls the air flow rate corresponding to the demand in the room, characterized by e.g. occupancy or CO_2-

concentration. DCV can operate at reduced air flow rates during a large amount of the occupancy reducing the energy use of the fan and ventilation losses for heating.

This ventilation system can reduce the energy use in buildings. In a study by Mysen et al. (2005) the energy demand was reduced respectively by 38% and 51% for a CO_2 controlled DCV compared to a constant air volume system (CAV) in a school building. Wachenfeldt et al. (2007) studied the energy demand for a CO_2 controlled DCV in a school building with use of both simulations and measurements. The energy demand for heating was reduced by 21% and for the fan by 87% compared to a CAV. The volume flow in this study was reduced by 50% for the simulated time period (11-17 Nov 2002). Maripuu (2009) measured the performance of a DCV system in a university building. With the decreased airflow rates the energy effect for the fans decreases respectively by 50%. This was monitored for a ventilation system with approximately 3500 operating hours/year.

However, there is still a large uncertainty about the ventilation efficiency of the room. Furthermore, control and operation of the mechanical system are more complex. Therefore, this paper evaluates the operation and performances of a DCV and the ventilation efficiency in the room in the new test classrooms at the Technology Campus Ghent of KU Leuven (Belgium). Measurement data of March and May 2015 are discussed.

2 METHOD

First, a description of the case study building and the system is presented. Afterwards, the measurement setup for the evaluation of the operation of the AHU and the ventilation efficiency is shown.

2.1 Case study building and system description

Figure 1 shows the plan and cross section of the new test classrooms at the Technology Campus Ghent of KU Leuven (Belgium). This case study building contains 2 large classrooms with 140 m^2 floor area and a maximum occupancy of 100 students each. The building is built according to the Passive House standard. This means that, amongst others, the building is very airtight.

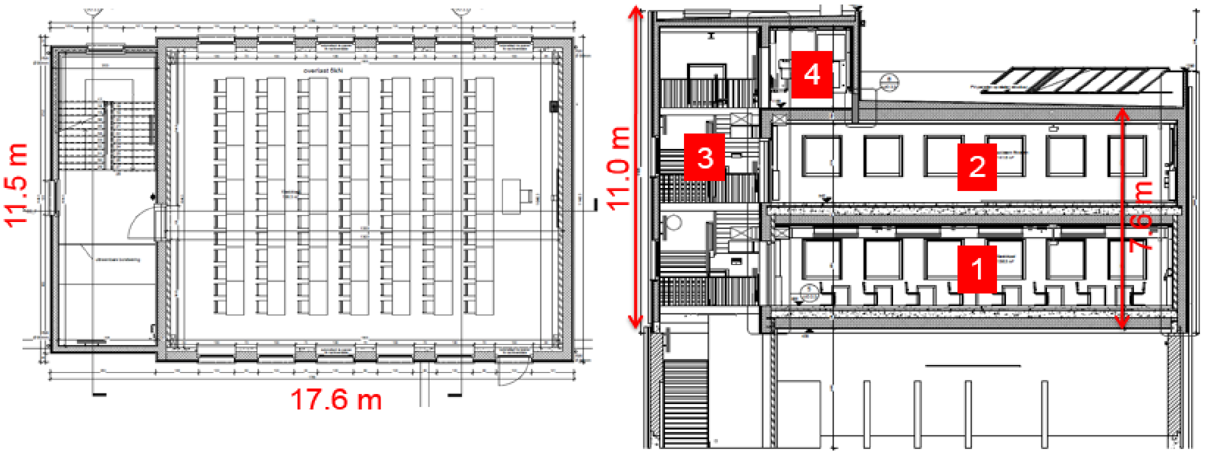

Figure 1 Plan and cross-section of the test classrooms: (1) classroom 1st floor (2) classroom 2nd floor (3) staircase (4) Technical room with AHU

Balanced mechanical ventilation is provided with a total supply airflow of 4400 m^3/h and a maximum power demand of 1.57 kW for the supply fan and 1.33 kW for the extraction fan. The AHU regulates the VAV boxes by sending a request signal to control the airflow based on CO_2-concentrations and operative temperature in the classrooms. Furthermore, the AHU controls the return signal of the VAV boxes for the extraction of air. Each classroom is a single zone with a supply and return VAV. For heating purposes, the air is preheated by air-to-air heat recovery, i.e. two cross flow plate heat exchangers connected in series with an efficiency of 78% according to EN 308 (1997). Additionally, a heating coil of 7.9 kW is integrated in the supply ducts of each class room. A modular bypass is included. A scheme of this HVAC system is shown inFigure 2. For the evaluation, the ventilation efficiency and indoor air quality (IAQ) in the classrooms, the operation of the AHU and the power demand for both the fan and heating batteries are analysed.

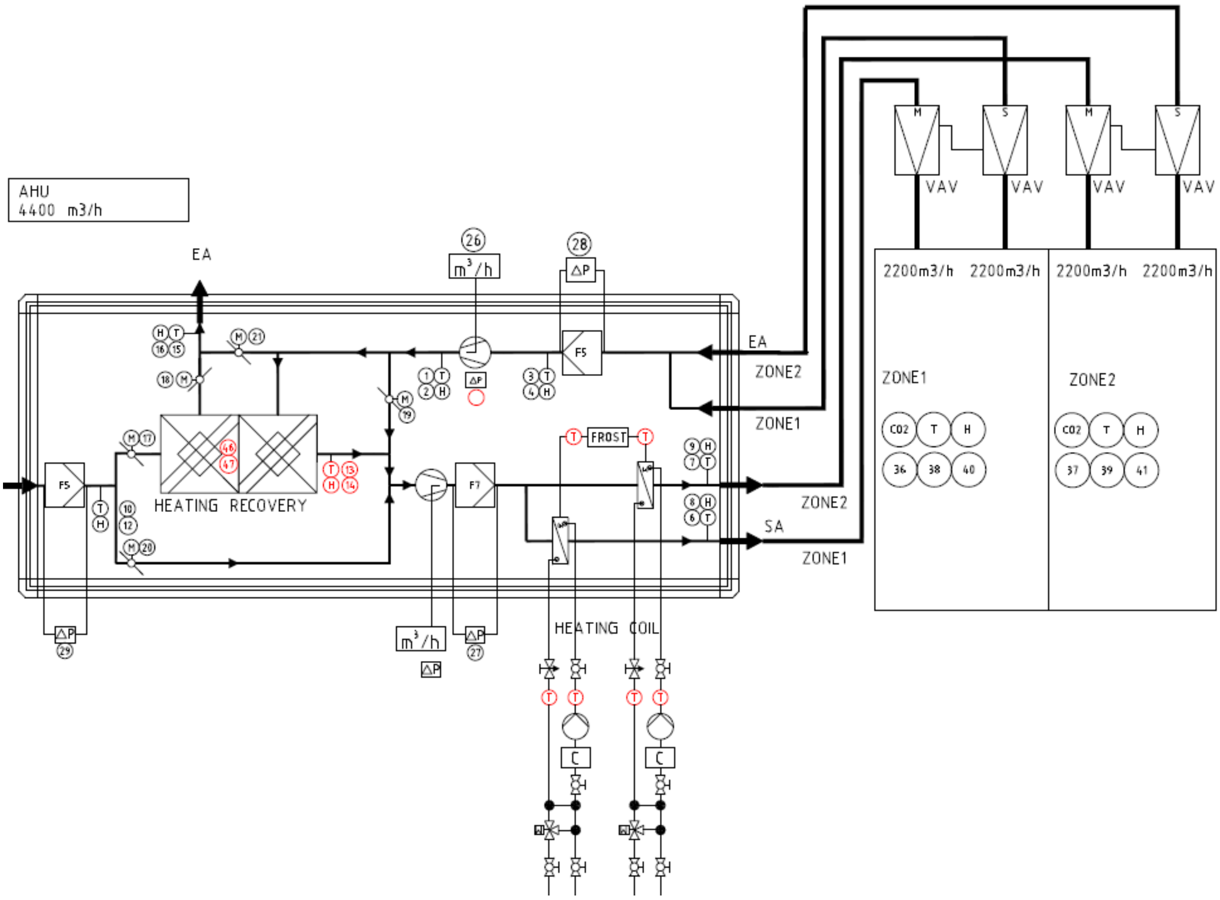

Figure 2 Scheme of air handling unit in the test classrooms of KU Leuven Technology Campus Ghent

2.2 Ventilation efficiency and operation/control of AHU measurement setup

First, the applied control strategy is evaluated. Three different scenarios for system control are evaluated, which are: frequency control, constant pressure and throttling. The control strategy that is used for the current system is constant pressure. To test the frequency control, the frequency of the supply fan is gradually increased from 10 to 60 Hz. The request position of the VAV damper is not adjusted in this scenario and is set to 50%. In the constant pressure scenario the duct pressure is maintained at 150 Pa. For the throttling scenario, the air flow is controlled by adjusting the position of the VAV damper. The frequency of the supply fan is not changed for this scenario and is set to 40 Hz.

To evaluate the detailed operation of the DCV system, the following data of the building monitoring system (BMS) are analysed during occupancy:

- supply and extract air flow rates in each classroom
- electricity use and active power of the fans
- supplied energy to and control of the heating coils

- control and position of VAVs
- position of bypass and recycling valves temperatures in air handling unit
- operative temperature and CO_2-concentration in the classrooms

Data are logged every minute. A typical week from 2 till 5 March is discussed.

The ventilation efficiency is evaluated by comparing the CO_2 concentrations during occupied hours in the classroom at five different measurement positions, shown on Figure 3. The $CO_2$5 sensor is placed near the CO_2 sensor of the room to verify if the values of the room sensor, used in the control system of the DCV, are reliable. The other sensors are placed near the people sitting in the classroom. The specifications of the sensors used are listed in Table 1.

Two scenarios are discussed: (1) high flow rate: air flow rate is set at 2000 m^3/h and is maintained at this value for the complete measurement period, (2) low flow rate: the frequency of the supply fan is set at 10 Hz which resulted in an air flow of 430 m^3/h. Measurements start from a constant situation in which the air temperature is uniformly distributed in the classroom. In addition, the occupancy of the room is more concentrated around the measurement position in the middle of the room compared to the other positions

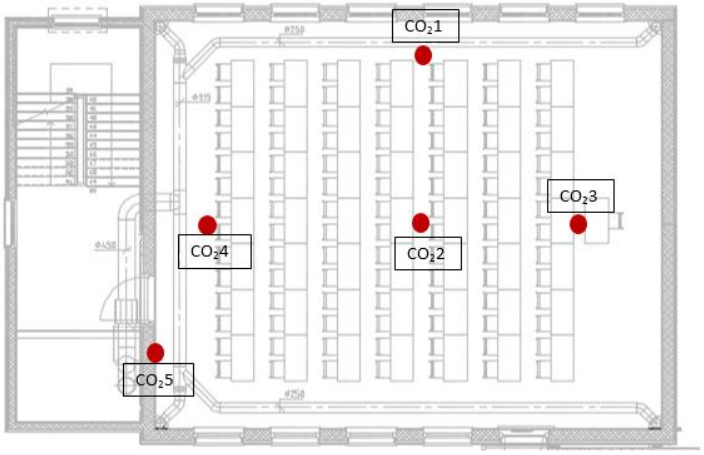

Figure 3 Plan of the classroom with the CO_2 measurement positions at 0.9 m high and 2.0 m high for $CO_2$5.

Table 1 Measurement equipment

Parameter	Type sensor	Accuracy	Sensor n°
CO_2	VAISALA GMW93, CO_2+T	±30 ppm + 2% of reading	$CO_2$4, $CO_2$5
CO_2	Telaire 700LI	±50 ppm or ±5% of reading	$CO_2$1,$CO_2$2, $CO_2$3
CO_2	E+E 80	±50 ppm + 2% of reading	CO_2 room

3 RESULTS

First, the results of the evaluation of the AHU control are presented. Afterwards, the operation of the DCV is analysed in detail. Finally, results of CO_2 measurements in the classroom are shown to evaluate the ventilation efficiency.

3.1 Control of the system

The results of the measurements of the normalised power demand as a function of the normalised ventilation flow rate in the three different scenarios are compared to the theoretical curve in Figure 4. The results show that frequency control is almost as efficient as the theory regarding the real power demand. The difference with between theory and frequency control is at maximum 5%. For constant pressure, i.e. the used control, the difference with the theory and frequency control real power demand, is for the lower air flows at maximum 150%. With larger air flows the difference in real power demand is reduced compared to the theory and the frequency control.

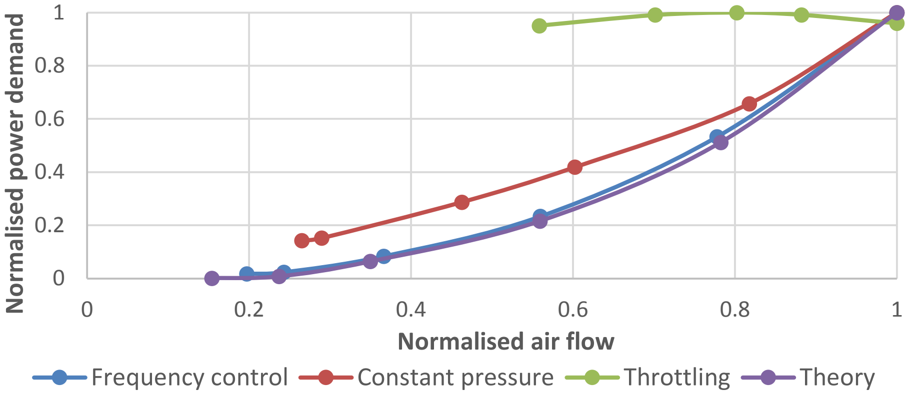

Figure 4 Real normalised power demand for different control strategies for varying air flow rates

3.2 Operation of DCV

In Figure 5 the CO_2 concentration and air flow is shown related to the occupancy and CO_2 set point in the classroom. Figure 6 shows the room, supply and outdoor temperature and the occupancy in the classroom. The results in both figures are from the time period of 2-5 March 2015. During this period the average outdoor temperature was 6.6°C with an average maximum and minimum of respectively 10.3°C and 2.7°C (KMI, 2015). The AHU is switched on from 8:00-18:00h except for the third day, where the AHU was switched off at 14:30h. During operating hours it can be seen that the air flow is approximately 1600 m^3/h during the hours with occupancy. The results also shows that after the end of a lecture the system still operates at an air flow rate of 1600 m^3/h to reduce the CO_2 concentration and the room temperature. When the classroom is not occupied the AHU is operating at a minimum air flow rate of 400 m^3/h.

The air flow in the classroom increases as a result of (1) a high CO_2 concentration or (2) a low room temperature. When the CO_2 set point (1100 ppm) is exceeded during operating hours, the air flow rate increases to a maximum of 1600 m^3/h to reduce the CO_2 concentration. For example, on the second day at 13:30h, the CO_2 concentration exceeds the set point as a result the air flow increases from 400 to 1600 m^3/h. Furthermore, on the fourth day it is noticed that the time switches of the AHU was switched off during the lunch break and switched on at 13:45h. However, the class already started at 13:30h, which causes a peak in CO_2 concentration of 2000 ppm.

Figure 5 clearly shows that when the AHU is switched on in the morning the air flow increases to a maximum of 2000 m^3/h. This is a result of a low room temperature in the morning. At night the system operates in standby mode and the heating set point is decreased from 22°C to 17°C. To increase the room temperature according to the heating set point the supply temperature increases to 40°C for a short time. Furthermore, on the first day of the measurements it can be seen that after the hours with occupancy the air flow rate increases from 1600 to 2200 m^3/h. When the lessons end at 12:30h it can be seen that the room temperature decreases below the heating set point to 21°C. At this time the supply temperature increases to 27°C according to the heating set point of the room. This indicates that still some optimisation is needed in the temperature control.

Moreover, the results show that there are still some problems with the operation of the ventilation system. It is shown that during high CO_2 concentrations the air flow only increases to 1600 m^3/h instead of the maximum of 2200 m^3/h. Furthermore, the response time of the system can be improved, since the air flow rate only increases when the CO_2 set point is exceeded.

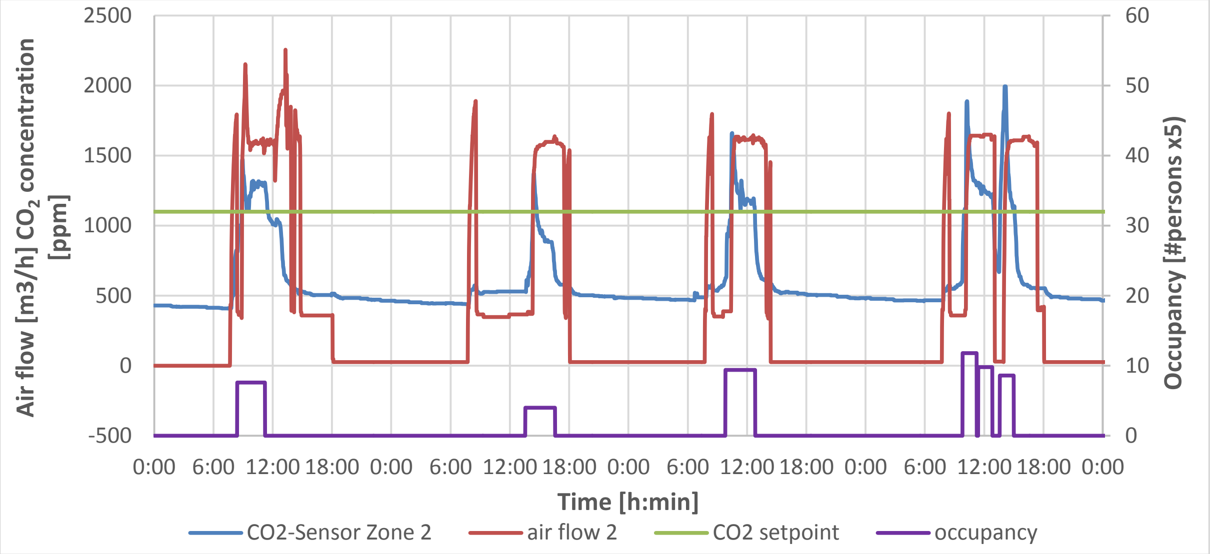

Figure 5 Operation of the flow according to the CO_2 concentration for the classroom (2-5 March 2015)

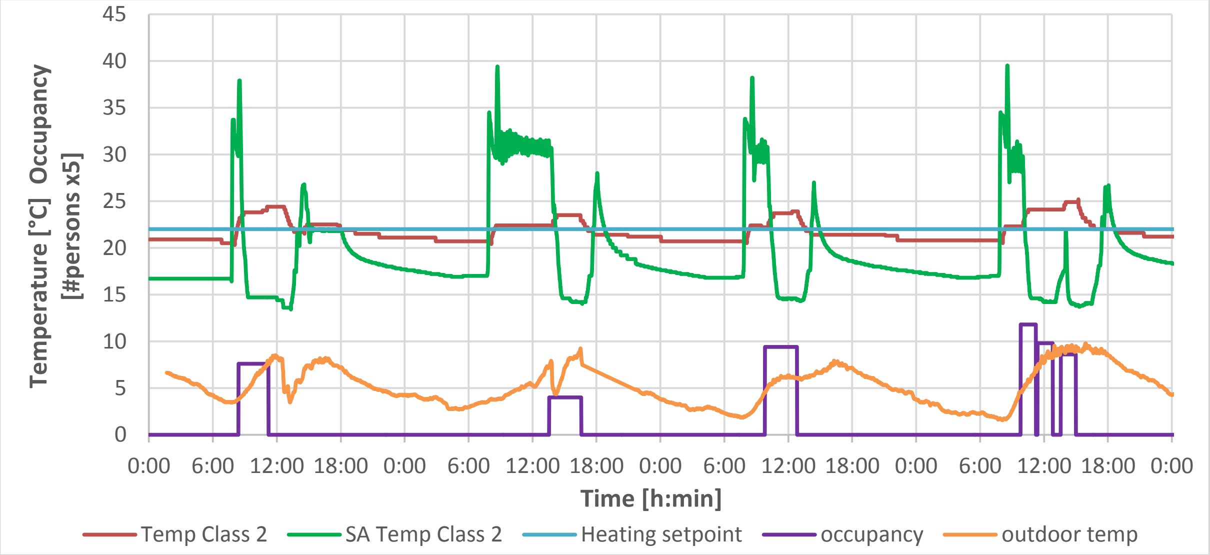

Figure 6 Operation of the supply and room temperatures for the classroom (2-5 March 2015)

In addition, Figure 7 shows the measurements of the active power demand of the fan and the thermal power demand for the heating coil for the classroom during the same period. These measurements are in line with the conclusions from the air flow rate and supply temperature on Figure 5 and 6. The highest peaks of 6 kW in the morning are found for the thermal heating power demand when the AHU is switched on. At this time point it was shown in Figure 6 that the supply temperature increases to 40°C to heat up the room according to the heating set point. Furthermore, there is a second peak of 3 kW in thermal heating power after the lecture on the first three days. When a lecture ends the room temperature rapidly decreases to levels below the heating set point. At this time the supply temperature increases from 15°C to 27°C.

For the fan electrical power it is shown that during high air flow rates the power use increases. When comparing the results for the fan electrical power demand and the air flow rate it can be seen that for the operating hours with no occupancy the fan electrical power decreases to 0.2 kW (13% of max) by an air flow rate of 400 m^3/h (18% of max).

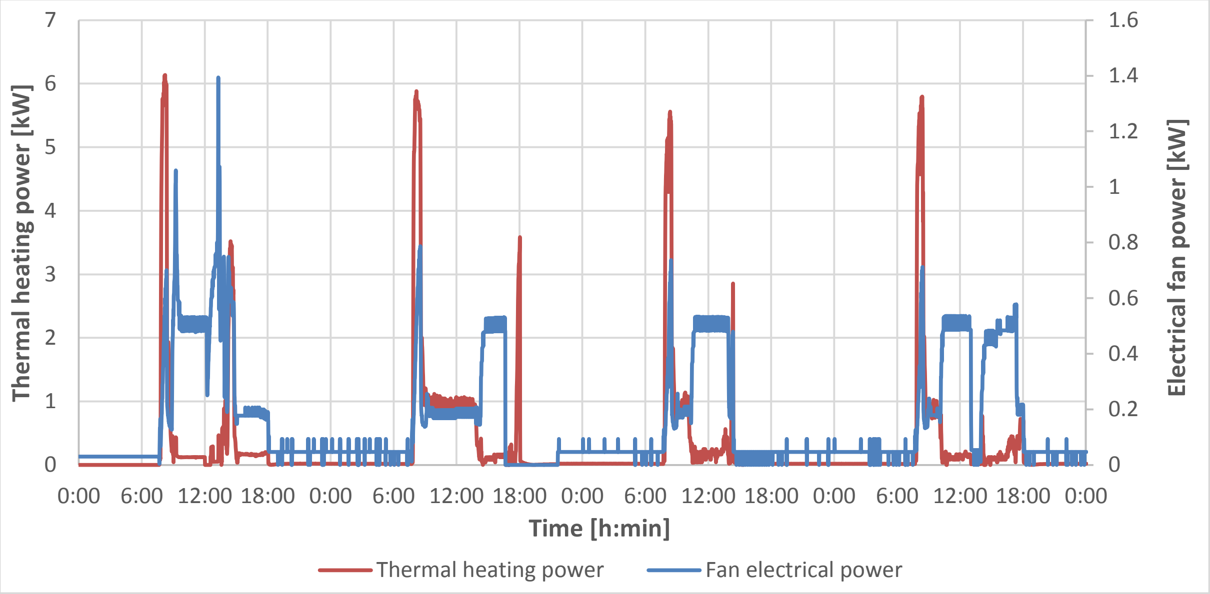

Figure 7 Electrical fan power and thermal heating power for the classroom (2-5 March 2015)

3.3 CO_2 measurements of ventilation efficiency in the classrooms

Figure 8 and 9 compare the CO_2 concentrations at five different locations in the classroom in case of a high respectively a low air flow rate. For the high air flow rate, shown in Figure 8, The difference in CO_2 concentration measured in the room is at some point 600 ppm, measured for the CO_2 2 and CO_2 room sensor. For the positions in the front (CO_2 3) and back (CO_2 4) the difference with the sensor in the middle is at maximum 500 ppm. The maximum values in the classroom near the people is 1200 ppm, which is still acceptable. According to the EN 15251 (2007) the maximum difference between inside and outside CO_2 levels is 800 ppm.

For the low air flow rate shown in Figure 9, the highest concentrations are found for the sensor placed in the front and the back of the classroom. Compared to the sensors placed in the middle of the classroom the concentration is at maximum 100 ppm higher.

The results for both high and low air flow rate indicate that for the position in the middle of the classroom, more fresh air is supplied compared to the measurement positions in the front and back of the classroom. This effect is especially noticed during a high air flow.

Furthermore, these measurements show that the room sensor do not deliver representative results especially in case of low air flow rates. The CO_2-concentration of this sensor was 300 ppm lower compared to the sensor located nearby. In case of a high air flow rate, the room sensor indicates always the highest concentration. The difference between the room sensor and the neighbouring sensor CO_2 5 is around 50 ppm, which is within the accuracy range. This indicates that the accuracy of the sensor is not good for measurements during low air flow rates.

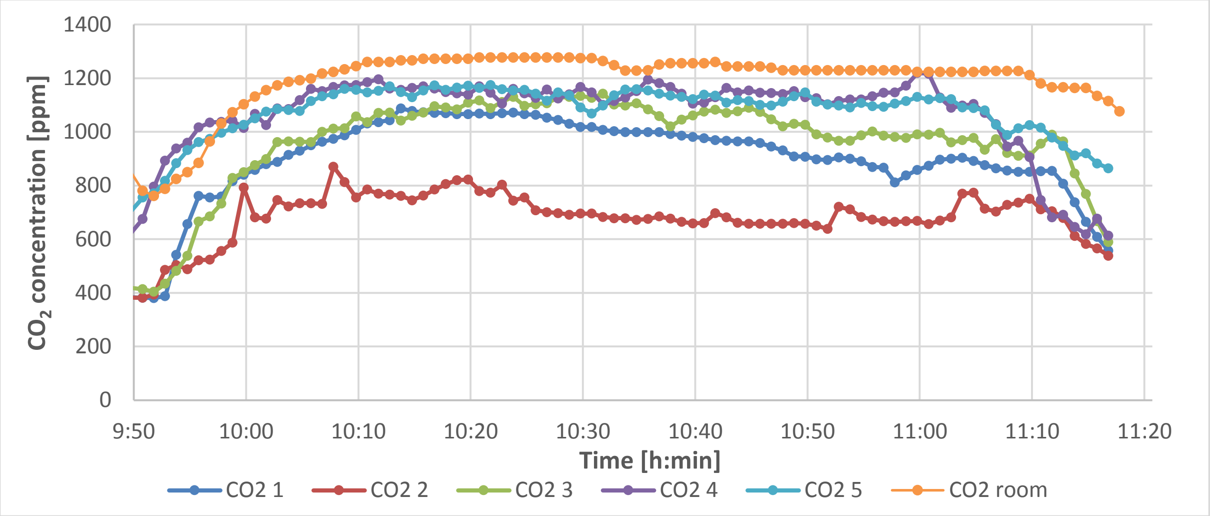

Figure 8 CO_2 concentration in the classroom during lecture (May 18, 9:50-11:10) with an air flow of 2000 m^3/h and an occupancy of 70 persons

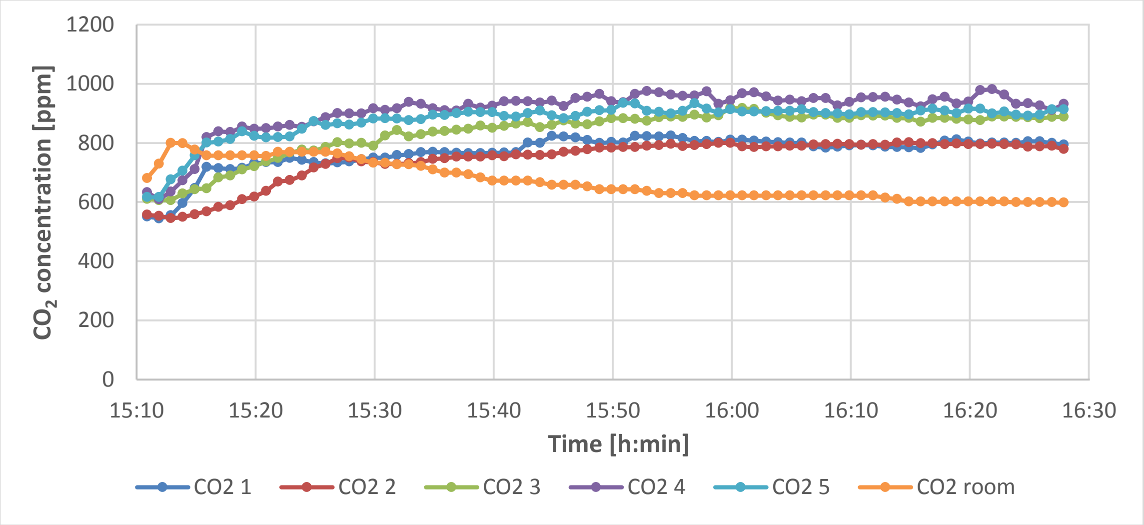

Figure 9 CO_2 concentration in the classroom during lecture (May 12, 15:10-16:30) with an air flow of 430 m^3/h and an occupancy of 30 persons

4 CONCLUSIONS

Operation and performances of a DCV and the ventilation efficiency in the room was evaluated in the new test classrooms at the Technology Campus Ghent of KU Leuven (Belgium). For the monitoring of the DCV system the operation was evaluated for a short time period of four days in March 2015. The control strategy showed that for frequency control the system is almost as efficient as the theory. Ventilation efficiency was evaluated by CO2 measurements in May at a high and low air flow rate.

The operation of the AHU shows that a demand controlled ventilation system responds well to the control parameters, which are the CO_2 concentration and the room temperature. The ventilation system is able to control and maintain the CO_2 and room temperature set points by adjusting the air flow rate to the demand. The active power demand of the fan and the thermal heating power of the heating coil shows that during operating hours the system does not operate

at maximum power. During the hours with no occupancy the system runs at a minimum air flow rate of 400m^3/h this is in total 32% of the operating hours.
Results show that during CO_2 measurements with a high air flow rate the highest concentrations were found for the position in the front and back of the classroom, with a maximum of 1200 ppm. The difference with measurement positions in the middle of the classroom was at maximum 500 ppm. At a low air flow rate the average value the maximum CO_2 concentration was 1000 ppm for the position in the back of the classroom the maximum difference was 400 ppm with the room sensor. However, the results showed that the values for the room sensor are not reliable with low air flow rate since the sensor placed next to the room sensor measured values which were on average 300 ppm higher.

This study shows that demand controlled ventilation is able to control the indoor set point parameters. The ventilation system operates most of the time at a reduced air flow rate, which reduces the electrical use for both the AHU and the heating system. However, it was found out that there are still some small problems with the operation.

5 ACKNOWLEDGEMENTS

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