European Green Cities Network

ENERGY EFFICIENT VENTILATION SYSTEMS

Cenergia Energy Consultants 2003

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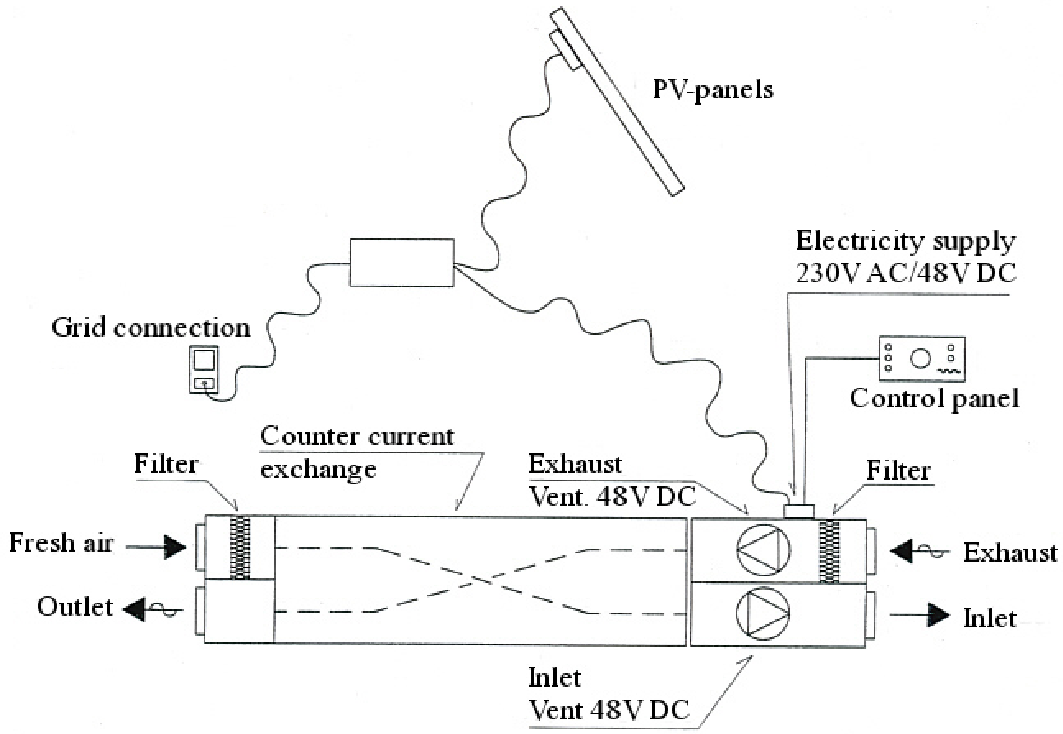
1 Introduction

With the increased demand for ventilation in the coming Danish Building Regulation 2005 and in the EU Energy Performance Directive for Buildings, both including new and strict requirements concerning energy use and indoor air quality, there is a large need for development of energy efficient ventilation solutions. It is therefore expected that a much greater investment in ventilation solutions with heat recovery where outlet air is used for preheating of inlet air will take place in the future.

In the picture 1 below is shown an example of a PV-Vent ventilation system where new efficient DC-fans are supplied with direct electricity from PV panels for additional electricity saving.



Picture 1. PV-Vent ventilation system.

The PV-Vent concept expresses a connection between utilisation of the sun as energy source and development of effective distribution and recovery methods for ventilation in a building, i.e. to combine the building integration of PV panels with high efficient ventilation systems. The PV panels produce direct current that immediately can drive DC motors with minimal consumption in a new generation of effective counter current heat exchangers. Hereby energy loss is avoided and also an expensive converter installation. The used type of heat exchanger from the Danish company EcoVent is of aluminium and utilise the counter current heat recovery principle.

To meet the demands for energy efficient ventilation system the following requirements should be satisfied:

- ✓ The efficiency of the heat recovery should be at least 80-90 %.
- ✓ Power consumption of the ventilation system should be only 30-40 W.
- ✓ The building should be complete air tight (natural infiltration should be 0,1 /h).
- ✓ The ventilation system should be installed inside the building envelope.
- ✓ The noise level should be less than 25 dB.

2 Building Integration Methods Including Focus on Total Economic Lifecycle Costs Optimised Energy Saving Package

In the following two examples from Denmark are shown on how building integrated PV-modules can be used already today in a cost effective way together with an energy saving package based on a 50 % funding for the PV-modules.

2.1 Total economic analysis concerning use of heat recovery ventilation and PV-modules for a housing scheme

The first example concerns a housing development with 42 flats in Herning, Denmark. Four alternatives to a normal reference solution is here considered.

The investment in a traditional heat supply to the houses (solution 1) is shown in the following together with four alternative solutions. There is a solution with heat recovery ventilation (solution II) and one where this is combined with utilisation of PV-modules (solution II a). There is a solution with heat recovery ventilation and air heating (solution III) and one where these are combined with utilisation of solar heating and PV-modules and additional insulation (III a).

Solution I (reference):

- Insulation standard according to the Danish building regulations;
- Heating by radiators;
- Ordinary exhaust ventilation, 60 W per dwelling in electricity consumption.

Solution II (reference including ventilation with heat recovery):

- As I but with 80-90 % efficient heat recovery, 30 W per dwelling in electricity consumption for ventilation tower.

Solution II a (reference including ventilation with heat recovery ventilation and approx. 2 m² PV-modules per house as basis of CO_2 neutral ventilation):

- As solution II but with PV-modules with a production equal to the annual electricity consumption (91 m² PV-modules), including 50 % funding.

Solution III (As II but with additional insulation and air heating, effect demand 3 kW per house):

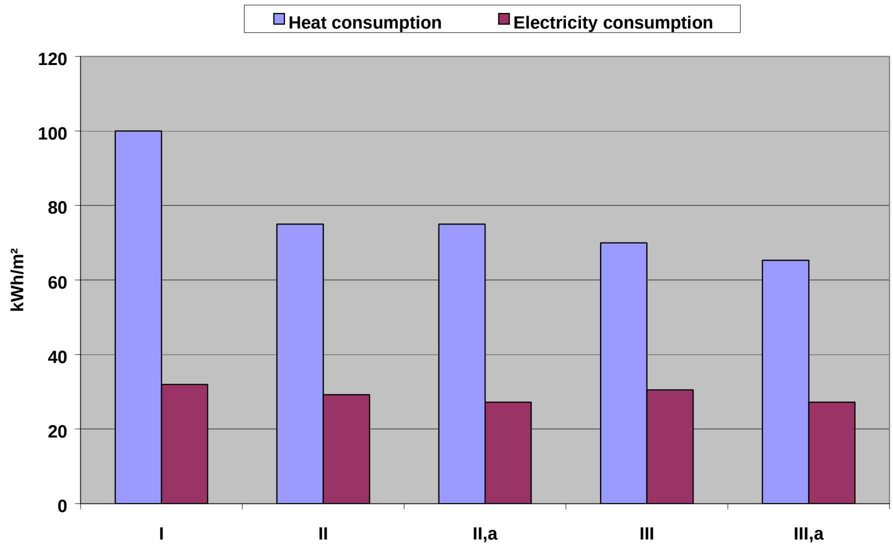
- Efficient heat recovery ventilation;
- Additional insulation;
- Air heating with maximum 40-50 W electricity consumption per house for ventilation;
- Heating via domestic hot water heating;
- Solar heating for domestic hot water.

Solution III a (as III but with approx. 3,5 m² PV-modules per dwelling):
- As solution III but with PV-modules (153 m²) and 50 % funding.

	I	II	II,a	III	III,a
1. Heating plant	100.000	100.000	100.000	75.000	75.000
2. Distribution, RV	210.000	210.000	210.000	0	0
3. Heating	1.260.000	1.260.000	1.260.000	100.000	100.000
4. Ventilation	504.000	1.134.000	1.134.000	1.680.000	1.680.000
5. Additional insulation	0	0	0	210.000	210.000
6. Solar heating	0	0	0	0	173.793
7. PV-modules	0	0	321.930	0	536.550
Total	2.074.000	2.704.000	3.025.930	2.065.000	2.775.343
Total including VAT	2.592.500	3.380.000	3.782.413	2.581.250	3.469.179

Table 1. Investments for three alternative solutions for heat supply.

The table does only include the parts that are important to the comparison of the five solutions. A traditional solution with central heating and radiators and with ordinary exhaust ventilation is thus DKK 2.592.500. If efficient heat recovery ventilation is introduced, the investment will increase with DKK 787.500. If PV-modules are installed too, the investment will increase with DKK 402.000. If additional insulation and air heating are utilised together with heat recovery, the total expenses will be DKK 2.581.250, which is almost the same as the reference. If also solar heating is used as a supplemental heat source and PV-modules for electricity production is combined with an improved insulation and air heating, the investment increases with DKK 888.000 compared to a traditional solution. The last solution has more investment demanding measures but by using air heating and by using the domestic water circulation as a heat distribution network for room heating, a traditional radiator system and supply ducts with mixing loops are saved. In this way a good solution for the environment with a good indoor air climate is obtained.

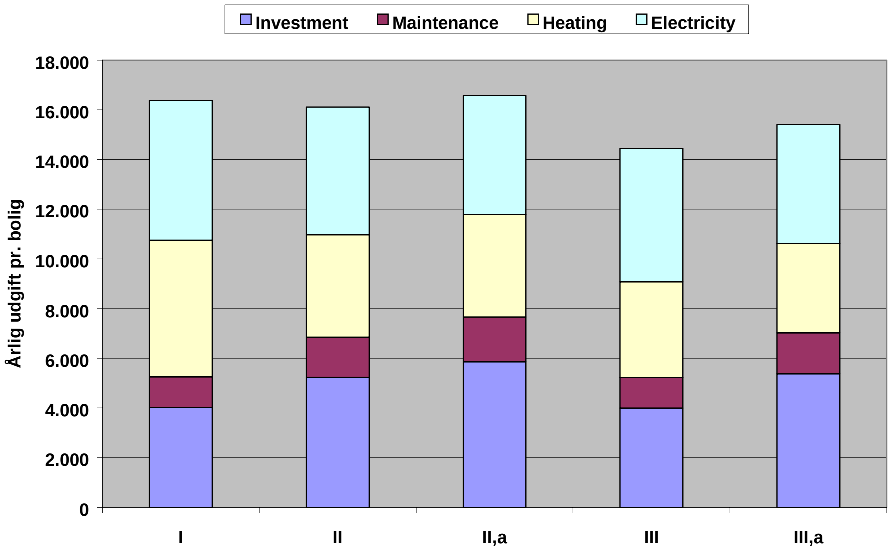


Picture 2. Annual heat and electricity consumption for the reference project (I) and 4 alternative solutions (ventilation with heat recovery (II), this with PV-modules (II a), ventilation with air heating (III) and this with PV-modules and solar heating III a)). Reduced CO_2-emission is 17, 20, 17 and 25 % respectively.

By introducing the measures mentioned for solution III, the heat and electricity consumption will be reduced, as shown in picture 2. The heat consumption decreases with 35 % and the electricity consumption with 15 %. The total result is an environmental improvement with a reduced CO_2-emission of 25 %.

An investment in environmental improvements will be favourable for the tenants if the total costs are not higher than if the dwelling is built with traditional solutions. The total costs can in this case be calculated as the expenses to cover the investment costs, expenses for additional maintenance and expenses for electricity and heating. Picture 3 shows the first years' expenses for electricity, heating, maintenance and the investment in energy environmental measures. The investment is based on an annuity loan over 30 years. The picture shows that part payment of the investment and expenses for maintenance increases concurrently with introduction of different measures but the supply expenses decrease at the same time.

It can be expected that the costs for the tenants increase due to the increasing district heating and electricity prices. A present value calculation includes future rise in energy prices. The result of a present value calculation is shown in table 1. It shows that the total present value is smaller than the reference for all four alternative solutions but it is smallest for the solution with air heating equal to the fact that the total costs during a long period are smallest for this solution. In other words, the investment in ecological measures is a favourable solution for the tenants. A considerable environmental improvement is moreover obtained.



Picture 3. First years' expenses in an average dwelling. The investment is repaid over 30 years and with 5 % p.a. Maintenance is 2 % of the investment. A reference (I) is compared to four alternative solutions (ventilation with heat recovery (II), this with PV-modules (II a), ventilation with air heating (III) and this with PV-modules and solar heating (III a)).

It is furthermore suggested that it as a general requirement must be documented that the dwellings are airtight and without cold bridges in the construction. This can be done by follow-up during the building process, including specialist assistance and by introducing a so called blower door test.

Technical data	I	II	II,a	III	III,a
Investments, I0	2.592.500	3.380.000	3.782.413	2.581.250	3.469.179
Annual maintenance, Ud	51.850	67.600	75.648	51.625	69.384
Annual expenses of electricity and heating, Uf	467.544	389.190	374.474	387.452	352.062
Expected financial life-span, n	30	30	30	30	30
Financial conditions					
Nominal rate, Rn	5%	5%	5%	5%	5%
Rate of taxation of interests, S	0%	0%	0%	0%	0%
Expected price rate of maintenance, Iud	2%	2%	2%	2%	2%
expected price rise rate of supply, Iuf	3%	3%	3%	3%	3%
Calculation of actual interest rates					
Actual interest rate of maintenance, Rrud	0,0304	0,0304	0,0304	0,0304	0,0304
Actual interest rate of supply, Rruf	0,0209	0,0209	0,0209	0,0209	0,0209
Calculation of present value factors					
Present value factor, maintenance, Fnuud	19,50	19,50	19,50	19,50	19,50
Present value factor, supply, Fnuuf	22,13	22,13	22,13	22,13	22,13
Calculation of present value					
Present value of continuing maintenance, Ud	1.011.151	1.318.298	1.475.251	1.006.763	1.353.081
Present value of continuing supply costs, Uf	10.346.604	8.612.665	8.286.987	8.574.186	7.791.014
Investments, Io	2.592.500	3.380.000	3.782.413	2.581.250	3.469.179
Result, present value = Io+Ud+Uf	13.950.254	13.310.963	13.544.650	12.162.198	12.613.274

Table 2. Present value calculation of five alternative solution proposals to the heat supply.

2.2 Total economic analysis concerning use of PV-modules and energy savings in connection with renovation of a one-family house

The house is a 150 m² one-family house from 1970, where we want to give the house an overall renovation where both walls, windows, floor and roof are changed. In the roof a new overhead light will be set up that will improve the daylight quality in the house. In addition to this we are interested in getting ventilation with heat recovery to obtain a good indoor air climate, just as we are interested in solar heating for domestic hot water. The question is just how economical these things are for the house owner.

Energy consumption

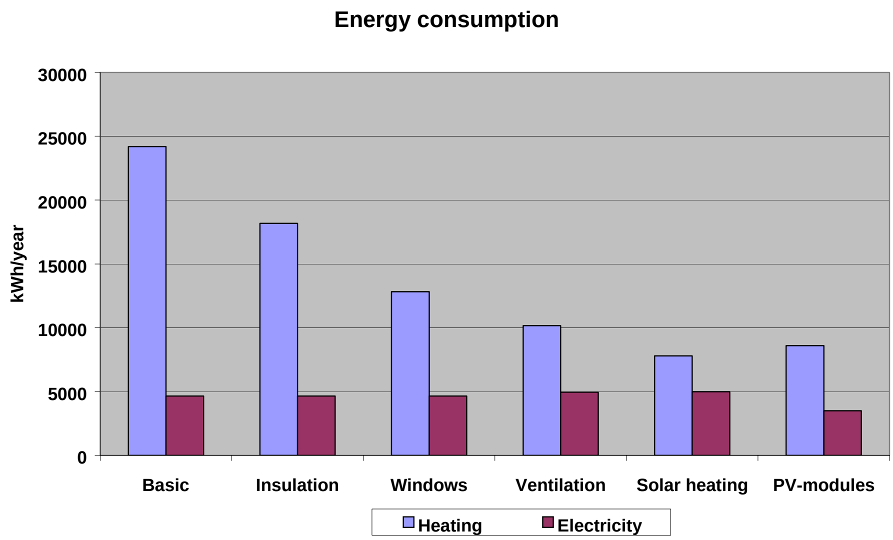
The energy consumption in the house for heating, domestic hot water, lighting and electric appliances can be put as shown in table 3.

	kWh	kWh/m²
Heating	17.556	121
Domestic hot water	3.000	20,7
Electricity	4.640	32

Table 3. Energy consumption for heating, domestic hot water and electricity

The heat consumption for heating is calculated according to the European standard based on the actual measurements and an average indoor air temperature of 20ºC. Energy for the domestic hot water, lighting and electric appliances are assumed on the basis of what is usual in a typical one-family house. Heat consumption in addition to this is net consumption, which means without loss in the oil fired furnace. If the efficiency of the oil fired furnace is assumed to be 85 %, the total annual energy consumption for heating and domestic hot water will be 24.184 kWh equal to 2.418 litre oil per year.

The insulation standard of the house is equal to the requirements on the time of erection, which means below the present standard. It is therefore possible to improve the house from an energy-wise point of view. In picture 4 the annual calculated oil consumption for heating and domestic hot water are shown with five different improvement suggestions.



Picture 4. Energy consumption for heating and domestic hot water and electricity consumption shown for different energy measures when these are added to the reference.

If the external walls are insulated on the outside with 100 mm insulation material and the ceiling and floor with 100 mm too, the heat consumption will be reduced with 25 %. If all windows and doors are replaced by low-energy glass the heat consumption is reduced by further 22 %. If ventilation with efficient heat recovery is introduced at the same time and the house is tightened carefully the consumption is reduced by approx. 11 %. If solar heating is installed (contribution ratio) as a supplemental heat source to the domestic hot water, the heat consumption will be reduced by 10 %. The last column shows the importance of mounting a 6 m² overhead light and a 10 m² PV-system. A modest increased of the heat consumption and a reduction of the electricity consumption will take place, partly from the electricity production in the PV-modules and partly from an increased insulation through the overhead light.

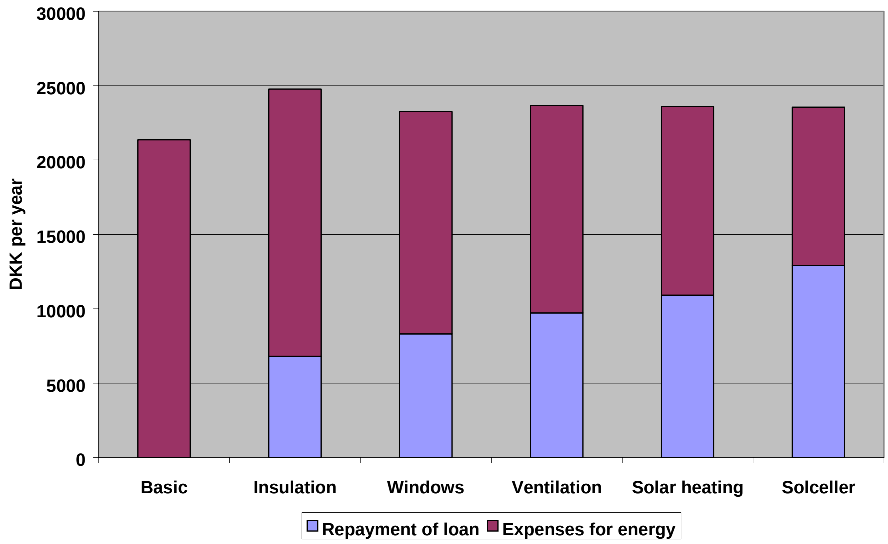
By implementing all the measures a saving of the heat consumption of 64 % can be obtained, equal to a annual oil consumption of 860 litre. The consumption can be reduced further by frequent use of a wood burning stove. The electricity consumption is expected to be reduced by 25 % even though the fans in the ventilation system and the circulation pump in the solar collector system are the occasion of a small increased electricity consumption.

Economy

The different energy saving measures demands an investment. If it is anticipated that the investment is financed by an annuity loan (5 %, 30 years) the first year's expenses for repayment and expenses for energy will be as shown in picture 5. The assumed prices are: electricity 1,66 DKK/kWh, fuel oil 0,56 DKK/kWh and a 50 % tax saving on interest is included.

If an increase of the energy prices is considered the profitability can be calculated by means of the present value method. This is shown in table 4. When the present value of the investment is positive the investment is profitable. The utilisation of PV-modules gives together with the other measures a positive economy in a 30 years period when 50 % funding for the PV-modules are obtained.

By assessment of the profitability the increase of the value of a house is also going to be considered and it can change the result considerably.

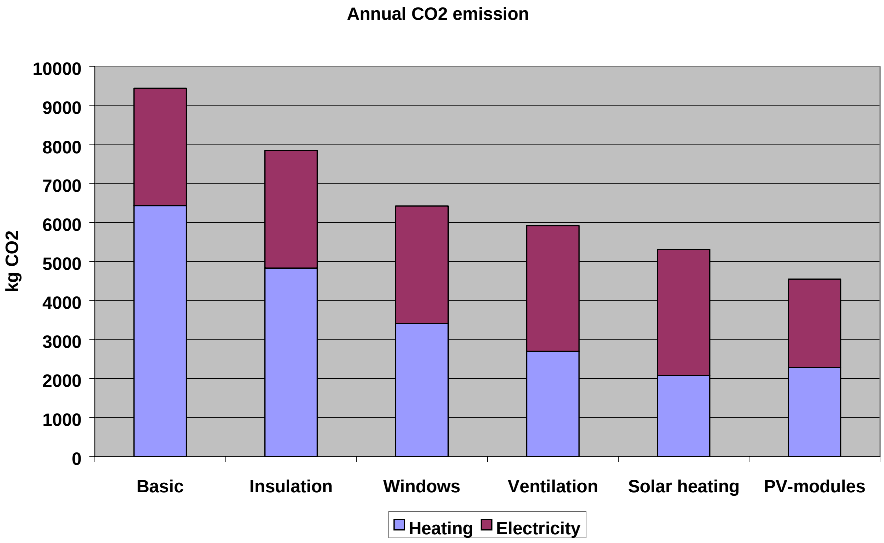


Picture 5. The first year's expenses for heating and electricity and repayment of loan for energy saving measures. For all alternative there is an extra cost in the first years. Over 30 years there is a balance in the economy.

The first year's expenses for the energy saving measures are increased a little (approx. 10 %) but in a number of years it is an advantage to introduce the shown measures on the basis of a total economy assessment and the CO_2 emission from the house is reduced by 50 %.

Environmental improvements

If the energy consumption is calculated to CO_2 emission a reduction from 9.500 to 4.500 tons per year is obtained, equal to 52 % per year. The result is shown in picture 6.



Picture 6. Environmental improvement shown as reduced CO_2 emission.

	Basic	Insulation	Windows	Ventilation	Solar heating	PV-modules
Investment, Io (DKK)	0	170.000	207.500	242.500	272.500	322.500
Current expenses per year, uo (DKK)	0	0	0	200	450	450
Annual saving, bo (DKK)	0	3.394	6.414	7.409	8.677	10.718
Expected economic life, n	30	30	30	30	30	30
Nominal rate, Rn	5%	5%	5%	5%	5%	5%
rate of taxation of interest, S	50%	50%	50%	50%	50%	50%
Expected price increase for current expenses., Iu	2%	2%	2%	2%	2%	2%
Expected price increase for energy, Ie	3%	3%	3%	3%	3%	3%
Real interest rate, expenses, Rru	0,0049	0,0049	0,0049	0,0049	0,0049	0,0049
Real interest rate, savings, Rrb	-0,0049	-0,0049	-0,0049	-0,0049	-0,0049	-0,0049
Present value factor, savings, Fnvb	27,84	27,84	27,84	27,84	27,84	27,84
Present value factor, supply, Fnvu	32,38	32,38	32,38	32,38	32,38	32,38
Present value of current expenses, Uo	0	0	0	5.567	12.526	12.526
Present value of savings, Bo	0	109.902	207.674	239.887	280.967	347.052
Investeringsbeløb, Io	0	170.000	207.500	242.500	272.500	322.500
Present value of the proejct, U=Bo-Uo-Io	0	-60.098	174	-8.180	-4.059	12.026

Table 4. Calculation of present value costs over 30 years for a reference and five alternatives added to the reference. This means ref. (basic) ref. + insulation (insulation) and so on. It is seen that the combined PV/daylight solutions leads to a positive economy over 30 years.

3 Project Examples with Energy Efficient Ventilation Systems

3.1 The Fruehøjgård Hammerthor Project in Herning

The Fruehøjgård Hammerthor project has the potential of actually creating a new Fruehøjgård-model of how healthy solar low-energy building can be realised in the Danish market.

All apartment renovations will include optimised insulation, efficient low-energy windows, energy efficient heat recovery ventilation (80-90 % efficiency, maximum 20-40 W electricity use for ventilation and low noise level less than 25 dB), in some cases also combined with air

heating. Furthermore use of PV-modules to match the electricity use for ventilation either at maximum solar or on a yearly basis (CO_2 neutral ventilation).
During the summer, natural ventilation will be a possibility and demand and user based ventilation rates will be a possibility too. It is intended to utilise passive solar and optimise use of daylight and low-energy solutions will be chosen for all common lightning investments. As part of the building process, special follow-up will take place on avoiding cold bridges and ensuring airtight constructions (including blower door test).

It is the general idea to optimise the complete heating and hot water solution, which will receive heat from a large CHP based district heating network. Consumers will be motivated to save energy by help of local energy meters and water savings will also be introduced. The energy use will be evaluated on a monthly and a yearly basis, e.g. by help of an energy survey system.

3.2 The Hammerthor Building

29 apartments will be realised in the Hammerthor complex in relation to an old small factory, which will be renovated and combined with some new built extensions.

As regards PV-modules it is the idea to integrate 70 m² crystalline PV-modules in the roof in connection to an asphalt-layer roof. Here co-operation with the roof system manufacturer Icopal is foreseen.

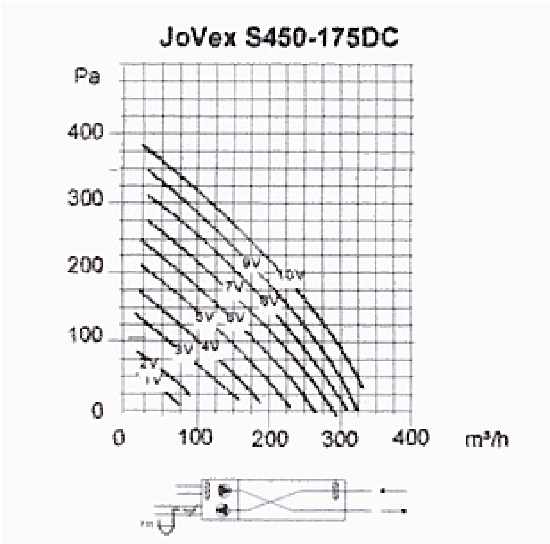
Picture 7 shows the ventilation system built in an apartment in Hammerthor. The ventilation is of the type JoVex S450 from EcoVent.

As experience has shown that it is important to avoid heat losses from HRV systems a solution with individual 15-25 cm thin air to air heat exchangers from the Danish company EcoVent has been chosen for the project. These can be integrated along the walls or loft in a simple way and with simple maintenance possibilities (e.g. change of filter). To make it possible to check the low electricity consumption for ventilation an easy check system for this is foreseen.

Picture 7. JoVex S450 ventilation system.

Picture 8 shows that the power consumption is approx. 35 W.

Picture 9 shows the efficiency of the heat recovery unit, which is a little above 80-85 %.

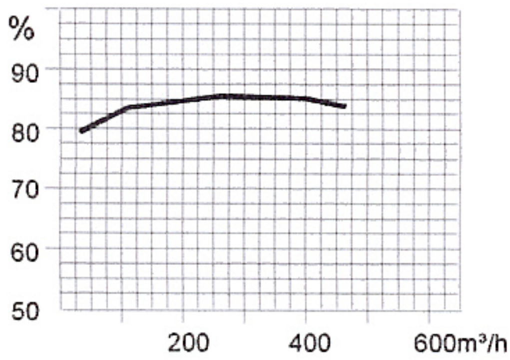


Totalt effektforbrug
Med regulator GR11 og strømforsyning PS250
ved styrespændingstrin (0-10V)

Vcontrol	W	Vcontrol	W
1	9	6	49
2 min*	12	7 max*	58
3	19	8	68
4 normal*	30	9	82
5	38	10	89

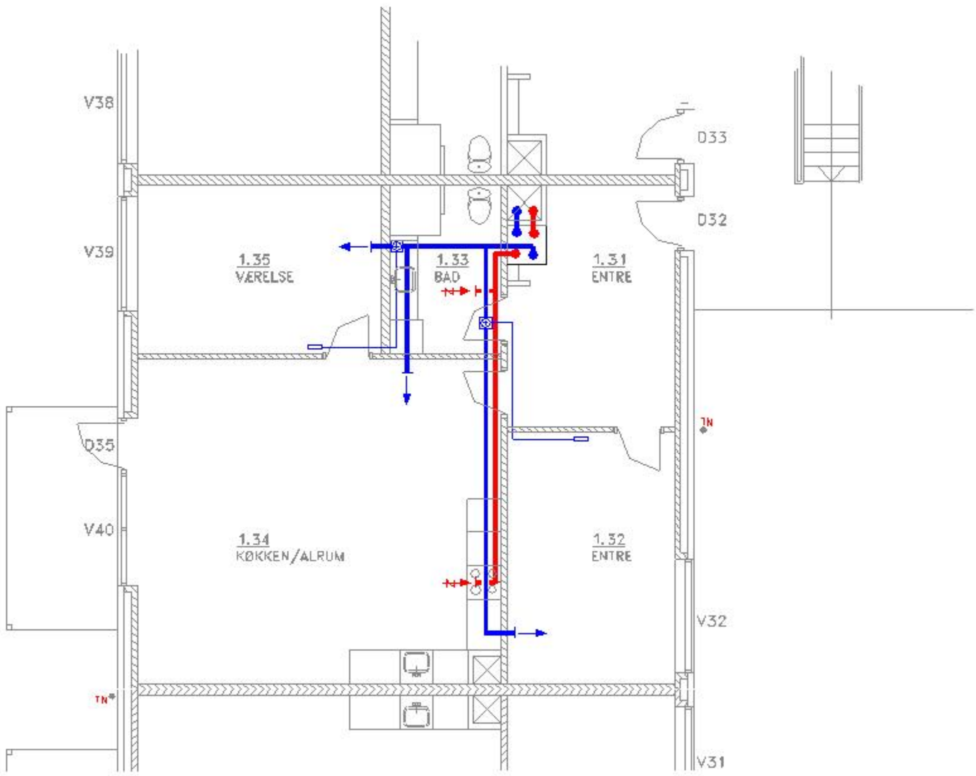
*) Fabriksindstilling

Picture 8. Power consumption.



Picture 9. Heat recovery efficiency.

Picture 10 shows a floor plan of an apartment in Hammerthor which shows how the ventilation system is installed in the apartment.



Picture 10. Ventilation system in an apartment in Hammerthor.

3.3 CO_2 Neutral House

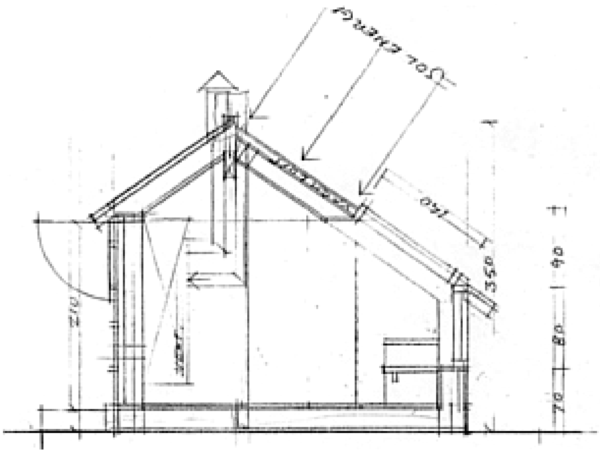
It is intended to realise a series of R&D activities concerning PV and use of heat pumps in Valby, Copenhagen, as part of the realisation of a local demosite for PV technology in connection to the large PV implementation plan for PV in Valby (see www.solivalby.dk).

In connection with this a CO_2 neutral house has been proposed, which can be realised by help of roof integrated PV panels and use of an electricity driven heat pump system in combination with a ventilation solution with countercurrent heat recovery and air heating.

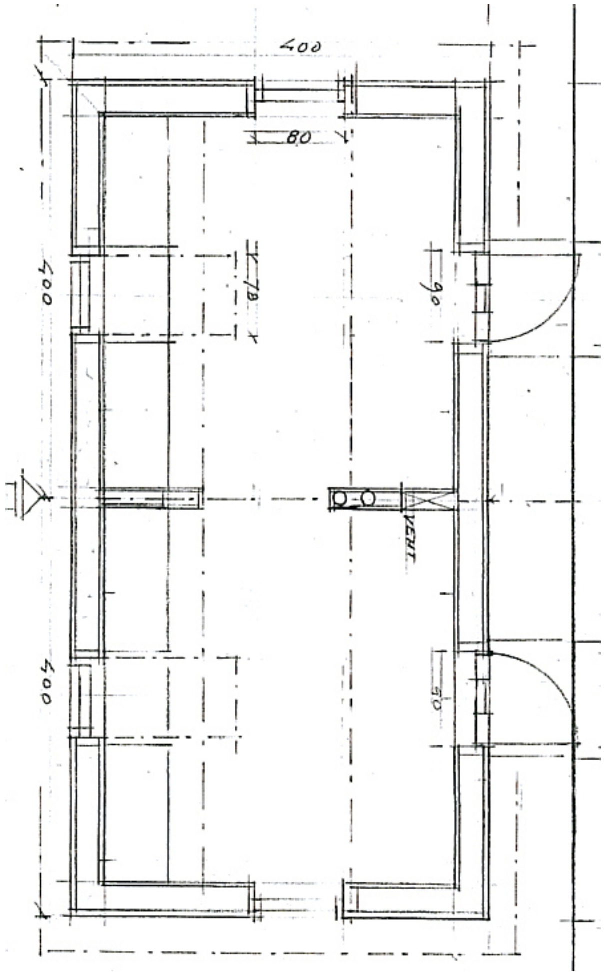
The idea is to cool PV modules by the evaporator in a heat pump, and in this way improve the electricity output of the PV modules and increase the heat pump COP factor. Calculation show that this can form the basis of a CO_2 neutral building.

Picture 11 and 12 below show drawings of a CO_2 neutral test house where the only 15 cm thick heat recovery ventilation unit and ducts are built into a partition wall.

This test house we build untill 1st of March where tests of different types will start first wit ha normal HRV system and later also with a combined HRV/air heating system in combination with a heat pump. PV panels are of the UNISOLAR type and in integration in a metallic roof from …. Installation is made with cellerlose fibre and a totally air tight solution is ensured.

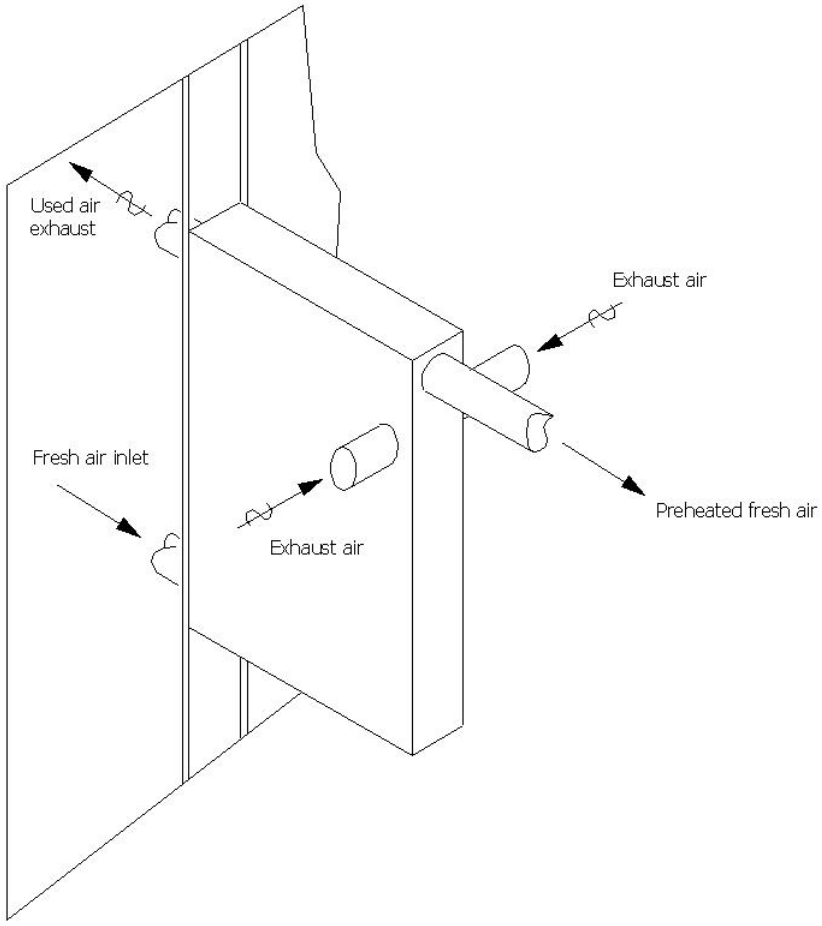


Picture 11. Sectional elevation of the CO_2 neutral house.



Picture 12. Cutting plan of the CO_2 neutral house.

Picture 13 below shows the partition wall with ventilation pipes in more detail.



Picture 13. Interior partition wall in which an only 15 cm thick a heat recovery unit and ventilation pipes are installed.

3.4 The Dalgasparken Building

This is a very interesting building project which includes a 5 storey building in the centre of Herning and aims at realising 42 apartments in the multi-storey building based on the economy shown in chapter 2.1. The apartments are each 110 m² in size. As a follow-up project, another 35 apartments in a 2-storey building will be realised.

The Fruehøjgård Housing Association has here been running an invited architect competition until June 2002 which was also used to optimise the economy of the project because contractors were involved in the 5 competing architectural teams. This is called a reverse tender process where the building economy is told to the competitors from the beginning. In connection to this the municipality of Herning allows extra costs for the energy saving solutions when the competitors can show that the lifecycle costs are improved for the tenants.

In relation to the architectural competition leading Danish specialist consultants, Sven Bertelsen and Henrik Davidsen were involved concerning the so-called "value" building process and were responsible for an innovative assessment system, where user value counts 20 %, environmental design is 15 %, technical design is 10 %, total economy is 10 % and building process is 15 % and architecture counts 30 % in the evaluation. This way of thinking has been created in connection to the Danish building development initiative “Project House” which aims at “double quality at half costs”. In relation to this the project is also included in a co-operation called builders for sustainability which is headed by the Danish Commerce and Housing Agency.

In connection to the architectural competition, the architects was asked to fill in the so-called Green Build energy and environmental point system to increase focus on energy efficiency and sustainability in general.

For the first phase with the 42 apartments in the 5-storey building it is aimed to install 105 m² PV-modules to be able to match electricity use for ventilation on a yearly basis as a complete CO_2-neutral solution. For the following 35 apartments another 85 m² PV-modules will be realised also here with support from the Danish SOLAR-1000 programme.

The Fruehøjgård Housing Association has pointed to the possible use of air heating in connection to heat recovery ventilation as an optimised heating solution, e.g. in combination with only one or two radiators in the living room. This will be tested in some of the apartments.

Building started in October 2002 and it is aimed to finalise building in October 2003.

Picture 14. Main entrance of Dalgasparken.