Effects of different heat and cold generation scenario (Heat pump versus district heating and chiller) in a building with variable air volume versus demand controlled ventilation systems




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The objective is to verify the operation of an installed system in an OfficeRetail building located in Sweden. The focus is on comparing the energy saving achievable with different ventilation systems with focus on keeping or improving the indoor comfort condition. The systems taken into account are: a constant air volume, a variable air volume and a demand controlled ventilation system. The energy saving is analysed considering two different heat & cold generation scenarios (heat pump versus district heating and chiller) in order to make the evaluation in terms of purchased energy and economy. The findings show the importance of continuous monitoring, the advantages of the choice of an advanced ventilation system and the importance of the chosen generation systems considering energy and economical costs.

Keywords: Demand controlled ventilation, Energy production, Energy distribution.

Introduction

Considering demand controlled ventilation, constant air volume and variable air volume systems two types of generic HVAC system can be categorized:

- constant air volume (CAV) - ventilation with constant airflow. This type of ventilation system is characterized by one or two manual operations (e.g. ON/OFF), chronological management or control of supply/extract temperature;
- variable air volume (VAV), in this case the control is managed in a manual or continuous mode with prefixed models or time steps.

A building's HVAC system must ensure a good indoor air quality and both thermal and acoustic comfort based on (EN ISO 7730, 1994; EN 15251, 2007). A variable air volume system with automatic control based on the real need, automatically adapting the supply air temperature and supply airflow to keep the target conditions in a building is defined as demand controlled ventilation (DCV). In other words, a DCV system is designed with the aim of supply a quantity of fresh air fitted with the need in every situation, ensuring the right quantity of fresh airflow and right environmental conditions in terms of temperature and relative humidity and air exchange. The parameters controlling a DCV system are: temperature and relative humidity, carbon dioxide (CO_2) and/or volatile organic compounds (VOC).

Office-Retail building Engelsons in Falkenberg (Western Sweden) was built in 2009. It is used as an office, retail with a packing area and a warehouse, and is considered as a multifunctional building with the indoor climate conditions controlled by a ventilation system and heating/cooling based on air and water: air diffusers with constant airflow and climate beams with constant volume on the air side and variable on the water side. The building envelope is made of steel and concrete (**Table 1**), all insulated in order to reduce the thermal losses.

The **HVAC system** is a constant air volume system (CAV) with three independent air handling units which are equipped with high efficiency rotary heat recovery: TA/FA1 with 1,000 l/s (3,600 m³/h) serves a warehouse, TA/FA3 with 1 200 l/s (4,300 m³/h) for a rented office and TA/FA2 with 1,800 – 2,400 l/s (6,500 – 8,650 m³/h) is the only monitored air handling unit and it serves as an office, a retail and a packing area (**Figure 1**). The evaluation of indoor climate and energy monitoring in the Engelsons can be found at (Errico 2014).

All of the offices are heated and cooled by climate beams. In the common areas (e.g. corridors) air diffusers with constant airflow are installed. The retail area is heated by air diffusers with constant airflow and cooled by central air, and post-installed fan coils. The warehouse is heated only with air diffusers specially designed for large spaces. The packing area is air heated via air diffusers and cooled with an active beam above the work desk, a split system to compensate the heat peaks during summer, and during winter time additional fan coils are turned on to satisfy the thermal balance and reach the indoor set temperature.

Lowering supply of fresh air inside the building (as a sum of airflow based on design occupancy rate and designated airflow per square meter) so called night mode allows energy saving by recirculation of the most part of indoor air (already at 20°C) with minimum fresh air supply of 0,35 l/s/m² (1,26 m³/h) based on (Boverket, 2011). The temperature difference between the recirculation air and the water in the coils is lowered. This means that the power supplied to the air is lower as well as the energy needed for heating the airflow from 14°C (possible temperature after the recovery) to 20°C. This will also allow the decreasing of the temperature by 2K, i.e. the extract air has to reach 18°C before the heating system increases the thermal power of water flow.

Energy production for heating and cooling is supplied by a ground coupled double effect heat pump of 55 kW with a COP = 4,85 and a EER = 3,85 that during winter time takes heat from the ground, whereas during

Table 1. Overview of main buildings´ characteristics as used for design of HVAC system.

Building	Value	Characteristics	U-value [W/(m.K)]	Surface [m²]
Floor surface	2,203 m²	Walls	0.315	1,483
Number of storeys	2	Floor	0.146	2,203
Height of each storey	3.8 m	Ceiling	0.193	2,203
Floor surface	2,203 m²	Windows	1.2	106

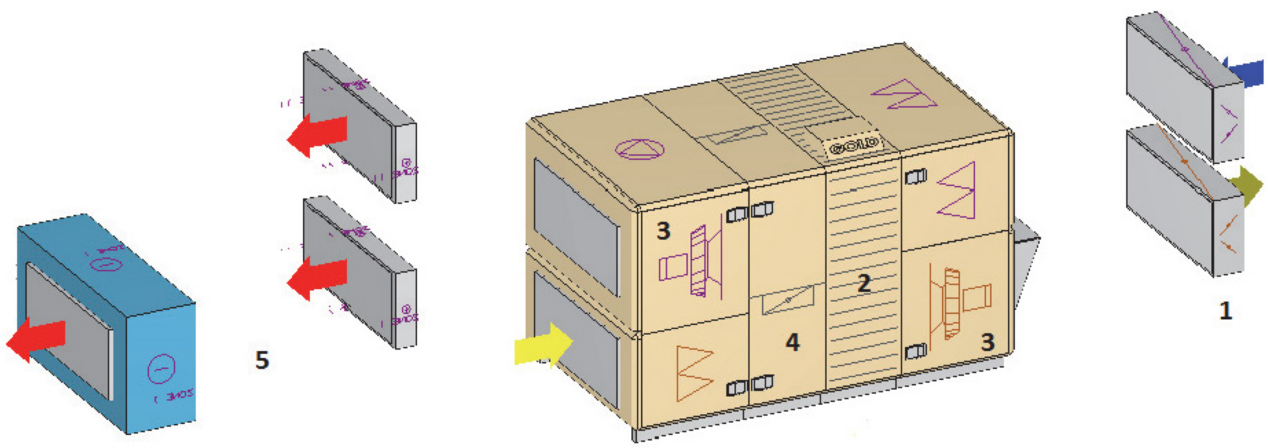

Figure 1. TA/FA2 dampers (1), recovery (2), fans (3), bypass section (4) and coils (5).

the summer it rejects the heat absorbed by the building back to the ground in order to avoid the thermal unbalance of it. As an auxiliary system is used an electric boiler of 42 kW and a classic split system cools the package area during the summer season.

Methods

The simulation scenarios for various ventilation systems (**Table 2**) are used to evaluate the actual state of the building in a verified simulated model (CAV), and potential improvements if installing more controlled systems such as VAV, DCV and DCV Class 1 with indoor climate set points according European standard (EN 15251 2007). The VAV system is modelled with reducing SFP and allowing a temperature gap of ± 2°C (cooling or heating mode) during the unoccupied period at nights. As for the DCV model, VAV model setup was applied and also a variation was allowed for the airflow from the minimum legal of 0,35 l/(s·m²) to a maximum of the design value for each zone. In addition, the schedule of the people presence was used considering a daily occupancy profile based on (Johansson 2005), occupancy rate of 50%. The energy modelling was done in a dynamical simulation tool IDA ICE (EQUA 2014).

It is particularly important to split the energy saving between ventilation (fans), heating and cooling energy, since fans are always powered by electric source, in comparison with the thermal capacity that can be produced in several ways. In the analysed system both fans and thermal are powered by electric sources respectively directly and by heat pump (HP). Now, if the thermal capacity was produced differently, e.g. district heating and chiller (DH–CH), the percentage of energy reduction for the aim, ventilation, heating or cooling was constant, but the differences in the production will affect the economical evaluation because of the different efficiency of the production and price for the different sources.

Energy production scenarios, economic evaluation and energy prices are used in evaluation of two scenarios:

- Installed HP: ground coupled double effect heat pump with COP = 4,85 and EER = 3,85. In that case the only energy entering in the building is the electric source.
- Scenario DH–CH: heating source is district heating (DH) and 28 kW air-water chiller (CH) with a EER = 3,25 measured for an outdoor temperature of 35°C.

The electric energy price (epp.eurostat.ec.europa.eu 2014) and for the district heating price (Falkenberg-energi 2014) are reported in **Table 3** with the exchange ratio €/SEK = 8,874 (Google 2014).

Results

Evaluation of energy consumption in different ventilation systems show a progressive decrease of the energy used for the entire conditioning system due to the improvement of the ventilation system only. Looking at energy results the energy can be split based on the components usage such as energy for ventilation (and air circulation), heating and cooling, everything in electric

Table 2. Simulation scenarios.

Name	Description
Scenario 1: CAV	Actual state of the building
Scenario 2: VAV	CAV system with night mode switched on
Scenario 3: DCV	Demand controlled ventilation system with 50% occupancy rate and the night mode switched on
Scenario 4: DCV Class 1	DCV with zones' set point for reach the Class 1 building

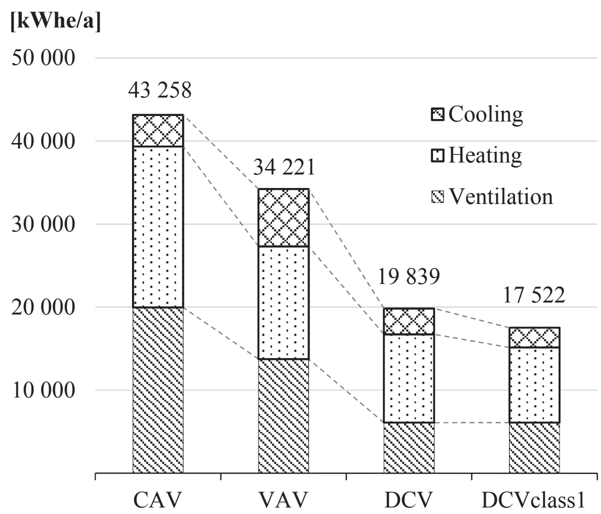

Figure 2. Overall annual simulated energy consumption for different systems´ scenarios.

Table 3. Energy price for electricity and district heating.

Electricity		District heating					
		Price category	Annual consumption	Fix costs		Variable costs	
[€/kWh$_e$]	[SEK/kWh$_e$]		[MWh$_t$/a]	[€/a]	[SEK/a]	[€/kWh$_t$]	[SEK/kWh$_t$]
0.135	1.2	(1)	80	2,569	22,794	0.08	0.70
		(2)	193	5,586	49,570	0.08	0.70

kWh per year. In total an overall energy reduction of 54% can be seen in the comparison DCV–CAV and of 42% in DCV–VAV. The largest energy reduction can be seen for ventilation, with a reduction of 56% (from VAV to DCV) and the impressive reduction of 70% (from CAV to DCV). When adjusting the indoor temperature in order to achieve the Class 1, an additional reduction of 12% can be seen from DCV to DCV Class 1 showing the importance of the correct regulation to achieve energy saving. The split of the overall consumption in heating, cooling and ventilation (energy for the air circulation) is fundamental for the economic analysis and the evaluation of the payback period in the installation of a ventilation system instead of another.

Comparison between installed HP and scenario (DH–CH) in operating cost shows the additional investment cost of a DCV system compared to a CAV system is approximately 12% and only 8% more compared to a VAV system (Errico 2014). HVAC operating costs play large factor in operating of a building, and it is based on expected modelled energy consumption for various ventilation systems based on partial costs (ventilation, heating and cooling), efficiency of production methods (COP for heat pump and EER for heat pump with EER for air-water chiller) and respective energy prices (for district heating and electricity). For the heating and cooling costs (**Figure 3**) large differences can be seen especially for the heating expenses. Moreover, if in both the scenarios the cooling operating costs rise and drops by exactly the same percentage (+81%, –55%, 23,6%) following the upgrade from CAV to DCV Class 1, the percentage of reduction in the heating expenses are not coupled because of the construction of the price of the thermal energy supplied by the district heating.

In **Figure 3** it is interesting to see how much the internal set points in the same installation affect the heating operating cost (DCV → DCV Class 1). Usually, to keep a higher comfort level inside a building, it is necessary

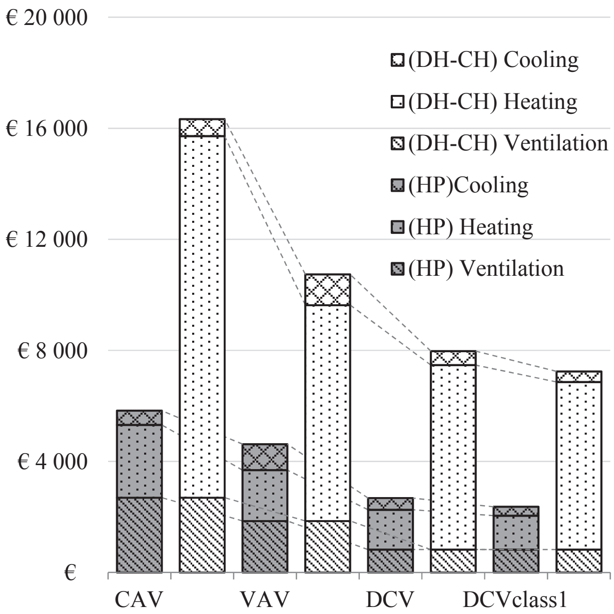

Figure 3. Comparison between the production scenarios (HP; DH–CH) in the different system scenarios CAV, VAV, DCV and DCV Class 1.

to use more energy and therefore create higher costs. Here we can see an energy reduction with decrease of operating costs. Because of that in the process of optimization from CAV to DCV Class 1 there is an additional final overall operating cost reduction from DCV to DCV Class 1 of 12% in installed HP case and of 9% in scenario (DH–CH). This additional reduction in the operating cost, achieved only by setting the correct internal temperature set points, highlights the clear importance that the right indoor temperature set points have on operating cost in systems.

Comparison between real installed HP and scenario (DH–CH) in regards of payback period (**Figure 4**) it can be seen that with a scenario (DH–CH) instead of the installed HP there is evidence in the reduction of the payback period. Reduction that amounts approxi-

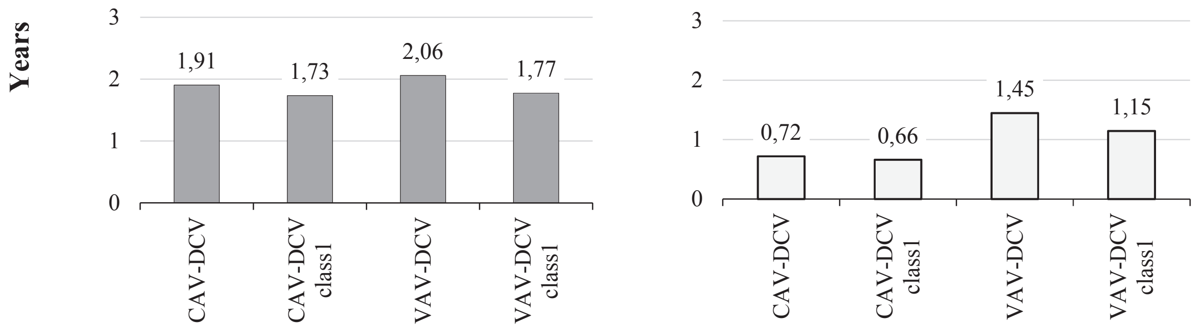

Figure 4. Payback period: installed HP and theoretical scenario (DH–CH).

mately to 60% in the system improvement scenarios from CAV to DCV and from CAV to DCV Class 1 and approximately to 30% in both VAV to DCV and VAV to DCV Class 1. In all the analyses it appears that the profitability of a DCV system is higher in the scenario (DH–CH) compared to the installed HP case. This consideration leads to think that the DCV system is more suitable if the production system is not at the top of the efficiency class. In both considered production scenarios (HP and DH–CH), the economical convenience is more remarkable in case of a system improvement scenario CAV–DCV instead of a system improvement scenario VAV–DCV.

Discussion and conclusions

The comparison of the CAV, VAV and DCV systems shows an energy reduction of over 50%, in the best case (from CAV to DCV) and will reach and keep the indoor temperature set points. It is important to state that this reduction is achieved simulating a conservative occupancy rate equalling to 50% (note that occupancy rate is around 28–30% in a typical office and around 25% occupancy inside a typical retail building). That means that the energy saving achievable with a DCV system could be even larger than the modelled one in this work. The energy to reach the indoor temperature set points cannot be separated from an economic assessment that has to evaluate the expense for the purchased energy.

The first production system is represented by the real installed ground coupled heat pump (HP), the second, based on a Swedish situation, is composed by district heating and chiller (DH–CH). With the HP the electric energy purchased is converted in thermal for heating passing through the COP and in the cooling energy trough the EER of the heat pump (constant EERs). In the DH–CH case the heating energy was considered to be used directly as purchased from the district heating distribution net, the cooling energy was considered supplied from the chiller passing through its EER, also here considered as constant. It is easy to understand that the HP system is more efficient than the DH–CH. Even though based on the presented results it can be stated that the payback period is shorter if the installed production system is inefficient, yet in both production scenarios the payback periods are rather short, in most of the system improvement scenarios less than two years. Because of that, considering that the additional investment is a small value compared to the overall cost, about 10%, and the short payback period, it can be stated that the choice of a DCV system instead of a CAV or VAV ventilation system is always economically profitable to ensure the good climate in buildings, not only in new buildings but also in retrofits. ■

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