Demand Controlled Ventilation.
A Detailed Study of Energy Usage by Simulation

B.R. Sørensen

Narvik University College, Building Science,
NO-8514 Narvik, Norway, e-mail: brs@hin.no

ABSTRACT

Detailed mathematical models of VAV equipment and subsystems have been developed and used to compose larger DCV systems with a large degree of detail. The models and systems take into account both flow/pressure distribution and thermal/contaminant dynamics. The models have been validated against measurements. A number of detailed simulation cases have been conducted. The results show that energy usage depends strongly depends on occupancy, flow rates, chosen set points as well as the outdoor temperature. This study shows that savings between 30 and 45% of energy usage for equivalent CAV systems can be expected, and that even better results may be obtained if further optimising the control strategy.

KEYWORDS

Demand controlled ventilation, VAV systems, energy consumption

INTRODUCTION

VAV systems were introduced to bring down energy usage for ventilation and cooling of buildings. While research on VAV systems in the early seventies primarily focused on the energy issue, more recent research also emphasizes on indoor air quality (IAQ). VAV systems are traditionally associated with temperature control and cooling loads. In areas where cooling is of less concern, the air flow needed for cooling and temperature control are in many cases too low to maintain proper air quality. The control decision parameter can also change from time to time. According to Kukla (1997), VAV fans run at about 60% of full load on average, during occupancy of a building. Some consequences of this are:

- Less energy is used for fan operation, heating, cooling and humidification.
- Less energy is used for heating of the rooms.
- Equipment can be sized smaller than a comparable CAV system. A diversity factor of 70-80% can be used in many cases.

The design air flow rate of a ventilation system can be separated into two different parts:

- Minimum air flow rate (load independent).
- Load dependent flow rate.

In general, the lower the minimum air flow rate is, the greater energy savings can be expected. If the minimum air flow rate is larger than the load dependent flow rate, a CAV system should be considered in favour of a VAV system, because the energy savings potential will be low. Some recommendations for the set point of CO_2 in DCV (demand controlled ventilation) systems for different room types are given in table 1. Numbers are based on the requirements given by Norwegian building regulations.

Other important factors related to energy savings are the control strategy and the type of fan control. To be able to deliver a required amount of air through all terminal boxes at any time, the fan must maintain a certain static pressure level in the duct. Proper static pressure control or fan differential pressure control prevent over-pressurizing ducts and pressure swings in the rooms (the key to energy savings). Energy savings are in this paper provided as percentage ratios, obtained by comparing simulation results from DCV systems to similar CAV systems operating under identical conditions. The computed total energy usage also includes local heaters and lights within the rooms of the building.

TABLE 1:
Recommended DCV CO_2 set points (based on an outdoor CO_2 concentration of 400 ppm), Sørensen (2003).

Type of building	m^2 / occupant	Recommended CO_2 set point:	Is VAV appropriate?
Offices	15	500 ppm	No
Schools, kindergartens, shops	2	800 ppm	Yes
Service buildings	1.4	850 ppm	Yes
Assembly halls	0.6	950 ppm	Yes

LITERATURE SURVEY

To establish the level of savings that can be expected, a literature survey on DCV was performed. From this it was found that:

- The magnitude of the savings can be expected in the range of 10-60%, dependent on building location, load pattern, system configuration, etc.
- CO_2 is an well suited indicator of the occupant load within a space. If the dominant contaminant sources are related to occupancy, the CO_2 concentration can successfully be used to determine the ventilation requirements of a DCV system.
- DCV by RH may be used in residential buildings to prevent condensation and mould growth. As a stand-alone variable of IAQ control, RH is not well suited. It gives a poor correlation with the occupant load, and measurements may contain a significant time lag. The variations of the outdoor RH level may have a magnitude of many persons.
- CO can be used together with CO_2 to detect smoking and other combustion related contaminants in the air. Other more common applications of CO control is found for instance in mechanical repair shops, car garages etc.
- VOC sensors are sensitive to odors and combustion products. However, for occupant load indication, CO_2 provide a better result. Hence, combined CO_2 and VOC has a potential for DCV, taking into account contaminants and odors generated by occupants, smoking and building related sources.
- Mixed gas sensors used together with a pattern recognition technique show promising results by means of IAQ control

MODELLING VAV SYSTEMS

A major part of this study has been to develop new and accommodate existing mathematical models for VAV components and equipment. A large number of models have been reviewed, and model libraries for VAV equipment and controls have been established. Four different model libraries were created; (1) pressure/flow models (static models to calculate flow distributions from flow resistance), (2) thermal models (dynamic models for heat transfer and heat accumuation), (3) contaminant models (dynamic models for contaminant transport and accumulation) and (4) controls models (various controllers, thermostats, sensors, etc). An example of a model library is shown in figure 1 (the thermal library).

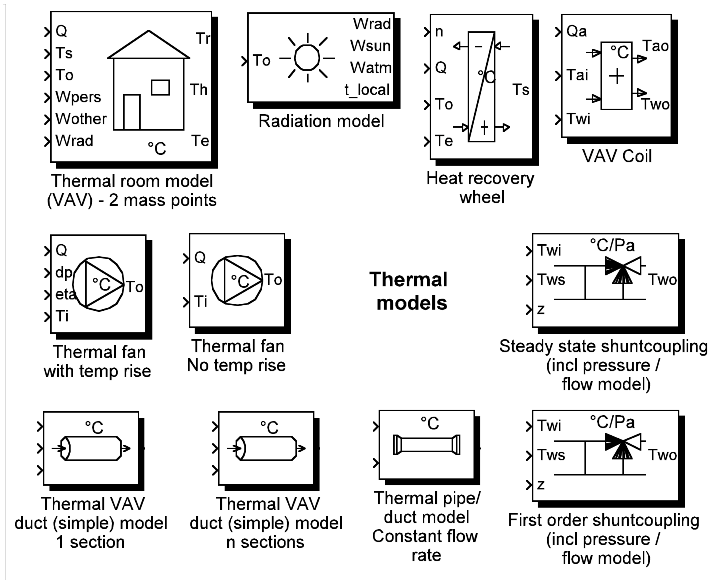

Figure 1: The thermal component model library

Model validation

The major component models were validated against measurements. The models produced consistent results when compared to measurements. Refer to Sørensen (2002) for further details.

Simulations systems and loads

The majority of the conducted case studies were based on the following two dynamic simulation systems:

- single zone system (conference room, cinema, auditorium etc.)
- multi zone system consisting of four zones or rooms (offices, meeting rooms, computer labs etc.)

In many buildings, large rooms such as assembly halls, auditoria, conference rooms, cinemas, gymnastic halls etc. have their own individual ventilation system. The single zone simulation system shown in figure 2 may represent any of these types of rooms. The system was mainly built of three subsystems, as shown in figure 2; (1) pressure/flow subsystem, (2) CO_2 subsystem, (3) thermal subsystem.

Likewise, a multizone system was established. The multi zone ventilation system served four identical classrooms in a school. Both systems were designed for a maximum of 800 ppm which approximately gives the same flow rate as mandated by the Norwegian Building Regulations. Minimum flow rates were determined from 2 liters/s per square meter floor area. The occupant load of the zones/rooms is given in table 2. Both systems had a AHU consisting of a backward inclined fan, a rotary heat recovery unit (HRU) controlled in sequence with water-to-air heating and cooling coils.

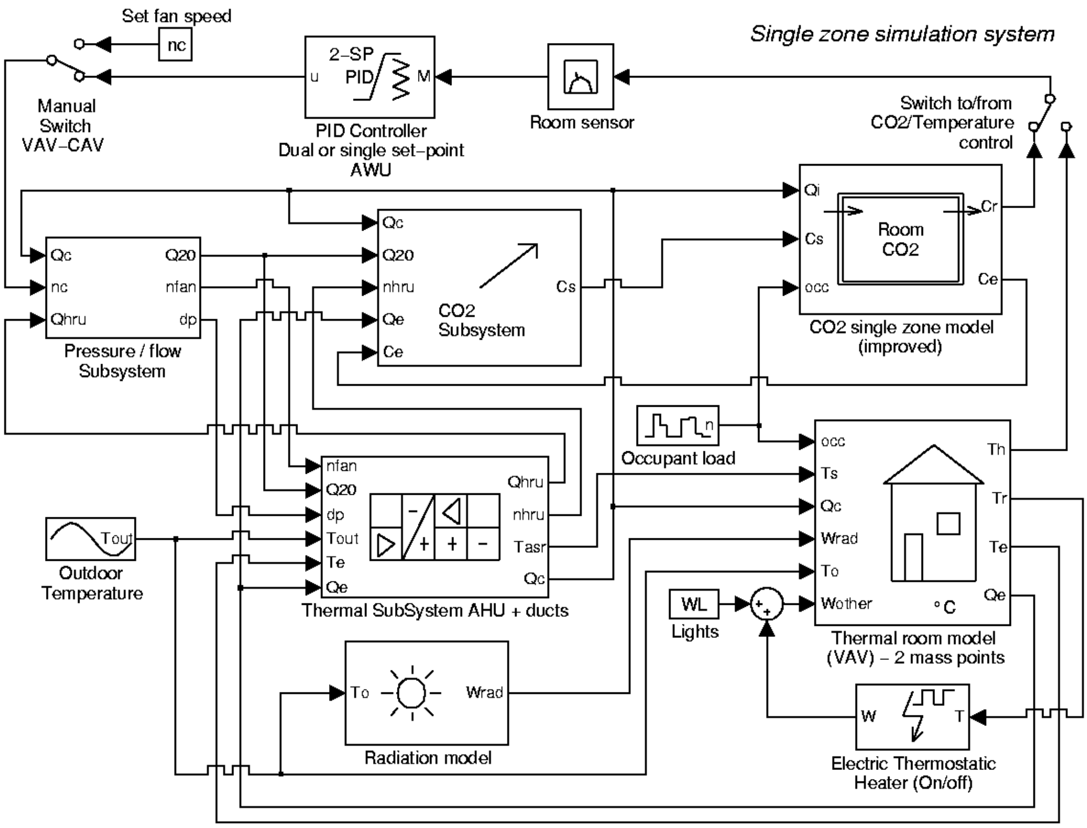

Figure 2: The single zone simulation system

TABLE 2:
Occupant loads for the single zone cases (left) and multi zone cases (right)

	Number of occupants Single zone systems			Number of occupants Multi zone systems (44%)			
Hour	High (61%)	Medium (50%)	Low (22%)	Room 1	Room 2	Room 3	Room 4
07^{00}	Ventilation on, no occupants						
08^{00}	55	35	5	25	0	25	15
10^{00}	10	10	10	0	0	0	0
10^{30}	65	65	25	25	25	30	30
12^{00}	5	0	0	0	0	0	5
13^{00}	60	40	30	15	25	25	25
15^{00}	20	0	0	8	3	5	25
15^{30}	60	50	20	8	3	5	25
17^{00}	0	0	0	0	0	0	0
18^{00}	Ventilation off, no occupants						

CASE STUDIES

The various case studies are described in detail in Sørensen (2002). These were as follows:

- Single zone - CO_2 DCV
- Single zone - temperature DCV
- Single zone - air quality control - the decipol controller
    - the CO_2 room level is used to estimate the number of occupants. This number, together with a predefined olf-emission from building materials, is used to calculate the decipol level in the room.

- Multi zone - CO_2 DCV (static pressure control and local damper throttling)
- Multi zone - simultaneous CO_2 and temperature DCV.
- Multi zone - CO_2 DCV - improved control of fan static pressure
    - To make control more optimized energy-wise, while retaining pressure control still, the static pressure set point is altered automatically.

RESULTS AND DISCUSSION

In figure 3 the percentage energy consumption for various seasons in Narvik and Oslo (Norway) at different occupancies are shown. It also shows that occupants are a significant heat source. In periods with heat demand, the energy gained from occupants is favourable since it is 'free energy'. This suggests that increasing number of occupants also increase energy savings. For a building with CAV ventilation since energy needed for air conditioning is almost independent of the occupancy and since local heaters are regulated. For a building with a CO_2 controlled VAV system this is not true. The energy required for air conditioning is not constant. Low occupancy ratios conduce low energy usage for air conditioning, but also a smaller amount of free energy to the room. During cold periods and low occupancy, the local room heaters have to work harder to meet the set point and thus consume more energy. On the contrary, high occupant numbers lead to high energy usage for air conditioning and a larger amount of free energy. Conclusively, the *actual* difference between savings at low and high occupant ratios is smaller than to expect (since it is partly cancelled out by free energy from occupants).

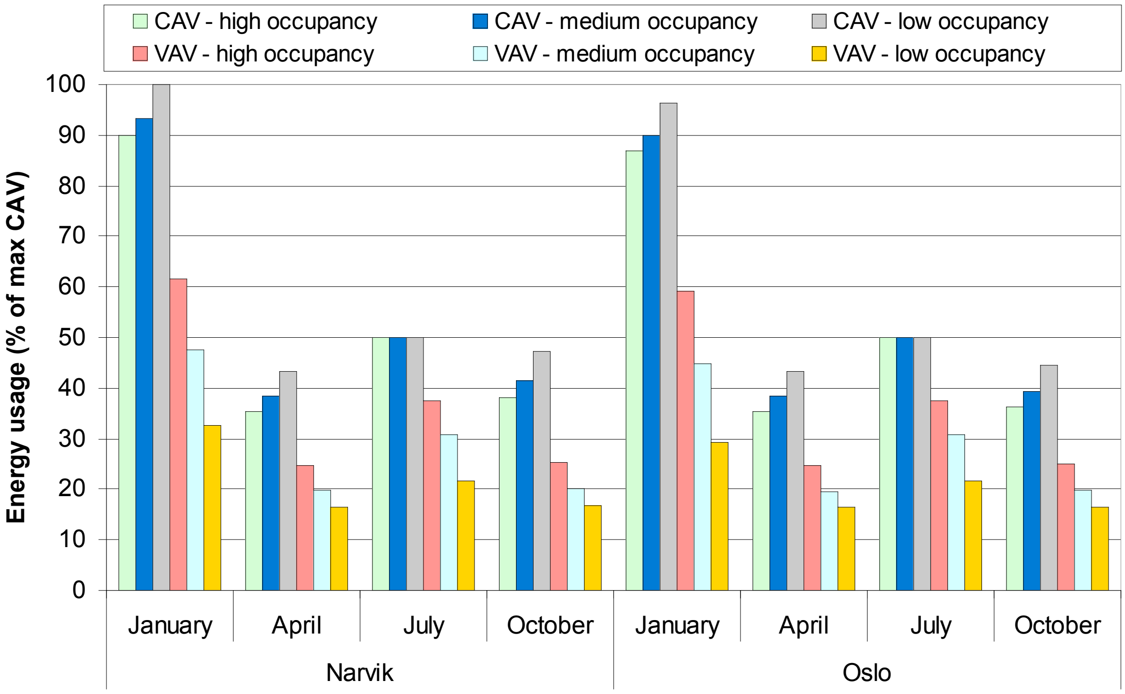

Figure 3: Percentage energy consumption for various seasons in Narvik and Oslo at different occupancies, relative to the case which used most energy (CAV, january, Narvik, low occupancy). The building had a single zone CO_2 DCV system.

Figure 4 shows the energy savings (percentage of CAV) for the conducted case studies. Savings between 30 and 45% of energy usage for equivalent CAV systems can be expected, and even better results may be obtained if further optimising the control strategy.

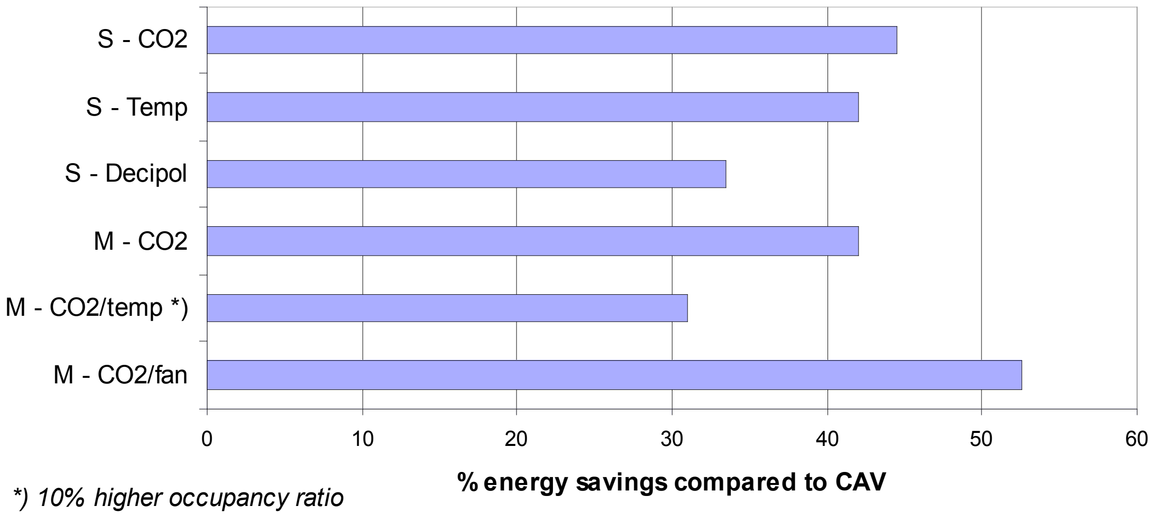

Figure 4: Energy savings (percentage of CAV) for the conducted case studies. Numbers are based on a occupancy ratio of approximately 50% during the day.

CONCLUSIONS

A VAV-DCV system has a considerable potential for energy reduction compared to a similar CAV system. This study shows that savings between 30 and 45% of energy usage for equivalent CAV systems can be expected, and that even better results may be obtained if further optimising the control strategy.

In general the following factors have shown to be the most significant:

- Occupancy ratio
- Control strategy
- Time period and locality (outdoor temperatures, window orientation)
- The coherent behaviour of different energy systems in the building.
- The objects and conditions which savings are compared to (AHU only or the complete building).

During the same outdoor temperatures, the geographical location of a building did not show to be equally significant.

REFERENCES

Kukla M. D. (1997). Situations to Consider when Variable Air Volume is an Option, *ASHRAE Transactions*, Vol. 103, Part 2.

Sørensen, B. R., Jensen B. (2003). Derivation of CO_2 control set points from air quality requirements. *Proceedings of the 4th International Conference on Cold Climate, Heating, Ventilation and Air-Conditioning "Cold Climate HVAC 2003", Trondheim – Norway*

Sørensen, B. R. (2002). Applications and energy consumption of demand controlled ventilation systems. *Ph.D Thesis. Doktor ingeniøravhandling 2002:34, NTNU Norway.*