MULTI-ZONE DEMAND-CONTROLLED VENTILATION IN RESIDENTIAL BUILDINGS: AN EXPERIMENTAL CASE STUDY

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ABSTRACT

Numerous studies have investigated the application of multi-zone demand-controlled ventilation for office buildings. However, although Swedish regulations allow ventilation rates in residential buildings to be decreased by 70 % during non-occupancy, this system is not very common in the sector. The main focus of the present study was to experimentally investigate the indoor air quality and energy consumption when using multi-zone demand-controlled ventilation in a residential building. The building studied was located in Borlänge, Sweden. This building was recently renovated with better windows with low U values, together with internally-added insulation materials. The building had natural ventilation, which decreased significantly after retrofitting and resulted in poor indoor air quality. Therefore, a controllable mechanical ventilation system was installed. The ventilation rate was controlled according to the demand in each zone of the building by CO_2 concentration as an indicator of indoor air quality in habitable spaces and relative humidity and VOC level in the toilet and bathroom. The study showed that multi-zone demand-controlled ventilation significantly reduced the CO_2 concentration leading to improvement in indoor air quality. However, building with demand-controlled ventilation consumed more energy than natural ventilation as it increases the ventilation loss by forcing more air into the building. Nevertheless, in the demand-controlled ventilation system, the energy consumption for the ventilation fan and ventilation loss was almost half of the constant high rate ventilation flow.

KEYWORDS

Demand-controlled ventilation, Indoor air quality, Energy consumption

1 INTRODUCTION

Approximately 73 % of the total energy demand in north European residential buildings is used for space and ventilation heating (Anisimova 2011). Poor insulation in old houses means that the share of space heating is higher than it is for ventilation heating. On the other hand, the addition of more insulation layers with low heat transfer coefficient (U value) in new and retrofitted buildings means that space heating demand is lower than it is for ventilation heating. Nevertheless, indoor air quality should not be sacrificed for energy saving through retrofitting; in other words, in buildings with natural ventilation, air circulation should not be lost by renovation. In Sweden 90 % of single family houses built before 1975 have natural ventilation (boverket 2009).

People spend around 90 % of their time indoors (Höppe 2002), and 60 % of it is spent in residential buildings. Previous studies (Joint Research Center, JRC) have shown that indoor contaminants are much more dangerous than outdoor pollutant. Therefore, it is essential to have enough ventilation rates to achieve acceptable indoor air quality in residential buildings. In order to decrease ventilation heat loss, energy-efficient ventilation systems, including heat recovery, or demand-controlled ventilation systems are advised. In heat recovery system, the heat from exhaust air is recycled and transferred to the incoming air. This system is more profitable in cold climates with high number of degree hours. In a demand-controlled ventilation system, the amount of ventilation air is adjusted to the occupants' needs, in addition to the constant rate for removing pollutants from furniture or building materials. This system decreases ventilation heat loss and energy for driving ventilation fans during un-occupancy compared to constant air volume. According to the Swedish building regulations (BBR), ventilation rates can be decreased from 0.35 to 0.10 $l \cdot s^{-1} \cdot m^{-2}$ when no one is home. A constant low rate of 0.1 $l \cdot s^{-1} \cdot m^{-2}$ is used to remove pollutants from furniture and building materials.

Demand-controlled ventilation systems are more common in office buildings due to more unpredictable occupancy levels. However, the need to reduce energy demand has led to this system also becoming interesting in residential buildings. Usually, if occupants are the main pollutants in the room, the CO_2 level is used as an indicator of indoor air quality. The general threshold for CO_2 is 1000 ppm. If the CO_2 concentration is greater than this threshold, the ventilation rate is increased. In residential buildings, odours from occupants, relative humidity (RH), and emissions from building materials, i.e. volatile organic compounds (VOC), all have a role in polluting the indoor air. Therefore, the efficient controlled set point for ventilation rates can be sensitive to VOC, RH and CO_2 variables. A system in which the ventilation rate is adjusted based on the demand in each zone is called a multi-zone demand-controlled ventilation system.

A previous study (Hesaraki and Holmberg, 2013) has shown that in new buildings with mechanical exhaust ventilation systems, reducing the ventilation rate during un-occupancy for eight hours caused a problem with indoor air quality (IAQ) regarding VOC concentration; specifically it was more than 0.1 ppm when the occupants returned home. This was due to high emission rates from building materials in initial years of construction. Therefore, a suggestion was made to increase the ventilation rate two hours prior to the occupants arriving home. In addition, in investigated time-controlled ventilation system the heating requirements for ventilation air and electricity consumption for the ventilation fan were decreased by 20 % and 30 %, respectively.

In old buildings usually there is no problem with VOC concentration. Therefore, as previous study (Hesaraki and Holmberg, 2013) suggested time-controlled ventilation is not needed in old houses to increase the ventilation rate before occupants arrive home. The aim of this study was to investigate the performance of multi-zone demand-controlled ventilation system in a retrofitted old house with respect to energy consumption and IAQ.

2 DESCRIPTION OF THE STUDIED BUILDING

A 92 m^2 two-story single-family house built in the 1950s, located in Borlänge, Sweden, was chosen for this study (see Fig. 1). To make the building more environmentally-friendly, the heating system of this building was changed from furnace to ground-source heat pump. In addition, to save energy this building was renovated with better windows with low U values, together with internally-added insulation materials. The building had natural ventilation, which decreased significantly after retrofitting. This was due to reducing the pressure difference caused by chimney (wind-effect) and decreasing the temperature difference (stack-effect) between indoors and outdoors by adding more insulation layers in the building envelope. Hence, because of insufficient air circulation in this building, mechanical ventilation was mounted to force the air to provide acceptable indoor air quality. To decrease heat loss and provide the exact amount of ventilation needed in each zone in this building, multi-zone demand-controlled ventilation system was installed. The controlled variables were VOC and relative humidity (RH) in the toilet and bathroom, and CO_2 for habitable spaces (see Fig. 2).

Figure 1 The two-story single family house selected for study in Borlänge, Sweden

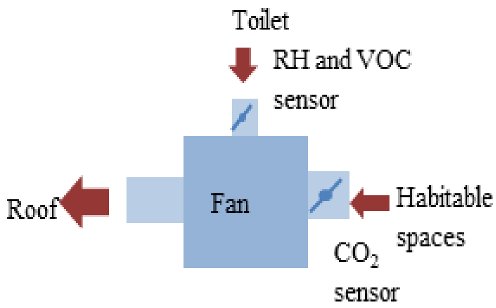

Figure 2 Multi-zone demand-controlled ventilation system for the studied building with RH, VOC and CO_2 sensor

3 METHOD

Experimental investigation was the main method used in this study. For measurements, concentration of CO_2 and RH was monitored as indicators of IAQ before and after installing demand-controlled ventilation. The indoor CO_2, RH and temperature is not uniform in the whole room (Seppanen et al. 1999). Therefore, to detect a mean value of CO_2, RH or temperature, the sensor should be placed in the breathing zone or in the exhaust valve. The latter was chosen for this study. In addition, with regard to energy consumption, ventilation fan energy consumption and ventilation heat loss were measured and calculated. In the ventilation heat loss calculation shown in Eq. (1), the ventilation flow rate was estimated from ventilation fan electrical energy consumption by having flow chart of installed fan in this system (see Fig. 3). The specific power for this fan was 0.14 W / ($m^3 \cdot h^{-1}$) at pressure 100 Pa and airflow 250 $m^3 \cdot h^{-1}$.

$$P_{ventloss} = q \cdot \rho \cdot c_p \cdot (T_{in} - T_{out}) \qquad (1)$$

where q is ventilation rate ($m^3 \cdot s^{-1}$), ρ is air density ($kg \cdot m^{-3}$), c_p is specific heat capacity ($J \cdot kg^{-1} \cdot °C^{-1}$) and T_{in} and T_{out} are indoor and outdoor temperature (°C), respectively.

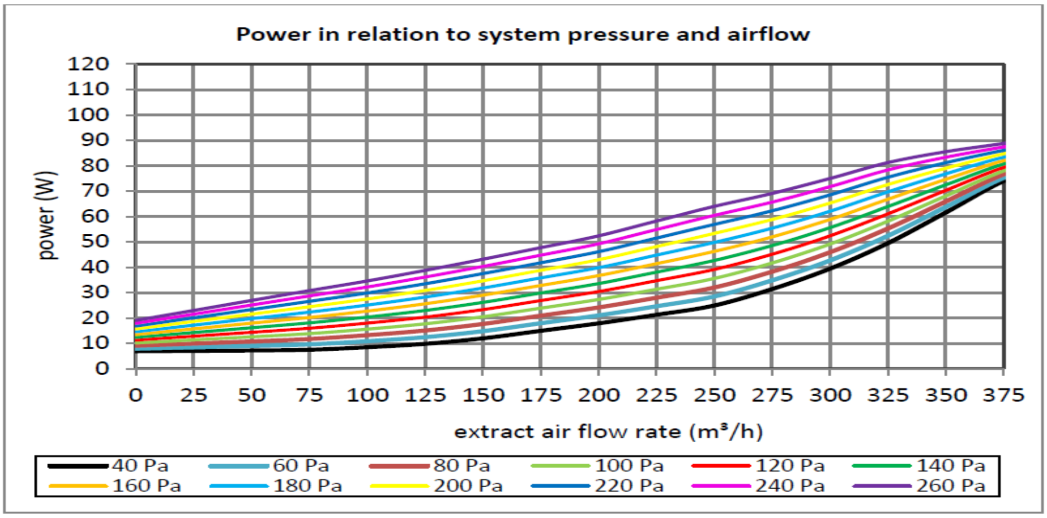

Figure 3 Power consumption of ventilation fan in relation to system pressure and airflow from device manual

4 RESULTS AND DISCUSSION

The results of the experiment are provided in two parts: indoor air quality and energy consumption.

4.1 Indoor air quality

For indoor air quality, two parameters were considered: RH and CO_2. Measurements were performed before and after installing the demand-controlled ventilation system. According to the field tests, the CO_2 level was higher than 1000 ppm most of the time when people were home before improving the ventilation system; that is, natural ventilation. Figs. 4 and 5 show the results during a weekday and a weekend, respectively.

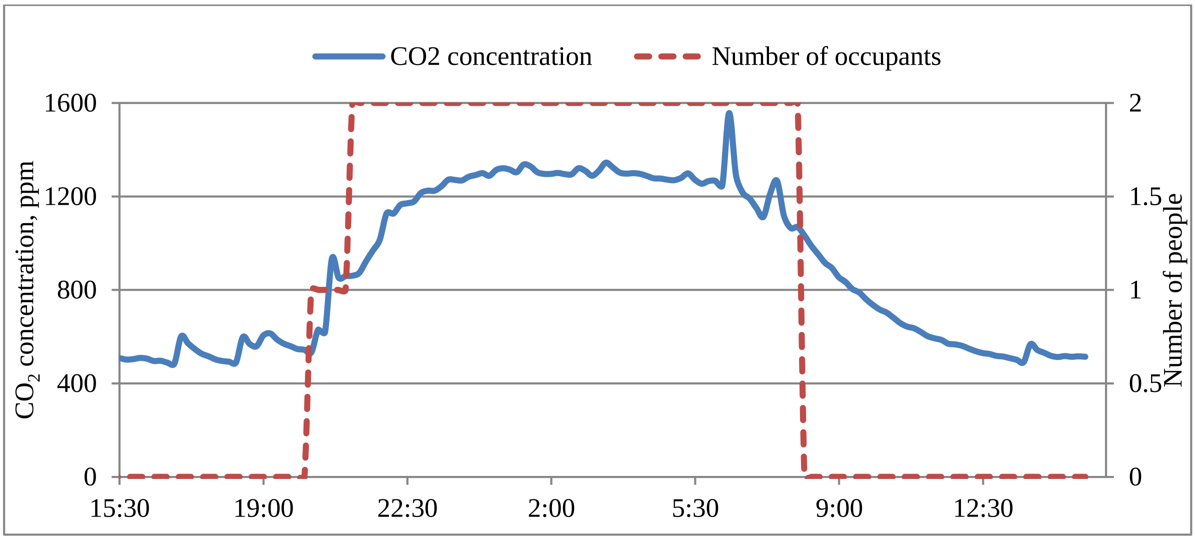

Figure 4 CO_2 level during a working day without demand-controlled ventilation system and with natural ventilation

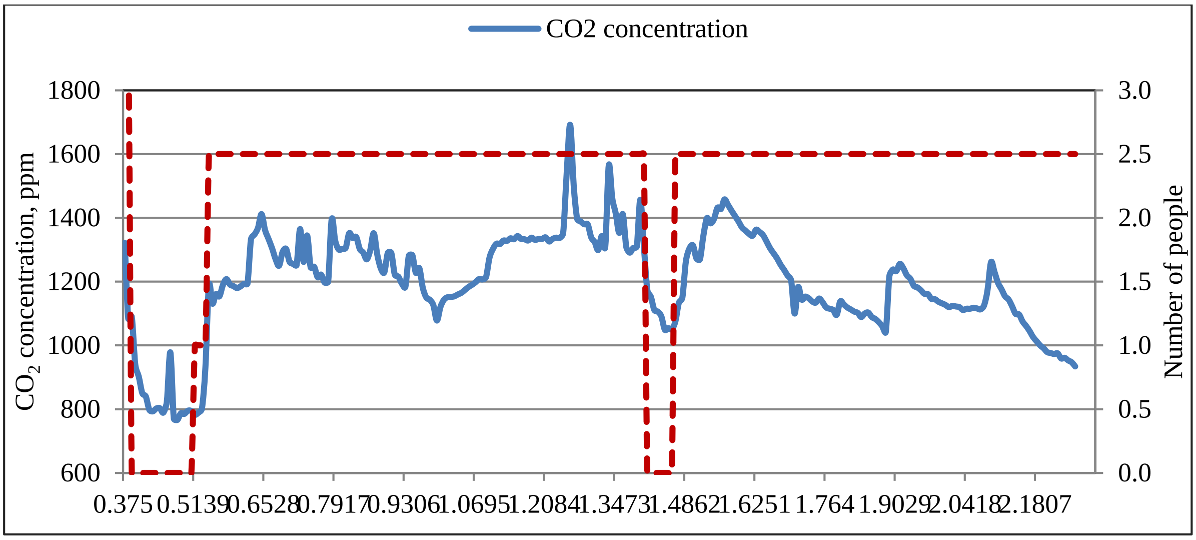

Figure 5 CO_2 concentrations during weekend with natural ventilation and without demand-controlled ventilation system

In the demand-controlled ventilation system, the CO_2 level was the main factor determining the ventilation flow rate. The threshold level was set to 800±50 ppm. As Fig. 6 shows, the CO_2 level never exceeded 800 ppm when using the demand-controlled ventilation system.

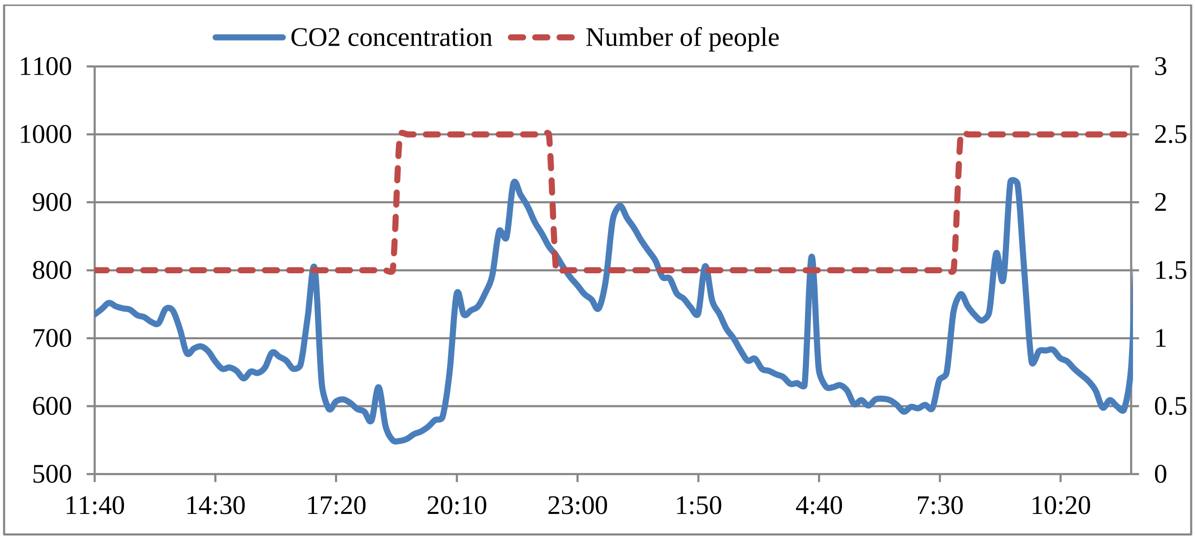

Figure 6 CO_2 concentrations during a working day with demand-controlled ventilation system

Measurements showed that the RH only affected flow rates during showering when using the demand-controlled ventilation system. For the rest of the time, the relative humidity was 40–60 % within healthy range.

4.2 Energy consumption

The degree hours method was used to estimate the ventilation heat loss. This is a simplified method of calculating the building energy demand for active heating. The degree hours depends on the building location, the chosen indoor temperature and the indirect/passive heat supply. The heating contribution from the limit temperature to comfort temperature is given by indirect/passive heating. Degree hours is 115080 °C·h· year^{-1} for an assumed active temperature of 17 °C and a mean outdoor temperature of 4.2 °C in Borlänge (Warfvinge and Dahlblom 2010).

ventilation heat loss and ventilation fan energy consumption for high constant ventilation rates, which is dominant in most multi-family houses in Sweden, was also calculated. Having degree hours, ventilation heat loss for natural, demand-controlled ventilation and high rate constant ventilation was calculated for this building (see Fig. 7). As can be seen, the lowest consumption is for natural ventilation due to the low flow rate and not having any mechanical ventilation. In the demand-controlled ventilation system, the energy consumption for the ventilation fan and ventilation loss was almost half of the constant high rate ventilation flow; in other words, 45 % and 22 % of ventilation heat loss and ventilation fan, respectively, are saved by demand-controlled ventilation. Due to the very low specific fan power of ventilation fan used in this system, there was not a great deal of saving in terms of ventilation fan power by using the demand-controlled ventilation system. However, savings for ventilation heat loss was significant compared to the constant high-rate ventilation.

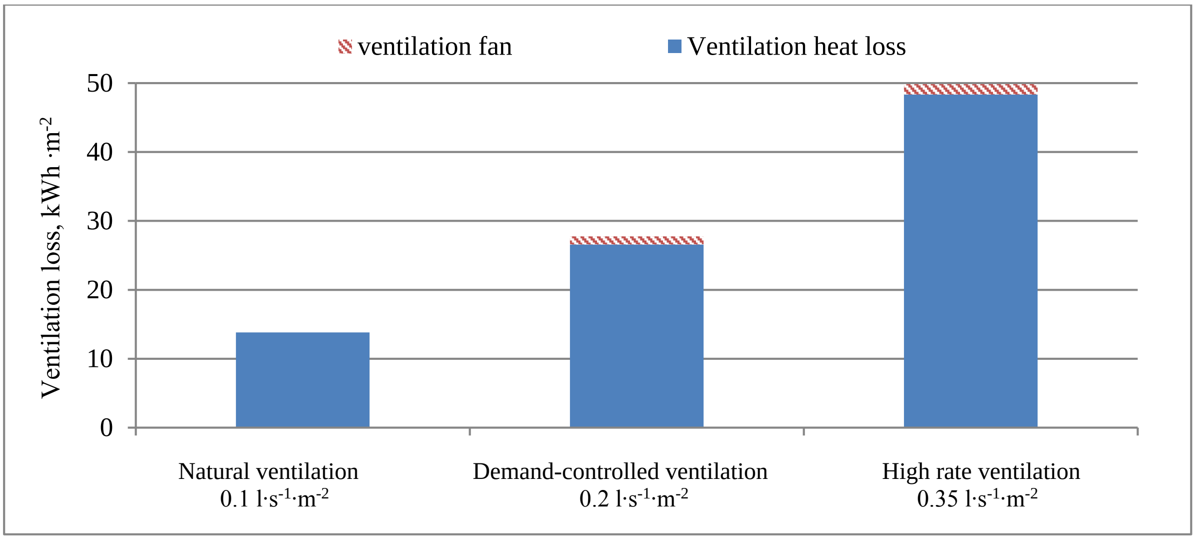

Figure **7** Energy consumption for ventilation heat loss and ventilation fan electricity consumption for natural, high, and multi-zone demand-controlled ventilation system

5 CONCLUSION

This study investigated the performance of multi-zone demand-controlled ventilation in a single-family house in Sweden. The studied building had been renovated with improved windows with lower leakage and insulated internally with more insulation layers. In addition, the heat source was changed from furnace to ground source heat pump. All these changes resulted in lower ventilation flow rate in this building, leading to poor indoor air quality. This was proved by measuring the CO_2 level, which was approximately 1400 ppm when the occupants were at home. This value is much higher than the common threshold level of CO_2 (that is 1000 ppm) as an indicator for acceptable IAQ. This indicated the need to improve the ventilation system in this building. For this purpose, a multi-zone demand-controlled ventilation system was installed in this building. The control set point for ventilation flow rate was based on the CO_2 level in habitable spaces and the relative humidity and VOC for the toilet and bathroom. Measurements showed significant reduction in CO_2 concentration leading to improvement in IAQ by using demand-controlled ventilation system. However, in demand-controlled ventilation energy consumption for ventilation heating was almost twice compared to natural ventilation due to higher ventilation rate. Nevertheless, using demand-controlled ventilation resulted in 44 % saving in ventilation heating and ventilation fan consumption compared to constant ventilation system. More experiments to measure actual heating consumption in the building studied are planned for autumn. The need to decrease energy demand in residential buildings without sacrificing indoor air quality highlights the application of demand-controlled ventilation system.

6 ACKNOWLEDGEMENTS

We are grateful to the Swedish Energy Agency (Energimyndigheten) and SBUF, The Development Fund of the Swedish Construction Industry for financial support.

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