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Larsen, Olena Kalyanova; Afshari, Alireza; Heiselberg, Per

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Investigation of ventilation strategies for the day-care institutions

Olena Kalyanova Larsen, Assistant Professor, Ph.D [1]
Alireza Afshari, Associate Professor, Ph.D [2]
Per Heiselberg, Professor, Ph.D [1]

[1] Aalborg University, Denmark
[2] Danish Building Research Institute, Denmark

KEYWORDS: *Mechanical ventilation, natural ventilation, demand controlled ventilation*

SUMMARY: *Two existing nursery buildings, a mechanically and a naturally ventilated one, were chosen for investigations of energy saving potential and IAQ , using the different from present ventilation strategies and their control principles. These investigations are carried out applying a dynamic building simulation tool BSim. Each building is modelled separately and each of these models is "calibrated" using the detailed experimental data. Calibrated models are then used to evaluate different ventilation strategies for these particular buildings. This paper is aimed to illustrate the differences in assumptions for building operation on the design stage and actual building operation. Finally, it is not argued in favour to one or another ventilation principle, but in favour of demand controlled ventilation.*

1. Introduction

Since 1995 the Danish building regulations required mechanical ventilation with supply and exhaust in the day-care institutions (CAV-systems). During the recent years it became possible to apply natural ventilation in the institutions, if automated control strategies are applied. Though, at the moment there is no systematic documentation available about the indoor air quality and energy use benefits with using one or another ventilation principle (Afshari et al., 2009).

There have been a number of attempts to compare mechanical and natural ventilation in terms of operation simplicity, energy efficiency, user acceptability, etc. This however is difficult to perform, as in ideal case different ventilation strategies must be tested empirically within one building.

Nowadays, different design tools are used for assessment of thermal and energy performance of buildings, for further analysis of ventilation strategies and occupant comfort that they can provide. Being able to compare different ventilation strategies can help to choose the optimal ventilation principle. Comparison of different ventilation strategies using thermal building simulation tools will highly depend on assumptions made in the models and also the limitations of the thermal building simulation tool. These uncertainties can be eliminated, to some extent, by empirical calibration of models against experimental data. Though, this is only possible for already existing and operating buildings.

Two existing nursery buildings, a mechanically and a naturally ventilated one, were chosen for investigations of energy saving potential and IAQ (indoor air quality), using the different from present ventilation strategies and their control principles. These investigations are carried out applying a dynamic building simulation tool BSim. Each building is modelled separately and each of these models is "calibrated" using the detailed experimental data. Calibrated models are then used to evaluate different ventilation strategies for these particular buildings.

This paper is intended to illustrate the "calibration" of models for the day care institutions against the experimental data. Here the user behaviour plays a significant role, due to the young age of the occupants and, in many cases, due to their unexpected behaviour, which is unlikely to be considered on the design stage, but cannot be disregarded in already existing building.

In addition, this paper is aimed to illustrate the differences in assumptions for building operation on the design stage and actual building operation. Finally, it is not argued in favour to one or another ventilation principle, but in favour of demand controlled ventilation.

2. Methods

In this paper two already existing buildings will be modelled and investigated. First, the main operational principles of the buildings are introduced. Evaluation of the energy saving potential in the case-study buildings is carried out using building thermal and energy simulation program BSim and different ventilation principles are investigated for each building. Following are the ventilation strategies to be simulated for further analysis of their potential and their limitations to be implemented in the day-care institutions:

Case-study 1

- Case 1. Actual building performance. Mechanically ventilated (CAV) building with presence of venting, initialized by occupants.
- Case 2. Designed building performance. Mechanically ventilated (CAV) building without occupant involvement.
- Case 3. Mechanically ventilated building with VAV-system, controlled according to CO2 or/and air temperature. With presence of venting initialized by occupants. The VAV-system capacity is the same as in case 1 and case 2.
- Case 4. Mechanically ventilated building with VAV-system, controlled according to CO2 or/and air temperature. With presence of venting initialized by occupants. The VAV-system capacity is 50% bigger than in case 3.

Case-study 2

- Case 1. Actual building performance. Automatically controlled natural ventilation (CO2 and temperature controlled) combined with pulse ventilation, increased infiltration flow rate and user manual control of the ventilation system (manual opening or closing of the windows).
- Case 2. Designed building performance. Automatically controlled natural ventilation (CO2 and temperature controlled) combined with pulse ventilation and air tight building.

To develop a reliable building model, which can fairly well predict building performance in terms of energy and comfort is difficult, as it requires detailed information about building use, occupants' habits and their activity level, constructional details of the building, building tightness, ventilation principles etc. In order to take these variables into consideration an observation and measurement programme was developed and performed in both case-study buildings.

2.1 Case-study 1: mechanically ventilated building

The building is located in a country site and it is therefore well exposed to wind and sun. It is one storey building made of brick. The building consists of three main group rooms, common room, activity area and an office area, as illustrated in FIG 1.

Group rooms (12, 16, 20) are the most and occupied areas of the building. The activity area (8, 9) is mostly unoccupied, and the office area (23, 24) is normally occupied for the first half of the day and during the meetings. The common room (6) is overloaded with the occupants at the lunch time, at apx. 11 am. At 10 am the children are normally gathered in corresponding to their age group rooms for 45-60 minutes. For that time the doors to the group rooms are closed. Some personnel in the institution has a custom to open the windows in the group rooms during these gathering hours or right after the gathering. After 11 am the doors to the group rooms are normally closed and most of the children and personnel spend their time outside on the playground.

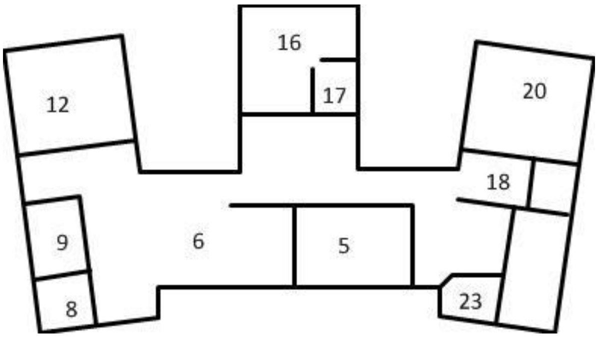


FIG 1. Plan of case-study 1.

The building is designed and dimensioned for approximately 50 children and 5 adults, with the ventilation flow rates calculated according to the Danish building regulations (Building regulations). It is ventilated mechanically, using CAV with mixing ventilation distribution principle. The air is supplied and extracted in almost every room. The ventilation system is running 24 hours a day.

Heat recovery unit and the complete ventilation system are located on the loft. It was measured that the supply air temperature is kept constant to approximately 20 ^{o}C. Heating of the building is arranged using floor heating in all rooms. The floor heating is water based, which is heated in a gas boiler, together with the water for the domestic use.

2.2 Case-study 2: naturally ventilated building

The building is located in a smaller town on the Northern coast of Denmark. In a neighbourhood of building, there are mainly one-storey buildings and some greenery without any tall trees.

It is one storey building, which functions as an after- and before- school institution. The institution opens at apx. 6 o'clock in the morning and stays open until 8:00, when children have to leave to school. After school pupils arrive at approximately 13:00 and stay there until 16:00. In between 8 and 13 o'clock the institution is cleaned by cleaning personnel and some cooking activities take place in a smaller kitchen. At the peak hours the institution can be occupied maximum by 100 pupils and 5-6 adults. The age of pupils at the institution is from 6 to 12 years old. The level of occupancy in the building is very sensitive to the outdoor weather conditions, as many children can be playing outside. More details about the occupancy level will be given later.
The building is divided into several zones, which are connected by an open-space common room (FIG 2). Six of these zones are directly connected to the common room, while 4 smaller rooms can be closed. Room height in the common room is significantly higher than in the other rooms (section in FIG 2). The core part of the building is wooden construction, while all appendixes to the building made of brick.

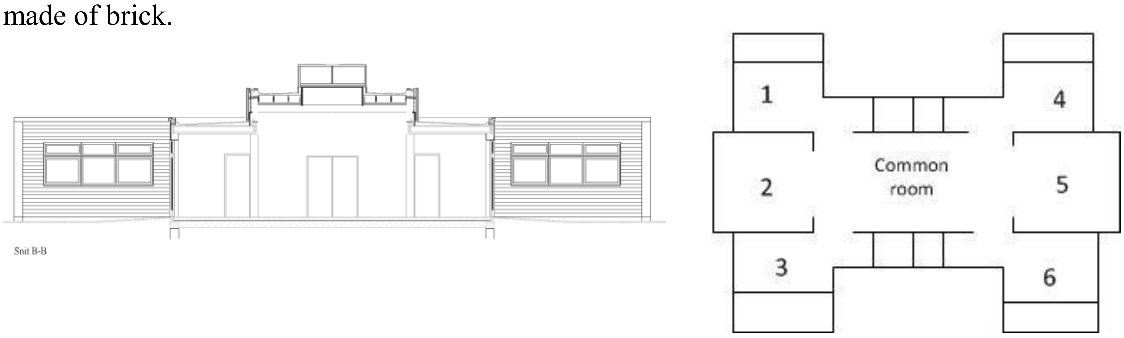


FIG 2. Section and plan of case-study 2 building.

The building is naturally ventilated, except for toilets and kitchen. In the kitchen there is a mechanical exhaust, which is activated in case of cooking. In the toilets, mechanical exhaust is installed together with the artificial lighting, activated by a motion sensor.

Natural ventilation is automatically controlled, but users have a possibility for manual control (opening windows) and can change the control strategy in the building, if needed. The natural ventilation principle is combined with the night cooling strategy, which is activated during warmer seasons.

The building is divided into 11 thermal zones, where the air temperature and CO2 are controlled. On average, the strategy of pulse ventilation is used. The opening degree of the openings will depend on wind direction and outdoor air temperature. When concentration of carbon dioxide in the zone exceeds 1000ppm or the air temperature exceeds a maximum set point, then pulse ventilation is overruled and the openings open outside of schedule for pulse ventilation.

2.3 Measurement and observation

The main measurement and observations principles from these two case-study buildings are explained in report by Larsen and Heiselberg (2009) and can be downloaded if more information is needed. In this paper, though, the focus is set on parameters that were found the most interesting.

Following are the parameters that were measured/observed in the day-care institutions: room air temperature, exhaust air temperature, supply air temperature, temperature gradient in building, concentration of CO2 in the occupied zones, concentration of CO2 in outdoor air, concentration of CO2 in exhaust air, air tightness of the building, electricity use in building, occupancy, observation of occupants' behaviour.

In general, the CO2-concentration has a role of indicator of ventilation effectiveness and occupancy level in the zone. It is recommended that the CO2-concentration must not exceed 1200ppm. The measurements of carbon dioxide and occupancy observation in the case-study buildings have led to the following results:

2.3.1 Case-study 1

In the case-study 1 the concentration of CO2 in exhaust air was measured for the whole building in the return duct of ventilation system. For a sunny day, when a lot of children spent their time outdoors, high concentration of CO2 is experienced only for the first half of the day. On a cloudy day, the peaks of CO2 concentration are also present in the afternoons. High concentration of CO2 is experienced in the group rooms in the period from 10-11 am, when all children are gathered in corresponding to their age group rooms. At 11 o'clock the concentration of CO2 increases in the common room, when all of the occupants are gathered for a lunch. Illustration of CO2- profile and occupancy profile is seen in FIG 3.

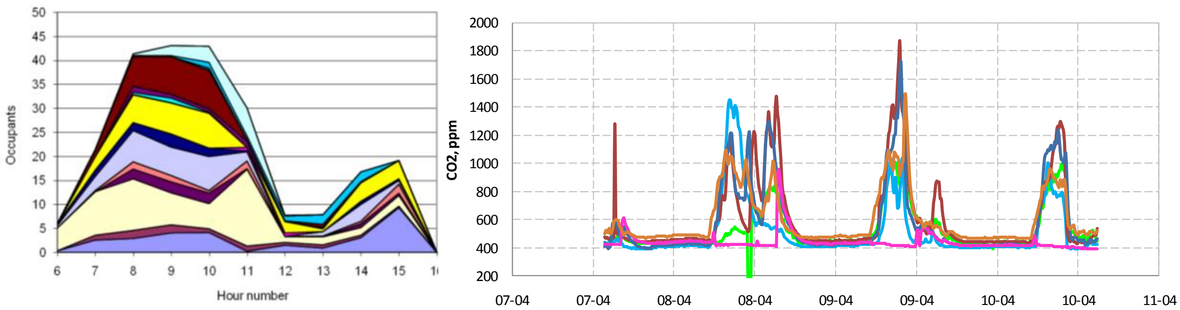


FIG 3. Case study 1: occupancy profile within a day for different rooms(left). CO2-concentrationin different zones 7-11 of April (right).

Ventilation flow rates in the mechanically ventilated building in different rooms of the building were measured and compared with the design flow rates. The measured and the design flow rates appeared to be different: measured flow rates are apx. 25% lower than the design flow rates. Still, these differences can be caused by measurement uncertainty or assumptions made towards the occupancy level in the building.

2.3.2 Case-study 2

For this building, the concentration of CO2 gives a notion occupancy pattern: morning and afternoon peaks of concentration correspond to the opening hours in the institution. In the break (between 9 and 12 o'clock) the concentration of CO2 is reduced to apx. 500ppm. This reduction of CO2 takes place due to functioning pulse ventilation and widely open windows in the building by cleaning personnel.

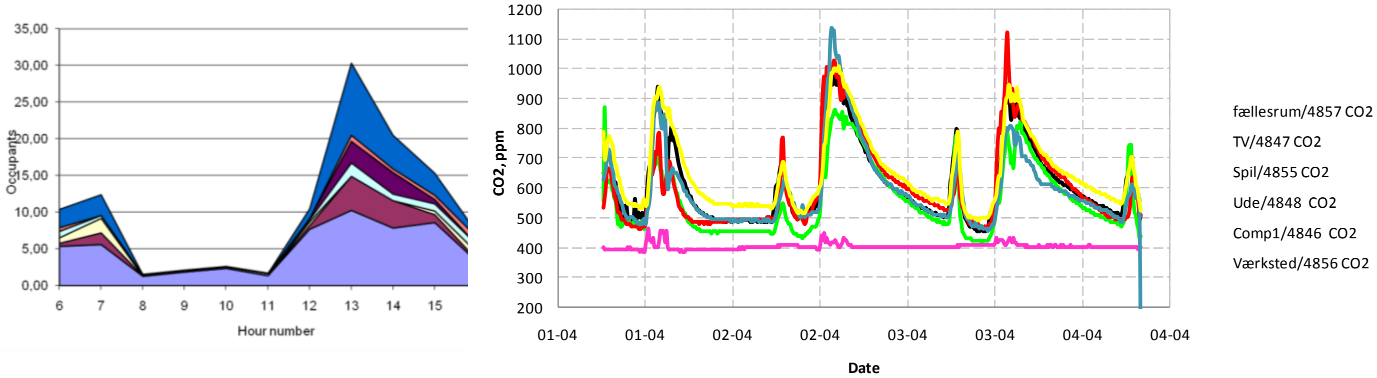


FIG 4. Case study 2: occupancy profile within a day for different rooms(left). CO2-concentrationin different zones 1-4 of April (right).

2.4 Modelling

The main intention with modelling different ventilation principles is further analysis of these ventilation strategies for each particular building in terms of energy efficiency and occupant comfort that they can provide. In this paper different ventilation principles must be tested for mechanically ventilated and for the naturally ventilated building. However, only one model (model of actual building performance) can be validated against the experimental data. In view of that, all limitations of building simulation tool must be addressed and all assumptions in the models must be carefully selected. For both of buildings some specific for the used building simulation software assumptions have been made. In the paper, however, only the most interesting of them are mentioned. Further details about the modelling assumptions can be found in report by Larsen and Heiselberg (2009).

First of all models of actual building performance must be developed and validated. It is necessary to note that due to careful observation of buildings' operation and occupants' behaviour, it was concluded that for both of buildings, the actual building operation is different from the designed one. The main differences appear due to occupants' behaviour, such as manual opening of the windows, manual control of ventilation system (in case-study 2) , occupant overload of some rooms, etc. The boundary conditions for the simulations (weather data) were received from the Danish Meteorological Institute (DMI) from the weather stations corresponding to building locations. The weather data is available for the period when the measurements were carried out in the corresponding day care institutions. DMI weather parameters were not enough to perform the calculation, as information about diffuse solar radiation should be available. The diffuse solar radiation was calculated using Skartveit and Olseth method (Skartveit and Olseth , 1987), making use of global solar radiation and cloud cover.

Modelling of CAV (constant air volume) balanced mechanical ventilation system (case-study 1) in BSim is straight forward. For an accurate calculation it requires knowledge of the ventilation flow rates, air tightness of the building and knowledge of characteristics of the ventilation system. Modelling of automatically controlled natural ventilation together with pulse ventilation is more challenging. Accurate calculation of natural flow rates requires knowledge of discharge coefficients for all openings, wind pressure distribution on the building, air tightness of the building, etc. The natural flow rates very sensitive to the wind pressure distribution. Meanwhile, it is difficult to make reasonable assumption for wind pressure coefficients for building of such complex geometry. Moreover, modelling of pulse ventilation along with other automatics of the openings and occupant behaviour is impossible

In condition of well-functioning automatically controlled natural ventilation system in the building, the natural ventilation in the building can be modelled as VAV-system (variable air volume). In that way one can be certain in the calculated air flow rates in the building and thus can avoid uncertainties associated with the pressure coefficients, discharge coefficients, opening areas, etc. For that reason the ventilation system in the case-study 2 is modelled as VAV mechanical ventilation system. Another interesting approach was found in the definition of pulse ventilation, which is realized in the model simply by increasing infiltration flow rates during the day time.

As a part of model validation procedure, measured and calculated concentration of carbon dioxide and air temperature are compared for common room and illustrated in FIG 6. Good agreement in prediction of CO2 concentration is reached. With regard to prediction of air temperature in the zones, the model performance can be doubted. Prediction of air temperature in the zones is rather different from the measured values. These differences, however, are explained by differences in modelling of ventilation system. In the actual building, there is a significant part of supply air to common room is received from the neighbouring zones. This air is already polluted and slightly warmer.

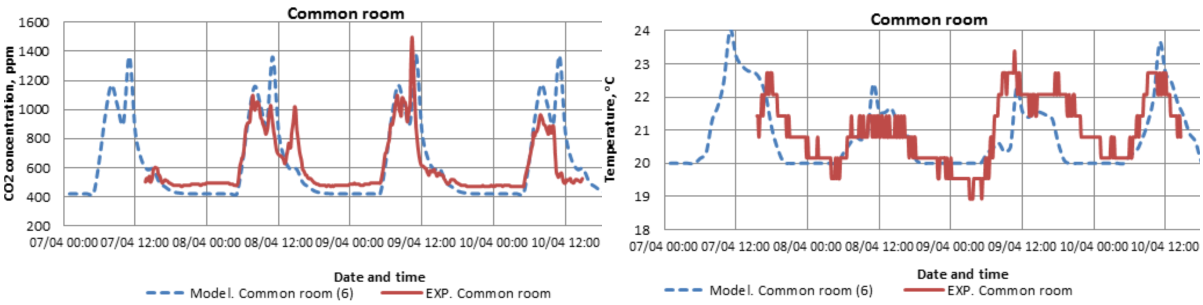


FIG 5. Measured and calculated CO2 concentration and air temperature in common room, case-study1.

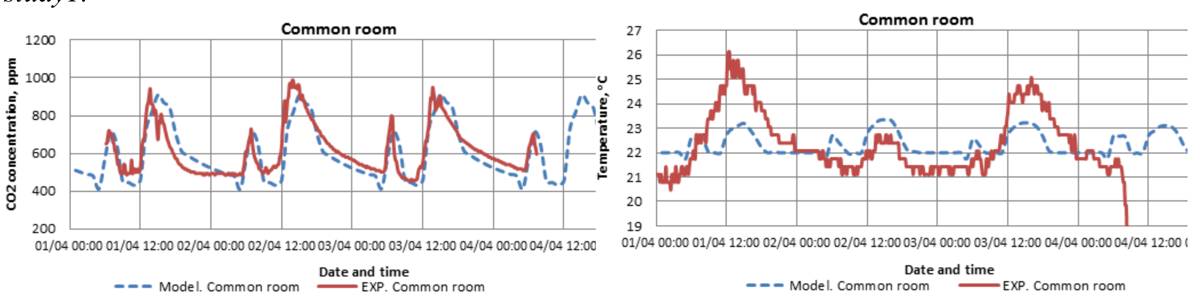


FIG 6. Measured and calculated CO2 concentration and air temperature in common room, case-study2.

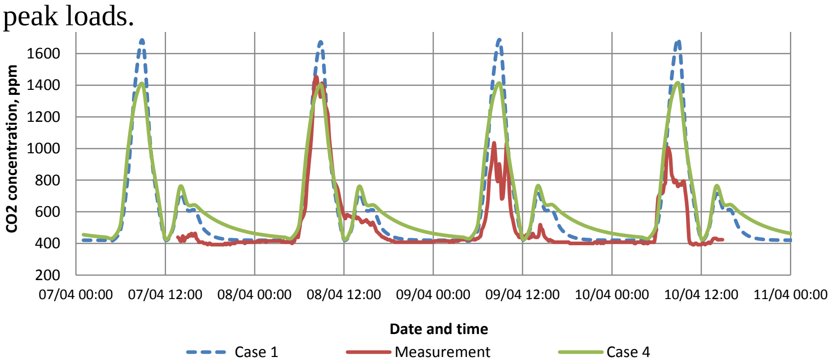
For the case-study 1, it has been observed that frequently unexpected behaviour of the occupants, their customs and building use might have a significant influence on building operation, i.e. frequent opening of doors to the outdoor playground, regular opening of windows for ventilation purposes, etc. In order to include the occupant behaviour in the model, it has been defined as a separate ventilation system with the schedule defined according to observations of user behaviour. In that case, however, it was difficult to define the exact air change rates. These air change rates were adjusted gradually until agreement between measured and simulated results for temperature and CO2 was achieved. It is important to mention, that these adjustments were very limited and no other changes to the model have been made in order to fix the results. In FIG 5 measured and calculated air temperature and CO2 concentration in the common room are compared after the adjustments to the simulation model. These adjustments to the model are referred as "calibration" of the model.

After the above described "calibration" of the case-study models, both models were locked and only the changes associated with earlier defined test cases took place. The results from the "calibrated" model in case-study 2 is compared against the measured energy use in the building to confirm the reliability of the model. It was measured to 115 kWh/m2 and calculated to 99 kWh/m2.

3. Results

In order to be able to compare energy use for heating and ventilation during the heating season, each test case is simulated for the design reference year (DRY). Meanwhile, evaluation of changes to indoor air quality and thermal comfort between the cases is also possible, as all of the cases were also simulated using 1 week of weather data from measurements. This allows comparison of each test case with 1 week of measurements. In both of the case-studies Case 1 defines the actual performance of the building, which is represented by "calibrated" model.

Case-study 1.
In Case 2 it is assumed that the building is ventilated only mechanically and the occupants' do not perform manual ventilation of the rooms. As a result, it was found that with user involvement, the concentration of CO2 is lower and the dilution of CO2 is faster. However, reduction of uncontrolled venting by users results in decreasing of energy use for heating. In Case3, the manual ventilation initialized by occupants is still present, but the ventilation system is temperature and CO2 controlled, using VAV-control. The maximum air flow rates are set the same as in Case 1, thus the system is running for 100% of capacity. It is found that in the group rooms, the concentration of CO2 has not changed compared to Case 1. This is because of the limited capacity of the ventilation system. Meanwhile, users by opening windows in the room, reduce the concentration of CO2 in the room to minimum. For the other rooms, the effect of VAV-control is clearly seen, but only in the afternoon hours, when the fresh air supply is at minimum. Finally, in Case 4, the ventilation system is temperature and CO2 controlled, using VAV-control. The capacity of ventilation system is set to 150% compared to Case 1. Here the occupants are still able to ventilate the building manually. In the FIG 7 it is seen that increasing capacity of ventilation system can improve indoor air quality during the peak loads.

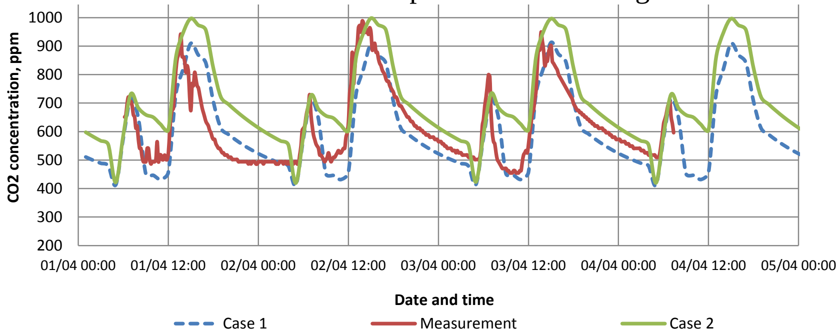


Case	Total, kWh	Specific, kWh/m2
Case 1	59142	70
Case 2	55007	65
Case 3	34655	41
Case 4	35996	43

FIG 7. Measured and calculated CO2 concentration for case-study 1 (left). Energy use for heating (right).

Case-study 2

In case 2, it is aimed to simulate building performance as it was designed, compared to actual building performance, which is simulated in case 1. In case 2, the infiltration flow rate in the building is reduced by 30%. No changes to ventilation system or pulse ventilation has been made. Changes in IAQ, compared with Case 1, are mainly seen for common room. It results in slow dilution of CO2 between morning and afternoon opening hours. Finally, increased concentration of CO2 is seen for the afternoon periods with peak loads. Changes in infiltration flow rates result in minor change of CO2 concentration when there are no occupants in the building.



Case	Total, kWh	Specific, kWh/m2
Case 1	49680	99
Case 2	45159	90

FIG 8. Measured and calculated CO2 concentration for case-study 2 (left). Energy use for heating (right).

4. Discussion

Ventilation systems, both natural and mechanical, in day-care centers are often sized for an average person load that rarely occurs in reality. There may be more or fewer children in each room than expected. This is exemplified in both case-study buildings. A solution could be that the ventilation system is designed so that the system has the capacity and flexibility to adapt to the actual number of people in the rooms. With demand-controlled ventilation the demanded volume of air can be delivered at the right time and in the right place while at the same time the airflow can be reduced when demand in room is low.

Demand-controlled ventilation requires a more sophisticated control and regulation system and this entails an expensive installation than either purely mechanical or natural ventilation. But with properly designed demand-controlled ventilation more energy can be saved while improving air quality, user comfort and health. The last obviously presupposes that the system is able to shift capacity between the individual rooms and provide increased airflow to the most congested areas. It is an added advantage that the ventilation system does not require attention from staff. It is controlled automatically.

For the time, when the architects are determined to design building with the flexible plan solutions, giving space to future user demands and changes in the building use, it is important that the technical systems in the buildings can follow such flexibility in the building use.

References

Afshari A., Heiselberg P., Reinhold C., Kalyanova O., Vachek U.M. 2009. Behovsstyret ventilation det bedste til børneinstitutioner. HVAC-magasinet, 11.
Larsen, O. K. & Heiselberg, P. 2009. BSim Models for 2 Case-studies of Naturally and Mechanically Ventilated Day-care Institutions: Aalborg : Aalborg University. Department of Civil Engineering. 67 s. (DCE Technical Reports; 67).
Danish Building Regulations http://www.ebst.dk/bygningsreglementet.dk
Skartveit A.and Olseth J.A. 1987. A model for the diffuse fraction of hourly global radiation, Sol Energy 38 (1987), pp. 271–274