

COST EFFECTIVE PV ASSISTED ENERGY EFFICIENT VENTILATION SYSTEMS FOR HOUSING

Peder Vejsig Pedersen, Cenergia Energy Consultants, Sct. Jacobsvej 4, 2750 Ballerup, Denmark, Phone: +45 44 66 00 99, fax: +45 44 66 01 36, e-mail: pvp@cenergia.dk, www.cenergia.dk.

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 more 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 figure 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. This type of technology has been developed in connection to an EU-Joule project, PV-VENT which was realised from 1997 to 2003. Since then several initiatives concerning practical applications have been made in Denmark, and in connection to a new EU-6FP project, Demo-house, these solutions will also be introduced in e.g. Poland and Hungary.

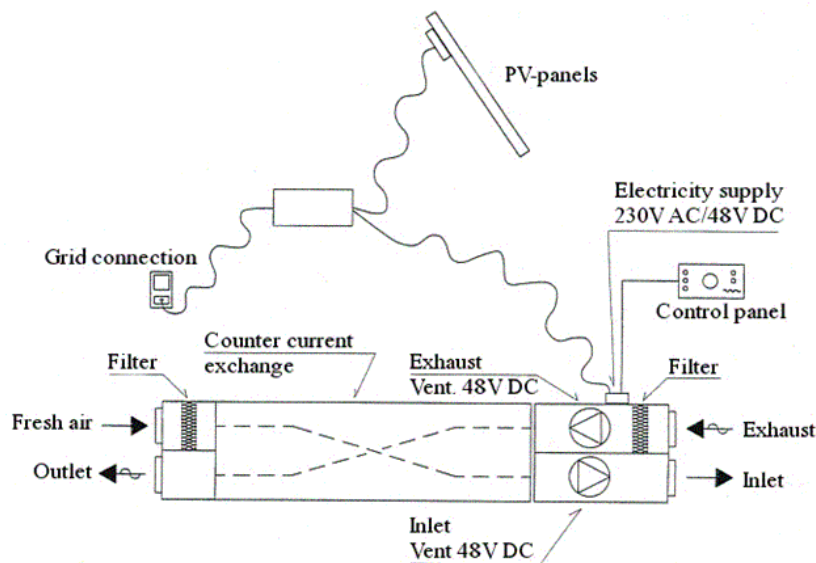


Figure 1. PV-Vent ventilation system.

The PV-Vent concept here expresses a connection between utilisation of the sun as an 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 can produce direct current that immediately can drive DC motors with a minimal electricity consumption in a new generation of effective counter flow heat exchangers.

Two types of PV-VENT systems can be considered here. One solution is where the PV-electricity is used directly by the energy efficient fans and supplemental electricity is taken from the electricity grid as in figure 1, and another solution is where PV-modules are grid connected and designed to match a reduced electricity use for ventilation on a yearly basis. The used type of heat exchanger from the Danish company EcoVent is of aluminium and utilise the counter flow 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 per housing unit.
- ✓ 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.

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

In the following two examples from Denmark are shown how building integrated PV-modules can be used already today in a cost effective way together with an energy saving package based on PV-module prices obtained in the Danish SOLAR-1000 programme (35-40 DKK/Wp).

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

The Dalgasparken Building project 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 later in this chapter. 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 the so-called “value” building process with an innovative assessment system was used, 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 were 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 CO₂-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 and the EU-Resurgence programme.

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



Figure 2. Main entrance of Dalgasparken.

Economy and savings.

The investment in a traditional heat supply to the apartments (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 CO₂ 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).

	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.

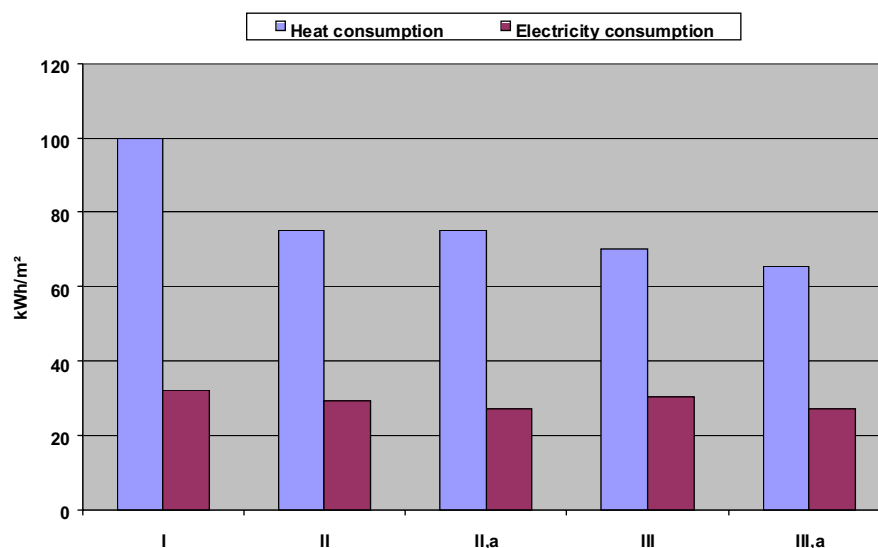


Figure 3. Annual heat and electricity consumption for the reference project (I) and 4 alternative solutions (ventilation with heat recovery (II), this with PV-modules (II a), ventilation with air heating (III) and this with PV-modules and solar heating III a)). Reduced CO₂-emission is 17, 20, 17 and 25 % respectively.

By introducing the measures mentioned for solution III, the heat and electricity consumption will be reduced, as shown in figure 2. The heat consumption decreases with 35 % and the electricity consumption with 15 %. The total result is an environmental improvement with a reduced CO₂-emission of 25 %. And in figure 3 it is seen that a good total economy for the tenants is obtained.

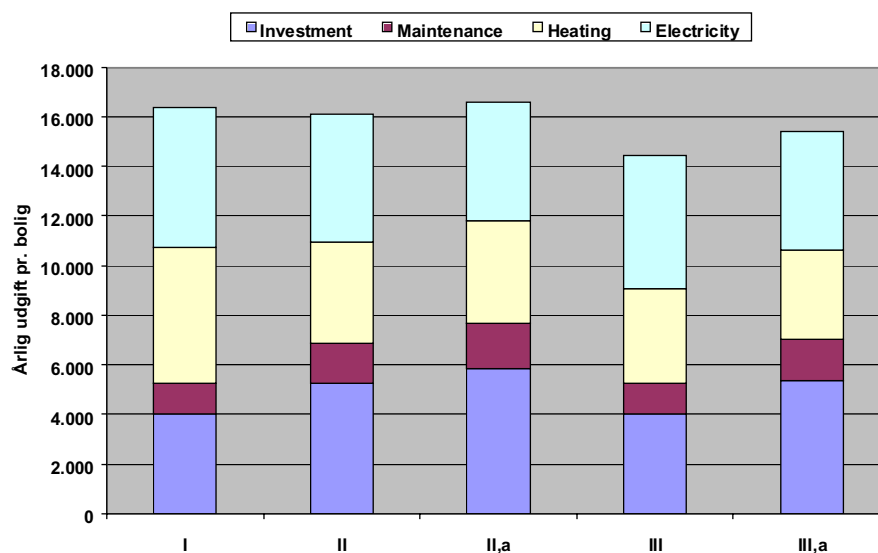


Figure 4. First years' expenses in an average dwelling. The investment is repaid over 30 years and with 5 % p.a. Maintenance is 2 % of the investment. A reference (I) is compared to four alternative solutions (ventilation with heat recovery (II), this with PV-modules (II a), ventilation with air heating (III) and this with PV-modules and solar heating (III a)).

In the Dalgsparken project 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.

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 (CO₂ 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.

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.

Figure 5 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.



Figure 5. JoVex S450 ventilation system from EcoVent.

Figure 6 shows that the power consumption is approx. 35 W.

Figure 7 shows the efficiency of the heat recovery unit, which is a little above 80-85 %.

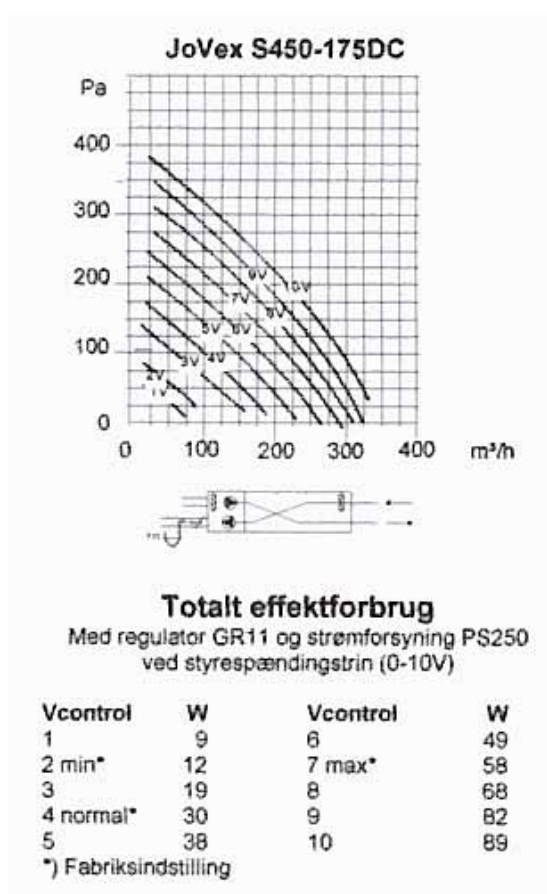


Figure 6. Power consumption.

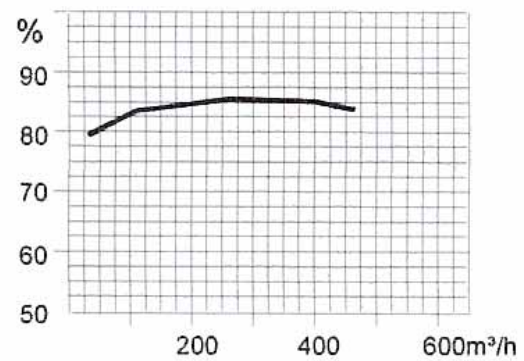


Figure 7. Heat recovery efficiency.

Figure 8 shows a floor plan of an apartment in Hammerthor which shows how the ventilation system is installed in the apartment.

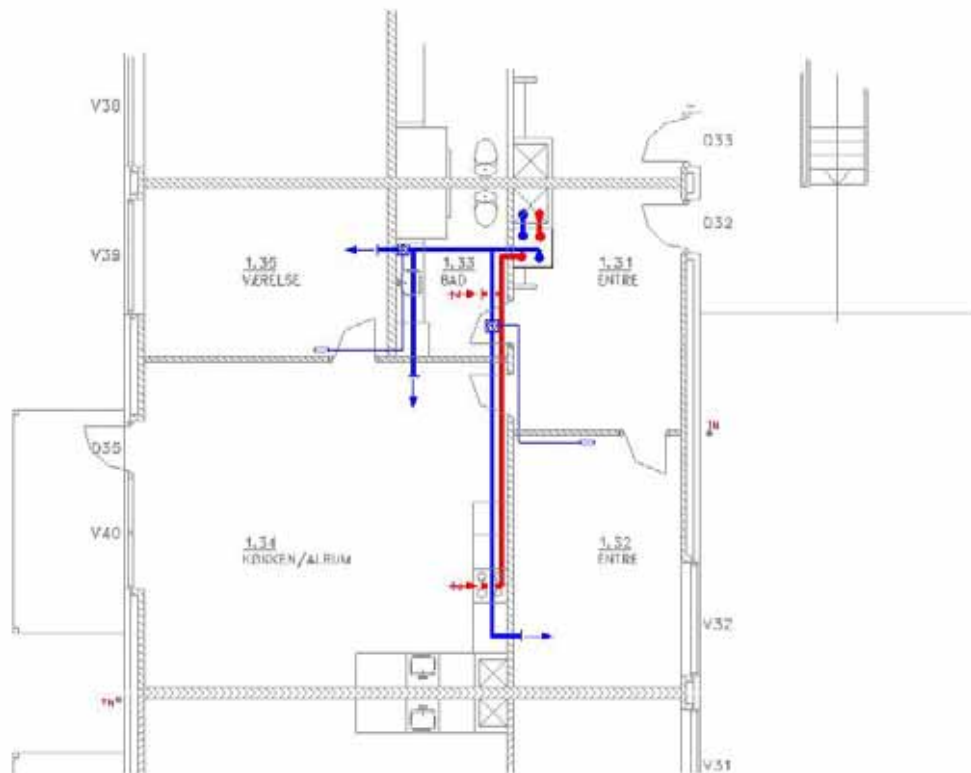


Figure 8. Ventilation system in an apartment in Hammerthor.

CO₂ 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 CO₂ neutral test house has been developed.

Figures 9-11 show the CO₂ neutral test house where the only 20 cm thick heat recovery ventilation unit and ducts are built into a partition wall. Besides is used a south oriented combined air solar collector / PV panel roof from the Finnish company Rannilla.

The constructions are made with cellulose fibre and a totally air tight solution without cold bridges has been ensured with insulation values of 1,5 W/m²C and energy windows from Velfac / Velux. By help of the energy efficient heat recovery system from EcoVent the overall design is quite near to being a “house without a heating system concept”.

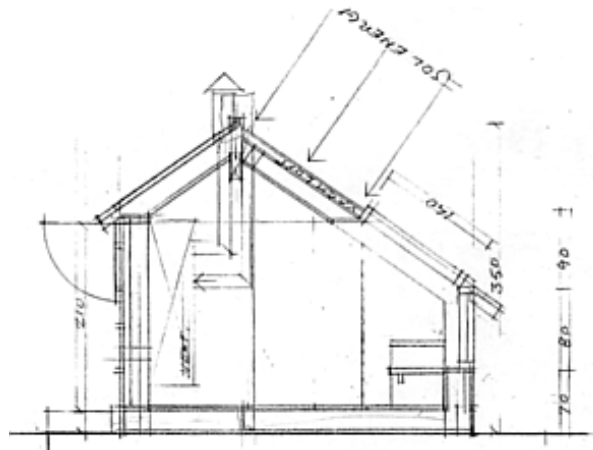


Figure 9. Sectional elevation of the CO₂ neutral house, which means that a normal heating system can be avoided. And the very little heat use can be covered by air heating and a very small heat pump which can also provide DHW.

CO₂ neutral test housing unit from Denmark



- Compact only 20 cm thick heat recovery ventilation unit placed in a partition wall. (EcoVent)
- Preheating of ventilation air in metallic roof with 13 m² PV modules covering ventilation and lighting demand from solar energy.
- Wooden air tight housing construction with paper granulate-insulation and no cold bridges. (U-value: 0.15 – 0.18 W/m²°C)
- Low-energy windows. Velux / Velfac.
- A "house-without-heating-system" concept



Figure 10. Exhibition of CO₂ neutral test house at Toftegårds Plads in Copenhagen (until end of 2003).

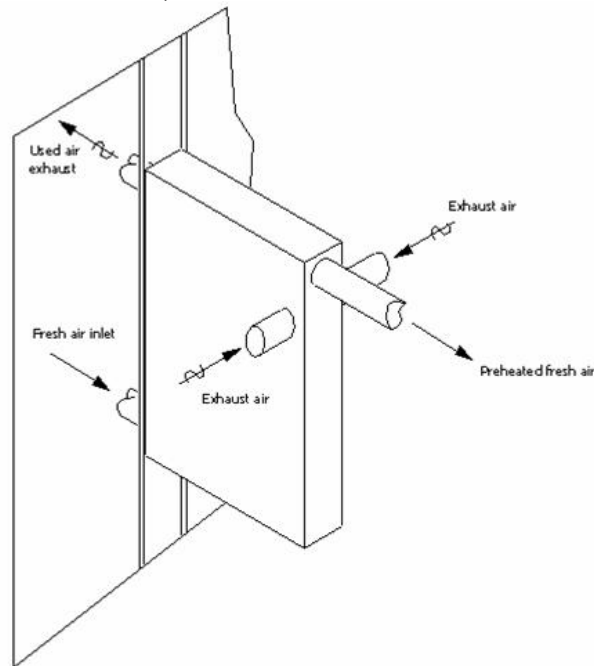


Figure 11. Interior partition wall in which an only 20 cm thick a heat recovery / air heating unit and ventilation pipes can be installed.

CO₂ neutral test house is developed by Cenergia, Nielsen & Rubow architects and Borry Henriksen.

CO₂ neutral low-energy wooden test house with paper granulate insulation and optimised ventilation with heat recovery

The energy and environmental specialist company Cenergia has in March 2003, in cooperation with the companies Borry Henriksen APS and the architects Thure Nielsen & Rubow, built a small 32 m² mobile low-energy wood house with paper granulate insulation from the company Ecofiber and with a 80-85% efficient heat recovery unit from EcoVent.

A new thing is that the wood construction system has been constructed in a way to make the house completely airtight and without cold bridges. Monitoring tests of air leaks of the house have shown the leaks to be so small that they nearly cannot be measured by Cenegia's "blower door test" equipment. Besides a thermo photography shows that there are in fact no cold bridges at all.

For the first time in Denmark there has, in connection with this project, been used a structural principle introducing a wood concrete plate / rabbet unit with a diffusion open membrane which according to Borry Henriksen makes the construction completely secure as to humidity. Built-in humidity sensors will be able to substantiate this. The paper granulate insulation of the house has been incorporated as to set the wall insulation in contact with the roof insulation, this has been done due to the settling of the insulation granulate.

The test house was built at the Ganløse Sawmill near Copenhagen where they also manufacture weekend cottages.

For the test house there has been used a level of insulation according to the new Energy Performance Directive for Buildings, EPD which is expected to be introduced in Denmark in 2005/2006, with an improvement in the level of insulation of approx. 33% as compared to the insulation level of today. Further energy windows, from the companies Velfac and Velux, have been used, and as regards ventilation a high-efficient heat recovery unit with a width of 20 cm only, was placed in a partition wall and with a low electricity consumption (max. 20-30 W).

The heat recovery unit which requires only short channel elements in order to take air in and out of the house as well as a short air intake channel in the house. Thus the installation price of the heat recovery unit can be kept at a low level, and at the same time a balanced ventilation can be obtained and a good indoor climate can be achieved.

On the metallic roof facing south PV modules are installed. This system has been developed by the Finnish manufacturer Rannilla, in such a way that the intake air is directed into a gap under the total roof so a solar heating of the ventilation air is possible.

At the same time the idea is that the PV modules (about 13 m²) produce electricity which on a yearly basis makes the house CO₂ neutral as regards ventilation and lighting.

PV-VENT system for renovation project

At Frederiksberg in Copenhagen several projects with use of PV-modules together with energy efficient heat recovery ventilation systems has been introduced. E.g. with solar ventilation towers for 167 apartments in Lineagården, PV-VENT systems at Lauritz Sørensens Gård with new apartments in the attic and PV-VENT system at Havremarken with individual heat recovery ventilation systems.

PV-VENT exhaust ventilation systems

New PV operated exhaust ventilation systems have been developed where solar energy can be used to:

- Ensure an increased ventilation rate for solar heated rooms
- Ensure an extra ventilation especially in the summer for natural ventilated buildings.

Examples of this is e.g. the PV assisted ventilation system for a 30 m² sunspace in Denmark as shown in figure 12 and PV assisted natural ventilation for the Engstrand School in

Hvidovre, near Copenhagen, Denmark, to be installed in November 2003 as illustrated in figure 13.



Figure 12. PV assisted ventilation system.

Figure 13. PV assisted natural ventilation system for Engstrands School.

PV-implementation plans in Valby Copenhagen

Cenergia co-ordinates together with Copenhagen Energy and Urban Renewal Copenhagen the work on a large-scale implementation plan for PV-modules in Valby in Copenhagen where 150.000 m² of PV-modules should be mounted until 2025. The idea is here to work with a very ambitious PV-implementation plan for an entire city part, Valby in Copenhagen. Here it is the aim when the sun is shining to cover up to 50% of the electricity supply from PV-modules in 2025, equal to 15% on a yearly basis.

The advantage of the suggested strategy is that the implementation of PV-modules in Valby, which has 45.000 inhabitants, can be a model of how large areas of PV-modules can be integrated in a whole city in a well-ordered way.

Today the installed electricity capacity in Valby is approx. 25 MW. If the consumption can be reduced so an installed electricity capacity of 20 MW is enough then a capacity from PV-modules of 10 MW will cover half of the electricity consumption when the sun is shining. (See also: www.solivalby.dk).

In figure 14 is shown examples of PV integration solutions shown in the “PV in Valby” website, www.solivalby.dk and other PV integration examples together with visualisation examples.

Besides is shown proposed PV integration for a new school in Valby in an old industrial area which is being redeveloped.

Here the Copenhagen Municipality has allocated funding to realise a PV demo site with 600-900 m² PV area and many different PV integration techniques.

Total budget is around 1 MEURO.

Examples of building integrated PV solutions:



Folehaven ecological laundry.



Detail from Folehaven.



CO₂ neutral test house. PV integrated in metallic roof.



CO₂ neutral test house with air solar collector function.



CO₂ neutral test house.



Lauritz Sørensensgård, PV integration detail.



Housing project Lauritz Sørensensgård, Frederiksberg
in Copenhagen. PV placed on top of ventilated
Canadian solar wall.



PV in old roof in housing block Trekanten at Frederiksberg



Trekanten, PV panels integrated together with solar ventilation towers which have built in duct work for heat recovery ventilation systems



PV on ventilation chimneys at Lundebjerg Skovlunde



PV panels in facade



PV panels at DTU



PV panels on family house



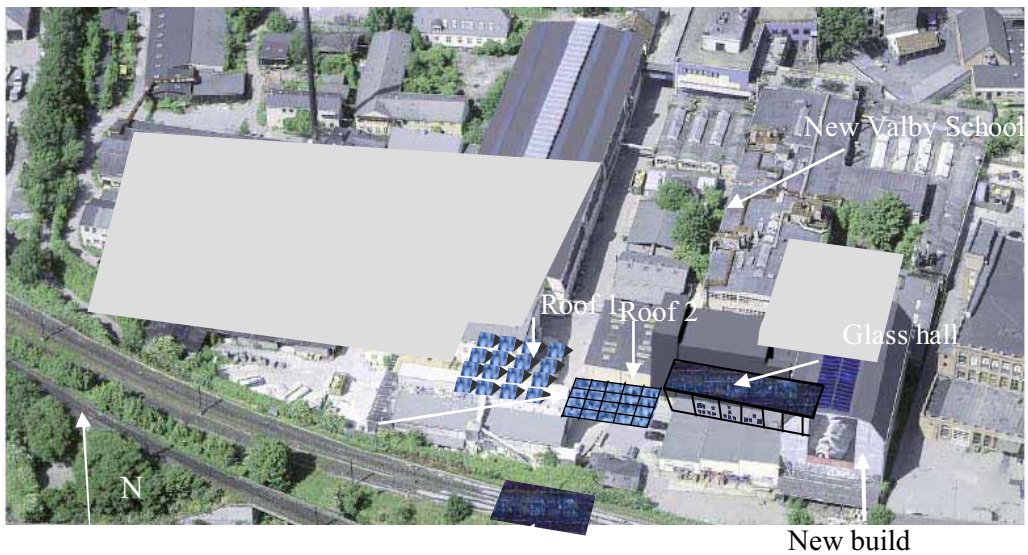
PV panels on flat roof at union SID head quarters in Copenhagen



PV shading systems (ALU-PV) at students house in Herning



PV shading systems (ALU-PV) at students house in Herning



New school in Valby with local PV demosite using 600-900 m² of PV-panels.

Examples from www.solivalby.dk

Visualisation:



Examples:



The SunVent Project

In 1998 the housing association, “PrivatBo” and “Frederiksberg Housing Foundation” obtained EU-Thermie support for a solar low energy retrofit housing project, SUNVENT”. The aim of this project is to establish so-called “solar ventilation towers” in connection to a retrofit of 167 apartments at Frederiksberg near Copenhagen in Denmark. At the same time partners from Germany (EBÖK) and Italy (Metec Engineering) has participated to give a feed-back on the proposed technology and participate in making re-view of the project as basis of proposing general recommendations for the European market.

The reason to make a suggestion to the builder to implement the use of “solar ventilation towers” as a new building element was due to experience gained from a previous EU-Thermie supported project at Østerbro in Copenhagen where counter flow heat recovery ventilation was utilised for 80 apartments with good results. Here it was a demand that the exhaust air was lead away over the roof of the building, and it was possible to integrate the exhaust ventilation ducts in a façade insulation project. But in many cases this is not possible and then it is necessary to make a space-demanding ventilation duct inside the building.

An alternative to this is instead to install a ventilation tower on the outside of the building (south or east/west facing facade) and place all the ducts here. At the same time it is possible to design the ventilation tower so the surface of it can be used to produce solar energy.

In figures 1 and 2 it can be seen how the architect Klaus Boyer Rasmussen from SolarVent has designed to integrate “solar ventilation towers” in the “SUNVENT” project in the housing estate “Lineagården” at Frederiksberg in Denmark. At the website www.solarvent.dk, there is more information about the project.



Figure 14. Solar Towers, Frederiksberg



Figure 15. The ventilation towers, Lineagården, Frederiksberg

The Solar Ventilation Towers

The “solar ventilation tower” is built with a surface of dark green painted perforated aluminium plates as an unglazed solar collector, which can preheat the ventilation air. A similar design is known from the so-called “Canadian Solar Wall”.

For some of the “solar ventilation towers” there is besides used a PVVENT design where building integrated PV modules is placed in the top part of the “solar ventilation tower” to run the ventilation fans.

A ventilation unit of the counter flow type with 80-90% efficiency and 30-40 W in the electricity use per apartment is placed in the attic. It is possible to make individual user control of the ventilation rate for each apartment by help of a special control box placed in the apartment. Also solutions with individual heat recovery units placed in each apartment are being demonstrated at Frederiksberg. Based on the success with the “SUNVENT” project the “Frederiksberg Housing Association” has recently decided to use the same heat recovery ventilation design in connection to an urban renewal project with 170 apartments at “Lauritz Sørensens Gård”. Here with an interior “shaft” solution in connection to the use of new prefabricated bathrooms and PV modules placed on the roof to run the ventilator fans.



Figure 16. Counter flow heat recovery unit.



Figure 17. 200 m² PV panels integrated in the south facing roof.

Calculation of energy consumption for heating and domestic hot water for old apartment blocks in Copenhagen.

In the following is shown the results of a calculation according to the EN-832 standard concerning energy consumption for heating and domestic hot water for old apartment blocks in Copenhagen where the size of the apartments are 55 m².

For the reference situation we look at old un-insulated apartment blocks in the centre of Copenhagen, where a large scale renovation is aimed at. Here the results of using two different ventilation strategies are studied according to the two demands we have in the Danish building regulations for new build. This is A: 35 litre of fresh air per second from kitchen and bath room (equal to 126 m³/h), which is a high demand for small apartments and B: an air exchange of 0.5 per hour.

The effect of using heat recovery on the ventilation air is presented and here there is a special view to the effect of ensuring a very good air tightness at the same time. An air exchange of maximum 0.1 per hour is aimed at, and results of 0.2 – 0.4 per hour is also illustrated and shows a high effect on the results.

The analysis is both presented for a 5 storey housing block where the roof is maintained as it is, and a situation where new build apartments are created in the roof are also illustrated.

In the calculation it is presumed that pipe distribution losses are 20% of the total heating demand and that domestic hot water consumption are 35 kWh/m² per year.

The results of reducing pipe heat losses to 10% and introducing 30% water consumption savings are also shown together with the effect of improving the energy glass in the windows to a 3 layer glass.

Besides there is an illustration of the effect of introducing solar heating to cover 65% of the yearly DHW demand.

There is also an illustration of the effect of including electricity use for ventilation in the analysis, which is particularly relevant in connection to the new EU-energy performance directive for buildings and certification schemes in connection to this.

The results concerning CO₂ emissions are also shown and there is also a calculation for concrete housing blocks of a similar size for comparison.

At the end there is a presentation of a total energy analysis which also includes the energy supply system with and without combined heat and power production. Here with 20% distribution losses and CHP production with 36% electricity efficiency together with 54% heat utilisation compared to normal electricity production with 36% efficiency alone.

The saved fuel based on CHP can be found by multiplying the delivered heat by 1,33 and adding it to the heat saving.

Renovation of 5 storey housing block with heat recovery ventilation in all apartments

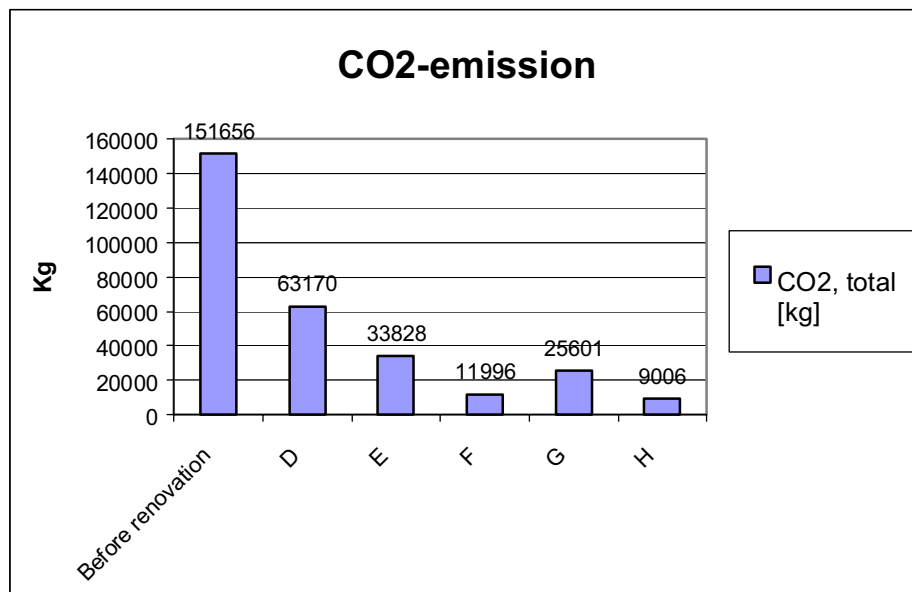
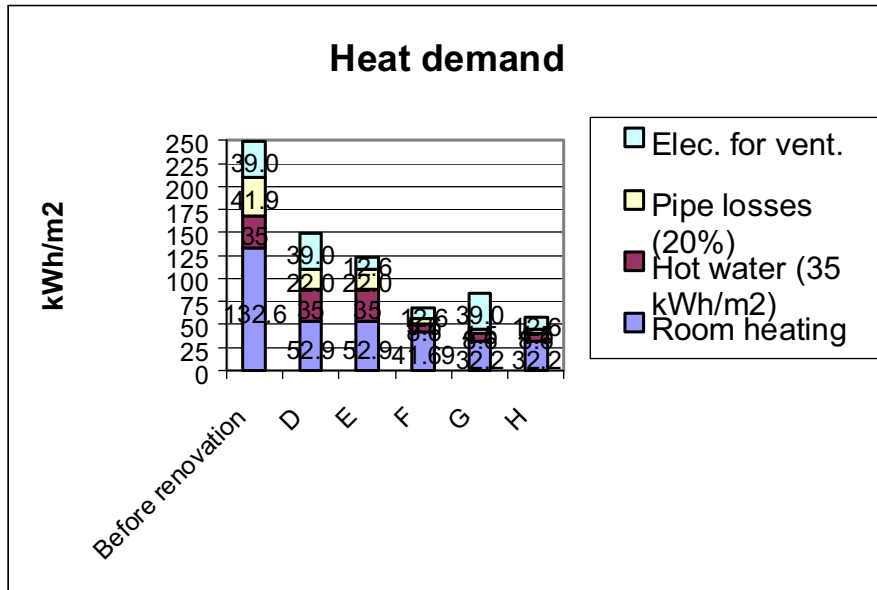
Below are showed energy results for a building block with 170 old apartments of 55 m² each in the following situations:

1. Before renovation
2. D: Renovated with ventilation with heat recovery with 35 l/s air and 0,1 /h natural air infiltration.
3. E: As D and furthermore heat recovery ventilation with low electricity use equal to 12,6 kWh/m²a heat loss instead of 39 kWh/m²a, where electricity use is transferred to heat by a factor of 3.
4. F: Mechanical ventilation with 0,5 /h air change and 0,1 /h natural air infiltration. Furthermore 3 layer glass windows with u-value of 1,2 W/m²K, solar heating system with 65 % saving for hot water and low energy ventilation equal to 12,6 kWh/m²a. The pipe loss here is only 10 % instead of 20 %.
5. G: As F but building block of concrete
6. H: As G and low electricity use of 12,6 kWh/m²a instead of 39 kWh/m²a.

More over CO₂ emission is also calculated in the following way:

For district heating CO₂ emission is 0,2 kg/MWh and for electricity CO₂ emission is 0,6 kg/MWh.

[kWh/m ²]	Before renovation	D	E	F	G	H
Room heating	132.6	52.9	52.9	41.69	32.2	32.2
Hot water (35 kWh/m ²)	35	35	35	8.6	8.6	8.6
Pipe losses (20%)	41.9	22.0	22.0	5.6	4.5	4.5
Total	209.4	109.9	109.9	55.9	45.3	45.3
Elec. for vent.	39.0	39.0	12.6	12.6	39.0	12.6
Total with elec. use	248.4	148.9	122.5	68.5	84.3	57.9
CO ₂ , [kg/kWh per m ²]	0.0653	0.0454	0.0295	0.0187	0.0325	0.0166
CO ₂ , total [kg]	151655.72	63169.93	33828.06	11995.76	25600.51	9006.28



The reduced electricity use per m² for ventilation (4,15 kWh/m²a) can on a yearly basis be covered by electricity production from 2,5 m² PV modules per apartment.