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Demand controlled ventilation (DCV) in school and office buildings: Lessons learnt from case studies

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ABSTRACT

Demand controlled ventilation (DCV) refers to a ventilation system with air flow rates that are controlled based on a measurement of an indoor air quality (IAQ) and/or on a thermal comfort parameter. DCV operates at reduced air flow rates during a large amount of the operation time and thus consumes less energy for fan operation and heating/cooling the supply air. The aim of the present research is to assess the IAQ, ventilation efficiency, and the operation and energy efficiency of real operating DCV systems in moderate climates.

Measurements are carried out for at least two weeks in autumn and winter 2015-2016. The following parameters were monitored: CO_2 concentrations and air temperatures at different positions in the room and at the extract air grill, position of the variable air volume (VAV) boxes, supply and extract air flow rates and the occupancy of the room. Four case studies with large and varying occupancy rate and with different use and ventilation systems are selected. Two classrooms and three landscaped offices were evaluated.

The results show that a DCV is interesting in rooms with a large and varying occupancy rate such as lecture rooms and landscaped offices. A good IAQ is measured in all cases studied even at reduced air flow rates. The effect of the reduced air flow on the ventilation efficiency is negligible. The VAV boxes react well to predefined set points for CO_2 concentration. During the measurement period, the reduction for fan energy ranges from 25 to 55% and ventilation heat losses 25–32% compared to a constant air volume system (CAV) with a design airflow rate of 29 m^3/(h.pers), i.e., IDA3 in EN 13779. However, commissioning of the DCV is necessary to obtain and maintain these performances.

1. Introduction

European buildings consume approximately 38% of the total energy consumption (Eurostat, 2014). Of this 38% total energy consumption, 25% is consumed by residential and 13% by non-residential buildings. In non-residential buildings the end use of energy for heating, ventilation and air-conditioning (HVAC) systems is 50% [18]. The energy needed for operation of ventilation systems in offices and educational buildings is estimated to be 10–50% of the total energy consumption in nearly zero energy buildings (nZEB) buildings [7]. To reduce energy consumption in buildings the EPBD directive requires that from 2020 all new buildings in the European Union have to be nZEB buildings. (The Directive 2010/31/EU (EPBD) at Art. 9) The heating demand of buildings is already decreased by increasing the insulation thickness and the air tightness of the building envelope. Further reductions can be achieved by optimization of HVAC systems.

One measure to improve the energy efficiency of HVAC systems is the implementation of demand controlled ventilation (DCV), which automatically adapts the air flow rates in relation to the actual ventilation demand, characterized by e.g., occupancy or CO_2 concentration. DCV operates at reduced air flow rates during a large amount of the operation time. Due to this decrease, less energy is needed for fan operation and heating/cooling the supply air [3]. Seppänen [21] showed that for further energy reductions in buildings, the application of DCV is an important factor.

The energy saving potential is demonstrated in the studies summarized in Table 1. In this table the climate region is included to make a distinction between colder and warmer climates. An extensive study with measurements and simulations performed in California [22] showed that DCV combined with air to air heat recovery resulted in the highest reductions for both energy consumption and costs with a maximum of 48%. Especially in rooms

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Table 1
Energy savings for implementing DCV in previous studies.

	Fan savings	Heat loss savings	Total energy savings (HVAC)	Climate region [12]
Smith and Braun [22]	–	–	48–52%	Csb, Csa
Stein, Zhou and Cheng [23]	51–62%	34–48%	–	Csb, Csa
Sun, Wang and Ma [24]	52%	–	–	Cfa
Mysen et al. [17]	–	–	38%	Dfc
Wachenfeldt et al. [25]	87%	21%	–	Dfc
Maripuu [13]	50%	–	–	Dfc
Ahmed et al. [1]	–	–	33–41%	Dfc

with a varying occupancy profile the energy saving potential is significant: maximum 52%. Stein, Zhou and Cheng [23] showed with measurements of the air flow, during a hot and a cold period for three different locations in California, that the impact of demand control is significant for all-air systems. Fan savings for the three locations were 51–62% and heating savings 34–48%. Implementing DCV resulted in expected savings of 25% for the electricity consumption and 41% on gas consumption used for heating. Sun, Wang and Ma [24], implemented a CO_2 based adaptive DCV in a multi-zone office building in Hong-Kong. Fan savings achieved with the DCV strategy were at least 52% compared with a constant air volume (CAV) system. However, this was only tested for a shorter period time period of 1 day.

The application of DCV has already been studied in colder climates with higher heating demands. Mysen et al. [17] showed that the energy demand in Norwegian school buildings was reduced by 38% for a CO_2-DCV compared with an CAV system. This energy reduction for ventilation was calculated based on measurements of occupancy in 157 classrooms at 81 randomly selected Norwegian schools from March to June 2002. Wachenfeldt et al. [25] showed with measurements and simulations (the analysed period is from 11–17 November 2002) of two school buildings in Norway that the energy demand for heating was reduced by 21% and the fan energy consumption 87% compared to a CAV system. Maripuu [13] showed that by implementing a DCV system in a university building with office rooms in Sweden the energy use for the fans was decreased by 50%. These savings were based on annual simulation results. Ahmed et al. [1] showed for the implementation of DCV a decrease of 33–41% for the energy needed for heating, cooling and fans in an office building with landscaped offices in Finland. The measured landscaped office had a floor area of 380 m^2 with a total of 30 work stations. In this study the energy savings for the implementation of DCV are derived from annual simulations. The simulated model was calibrated using measurement data.

The impact of DCV on indoor air quality (IAQ) has been sufficiently studied in the literature. However, most studies mentioned, only focus on the IAQ and not the related energy savings. IAQ is an important factor during the design of the ventilation system. The IAQ affects both the comfort and the health and productivity of the building users [14]. The impact of the air flow rate and the CO_2 concentration on the user's performance is equally important with regard to the economic relevance of ventilation. Seppänen, Fisk and Lei [20] combined results of nine studies and concluded that increasing the air flow rate has an impact on the work performance of the user. The effect was at maximum 4% on the performance rate of the building occupant.

The aforementioned study by Ahmed et al. [1] is one of the few studies combining energy savings and the impact of DCV on IAQ. Here, the measurement results of the CO_2 concentration inside the landscaped office indicated a good IAQ with concentrations below 900 ppm during operating hours. In a study of Kolarik et al. [11] field measurements were performed in 4 offices of a refurbished university building with DCV. The installation of DCV during the refurbishment resulted in decreased CO_2 concentrations as a result of increased airflow. However, it did not result in statistically significant improvement of perceived IAQ.

Since DCV not only operates at the design air flow rate, there might be an impact on the air distribution inside the room. The air flow pattern is affected due to the lower air flow rates and velocities and might not cover the whole occupied zone. Fisk et al. [8] measured the spatial variability of CO_2 concentration in occupied meeting rooms with DCV. In a crowded conference room the CO_2 concentration varied for the different measurement positions up to approximately 300 ppm and fluctuated substantially with time for the measurement positions. Measurements for ventilation efficiency in a landscaped office with DCV by Rey Martínez et al. [19] showed values between 0,55 and 0,66. The efficiency was affected by supply air that was mixed with extract air resulting in a higher CO_2 concentration at the supply.

Previous studies focused primarily on energy reductions whereas the aim of ventilation is to provide a good IAQ and ventilation efficiency. Additionally, current studies are performed in colder or warmer climates. Nevertheless, data for moderate climates are still missing. The aim of the present research is to assess the IAQ, ventilation efficiency, operation and energy efficiency of real operating DCV systems in a moderate climate. Five rooms with large and varying occupancy profiles in four different school and office buildings in Belgium are selected. Overall conclusions resulting from these case studies are now discussed.

First, a description of the case study buildings and the systems is presented. Afterwards, the measurement setup for the evaluation of IAQ, ventilation efficiency and energy efficiency is shown. Section 4 presents the results of all the measured case studies and finally the conclusions are presented.

2. Case studies

This section discusses all the evaluated case studies. A short description is given of the selected case studies. All the case studies analysed are located in Belgium (climate region Cfb). Measurements are conducted for over two consecutive weeks during a heating demand period. Case studies are selected based on room type (lecture rooms and landscaped offices) and ventilation system (mechanical balanced and natural supply with mechanical extraction). Other selection criteria were building use and rooms with a large and varying occupancy profile.

Table 2 summarizes the ventilation, room and control properties of the case studies and gives more information about the use. Four different case study buildings are analyzed with 3 different types of rooms:

- classroom
- lecture room
- landscaped offices.

In all the case studies the DCV system is controlled by measured CO_2 concentration. With exception of kindergarten "De Boomhut" the ventilation system is also temperature controlled (all-air HVAC). For all the case studies a brief description is given