Demand controlled ventilation (DCV) for better IAQ and Energy Efficiency

Mari-Liis Maripuu (Ph.D.)
CIT Energy Management AB, Sweden
mari-liis.maripuu@cit.chalmers.se

Introduction

In a Demand Controlled Ventilation (DCV) system the ventilation airflow rate is continuously matched with the actual demand. By this, the DCV system offers an obvious advantage compared to conventional Constant Air Volume flow (CAV) systems. Due to decreased average airflow rates, less energy is needed for fan operation and for heating and cooling of the supply air. Moreover, a DCV system based on room temperature control also eliminates the need of additional heating in rooms when the cooling capacity of the supply air exceeds the cooling capacity needed, e.g. when the room is unoccupied or when the solar heat load is low. **Figure 1** illustrates this situation. This advantage in terms of energy savings is often overlooked.

A DCV system based on air-quality control adapts the airflow rate to the actual pollution load, which often is proportional to the occupancy. For example, all the rooms in an office building or in a school are almost never occupied at the same time. Furthermore, it is most unlikely that the peak level of occupancy occurs simultaneously in all occupied rooms. For instance, quite a few studies show that in cellular offices usually less than about 50% of the office rooms are occupied at the same time. Studies in a number of school buildings reveal the average occupancy to be up to 30%. Details and information about these studies can be found in the references [1 and 2]. The bigger the variation between the minimum and peak loads, the more energy savings can be expected with a DCV system based on air-quality control.

Even if there are obvious functional advantages with a DCV system, the system itself is somewhat more complex than a CAV system. A competent design and a careful installation, commissioning and maintenance are required to ensure the expected performance. DCV systems have been in use for 30 years or more, but in quite limited numbers due to poor experiences. Most common

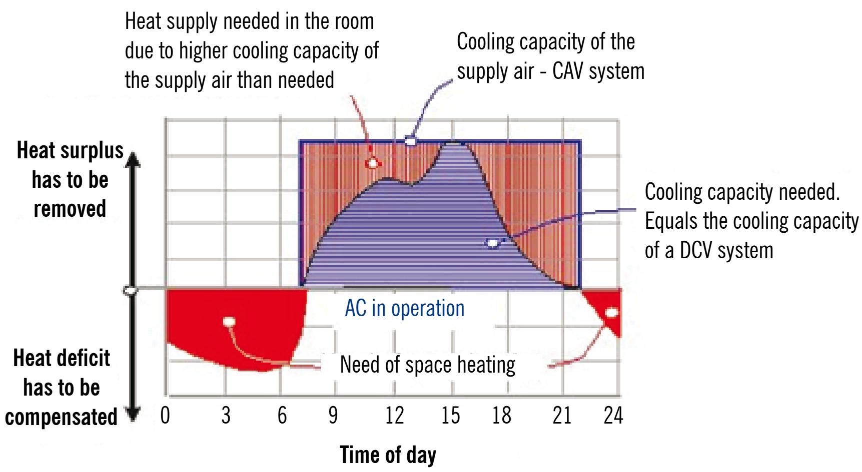

__Figure 1.__ Comparison of DCV system with CAV system in the application of thermal comfort control (air-based cooling). Typical variations of heat surplus and heat deficit in an office room. In a CAV system additional heat supply is needed in the room when internal heat generation falls below the cooling capacity of the supply air.

problems have been poor indoor climate and operational problems. The main reason has been lack of proper components and limited understanding of DCV system design. Improper selection and design of airflow control and supply air devices has been a common cause of excessive noise and draught in occupied spaces, but has also led to under- or over-cooling of the premises. Furthermore, quite a few problems with performance of the sensors controlling the airflow rates have been reported [1].

However, most of these problems were reported more than ten years ago. During the last ten years the development of the DCV system technology and its components has made it possible to establish cost efficient well performing DCV systems, hence making the application of DCV in commercial buildings quite common, at least in Sweden. Nevertheless, there are still certain challenges to face when applying this kind of technology optimally for indoor climate control.

Defining Demand Controlled Ventilation (DCV) systems

For the purpose of this article, it is firstly necessary to clarify the concept of DCV applied here. In the literature, there are often confusing concepts and definitions regarding demand controlled ventilation. Furthermore, DCV is very often referred to control of indoor air quality only. Here Demand Controlled Ventilation system is defined as a ventilation system with feed-back and/or feed-forward control of the airflow rate according to a measured demand indicator. The demand is determined by set of values and parameters affecting thermal comfort and/or air quality. A more detailed background can be found in [1].

The main indicator for thermal comfort is room temperature or sometimes a combination of temperature and humidity (specific enthalpy).

The main indicator for air quality is the composition of air in terms of gases, particles, etc. Carbon dioxide is the most common indicator for air quality related to human occupancy. The ventilation flow rate, as determined by requirements on air composition or air quality, is known as the hygienic ventilation flow rate. Control may rely on the measured state of air (feed-back control), the measured load (feed-forward or predictive control) or a combination of these two.

According to this concept, a DCV system requires a VAV system, and most VAV systems, but not all, operate as DCV systems. Only the VAV systems where the airflow rate varies continuously according to the actual demand are considered as DCV systems. Thus, VAV systems where the airflow rate varies according to a predetermined pattern or manual control are not considered as DCV systems.

Technical challenges of building up a DCV system

The fundamental requirement on a DCV system is to assure good indoor climate with reference to indoor air quality, thermal comfort and acoustic environment. In addition, this goal should be achieved cost-effectively and with a minimum of purchased energy.

The complexity of the technical solution of a DCV system and the system layout is to a great extent dependent on how the pressure unbalance in the system is absorbed. The airflow rate in individual rooms is adapted to the demand either by variable supply air diffusers in the room or by airflow control dampers in the duct in connection with the supply air devices. As the variation of airflow rates leads to variations of the static pressure in the system, pressure control methods should be applied to avoid an excessive increase in pressure at the airflow control devices when the average airflow rate is low. A common practice for static pressure control is to adjust the fan speed, while the static pressure in the system is kept on a level that can assure a proper operation of the flow control devices.

Depending on the location of the static pressure sensor and on the variation range of the airflow rates, the pressure rise that must be throttled off somewhere in the air distribution system can still become relatively high. It is essential that this pressure variation is managed in a way that good functioning properties of the airflow control devices are ensured. This means that the airflow rates supplied to the individual rooms must be insensitive to the pressure variations in the duct. In practice it is often necessary for the chosen airflow control components to manage a pressure drop of at least 100 Pa without a disturbing generation of noise. It is also vital that the supply air diffusers provide a stable air movement pattern in the room, which must be independent of the supply airflow rate. Neither at high air flow rates, nor low airflow rates, should there be any risk of draught in the occupied zone. The risk of draught may occur when traditional CAV supply air devices are used in a DCV system.

For energy efficient performance of a DCV system, the airflow control devices and supply air diffusers should be able to control the airflow rate within a wide range. In order to obtain an efficient airflow rate control in a temperature controlled DCV system, it is important that the supplied air has a low temperature; about +15°C to +16°C can be recommended. The supply air devices must be able to supply air with such comparably low air temperature without any risk of draught. This is one reason why supply air devices for displacement ventilation are unsuitable in temperature controlled DCV systems. A displacement type of supply air device usually needs about at least +19°C supply air temperature and that defines the supply air temperature for the whole system. Therewith the supply air will have a very limited cooling capacity and the DCV system will in practice operate as a CAV system. One displacement supply air device might jeopardize the DCV function of the whole system.

With low supply air temperatures it is also important that the duct system manages the varying airflow rates without considerable heat gains. When the airflow rates are decreased the heat gains in the duct system can have significant effect on the supply air temperature. Insulating all of the ducts in the system is a basic requirement to maintain the required cooling capacity of the supply air. Bigger effect for decreasing the heat gains can be achieved by increasing the insulation thickness on the main ducts instead of increasing the insulation thickness on the connection ducts [1].

It should also be noted that a DCV system puts a higher demand on the fan design and its performance. The fan is expected to operate in a stable manner over a wider airflow range compared with a CAV system. If this is not addressed, problems with noise may occur in addition to problems with controlling the airflow rates accurately, leading to poor energy performance of the fans in general.

Control of room air quality – a challenge for the sensing technology

An air quality controlled DCV system adapts the airflow rate continuously to the actual pollutant emissions from activities and processes in the room. However, control of indoor air quality with sensor methods can be somewhat more complicated than control of thermal comfort.

Firstly, it can be difficult to define the reference parameters influencing indoor air quality that the sensors must measure. There are no sensors that measure the "quality" of air. Instead, quantitative parameters, as the composition of air in terms of gases and particles, can be measured and linked to the air quality. However, in many cases the link between the perception of air quality, the concentration levels of various substances and their influence on comfort and health is still somewhat unclear.

Secondly, the available sensing technologies set the limits. The choice of an indicator or pollutant for control of air quality is to a great extent dependent of the possibilities to measure this parameter. The sensors applicable for indoor air quality control are based on measurement of gaseous compounds. It is relatively simple to measure just one substance, as carbon dioxide (CO_2), which is considered as a fairly good indicator of pollutants due to human occupancy. Greater challenges are faced when a combination of substances, e.g. volatile organic compounds are to be considered. There is a large amount of different organic compounds at different concentrations in indoor air. The real health and comfort impact of many of these individual components and their combinations at the usually low concentrations is still relatively unclear. The mixed-gas sensors available on the market measure non-selectively a wide range of gases and they do not indicate which gases are detected or what their concentration might be.

Thirdly, even if there are available technologies for measuring the required parameter, the sensor must fulfil certain requirements in order to be applicable for ventilation control. Sensors for indoor air quality control with a DCV system should give fast, stable and reliable output signals corresponding to the value of the specified quantity measured. Incorrect measurement of specified reference quantities can lead to under- or over-ventilated rooms, resulting in uncomfortable indoor climate or excessive use of energy. In addition, the correct location of sensors is vital to achieve the required performance from any control system.

Quantitative requirements for indoor air quality sensors have been developed based on ventilation guidelines and standards [1]. A detailed sensor study with a number of CO_2-sensors and mixed-gas sensors showed that there are several CO_2-sensors that fulfil the established requirements set on sensors. However, the application of the tested mixed-gas sensors for ventilation control is not decided upon. It is not clear how the output of mixed-gas sensors should be interpreted. Another limitation for the application of mixed-gas sensors is related to lack of available standards describing acceptable concentrations for many common air contaminants for non-industrial buildings.

Examples of case studies on DCV system performance

Demand controlled ventilation systems have been installed in several different types of commercial buildings in Sweden. However, only few studies on energy and indoor climate performance have been reported recently.

Two case studies were carried out about 5 years ago in two office buildings where one type of a modern DCV system solution was installed [1]. The first case study was a retrofit project, where the existing CAV ventilation system was replaced with a DCV system. The second case study building consists of two parts: one part was newly built and the other part fully renovated. Both of the case study buildings have similar DCV system layout. The DCV supply air devices in the rooms are controlling the airflow rates after temperature and occupancy sensors. The supply air temperature is about +15°C.

The case studies showed that it is possible to build-up a well-functioning DCV system that functions as expected from thermal comfort and energy points of view. Due to the low supply air temperature, the airflow rate control versus the heat load in the rooms is effective. The air-to-air heat recovery system accounts for all almost all the air heating needed and there is almost no need for additional heating with the heating coil in any of the case study buildings.

Figure 2 shows the duration diagram of the supply airflow rates and the corresponding electricity use of the supply air fan. The data were measured hourly during one year in one of the building parts of the second case study building. This building part consists of 58 cell office rooms and a number of meeting rooms. The total designed airflow rate for all rooms is 3.0 m^3/s. As shown in the figure, the DCV system never reached this airflow rate during the measurement period. The maximum measured supply airflow rate was approximately 76% of the maximum airflow rate of all rooms. Moreover, it operated with less than 45% of the design airflow rate during 80% of the operating hours, i.e. during about 3900 hours/year. These low values compared to the design values can be explained by a low use of the rooms. In **figure 2** comparison is made with a CAV system, with the values estimated as if the system would have operated with constant air volume flow rate.

Taking into account occupancy profiles and load variations in the building, there is a possibility to optimise the size of the central components and the duct system of a DCV system. Additionally, dimensioning based on the airflow rates needed in reality is important for achieving good control properties of the whole DCV system. Over-dimensioning of fans, when the main operating range will remain at a very low capacity, can lead to control problems and considerable decrease in total efficiency of the fan system. Improved knowledge of the occupancy patterns in different types of buildings would be of great help for a correct DCV system design.

How to assure that the expected performance of a DCV system is achieved?

In order to guarantee adequate performance of a DCV system and to achieve the expected energy savings, it must be designed, installed, commissioned and operated under a constant and

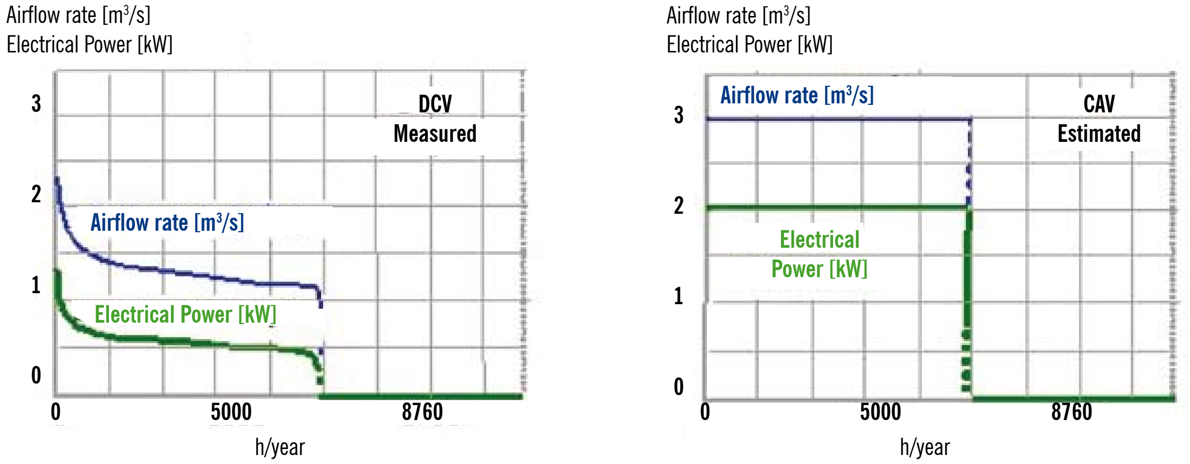

Figure 2. *Measured supply airflow rate and supply air fan electrical power in a 2500 m^2 office building with a DCV system. One year hourly measurements (left graph) compared with a corresponding theoretical (reference) CAV-system (right graph). The total designed airflow rate for the building is 3.0 m^3/s.*

complete commissioning process. The following key-points should be kept in mind in order to build up a well-functioning DCV system:

- Full understanding of the system principles and accurate system design. It is essential to correctly understand the concept and function of the whole system, from individual rooms to central air handling unit.
- Right choice of components. It is essential to clarify which requirements are to be set on the system and its components. A detailed analysis should be carried out about which demand decides the DCV function, which the proper indicators of this demand are, which sensing technologies are applicable, which suitable components for airflow rate control are to be chosen, how the pressure control is to be obtained, etc.
- Full understanding of the control system for DCV systems, right choice of control strategies and components. It is essential to evaluate which requirements to set on the control system and which input parameters to choose for the whole system. The locations of the sensing points are equally important.
- Correct installation and commissioning. It is important that the system is installed according to its design and that it is commissioned in a way that ensures that right operation of the system is achieved.
- Proper maintenance of the system. The personnel taking care of the system must be fully qualified to manage the complex control and fault detection.

Getting the best out of a DCV system implies that all of the above mentioned factors are taken into account. More detailed practical guidelines in these areas should be developed in order to assure the best performance of demand controlled ventilation.

References

[1] Maripuu, M-L., 2009. Demand Controlled Ventilation (DCV) Systems in Commercial Buildings. Functional Requirements on Systems and Components. (Chalmers University of Technology, Building Services Engineering), Gothenburg

[2] Johansson, D., 2010. Measured occupancy levels in twelve Swedish School class rooms. Clima 2010 Conference, Antalya

Swegon Air Academy has during 2010 been focusing a lot on Demand Controlled Ventilation (DCV) as a method to decrease the energy use in buildings with varying occupancy. Tech Dr Mari-Liis Maripuu from CIT Energy Management in Gothenburg has been invited as a lecturer at a number of Swegon Air Academy seminars on the subject in a number of countries in Europe. She has written this article, describing the DCV system's advantages and challenges.