Comparison of two ventilation control strategies in the first Norwegian school with passive house standard

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ABSTRACT

The Marienlyst School is the first educational building in Norway built according to the passive house standard. This building benefits from a super-insulated and airtight envelope. While this reduces the heating demand largely, it also enhances the risk for poor indoor air quality and overheating compared to conventional buildings. It is therefore particularly important to implement an efficient ventilation strategy in order to avoid adverse effects on the health, well-being and productivity of the pupils**.**

In this context, the perceived indoor climate resulting from two different ventilation control strategies was evaluated in one classroom of the building. Both strategies consisted in varying the ventilation rate according to room demand, *ie.* Demand Controlled Ventilation (DCV). The existing strategy consisted in varying the ventilation rate in order to maintain a constant carbon dioxide concentration of 800 ppm in the classroom. A new strategy was implemented which consisted in a combined CO_2 and temperature DCV, *ie.* to control towards a proportionally lower CO_2 concentration when the indoor temperature increased. The aim with this strategy was to address both overheating and the fact that perceived indoor air quality decreases when temperature rises.

Indoor climate measurements, as well as questionnaires on the perceived indoor air quality and thermal comfort filled up by the pupils were used to compare both strategies. The data from the questionnaires were then analyzed using a random effect linear regression model. The regression analysis revealed that the initial ventilation strategy was responsible for discomfort resulting from too high variations in the indoor temperature. The new combined CO_2 and temperature DCV strategy provided a perceived indoor climate which was significantly better than the existing strategy. Therefore, the developed ventilation strategy appears to be a relevant solution in order to address the problem of overheating and perceived indoor air quality in educational buildings with passive house standard.

KEYWORDS

Demand-Controlled Ventilation, passive house, questionnaires, indoor climate, school

1 INTRODUCTION

The Marienlyst School is the first educational building in Norway built according to the passive house standard (NS 3701, 2012); see Fig.1. It has been operational since 2010, with around 500 pupils of age 13 to 15. This building benefits from a super-insulated and airtight envelope (U-values ranging from 0.05 to 0.12 W/m²K for the envelope, and air leakage inferior to 0.6 vol/h under 50 Pa). While this reduces the heating demand largely, it also enhances the risk for poor indoor air quality and overheating compared to conventional buildings. It is therefore particularly important to implement an efficient ventilation control strategy in order to avoid adverse effects on the health, well-being and productivity of the pupils and school staff (Wargocki, 2000) (Sundell, 2011).

Figure 1: a) Marienlyst school, Oslo. b) View of a classroom.

In educational buildings, large variations of occupancy occur between periods with empty and occupied classrooms. This results in large variations of the heat and pollutant loads in the rooms, which is especially challenging in terms of control of the ventilation system.

Demand Controlled Ventilation systems (DCV) consist in varying the ventilation rate according to a demand measured at room level, and seems therefore particularly fitted to educational buildings. In fact, previous studies have reported that DCV systems can reduce the energy use due to ventilation in the average classroom up to 51% compared to a system operating with full airflow from 7:00 am to 5:00 pm (Mysen, 2005). It is however necessary to evaluate how DCV strategies perform in practice, particularly in the new context of educational buildings with low energy demand.

In this prospect, a new combined CO_2 and temperature DCV strategy was implemented in a classroom of the building. The objective of this study was to assess whether the new strategy provided a better perceived indoor climate than the existing ventilation control strategy, using both indoor climate measurements and questionnaires filled in by the pupils.

2 METHODOLOGIES

2.1 Ventilation control strategies

The existing control strategy in the building consisted in varying the ventilation rate in order to maintain a constant carbon dioxide concentration of 800 ppm in the classroom (constant CO_2 control). In fact, the indoor CO_2 concentration can be used as a proxy for the bio-effluents concentration in the room. Staying under a given value therefore guarantees a certain indoor air quality level.

In addition, an "overheating mode" was included in the existing strategy. It consisted in forcing the opening rate of the Variable Air Volume ventilation dampers to 100% when the indoor temperature reached 23.8°C and until the temperature got down to 23°C, independently of the CO_2 concentration in the room. This resulted in a larger amount of outdoor air being supplied through the ventilation system, which aimed to prevent overheating in the classroom.

A new strategy was implemented which consisted in a combined CO_2 and temperature control. It consisted in controlling the ventilation rate towards a proportionally lower CO_2 concentration when the indoor temperature increased over 22.5°C; see Figure 2. The aim with this strategy was to address both overheating and the fact that perceived indoor air quality decreases when indoor temperature rises. In fact, previous studies have revealed that a lower concentration of bio-effluents is perceived as acceptable when the indoor temperature is high (Mysen, 2005). As a consequence, the ventilation rate should be increased for higher indoor temperatures in order to maintain an acceptable perceived indoor air quality in the classrooms.

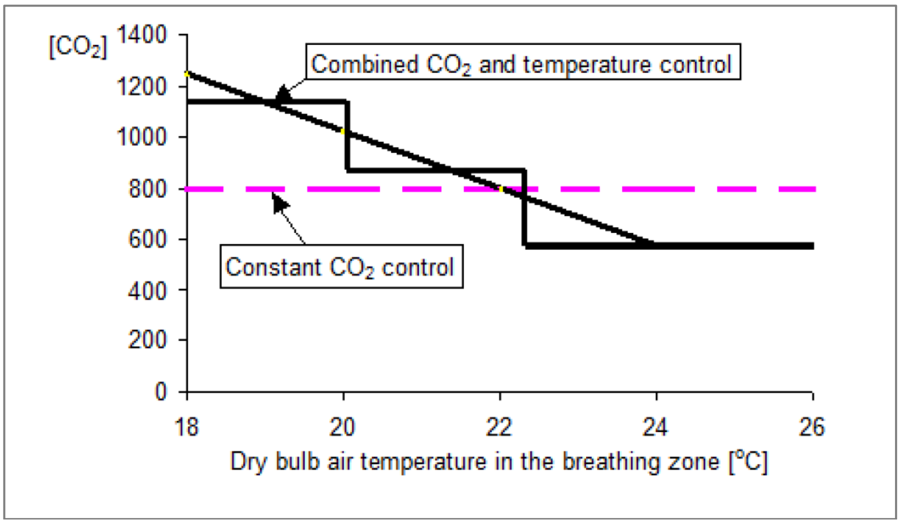

Figure 2: Combined CO_2 and temperature control (Mysen, 2005).

2.2 Questionnaires and regression analysis

In order to compare the performance of the two ventilation strategies described above, a case cross over study was carried out in one classroom of the building during February, March, and May 2012, see Table 1.

Table 1: Date and ventilation control for the interventions

Date	20 February 2012	14 March 2012	30 May 2012
Ventilation control	Constant CO_2 with "overheating mode"	Combined CO_2 and temperature	Combined CO_2 and temperature

At the end of each class session, the pupils were given a questionnaire with 19 questions relating to Sick Building Syndrome-symptoms and perceived indoor climate. On each question, the pupil gave a value between 0 and 1, ranging from very comfortable to very uncomfortable. The questionnaire also included health questions, such as whether a pupil suffered from asthma or cold.

Data from the questionnaires were analyzed using a random effect linear regression model with the score for each question as the dependent variable. The two ventilation control strategies: "Constant CO_2 control" and "Combined CO_2 and temperature control" represent the main independent variable. We also include gender and whether the pupils suffered from cold or asthma as independent variables, in order to be able to compare the ventilation control strategies independently of these factors. Statistical analyses were performed using the program R (R development team, 2013) and the R package lme4 (Bates, 2013).

3 RESULTS

3.1 Actual conditions during the interventions

The CO_2 concentration inside of the room, as well as indoor temperature were measured every 2 minutes.

The measurements during the intervention on February 20 with constant CO_2 control are plotted on Figure 3. The setpoint for the indoor CO_2 concentration derived from the ventilation control strategy is also indicated on Figure 3, as well as the periods where the "overheating mode" was used (override of the constant CO_2 control and full opening of the ventilation dampers).

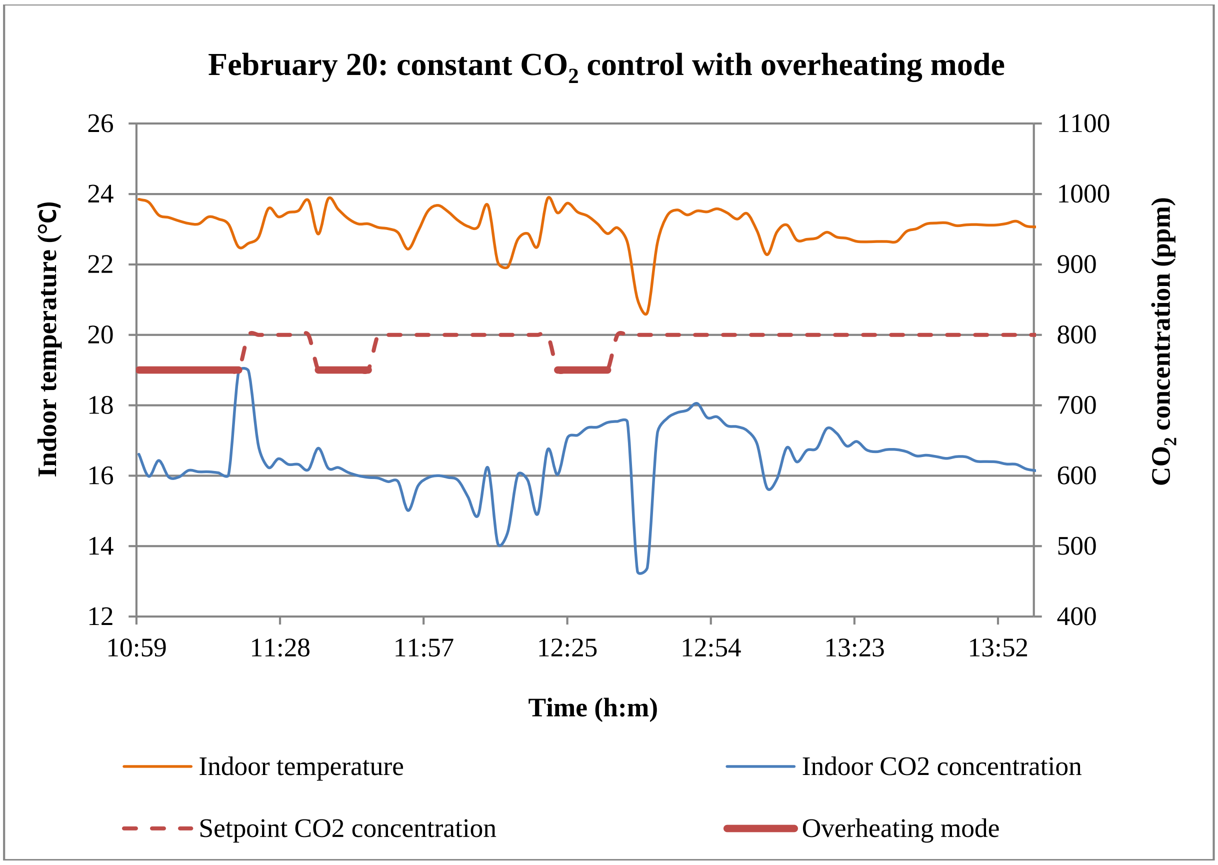

Figure 3: Measured indoor climate parameters on February 20 (constant CO_2 control with "overheating mode")

The measurements during the interventions on March 14 and May 30 with combined CO_2 and temperature control are plotted on Figure 4 and Figure 5, respectively. Similarly, the setpoint for the indoor CO_2 concentration derived from the curve presented on Figure 2 is also indicated.

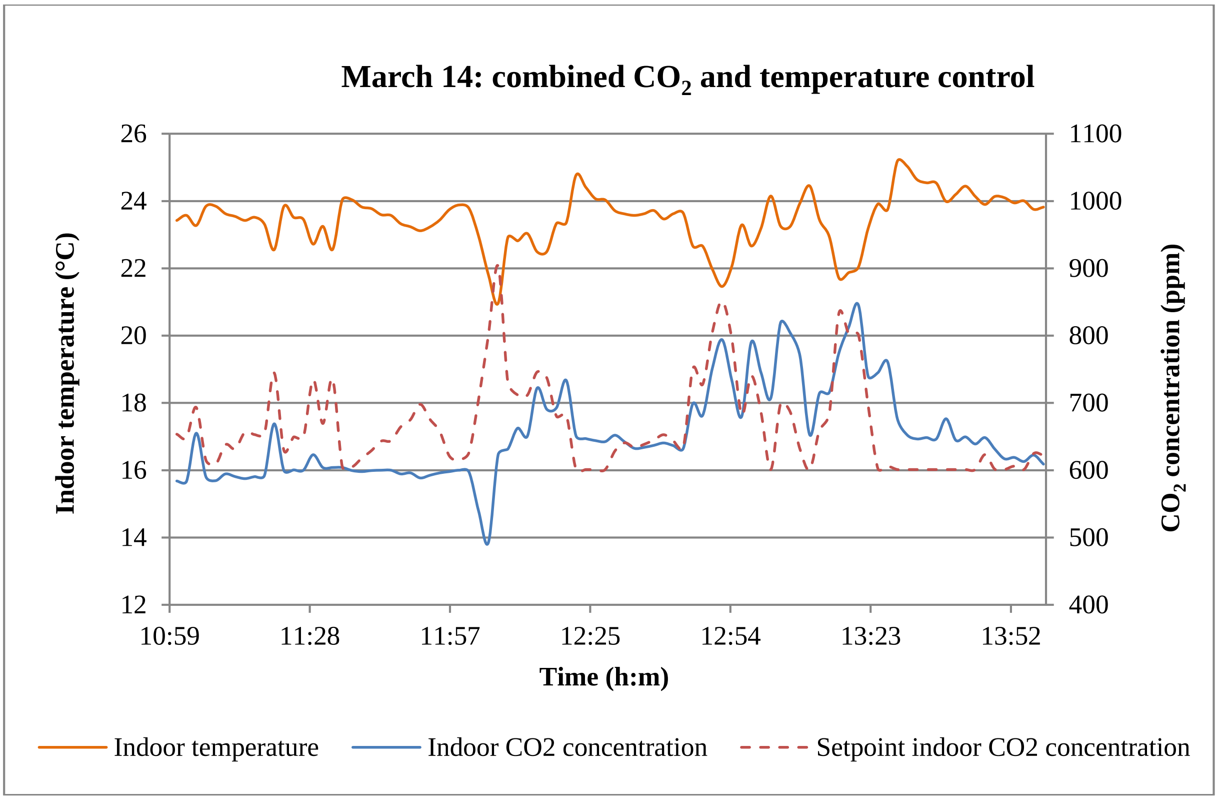

Figure 4: Measured indoor climate parameters on March 14 (combined CO_2 and temperature control)

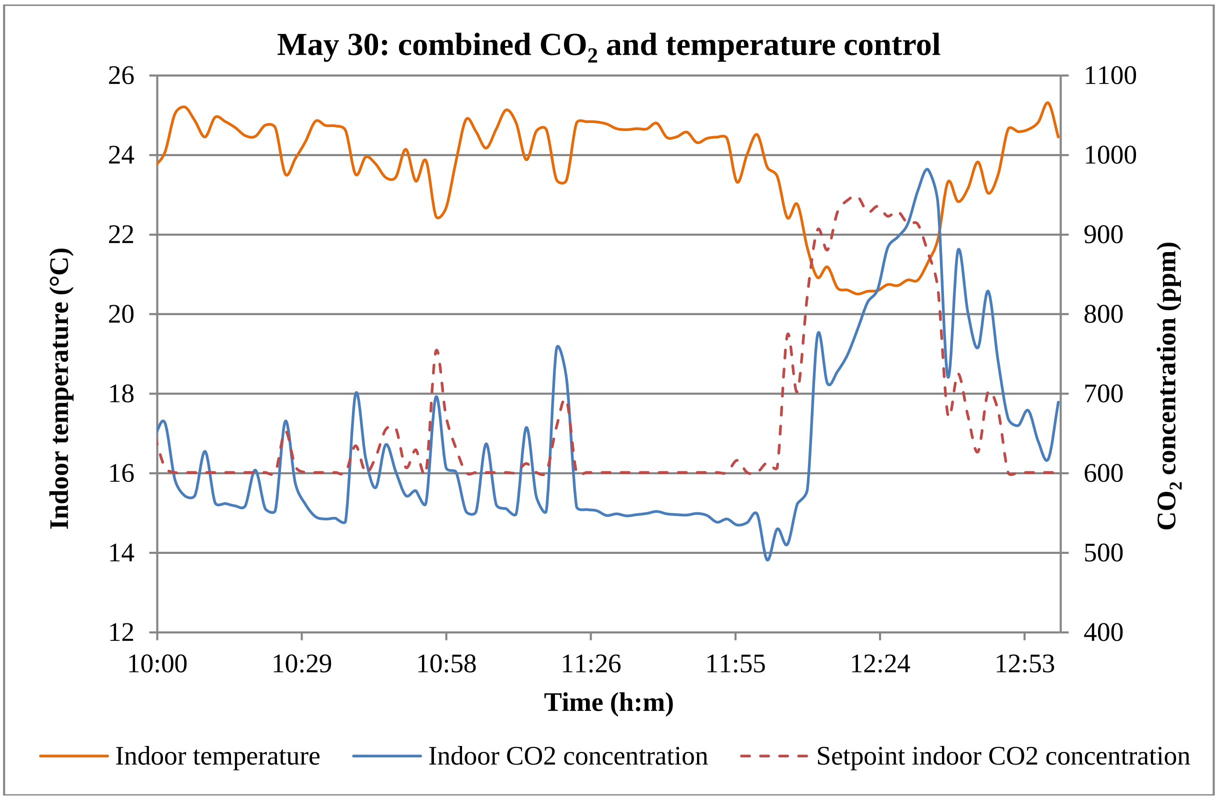

Figure 5: Measured indoor climate parameters on May 30 (combined CO_2 and temperature control)

The following observations were made:

- On February 20, the indoor temperature reached 23.8°C on three occasions, causing the "overheating mode" to override the constant CO_2 control of the ventilation rate, and supplying an increased amount of fresh air into the room. As a consequence, the indoor CO_2 concentration was lower than 800 ppm. A clear drop of the indoor temperature and indoor CO_2 concentration can be noticed subsequently to each of period of "overheating mode".
- On March 14 and May 30, the indoor temperature exceeded 22.5°C. As a consequence, the combined CO_2 and temperature control strategy controlled towards a lower concentration of CO_2 (see the red dotted line on Figure 4), down to 600 ppm. The actual CO_2 concentration in the room agreed fairly well with the CO_2 concentration setpoint on both days.
- On May 30, the classroom was empty from 12:00 to 12:30. As a consequence, the indoor temperature dropped down to 20.5°C, which caused the combined CO_2 and temperature control strategy to control towards a higher concentration of CO_2. This illustrates the ability of this ventilation control strategy to help saving energy by reducing the ventilation rate when the room is empty.
- The temperature in the classroom was relatively high for all cases, ranging from 23.1°C to 23.7°C on average. This is most certainly due to the high efficiency of the building envelope. Moreover, the temperature was relatively similar during all three interventions; see Table 2 for average values during the interventions.
- Likewise, the indoor CO_2 concentration was similar for all cases and relatively low, ranging from 622 ppm to 652 ppm, see Table 2.

Table 2: Average indoor temperature and CO_2 concentrations during the interventions

	Average indoor temperature (°C)	**Average indoor CO_2 concentration (ppm)**
20 February (constant CO2 control with overheating mode)	23,1	622
14 March (combined CO_2 and temperature control)	23,5	652
30 May (combined CO_2 and temperature control)	23,7	635

3.2 Regression analysis

39 pupils answered to the questionnaires. Among them, 19 answered to all three questionnaires and were considered in the regression analysis.

The regression strategy revealed that there is a significant relationship between the ventilation control strategy and to what extent the pupils are bothered by temperature variations in the classroom (p-value = 0.018); see Table 5 for the results from the linear regression. The new combined CO_2 and temperature strategy reduced the discomfort by variations of the indoor temperature significantly compared to the existing strategy (constant CO_2 control with "overheating mode"). The fact that the pupil had a cold, or the gender of the pupil did not have any significant impact on the results.

The other questions did not reveal any significant difference between both control strategies.

Table 5: Results from the linear regression

Variables	Estimate	Std. Error	Df	T-value	P-value
Combined CO_2 and temperature control (reference: constant CO_2 control)	–0.28	0.11	26.24	–2.53	0.018 *
Gender male (reference: female)	–0.22	0.14	19.33	–1.62	0.121
Has a cold (reference: Does not have a cold)	0.15	0.12	34.45	1.21	0.238

*Signif. codes: p-value < 0.01:**, p-value < 0.05:**

4 DISCUSSION

The regression analysis revealed that the initial ventilation strategy was responsible for discomfort resulting from too high variations of the indoor temperature. The hypothesis is that the rough control of the ventilation rate for this control strategy was accountable for this.

In fact, right after a period under "overheating mode" with high ventilation rate, the indoor CO_2 concentration was much lower than 800 ppm; see Figure 3. As a consequence, as soon as the constant CO_2 control mode was active again (*ie.* indoor temperature 23°C), it controlled towards the lowest ventilation rate. This resulted in fluctuations between maximum and minimum ventilation rate, which may be responsible for the obtained results.

The combined CO_2 and temperature control strategy allowed to have more gradual variations of the ventilation rate according to room temperature, which is likely the reason why it allowed to significantly reduce the perceived discomfort by temperature variations.

Moreover, the results from the measurements revealed that the indoor temperature was somewhat high in the classroom, which is certainly accountable to the efficient building envelope. This underlines the importance of having a ventilation control strategy capable of providing a higher ventilation rate when this occurs, in order to maintain an acceptable perceived indoor air quality.

5 CONCLUSIONS

A combined CO_2 and temperature ventilation control strategy was efficiently implemented in a classroom of the first school in Norway with passive house standard.

Questionnaires concerning the perceived indoor comfort and indoor air quality were carried out. The regression analysis revealed that the existing ventilation strategy was responsible for discomfort resulting from too high variations in the indoor temperature.

The new combined CO_2 and temperature strategy provided a perceived indoor climate which was significantly better than the existing strategy. Therefore, this ventilation strategy appears to be a relevant solution in order to address the problem of overheating and perceived indoor climate in educational buildings with passive house standard.

6 ACKNOWLEDGEMENTS

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