DEMAND-CONTROLLED HYBRID VENTILATION - AN ALTERNATIVE?

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ABSTRACT

The performance of a demand-controlled hybrid ventilation system (DCHV) has been compared with that of a balanced mechanical ventilation system with heat recovery (MHR) in respect of their energy use and corresponding environmental impact in a typical Swedish school. Energy demands have been calculated with the IDA program, and environmental impact with the EFFem program. Technical and monitoring data from a pilot study in Falkenberg has been used in order to define and verify the simulation model. The results shows that the total energy demands are close to the same for the two ventilation principles, but with differences in the relative proportions of electricity and heat uses. The main factor that had an influence on the environmental impact was found to be the availability of district heating, based on energy from low environmental impact sources. It is therefore unsafe to base a decision on outdoor climate information alone. It is important also to make an environmental analysis, together with assessments of costs and analyses to ensure that adequate indoor environmental conditions will be delivered.

INTRODUCTION

The Swedish Parliament has decided that nuclear power will be phased out, which therefore means that electricity has become a high-value energy carrier – an energy source effectively, for many purposes. This resulted in a change to the Swedish Building Regulations (BBR94), to permit the use of natural and hybrid ventilation systems (Thurell, 1998). Over 100 buildings (mostly schools) have therefore been built during the 1990s in Sweden with natural ventilation systems, with or without the assistance of supplementary fans. Elsewhere in the world, too, new building designs and retrofitting of old buildings have turned towards greater use of sustainable technologies, such as natural ventilation and cooling (Delsante and Vik, 2001).

However, experience from these buildings has raised questions of whether the necessary ventilation performance can be provided during long periods of the year when the differences between indoor and outdoor conditions are too small to generate sufficient driving forces. In order to ensure the necessary ventilation rate, a few schools in Sweden have been built with hybrid ventilation systems over the last few years. Hybrid ventilation is described by Heiselberg 2002 as the merging of both natural and mechanical ventilation systems to produce a system that combines the best of the two technologies. Such systems have intelligent control systems that can automatically switch between natural and mechanical mode.

With hybrid ventilation systems, it should be possible to use a minimum of electricity while at the same time maintaining the necessary indoor comfort requirements. Another advantage is that hybrid ventilation is quiet, although a disadvantage is that energy use for heating is high (especially in a cold climate region), since heat recovery is complicated. The heat loss problem can, however, be tackled by using the advanced control system to give demand control of the ventilation. With a balanced mechanical ventilation system, it is possible always to meet the indoor comfort requirements, even though there are often problems with noise. Balanced ventilation makes heat recovery easier, but often the systems need to operate at high static pressures and thus require fan-motor sets with high electricity use.

When choosing between a demand-controlled hybrid ventilation system (DCHV) and a balanced mechanical ventilation system with heat recovery (MHR), the question arises as to whether the electricity savings offset the loss in heating use of district heating? To make an assessment, there is a need for information about which type of ventilation that has the least outdoor environmental impact. However, the environmental impact will be dependent on the local availability of energy sources for district heating as well as on the outdoor climate conditions.

The aim of this work has been to compare energy efficiency and environmental impact for a DCHV-system with an MHR-system for a school in three different parts of Sweden.

THE TÅNGA SCHOOL

The Tånga school was built in 1968, and includes classrooms, workshops, dining hall, kitchen, gymnasium and offices. A demand-controlled hybrid ventilation system was installed during a renovation in the late 1990s, since the education authority was interested in implementing energy-saving features. At the same time, international interest in hybrid ventilation systems was also increasing, with a working group (Annex 35, HYBVENT) within the International Energy agency having been created (Heiselberg, 2002). The work of the Annex included twelve pilot studies of hybrid ventilation systems around the world, with one of the pilot studies being the Tånga school in Sweden. The Tånga school has therefore been monitored for two years, with careful evaluation of indoor climate and energy use (Wahlström and Nielsen, 2001 and 2002; Blomsterberg et al., 2002). The results show that a demand-controlled hybrid ventilation system can provide adequate indoor comfort, while minimising electricity use for ventilation.

The demand controlled hybrid ventilation system

The Tånga school in Falkenberg is a two-story building with three wing, each with three classrooms on each storey. Each wing has been retrofitted with a hybrid ventilation system controlled by a Building Energy Monitoring System (BEMS). The main principle of ventilation is by passive stack: to increase the natural forces, solar chimneys have been installed on the roof of each wing. In order to maximise passive stack ventilation, care has been taken to reduce the total pressure drop through the distribution ducts during operation. This has required large ducts, with a minimum of obstructions. Existing stairwell openings have been used to lead the exhaust ducts from the classrooms to the chimney. The solar chimneys are 6 meters high, with flat plate solar air collectors that heat the air in the chimney when solar energy is available. When stack effect is not sufficient to ventilate the school, ventilation is maintained by low-energy exhaust fans to supplement the existing stack effect. The BEMS controls the changes between different modes, with the system being designed for natural ventilation in the winter months, early spring and late autumn.

Outdoor air is distributed to the rooms through several air intakes in the exterior walls into a stub duct from where it is distributed to the room. Convectors under the stub duct preheat the fresh air. This provides mixed ventilation in the classrooms. As the school is situated in a quite clean environment, it has been considered acceptable to avoid the use of filters, which would increase the pressure drop through the air intakes. The extract air is evacuated through air terminal devices on the opposite side of the room, into vertical ventilation ducts. To prevent air from going backward through the duct system, all of the classrooms have their air intakes on the predominant wind direction side.

Local dampers are mounted in the air intakes and in the exhaust duct of each room, to allow individual control of the flow rate in each classroom. The BEMS and a CO_2 sensor in each room control the local dampers. At 06:00 the dampers are opened 50 % so that the classrooms are aired before the pupils arrive at 08:00. During the day, the CO_2 sensor controls the local dampers, and at 18:00 they are closed again. In addition, the class teacher can override the local control system and manually change the position of the local dampers between 50 and 100 %.

Figure 1. Picture of the Tånga School. Supply air intakes are placed below the windows. The right half shows one wing of the building with the solar chimney on the roof.

METHOD

In order to investigate if a DCHV system would be more energy-efficient or/and more environmentally beneficial that an MHR system, the Tånga school pilot study has been used as base case. One classroom of the base case has been modelled with an air flow simulation program that calculates the heating and electricity use. Actual measured data from the Tånga school has been used to calibrate the simulation model. Calculations have been made for two different ventilation principles for the same school, situated in three different parts of Sweden (Falkenberg, Gothenburg and Stockholm). Falkenberg and Gothenburg have been represented with a Gothenburg normal year climate profile (1977, Säve airport), while Stockholm has been represented with a normal year climate profile for Stockholm (1977, Bromma airport). The results have then been used for evaluating the environmental impact in three different ways from the total energy use, by means of an environmental assessment program and two environmental assessment methods. Data for district heating systems in the different cities has been used, with electricity being considered as produced in two different ways.

The IDA-ICE simulation tool

IDA-ICE is an analysis software to investigate the thermal indoor climate of separate rooms (thermal zones) in a building, as well as the energy use for the whole building, with high accuracy. The system analysed is a building comprising one or several rooms (zones), a primary heating and cooling system and one or more air handling units. The building may be shadowed by neighbouring buildings. The air inside the building will contain both moisture and carbon dioxide. Weather data are read from files containing either real or synthetic data. The influence of wind is considered.

The IDA-ICE program has been used here to model a single zone, consisting of one classroom, and to calculate the performance, in terms of heating and electricity use, of defined ventilation rates from the pilot study.

The base case, with demand-controlled hybrid ventilation system

Tånga school has been used as the base case, and the model has been built up with conditions corresponding to one of its classrooms. The classroom is 61 m^2 and faces south-west. The simulations have been made on the basis of occupation by 20 adults which, in terms of internal heat input, is intended to correspond to 30 pupils, from 8 to 12 a.m. and from 1 to 5 p.m. Furniture covers 20 m^2 of the room, and electrical equipment of 150 W is in use for the whole day. Ventilation operates from 6 a.m. to 6 p.m.

Air is supplied through leakage in the exterior walls that corresponds to the air intake devices in the Tånga school, while exhaust air is controlled by a variable air volume principle, controlled by the CO_2 concentration in the classroom. The model has no option for natural ventilation, and has therefore been simplified for hybrid ventilation so that the mode with the low-energy exhaust fans operating is used year-round. However, air flows correspond to those that were measured at the Tånga school, with the extra electrical energy used in the natural ventilation mode being considered as small. However, this results in a slight overestimation of the electricity use in the demand-controlled hybrid ventilation case. The simulated performance of heating and electricity use for the DCHV system in Falkenberg has been checked against measured values from the pilot study, and shown to be closely in agreement.

The balanced mechanical ventilation system with heat recovery

The same classroom has then been modelled with a balanced mechanical ventilation system, with the supply and exhaust air volumes set at a constant 210 litres per second, which corresponds to 7 litres per second and person, which is the national requirement for minimum ventilation air flow rates. The system has a heat recovery unit with an efficiency of 60 % and a SFP-value of 1.7 kW/(m^3/s). Ventilation operates from 6 a.m. to 6 p.m. The same indoor comfort parameters have been used for the two ventilation principles.

The EFFem environmental assessment tool

EFFem is a free-to-use Internet tool that aims to give a fast, transparent and objective overview of environmental effects for different energy sources, to assist users in environmental assessments of a building's energy use (Wahlström 2003). It consists of a data base with default data of efficiencies of energy systems, nine different emissions representing different energy sources, and a method for estimating the environmental impact of the emissions. Emission data has been taken from inventories of different energy sources during their complete life cycles, "from cradle to grave". The tool is built up so that assumptions, boundary conditions and calculations are transparent, and it is easy to change default values when better values are known. Operation energy use is needed as an input, and the results are given as total emissions and impact on global warming, acidification, photochemical ozone formation, eutrophication and fine particles.

District heating and electricity are often produced centrally in different production units that are connected to the same distribution network, and it is possible to define the mix of production units for district heating and electricity that should be considered in the assessment.

The EFFem tool has been used here to calculate total emissions and the impact of global warming. The impact of global warming is calculated by weighting of greenhouse gases, and is expressed in kg CO_2-equivalents. The weighting factors are based on scientific data, and represent the emissions' impact on global warming according to the Swedish Environmental Council 2000. The results are, therefore, more or less objective.

The results from the EFFem tool consist of impacts of several different environmental effects, in addition to global warming. If the environmental assessment is also to include the other effects, it might be very difficult to obtain an overall view. Several assessment methods intended for different purposes have been developed over the last decade in order to facilitate the assessment of life cycle inventories in general. They weigh different environmental effects into one or a few figures. The weighting factors could be based on (for example) social aspects, and are decided against a limited scientific background, which means that the results are based on subjective valuations. Two examples are used in the present work: the EPS and the Eco-indicator 99 method, while several other methods are presented in Bjørn et al. 2004.

Table 1. Weighting factors for the EPS (Steen, 1999 and Ryding et al. 1998) and Eco-indicator 99 (Goedkoop and Spriensma, 2000) environmental assessment methods, with examples of weighting factors for assessment of global warming impact (Swedish Environmental Council, 2000)

Emission	**EPS** (ELU/kg)	**Eco-indicator 99** (Pt/kg)	**Global warming** (kg CO_2-eqvivalents/kg)
CH_4	2.72	0.114332	21
N_2O	38.3	1.79	310
CO	0.331	0.00332	0
CO_2	0.108	0.00545	1
NH_3	2.90	3.42	0
NmVOC	2.0	0.05	0
NO_x	2.13	2.745	0
SO_x	3.27	1.5012	0
Particles	36.0	9.74	0

The EPS environmental assessment method

The EPS (Environmental Priority Strategies) environmental assessment method is used in production choices in manufacturing industry, and expresses the additional environmental load that use of a resource, a pollutant, a material, a process or an activity will cause during its complete life cycle. The value of the environmental index is based on the influence of one or more of the five protection objectives: biological diversity, human health, the ecosystem's sustainability, natural resources and aesthetic values. The impact of the protection objectives is evaluated in terms of how much money the inhabitants in the OECD countries would be willing to pay in order to restore the protection objectives to their reference condition (the condition in 1990). In other words, the valuation is based on the willingness of OECD country inhabitants to pay in order to avoid environmental change. The environmental load is expressed in ELUs (Environmental Load Unit), (Steen, 1999 and Ryding et al. 1998).

The Eco-indicator 99 environmental assessment method

Eco-indicator 99 is based mainly on life cycle analysis, supplemented with a concept of what are known as eco-indicators. The eco-indicators are an aggregated (~ added to a total from all contributions) measure of the environmental load of a manufacturing process or material. The result from the inventory analysis is converted into damage factors, with three damage categories; human health, ecosystem quality, and resources. The three categories have different units, and are therefore normalised and then weighted into a single indicator. The weighting factors are defined by a written panel procedure among members of a Swiss discussion platform on LCA, and are thereby subjective and cannot be considered to be representative of the average European. The standard Eco-indicator value can be regarded as a dimensionless figure. The Eco-indicator point (Pt) is used as the name. The value of 1 point represents one thousandth of the yearly environmental load from one average European inhabitant (Goedkoop and Spriensma, 2000).

Electricity

Electricity is distributed through a grid that is often directly connected to grids all over Europe and also to other parts of the world. Since global warming is a global effect, it does not matter if the impact is reduced locally or elsewhere. For example, electricity will an excellent choice if only Norwegian power, which mainly consists of hydro power, is considered in the assessment. Due to the market situation, a reduction in electricity use could cause Norwegian electricity to be used instead of coal power produced in another European country, when it would be beneficial to reduce the electricity consumption in Norway as well. This means that the environmental assessment for electricity is complicated, since the total market situation should be taken into account, and this is reflected by the choice of system boundary. In the present study, two different ways have been used to define the system boundary for the mix of electricity production:

- European average mix (EU mix), which consists of the percentage composition of production units within the system boundary, here defined as EU average 2001 (IEA, 2002). This definition will describe the actual contribution from the building to environmental impact.
- Marginal mix, which consists of the production unit for peak power, here defined as electricity produced in a coal-fired power plant. A reduction in electricity consumption will allow production from this unit to be reduced. This definition describes how environmental impact will decrease with electricity-saving measures.

District heating

District heating networks are physically separated from each other, which gives them clear system boundaries. Their mix of production units can be very different, from one network to another, and so also their environmental impact. It can be very misleading to calculate the environmental assessment based on a national or European mix of production sources. Data is needed on production units for the specific district heating network, and these are given in Table 2.

Table 2. Percentage of energy sources in different district heating networks (Fjärrvärmeföreningen, 2005).

Energy source	Falkenberg	Gothenburg	Stockholm
Waste heat		30.5	
Natural gas	4.4	26.3	
Waste combustion	2.2	25.0	10.8
Heat pump		11.0	36.8
Oil	2.2	4.9	16.5
Tall oil pitch		2.2	10.8
Electricity		0.1	2.7
Biofuels	91.1		11.5
Coal			10.6
Town gas			0.3

RESULTS

The differences in energy use between the two ventilation principles are that the MHR system uses a lot of electricity for fans, but can recover heat in the exhaust air and thereby reduce the district heating demand. The DCHV system needs only a small amount of electricity for fan power in the summer, but has no means of recovering heat from the exhaust air in the winter. The total energy use is almost the same for the two systems, both for the Gothenburg and the Stockholm climate, see Figure 2.

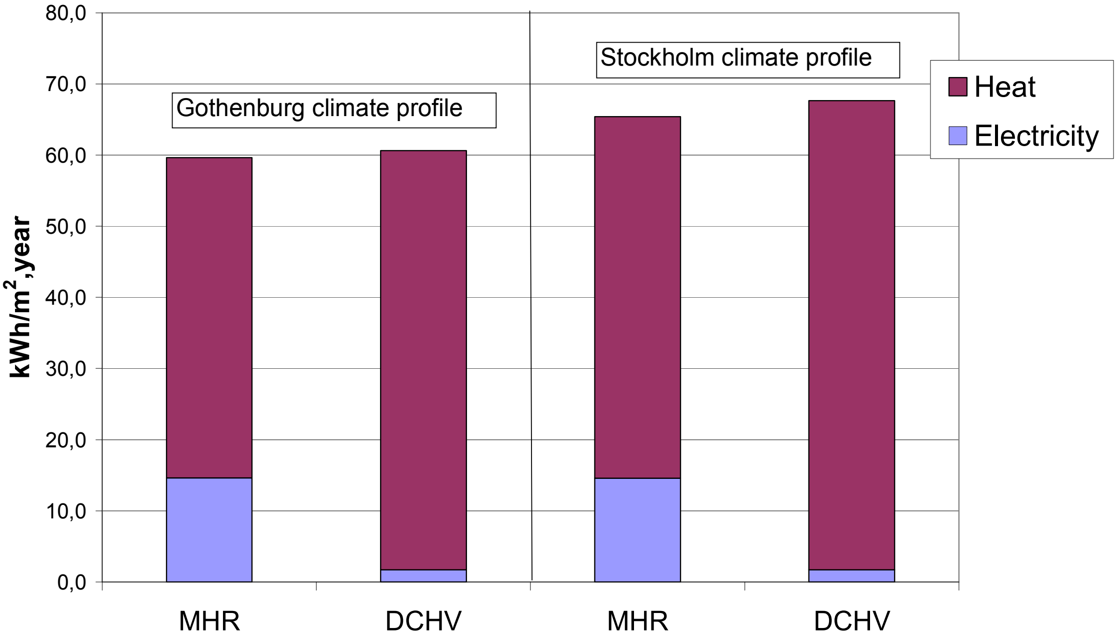

Figure 2. Electricity and district heating use for two ventilation principles in the Tånga school, theoretically sited in two different outdoor climates. The total energy use is almost the same for the two ventilation principles, although the proportions of electricity and district heating are quite different.

Emissions from the different energy sources

The environmental impact from each energy source must be considered in order to decide whether the additional electricity saving outweighs the loss in heat demand from district heating. The EFFem environmental assessment program has been used to calculate emissions from each energy source for each energy distribution network. The results are given in Table 3.

Table 3. Emissions from the different energy sources (EFFem, 2005).

Emission (mg/kWh)	**Electricity (EU-mix)**	**Electricity (Marginal)**	**Gothenburg District heating**		**Falkenberg District heating**		**Stockholm District heating**	
			EU-mix	Marginal	EU-mix	Marginal	EU-mix	Marginal
CH_4	1554	9579	80	418	28	28	870	2335
N_2O	70	353	51	63	488	488	121	173
CO	247000	819900	116300	140500	37900	37900	183800	288300
CO_2	29	13	5,85	5,16	16	16	15	13
NH_3	3,1	21	3,26	4,02	9,8	9,8	4,83	8,15
NmVOC	11	17	8,5	8,74	115	115	27	28
NO_x	255	373	207	213	467	467	465	485
SO_x	70	357	14	27	83	83	71	123
Particles	217	610	147	164	133	133	451	523

Assessment of environmental impact

The impact of the two ventilation principles on global warming has been evaluated using the EFFem tool (see Figure 3,) with the EPS environmental assessment method (see Figure 4) and with the Eco-Indicator 99 environmental assessment method (see Figure 5).

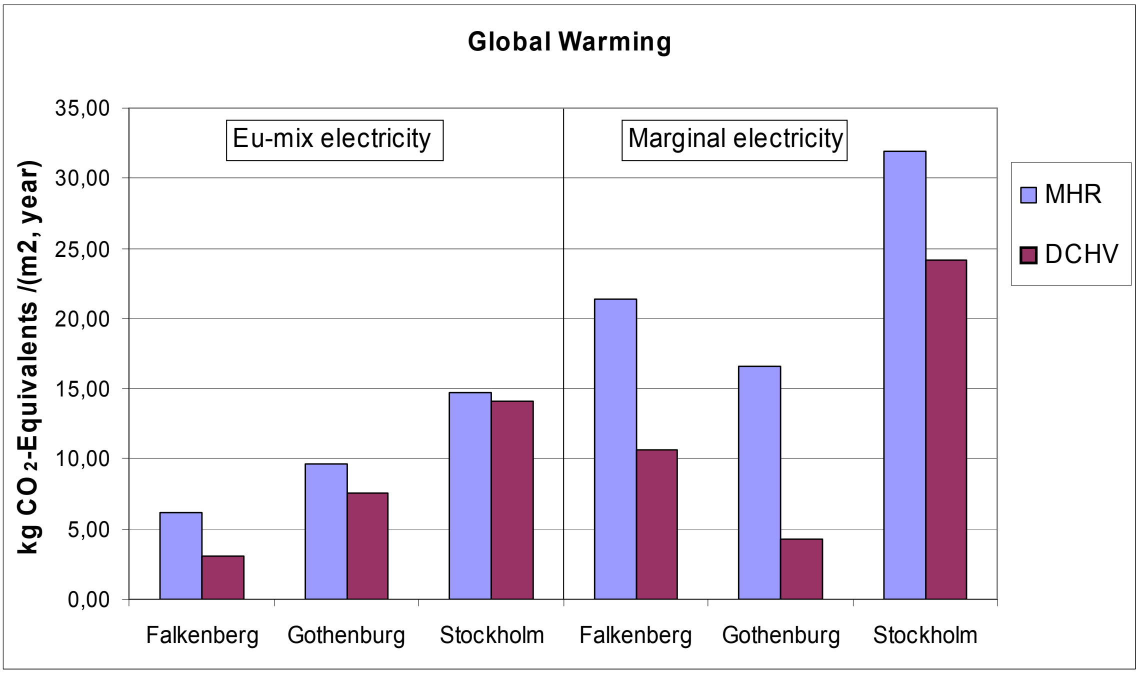

Figure 3. Impact of global warming for MHR and DCHV ventilation principles in the Tånga school, sited in three different cities. Electricity is considered as an EU mix to the left and as marginal production (peak power) to the right.

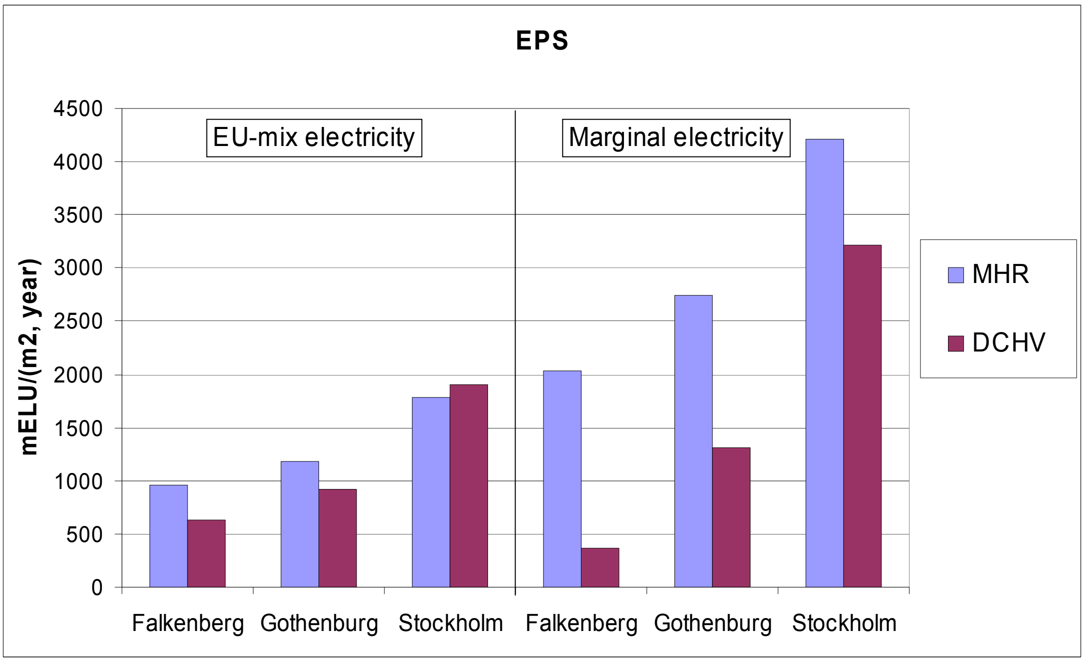

Figure 4. Environmental assessment with the EPS method for MHR and DCHV ventilation principles in the Tånga school, sited in three different cities. Electricity is considered as an EU mix to the left and as marginal production (peak power) to the right.

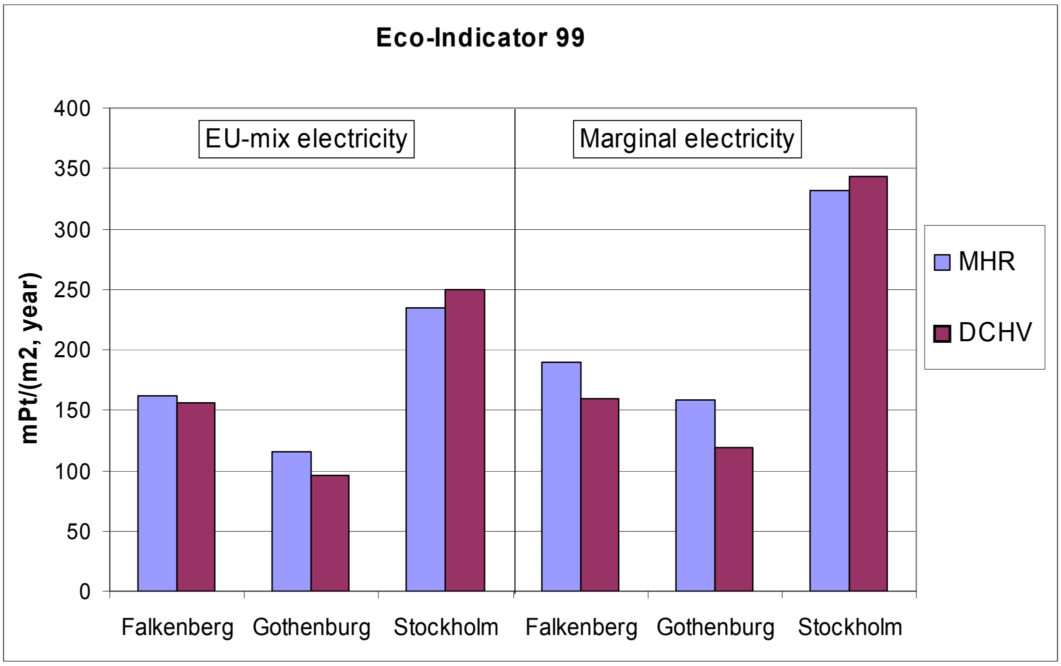

Figure 5. Environmental assessment with the Eco-Indicator 99 method for MHR and DCHV ventilation principles in the Tånga school, sited in three different cities. Electricity is considered as an EU mix to the left and as marginal production (peak power) to the right.

DISCUSSION AND CONCLUSIONS

The energy use and corresponding environmental impact of a demand-controlled hybrid ventilation system (DCHV) and that of a balanced mechanical ventilation system (MHR), as operated in a typical Swedish school, have been compared. The school has theoretically been sited in two different climates in three different Swedish cities. Data for district heating networks in the three different cities has been used, while electricity has been considered as produced either as European average mix or as marginal production.

The difference in energy use between the two systems is that the MHR system uses more electricity for its fans, but can recover heat in the exhaust air and thus reduce the district heating energy demand. The DCHV system needs only a small amount of electricity for fan power, but cannot recover heat in the exhaust air. The total energy use is almost the same for the two systems, and electricity would have to be compared with district heating in order fully to evaluate the systems. The indoor climate is the same for both systems.

The environmental impact of global warming and the impact as seen by two different environmental assessment methods (EPS and Eco-indicator 99) have then been calculated. The results show that a DCHV system is better for the environment in Falkenberg and Gothenburg, regardless of whether electricity is considered as an average mix or as marginal power. This is due to the fact that Falkenberg district heating is produced mainly from biofuels, while Gothenburg district heating is produced mainly from waste heat, waste and natural gas combustion.

Stockholm district heating consists of more fossil fuels, and the MHR system that uses less district heating energy will be preferable when electricity is considered as an EU mix for all environmental assessment methods. If electricity is considered as marginal power, the DCHV system becomes more preferable when assessed in terms of global warming or with the EPS method. The EPS method has high weighting factors for global warming gases, and so the assessment will be close to one that considers only global warming. The Eco-indicator 99 programme produces a more balanced weighting between the different emissions, so that the MHR system will be preferable even when the electricity is marginal power. A comparison of the evaluations for the different cities shows that in order to have a sound decision basis, it is wise to make environmental assessments with several different assessment methods.

Availability of a district heating system based on low environmental impact energy sources was found to be a determining factor when comparing the environmental impact. It is therefore unwise to base a choice between ventilation principles on outdoor climate information alone. It is particularly relevant also to make an environmental analysis before designing the system, together with assessments of costs and investigations to ensure that the necessary indoor environment will be provided.

This comparison has compared an MHR system with a DCHV system, since both systems will have reasonable investment costs. However, a demand-controlled MHR system would of course have even lower energy use but higher investment costs.

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