EVALUATION OF SOME DCV CONTROL STRATEGIES BASED ON BUILDING TYPES

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ABSTRACT

During the recent decades, energy consumption of buildings, together with the costs for operation, has gained increasing concern. HVAC systems stand for a significant share of the total energy consumption in buildings. Demand-controlled ventilation (DCV) has proved to be an efficient system that gives opportunity to strongly reduce energy consumption, especially when contamination loads or temperature load vary during the operating hours. 30-60% energy reduction can be expected by applying proper DCV. However, while focusing on energy savings, it is important to simultaneously maintain acceptable indoor air quality (IAQ) and thermal comfort. There is thus a need for a balance of emphasis between different IAQ factors such as CO_2 concerntration, volatile organic compounds (VOC), etc. when the DCV control strategies are assessed and implemented.

The aim of this paper is to provide advices for choosing DCV control strategies by evaluating existing ones such as CO_2 concentration control, Multi-zone control, dynamic-occupancy-detecting control etc. by matching them with users' preferences according to different building types for residential buildings, office buildings and schools.

KEYWORDS

DCV, evaluation, control strategies, building type preferences

1 INTRODUCTION

The aim of ventilation in a building is to provide users with good and comfortable indoor air environment. It should be noticed that 'good' and 'comfortable' are subjective conceptions, which depends on not only objective composition of the air handling components, but also users' individual experiences. To achieve this aim of ventilation, there are mainly two approaches. One is to regulate indoor air handling components by using technical means, diluting or removing contaminants and improving air 'freshness'. The other is to determine IAQ preferences of different user groups through the investigation of different building types or research about building regulations and standards. The first one is to achieve more efficient and more economical methods through engineering, such as better control behavior, new detection technology or sensors with higher quality etc. The latter belongs to a certain extent to a more sociological related category.

After more than 20 years of research and application, demand-controlled ventilation (DCV) has proved to be an efficient mean that provides opportunity to strongly reduce energy consumption when contamination loads or temperature load vary during the operating hours. However, as researched further, a lot of control strategies are developed which take more and more parameters into account simultaneously. This leads to more complex systems, and increased number of components. Growth in the complexity of DCV systems directly results in growth in possibility of malfunction or error in measurements and control. There is thus a need to emphasize a balance of different IAQ factors such as CO_2 concentration, volatile organic compounds (VOC), etc, namely to chose the most representative indicator when the DCV control strategies are assessed and implemented and the complexity of DCV system should be taken into consideration while evaluated. ‘All in one’ solutions are not always the best choice.

The aim of this paper is to provide some basis for selecting DCV control strategies by reviewing and evaluating existing ones such as CO_2 concentration control, Multi-zone control, dynamic-occupancy-detecting control etc., and further by matching them with users’ preferences according to different building types for residential buildings, office buildings and schools.

2 REVIEW OF SOME DCV CONTROL STRATEGIES ACCORDING TO BUILDING TYPES

2.1 Residential buildings

In many countries ventilation with constant air volume (CAV) is mostly chosen type in dwellings. Due to fewer fluctuations in the occupancy level, there is less expected energy saving potential caused by change in number of occupants in dwellings compared with other building types like schools or offices. However, DCV can still be a good solution for energy saving in dwellings. On one hand the contaminants from users’ activities vary during the day and the houses are unoccupied for a long time (usually the working hours) every day. It is hence possible to reduce energy consumption considerably by implementing proper DCV. On the other hand, because of small number of occupants and relatively regular (more predictable) activity patterns, DCV in dwellings requires smaller systems and simpler control strategies.

2.1.1 Description of control strategy

Besides CO_2 concentration, moisture is also important to dilute or remove by ventilation in residential houses. Research on different DCV control strategies shows that it is possible to achieve energy savings by using CO_2 or humidity controlled ventilation to reduce flow rate while maintaining acceptable IAQ [1]. A control strategy was developed by two Danish researchers to reduce energy use without large change in IAQ and moisture concentration compared with CAV. To simplify the system and reduce the investment costs of DCV, this developed control strategy is based only on measurements in the air handling unit that control the speed of the fans. There are only two ventilation rates: either a high rate designed to maintain acceptable IAQ while the occupants are present in the house or a low rate designed to remove contaminants due to building materials or indoor equipments while the house is unoccupied. The movement of occupants (entering or leaving the house) is based on measured difference in CO_2 concentration between the exhaust air and outdoor air. The difference in absolute humidity between exhaust air and outdoor air is used to assure that the high ventilation rate is maintained until the humidity in the dwelling is below a certain threshold [2].

This control strategy was tested in a single family house with a floor area of $140m^2$. Occupants were two adults and two young children, and all occupants were out of the house during working hours for work or school. The measurements were focused on CO_2 concentration and humidity in the living rooms. The chosen flow rates for the test house were

216m^3/h for the high rate and 80m^3/h for the low rate, based on the requirements in Danish building regulations and indoor air quality standards [2].

While choosing different threshold levels for difference in CO_2 concentration and threshold for difference in absolute humidity between the exhaust air and outdoor air, the aforementioned control strategy was tested in four different periods. The results are summarized in Table 1.

Table 1. Results from four different time periods [2].

Series	**Measurement period**	**Threshold for difference in CO_2 concentration [ppm]**	**Threshold for difference in absolute humidity [g/kg]**	**Fraction of time on low fan**
1	20/2-26/2 2009	100	1	13%
2	18/3-26/3 2009	200	2	31%
3	28/3-13/4 2009	100	2	34%
4	15/4-24/4 2009	150	2	37%

The best result was obtained with a 150ppm limit on difference in CO_2 concentration and 2 g/kg limit on difference in absolute humidity. In this case, the ventilation was running with the low ventilation rate 37% of the time. By assuming that electric power depends on air flow rate to the third, electricity consumption is theoretically reduced by 95% while reducing the flow rate from 216m^3/h to 80m^3/h. Thus, operating on the low flow rate 37% of the time resulted in 35% lower electricity consumption compared to CAV.

It is shown in Fig. 1 that the implemented control strategy does cause significant change in IAQ. Both CO_2 concentration and indoor moisture level were kept within the designated limit most of the time.

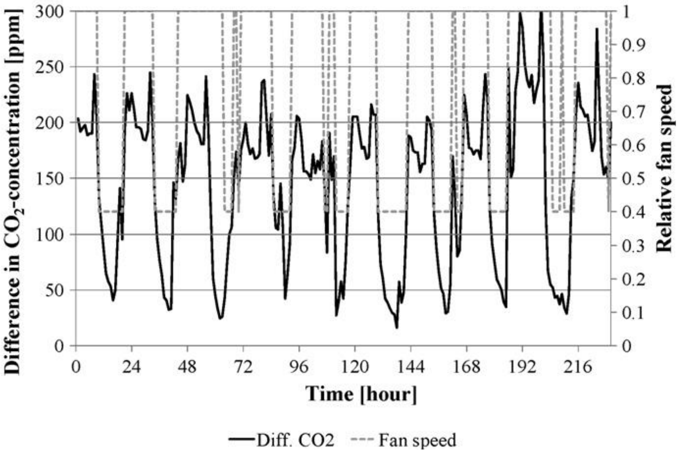


Fig. 1. Difference in CO_2 concentration between extracted air and outdoor air, and relative fan speed for series 4 (150 ppm, 2 g/kg). Time 0 h is midnight [2].

2.1.2 Evaluation of control strategy

The control strategy has following advantages:

1. Simple. There are only four control parameters need to be calculated: the high ventilation air flow rate and the low one, the limit of difference in CO_2 concentration between extracted air and outdoor air and the limit of difference in absolute humidity between extracted air and outdoor air. And only the two differences above need to be measured during operating period.

2. Inexpensive. All components used for the control are located in the air handling unit. That suggests very limited investments on implementing DCV in single family house compared with other building types.
3. Reliable data. The control strategy is tested in field experiment which provides more reliable data than only in simulations.

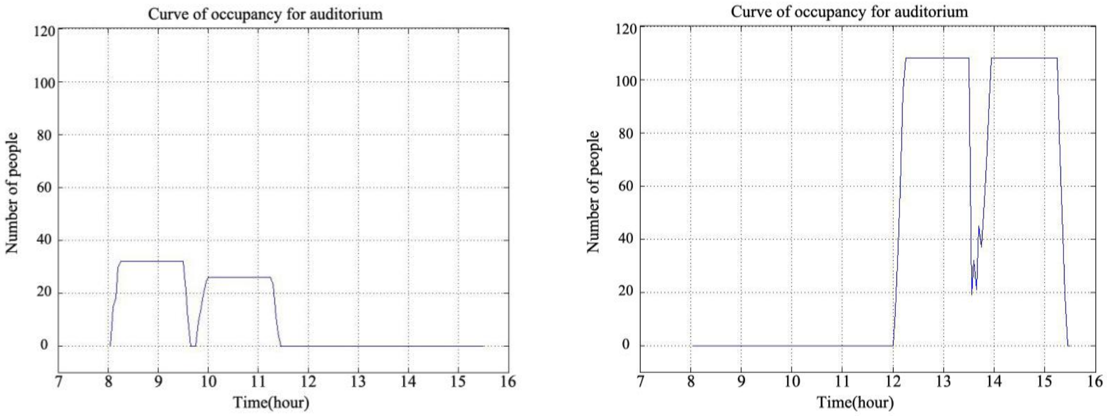
This control strategy satisfies requirements for DCV in residential buildings: simple, inexpensive, and easy to operate. However, in order to achieve the benefits of this control strategy, there are two issues that need further research:

1. The high and low air supply rates are the key parameters of this control strategy; they are calculated based on the relevant Danish residential building regulations. When applied in other countries or regions, the control strategy needs to be adapted to the respective building regulations and indoor air quality standards. The difference between the air supply rate when the house is occupied and the minimum air supply rate when the house is unoccupied directly affects the efficiency of this control strategy.
2. The relationship between length of low air flow rate duration and electric power saving potential is influenced by a series of parameters such as fan type, the efficiency of the heat recovery etc. Although the field experiments verify that this control strategy is able to achieve low air supply rate for nearly 40% of the operating hours, the energy saving capacity need to be confirmed by taking the actual technical parameters of components in the DCV system into consideration

2.2 Schools

The pollution loads pattern in schools is quite different from other building types. People play a more important role as pollution source than in office- or residential buildings. Thus the pollution loads concentration (mainly CO_2) can vary significantly during occupied period in local places such as class rooms or auditoriums due to strongly changing occupancy.

In order to study the pattern of occupancy change in school, records of occupancy changes are taken for three different classrooms in a college in two weeks for each classroom. By taking records for a large auditorium in two working days as an exsample, it is shown in Fig. 2 that occupancy changes significantly each day and the occupied period is not of the same pattern or magnitude for different days. That means occupancy pattern in schools is not so fixed as in office- or residential buildings but more unpredictable.



(a) (b)

Fig. 2. Record of occupancy variations for a large auditorium during two different days (a), (b).

In order to operate DCV effectively in schools under the condition of such unpredictable occupancy changes, detecting current–time population accurately is the weighting factor

2.2.1 Description of control strategy

Dynamic-occupancy-detecting control was developed to obtain a reliable calculated current–time population to determine the minimum required outdoor air flow rate [3].

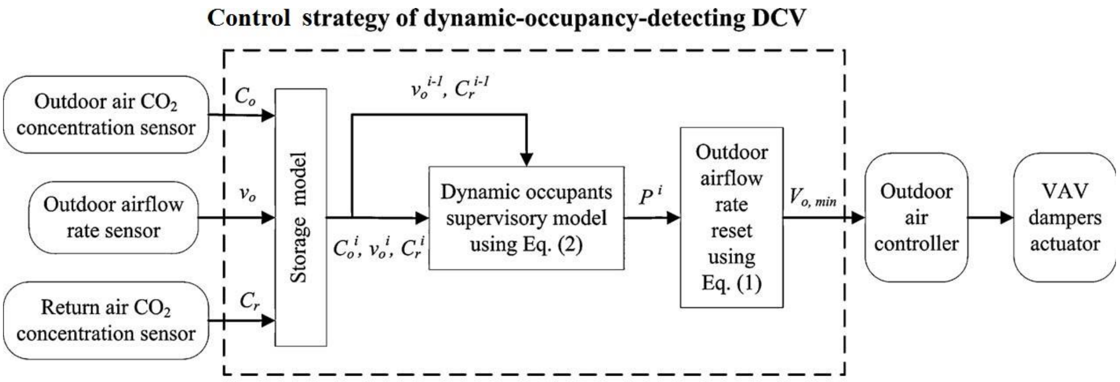


Fig. 3 Control strategy scheme of dynamic occupancy detection [3]

As shown in Fig. 3, three parameters are measured by sensors and saved in a storage model: the indoor CO_2 concentration, the outdoor CO_2 concentration and the outdoor air flow rate. The dynamic occupants in controlling zone is detected based on the difference between indoor and outdoor CO_2 concentration, and the minimum outdoor air flow rate is calculated by Eq. (1).

Required outdoor air flow rate is determined by the combination of occupant-related and area-related contaminant (odor) concentrations. The equation for required outdoor air flow rate according to ASHRAE Standard [4] can be depicted as:

$$v_{o,\mathrm{min}}^{i} = R_P \times P^i + R_a \times A \tag{1}$$

Where

$v_{o,min}^{i}$ is the total minimum outdoor air flow rate at time i,
R_P is the outdoor airflow rate required per person,
P^i is the total number of occupants at time i,
R_a is the outdoor airflow rate required per unit area,
A is the total occupied floor area.

The current–time population P^i can be calculated by Eq. (2) [5]. The values at time *i-1* and time *i*, which represent the previous and current sampling time, are measured and used as inputs for the dynamic occupant supervisory model.

$$P^i = \frac{(v_o^i + v_o^{i-1}) \times (C_r^i - C_o^i)}{2S} + \frac{V \times (C_r^i - C_r^{i-1})}{S\Delta t} \tag{2}$$

Where

v_o is total outdoor air volume,
C_r is the CO_2 concentration for indoor air,
C_o is the CO_2 concentration for outdoor air,
S is the CO_2 emission rate per person,

V is the total occupied floor volume,
Δt is the sampling interval.

Fig.4 shows that the calculated results from the dynamic occupancy detection model are very close to the actual current–time population when tested in an office room. Accurate indoor dynamic occupancy is calculated by using this control strategy to determine the minimum required outdoor air flow rate.

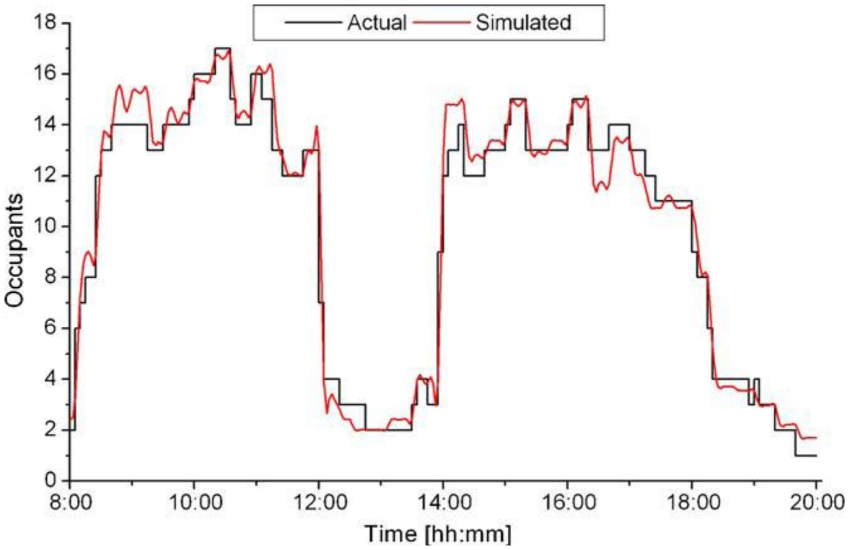


Fig. 4 Comparison of population between actual and dynamical detection of occupants for an office [3].

2.2.2 Evaluation of control strategy

The aforementioned control strategy has the following advantages:

1. Simple calculation models. Only three parameters need to be measured: the indoor CO_2 concentration, the outdoor CO_2 concentration and the outdoor air flow rate. Only two equations are applied in calculation.
2. Acceptable accuracy. Experiment shows calculated current–time population from the dynamic occupancy detection model are very close to the actual value to determine the minimum required outdoor air flow rate.

The dynamic-occupancy-detecting control strategy adapt to unpredictable occupancy in schools by providing a calculated current–time population with exceptional accuracy, but there are some factors which impact the actual accuracy of this control strategy:

1. Sensors. Due to there are only three parameters measured to calculate current–time population, the detecting accuracy at each sensor will strongly impact the final calculated result. In order to guarantee reliable measurements, assessment of number of sensors, location of sensors etc. must be performed.
2. Further test. As this control strategy only solve the problem to produce a detected occupancy by using a quite simple calculation model, its applicability to actual DCV system in schools and potential of energy saving need to be further tested in specific situations.

A similar occupancy calculation procedure was also decribed in [6].

2.3 Office buildings

Similar to residential buildings, office buildings have relatively regular change over time in the number of users since they are occupied during the working hours only. However, in practical situations, it is rare that all the rooms in office buildings are occupied at the same time. In order to determine the potential energy savings and optimize the capacity of a DCV system, it is necessary to know the occupancy level. Occupancy factor, which is defined as the actual number of occupied rooms, divided by the total number of rooms, is often used to describe the occupancy level. Early study shows that OF (occupancy factor) is about 50% most of the time, and the peak OF is 70%. Typical fluctuation of OF in an office building is shown in Fig 5 [7].

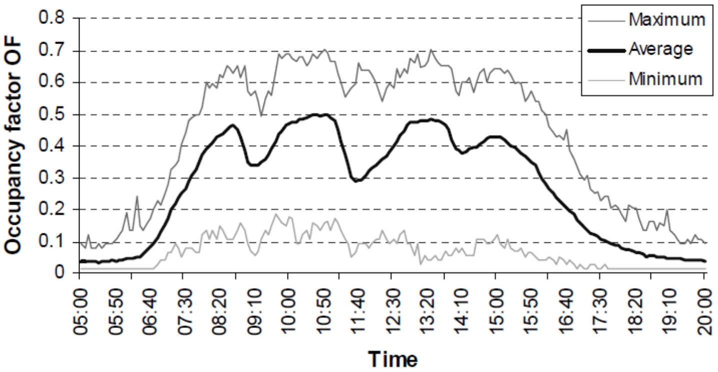


Fig. 5. Occupancy factor for offices for all working days over the one year measurement period for a case study in an office building [7].

The fluctuation of OF for offices is caused by occupants moving from offices to break rooms at noon, or to meeting rooms at any time of the day. Due to this movement, some zones in the office building become over-ventilated or under-ventilated although the total number of occupants does not change significantly. Under such conditions, multi-zone control has potential to provide proper IAQ.

2.3.1 Description of control strategy

Based on dynamic-occupancy-detecting control, a multi-zone DCV control strategy is developed with consideration of local IAQ satisfaction in each zone. As shown in Fig. 6, total required outdoor air flow rate is first calculated based on detection of total occupancy [8]. Required outdoor air flow rates in different zones are then calculated based on their own occupancies. By detecting the critical zone (or room), total outdoor air fraction is corrected by outdoor air fraction of the critical zone. At last the corrected outdoor flow rate is calculated. A more precise formulation of the calculation model can be found in [8]. This is a type of distributed DCV that works efficiently. Distribution is not dependent on the measurement of pressure, and more accurate demand based flow rates to the zones can be obtained.

2.3.2 Evaluation of control strategy

Validated in both simulation and field test [8], the multi-zone DCV control strategy can help to reduce the energy consumption and running cost without significant IAQ reduction (compared to the conditions normally provided by a CAV system). Special attention must be directed to local IAQ when this control strategy is implemented. To enable online control and ultimately achieve better local IAQ, this control strategy needs an Intelligent Building Management (IBM) and Integration platform as overall communication platform for operating the DCV strategy efficiently. Establishing IBM systems may lead to increased investment costs, but it is generally believed that operating costs will be lower, especially for large buildings. In [8], investigations were performed for a 500m high skyscraper of about 321,000 m^2 floor area.

The balance between the control accuracy and system size as well as initial investment on equipment to achieve this control strategy needs to be further evaluated when implementing in office buildings of different sizes.

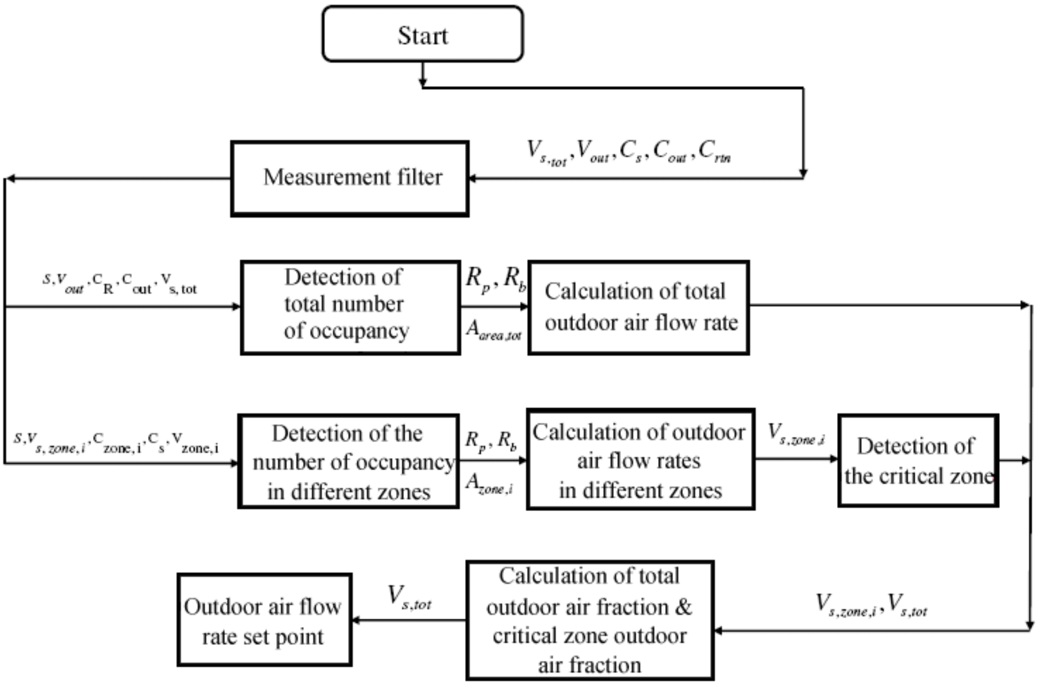


Fig. 6 Flow chart of multi-zone DCV [8]

SUMMARY AND CONCLUSIONS

A few relevant DCV control strategies have been reviewed in this paper. Each type of building has its own load patterns, and therefore also a corresponding building type-related preference for DCV control strategy. Although CO_2 concentration is a commonly chosen control objective and in many cases used as the main parameter, there are other factors according to building type-related preference for residential buildings, schools and office buildings that need to be assessed.

1. Residential buildings. The expected energy savings potential is not so high as for other building types due to the relatively fixed occupant behavior and small size of houses/apartments/dwellings. DCV can however still be a good solution for energy savings in dwellings as they are unoccupied in long periods every day. These characteristics also suggest a simplified control strategy, which is easy to operate and not too expensive to establish.

2. Schools. Compared with that in other building types, indoor contaminants in schools are to a great extent occupancy-related due to the large number of occupants and significant variations both during one day and between different days. To address an efficient DCV strategy for schools, that is able to maintain IAQ conditions at acceptable levels at all times, detecting the occupancy of the different rooms may be crucial. However, the fluctuations in the number of occupants make it difficult to predict the occupancy accurately, and a dynamic-occupancy-detecting control strategy can be a solution. This also enables possibility for direct flow control (not using duct static pressure or fan differential pressure as control objectives of the fans).

3. Office buildings. Similar to residential buildings, office buildings have relatively regular change in contaminant load over time; just they are occupied during the working hours. However the total occupancy has not so large change as in schools, the local IAQ should be paid attention to due to that not all the rooms in the office building are occupied simultaneously. Over-ventilation or under-ventilation is caused by the movement of people within the building and unsatisfied local IAQ is formed. Both lower energy use and better local IAQ should be the target for implementing DCV in office buildings.

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