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# Ventilative cooling as a solution for highly insulated buildings in cold climate

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**Abstract**

One of the downsides of super insulated building envelopes is their facility to be overheated needing removal of excess heat. The removal of surplus heat is often done by mechanical cooling. However, energy consumption related to mechanical cooling is incompatible with achieving zero energy buildings.
This paper compares the application of hybrid window ventilation through validated IDA ICE simulations of an already existing kindergarten in Norway to simulations of the same kindergarten using DCV and VAV (both without cooling) and exhaust fan and only window controlled natural ventilation(these two last with night set back allowed). Results show important energy savings when using ventilative cooling as outcome of the low outdoor temperatures and the same applies for night cooling. Regarding thermal environment and indoor temperatures, for really warm days, it is hard to sustain acceptable temperatures without the use of night set back or mechanical cooling.


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*Keywords:* Ventilative cooling; Windows controlled ventilation; Night cooling; Simulation;IAQ; Thermal comfort

## 1. Introduction

New and refurbished buildings have to relate to ever increasing standards regarding energy efficiency and energy consumption. Well insulated building envelopes with low air leakages have reduced heating demands. One of the weaknesses of this extra insulation is that buildings are easily warmed up to such a degree that in order to sustain an acceptable indoor climate, removal of excess heat becomes a need. Ventilation has an important role in a building's indoor air quality (IAQ) and comfort [1]. As people tend to spend most of their time indoors [2], IAQ requirements become more strain. In addition, ventilation energy use accounts for 20 to 40% of the total final energy consumption in developed countries [3]. Heating, ventilation and air-conditioning systems (HVAC) are responsible for 39% and


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31% of primary energy end-use in residential and commercial sector respectively [4]. The removal of surplus heat is often done through mechanical cooling (MC). However, energy consumption related to MC is considered incompatible with realizing zero balance. As a response, the use of Ventilative cooling solutions (VC) is settling [5].

VC refers to the use of ventilation air in order to reduce or eliminate the need for mechanical cooling. VC can be applied through both mechanical and natural ventilation strategies, as well as a combination. To achieve efficient VC while ensuring an acceptable thermal climate, one should include measures that provide minimization of heat gains. VC should therefore be perceived as an integrated part of an overall system including solar shadings, minimization of internal heat gains and intelligent use of thermal mass [5] and should be combined with night set back.

This work examines the application of ventilative cooling in cold climates through simulations of an already existing kindergarten in Norway (Solstad). This has a mixed-mode ventilation system integrating mechanically balanced ventilation with motor controlled windows. Natural ventilation is considered one of the most effective techniques for cooling whenever outdoor temperatures are lower than indoor, or when adaptive comfort criteria can be applied [6]. Through the use of intelligent control strategies, the studied kindergarten aims to switch between mechanical and natural ventilation to reduce energy consumption while preserving satisfactory indoor climate.

The overall scope of this paper is to evaluate the performance of the Solstad ventilation solution with regards to indoor climate and energy consumption and to compare the results to conventional all-mechanical (no cooling) ventilation systems to evaluate the most energy-efficient without compromising the IAQ and comfort.

## 2. Methodology

### 2.1. Building description

The simulated building (simplification of the real) is the first floor of Solstad kindergarten (see Fig 1). The simulated climate is Oslo/Fornebu, very close to Larvik climate, (location of Solstad) due to availability IDA ICE. The simulation was performed for the year 2013. Each zone is occupied by a different number of children and adults, following real occupancy profiles. Table 1 shows the number of occupants in each zone, as well as their floor areas. In the simulation, it is assumed that nobody is present in winter garden and locker room. But the other zones are occupied according to the schedule in Table 1.

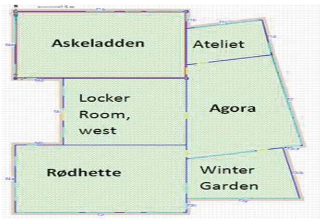
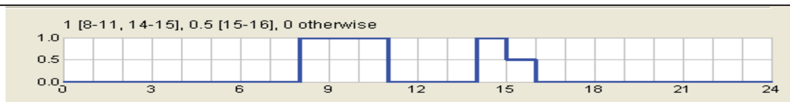
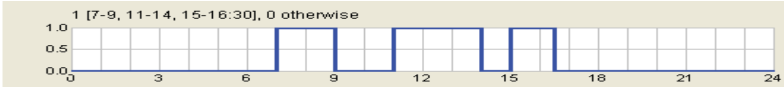
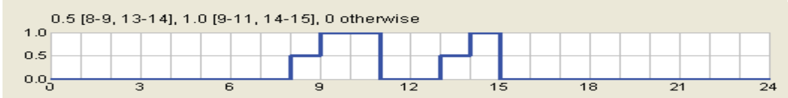



Fig. 1. (a) a plan drawing of the school building as it appears from the south façade in IDA ICE; (b) A 3D view

### 2.2. Balanced Mechanical Ventilation

Norwegian standards for ventilation require that a building with light activity occupants should have ventilation that ensures: 0.7l/ (s.m$^2$) and 7 l/ (s.person) of fresh air when the room is in use and 0.1 l/(s.m$^2$) otherwise [7]. For the Variable Air Volume (VAV) ventilation, these parameters will be used in the simulation to fix the minimum and maximum mechanical supply and return air flow rates for each zone. For the Constant Air Volume (CAV) ventilation, the supply and return air flow were fixed so that 0.5 air changes per hour are ensured disregarding occupancy.

Table 1 Description of each zone in the building and schedule of occupants in each zone

| Zones | Occupants | Floor Area (m2) | Occupants' schedule |
|---|---|---|---|
| Agora | 20 | 81.62 |   |
| Rødhette, | 21 | 99.12 |   |
| Askeladden | 21 | 99.62 | |
| Ateliet | 8 | 25.21 |   |

Both CAV and VAV have an air handling unit (AHU). This AHU filters, heats, and circulates air in a building. Since it is a balanced ventilation system, it has two fans: one supplying outdoor air into the building and the other exhausting stale interior air. The supplied air goes through the heat recovery system and the heating coils that maintain the set point temperature (19 ºC if the ambient temperature is less than 17 ºC, otherwise the set point temperature is the outside air temperature). In the AHU, the heat exchanger efficiency is 80% and it only operates when the outdoor temperature is less than 16 ºC.

The AHU unit is used for every zone except for winter garden which doesn't have any AHU and locker room which has exhaust- only ventilation (no supply of air).

The VAV used is controlled by the temperature and the $CO_2$ concentration, which are respectively between 20 - 25ºC and 700 - 1100ppm. Air is supplied according to the $CO_2$ concentration in the zone. If the concentration is below 700ppm, little air is supplied and when it exceeds 700ppm, more and more air is supplied in order to keep the $CO_2$ concentration between 700 and 1100ppm. Air flow rates will increase linearly.

### *2.3. Hybrid ventilation(exhaust fan and/or window opening)*

Two different hybrid ventilation systems were simulated: one with exhaust-only fans and the second case of pure natural ventilation with no fans at all. In both systems, ventilation is ensured by the opening of the windows, which is controlled by the model in Figure 2. This window opening is controlled differently in the summer, winter and night periods. When the windows are closed, the exhaust-only system uses the exhaust fan to ventilate and the system with no fans relies on the leakages, openings and cracks. During summer, sustaining thermal comfort is the priority, and the main control parameter is indoor air temperature. During winter, indoor air quality is the priority, and $CO_2$-level the main control parameter. The switch between summer and winter operation occurs when the average outdoor temperature through the course of a day is below/above 12 °C. Table 2 describes the seasonal control strategies.

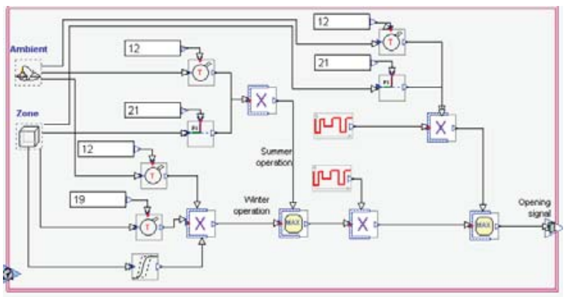



Figure 2: Window Opening Controller

Finally, the night time ventilation is quite similar to the summer time ventilation except that it only functions outside of the ventilation scheduling time, which is from 4:30 pm to 6 am; and the degree of window opening is limited to 50 % at night. Just like the summer operation, the night ventilation only functions when the outdoor temperature exceeds 12 ºC.

Table 2: Description of seasonal control strategies for ventilation operation at the kindergarten.

| Winter operation | Summer operation |
|---|---|
| During winter, window operation is limited in order to prevent cold draught and large heating demands. The exhaust fan when available operates with a zone set point of 900 – 1200 ppm $CO_2$, whereas window operation has a $CO_2$-setpoint of 700 – 1500 ppm. Window operation is only allowed when the indoor temperature exceeds 19 °C, and is limited to 50 % of maximum opening. This setup entails that mechanical ventilation handles most of the ventilation needs as it has a stricter $CO_2$-setpoint than the windows. Window operation will only occur if the mechanical system is insufficient in controlling the $CO_2$ concentration in the zone. | During summer, the zone repoint for window operation is indoor temperature over 21°C. The exhaust fan when available operates with a $CO_2$-setpoint of 900 – 1300 ppm. Seeing that indoor temperatures will exceed 21 °C much of the summer season, mechanical ventilation is not utilized very often as air flow rates needed in order to remove surplus heat often are larger than air flow rates needed for $CO_2$ control [8]. Summer operations allow night-time ventilation. If zone temperatures exceed 23 °C after operating hours, the building will use window ventilation to cool down the zones to a minimum of 18 °C with a limitation in window opening of 50 %. |

## 3. Results and Analysis

For each ventilation system, the main parameters analyzed were the $CO_2$ concentration, the operative temperature and the total energy consumption. The outdoor $CO_2$ concentration has been fixed at 400 ppm and the indoor concentration must be lower than 1000 ppm. In addition, the operative temperature is a simple indicator of thermal comfort. For a kindergarten, the recommended value for operative temperature is at most 23.5 ± 2.5 °C in summer and 20.0 ± 3.5 °C in winter [7]. Finally, for the energy consumption, the energy used for zone heating and ventilation will be considered. This includes the energy from the radiators in the rooms, as well as the energy used to heat the supply air in the AHU.

The simulation result of the different ventilation systems shows significant differences in the IAQ (Fig 3a) and indoor thermal comfort (Fig 3b). The mechanical ventilated solutions achieve a satisfactory IAQ equally to the exhaust ventilation; however, due to drop on temperatures in the room, the "no fans" solution can't open the window and the concentrations of $CO_2$ result higher for this case.

During summer CAV and VAV systems have the highest operative temperature because these systems have no active cooling system and they do not profit of the ventilative cooling through windows opening. The simulation was performed in a low energy building, that following current standards does not include cooling systems. Both CAV and VAV have almost equal operative temperatures because they both have nearly the same air supply flow during this particular day. For both hybrid ventilation cases, since the indoor air temperature is higher than the outdoor temperature, when the window opens, cooler air enter the room, thus reducing the operative temperature. For the exhaust and no fans case, as they are both allowed to have night setback and window opening during the day, the temperature in the warmest room only is over 25 °C during the last hours of the day when children are actually not any more at the kindergarten but when the sun is highest. Night cooling is simulated from the 1$^{st}$ of May to the 30$^{th}$ of September between 4:30 pm and 8am for the exhaust case and no fan. Outdoor air was supplied to the zones through ventilation fans (without any heating or cooling) if the indoor temperature is more than 19 ºC in order to cool it before being occupied. Figure 4b shows the simulation result for the warmest day of the simulated year. Night cooling is a very effective way of cooling the building with minimum energy demand.

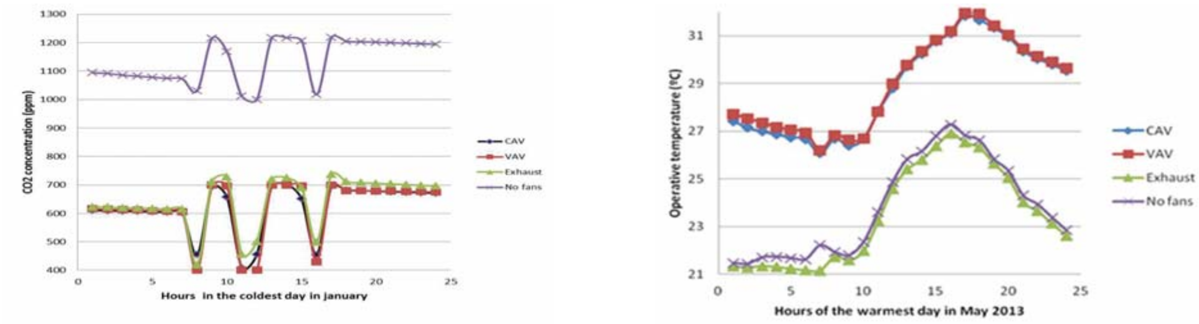



Figure 3(a) $CO_2$ concentrations during January for the four ventilation strategies (b) Operative temperature for the different ventilation systems during May

Regarding energy consumption (Fig. 4) shows that the "Exhaust ventilation" strategy is the one having the highest energy use due to the demand for heating; as a result of the uncontrolled infiltration and no heat recovery unit, the space heating demands increase. The "no fan" strategy has very low air supply and therefore the space heating consumption is very low in comparison to the other strategies (though the air supplied is not conditioned).

The yearly energy reduction is 27% when comparing VAV to CAV. This is mostly due to non-permanent occupancy of the room. When the classroom is filled with the designed number of students the energy use for both VAV and CAV is the same, as they have dimensioned equal air flow rates. However as the VAV case can reduce the airflow rates directly related to the occupancy it results in energy savings. When comparing VAV to exhaust ventilation the energy savings rise up to 70 %. This is mostly due to the continuous running of fans and opening of the windows until when outdoors temperatures are 12 ºC, corresponding with a large heating demand. In addition exhaust ventilation does not profit from heat recovery. If the set point of the exhaust fan was also set to 900 ppm this difference would be sensibly (down to 33% with electrical radiators).

Finally compared to the case with no fans and all the ventilation happens by means of window opening and leakages, the energy saving as a result of using VAV is only 10 % due to the fact that there is no heat recovery when we have pure natural ventilation. The $CO_2$ concentrations in this case are kept low as a result of the fact that natural ventilation ensure in the simulation 0.5 ach.

Mixed mode ventilation using exhaust fans seems to be a very good solution regarding thermal comfort; however, due to too long periods with window opening in winter the energy use is the largest. The question now is: should energy use be prioritized over the indoor air quality and comfort? When controlling the windows with exhaust and windows ventilation so that the maximum 1000 ppm are satisfied (still within standard demands), the energy use drops sensible to levels slightly higher that CAV (the difference with the space heating demands due to no heat recovery). In this case the exhaust solution is optimal as it allows for free cooling during summer and the consumption is slightly higher. However in such a case, the performance of the children may drop. Test such as the carried out by Warkoci [9] showed that increasing the air flow rate from 3 to 8.5 l/s produced a significant improvement in the performance of school children in calculation and language-based tests. The best solution seems to be the combination of exhaust ventilation during summer and VAV during winter. This will give the best combination of energy use and indoor air quality.

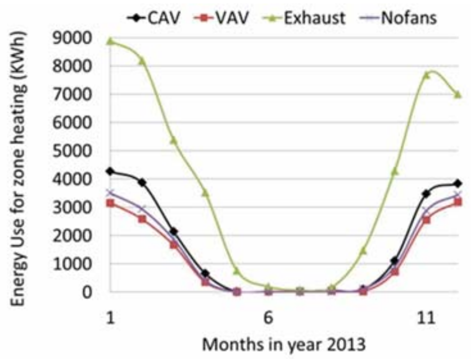



Figure 4 Energy use for zone heating for different ventilation systems

## 4. Conclusions

In this paper, an example of mixed mode ventilation has been analyzed with regards to the indoor climate. The presented school has been simulated with four different ventilation solutions to analyze the thermal comfort and $CO_2$ concentrations and energy use.

From the simulations it can be concluded that the control algorithm of the window opening vs the functioning of the extraction fan must be improved so that the concentration of $CO_2$ can go slightly higher and so not as much energy is needed to conditioning of the air.

Compared to mechanical ventilation one can conclude that mixed mode ventilation is very suitable for ventilative cooling and in the simulated case, one can keep acceptable indoors temperatures even when outdoors temperatures are around 25°C. However, for winter ventilation the control algorithm for the window opening has to be carefully tuned to avoid too high space heating demands.

## 5. Acknowledgement

The Research Council of Norway and the “E-coniiaq” project “Reduced Energy Consumption in Buildings – Impacts on Indoor Air Quality", as well as the SINTEF/NTNU “The research centre of Zero Emissions Buildings” (ZEB), grant number 193830 are gratefully acknowledged for financial support.

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