Requirements for well functioning Demand Controlled Ventilation

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Introduction

IPCC (The Intergovernmental Panel on Climate Change) recommends a 50% reduction of manmade CO_2 emissions before 2050 to avoid severe problems of global warming. The IEA report "Energy Technology Perspective 2008" has presented the Blue Map scenario on how to achieve this emission reduction (IEA report, 2008).

A consequence for the building sector is that a widespread conversion of buildings to very low energy consumption and even zero energy buildings is necessary. The EU Parliament approved in 2010 a directive (EPBD Recast) that requires member states to implement ambitious plans to upgrade much of the existing building stock to nearly zero energy buildings (NZEB) by 2020, with intermediate goals to be set for 2015.

Ventilation constitutes a major share of the total energy use buildings of existing non-commercial buildings in the Nordic countries, typically 35-50% for office buildings (Wigenstad and Grini, 2010). Existing office buildings in Norway have an average energy use of 245 kWh/m^2 according to Enova (2010).

Most non-residential buildings have Constant Air Volume (CAV) ventilation leading to over-ventilation in periods with low or no occupancy. Comparison of perceived indoor climate in schools with CAV-systems and DCV-systems does not indicate that CAV-systems add extra quality to the indoor climate (Mysen Doctoral Theses 2005). The purpose of extra ventilation with CAV-systems is therefore questionable as it leads to additional energy use.

Demand controlled ventilation (DCV) considerably reduces the ventilation airflow rates and energy use compared to CAV systems. This conclusion is based on an inspection of 157 classrooms in primary schools (Mysen et al. 2005). Installation of variable air volume systems (VAV) can reduce the need for air heating by more than 90% and electrical energy for air distribution by 60% (Maripuu and Jagemar 2004, Maripuu 2009). DCV is probably a prerequisite to achieve the ambitious energy-goal for existing commercial buildings.

However, evaluation of real energy use demonstrates that this potential is seldom met. DCV-based ventilation systems must become more reliable to close the gap between theoretical and real energy-performance. This unfortunate experience with DCV seems to have many causes. Identified key factors for improvement so far are: to avoid wasted energy use because of unnecessary throttling, inadequate specifications, hand-over documentation and balancing report for DCV, and a clearly defined and placed responsibility for the overall functionality. This paper presents energy related differences between DCV-systems and recommends requirements for improved energy functionality.

Alternative DCV-systems

Figures 1 to 3 show the supply ductwork of in principle different DCV-systems: "Pressure Controlled DCV" (PC-DCV) and "Static Pressure Reset DCV", and "Variable Air Supply Diffusor". The exhaust system is similar in principle, or based on a master-slave concept related to the supply air flow.

Pressure controlled DCV

Traditional DCV systems (**Figure 1**) are based on static pressure control, PC-DCV. The purpose of static pressure control is to indirectly control the airflows by controlling the pressure in a strategic duct position. The solution can be improved by additional static pressure branch control. PC-DCV requires installation of active VAV-units controlling supply and exhaust air flows to each VAV-room/zone and static pressure tubes in the main duct. Ventilation systems covering vast areas or several floors will probably need additional VAV-units and static pressure tubes controlling the main branches. CAV terminals must be connected to specific CAV branches, or they must branch off close to the pressure sensor. If this is not possible, such rooms must have "individual VAV-units" with active control dampers to ensure constant air flow with variable duct pressure. Controlling fan speed to maintain a constant static fan pressure rise, will result in unnecessary throttling along the critical path during most of the AHUs operating time, and therefore unnecessary fan energy use. The worst case is only a proportional fan energy and flow rate reduction (Schild and Mysen, 2009), while the ideal case is energy reduction according to the cube fan law (ASHRAE, 1996). The latter case assumes no laminar flow elements in the AHU, and zero minimum pressure drops at control points. One unfortunate experience of pressure controlled DCV system is that minor changes in room demand just redistribute airflow in the duct system with the airflow in the AHU being more or less constant, and no energy saving is actually achieved. This is probably enhanced by factors like low sensor accuracy, poor ductwork air tightness and unfavorable location of the preassure sensor. This makes it questionable whether fresh air is supplied with sufficient accuracy and minimum possible energy use. Another challenge with pressure controlled DCV is where to locate the pressure sensor for optimal functionality.

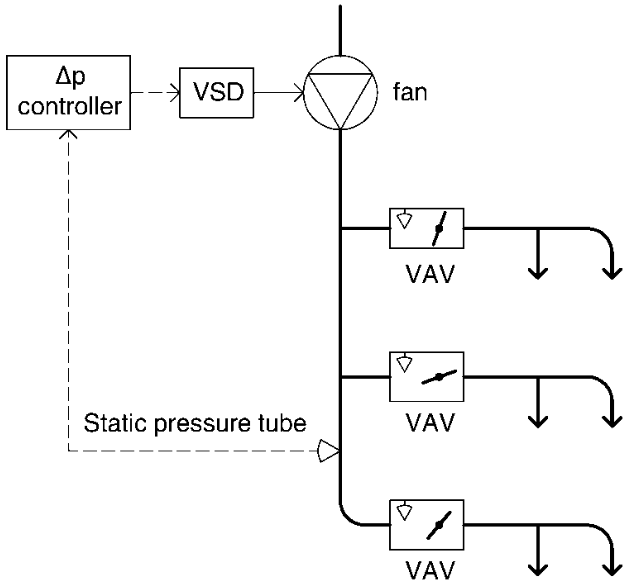

Figure 1. Principle of constant static pressure control. The critical path VAV damper is in max position only at times of maximum flow rate demand.

Static Pressure Reset DCV

Figure 2 shows an implementation of modern Static Pressure Reset DCV. Static Pressure Reset Control (SPR-DCV) is used to make pressure controlled systems more energy-efficient by emulating direct flow control functionality.

SPR constantly tries to satisfy all air flow requirements with a minimum of the fan speed drive by ensuring that the VAV damper(s) along the present critical path (**Figure 2**) are in a maximum open position, thus the SPR controller is frequently called an "optimizer". The duct path with the greatest flow resistance from the AHU to any terminal is called the '*critical path*'.

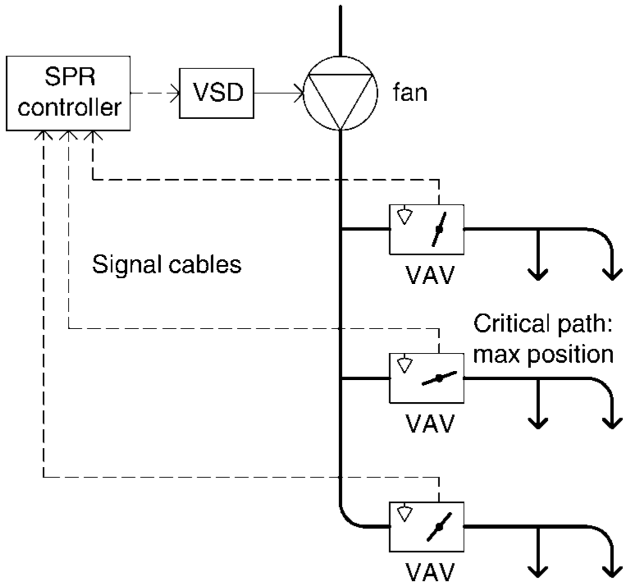

Figure 2. Illustration of SPR control. At least one VAV balancing damper is in max position (the critical path).

Dampers cannot be 100% opened due to need for control authority, i.e. to prevent excessive servo motor wear due to 'hunting'.

SPR-DCV requires additional controls (relative to Pressure controlled DCV) for continuously optimising the VAV-damper-position (either standalone controllers or BMS programming). A traditional SPR system will also have duct pressure sensors controlling the branch dampers, whereas modern systems need no pressure sensors.

Well-functioning SPR represents the ideal case in terms of energy use, and air flow rate accuracy. The catch is that SPR systems require more control components and hence are potentially more complicated and less robust. SPR-DCV has probably higher investment cost than pressure controlled DCV due to extra controls for continuously optimising the VAV-damper-positions.

Variable Supply Air diffuser DCV

Figure 3 shows the principle with Variable Supply Air Diffuser (VSAD-DCV). The air terminal units have a built-in VAV-unit and an occupancy and temperature sensor; hence there is no need for additional active control dampers in the duct system. Each VSAD covers the area beneath the air-terminal-device. Required air flow rate, actual air flow rates, temperature and corresponding opening percentage of the VAV-unit is communicated to the BMS regulating the fan speed drives in the AHU so that all the terminal devices are satisfactorily close to requirements and at any time, there is at least on fully open air terminal device. This solution requires variable supply air diffusers with good airflow control properties and with a low noise generation even at a high pressure drop over the device. Noise properties are especially important since potentially noise generating throttling appears so close to the occupied zone.

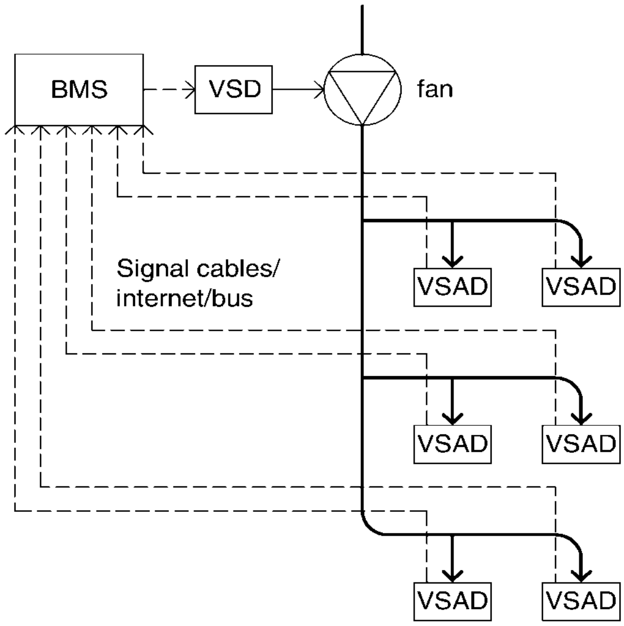

Figure 3. Principle of VSAD-DCV.

Requirements for well-functioning DCV

- 'Poor' represents systems with poor efficiency at part load. This includes mostly traditional methods that are now outmoded, such as inlet vane dampers, discharge dampers, variable-pitch fansand inefficient VSDs such as triacs. The efficiency of some of these systems varies greatly; some may be worse or better than the 'poor' curve. It also represents VAV systems for which the fan speed is controlled to maintain a constant fan pressure rise, irrespective of flow rate.
- 'Normal' represents systems for which the fan pressure drops marginally as flow rate is reduced. This includes VAV systems with the fan speed controlled to maintain a constant static pressure towards the end of the main duct.
- 'Good' represents systems for which the fan pressure decreases with flow rate. This includes best-practice VAV systems with fan speed regulated by a VFD with a typical Static Pressure Reset controller (SPR, also known as an 'optimizer'; see Figure 2). SPR constantly tries to minimize duct system resistance by ensuring that the VAV damper(s) along the present critical path are fully open. VFD controlled AC fans sized <3.7 kW cannot fall in this category, irrespective of pressure control scheme, because these small inverter VFDs have high losses.
- 'Ideal' represents real systems with efficient VSDs and where the fan pressure falls ideally at low flow rates. This includes VAV systems with perfect SPR control (i.e. 100% open control dampers along on the critical path), or reducing fan speed in CAV systems with fixed duct components (constant k-value). For example, night time operation of a CAV system with a flow rate of 20% (r = 0.2) will reduce the SFP to about 19% of $SFP_{max\ load}$. AC fans sized <15 kW cannot fall in this category, irrespective of pressure control scheme, due to higher losses in their VFDs.

An expert group from norwegian industry and R&D-partners, have suggested new requiremens for well-functioning and economical beneficial DCV based on indentified success criteria's (Mysen et al 2010). Here are some of the new requirements:

- Specific Fan Power (SFP) is normally required and controlled at maximum air flow. However a DCV system will have airflow between 30 and 80% of maximum air flow depending mainly on diversity factor for dimensioning and base ventilation level. At design level, there are only small differences between the system's SFP, but at lower airflow rates there are major differences depending on the control strategy (**Figure 4**). It is important to require maximum SFP-value for two operating scenarios, maximum airflow and reduced airflow, to ensure an energy efficient control strategy

- Fitting a DCV-system, typically involves several contracts including BMS (Building Management System), Ventilation system and Electrical Equipment. However, the overall responsibility for the system functionality must be clearly defined and placed in one contract.
- Adequate specifications, hand-over documentation and balancing report suitable for DCV-systems must be used.
- Components, such as sensors, that have proper functionality and acceptable measurement uncertainty throughout their predicted lift expectancy, for instance:
  - o CO_2-sensors +/-50 ppm
  - o Temperature sensors +/-0.5°C
- Some of the sensors should be controlled at site.
- Sensors must have an appropriate position (inner wall, not to close to doors or breathing zones)
- An airflow change in any room should give approximately the same change in the total airflow at the fan.
- Function of crucial components such as fan energy use, VAV-damper positions, air flow rates at room level etc. should be logged and controlled.
- Maximum diversity factors for dimensioning and assumed average use for energy calculations, together with specified running conditions during control procedure must be specified.
- Prospective economical penalty is agreed upon before performance test during final commissioning procedure
- There should be an inspection and review of the DCV- system after a period of normal operation, e.g. 1 year.

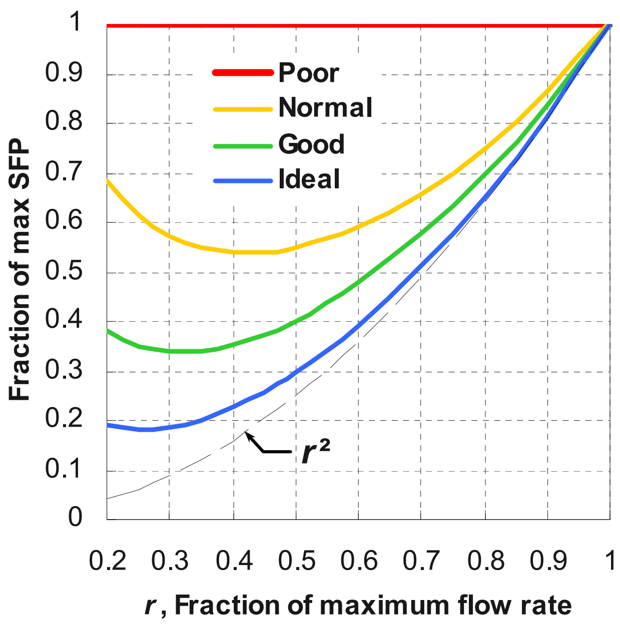

Figure 4. Illustration of covariation between airflow rate and SFP-value for Poor, Normal, Good, and Ideal DCV-systems (Schild and Mysen 2009).

Acknowledgements

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