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BSim Models for 2 Case-studies of Naturally and Mechanically Ventilated Daycare Institutions

Project: Energibesparelser i børneinstitutioner ved valg af den optimale ventilationstekniske løsning tilpasset konkretesituationer

Larsen, Olena Kalyanova; Heiselberg, Per

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by

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1. Introduction

This report is prepared within a project "Energibesparelser i børneinstitutioner ved valg af den optimale ventilationstekniske løsning tilpasset konkrete situationer" and it is intended to provide reader with complete information necessary for evaluation of assumptions made in the models and conclusions derived from the results of simulation of two different institutions in various operational modes.

Thermal models are prepared for two buildings, which are: SFO Nymarken in Kerteminde and SFO Spirehuset in Hirtshals. The main operational principles in these buildings are significantly different, as SFO Nymarken is mechanically ventilated and SFO Spirehuset is naturally ventilated.

All of the simulations were carried in BSim, and all of the models are simulated in the current version of BSim, which is version 6,8,9,8.

2. BSim

BSim is an integrated PC tool for analysing buildings and installations. BSim includes a collection of advanced tools for simulating and calculating e.g. thermal indoor climate, energy consumption, daylight conditions, synchronous simulation of moisture and energy transport in constructions and spaces, calculation of natural ventilation and electrical yield from building integrated photovoltaic systems [1].

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                      http://www.dbur.dk   (English)
                      http://www.bsim.dk   (BSim homepage)

Calculations in BSim performed in a steady state condition for the each time step. The software contains also accumulation of heat and moisture calculations. There are two or more time steps per hour.

Further information about BSim is prepared on basis of BSim help file [3].

Zones
A building consists of an arbitrary number of zones, which are limited by an arbitrary number of surfaces. The zone air is represented in the building description as a nodal point, for which air temperature and water vapour content are calculated. It is assumed that the air in a zone is fully mixed. However, the temperature stratification in a zone can be modeled by means of Kappa-model, which is highly dependent on user assumptions/inputs.

External environment
This is so-called virtual zone, e.g. the outside air, the condition of which is not to be calculated, but is given by data from a file or a timetable, defined by user.

Transmission of solar radiation to the zone
XSun, which forms a part of the BSim software suite, can be used for the detailed analyses of the path of direct solar radiation through a building. It is possible to see where and when the sun strikes any face in the model. The direct solar radiation through the external and internal window will be distributed geometrically correct according to the solar path, while the diffuse solar radiation will be distributed according to surface area weighting.

Solar radiation
From the values given in the weather data file BSim is able to calculate the solar incidence on an arbitrarily oriented surface. Petersen's model is the default one for calculation of solar incidence in BSim. Available models for calculation of solar incidence in BSim are: Petersen's, Munier's, Lund's and Perez's.

Longwave radiation exchange between the model and ambient
Only the radiative exchange to the sky takes part in the simulation. There is thus no radiative exchange with eventual other buildings in the model and nor with eventual advanced parts of the building itself. The radiative heat exchange is thus only dependant on the temperature difference between any surface and the sky, respectively the ground and the tilt of the surface.

Internal longwave radiation exchange
It is only possible to simulate long-wave radiative exchange in tsbi5 in those rooms, which are convex, in order to enable calculation of view factors in BSim. When the internal longwave radiation exchange is to be calculated then the convective heat transfer coefficients are calculated separately for each surface, otherwise a combined value of convection and radiation is used.

The longwave radiation exchange from the surfaces of the glass and the surrounding surfaces with average emission coefficient (e = 0.94) is used for all surfaces made of glass.

Outdoor surface convection coefficient
Next to calculating the long wave radiation effects, the heat transfers coefficient between the outdoor air and the first node point on the exterior side of the construction is calculated as a function of wind speed.

Glass temperature
In the model, different absorption and reflection at the two glass faces are used in the calculation of the absorbed amount of radiation in the glass. Then the temperature for the glass surfaces is calculated as a

heat balance to the air temperature next to the glass surface, including the amount of absorbed energy in the glass face.

Heat balance for the zone air

The heat balance for the air in a zone does not make allowance for the heat capacity of the air which means that the air momentarily adjusts itself to alterations in the surroundings, includes:

- heat flows from adjoining constructions
- heat flows through windoors
- solar radiation through windoors (of which only a limited amount is assumed to be induced to the air)
- thermal contribution from various heat loads and systems
- air penetration from outdoor air (infiltration, venting)
- air supplied from ventilation systems
- air transferred by from other zones (mixing)

Heat transmission in the constructions

The constructions consist of one or more layers, which are assumed to be homogeneous, consisting of one material, which is characterized by thermal material values. The heat transmission internally in the constructions is described non-stationary, i.e. by making allowance for each individual layer's thermal capacity. Thick material layers are divided into several thinner layers (control volumes).

Heat transfer coefficients at the window surfaces are calculated in the same way as the heat transfer coefficients for the wall containing the window.

Air mass balance

If an un-balanced air-stream is introduced in any thermal zone, this will automatically be balanced with in- or exfiltration of air from the outdoors in the tsbi5 simulations. This happens even if the thermal zone has no direct connection (faces) to the outdoors.

Control

All systems in BSim are controlled on the basis of an operative temperature in the thermal zone to which they are attached. However, it is possible to adjust the control system for application of the air temperature instead for the operative air temperature.

3. The main principles of buildings' operation

In this chapter, the main operational principles of the buildings are described, based on 1 week of observation of their functioning and operation. These observations are supported with the detailed measurements, which are described in the next chapter.

SFO Nymarken

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 was built in connection with a school, located 30 meters away from SFO Nymarken. Except for the school-buildings, there are no other buildings in the neighborhood.

SFO Nymarken consists of three main group rooms, common room, activity area and an office area, as illustrated in Figure 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. The working hours in the building start at 6 am, when most of the children arrive and get gathered in the common room for breakfast. At apx. 8 am SFO-children go to school and the number of occupants in the building is reduced by apx. 20%. They return back to the institution at 1 pm. All children have left the institution by apx. 4pm, while cleaning personnel leave the building at apx. 5pm.

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.

The building is designed and dimensioned for approximately 50 children and 5 adults, with the ventilation flow rates calculated according to BR08. 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.
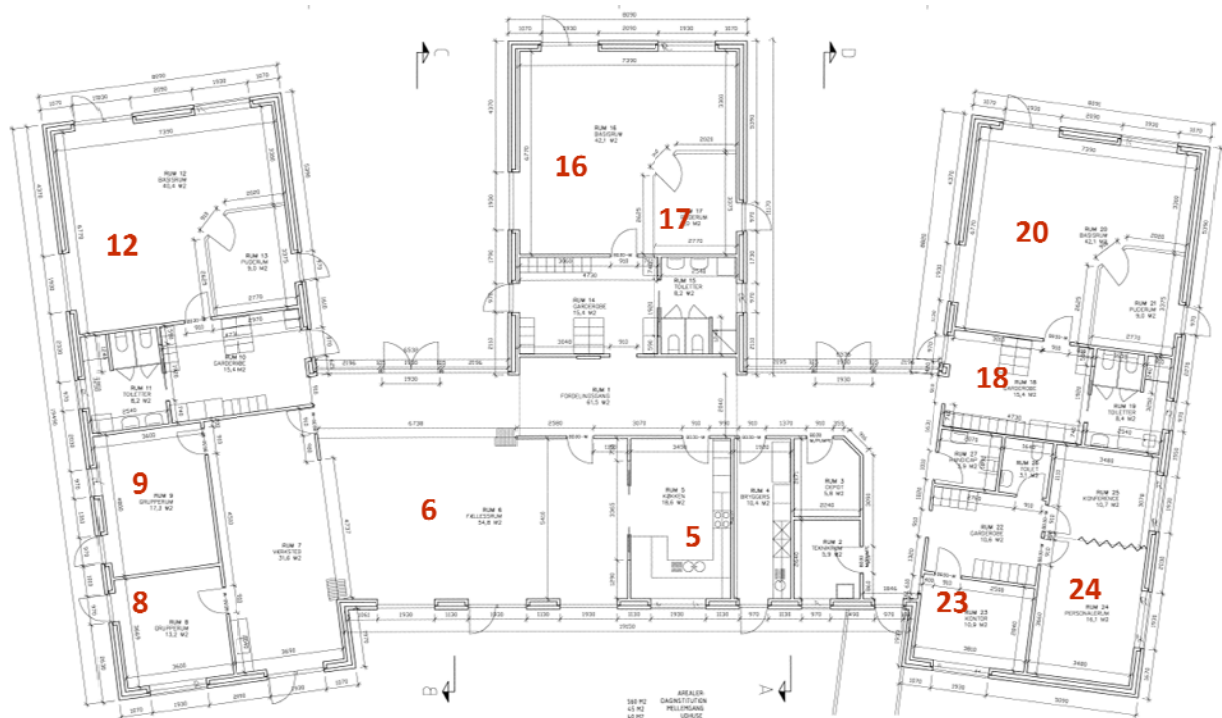
Figure 1. Plan of SFO Nymarken

SFO Spirehuset

The building is located in a smaller town Hirtshals on the Northern coast of Denmark. In a neighborhood of SFO Spirehuset, there are mainly one-storey buildings and some greenery without any tall trees. The distance from Spirehuset to the nearest buildings is quite long and therefore Spirehuset is well exposed to wind and sun. However, there is a small artificial hill 200m away from South-Western facade. The area around the building can be identified as suburban.

SFO Spirehuset 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 building is divided into several zones, which are connected by an open-space common room (Figure 4). Five of these zones are directly connected to the common room, while 5 smaller rooms can be closed. Room height in the common room is significantly higher than in the other rooms (see the central core in Figure 2).

Figure 2. Section of SFO Spirehuset.

The core part of the building is wooden construction, while all appendixes to the building made of brick.

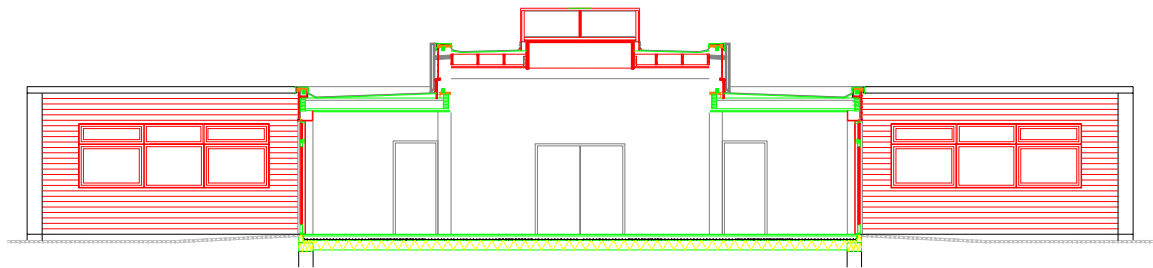The level of occupancy in the building is very sensitive to the outdoor weather conditions, as many children can be playing outside. Approximate timetable for the building operation is as following:

6:00 -8:00	10-30 occupants
8:00-13:00	1-2 occupants
13:00-14:00	30-100 occupants
14:00-16:00	10-100 occupants (children can be playing outside)

More details about the occupancy level will be given in the next chapter, together with the results of measurements.

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.

Cross and stack ventilation principles are applied for natural ventilation of Spirehuset. The stack ventilation works due to air inlets located in the windows, at a normal window height, while exhaust openings are located in the roof. The air is entering smaller zones, in the corners and sides of the building. Then, the air is gathered in the common room, located in the centre of Spirehuset. To support stack effect, the height of the common room is designed higher than of the other rooms. In the common room, the air is extracted through the roof openings, as seen in Figure 3.

Spirehuset is divided into 11 thermal zones, where the air temperature and CO_2 are controlled, depending on ventilation strategy. On average, the strategy of pulse ventilation is used. In that case the openings are open to a certain degree for 180 seconds. 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.

Night cooling is automatically controlled according to set point for air temperature in the building. Presently, minimum air temperature for night cooling is fixed at 18°C and average air temperature is set to 21°C.

Winter operation of the system
00:00 Openings closed
06:00 Fresh air supply
06:05 Ventilation acc. to need for fresh air + pulse ventilation
17:00 Openings closed

Summer operation of the system
00:00 Optimized night cooling
06:00 Fresh air supply / cooling
06:10 Comfort ventilation+ pulse ventilation
17:00 Optimized night cooling

During the weekends the ventilation system is off.

Timetable for the pulse ventilation
Maximum opening for pulse ventilation is 25% and maximum airchange rate is 0.5 1/h.

Vinter Puls	Sommer puls
08:00	08:00
09:00	09:00
09:30	09:30
10:00	10:00
11:00	11:00
12:00	12:00
13:00	13:00
13:30	13:30
14:00	14:00
14:30	15:00
15:00	15:30
15:30	16:00
16:00	16:30
16:30	17:00
17:00	18:00
	19:00
	20:00

Table 1. Timetable for pulse ventilation in SFO SPirehuset.

The building is heated using water-based floor heating, which is provided from the district heating systems.

Figure 3.Exhaust openings, view from the roof (left). Exhaust openings for stack ventilation in the common room (right).
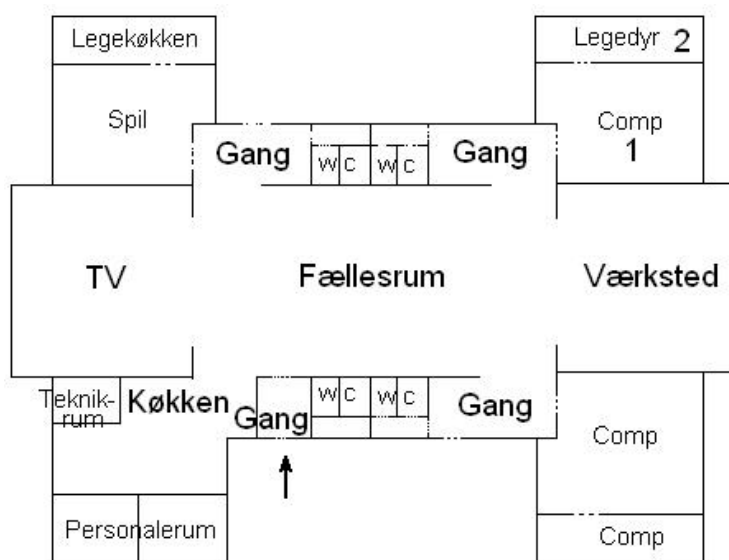
Figure 4. Plan of SFO Spirehuset

4. Measurement programme in the buildings

As a part of this project, detailed monitoring of indoor air quality, comfort and energy use in 4 mechanically and 4 naturally ventilated kindergartens were conducted. Looking upon these observations and measurements one representative for each category building has been chosen. SFO Spirehuset, represents naturally ventilated building and SFO Nymarken represents mechanically ventilated building. Both of the buildings are functioning as SFO and therefore have similar operational hours and user profile, as explained in the previous chapter.

One of the main goals in the project is evaluation of energy saving potential in the kindergartens by application of an optimal ventilation strategy in specific cases. Evaluation of the energy saving potential can be carried out using building thermal and energy simulation program. This, requires development of a reliable building model, which can fairly well predict building performance in terms of energy and comfort. In practice, however, it is difficult to set-up such a reliable model, 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 verify the reliability of the model it has to be validated according to the experimental data and observations of building operation and occupants' behavior, if available. In this chapter, the main measurement and observations principles from two chosen buildings are explained. These are then used as an input for the models and also used for empirical validation of these models.

Following are the parameters that were measured/observed in SFO Spirehuset and SFO Nymarken:

- Room air temperature
- Exhaust air temperature
- Supply air temperature (valid only for SFO Nymarken)
- Temperature gradient in building (valid only for SFO Nymarken)
- Concentration of CO_2 in the occupied zones
- Concentration of CO_2 in outdoor air
- Concentration of CO_2 in exhaust air (valid only for SFO Nymarken)
- Air tightness of the building (the results are unreliable and can will not be reported)
- Electricity use in building
- Occupancy
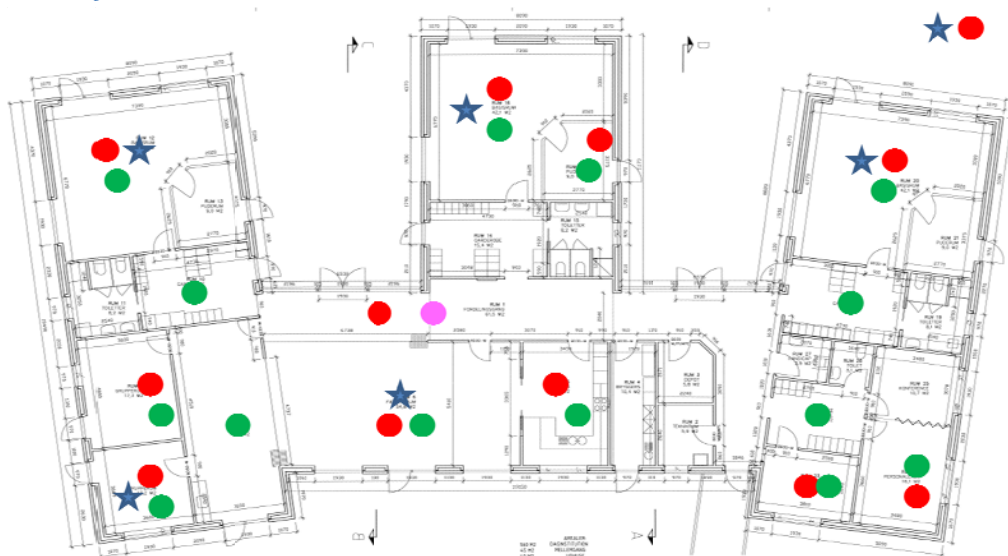- Observation of occupants' behavior

SFO Nymarken

Room air temperature was measured in a number of zones (Figure 13) on the height of apx. 1.4 m (Figure 6). In most of cases sensor was placed so, that it was not exposed to the direct solar radiation from the windows. The air temperature in the rooms appeared to be rather stable, without significant variation during the day and without notion of overheating. On average, the air temperature was 21 ^{o}C, which is 1 ^{o}C higher than the supply air temperature. For the periods with high occupancy, the temperature increases up to 22-23°C.

Supply air temperature was measured in a few points: in two biggest fresh air supply openings in the building (Figure 7) and in the ventilation system after the heating unit. According to the measurement results (Figure 9) it is concluded that the supply air temperature is kept constant by ventilation system to 20°C. Due to some heat losses from the ventilation ducts on the loft, an actual supply air temperature in the building was apx. 19°C. It s also noticeable that there was a period of time (at apx. 3am on 9th of April) without preheating of the supply air.

Exhaust air temperature was measured at the top of room, next to an exhaust opening (Figure 6). This was also measured by positioning a temperature sensor in the ventilation system, before the heat recovery unit. The results of these measurements can be seen in Figure 9 and Figure 10.

Because of the long-term measurements (1 week), the frequency of air temperature records was 1 time per 5 minutes.

Figure 6. Positioning of CO2 and temperature sensors in room 12 in SFO Nymarken (left). Measurement of exhaust air temperature in room 12 in SFO Nymarken (right).

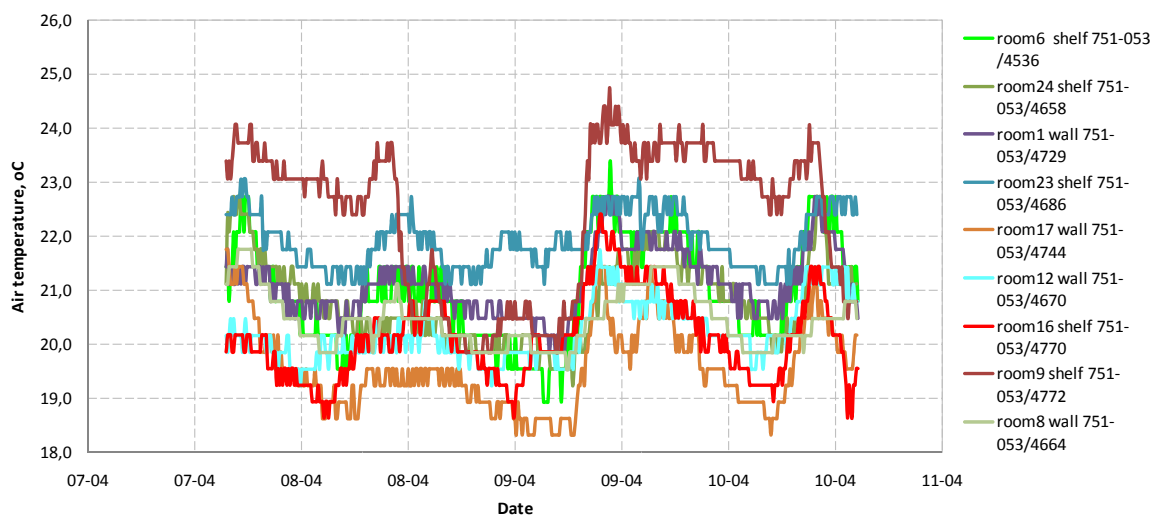**Figure 7. Positioning Measurement of supply air temperature in SFO Nymarken.**

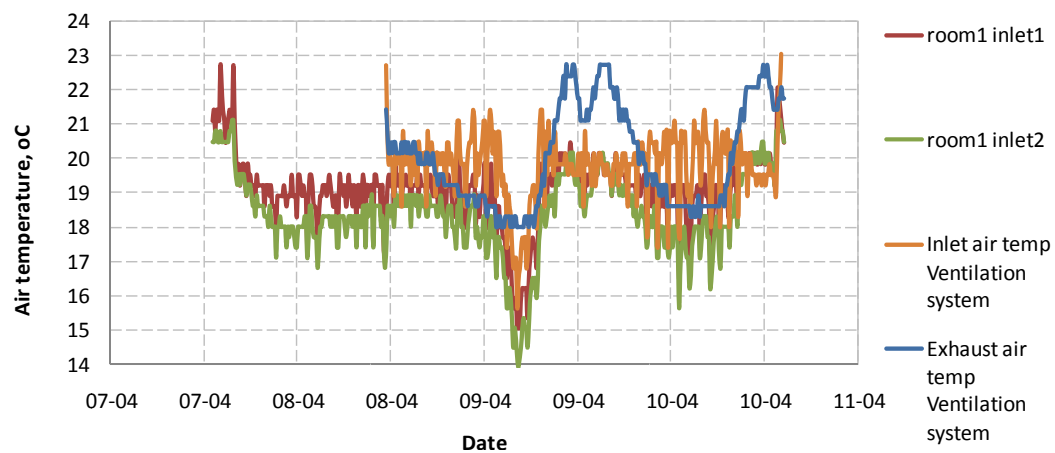**Figure 8. Room air temperatures in SFO Nymarken.**

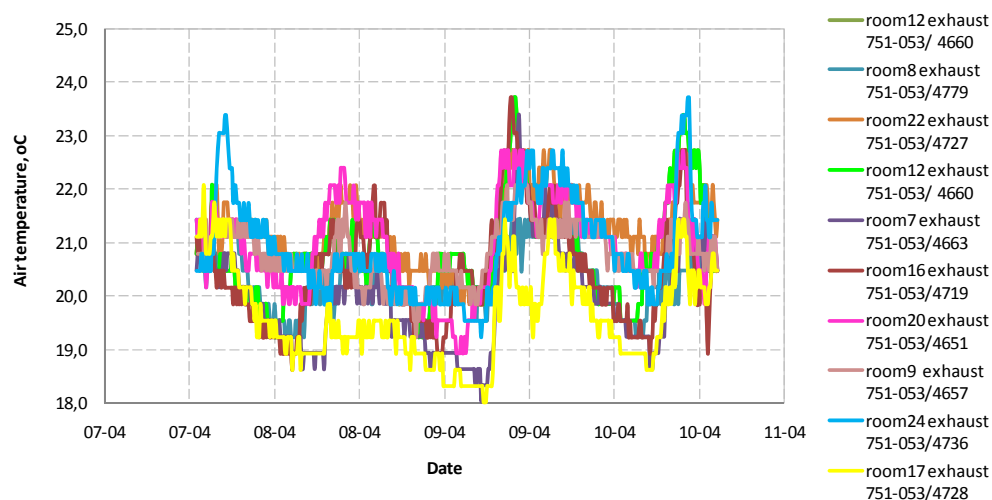**Figure 9. Supply and exhaust air temperatures in SFO Nymarken.**

Figure 10. Exhaust air temperatures in SFO Nymarken.

The concentration of carbon dioxide in the occupied zones was measured at the same height, as the room temperature (Figure 5). The concentration of CO_2 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 (9th and 10th of April), high concentration of CO_2 is experienced only for the first half of the day, for more cloudy day, the peaks of CO_2 concentration are also present in the afternoons. High concentration of CO_2 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 CO_2 increases in the common room 6, when all of the occupants are gathered for a lunch.
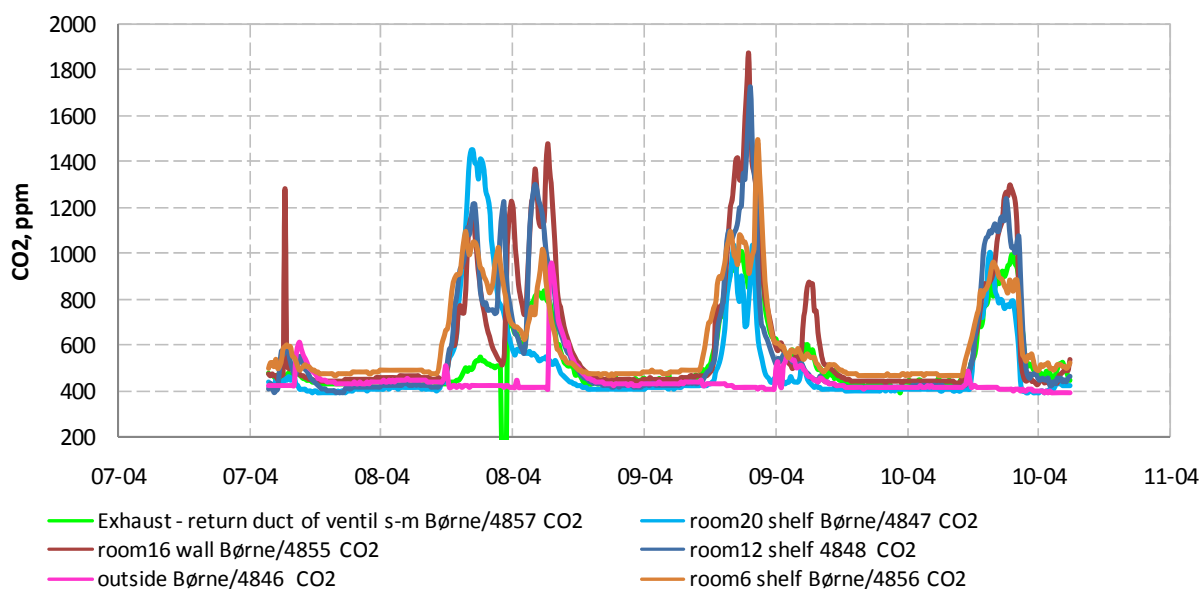

Figure 11. CO2 concentration in SFO Nymarken.

Measurement of outdoor air temperature and concentration of CO2 are also available. Measurement of CO2 in the daytime, however, is influenced by nearby playground and children's interest to the equipment.

Electricity use in the building was recorderded every morning and evening. This is also supported by periodic observation of electricity use during the day time Table 2.

Date	Time	Electricity use, kWh
07-Apr-2008	17:00	0119626
08-Apr-2008	06:45	0119651
08-Apr-2008	10:15	0119665
09-Apr-2008	10:15	0119717
09-Apr-2008	12:00	0119723
09-Apr-2008	15:40	0119731
10-Apr-2008	06:30	0119758
10-Apr-2008	13:45	0119780

Table 2. Electricity use in SFO Nymarken.

Since the heating system in the building is connected to a gas boiler, usage of the gas in the building has been noted (Table 3).

Date	Time	Gas consumption, m^3
07-Apr-2008	17:00	41430.863
08-Apr-2008	06:45	41443.380
08-Apr-2008	10:15	41446.170
09-Apr-2008	10:15	41475.553
09-Apr-2008	12:00	41476.328
09-Apr-2008	15:40	41477.982
10-Apr-2008	06:30	41490.632
10-Apr-2008	13:45	41494.650

Table 3. Use of gas in SFO Nymarken.

Occupancy in the different zones of the building has been recorded every 15 minutes. This data was then processed and averaged for every 1 hour. As a result, three occupancy profiles (one profile for each day of observation) were obtained (Figure 12, ill. 1-3). On the basis of these profiles, an average occupancy profile for a day is produced (Figure 12, ill. 4).
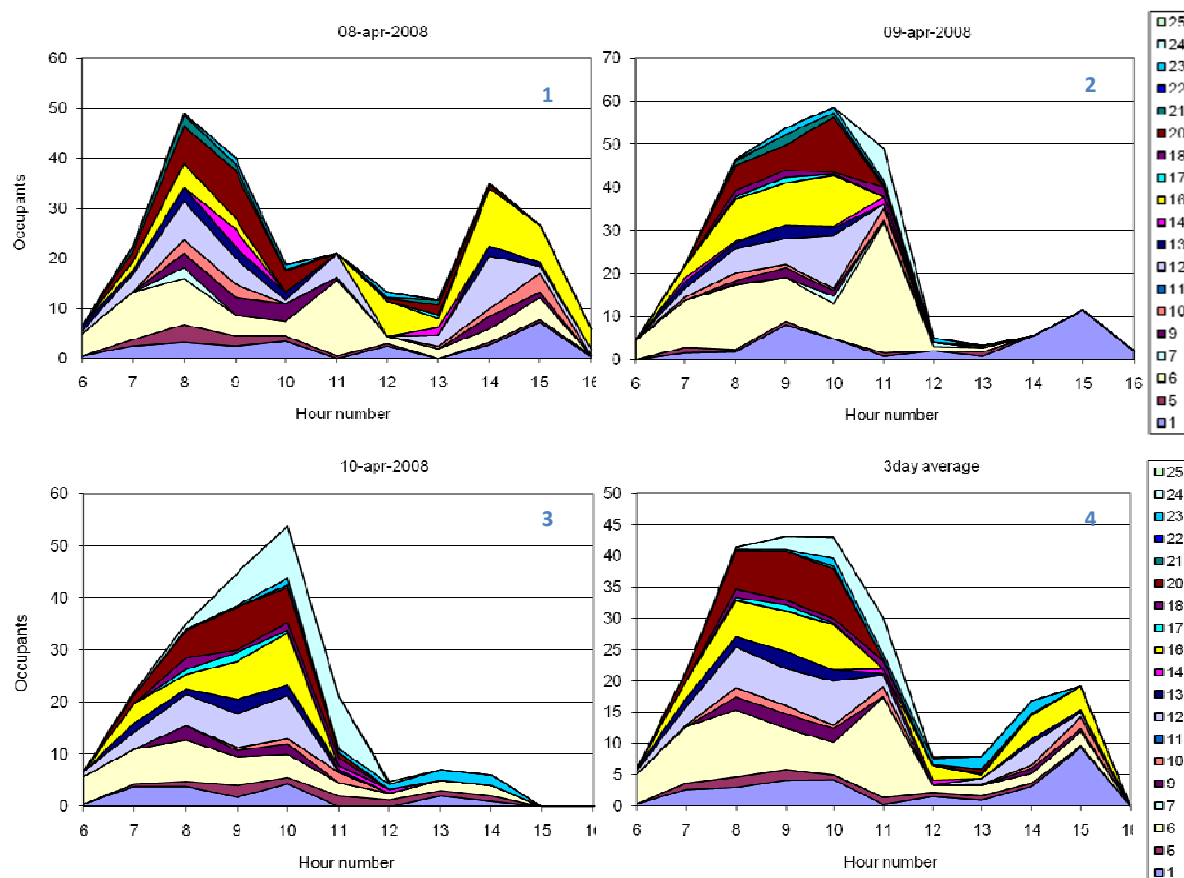
Figure 12. Occupancy profiles in SFO Nymarken: 1. on April, 8th, 2. on April 9th, 3. on April 10th, 4. 3-days average profile.

Ventilation flow rates 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.

Comparison of measured and designed flow rates

According to the building regulations BR08 [4]: "Opholdsrum i daginstitutioner skal ventileres med et ventilationsanlæg, der omfatter såvel indblæsning som udsugning. Indblæsningen med udeluft og udsugningen skal være mindst 3 l/s pr. barn og mindst 5 l/s pr. voksen, samt 0,4 l/s pr. m² gulv. Hvis der benyttes ventilationsanlæg med variabel ydelse i afhængighed af belastningen, kan der afviges herfra, når der er reduceret behov."

Assuming following occupancy, the design flow rate in the building is calculated.

Occupancy: 50 children and 5 adults.
Floor area: 560 m²
Design flow rate: 1625m³/h
Measured flow rate: 1225 m³/h (75% of the design flow rate)

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SFO Spirehuset

SFO Spirehuset is ventilated using natural ventilation principle. The building is equipped with sensitive control system, which operates openings in the building according to the need of fresh air in the building.
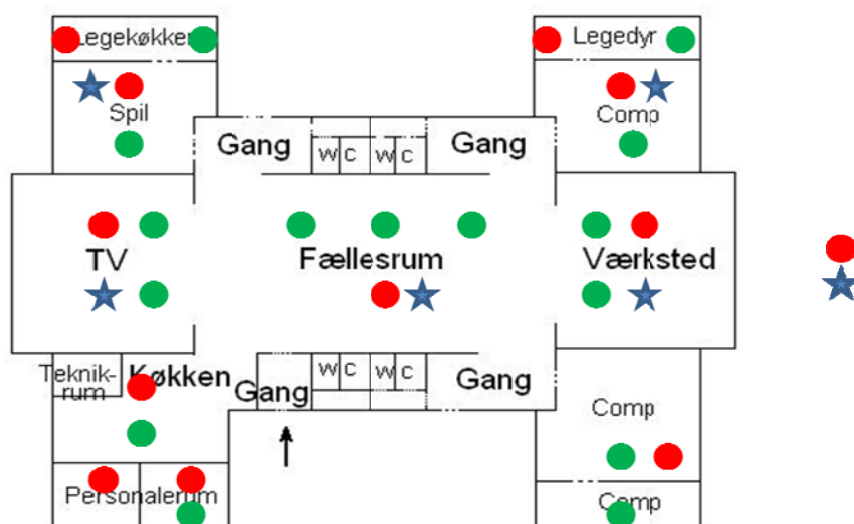

Figure 13. Measurements in SFO Spirehuset: red – room air temperature, green – air temperature in exhaust, blue – CO2 concentration.

Room air temperature was measured in a number of zones (Figure 13) on the height of apx. 1.4 m (Figure 14). In most of cases sensor was placed so, that it was not exposed to the direct solar radiation from the windows. The results of these measurements are illustrated in Figure 15. It is seen that on average, the air temperature in the building is apx. 22 ^{o}C. However, with increase in occupancy, the air temperature increases up to 25°C. This is characteristic for the lunch time period (from 12 to 2 o'clock in the afternoon), when all of the occupants are gathered in the common room or if there are many children gathered in one particular activity room. At night, the air temperature in the building is reduced.

Exhaust air temperature was measured at the top of the room (Figure 6). Such positioning of the measurement equipment, however, is not sufficient, as the temperature sensors were exposed to the direct solar radiation. Besides the exhaust air temperature in the building, the temperature gradient was measured in the Common room.

The frequency of all air temperature records was 1 time per 5 minutes.

Figure 14. Positioning of measurement equipment in Common room in SFO Spirehuset (left). Measurement of exhaust air temperature (right).
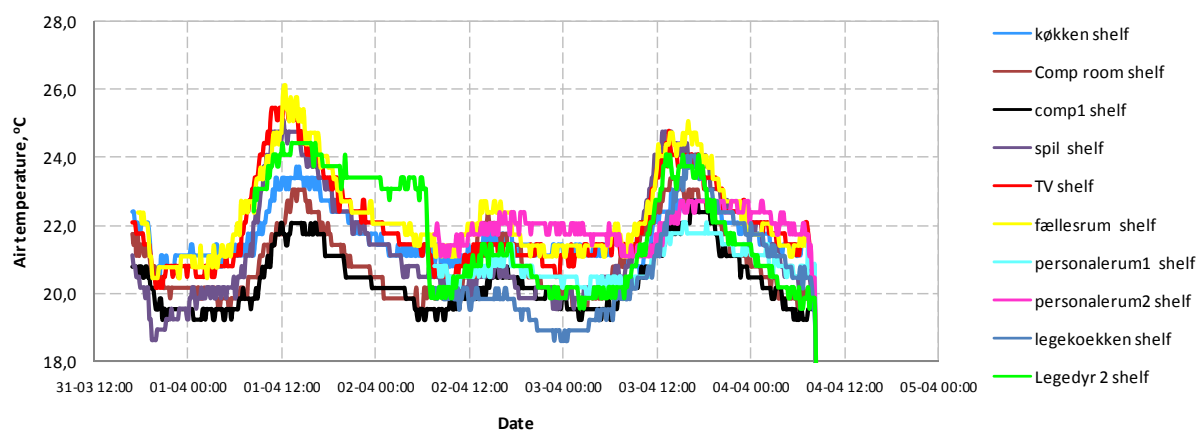

Figure 15. Air temperature in SFO Spirehuset.

The concentration of carbon dioxide in the occupied zones was measured at the same height, as the room temperature (Figure 14). The concentration of CO_2 gives a notion occupancy pattern in the building: 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 CO_2 is reduced to apx. 500ppm. This reduction of CO_2 takes place due to functioning pulse ventilation and widely open windows in the building by cleaning personnel.
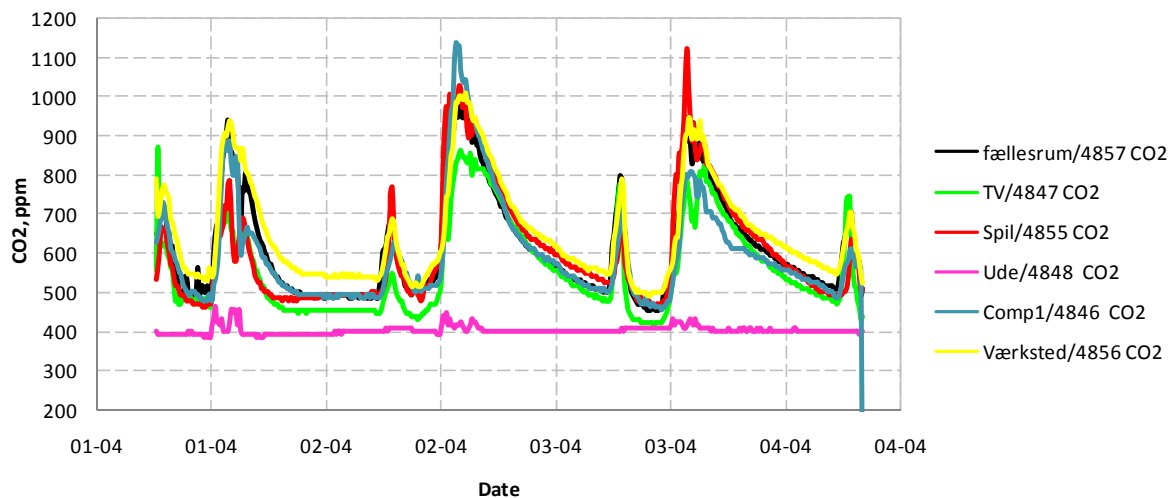
Figure 16. Concentration of CO2 in SFO Spirehuset.

Similar to SFO Nymarken, the measurement of CO_2 concentration in the outdoor air in the daytime, is influenced by nearby playground and children's interest to the equipment.

Occupancy in the different zones of the building has been recorded every 15 minutes. This data was then processed and averaged for every 1 hour. As a result, three occupancy profiles (one profile for each day of observation) were obtained (Figure 12, ill. 1-3). On the basis of these profiles, an average occupancy profile for a day is produced (Figure 12, ill. 4).

Calculation of the infiltration flow rate

In Figure 16, it is clearly seen the dilution of carbon dioxide after the opening hours in the building (from 02-Apr to 04-Apr). These curves can be used to estimate the infiltration flow rate in the building, including additional infiltration/exfiltration in the building.

Accordingly, the air change rate caused by infiltration is as given in Table 4.

	Air change, 1/h
02-Apr 17:00 to 03-Apr 05:00	0,13
03-Apr 17:00 to 04-Apr 05:00	0,09
Average value	0,11

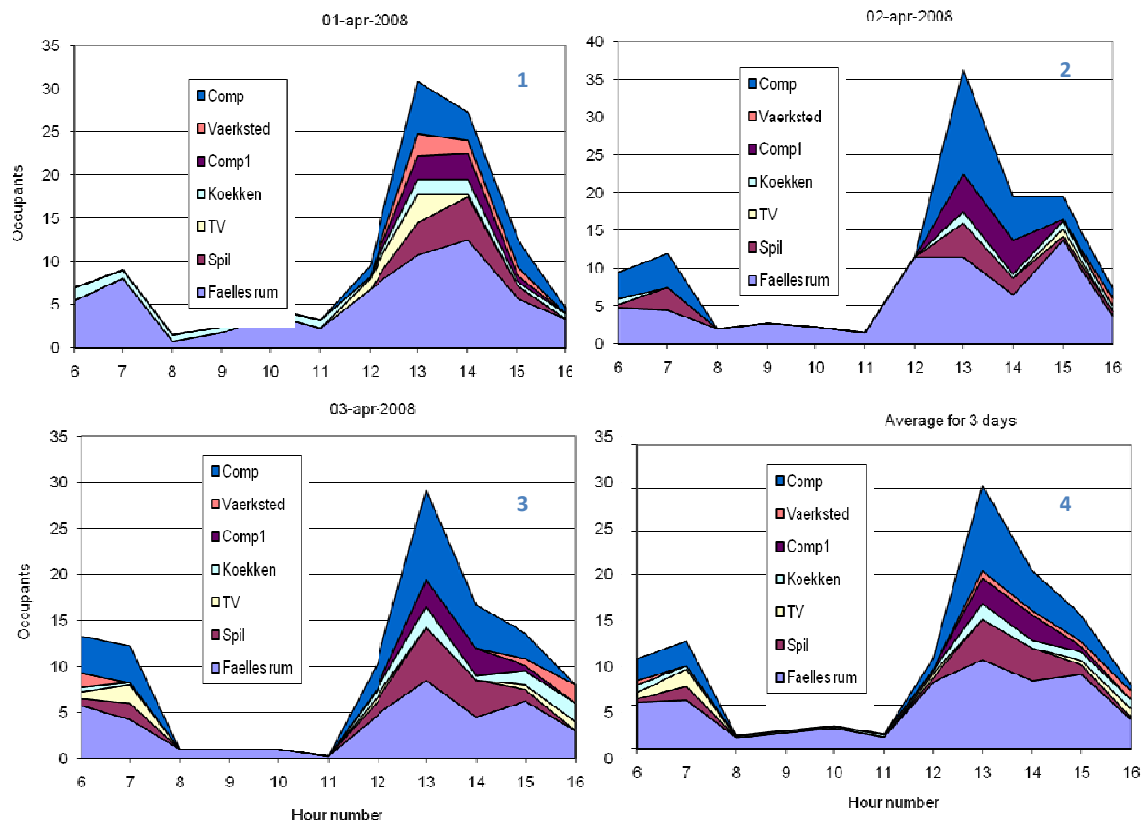**Table 4. Infiltration in SFO Spirehuset.**

Figure 17. Occupancy profiles in SFO Spirehuset: 1. on April, 8[1st], 2. on April 2nd, 3. on April 3rd , 4. 3-days average profile.

5. Aim of modelling. Modelling possibilities

The main intention with modelling different ventilation principles in SFO Spirehuset and SFO Nymarken is further analysis of these ventilation strategies for each particular building in terms of energy efficiency and occupant comfort that they can provide. Being able to compare different ventilation strategies will help to choose optimal ventilation principles when designing and dimensioning institutions for children.

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 validation of models against experimental data. In this project 4 ventilation principles must be tested for mechanically ventilated building and 4 principles 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.

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' behavior, 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' behavior, such as manual opening of the windows and manual control of ventilation system (in case of SFO Spirehuset).

Modelling of CAV balanced mechanical ventilation system 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 behavior is impossible. In BSim there is no module suitable for simulation of pulse ventilation performance. Several assumptions should be made in order to realize a reliable model for actual performance of SFO Spirehuset, as explained in the following chapters.

Following are the ventilation strategies to be simulated for further analysis of their potential and their limitations to be implemented in the daycare institutions:

Mechanically ventilated SFO Nymarken
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 CO_2 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 CO_2 or/and air temperature. With presence of venting initialized by occupants. The VAV-system capacity is 25% bigger than in case 3.

Case 5. Mechanically ventilated building with VAV-system, controlled according to CO_2 or/and air temperature. With presence of venting initialized by occupants. The VAV-system capacity is 50% bigger than in case 3.

Naturally ventilated SFO Spirehuset

Case 1. Actual building performance. Automatically controlled natural ventilation (CO_2 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).

Case2. Designed building performance. Automatically controlled natural ventilation (CO_2 and temperature controlled) combined with pulse ventilation and air tight building.

Case 3. Automatically controlled natural ventilation (CO_2 and temperature controlled), no pulse ventilation and air tight building.

Case 4. Automatically controlled natural ventilation (temperature controlled) combined with pulse ventilation and air tight building.

6. Empirical validation of models (1 week)

Empirical validation of the models is carried out for case 1 model for each of the buildings. Most of the inputs in the models were determined from available documentation for building systems and from observations of building performance.

The boundary conditions for the simulations (weather data) were purchased from the Danish Meteorological Institute (DMI) for a corresponding weather station: Årslev and Odense for SFO Nymarken, Hirtshals and Skagen for SFO Spirehuset. The weather data is available for the period when the measurements were carried out in the corresponding daycare institutions. The weather data consists of following parameters for every hour:

- Wind speed
- Wind direction
- Air temperature
- Relative humidity
- Atmospheric pressure
- Global radiation
- Cloud cover

These 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 [2], making use of global solar radiation and cloud cover.

Model SFO Nymarken. Case 1

Location
Following coordinates define the geographical location of the model:

Time zone	+1 hr MGT
Degrees of longitude	10°36'E
Degrees of latitude	55° 25' N
Altitude	20 m

Table 5. Geographical and site parameters for the model of SFO Nymarken

Thermal properties of the constructions
U-values for the constructions are calculated by BSim when the material properties of the constructions are defined by user. The U-value is calculated according to the Danish Norms DS 418. In the model, construction components of the walls, floors and ceilings are defined according to available drawings of the building, which resulted in the following properties:

- Ext.wall U=0.25 W/m2K

- Floor U=0.17 W/m2K
- Roof U=0.15 W/m2K

U-value of the window is not known and assumed as U=1.67 W/m^{2}K. g-value of the glazing is assumed to be 0.66.

Model geometry

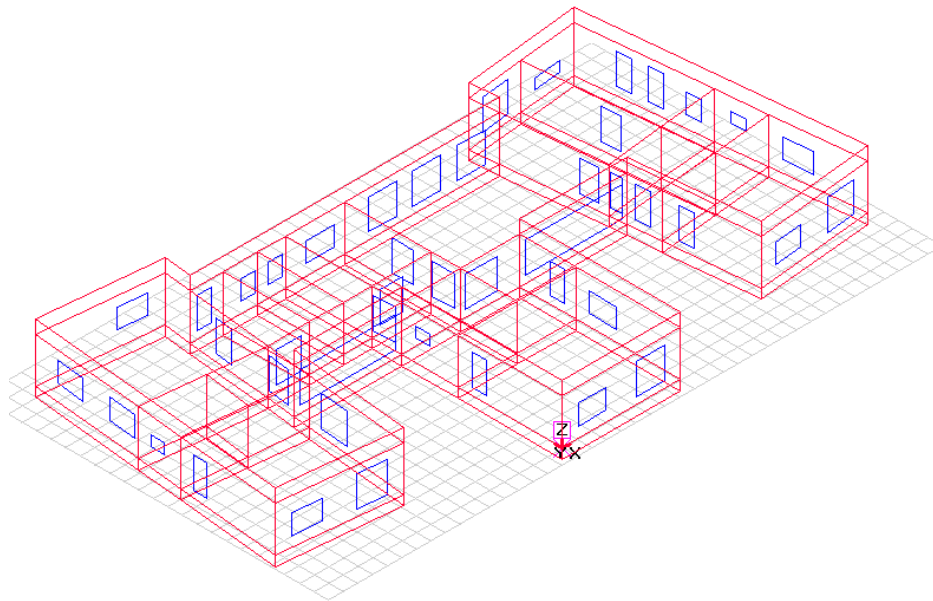Model geometry is followed the architectural drawings of the building.

Figure 18. SFO Nymarken - model geometry.

Following are the thermal zones in the model:

- Common room
- Office
- Three group rooms
- Activity room
- Bathrooms
- Kitchen
- Corridor
- Technical room

Besides these main zones there are two supplementary zones: unheated loft space and a gap (basement) underneath of the building, which is used to simulate floor heating in the building, as it will be explained later. All of the thermal zones "equipped " with various systems, in order to simulate building performance.

Systems

Besides the thermal loads in the building, there are three systems, which define the building performance. These are: ventilation with heat recovery and heating unit, water floor heating and user controlled venting. It is important to be able to model all of these components and to consider longwave radiation heat exchange within the thermal zones. One issue cannot be prioritized above the other. However, simulation of the floor heating for the geometry of the building is not possible if the longwave radiation heat exchange is calculated. This is due to complexity in calculations of view factors. In order to overcome this barrier, the floor heating in the building is modeled by creating a separate zone underneath of the building. This thermal zone is heated using the heating system with the set point located in the corresponding thermal zone above. All in all there are 10 underfloor zones, which simulate the floor heating in the corresponding zones above. In these "floor heating" zones the floor construction to the ground is set the same as in the actual building, in order to be able to simulate the heat losses to the ground. The side walls in these zones are set to be adiabatic, so they do not contribute to the heat losses from the zone.

The air temperature in all zones in the building is primarily controlled by the ventilation system, in order to ensure the maximum heat recovery in the calculations. Though, the ventilation system is not equipped with the heating unit. All additional heating, necessary to maintain the set point in the building is supplied through the floor heating in the corresponding zones.

The main assumptions regarding venting will be later introduced in this chapter.

One of the limitations of this model is the definition of the thermal zones in the building. Thermal zone in BSim is simulated as a separate zone, without naturally existing flow patterns (mixing of air) between the zones with different temperatures, unless the multizone model is activated. The multizone model should be activated only for calculation of natural ventilation that is not the case for SFO Nymarken, which is mechanically ventilated.

Another way defining air mixing between the zones is making use of system "mixing". Activation of mixing system in the model will result in unbalanced air-flows in the building, which will be balanced automatically by infiltration or exfiltration to the outdoor - no matter if the thermal zone is completely surrounded by other rooms or thermal zones. Therefore it is chosen not to use mixing in the model, as it will result in highly unpredicted flow patterns in the building.

People
People load in the zones is entered according to the observation of occupancy in different zones, as illustrated in Figure 12. The nominal heat and CO2 gain from people in the room will depend on occupants' activity level and clothing. In the model, the nominal heat gain from the occupants is set to 0,1kW.

Equipment
Electricity use in the building is approximated according to observations of equipment use, and records of electricity consumption. The results of this approximation are given in Table 6.

Thermal zone	Electricity use, %	Electricity use, kW

Common room	12	0,36
Office	6	0,18
Group room 20	7	0,21
Group room 16	7	0,21
Group room 12	7	0,21
Activity room	3	0,09
Bathrooms	3	0,09
Kitchen	20	0,6
Corridor	5	0,15
Technical room	30	0,9

Table 6. Electricity use in different zones of SFO Nymarken

Following is the schedule for the electricity use:

 6:00-10:00   50%

10:00-12:00   100%

12:00-17:00   67%

Infiltration

The infiltration flow rate in the building is set to:

0,12 l/sm2   - for working hours

0,09 l/sm^2 - outside of working hours

The schedule for infiltration is given in Figure 19.
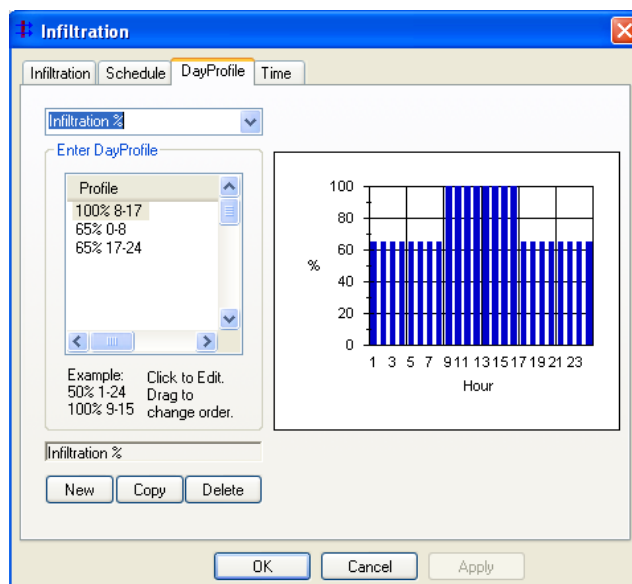
Figure 19. Schedule for infiltration in SFO Nymarken.

Floor heating (heating in underfloor zones)

The heating is activated for the whole heating season and it is controlled as illustrated in Figure 20. The sensor for the heating is always placed in the zone above. The maximum heating power, available in the radiator at all outdoor temperatures below the design outdoor temperature is set depending on size of the thermal zone and its internal loads.
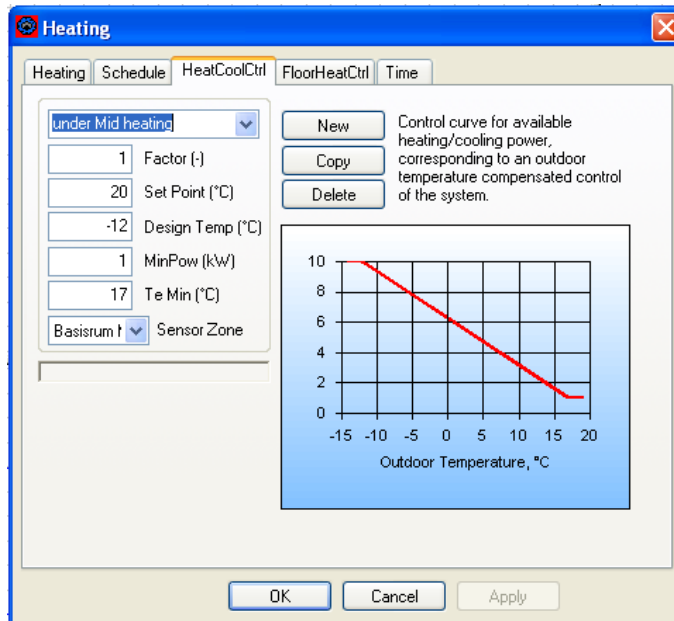
Figure 20. Heating control in underfloor zones in SFO Nymarken.

Ventilation

For the present model, it is chosen to follow the measured and disregard the design ventilation flow rates in the building.

Following are the ventilation flow rates set for the different thermal zones, Table 7.

Thermal zone	Supply, m^3/s
Common room	0,054
Office	0,043
Group room 20	0,033
Group room 16	0,031
Group room 12	0,026
Activity room	0,023
Bathrooms	0,234
Kitchen	0,029
Corridor	0,074
Technical room	0,01

Table 7. Ventilation flow rates in SFO Nymarken.

In Figure 21, the main characteristics of the ventilation system are given. As it was explained earlier, it is assumed that the ventilation system is only equipped with the heat recovery unit. There is no heating or cooling unit. This means that the maximum supply temperature will depend only on heat recovery.

The control of the ventilation system is defined according to "InletControl", Figure 22. The temperature set point is set to 21°C that is above the heating set point. In that way the ventilation system control overrules the heating control. The system is always activated.

Figure 21. Ventilation system in SFO Nymarken.
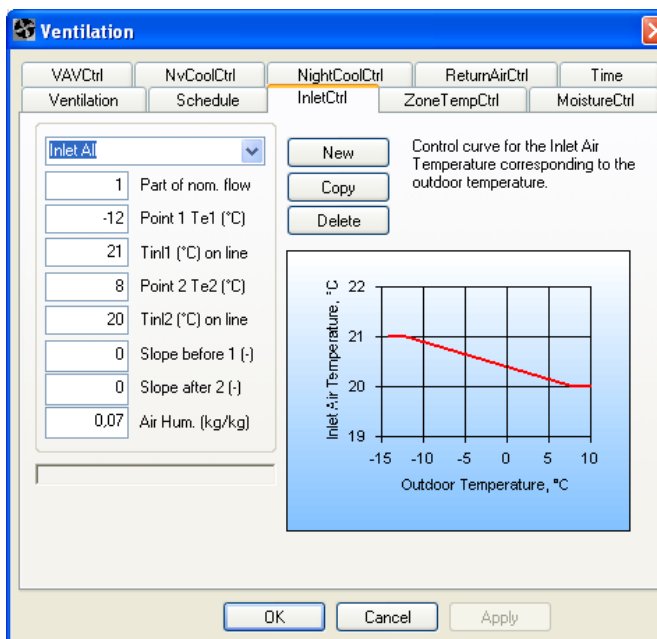
Figure 22. Control of ventilation system in SFO Nymarken.

Venting

Venting control simulates windows or ventilation openings being opened, in this building, it is activated in order to simulate uncontrolled occupant behavior. The calculation principle of the flow rates in BSim is rather simplified. For more information see [3].

The venting is activated only in the group rooms and its maximum flow rate is set to 1,5 1/h (Figure 23). Users open the windows independently from the thermal or IAQ conditions in the zones, therefore the control principle of venting is overruled so, that the windows are open according to the defined schedule (Figure 23). Since the measurements in the building were carried out during the warmer season, the openings in the group rooms were open from 10 am until the end of the day.

Figure 23. Venting in SFO Nymarken.

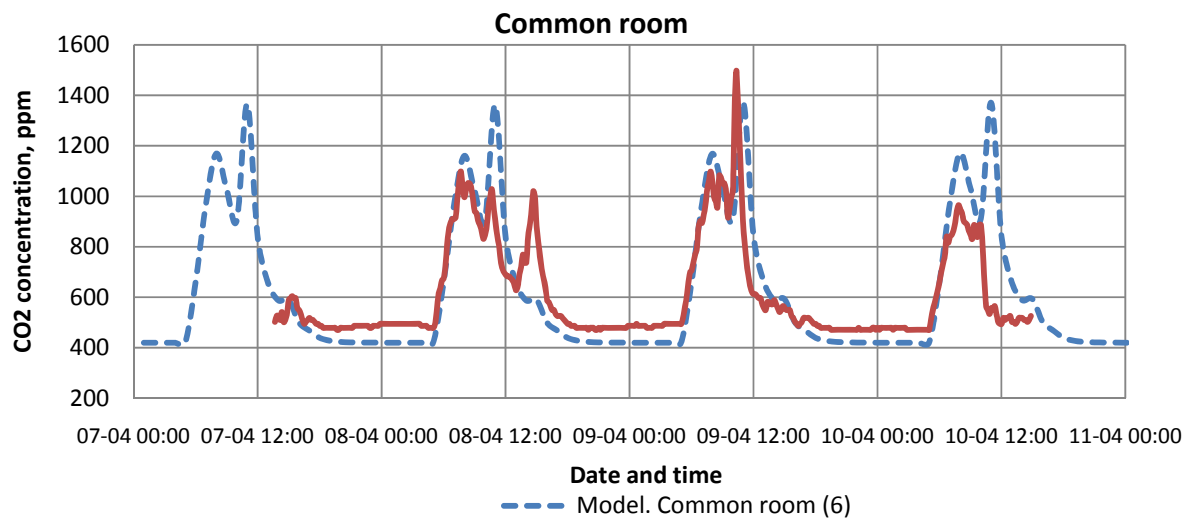**Figure 24. Schedule for venting in SFO Nymarken.**

Results of simulation

CO2

Room 12

Room 16

Room 20

Common room

Air temperature

Room 12

Room 16

Common room
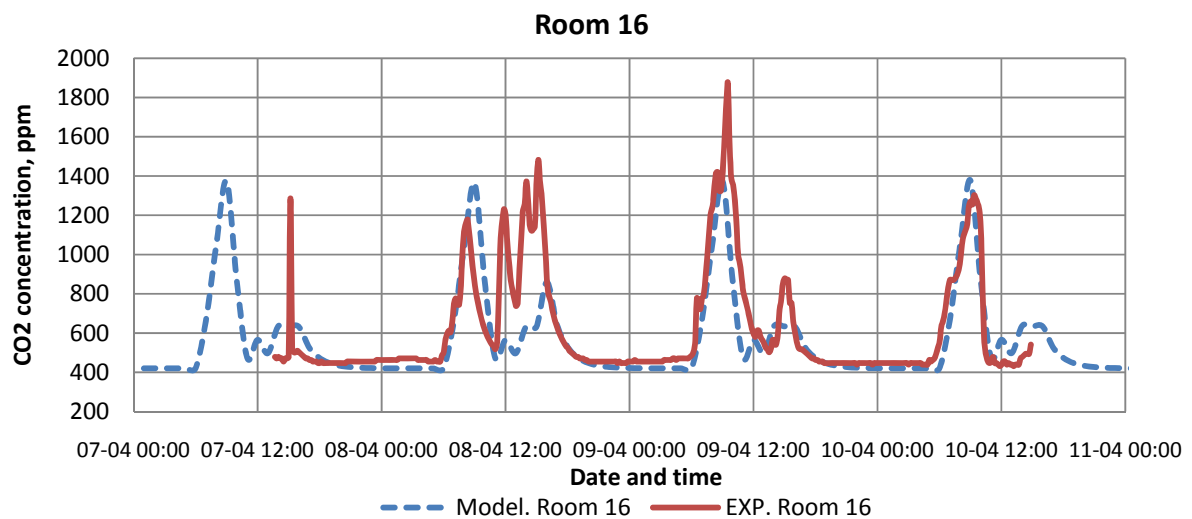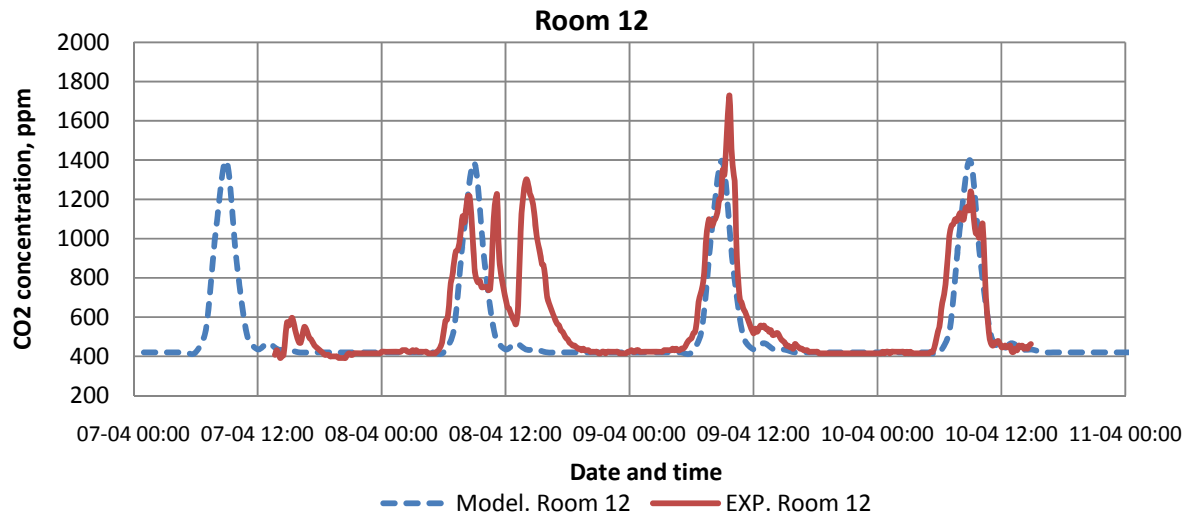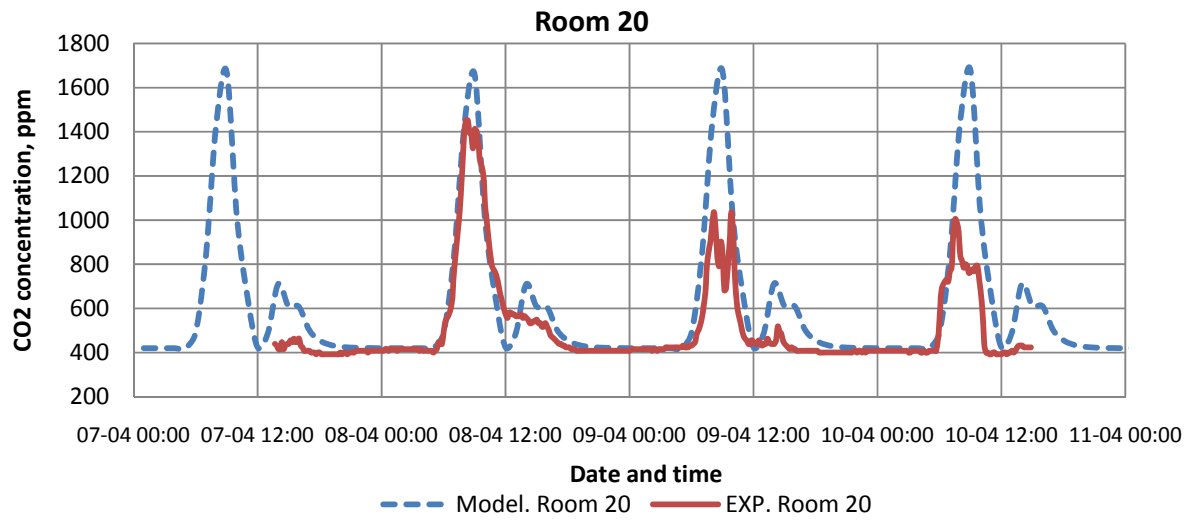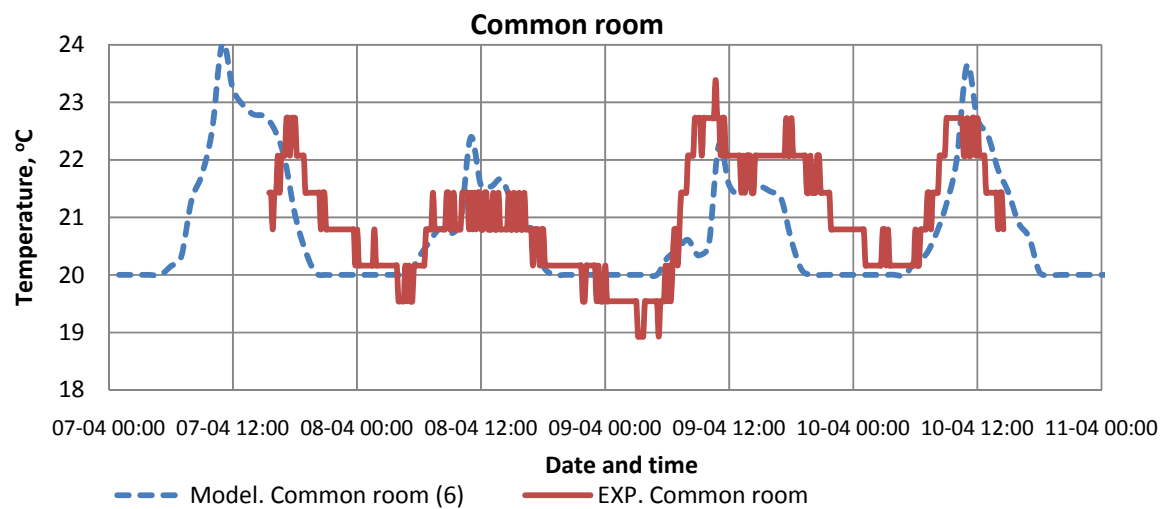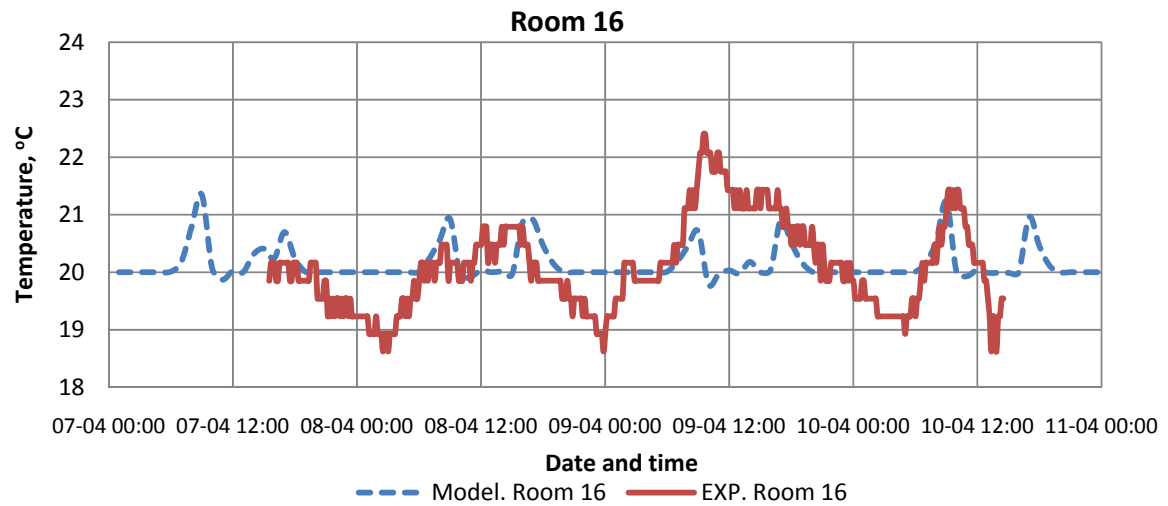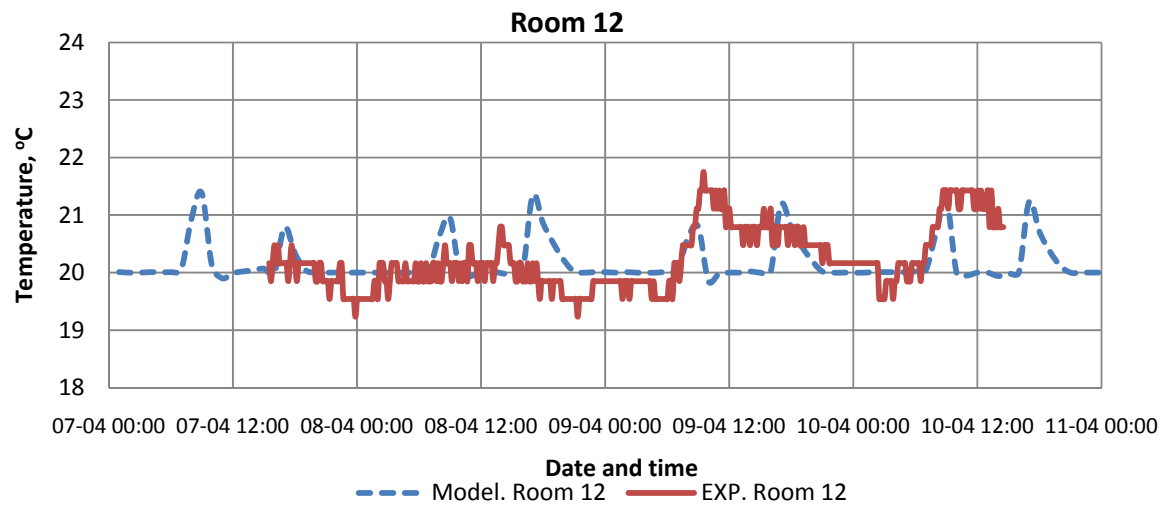
Summary for SFO Nymarken

In the above figures, measured and calculated carbon dioxide and air temperature are compared, in order to validate the model of SFO Nymarken.

Rather good agreement in CO2 predictions is seen for three out of four zones: there are periods when results of simulation exceed the measurement results and there are also some periods, when simulated concentration of CO2 is lower than measured. This is not the case for Room 20. In this zone, calculated concentration of CO2 is always higher than the measured one. This can either be explained by difficulties in observation of occupancy level or by method how an average occupancy profile was developed.

With regard to simulated and measured air temperature in the building, good agreement is reached between the measurements and simulations.

Model SFO Spirehuset. Case 1

Location

Following coordinates define the geographical location of the model:

Time zone	+1 hr MGT
Degrees of longitude	9°58'E
Degrees of latitude	57° 35' N
Altitude	15 m

Table 8. Geographical and site parameters for the model of SFO Spirehuset.

Thermal properties of the constructions

In the model, construction components of the walls, floors and ceilings are defined according to available drawings of the building, which resulted in the following properties:

- Light wall U=0.14 W/m2K
- Brick wall U=0.29 W/m2K
- Floor U=0.14 W/m2K
- Roof U=0.14 W/m2K

U-value of the window is not known and assumed as U=1.67 W/m^2K. g-value of the glazing is assumed to be 0.66.

Geometry

Following are the thermal zones in the model:

- Common room
- Three activity rooms
- Bathrooms

Besides these main zones there is a supplementary zone: a gap (basement) underneath of the building, which is used to simulate floor heating in the building, as it will be explained later. All of the thermal zones "equipped " with various systems, in order to simulate building performance.

Systems

In order to model the actual performance of SFO Spirehuset, following systems must be carefully defined:

- CO_2 and temperature controlled natural ventilation
- Pulse ventilation
- Infiltration
- Opening of windows by the occupants (manually controlled venting)

There are few possibilities to model such combination of systems in a building:

1. Combining natural ventilation with pulse ventilation and venting into one system. This will allow an application of multizone model, which is able to perform detailed calculation of the natural air flow, depending on opening degree. The opening degree will depend on the control strategy of the system and obtained by iteration in BSim. Infiltration can be modeled as a separate system.

   These advance calculations, however, cannot solve the problem of missing input data such as pressure difference coefficients and discharge coefficients for the openings. As a consequence these advanced calculations will not improve the accuracy of simulation.

2. Assuming that the control of the natural ventilation flow rate in the building is efficient, it is possible to replace the natural ventilation system by VAV-controlled mechanical ventilation. Relying on the same assumption of efficient control of natural ventilation, the pulse ventilation can be disregarded. Finally, venting can be modelled as a separate system, activated according to a certain schedule. Infiltration can be modeled as a separate system.
   In general, modelling of VAV-system in BSim is not possible, but for the cases when no heat recovery is used, it is possible to model VAV-system by use of "ReturnAirCtrl" function.

   This method, however will result in the unrealistic distribution of carbon dioxide in the thermal zones due to lack of pulse ventilation. This is issue is solved in possibility 3.

3. Again, assuming that the control of the natural ventilation flow rate in the building is efficient, it is possible to replace the natural ventilation system by VAV-controlled mechanical ventilation. In order to build a realistic ventilation model of SFO Spirehuset, pulse ventilation must be taken in consideration.

   In description of systems in SFO Spirehuset, it is explained that pulse ventilation is limited to air change of 0,5 h^{-1}. Furthermore it can be assumed that an average air flow rate due to infiltration correspond to 0,3 h^{-1} and it is modeled as a supplementary air change rate to infiltration. For example: measured infiltration is 0,11 h^{-1}, supplementary to infiltration, pulse ventilation is 0,3 h^{-1}. Accordingly, the infiltration is modeled with the value 0,411 h^{-1} for the period of time when pulse ventilation is activated. For other time the infiltration is modeled as 0,11 h^{-1}.

    Finally, venting can be modelled as a separate system, activated according to a certain schedule. Infiltration can be modeled as a separate system.

Possibility 3 is considered to be the best approximation to an actual building performance.

One of the limitations of this model is the definition of the thermal zones in the building. Thermal zone in BSim is simulated as a separate zone, without naturally existing flow patterns (mixing of air) between the zones with different temperatures, unless the multizone model is activated. The multizone model

should be activated only for calculation of natural ventilation that is not the case for SFO Spirehuset, which is simulated as mechanically ventilated.

Another way defining air mixing between the zones is making use of system "mixing". Activation of mixing system in the model will result in unbalanced air-flows in the building, which will be balanced automatically by infiltration or exfiltration to the outdoor - no matter if the thermal zone is completely surrounded by other rooms or thermal zones. Therefore it is chosen not to use mixing in the model, as it will result in highly unpredicted flow patterns in the building.

People

People load in the zones is entered according to the observation of occupancy in different zones, as illustrated in Figure 17. The nominal heat and CO_2 gain from people in the room will depend on occupants' activity level and clothing. In the model, the nominal heat gain from the occupants is set according to

Thermal zone	Nominal heat load, kW
Common room	0,12
Comp	0,072
Comp1	0,17
Spil	0,1

Table 9. Nominal heat load from occupants in SFO SPirehuset.

Equipment

Electricity use in the building is approximated according to observations of equipment use, and records of electricity consumption. The results of this approximation are given in Table 10.

Thermal zone	Electricity use, %	Electricity use, kW
Common room	66	1,5
Comp	22	0,5
Comp1	6	0,13
Spil	6	0,13

Table 10. Electricity use in different zones of SFO Spirehuset

Following is the schedule for the electricity use:

6:00-10:00	100%
10:00-11:00	44%
11:00-15:00	100%
15:00-16:00	44%

Infiltration

As explained above, an additional infiltration rate should help to count for pulse ventilation. The infiltration rate is defined for common room as:

$0,11\ h^{-1}$ -estimated infiltration according to measurements (30%)
$0,266\ h^{-1}$ - assumed air change rate in the building due to pulse ventilation (70%)
$0,366\ h^{-1}$ - total infiltration (100%)

Following is the schedule for infiltration in common room:

0:00-8:00   30%
8:00-20:00   100%
20:00-24:00   30%

Infiltration rate in other rooms:

$0,08\ h^{-1}$ -estimated infiltration according to measurements (36%)
$0,14\ h^{-1}$ - assumed air change rate in the building due to pulse ventilation (74%)
$0,22\ h^{-1}$ - total infiltration (100%)

Following is the schedule for infiltration:

0:00-8:00   36%
8:00-20:00   100%
20:00-24:00   36%

During the weekends, the infiltration in all zones is set to 30%

Floor heating (heating in underfloor zones)

The heating is activated for the whole heating season and it is controlled as illustrated in

Figure 25. The sensor for the heating is always placed in the zone above. The maximum heating power, available in the radiator at all outdoor temperatures below the design outdoor temperature is set depending on size of the thermal zone and its internal loads.
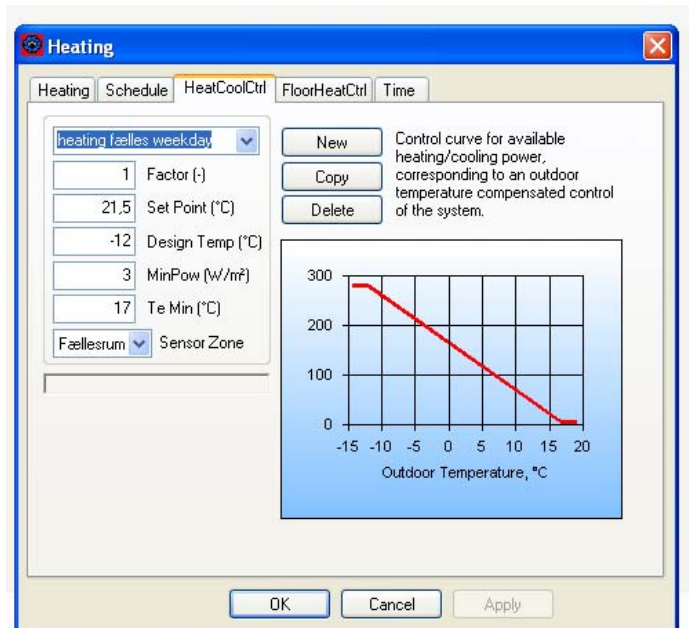
The set point for heating is 21,5 ^{o}C.

Figure 25. Heating control in underfloor zones in SFO Spirehuset.
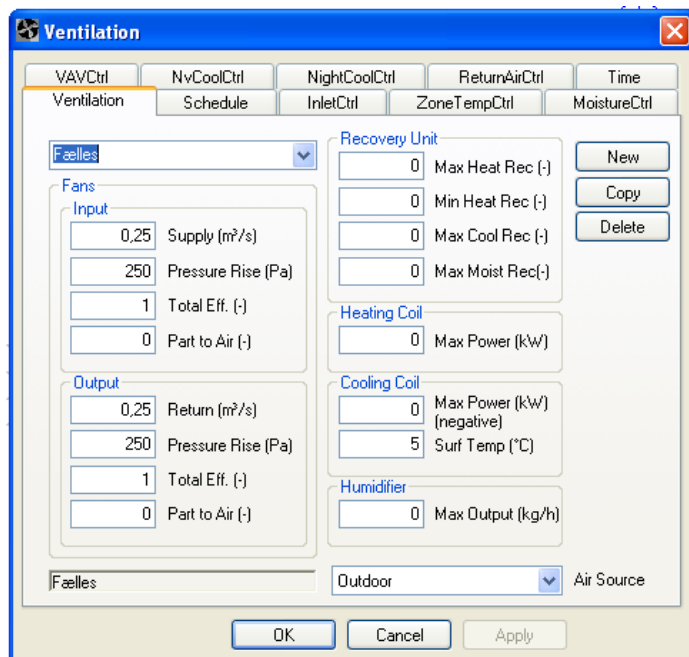
Ventilation
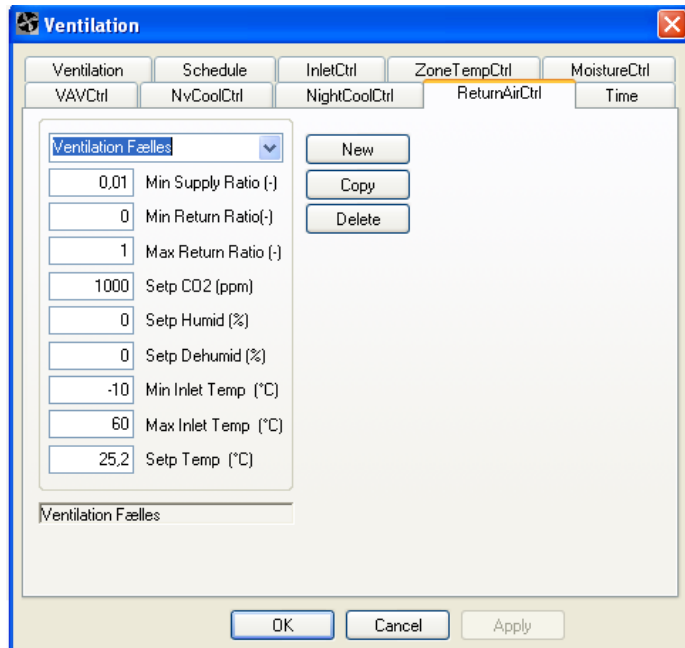

Figure 26. Ventilation system in SFO Spirehuset.

Figure 27. Control of ventilation system in SFO Spirehuset

As it is explained earlier, automatically controlled natural ventilation system in the building is replaced by VAV-controlled mechanical system. For that reason the supply air flow rate in the thermal zones must be assumed. It is set to approximately 1 air change rate in all thermal zones.

In Figure 26, the main characteristics of the ventilation system are given. The system does not include heat recovery unit (heat recovery is set to zero) neither the cooling/heating unit.

The control of the ventilation system is according to air temperature and carbon dioxide concentration is defined using "ReturnAirCtrl,"Figure 22.

Minimum supply ratio for ventilation system is set to 0,01 that corresponds to air change rate of $0,01h^{-1}$. Maximum recirculation rate is set to 1 in all zones. This means that each time there is no need for fresh air – the air in the thermal zone will be reused. That corresponds to situation when all of the opening in the zone are closed. The amount of fresh air to the zone is controlled according to CO_2 concentration and/or temperature.

The ventilation system is switched off during night (0:00-6:00 and 19:00-24:00) and weekends.

Venting

Venting is included into systems in order to model uncontrolled opening of windows in common room. It is always activated according to a certain schedule, which is defined from observation of occupant behavior.

Schedule for venting is as following:

9:00-11:00 – windows open by cleaning personnel

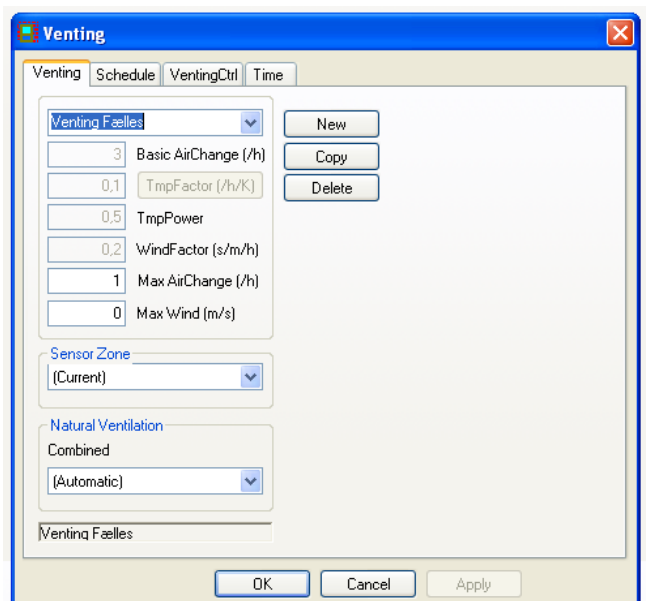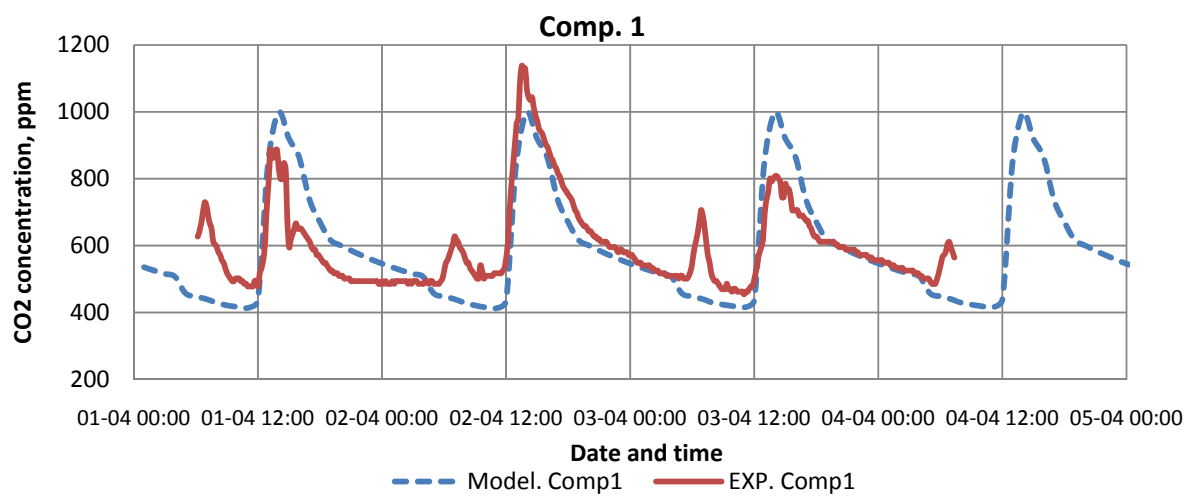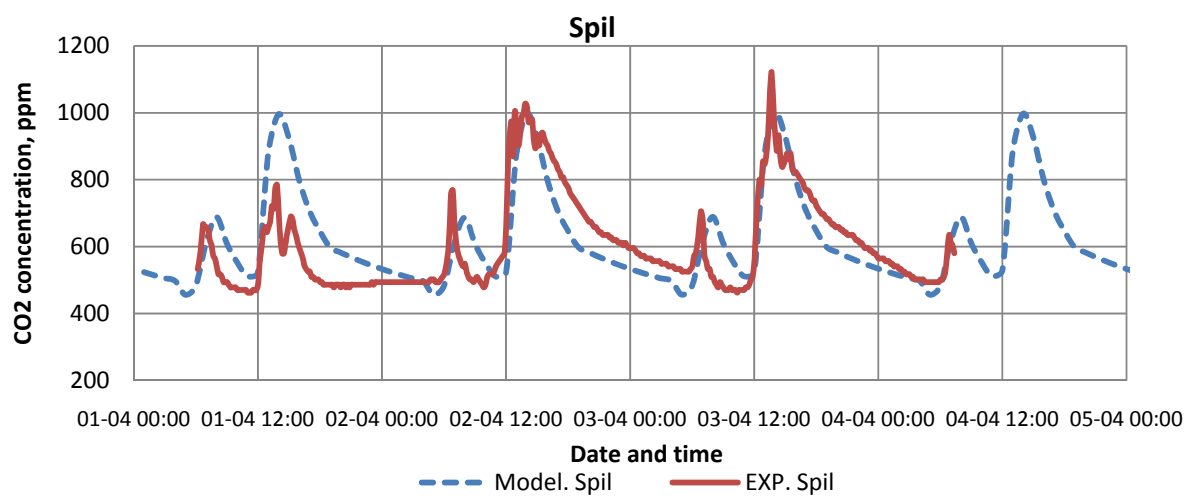05:00-06:00 – fresh air ventilation (scheduled opening of windows in common room)
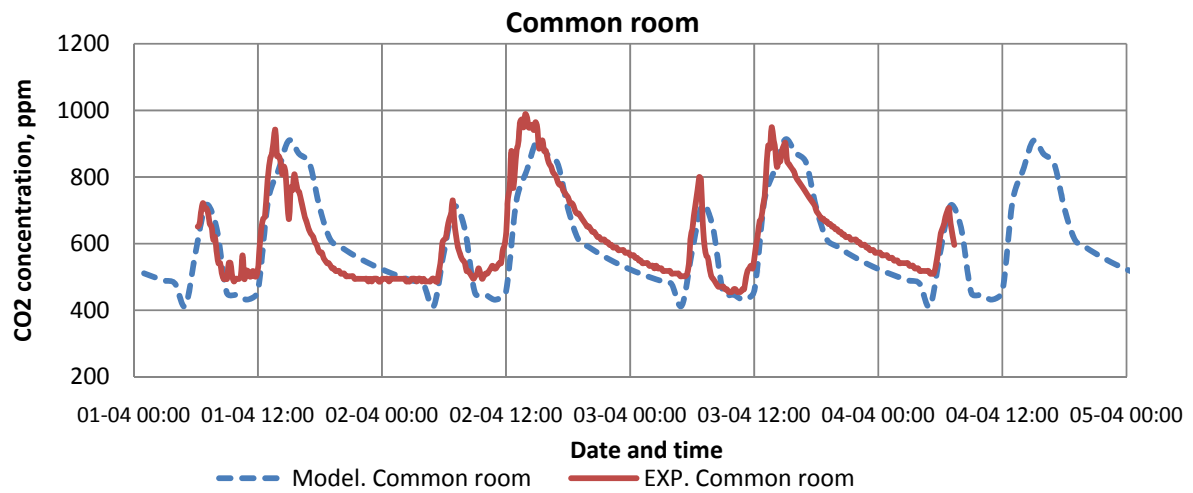

Figure 28. Venting control in SFO Spirehuset

Results of simulation

CO2

Common room

Spil

Comp. 1

Air temperature

Common room

Comp.1

Spil
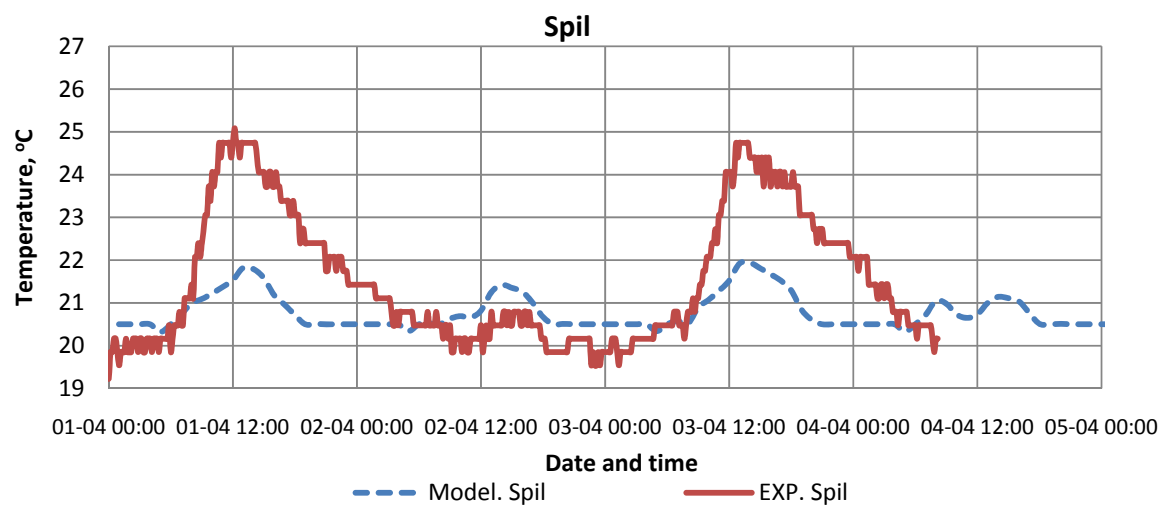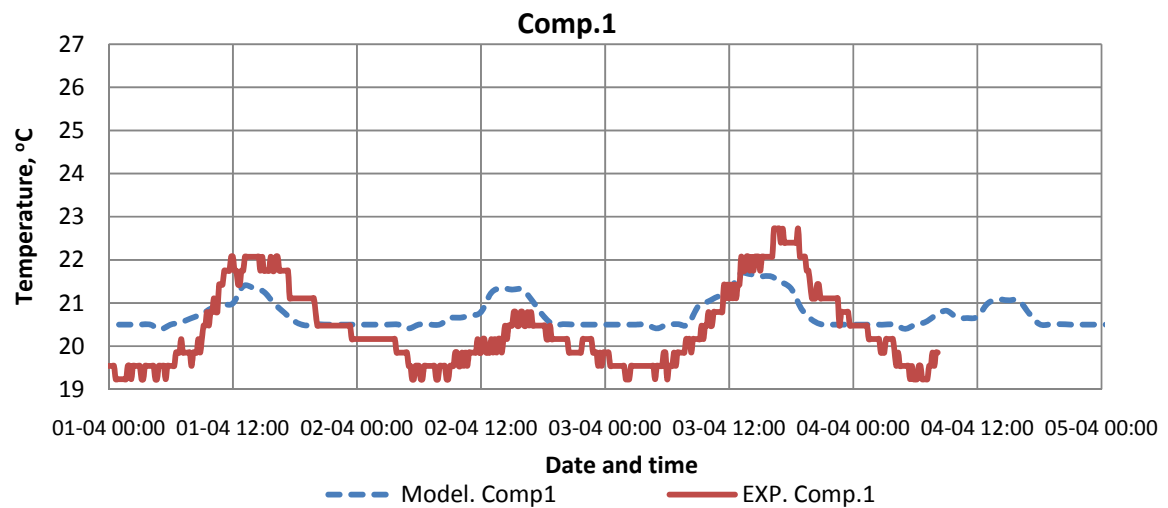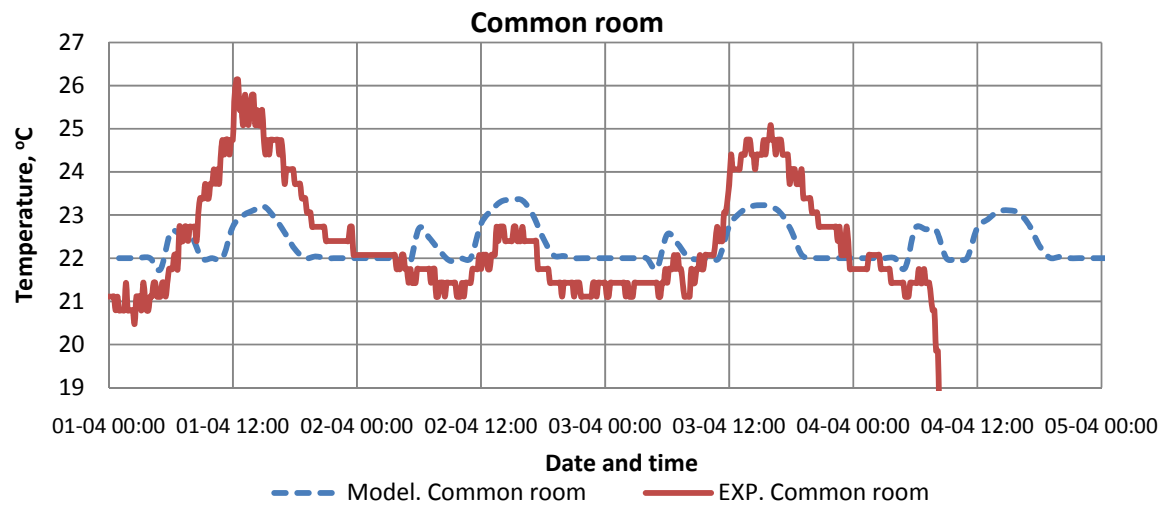
Summary for SFO Spirehuset

As a part of model validation procedure, measured and calculated concentration of carbon dioxide and air temperature are compared for three zones.

As a result, good agreement in prediction of CO_2 concentration is reached. It is noticeable that the decay in CO_2 concentration during the working hours is different from the decay during the hours when ventilation system is off. This was realized due to a simple sensitivity study of possibilities for modelling pulse ventilation in the building.

Calculated CO_2 concentration is the same for every day. This is because for each day in the model the occupancy in a thermal zone is modeled according to the same profile.

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 neighboring zones. This air is already polluted and slightly warmer. Also the presence of vertical temperature gradient, present in the building is not included into the model.

7. Comparative models (heating season)

The main objectives for the comparative models are described in chapter 5, which includes also the definitions for different comparative cases for SFO Nymarken and SFO Spirehuset.

These cases are prepared on basis of already validated models of Nymarken and Spirehuset. Only minor adjustments to the validated models had to be made in order to fulfill the requirements for each of the test cases. In the following sections, the main assumptions made in each of the test cases are explained.

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 weather data from validation test case. This allows comparison of each test case with 1 week of measurements.

For all of the models heating season is set for: Week 1 - Week 19 and Week 39 – Week 53.

In the following sections, there will be no results presented for the room air temperature, this is because room temperature is controlled by heating and any changes in volume flow rates or occupant behavior were compensated by heating in order to maintain the set point for the room temperature. Therefore, the temperature profile in all test cases is the same as in an actual case 1.
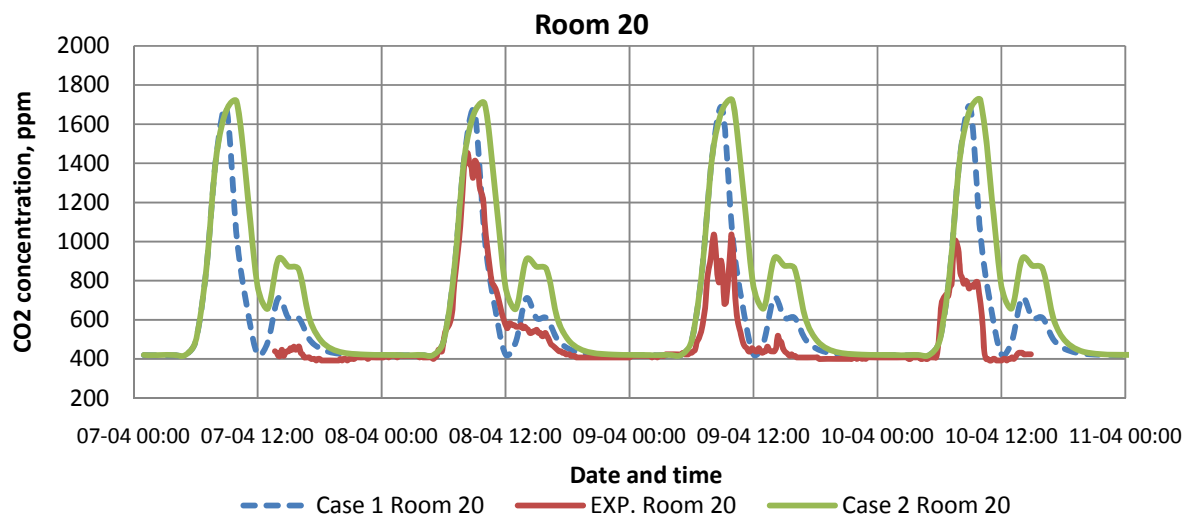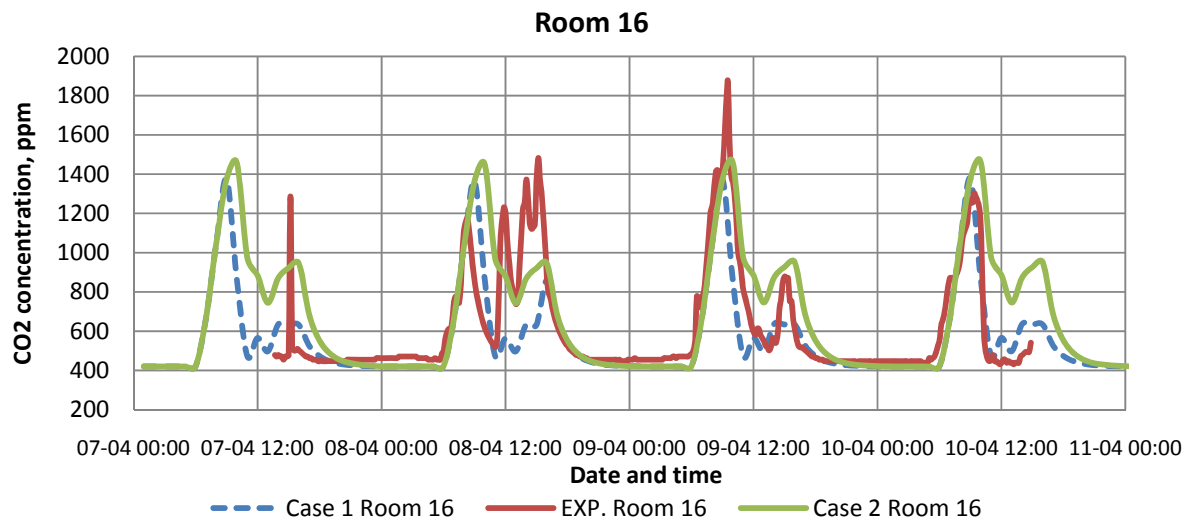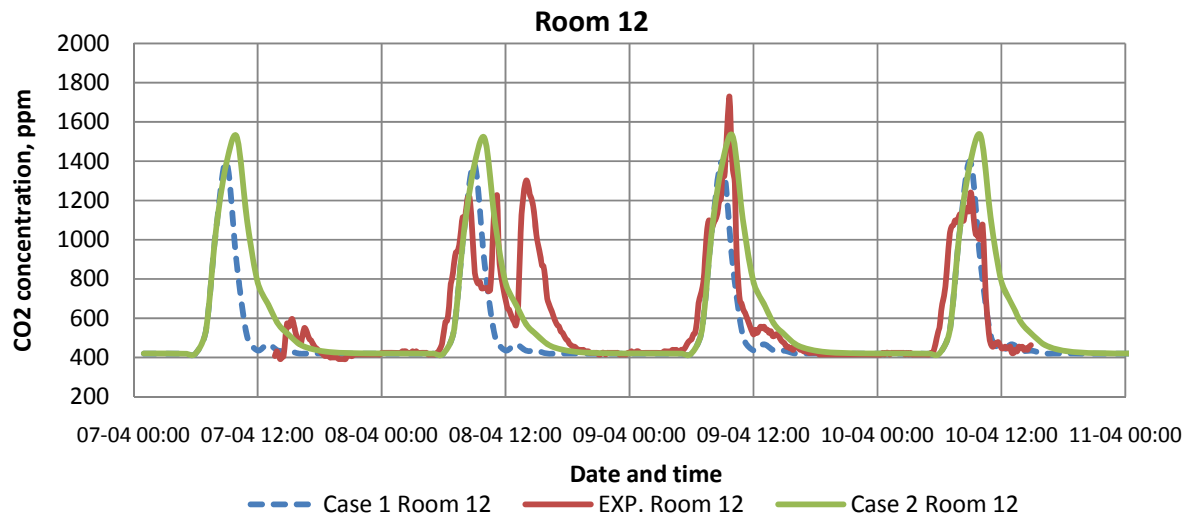
Model SFO Nymarken

Case 2

In Case 2, venting is deactivated: it is assumed that users do not have a possibility to influence the IAQ and comfort. There have been no other changes to case 2, compared with case 1.

There was no user-activated venting in the common room, consequently the concentration of carbon dioxide in case 1 and case 2 in common room is the same. The distribution of CO_2 in the common room is therefore not included into the following figures.

From the following figures, it is seen that with user activated venting, the concentration of CO_2 is lower and the dilution of CO_2 is faster. However, reduction of uncontrolled venting by users results in decreasing of energy use for heating, as will be demonstrated in the following chapter.

Room 12

Case 1 Room 12 — EXP. Room 12 — Case 2 Room 12

Room 16

Case 1 Room 16 — EXP. Room 16 — Case 2 Room 16

Room 20

Case 1 Room 20 — EXP. Room 20 — Case 2 Room 20

51

Case 3

In Case 3, the venting, initialized by occupants is still present: venting system is activated. However, the ventilation system is temperature and CO2 controlled, using VAV-control. VAV-control of ventilation is realized due to "ReturnAirCtrl". The set-point for CO2 control is set to 1000ppm and for temperature control is set to 25.2^{o}C.


Maximum share of recirculation flow is set to 1. In this way the air is continuously recirculated until the set point for CO2 or temperature is reached. When the set point is reached, then fresh air is supplied into the zone. Minimum share of fresh air supplied into the zone is 0.1 h^{-1}.

The energy use for running recirculation fan is not accounted for when the air is recirculated.

The maximum air flow rates are set the same as in case 1, thus the system is running for 100% of capacity.

It is seen that in Room 12 and Room 16, 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.

Room 12

Room 16

Room 20

Common room
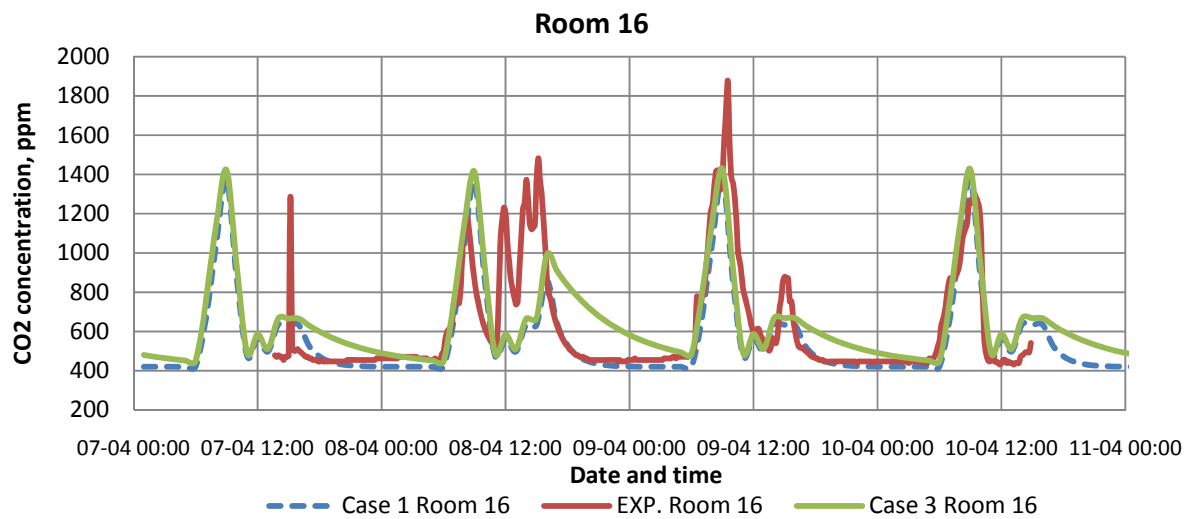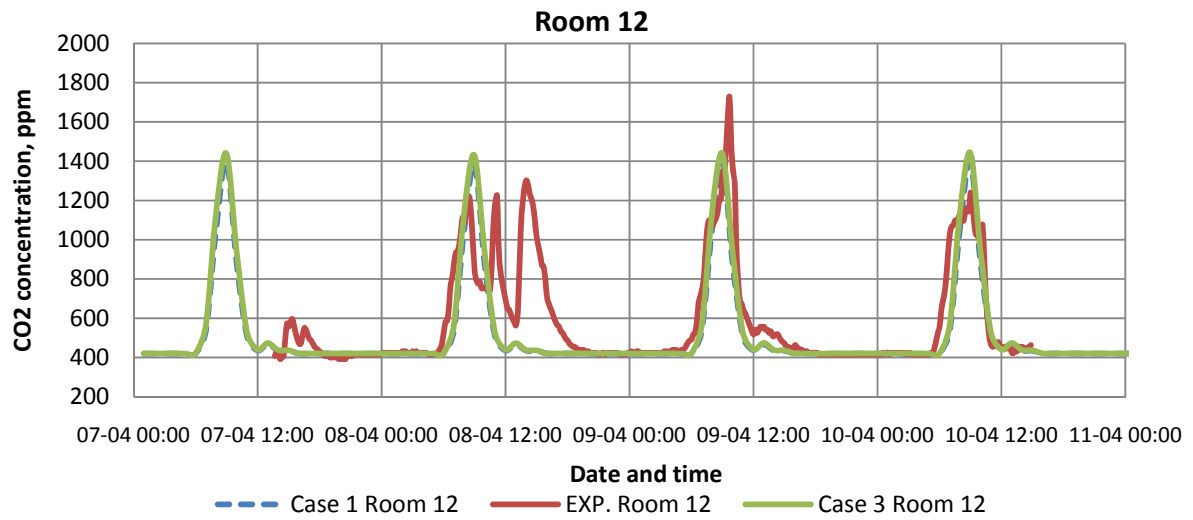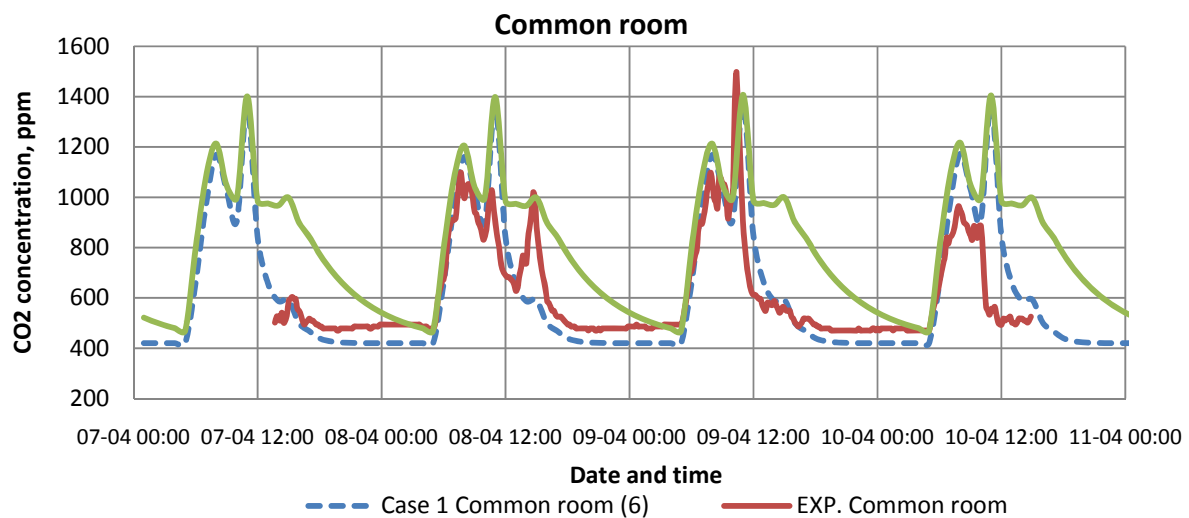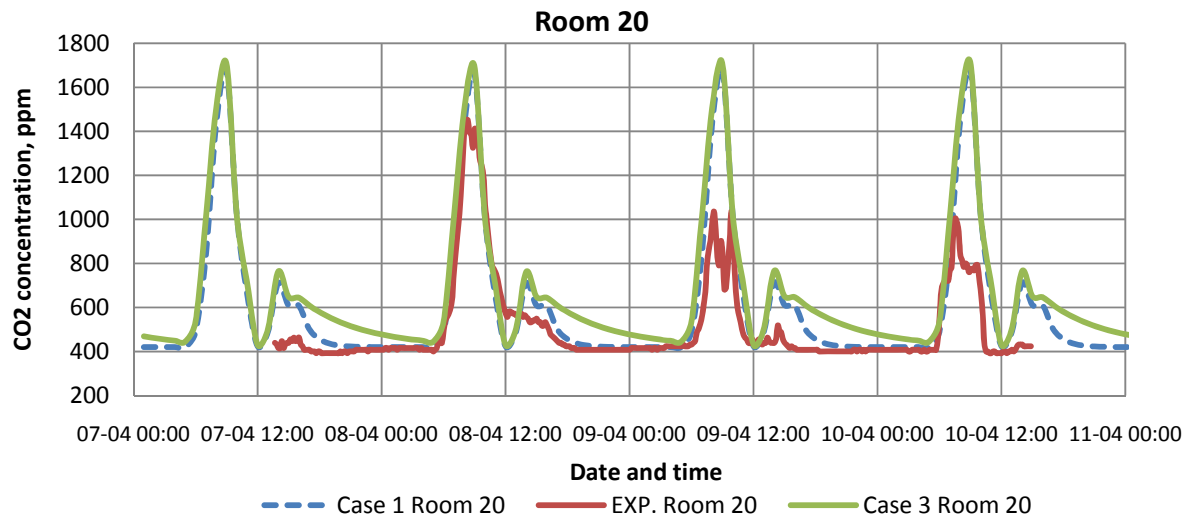
Case 4

In Case 4, the ventilation system is temperature and CO2 controlled, using VAV-control. VAV-control of ventilation is realized due to "ReturnAirCtrl". The set-point for CO2 control is set to 1000ppm and for temperature control is set to 25.2°C. The capacity of ventilation system is 125% compared to case 1. User controlled venting is also present.

In order to reach 125% of system capacity, it is assumed that the system is replaced by a bigger one, with higher efficiency (65%, in case 1: system efficiency was 61%).
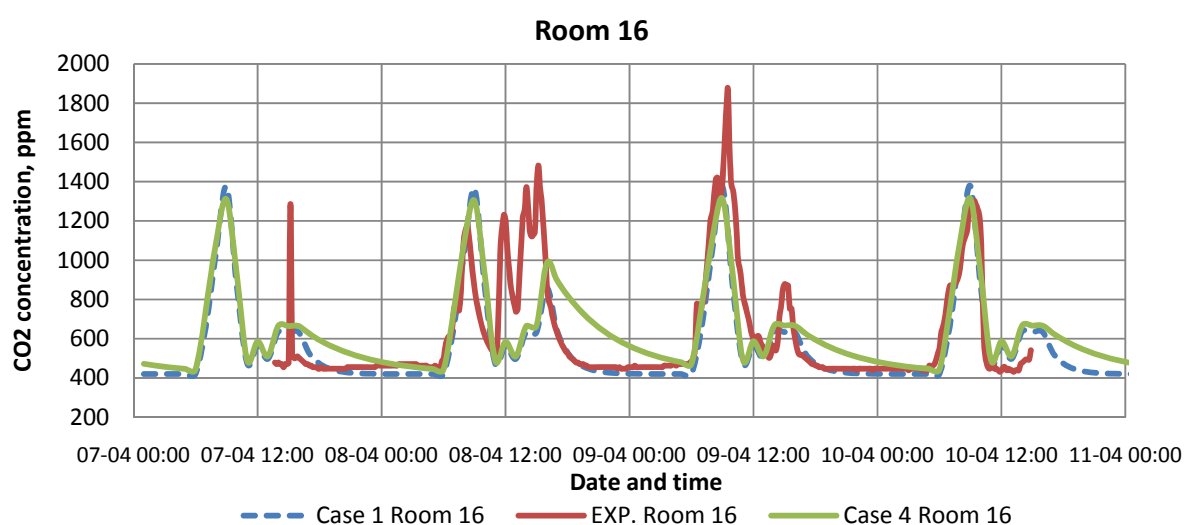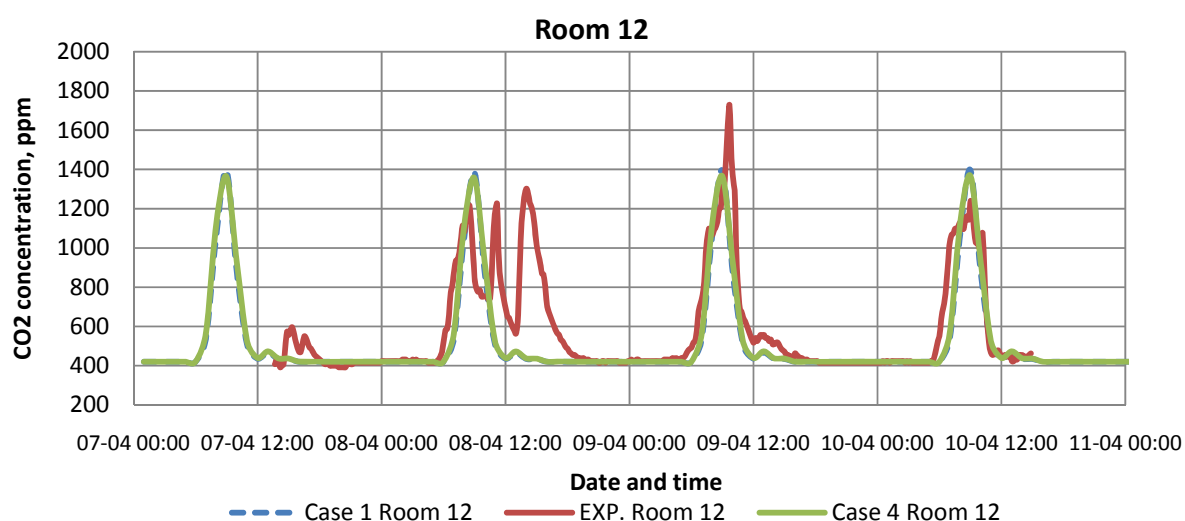
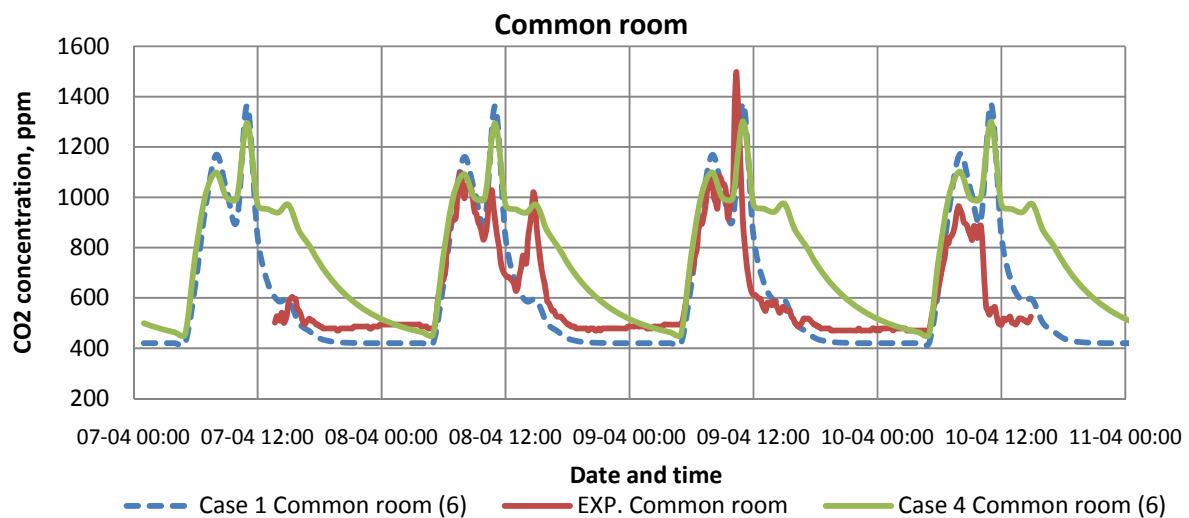Following are the air flow rates used in the model, these are 25% higher than in case 1:
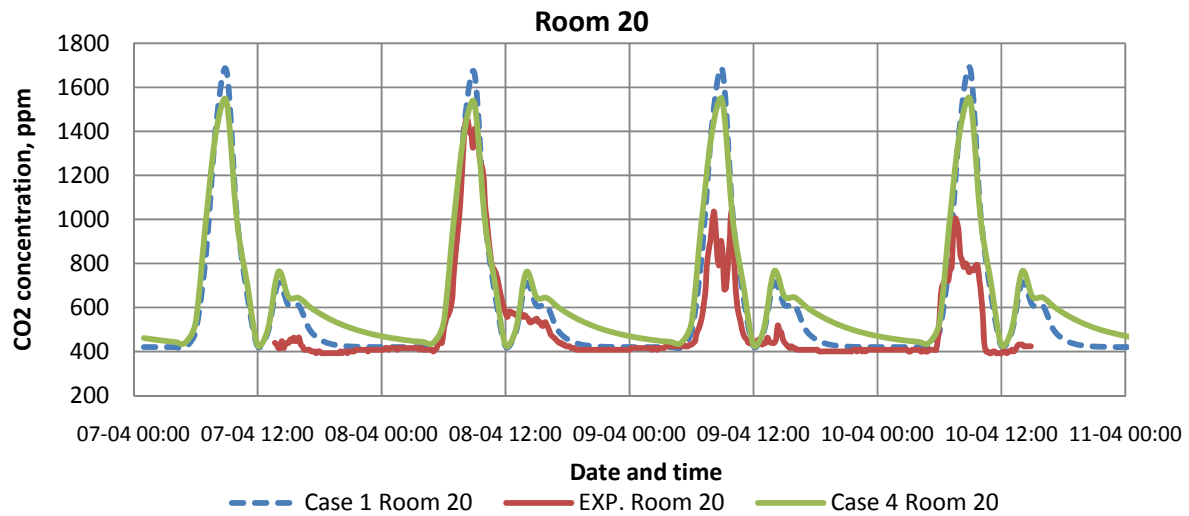
Thermal zone	Supply, m³/s
Common room	0,068
Office	0,054
Group room 20	0,041

Group room 16	0,039
Group room 12	0,031
Activity room	0,029
Bathrooms	0,29
Kitchen	0,037
Corridor	0,093
Technical room	0,013

Table 11. Ventilation flow rates in SFO Nymarken, Case 4.

Some changes in the energy use were observed in case 4, compared to case 1 (see next chapter for more information), however, no significant improvement in IAQ was achieved during the peak loads in the institution.

Room 20

CO2 concentration, ppm

Date and time

- - - Case 1 Room 20   —— EXP. Room 20   —— Case 4 Room 20

Common room

CO2 concentration, ppm

Date and time

- - - Case 1 Common room (6)   —— EXP. Common room   —— Case 4 Common room (6)

Case 5

In Case 5, the ventilation system is temperature and CO2 controlled, using VAV-control. The capacity of ventilation system is 150% compared to case 1. User controlled venting is also present. VAV-control of ventilation is realized due to "ReturnAirCtrl". The set-point for CO2 control is set to 1000ppm and for temperature control is set to 25.2^{o}C.

In order to reach 150% of system capacity, it is assumed that the system is replaced by a bigger one, with higher efficiency (65%, in case 1: system efficiency was 61%).

Following are the air flow rates used in the model, these are 50% higher than in case 1. No increase of flow rate is designed for the toilets

Thermal zone	Supply, m^3/s
Common room	0,082

Office	0,065
Group room 20	0,049
Group room 16	0,047
Group room 12	0,037
Activity room	0,035
Bathrooms	0,29
Kitchen	0,044
Corridor	0,11
Technical room	0,015

Table 12. Ventilation flow rates in SFO Nymarken, Case 5.

In the following figures it is seen that increasing capacity of ventilation system can improve indoor air quality during the peak loads.

Room 20

Common room
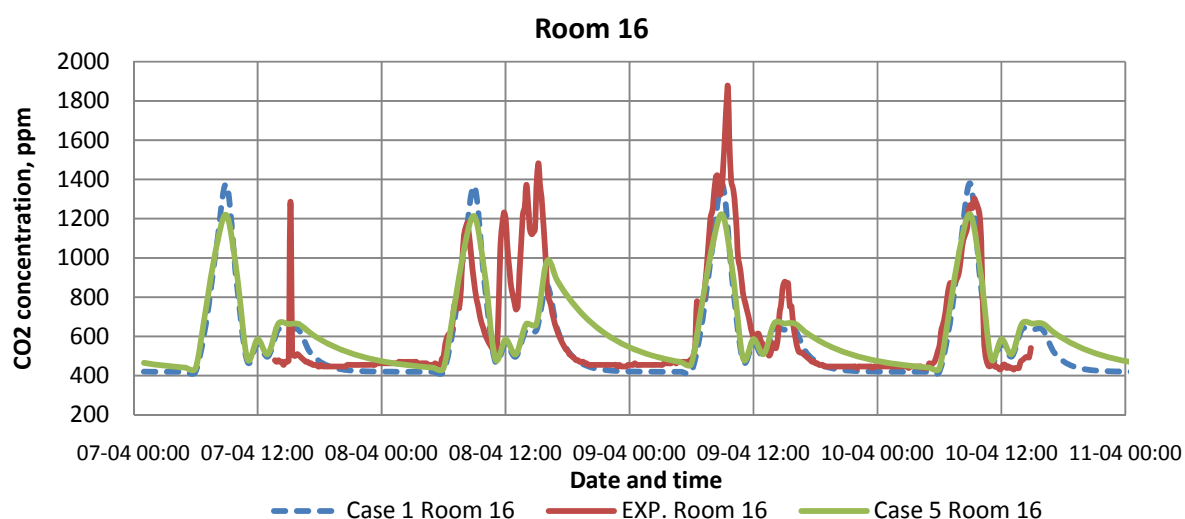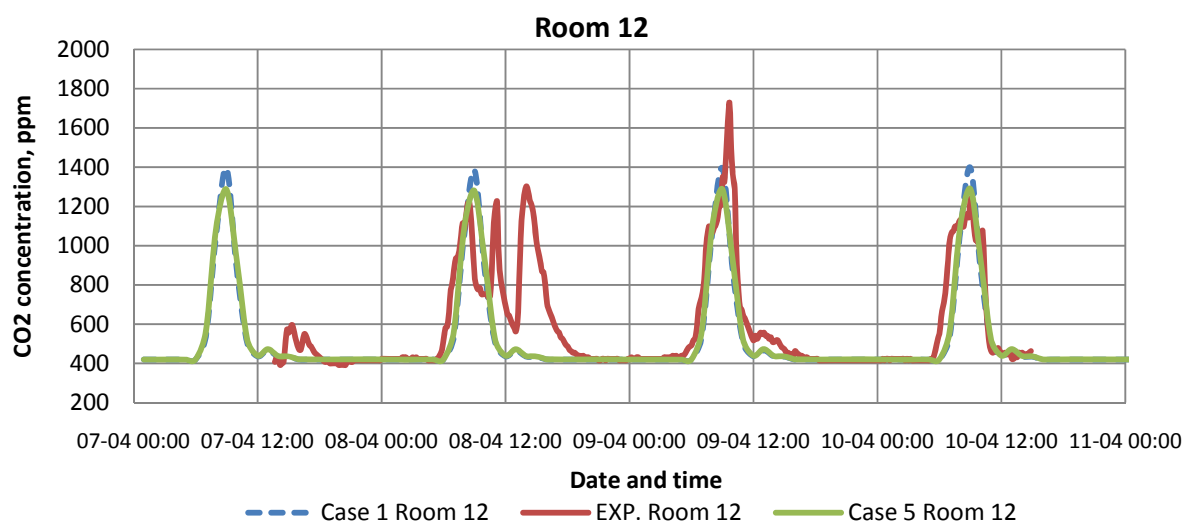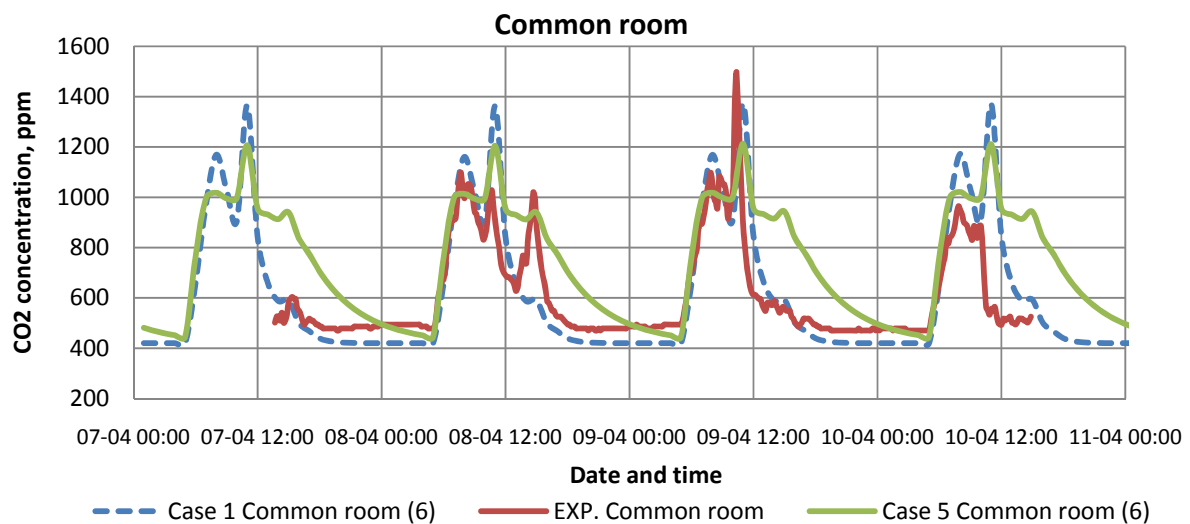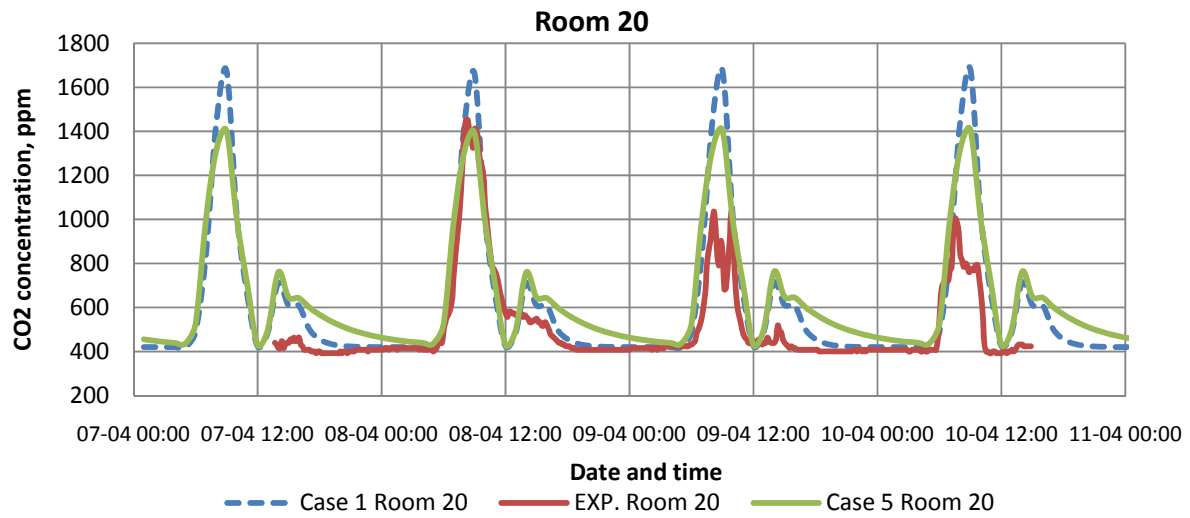
Energy use in comparative models

Case	Total, kWh	Specific, kWh/m2
Case 1	59142	70
Case 2	55007	65
Case 3	34655	41
Case 4	35396	42
Case 5	35996	43

Table 13. SFO Nymarken. Energy use in comparative models.

The ventilation flow rates in case 1 – case 3 are significantly different. Reduction of ventilation flow rates is clearly reflected on IAQ and energy use.

Application of VAV controlled system of increased capacity results in a slightly higher energy use, but it helps to improve IAQ during the peak loads.

Model SFO Spirehuset

Case 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%. User controlled opening of the windows is deactivated, however, night venting is kept as a part of ventilation strategy in the building. No changes to ventilation system or pulse ventilation has been made.
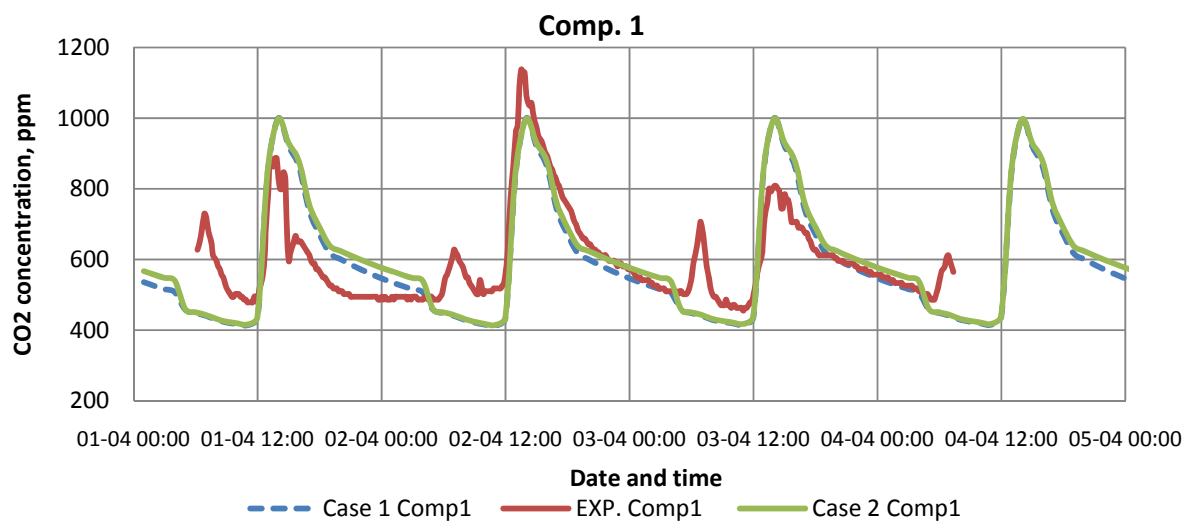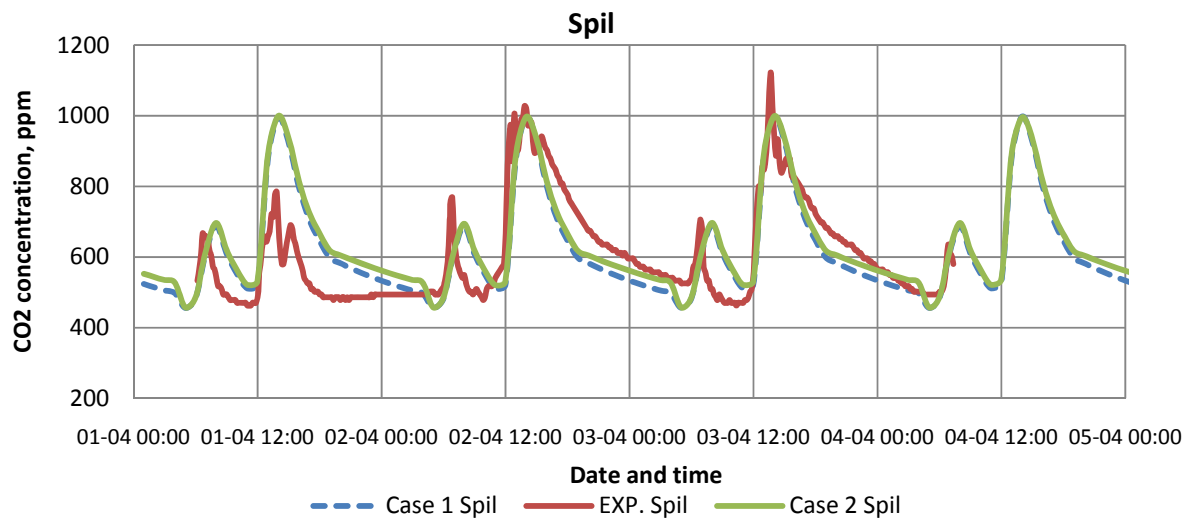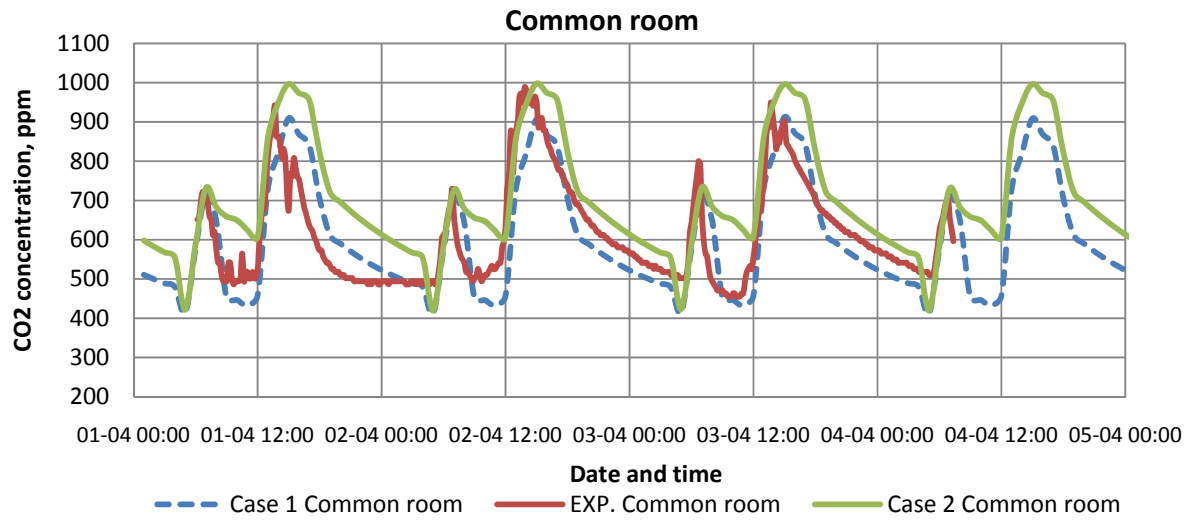
The infiltration rate is defined for common room as:

$0,08 \text{ h}^{-1}$	-estimated infiltration (30%)
$0,266 \text{ h}^{-1}$	- assumed air change rate in the building due to pulse ventilation (70%)
$0,274 \text{ h}^{-1}$	- total infiltration (100%)

The infiltration rate in other rooms:

$0,06 \text{ h}^{-1}$	-estimated infiltration (30%)
$0,14 \text{ h}^{-1}$	- assumed air change rate in the building due to pulse ventilation (70%)
$0,20 \text{ h}^{-1}$	- total infiltration (100%)

Changes in IAQ, compared with case 1, are mainly seen for common room, where user controlled venting is no longer activated. It results in slow dilution of CO_2 between morning and afternoon opening hours. Finally, increased concentration of CO_2 is seen for the afternoon periods with peak loads.

Changes in infiltration flow rates result in minor change of CO_2 concentration when there are no occupants in the building.

Common room

Spil

Comp. 1

Case 3

In this case, it is still assumed that the infiltration flow rates are 30% less than measured. Moreover, user controlled venting is not present and there is no pulse ventilation in the building.

As a result, following is the input used when defining infiltration flow rates for common room in the model:

$0,08\ h^{-1}$ -estimated infiltration (100%)
$0\ h^{-1}$ - assumed air change rate in the building due to pulse ventilation (0%)
$0,08\ h^{-1}$ - total infiltration (100%)

For other rooms:

$0,06\ h^{-1}$ -estimated infiltration (100%)
$0\ h^{-1}$ - assumed air change rate in the building due to pulse ventilation (0%)
$0,06\ h^{-1}$ - total infiltration (100%)

In this case 3, the dilution of CO_2 is slow and generally higher concentration of CO_2 is experienced during the working hours. When CO_2-level of 1000ppm is reached, then the fresh air is supplied into the building. Still, due to the ventilation strategy the reduction of CO_2 concentration to the level of outdoor air is happening due to automatic venting, which is scheduled for 5am.

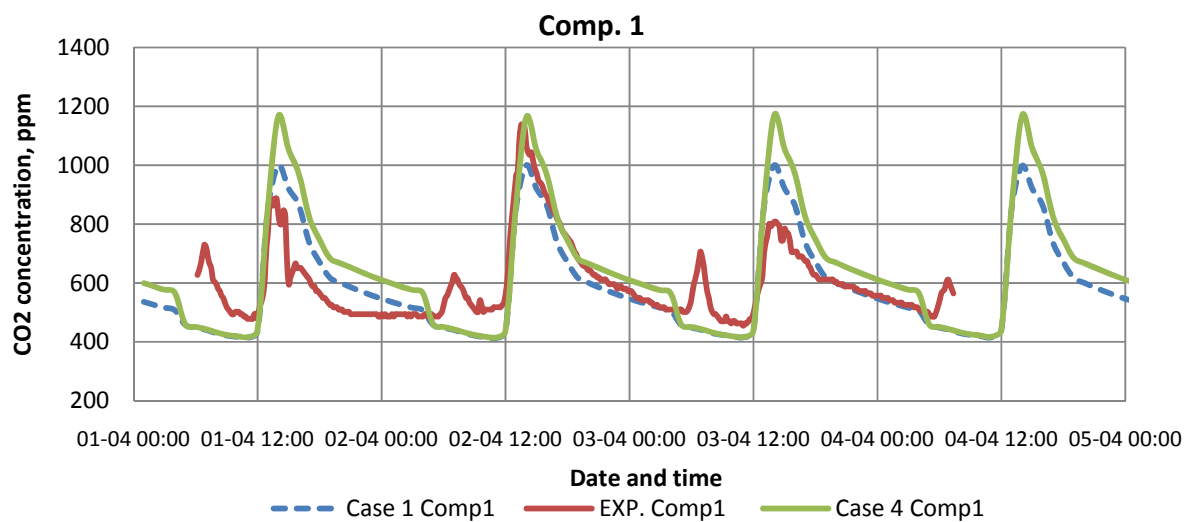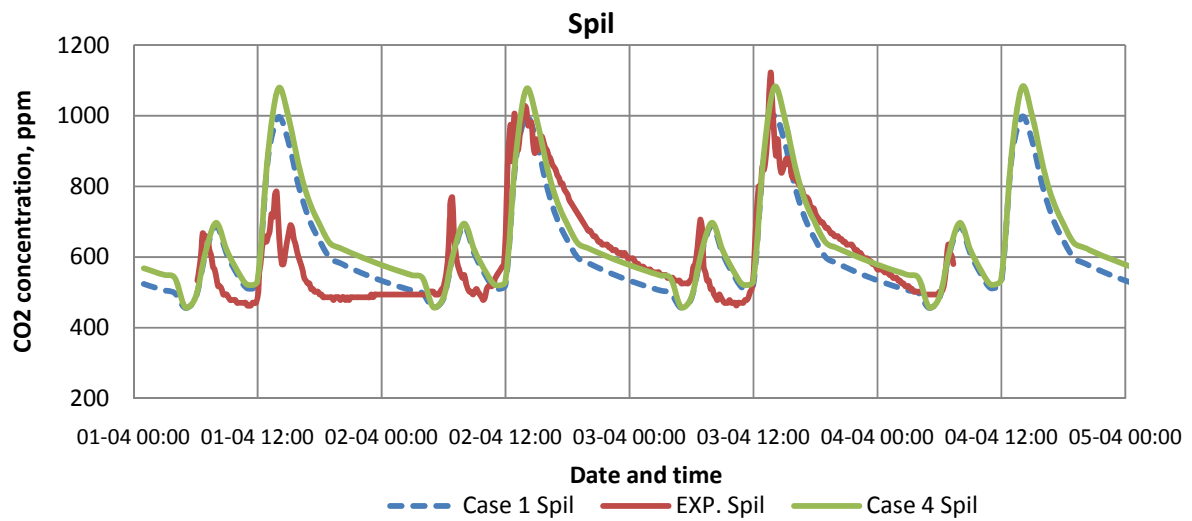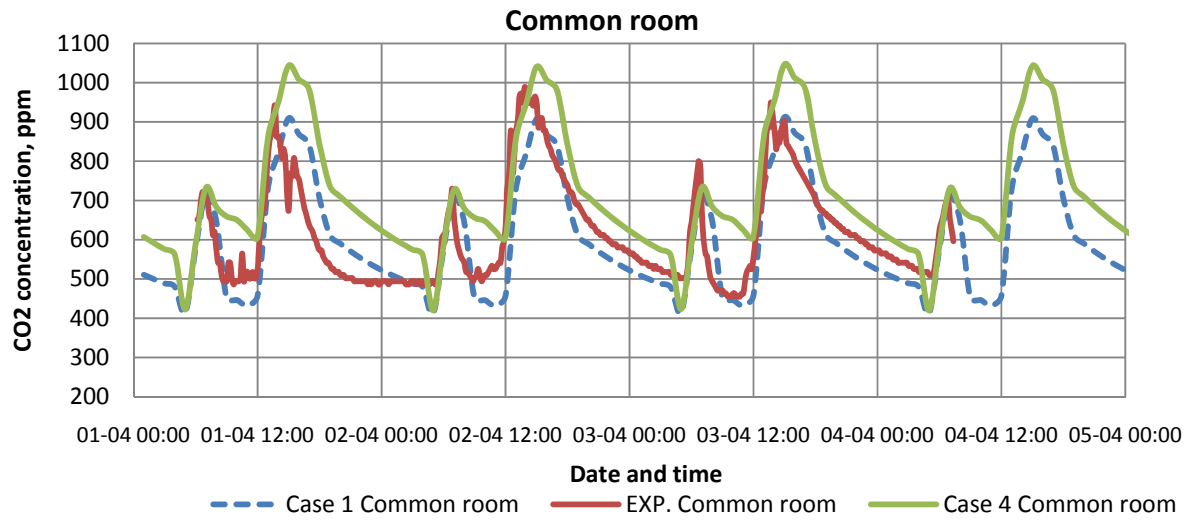**Common room**

Spil

Comp. 1

62
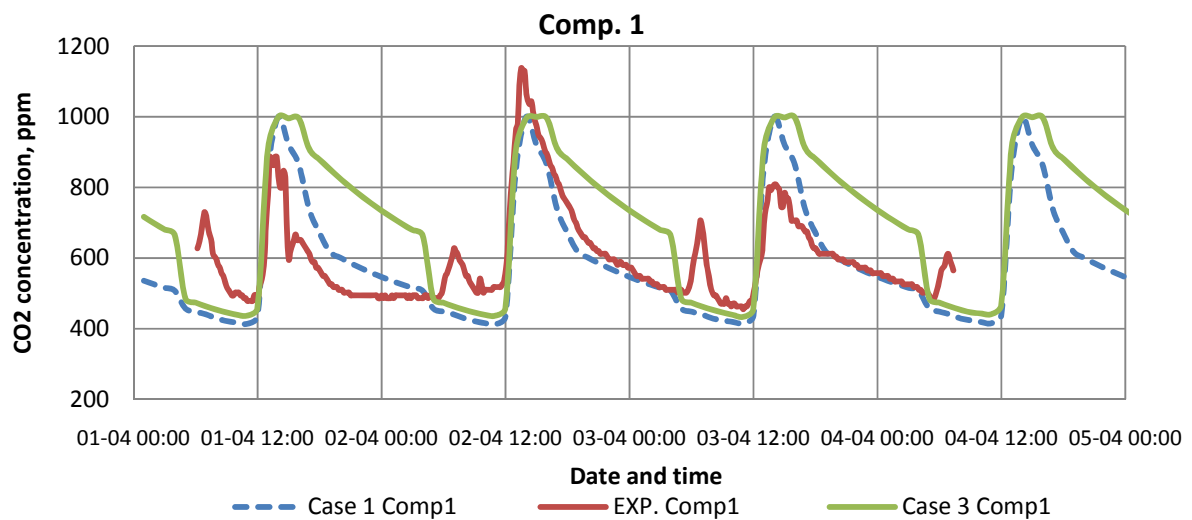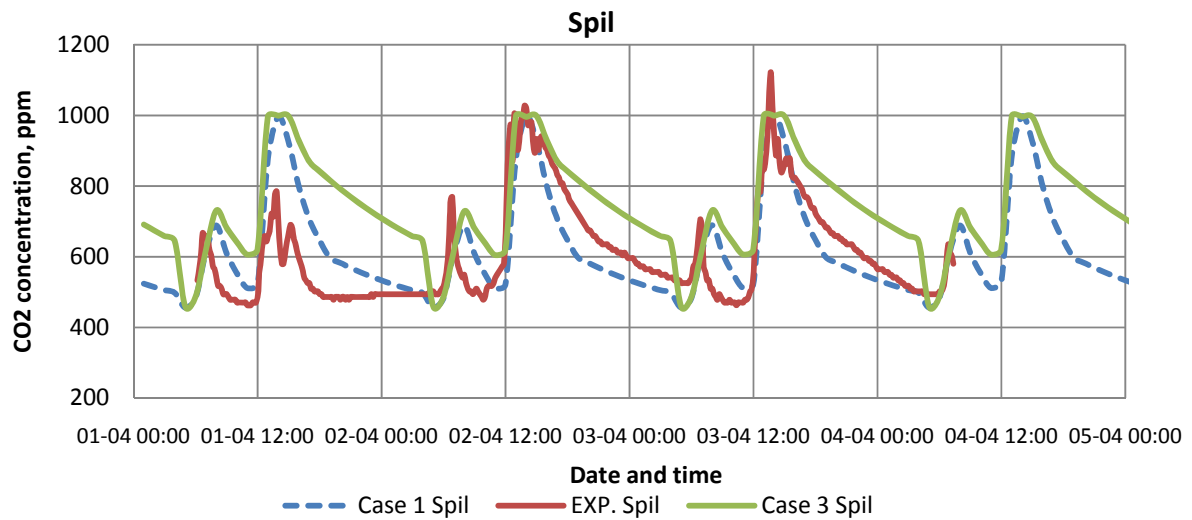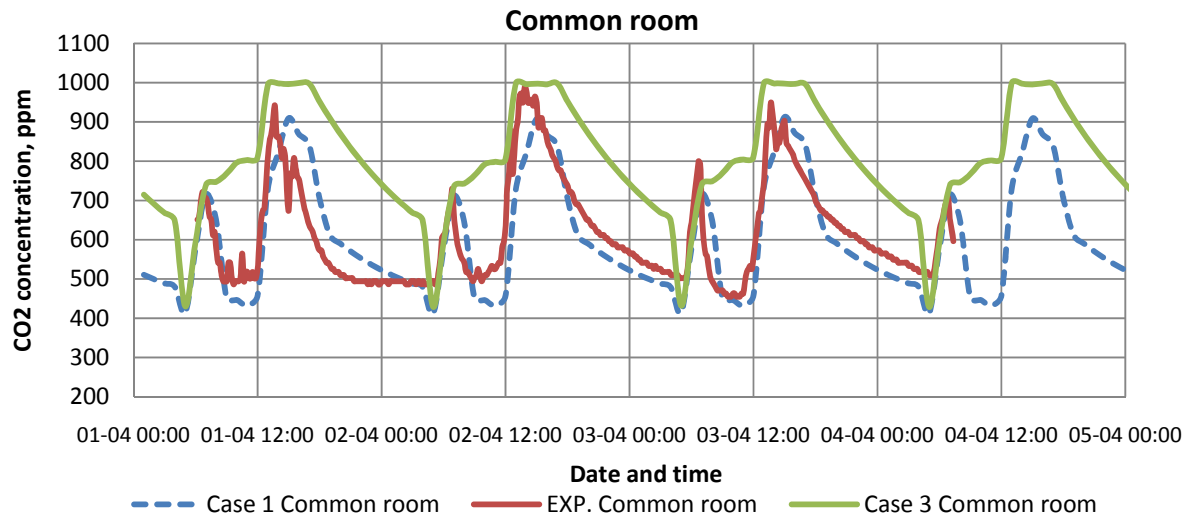
Case 4

In this case 4, natural ventilation is controlled only according to temperature only. The pulse ventilation is present and the infiltration flow rates are 30% less than in case 1. User controlled natural ventilation is deactivated.

The set point for temperature control of ventilation system is set to 25.2^{o}C.

High room temperatures in the building are experienced for only short periods during the peak loads. As a consequence, the results for temperature controlled ventilation system are very similar to what was observed with CO_2 and temperature controlled ventilation system. However, short periods with increased concentration of CO_2 compared to case 1 are present.

Common room

Case 1 Common room — EXP. Common room — Case 4 Common room

Spil

Case 1 Spil — EXP. Spil — Case 4 Spil

Comp. 1

Case 1 Comp1 — EXP. Comp1 — Case 4 Comp1

Energy use in comparative models

Case	Total, kWh	Specific, kWh/m2
Case 1	49680	99
Case 2	45159	90
Case 3	42422	85
Case 4	39425	79

Table 14. SFO Spirehuset. Energy use in comparative models.

Energy used for heating and domestic hot water use during 2008 is known for SFO Spirehuset, which is given below. The results of simulation for case 1 agrees very well with this empirical data.

115 kWh/m2

A stepwise reduction of air change rate in the building is defined through case 1 to case 3, starting with the maximum air change rate in case 1 and ending with the minimum air change rate in case 3 . A similar stepwise reduction is also seen in energy use when case 1 –case 3 are compared.

Comparison of case 4 cannot be direct, as in that case is rather different due to temperature controlled ventilation.

8. Refferences

1 . http://www.sbi.dk/en/publications/programs_models/bsim/bsim-building-simulation

2. A. Skartveit and J.A. Olseth, A model for the diffuse fraction of hourly global radiation, Sol Energy 38 (1987), pp. 271–274

3. BSim Help file

4. http://www.ebst.dk/br08.dk/BR07/0/54/0