Variable ventilation airflow rate in dwellings – costs and benefits

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SUMMARY

Ventilation systems with variable airflow rates (VAV) can be used to decrease the amount of energy used to heat and cool the supply air and move the supply and exhaust air. Additionally, the occupancy detection system can work together with the heating and cooling system and decrease other energy uses by changing the indoor climate demands when building is not occupied. However, a VAV system has higher installation and maintenance costs than a system with constant airflow rate (CAV). This paper gives examples of energy use and life cycle costs (LCC) for different ventilation systems in dwellings. The LCC was calculated with a computer program for LCC calculations of indoor climate systems, ProLive. The occupancy level of a building is one of the most important parameters regarding the energy use calculations of VAV systems. The results show that it can be beneficial with variable airflow rate in dwellings from an LCC perspective.

INTRODUCTION

People spend up to 90% of their time indoors [1]. To ensure people’s health and comfort when they are indoors, the indoor air quality and thermal comfort must be appropriate. An indoor climate system, consisting of heating, cooling and ventilation, serves this purpose [2,3]. The aim of the indoor climate system is to provide the building with a good thermal comfort and indoor air quality. The indoor climate system must also use as little energy as possible.

This paper focuses on the ventilation systems and the airflow rates of the ventilation systems in detached houses and multifamily dwellings. Each ventilation system can either have a constant airflow rate (CAV) or a variable airflow rate (VAV). The idea behind having a variable airflow rate is to cool with air, to heat with air, or to decrease the airflow rate at lower occupancy levels to ventilate when there is a need for it only. Variable airflow rate ventilation based on the demand for air only is sometimes called Demand Controlled Ventilation (DCV). Ventilation systems with variable airflow rate based on the demand for air can be used to decrease the used amount of energy to heat and cool the supply air and move the supply and exhaust air. However, a variable airflow rate ventilation system has higher installation and maintenance costs than a system with constant airflow rate.

This paper presents the life cycle costs (LCC) for different ventilation systems in dwellings both with and without variable airflow rate based on the occupancy. In dwellings in Sweden, variable airflow rate is very rare except for the fact that the stove hood often can be set to different airflow rates. This is a smaller part of the total airflow rate and the idea is not to reduce the airflow rate at low occupancy levels.

Objectives and limitations

The life cycle costs of the heating and ventilation systems were simulated using a computer program for life cycle costs of indoor climate systems, ProLive. The life cycle costs were done both with and without variable airflow rate for multifamily apartments and detached houses.

The occupancy level of a building is one of the most important parameters regarding the application of variable airflow rate ventilation systems. The occupancy level has not been measured. However it has been a parameter in the calculations. Only theoretical buildings have been simulated, one typical multi family dwelling and one typical detached house. Field measurements were not an alternative, since it would be difficult to measure the life cycle cost, particularly for variable airflow rate ventilation, that rarely exists in dwellings.

METHODS

One problem with the design of an indoor climate system is that there has been a predominant focus on initial costs. A life cycle approach could improve both the energy and economic performance of the indoor climate system. The life cycle cost of a product is the sum of all costs related to that product over its entire life span. Future costs are discounted to the value of today, the net present value, by the use of a discount rate of interest.

The computer program ProLive was developed to calculate life cycle costs for indoor climate systems in offices, schools and dwellings [4]. It handles thousands of combinations of heating, cooling and ventilation systems typical for Sweden and takes into account the initial costs for buying and mounting components through a power demand calculation, energy costs, maintenance costs, repair costs and costs for space loss due to system components. Costs are based on Swedish prices from Sektionsfakta [5], which is a known cost database for the building sector. Outdoor climate is obtained from the computer program Meteonorm [6], which simulates outdoor climate data for the entire world. ProLive has features to model productivity and health costs based on indoor temperature and airflow rate even if the user has to provide the correlation data between the parameters and the costs. ProLive uses Swedish costs in SEK excluding VAT (25% value added tax). 1 SEK ≈ 0.14 US$ ≈ 0.11 € as of 2007-02-15.

In this study, the price of heat was set to 0.6 SEK/kWh and the price of electricity was set to 0.8 SEK/kWh excluding VAT. The discount interest rate was assumed to be 1% for electricity, 2% for heat and 3% for other costs representing a real price increase for heat and even more for electricity. An annual value of 800 SEK/m² was assumed for space loss. It was assumed that there is a 20% deduction from the initial costs for both air and hydronic components compared to Wikells [5]. A 40 year calculation period was used. The scrap value was assumed to be zero. The occupancy detection cost was assumed to be 766 SEK, which is supposed to be equal to an IR occupancy sensor and the mounting of it. This could consist of a manually operated switch inside each apartment and the detached house respectively.

Buildings

None of the buildings were set up with cooling. Hydronic radiators were used for heating. Assumed data for the buildings are given by Table 1. The outdoor climate data are from

Stockholm, Sweden. Table 2 gives the apartment areas, the window areas, the heat transmission areas and the number of people per apartment. The rooms with supply devices are the rooms that are not kitchens or bathrooms. Exhaust devices are located in the kitchen and in the bathrooms.

The multifamily dwelling was assumed to have four storeys with two one-room, two two-room, two three-room and two four-room apartments on each storey. It was assumed that there were two exhaust devices for each apartment, except for the four-room apartments where it was assumed that there were three exhaust devices. The building was assumed to be a medium weight construction.

The detached house was set up with two storeys. There were three exhaust devices on the bottom floor and two on the second floor while there were two supply diffusers or air inlets on the bottom floor and three on the second floor. It was assumed that four persons were living in the house.

Table 1. Data for the simulated buildings. Internal load refers to the internal heat gain excluding people. Heat transmittance is the average value for the building.

	Detached	Multi family		Detached	Multi family
Storey height	3 m	3 m	Chiller COP	2	2
Building length	12 m	43.3 m	Room temperature	22°C	22°C
Building width	8 m	12 m	Internal load presence	3 W/m²	3 W/m²
Total floor area	192 m²	2080 m²	Internal load abscence	1 W/m²	2 W/m²
Heat transmission area	288 m²	Table 2	Heat recovery eff.	0.8	0.8
Window area	15 m²	Table 2	Heat plant eff.	90%	0.9
Heat transmittance	0.25 W/(m²·K)	0.365 W/(m²·K)	Solar rad. trans.	0.5	0.4
Supply air temperature	18°C	18°C	Leakage at 50 Pa	0.8 l/(s·m²)	0.8 l/(s·m²)

Table 2. Data for the multi family dwelling. The building was set up to consist of two of each of the listed apartments per storey and four storeys.

Nbr of rooms/apartment	1 room	2 rooms	3 rooms	4 rooms
Nbr of persons/apartment	1	2	3	4
Window area	3 m²	6 m²	8 m²	9 m²
Apartment area	30 m²	50 m²	80 m²	100 m²
Heat transmission area	34.2 m²	57.0 m²	91.2 m²	114 m²

Ventilation systems

Specifications of the indoor climate regarding thermal comfort and air quality are determined by requirements, recommendations, national regulations, or by the building's user. This helps to simplify the design process of an indoor climate system. Usually, the minimum and maximum temperatures and the supply airflow rate are set according to the amount of activity in the building. In Sweden, the requirement is currently 0.35 l/(s·m²), where the area refers to the floor area [3]. If nobody is in the building, there is no need for airflow at all if no situation may arise with health risks indoors. This can be solved by a certain minimum airflow rate or by starting the ventilation a certain time before the house or apartment is occupied. Since it requires planning from the user, the most realistic way is to set a minimum airflow rate.

The systems included in this study were, exhaust ventilation system (E) with air inlets at the windows in the rooms that were not kitchens or bathrooms, and supply and exhaust ventilations system with heat recovery (SEH) with ceiling diffusers for supply air. Constant airflow rate and variable airflow rate were simulated. In the case of the variable airflow rate system, an airflow control damper (two for the supply and exhaust system) and an occupancy detector for 766 SEK were assumed to be included for each apartment in the multifamily dwelling. That means that the airflow rate was varied for the entire apartment and not for each room in each apartment. For the detached house, it was assumed that the airflow rate for the entire house was varied in the same manner. There is need for an occupancy detector but not for dampers since it is enough to control the air handling unit, and that option is included in air handling units on the market.

Occupancy

The occupancy rate is noted O_P. It is the ratio between the actual number of people in the building at a certain time and the number of people the building is designed for. In this study, it was assumed that O_P was constant over the year, which reduces the number of parameters. Johansson [5] analyzed this simplification. The fan electricity was influenced slightly by the use of a time distributed occupancy rate since the fan power is not linear to the airflow rate. The energy for heating and cooling is influenced even less.

$O_p = 0$ means that the building is unoccupied. $O_P = 1$ means that the building has full occupancy. It is assumed that the designed airflow rate of 0.35 l/(s·m²) is needed when $O_p = 1$ and that it is reduced linearly according to Equation 1 when O_P decreases. The coefficient α sets the airflow rate ratio compared to 0.35 l/(s·m²) at $O_P = 0$ and q is the airflow rate in l/(s·m²) where the area refers to the floor. In the study, $\alpha = 0$ and $\alpha = 0.33$ were tested. At $O_P = 0$, that means an airflow rate of 0 for $\alpha = 0$ and 0.1155 l/(s·m²) for $\alpha = 0.33$. The occupancy rate also influences both the internal load from people and the internal load, excluding load from people according to Table 1.

$$q = 0.35 \cdot \left(O_P + \alpha\left(1 - O_P\right)\right) = 0.35 \cdot \left(O_P\left(1 - \alpha\right) + \alpha\right), \qquad (1)$$

RESULTS

Table 3 gives the resulting life cycle costs for the different simulated buildings and ventilation systems at $O_P = 60\%$ and $\alpha = 0.33$. From here, it is shown that it is best to live in a detached house with a supply and exhaust ventilation system with heat recovery and variable airflow rate. In the costs hydronic heating, connection to district heating is included.

Figure 1 shows the life cycle cost and the energy cost for the different systems in the multi family dwelling as a function of O_P. Lower O_P means reduced average internal heat load which increases the need for heating but if the airflow rate is reduced at the same time, this increase is dampened or turned to a decrease. Figure 2 gives the life cycle and energy costs for the detached house. Figure 3 shows the accumulated life cycle cost over time, which is the life cycle cost at a certain calculation period for both simulated buildings. It takes a little less than ten years to benefit from heat recovery and around 15 years to benefit from variable airflow rate.

Table 3. Output data from ProLive for the two simulated buildings. The costs and the LCC refers to the entire calculation period, 40 years. The areas in the denominators of the units are the floor area. O_P = 60% and α = 0.33.

Building	Multi family dwelling				Detached house			
Ventilation system	E		SEH		E		SEH	
Airflow rate	CAV	VAV	CAV	VAV	CAV	VAV	CAV	VAV
Air heating energy / (kWh/(year·m²))	0	0	3.8	3	0	0	2.8	2
Hydronic heating energy / (kWh/(year·m²))	66.8	52.2	29.7	27	69.2	57.3	42.4	40.1
Electrical fan energy / (kWh/(year·m²))	1.8	1.5	6.9	4.2	3.2	2.8	5.7	4.5
Total energy / (kWh/(year·m²))	69	54	41	34	72	60	51	47
Changed volume / (m³/(m²·year))	11038	8080	11038	8080	8623	6312	8623	6312
Initial cost, ventilation / SEK	160	190	281	311	74	84	148	159
Initial cost, hydronic heating / SEK	271	271	243	243	371	371	352	352
Initial cost, total / SEK	431	461	524	554	445	455	500	510
Cost, electricity / SEK	47	40	182	111	84	73	149	118
Cost, heat / SEK	1096	856	550	492	1136	941	743	690
Cost, maintenance / SEK	96	102	113	119	115	117	123	125
Cost, repair / SEK	27	76	79	128	23	40	86	103
Cost, space loss / SEK	108	108	278	278	25	25	84	84
Life cycle cost / SEK	1804	1643	1726	1682	1828	1650	1685	1630

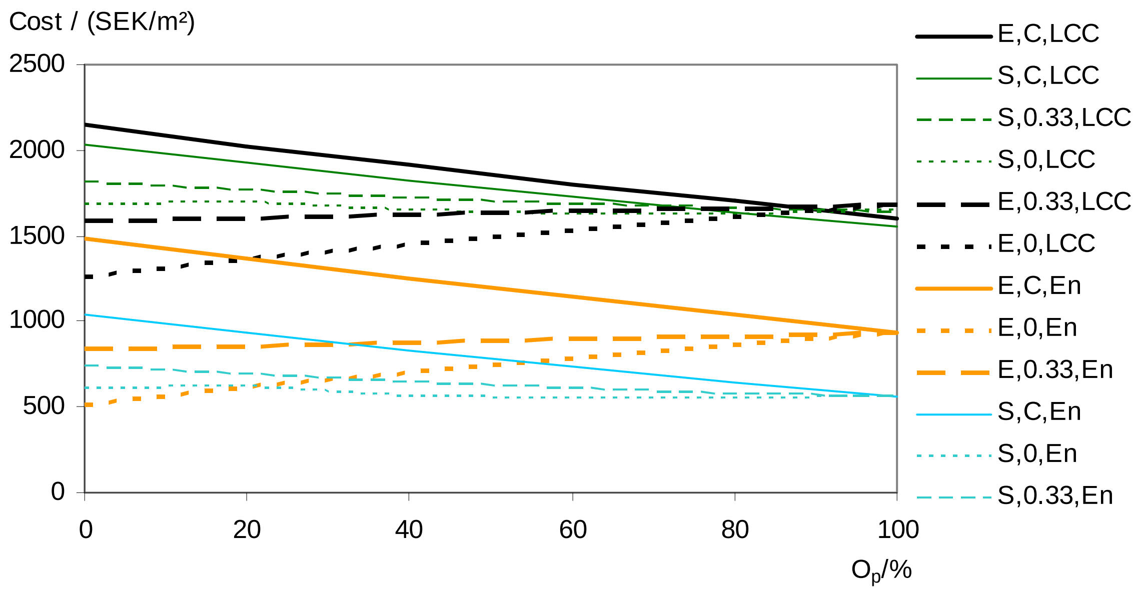

Figure 1. Life cycle cost (LCC) and energy cost (En) per floor area for the multi family dwelling. E means exhaust ventilation, S means supply and exhaust ventilation, C means constant airflow rate, 0 means α = 0 and variable airflow rate and 0.33 means α = 0.33.

The average U-value, which describes the heat transmittance through the building per area and temperature difference, and the building length, which affects the floor area, was varied for the detached house with the results shown in Figure 4. Bought energy would also be needed for household electricity and tap water which is not included in this simulation.

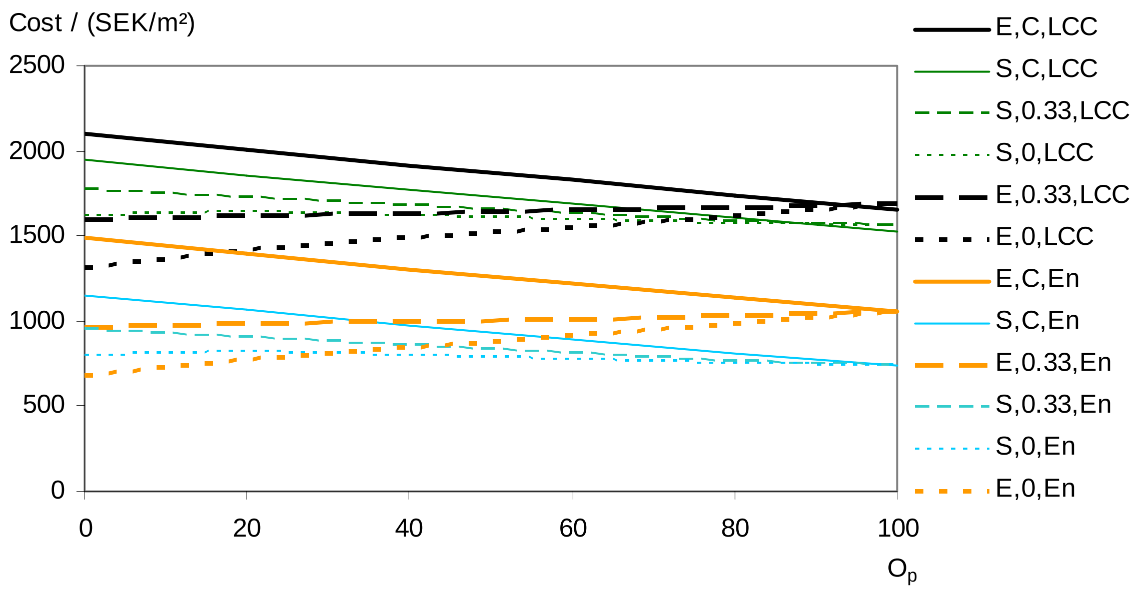

Figure 2. Life cycle cost (LCC) and energy cost (En) per floor area for the detached house. E means exhaust ventilation, S means supply and exhaust ventilation, C means constant airflow rate, 0 means $\alpha = 0$ and variable airflow rate and 0.33 means $\alpha = 0.33$.

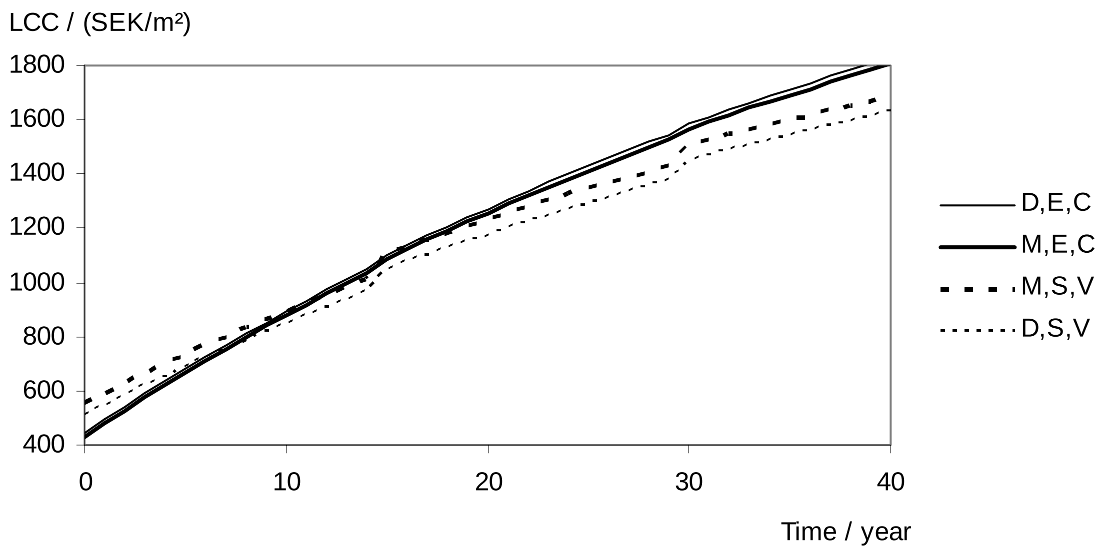

Figure 3. Accumulated life cycle cost (LCC) per floor area. E means exhaust ventilation, S means supply and exhaust ventilation, C means constant airflow rate, V means variable airflow rate with $\alpha = 0.33$, D means detached house and M means multi family dwelling. $O_P = 60\%$.

If it is assumed that the occupancy is either 100% or 0 in a certain apartment or house, a certain occupancy rate must correspond to a specific part of the day when the apartment or house is occupied. In Figure 5, it was assumed that the building was occupied during nights and empty during the days to test the assumption of using an average constant occupancy rate. This set up also gives the option to reduce the requirements on the indoor temperature when unoccupied. This possible temperature span decreases the energy use for this light weight detached house.

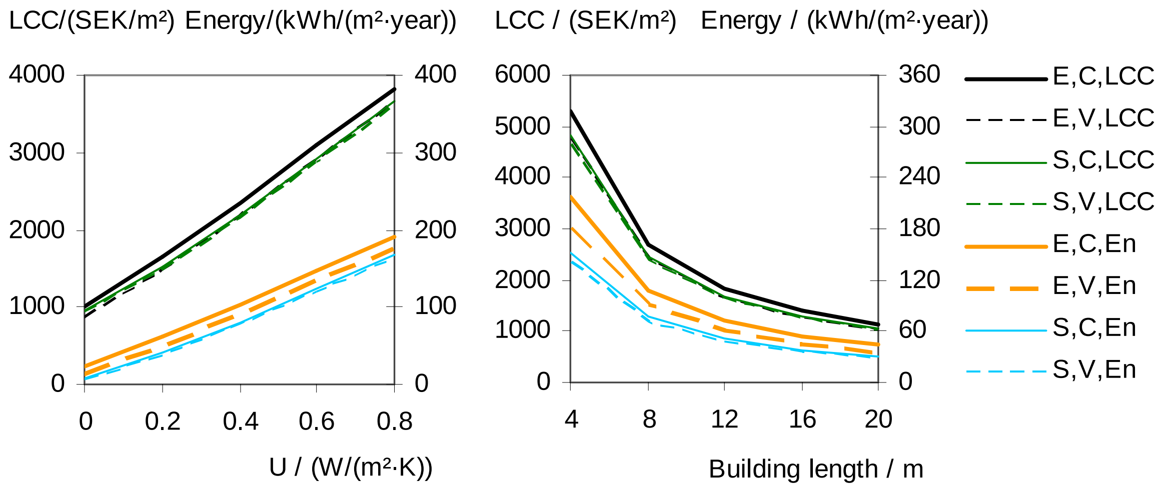

Figure 4. Life cycle cost (LCC) and annual energy use (En) for heating and fans for the simulated detached house when the U-value and building length were varied respectively. E means exhaust ventilation, S means supply and exhaust ventilation, C means constant airflow rate, V means variable airflow rate at $\alpha = 0.33$.

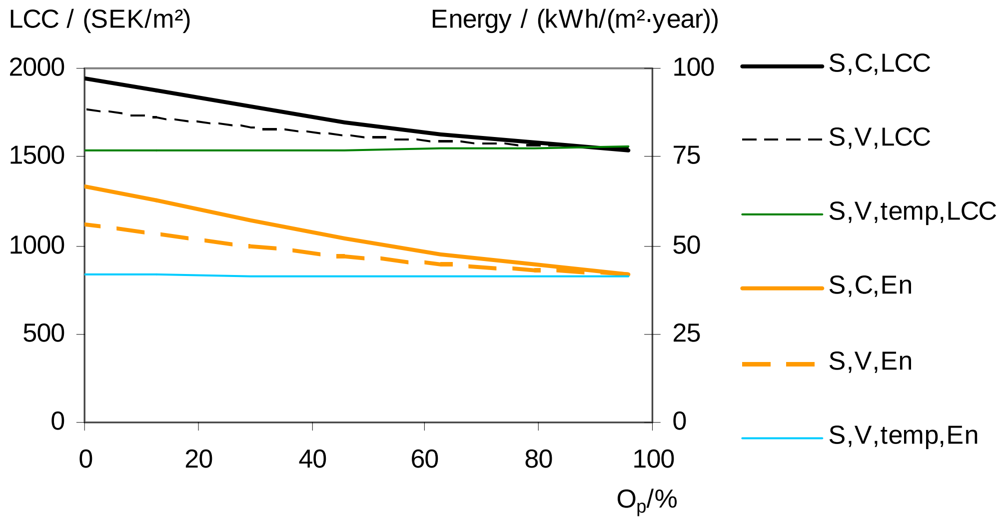

Figure 5. Life cycle cost (LCC) and annual energy use (En) for heating and fans for the simulated detached house as a function of O_P when the house was assumed to be occupied during nights. S means supply and exhaust ventilation, C means constant airflow rate and V means variable airflow rate at $\alpha = 0.33$. temp means that the demands on temperature in that set up was changed during absence from 22°C to a span from 18°C to 26°C.

DISCUSSION

It has been shown that occupancy controlled variable airflow rate ventilation systems can be beneficial from a life cycle cost perspective in both multifamily dwellings and detached houses. The simulated occupancy detection cost was 766 SEK per apartment or house. This cost is reasonable for a manual system where the user chooses the number of people, for example at the main door. Right now, a lot of development is going on regarding cheaper sensors for detecting occupancy. There are indications that industry will come up with carbon dioxide sensors in this price range, which would be an alternative that is not dependant on the user to work properly. It would be possible to control each single room in each apartment or in the detached house instead of controlling the entire apartment or detached house but that would be more complicated and expensive. By doing that, air could be supplied where people are in the building which initiate a discussion of the form of the requirements on airflow rate. ProLive does not simulate that at this point of time but it could be a feature in the future.

It has also been shown that supply and exhaust ventilation with heat recovery can have a lower life cycle cost than exhaust ventilation systems, which has a lot of other disadvantages including draughts and poor control of the air movements as example [7].

Simplifications have been made. An example is the constant temperature efficiency of the heat recovery unit, which in reality would increase the benefit from lower airflow rate because of higher efficiencies at lower airflow rates. Another example is the constant occupancy rate over time. In fact, it varies both over the day, which does not seem to have much influence, and over the year which probably has more of an influence but such measured data is lacking.

With an occupancy detection system, it would be possible to control, for example, lighting or other use of house hold electricity. It is perhaps rather common that people switch off the lighting when they are not indoors but if it is assumed that 200 W per house could be controlled by the occupancy and O_P = 60%, 3.7 kWh/(m²·year) can be saved from the household electricity for the simulated detached house. On the other hand, the need for heating energy will increase since the internal heat load provides a certain amount of heat.

In this study, it has been assumed that the nominal airflow rate was set according to the Swedish building code. This airflow rate is based on the floor area and not on the occupancy rate, which should be the parameter controlling the airflow rate. It can be discussed whether or not the requirements in the building code are appropriate since the airflow rate per person will depend on the nominal floor area per person. From a moisture perspective, it can be argued that the indoor vapour content will increase if the airflow rate is reduced parts of the day. On the other hand, during winter time, the risk of having dry air will decrease with variable airflow rate. The occupancy detection could also be based on vapour production or a combination of occupancy parameters. More research is needed regarding the most apparent parameter in this study, the occupancy rate. Measurements will hopefully be performed in the future.

REFERENCES

1. Lech, J.A., Wilby, K., McMullen, E., Laporte, K. 1996, The Canadian human activity pattern survey: Report of Methods and Population Surveyed, Chronic Diseases in Canada, 17, 3/4
2. Nilsson, P.E., editor 2003, Achieving the desired indoor climate, Studentlitteratur, Lund, Sweden
3. Boverket 2002, Boverkets byggregler – BFS 1993:57 med ändringar till och med 2002:19, Karlskrona, Sweden, in Swedish
4. Johansson, D. 2005, Modelling Life Cycle Cost for Indoor Climate Systems, Doctoral thesis, Building Physics, Lund University, Lund, Sweden, Report TVBH-1014, http://www.byfy.lth.se
5 Wikells Byggberäkningar AB (2003), Sektionsfakta-VVS, Wikells byggberäkningar AB, Växjö, Sweden, http://www.wikells.se/, 2005-05-31, in Swedish
6. Meteotest 2003, Meteonorm handbook, manual and theoretical background, Switzerland, http://www.meteonorm.com/, 2005-06-01
7. Engdahl, F. 2002, Air - for Health and Comfort – An anlysis of HVAC Systems’ Performance in Theory and Practice, Doctoral thesis, Dep. of Building Physics, Lund University, Sweden, Report TVBH-1013