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Demand controlled ventilation
A case study for existing Swedish multifamily buildings

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Abstract

The aim of the work accounted for in this paper has been to investigate a demand controlled ventilation (DCV) system for a typical Swedish multifamily building with exhaust ventilation. Another aim has been to apply and evaluate the IDA Indoor Climate and Energy (ICE) simulation software in this application. The work has been related to a renovation project of a large number of apartments with exhaust ventilation systems recently carried out by a Swedish municipal housing association.

A typical apartment, chosen among 1000 existing apartments, has been modelled using IDA Climate and Energy simulation software. Four exhaust ventilation system concepts have been evaluated:

1. reference system with constant air volume flow;
2. demand controlled ventilation system: carbon dioxide control, variable air flow;
3. demand controlled ventilation system: humidity control, variable air flow;
4. demand controlled ventilation system: occupancy control, variable air flow.

The simulations show that it would be possible to achieve energy savings using occupancy and/or humidity controlled ventilation to reduce the average ventilation flow rate while keeping an acceptable indoor climate. Based on the simulation results a demand controlled ventilation system is developed and implemented in occupied apartments in order to investigate the performance.

A measurement based validation of the simulation program indicates that it can be applied reliably.
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Keywords: Demand controlled ventilation; Indoor air quality; Simulation software; Relative humidity; CO_2 concentration; Measurements; IDA Indoor Climate; Energy

1. Introduction

A recently initiated renovation project carried out by the municipal housing association Bostads AB Gårdsten has made it possible to investigate and test more in detail different strategies for ventilation by exhaust air. A large number of the apartments in Gårdsten have or will have exhaust ventilation systems and there has been an interest to investigate the possibilities to reduce the heat requirements for ventilation.

A literature survey about demand controlled ventilation (DCV) has been carried through and the main requirements on ventilation in residential buildings and the most typical ventilation systems installed in residential buildings has been studied. The literature survey is accounted for in [1]. One conclusion from the literature study is that there is a lack of well-documented case studies for residential houses [2]. Studies performed on DCV in residential houses indicate that it may be possible to reduce air flow rate below the flow rate stated in national regulations, without harm in the indoor climate, thus achieving some energy savings [3,4].

Tools to simulate the energy performance of buildings have become more and more applicable for practical purposes, especially in design of more advanced heating, ventilation and air-conditioning systems for service buildings and advanced low energy buildings. However, they are often not applicable for studying ventilation issues. The above mentioned renovation project would make it possible to investigate the potential use of a common tool in a residential application.

1.1. Aim

The main aim of the paper is to account for a study and proposal of a DCV system for Swedish multifamily

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buildings. The proposed system should have an investment cost that are in due proportion to annual energy savings and be from technical point of view simple enough to ensure long time operation without technical problems.

In parallel the aim is to illustrate that simulations performed by IDA indoor climate and energy program (ICE) [5] is a useful method for analysis of the performance of a demand controlled exhaust ventilation system for a Swedish apartment building.

1.2. Method

Among the number of the existing apartments a typical apartment is chosen as the reference apartment. A model of the reference apartment is created in the IDA ICE simulation software. The simulation model is verified using measurements in the reference apartment and established calculation methods.

A number of different DCV strategies is analysed by simulations. Based on the simulation results a test system is installed in apartments in one occupied building. The performance of the test system is to be evaluated by measurements and further simulations.

2. Reference apartment

The reference apartment is a typical apartment located in the high-rise 3 storey building and consists of a kitchen, a combined laundry and bathroom, a bedroom and a living room. The total area of the apartment is 67.5 m^2. The apartment is equipped with a hydronic radiator heating system and with an exhaust ventilation system with air outlet vents in the kitchen and in the bathroom facing north. Outdoor air inlets are applied in the form of brush sealings in windows and balcony doors in the sleeping room and in the living room facing south.

The reference apartment is located in the district called Västra Gårdsten, Gothenburg, Sweden, which comprises about 1000 apartments from the early 70s. There are two types of buildings: high-rise buildings with 3 and 5 storeys and low-rise buildings with 3 storeys. All buildings are constructed of prefabricated concrete element blocks, they have flat roofs and are equipped with 2-pane windows, exhaust and supply ventilation systems and hydronic radiators for heating.

3. Apartment model

A model of the reference apartment was created in the ICE simulation software. The location of rooms, windows and doors, as well as their sizes and construction in the model correspond to the real situation. The model apartment is situated in the middle of the building and it is assumed that the there is no heat flow to or from the adjacent apartments. A simplified drawing of the apartment is shown in Fig. 1.

3.1. IDA Indoor Climate and Energy (ICE)

The ICE software is reckoned among generally accepted general-purpose tools. A general-purpose simulation program treats the mathematical model as input data, thus allowing simulating a wide range of system designs and configurations.

ICE makes it possible to model a building including its heating and ventilation system. The model can include one or more zones (rooms), a primary system (the subsystem containing chiller and boiler) and one or more air handling systems. The model can be used with standardised or spec-

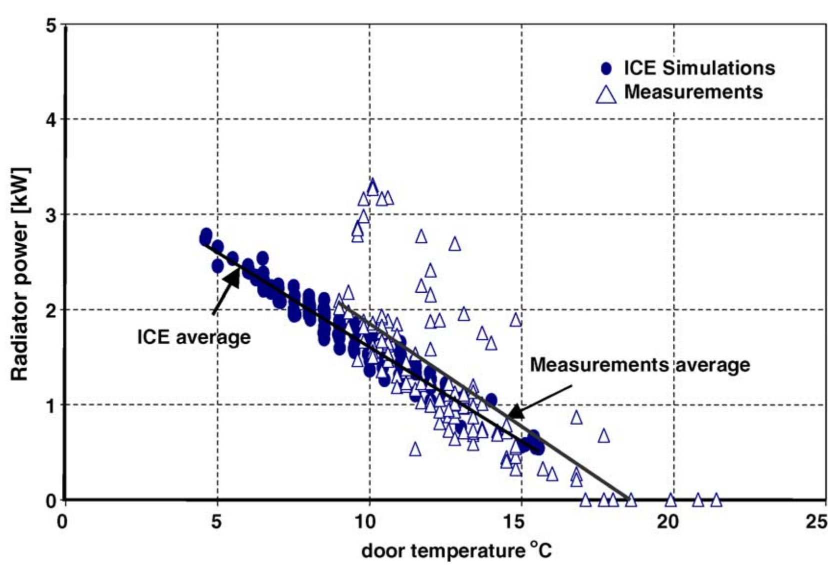

Fig. 1. Comparison of CO_2 concentration in the bedroom.

ified climate data. Surrounding buildings or other objects shading the building can be considered.

ICE can be used to study the indoor climate in the zones, as well as the energy use in the zones and the entire building. ICE models the humidity, as well as the carbon dioxide content, of the air inside the building. A user interface enables to define, build up and simulate different cases. Predefined building components can be loaded from a database. This can also be used to store personally defined building components [5].

The results of simulation can be obtained on 1 h basis. The simulation itself works with time steps, which are adapted to how fast conditions change, i.e., if there are rapid changes, the time intervals can be much shorter than 1 h. Measuring points for different parameters coincide with the location of occupants in the room.

3.2. Heating and ventilation

The modelled apartment is equipped with water feeded radiators in each room designed to ensure a room temperature not lower than 20 °C. The ventilation is provided for by an exhaust ventilation system with air outlets in the bathroom and in the kitchen, where the airflow is controlled to be constant or demand controlled. Outdoor air is supplied by air inlets in the bedroom and in the living room, which are modelled as openings in the external walls and is mixed with the internal air. Internal air is distributed by openings in the internal walls (equal to existing air gaps under the internal doors).

The radiators will cover the heat demand for heat losses and for heating of the supplied ventilation air. This means that reduced ventilation airflow will result in reduced radiator heat. The radiators are designed for 80 °C supply and 60 °C return temperature and are controlled by thermostat, which has a value of P-band (proportional band) equal to 2 K. Location of the radiators and thermostat is shown in Fig. 1.

3.3. Outdoor climate

Weather data are obtained from one hour based weather data files containing information on actual or synthetic weather. There is a possibility to obtain different climate data files. The study is carried out using weather data from the ICE files valid for Säve, a weather measuring station close to the Gårdsten site.

3.4. Internal loads

Different internal loads affect the indoor climate in an apartment, as for example heat emission, water vapour generation, CO_2 generation etc. All these factors were taken into account in the computer model. The following loads have been considered in the simulations:

- Heat, water vapour and CO_2 emitted by occupants.
- Heat generated by lighting and other equipment.
- Heat emitted during food cooking.
- Water vapour emitted during food cooking and showering.
- Water vapour emitted during clothes drying.

Each type of internal loads has its own working schedule, which is closely related to the occupants' schedule. The occupants' behaviour has a major influence on the performance of DCV. There are two occupants in the modelled apartment. The occupants "move" from room to room according to the assumed time schedule. It is assumed that the occupants have different amount of clothing and different level of activities depending on the type of the room.

4. Model verification

A number of parameters are being measured in one building with 12 apartments in order to have an initial understanding of the real performance and to allow a basic verification of the apartment model. The heat supply is measured with heat meters on the main branches of the heating system (radiators) together with the electricity used by the exhaust fans. The exhaust airflow is adjusted to the same value in all apartments and the indoor climate, i.e. room temperature, relative humidity and carbon dioxide concentration is measured in random apartments [1]. The measurements presented here are taken from the ongoing measurements.

Fig. 2 shows a comparison of measured and modelled radiator power as a function of outside temperature for a short period in the spring. The heat demand is measured for three apartments located on the top of each other (ground floor, first floor and second floor). The heat demand was simulated by the ICE model for one apartment (first floor) therefore the modelled value is multiplied by three for comparison with the measured values. Measurements in some apartments showed that the mean indoor air temperature was equal to 23 °C, which is used as the initial condition in the computer model.

Average values presented in Fig. 2 are shown both for measured and simulated values. As it can be seen the average values are very close to each other and this indicates that ICE program is reliable for simulations.

Fig. 2 shows that modelled and measured values are slightly different, which mainly is due to the absence of heat losses through the roof and to the ground in the ICE model. Future evaluation of the system performance will be based on a model of the whole building.

Concerning CO_2 concentrations it is not quite clear how ICE program handles this issue. In order to get some feeling about the reliability a comparative calculation has been made based on basic Eq. (1).

$$C_{\mathrm{r}}(t) = C_{\mathrm{s}} + \frac{M}{V} - \left(C_{\mathrm{s}} + \frac{M}{V} - C_{\mathrm{r}(0)} \right) \exp\left(- \left(\frac{V}{v} \right) \tau \right) \tag{1}$$

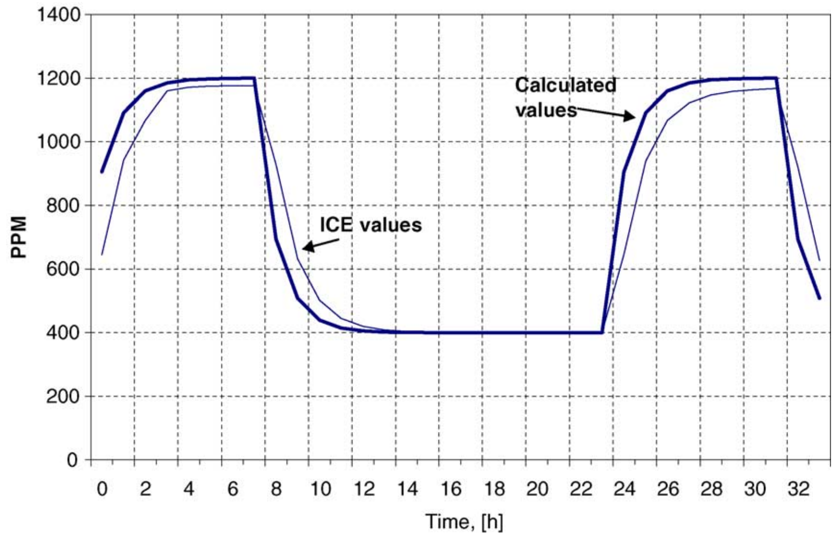

Fig. 2. Reference apartment (67.5 m^2) and principle scheme of air flow in the apartment.

where $C_r(t)$ is CO_2 concentration in the room at time t, (ppm); C_s is CO_2 concentration in the supply air, (ppm); M is CO_2 generation rate in the room, (kg/h); V is ventilation rate, (m^3/h); $C_{r(0)}$ is initial CO_2 concentration in the room, (ppm); v is room volume, (m^3); τ is time, (h).

The calculations with this Eq. (1) are based on the same internal load pattern that has been used in ICE simulations. The results are shown in Fig. 3. As it can be seen, the results correspond well in between.

Furthermore, the heating energy demand for ventilation simulated by the ICE model is verified by the basic equation shown below.

$$\text{Energy use} = \frac{1.22 \times V \times \text{degree hours}}{1000} [\text{kWh}], \quad (2)$$

where V is the air flow rate in l/s.

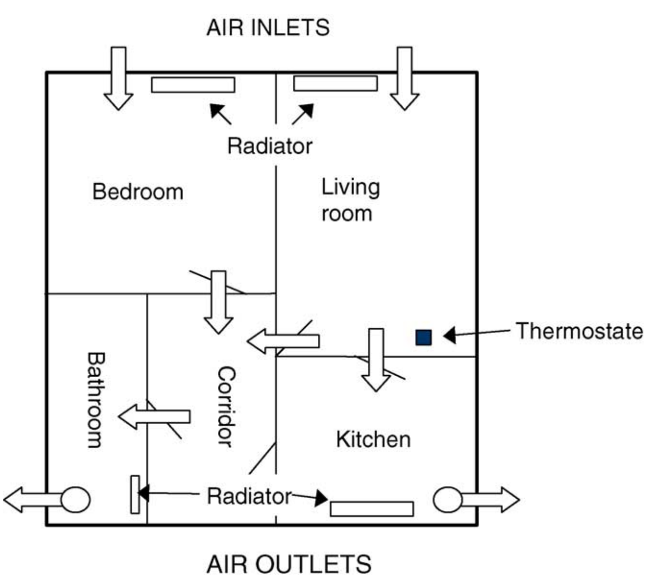

Fig. 3. Comparison of measured and ICE modelled radiator power for three apartments, as a function of outside air temperature.

The air flow rate is 30 l/s and the number of degree hours for a typical year in Säve measuring station in Gothenburg is about 81000 °C h, which results in an annual heat demand for ventilation very close to the value of 3000 kWh obtained by the simulation.

5. Ventilation

5.1. Reference ventilation system

The reference is an exhaust ventilation system where the ventilation air is removed from the apartment at a constant flow rate, independent of external or internal factors. Air is extracted from the kitchen and the bathroom and is replaced by outdoor air inlets in the bedroom and the living room. The air is distributed to the exhaust outlets through the openings under the doors. The size of air gap is the same under all doors. Fig. 1 shows a principal scheme of the reference apartment with air flows indicated.

The outdoor air intake and air movements between rooms will depend on if internal doors are open or closed. To some extent outdoor pressure conditions due to wind and temperature differences have influence as well. The reference case is therefore modelled in two cases, with all internal doors open (except bathroom door during showering) and with all internal doors closed.

The total exhaust airflow extracted from the apartment in the reference case amounts to 30 l/s: 15 l/s extracted from the kitchen and 15 l/s from the bathroom. This means that the specific airflow is about 0.44 l/s m^2, i.e. above the minimum level of 0.35 l/s m^2 according to Swedish regulations.

5.2. Demand Controlled Ventilation

Three types of ventilation control strategies are used in the project:

- CO_2 control.
- Relative humidity control.
- Occupancy presence control.

CO_2 or relative humidity sensors are located in the bathroom and the kitchen and are used to control the exhaust airflow. In the model the presence of occupants is scheduled (time based), which corresponds to occupancy sensors in real case.

The exhaust air flow rate varies from a base flow of 10 l/s to a maximum airflow of 30 l/s. The base air flow is kept at the minimum sensor's set point, and the maximum air flow is reached at the maximum set point of the sensor. Different strategies were simulated with different maximum set points. In the case of carbon dioxide control three maximum set points were modelled: 800, 1000 and 1200 ppm. In the case of relative humidity control the following maximum set points were studied: 60, 70 and 80%.

The occupancy presence control strategy is directly related to the occupancy schedule, i.e. the ventilation airflow is kept at the minimum value of 10 l/s when there are no occupants and at maximum of 30 l/s when the apartment is occupied.

The influence of the radiator thermostat settings on indoor climate as well as on heating energy demand is studied by simulating two different P-band values: 2 and 4 K.

6. Simulation results

6.1. Reference case

The reference case was simulated in two modes: with all internal doors opened and all internal doors closed. The results show that closed or open doors has a major influence on the indoor climate.

In the reference case with a constant ventilation flow rate of 30 l/s the CO_2 concentration, as well as the relative air humidity, can be kept on reasonable levels (<1200 ppm and <70%), even with all doors closed and with two persons in the bedroom; the outdoor air inlet flow in the bedroom with all doors closed is 7.5 l/s which is close to recommended 4 l/s per person.

There is a risk for increased relative humidity in the case with doors opened in the whole apartment. This is caused by transport of humidity from the bathroom to other rooms. Relative humidity can reach 90% level in the rooms during summertime. However, this is usually not a real problem as in reality occupants open windows for airing the apartment, especially during the warm time of the year. In the model all windows are assumed to be closed all year around.

6.2. DCV

Both CO_2 and the occupancy control strategies result in a similar air quality (CO_2 concentration level).

The both strategies increase the risk for high humidity levels in comparison to the reference case with open doors. The RH control strategy results in reduced air quality (increased CO_2 concentration level) in comparison to the reference case with open doors.

6.3. Energy

Fig. 4 shows the annual heat demand for ventilation using studied demand control alternatives in comparison to the reference case. Both the CO_2 and the RH control strategy may result in >50% reduction, while the occupancy control strategy results in about 20% reduction of the annual heat demand for ventilation, if the indoor climate is regarded as acceptable.

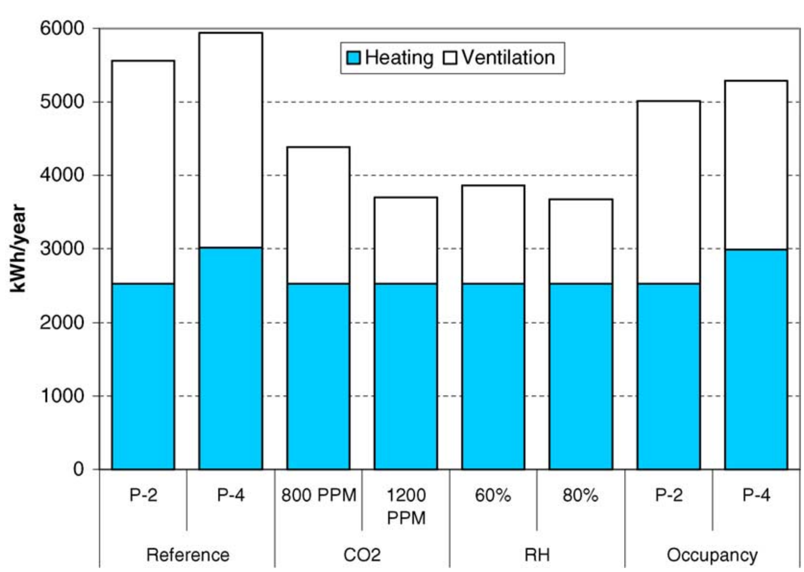

Fig. 4. Comparison of annual heat demand using different control strategies.

Lowering the maximum CO_2 set point from 1200 to 800 ppm will not have a major influence on the risk for high humidity levels but will increase the heat demand for ventilation with CO_2 control. On the contrary increasing the maximum RH set point from 60 to 80% will not have a major influence on the air quality but will reduce the heat demand for ventilation with RH control.

It is also shown that a less suitable radiator thermostat setting will increase the total heat demand. It is thus important to combine DCV with a proper radiator system adjustment and thermostat setting in order to assure the desired reduction of the heat demand.

7. Test installation

A test system based on the simulation results was installed in one occupied building in Västra Gårdsten. The test installation will make it possible to compare the performance of the DCV system in comparison to the performance of a more traditional exhaust ventilation system (reference system) under real conditions. The test installation comprises a DCV system with an exhaust vent, a humidity sensor, a switch in the door lock, necessary controls and a power supply unit. The exhaust vent has a variable opening managed by a small electrical motor and a control unit that opens and closes the vent depending on signals from the humidity sensor and the door lock.

8. Conclusions

The DCV has a positive influence on the heating energy demand and confirms in several aspects findings in previous studies. However, some aspects may be added regarding the negative influence on indoor climate from different DCV strategies and rather demanding occupant loads.

The economic feasibility of application of DCV in residential applications is further questionable as the economic space is rather small and the possibility to save energy to a large extent depends on the occupant behaviour. The main outcome of the study is thus a rather simple DCV system that is tested under realistic conditions in an occupied building. The monitoring of the test installation is still continuing and therefore it is too early to draw some conclusions on the performance of the system.

The simulations carried out for the reference apartment with exhaust ventilation has made it possible to get a considerable experience with the ICE model in this application.

The results obtained by the simulations seem to be correct e.g. regarding room temperature, moisture content and CO_2 concentration for the applied control strategies. The verification of the ICE model did not show large deviation of the simulated values from the calculated or measured. The ICE model has potential to be used in studies of the detailed performance of residential buildings.

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