Commissioning for energy-optimal Demand-Controlled Ventilation

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Demand-Controlled Ventilation (DCV) must become more reliable to close the gap between theoretical and real energy-performance. This paper addresses the following critical control points during commissioning of a DCV:

- energy-efficient and accurate DCV system
- balancing procedures
- handover procedures

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Introduction

When correctly implemented, Demand-Controlled Ventilation (DCV) can reduce the energy consumption of ventilation by more than 50 % (Maripuu, 2009). However, evaluation of real energy use demonstrates that the energy saving potential is seldom met (Mysen et al., 2010). DCV-based ventilation systems must become more reliable to close the gap between theoretical and real energy-performance. These unfortunate experiences with DCV have many causes, including: inadequate specifications and handover documentation, balancing report not suitable for DCV, communication errors and lack of knowledge about DCV systems among decision makers. Based on this experience from case-studies, an expert group has developed new requirements and handover documentation (Mysen and Schild, 2013). The work is carried out in the Norwegian R&D-project reDuCeVentilation (http://www.sintef. no/Projectweb/reDuCeVentilation/).

DCV systems are ventilation systems in which the airflow rate is controlled automatically according to a measured demand at room level. This means that DCV systems must have a feedback control, for instance a sensor in the room giving a continuous measurement of the indoor air quality. This signal is then used to control the airflow rate according to the desired indoor air quality level.

VAV stands for Variable Air Volume. It is a broader term than DCV, as it encompasses all systems with variable airflow rate, irrespective of the type of control. Only VAV systems that control the airflow rate according to a measured demand in the room, and not according to a preset value, are considered as DCV in this paper. Normal VAV dampers in DCV systems are denoted by DCV damper in this paper.

The commissioning, balancing, and control of a DCV system consist of the following work steps presented in **Figure 1**.
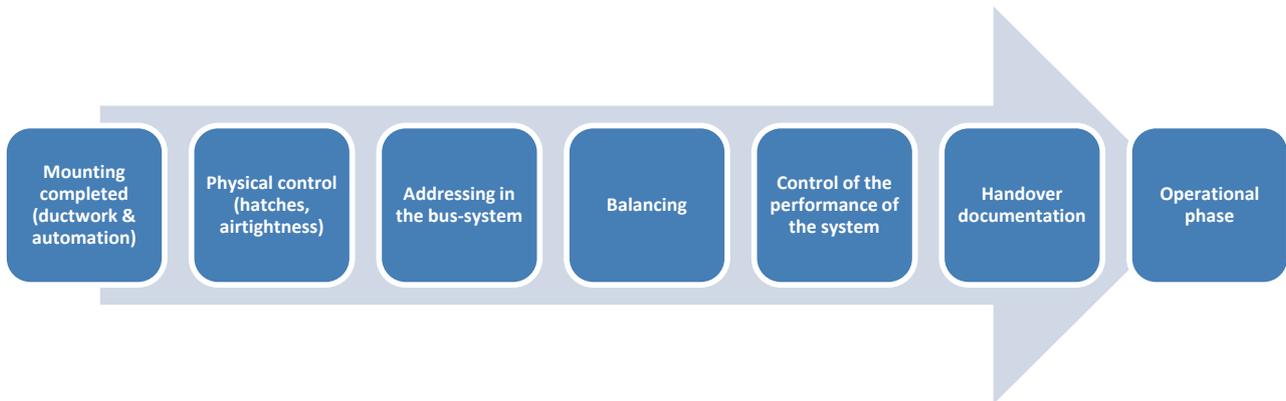
Figure 1. Recommended work steps subsequent to the mounting of the ventilation system.

This paper addresses the following critical control points during the commissioning of a DCV:

- energy-efficient and accurate DCV-system
- balancing procedures
- handover procedures

Energy-efficient and accurate DCV system

Specific Fan Power (SFP) is normally required and controlled at maximum airflow rate. However, a DCV system will typically have airflow rates between 30 and 80% of the maximum airflow rate, depending on diverse factors for dimensioning and on the minimal

ventilation rate. At maximum airflow rate, there are only small differences between the system's SFP depending on the control strategy (**Figure 2**, r = 1), but at lower airflow rates (**Figure 2**, r < 1), there are major differences depending on the control strategy. It is important to require a maximum SFP-value for two operating scenarios: maximum airflow rate and reduced airflow rate, in order to ensure an energy efficient control strategy.

The most important control points are presented in **Figure 2**.

Airflow rate accuracy should be controlled. A variation of the airflow rate in any room should correspond to approximately the same variation of the total airflow rate through the air-handling-unit (AHU). This test will reveal whether a pressure-controlled DCV system redistributes part of the airflow rate because of insufficient precision or wrong placement of the pressure sensor.

Critical components such as CO_2-sensors should be checked on-site. One control point for CO_2-sensors is to check whether they all give the same CO_2 concentration (ppm-results) when the building is empty during the evening/night.
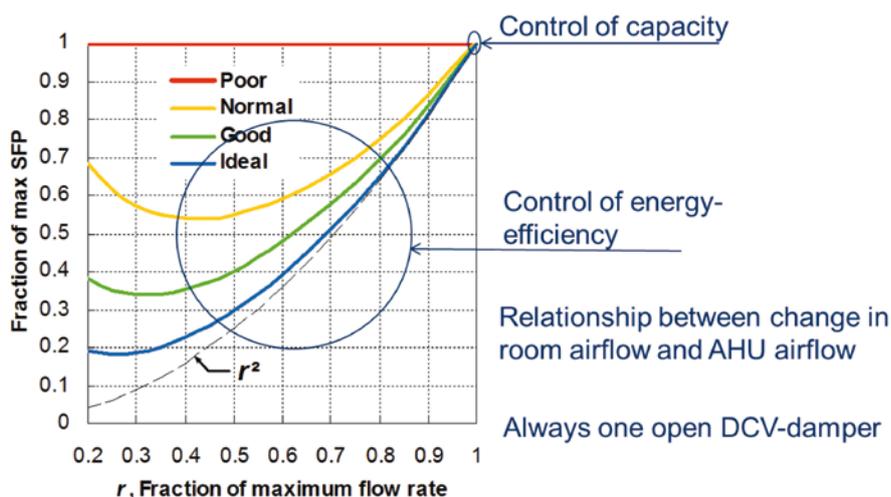

Figure 2. The most important control points. Measurement of SFP with partial load, control of the compliance between airflow rate at room level and total airflow rate, and control that there is always one DCV damper in max open position with the help of the Building Management System (Schild&Mysen, 2009).

Deviations during commissioning are normal and should be expected. Unfortunately, there is seldom time planned ahead to improve the system. A better solution is to, in advance, agree upon a model for economic compensation to take into account the deviations from the requirements which affect the energy consumption. Economic compensation caused by deviation between required and measured SFP-value, has been tested in Norway.

A DCV system is a dynamic system and should be tested and tuned-in for both summer and winter conditions. There should be an inspection, function test and review of the DCV- system after a period of normal operation, e.g. 1 year.

Balancing procedure for different DCV systems

There are several DCV systems and these principles are defined and described by Mysen (Mysen and Schild, 2011). Some of the DCV principles require special balancing procedures; this paper addresses "Pressure Controlled DCV" and "Damper optimised DCV".

Pressure controlled DCV

Pressure-Controlled DCV (PC-DCV) correspond to the traditional DCV systems (**Figure 3**). The purpose of static pressure-control is to indirectly control the airflow rates by controlling the pressure in a strategic duct position. PC-DCV requires installation of active DCV units controlling supply and exhaust airflow rates to each DCV room/zone. Controlling fan speed to maintain a constant static fan pressure rise, will result in unnecessary throttling along the critical path during most of the AHU's operating time, and therefore unnecessary fan energy use. The duct path with the greatest flow resistance from the AHU to any terminal is called the 'critical path', and is used to dimension the necessary fan pressure rise.

One unfortunate experience concerning PC-DCV systems, is that minor changes in room demand just redistribute the airflow rate in the duct system, while the airflow rate in the AHU remains more or less constant. The consequence is that no energy saving is achieved, or that the amount of supply air is insufficient. This is normally caused by inadequate precision or wrong placement of the pressure sensor, for example a placement to close to the AHU or next to a branch. A rule of thumb is to place it ¾ out in the main duct.
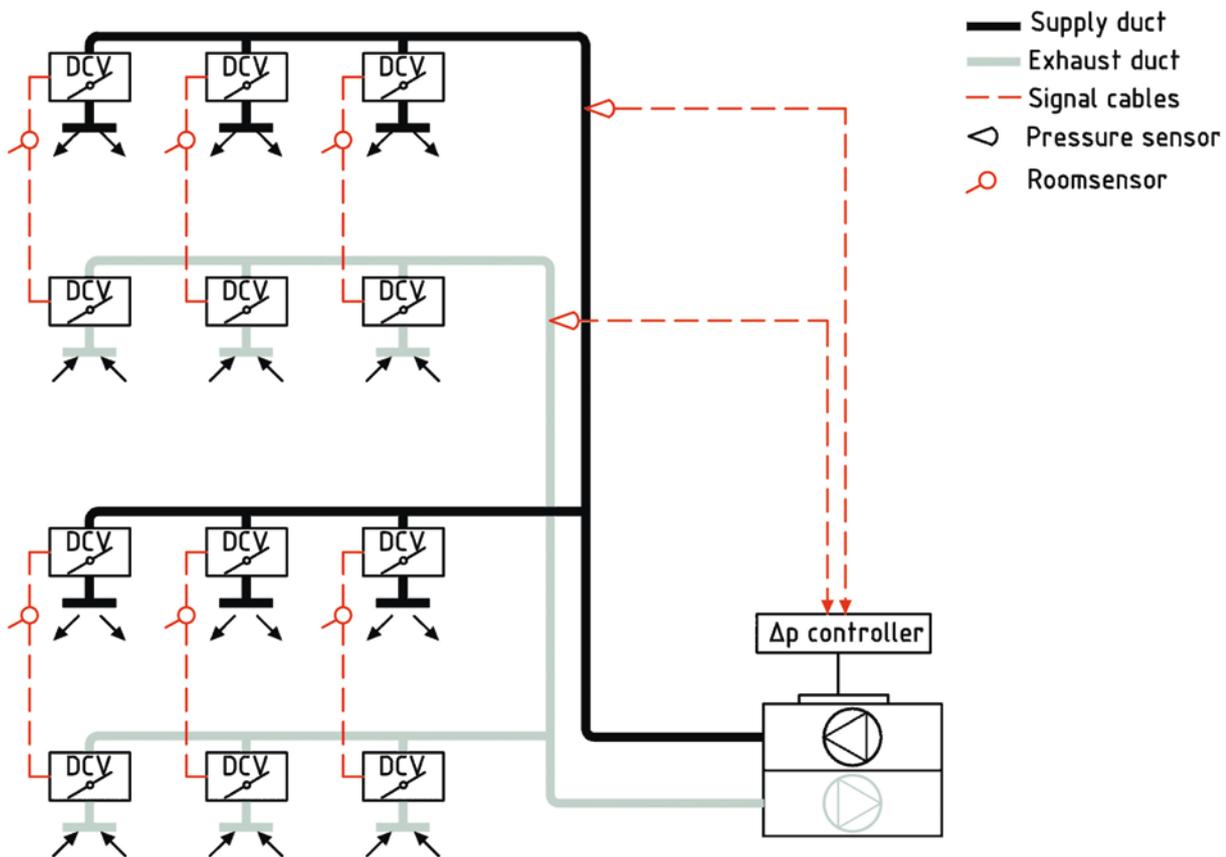

Figure 3. Pressure-controlled DCV system. The fan speed is controlled to keep the static pressure in the main ventilation duct constant, at the location of the pressure sensor.

The main purposes when balancing a PC-DCV system are:

- controlling the placement of the pressure sensor
- setting the right pressure set point

In addition, the balancing will reveal connection and communication errors.

Balancing of a PC-DCV system consists of the following steps:

- Control that all the DCV units have supply voltage and no polarity error
- Control that the pressure sensor is mounted on a location with stable static pressure or uniform velocity profile, by performing measurements over the duct cross section with a Pitot-tube or a hot-wire anemometer.
- Select a pressure set point which is slightly higher than necessary. This can be deduced from pressure drop calculations, or empirically.
- Program the actual maximum and minimum airflow rate values (V_{max} and V_{min}) on each DCV damper and set the dampers to automatic mode. Control that all the DCV dampers get the maximum airflow rate, and read the opening rate.

- Find the index damper, which is the damper with the highest opening rate.
- Adjust the pressure set point until the index DCV damper gets the maximum airflow rate without throttling (about 80 % opening rate). You have then found the energy optimal pressure set point, which is the lowest pressure set point which provides the right airflow rates according to the designed values.
- Complete the VAV control form. The completed control form should be included in the documentation of the ventilation system.

Damper-optimized DCV

Damper-optimised DCV consists in controlling the airflow rate in the main duct according to the position of the dampers, such that at least one of the dampers is in a maximum open position (**Figure 4**). The purpose is to ensure minimum fan energy consumption by looking for a minimum pressure rise over the fan. This is achieved if one duct path (critical path) is always open. With damper-optimised DCV, the required airflow rate, the supplied airflow rate as well as the damper angle are recorded for all the DCV dampers. This information is sent to a controller which regulates the fan speed.
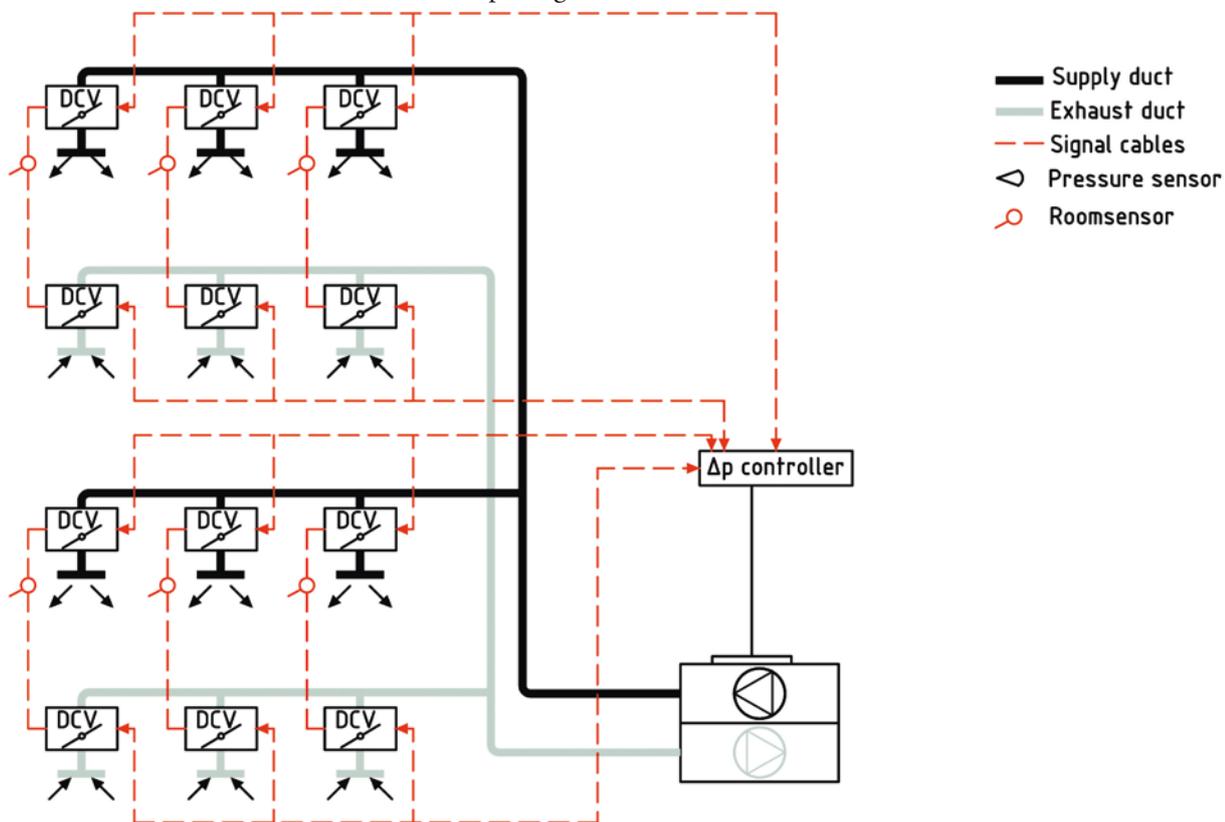

Figure 4. Damper-optimised DCV system.

Figure 5. Recommended VAV control form (http://www.sintef.no/Projectweb/reDuCeVentilation/)

Balancing of DCV units in damper-optimized systems is very simple, and consists in specifying minimum and maximum design airflow rate for each DCV unit. This can be done either through the bus-system or by connecting a programming device directly on the DCV units. Various programming devices are used by the different suppliers.

Balancing of a damper-optimised DCV system consists of the following steps:

- Control that all the DCV units, room sensors/ room regulators etc. have supply voltage and no polarity error.
- Program the actual maximum and minimum airflow rates values (V_{max} and V_{min}) on each DCV damper and set the dampers to automatic mode.
- If the DCV units do not give the expected response, check the polarity on the supply voltage.
- Complete the VAV control form. The completed control form should be included in the documentation of the ventilation system.

Hand-over documentation
VAV control form

Problems during operation occur most often for maximum or minimum airflow rates. Tests should therefore be carried out for these two operating situations. For each of these situations, it is necessary to consider each DCV unit and to override the control signal from the room sensor (*e.g.* temperature) in order to force the DCV unit to respectively max and min airflow rate, and to document both the airflow rate and the opening rate. The opening rate tells whether the DCV units work within a favorable range (40 to 80%) and whether the pressure set point is balanced.

This requires four control measurements per DCV unit. Such a control procedure is particularly relevant for DCV systems with pressure-control and limited control possibilities from the BMS.

A special VAV control form is designed for this purpose (**Figure 5**).

Procedures for load tests at maximum and minimum loads/airflow rates have been developed (Mysen and Schild, 2013).

Automated load test

Manual load test are time consuming, and it has proven to be very difficult to override DCV units during a load test. One should therefore strive to automate the load test completely by programming it in the control panel, or in the BMS. This has several advantages: it can be a complete test (not spot-checking) with all combinations of overriding, it reduces costs significantly, and can be repeated as often as needed (one time per year during normal operation, or after changes in the system). ■

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