Optimum ventilation design and use of healthy building materials

Within present years there has been much focus on how to secure a good indoor climate. At the same time it has been proven that the many new types of building materials that are used today can be a considerable reason to a poor indoor climate. This is one the reasons why the requirements to ventilation have been raised in the latest building regulations, BR-95. Many people think in this connection that there is a great need to do more to protect ourselves against building materials that are degassing during long period and thus implement on the indoor climate in a negative way. E.g. professor Fanger from the Danish Technological University's Institute of Energy Technology, the department of indoor climatic research, think that we are going to introduce more source control and thus avoid the poor building materials.

In connection with the EU/Thermie project European Green Cities, where e.g. Cenergia, the urban renewable company SBS Byfornyelse and the municipality of Copenhagen are partners, one of the partial aims is to try to develop optimum ventilation solutions in combination with use of healthy building materials.

The intention is on the basis of an energy saving target to examine if use of healthy building materials can cause that we can be satisfied with a smaller basic ventilation than required in the present building regulations, so user and moisture control of the ventilation will be possible to a large extent.

Indoor climatic conditions

Adults produce by medium activity approx. 18 litre CO_2/h. CO_2 is often used as a standard for the air quality regarding how it is influenced by human beings. The content of CO2 is 300-500 PPM (parts per million) in the air outside. The requirements to the air inside are usually approx. 1000 PPM, sometimes up to 1500 PPM.

The content of CO_2 can vary in a sleeping room from 500 PPM by day (by airing) and up to 3000 PPM by night. To secure a CO_2 level of approx. 1000 PPM in houses an air change of 25 m^3/h per person is considered to be sufficient. But if there is a smoker in the room the demand is increased to 625 m^3/h per person.

The moisture inside the house should at the same time be kept at a suitable level with a relative humidity of 30-60%.

The standard for a required air change in houses is usually fixed at 0.5 times per house. If it is above this level the result can be too dry air in the winter.

The standard demand to air change in wet rooms as kitchen and bathroom is 20 l/s (72 m^3/h) and 15 l/s (54 m^3/h) respectively, a total of 126 m^3/h. In small houses (less than 120 m^2) the demand of 126 m^3/h the toughest. The ventilation demand increases in large houses due to the requirements of an air change of 0.5 times per hour.

In sleeping rooms there are special requirements to a high air change to avoid problems with house dust mites, which might result in allergy and that are on a high level in September/October. Tests have proven that if you can secure that the moisture does not exceed 7 g water vapour/kilo air it will have a useful effect on avoiding house dust mites. Another test has shown a very useful effect by use of mechanical ventilation with both air extraction and air supply. Ventilation in sleeping rooms of approx. 5 l/s per person will usually be sufficient.

A Canadian examination have also shown the necessary requirements to a minimum ventilation due to the indoor climatic conditions (regarding particles, VOC, formaldehyde, radon and CO_2). The demand varied between 10-50 l/s (36-180 m^3/h) so the highest demand was due to particles and CO_2 (1000 PPM). At the same time the worst problems with the indoor climate seemed to be from spring to autumn.

At the Institute for Energy Technology at the Technical University in Denmark, the Department for Indoor Climate Research they work with development of models to anticipate how the air quality will be inside a building before it has been built. This does e.g. happen in connection with a database with healthy building materials, Indoor Air Pollution Sources in Buildings. The idea is here to work with source control about degassing from building materials. The philosophy is that health and comfort are the most important background for making buildings and approx. 40% of the total energy consumption are for this purpose.

Tests at the Technical University in Denmark have shown that the three most important things that influence on the indoor climate is human beings, degassing from building materials and ventilation systems that have not been maintained.

In connection with the development of the database of healthy building materials they have at the Technical University made a sensory test (odour test) of different building materials with 40 testees, after the materials had been ventilated one time per hour in 30 days after they had been provided. The temporary results are shown in figure 2.19.

	Number of unsatisfied (%)
Jointing materials	3-4
Medium hard floor covering (vinyl, polyelefine and linoleum)	8-89
Hard floor materials (mainly wood)	45-93
Carpets	82-97
Ceilings	17-93
Walls (including paint)	
Concrete	75-85
Plaster	33-94

Figure 2.19. Temporary results of test of how building materials influence the indoor climate made at the Technical University in Denmark.

As you can see there are very large variations. To be sure not to use materials that influence the climate regarding odour, it is important to develop a practise for construction, to document how the used materials will react in this field.

Energy consumption for ventilation

Swiss research has tried to find an improved basis for how to define requirements to ventilation in houses, also houses with ventilation with heat recovery and air ducts for preheating of the ventilation air in the ground.

They have e.g. defined how much electricity it is reasonable to use compared to the size of the ventilation system. On this background they work with a required maximum electricity consumption of 0.35 W/m^3 per hour for ventilation systems with heat recovery, which in Denmark is equal to approx. 44W (at 126 m^3/h) and about 50% if it is an exhaust ventilation system. Compared to this the requirement in the Danish building regulations from 1995 is 87 W.

For ventilation systems with heat recovery a size has been defined, ETA, the electrothermal utilisation factor, which is the ratio of the heat output to the electricity consumption. In test houses in Switzerland measurements have shown between 5 and 11 ETA and the suggested standard requirement is 7 ETA.

It is suggested to use a 20 metre duct in a depth of 1 metre as air ducts for preheating of ventilation air, with an velocity of maximum 2 m/s. It has been proved that there are not problems with condensation in the ducts in summer as they had feared.

At the same time the following three ventilation levels have been suggested:

- Basic ventilation: 0.3 times per hour;
- Increased ventilation: 0.5 times per hour;
- Forced ventilation: more than 0.5 times per hour.

As regards the sound level it is stated that even though the standard requirements are 30-35 dB for ventilation it is going to be considerably lower if people are going to be satisfied – rather 20-25 dB. This is equal to Cenergia's experiences.

If we are going to use the same philosophy in Denmark we could take basic ventilation of 0.3 times per hour as our starting point or alternatively the minimum requirement to ventilation on account of CO_2, which is of 25 m^3 per hour per person. The basis ought at the same time to be to document use of building materials without degassing so it is healthy materials.

We could also make user and moisture control possible to increase the ventilation in some periods, e.g. to 0.5 times per hour or 126 m^3/h. This would cause a 50% reduction of the air change into and out of a house in long periods and at the same time it reduces the electricity consumption to 20-30% of what it would have been. A considerable heat saving can also be obtained.

In the so-called Passiv Haus project near Damstadt in Germany they have during some years proven that under the right conditions it was sufficient with a ventilation level of 25 m^3/h per person or an air change of 0.22 per hour. Here an earth exchanger has been used in connection with a ventilation system with counterflow heat recovery and low electricity consumption, as it secures against frost in winter and makes cooling possible in summer, where the heat exchanger is bypassed.

In this project it is also possible to change the ratio of air supply to living rooms, sleeping rooms to bathroom/kitchen in the ratio (30/70%) and (70/30%) – but this is a rather expensive solution.

Development of energy efficient ventilation designs for housing ventilation

With the increased requirements to ventilation in BR-95 there are both in connection with new building and rehabilitation projects a demand to development of energy efficient ventilation system for living-quarters in blocks of flats.

Today the usual ventilation system consists of exhaust hoods in kitchen and bathroom. Either in the shape of a small ventilation unit, which can be turned on when there is a demand, or common exhaust ventilation for several flats at a time.

In the new building regulations it is as something new required that mechanical ventilation has to be turned on al the time. This it due to consideration of the indoor climate that has been worse within the last decades because the houses are too tight and have moisture problems and to the use of new materials with unhealthy emissions. The regulations do also require maximum electricity consumption for ventilation, which will be approx. 87 W or 762 kWh per year due to future requirements of mechanical ventilation of 126 m^3.

The heat supply that is necessary to cover a ventilation demand of 126 m^3/h is approx. 2600 kWh per year. In a situation with improved insulation and windows this means that in the future the ventilation field is considered to be the must difficult to secure good solutions of. An in this connection we must pay attention to the fact that it is not possible just to have natural ventilation if we want to reduce the energy consumption for heating by 50%.

Due to the increased requirements to ventilation in the new building regulations and also a reduced energy consumption we can expect a much increased commitment to ventilation systems with heat recovery in the future, where the exhaust air is used to heat the supply air.

In several years Cenergia has been working with development of energy efficient ventilation systems with heat recovery in connection with a number of EU-funded demonstration projects in Denmark and abroad. This development has primarily taken place in a close cooperation with the ventilation company TermoVex, which market an efficient so-called counterflow heat recovery unit with approx. 80% efficiency.

In resent years this development has been characterised by a want to develop ventilation systems with heat recovery, where the electricity consumption is as low as possible. In connection with the building projects Skotteparken, Egebjerggård and Havrevangen a new type of ventilation system for four dwellings with heat recovery has been developed. Where the electricity consumption even with this old type of ventilation system is approx. 50 W/dwelling with an air change of 54 to 100 m^3/h. In the building project Agernskrænten a further development of these systems as real air heating systems have taken place.

Continuous work is taking place to improve the electricity output and the thermal efficiency. The electricity consumption has been reduced in a new batch of ventilation units with backward curved blades, from the former usual level of 160 W to 88 W. Also a new DC-motor has been made, with an electricity consumption including converter of 20% below this level. In the building project Skotteparken there is a ventilation system with heat recovery for 18 dwellings. The system has a new electricity efficient ventilation unit, in some houses it is combined with floor heating in the lower storey and air heating on first floor.

I connection with rehabilitation of 80 flats for the housing association AAB at Østerbro in Copenhagen, new individual ventilation systems with heat recovery have been developed, where the electricity consumption has been reduced as much as possible. In 16 of the flats the ventilation air is preheated in the newly developed solar wall with transparent insulation. This development has been followed up in an EU/Thermie funded project called the European Green Cities. This project is coordinated by Cenergia in cooperation with Green City Denmark and it includes solar heating – low-energy demonstration projects in 11 different cities in 9 EU-countries. In cooperation with the urban renewal company SBS byfornyelse a new urban renewal project at Vesterbro in Copenhagen has been made with common energy efficient ventilation systems with heat recovery for several flats at a time.

In another EU/Thermie funded project at Frederiksberg a further development of this type of system will be made in the shape of so-called solar energy ventilation towers.

In 1996 Cenergia obtained in addition to this EU/Thermie funding to a research and development project about the field PV-modules and efficient ventilation with heat recovery, PV-VENT, in cooperation with the housing association FSB and an number of other partners. The background for this project is to work with building integration of PV-modules, which is used in connection with ventilation where there is as continuous demand for electricity.

Figure 2.20 shows an example of a PV-VENT ventilation system, where DC-ventilators get electricity directly from PV-modules to make additional heat savings.

Figure 2.20. PV-VENT ventilation system.

In the housing area Farumsødal, which is an EU-funded demonstration project with 67 houses there are optimised ventilation systems with counterflow heat recovery and new DC-fans with a low electricity consumption. The electricity consumption has been measured to be as low as 20W for both fans even when 126 m^3 air is blown into and out of the house per hour. Figure 2.21 shows the installation of this kind of system, which is very compact and with short supply ducts both for air supply and extract air.

The sound level is as low as 20 dB, which cannot be heard by the tenants at all.

Figure 2.21. Example of a ventilation system with heat recovery built into the wall.

When discussing the demand for development of new and more efficient ventilation systems, especially for ventilation of living-quarters, it can be relevant to refer to the conclusions at a round table discussion at SBI’s office in January 1997 about this subject where I participated:

- People make too little of service and cleaning of ventilation systems;
- Many tenants do not understand that ventilation systems are a necessity;
- Many systems cause inconvenience due to noise and draught and they are being mistreated or sabotaged;
- The energy consumption can be reduced by:
  - demand driven ventilation;
  - Use of energy efficient components in optimum designed systems.

In section 2.8 there is a statement of the economy of both the new efficient ventilation systems with heat recovery and of solutions with combined of building integrated PV-modules.

PV-VENT systems

On the basis of the work with building integration of PV-modules and new and more efficient ventilation systems with heat recovery I have succeeded in obtaining funding for a research and development projects in this field from the EU/joule programme in 1996. This project got the name PV-VENT and it is commented upon in section 3.2.3. At the same time as the realisation of the PV-VENT project the company SolarVent was established. Its business is to market and initiate new projects with solar assisted ventilation.

The name PV-VENT describes the connection between the utilisation of the sun as an energy source in a wide sense and the development of an efficient way to distribute and recover heat from the ventilation air of a building. This means to combine building integration of PV-modules with high-efficient ventilation systems. The PV-modules produce direct current, which can run DC-motors with low electricity consumption directly. These are being used in a new generation of efficient counterflow heat recovery units. Then an expensive converter installation, which causes an energy loss in the collected solar energy, is not necessary. This type of exchanger utilises the counterflow heat recovery principle and has been developed by TermoVex in Denmark.

The counterflow exchanger operates with an electricity consumption of only 20-30 W, this is equal to 150-200 kWh per year. 25-50% of this electricity consumption can in principle be covered by electricity from building integrated PV-modules. With a free orientation against south the optimum area of PV-modules is estimated to be 0.7 m^2/house for crystalline PV-modules and 2 m^2/house for amorphous PV-modules. For an east or west facing orientation it will be 1 and 3 m^2/house.

Dependent on how the PV-modules are integrated into the building they will also be able to preheat air to the heat exchanger. By production of preheated ventilation air behind the PV-modules a desirable cooling is also obtained, especially as to the crystalline modules.

The ventilation system can be made either as a common system or individual systems.

Common ventilation systems

A common ventilation system for several houses is a system where the ventilation units (including the heat exchanger) is placed on a central place in the building with supply and exhaust ducts carried to each dwelling, e.g. in a shaft. The placing of the ventilation unit will often be in an attic or in a modulear.

For common systems for several dwellings at a time there is as fire prevention a requirement of a flow resistance above the supply ducts of 100 Pa. This will usually mean an increased electricity consumption of minimum 170 kWh per year per dwelling.

Individual ventilation systems

Individual ventilation systems are systems that are collected in each dwelling. Then there are ventilation units, ducts and supply and exhaust ducts in each dwelling. Exhaust is, however, going to be above the roof, e.g. via a shaft.

Power loss

Crystalline modules are easily affected by partial shadows, which leaves whole sections out of operation. Furthermore they are dependent of not too hot air to be able to operate. A possibility of cooling is going to be incorporated. Crystalline modules are therefore going to be installed isolated.

Amorphous modules are much less sensitive and they can to a larger extent be integrated at more marginal positions with success.

Smudge will generally reduce the efficiency but it is difficult to avoid it. However, the reduction is only a few percent of the yield. Vandalism can just be avoided by careful consideration of the placing of the PV-modules, which means out of reach.

Ventilation demand and energy loss

The tendency of improving the insulation power in buildings, according to statutory regulations, increasing the heat loss from the different building parts and improving the tightness in a still larger scale cause a corresponding demand of securing the air change. A considerable reduction of the heat loss has improved the comfort as to a minimisation of draught etc., but it has also made a general soil for bad air. BR-95 requires an air change of 126 m^3/h per house all the year round. The energy gain of the insulation is then lost if not the ventilation reduces its energy consumption. The immediate ventilation demand according to BR-95 result in a heating demand of approx. 2600 kWh per year per house. In BR-95 there is at the same time requirements of a maximum electricity consumption for mechanical ventilation of 87 W per house, equal to 762 kWh per year per house.

A reasonable target for reduction of the heating energy consumption in connection with low-energy building is 35-50%. This can only be obtained by a considerable reduction of the energy consumption for ventilation and a high efficient heat recovery. Efficient counterflow heat recovery units can recover up to 80-90% of the heat in the exhaust air. Ventilation units run by PV-modules can also reduce the energy consumption e.g.

Electricity efficient ventilation system with counterflow heat recovery

The ventilation system in the PV-VENT project is an electricity efficient ventilation system with so-called counterflow heat recovery of the ventilation air, where the exhaust air preheats the supply air. By use of counterflow heat recovery an 80-85% recovery of the heat from the exhaust air can be obtained, in an ordinary cross heat recovery unit it is only approx. 65%. The electricity consumption is dependent on the conditions as low as 20-40 W per flat, where the maximum requirement in BR-95 for only an extraction system is of 87 W. This means that you can reduce the consumption to 150-300 kWh per year, where the 87 W will amount to 760 kWh per year. If you look on the ratio of the electricity consumption to the heat saving it is for ordinary cross heat exchangers approx. 1:3, which is not profitable as the electricity price is usually 2.5 times higher than the heating price. For ventilation systems with counterflow heat recovery this ratio is approx. 1:9, which is much better. By connection to PV-modules the ratio can be increased to almost 1:15, which is very good. These ratios are illustrated in detail in figure 2.2.3.

Individual ventilation systems

The advantages of individual ventilation systems are that a possibility of individual user control is available and that the heat recovery unit can be placed inside the house and then the house benefits from the heat loss. As regards operation and maintenance it is required that the filters are being changed approx. each year or every six months, but this can easily be done by the tenants as there is also a so-called filter guard that tells the tenants when it is time to change filter.

TermoVex Denmark has developed a compact heat recovery unit for individual systems, which is easy to place. The heat recovery unit is made as small as 25-35 cm deep, 190 cm high and 92 cm wide. Figure 2.22 shows the design and possibilities of connection for the heat recovery unit, which can include ventilation fans, filters, sound insulation, user control and connection to PV-modules. The heat recovery unit can e.g. also be installed in connection with a false ceiling in the kitchen, hall or bathroom or on an end wall, in a dividing wall or in connection with kitchen units. As an alternative it can also be placed outside, e.g. built into a solar wall as shown in figure 2.24, in a ventilation shaft integrated in connection with a glazed patio or in a ventilation tower with a surface that is partially covered by PV-modules. In section 3.2.5 there is an example of a ventilation tower with solar energy function.

According to figure 2.23 the ventilation loss in a low-energy house is calculated to be 2610 kWh/year, with an air change of 126 m^3/h, equal to the requirements in BR-95.

An air change of 126 m^3/h results in a ventilation loss of approx. 3600 kWh per year, but due to the free heat contribution the heat loss in a low-energy house will only be 2610 kWh. As people are not always perfect users, the annual saving possibilities will be somewhere between the two amounts, but we will, however, use 2610 kWh as a basis.

With the latest type of counterflow heat recovery unit up to 85% of this value can be saved, equal to approx. 2200 kWh per year. In addition to this part of the electricity consumption, which is already low (30 W compared to 87 W that is the new maximum requirement in BR-95), is recovered. The annual heat saving will according to figure 2.23 be 2351 kWh. The low electricity consumption does also imply that compared to the BR-95 level a saving of approx. 500 kWh per year can be expected. By calculating with a heating price of 0.4 DKK and an electricity price of 1.15 DKK/kWh the annual saving will be 2351 × 0.4 + 500 × 1.0 = 940 + 575 = 1515 DKK.

Additional investments compared with ordinary extraction ventilation are approx. 10000 DKK/house by use of individual ventilation systems. The additional yearly expenses for maintenance are fixed at 1.5% of the additional investments, equal to 150 DKK/year.

In low-energy houses there is furthermore regarding to the total power demand a considerable dependence on if you use heat recovery or not.

It is therefore estimated that a 10% saving of the usual investment in a heat supply system and heating system can be obtained dependent on if you use heat recovery. In new-built projects this is a saved investments of 5000 DKK/house.

On the conditions above the total economy will then be:

Total energy savings per year	1515 - 150 DKK/year	1365 DKK/year
Additional investments	(10000 – 5000 DKK) × 1.15	5750 DKK
Simple pay-back time	5750/1365 DKK	4.2 years

The amounts are a little different than in figure 2.23 as the energy prices has been increased a little and maintenance is included.

Additional investments of 5750 DKK/house will with capital costs of 4% result in annual expenses of 230 DKK for council houses. At the same time provisions of 3% will lead to an annual expense of 173 DKK. Compared to the total annual additional expenses of 403 DKK of the annual operating savings of 1365 DKK will, however, be considerably larger. And where the ratio of electricity consumption to heat savings according to figure 2.23 of 1:2.7 was relatively bad, this has now been improved to 1:8.9.

By use of PV-modules the additional expenses for this can in a perfect case be expected to be 5000 DKK with 3 m² amorphous PV-modules (2000 DKK/m² installed modules and a small reduction due to saved alternative building surface).

The result will then be a pay-back time of 7.2 years including PV-modules, a very good ratio of electricity consumption to heat saving of 1:14.7 and a saved primary energy consumption of 4023 kWh.

And in some years when a market for this type of ventilation systems driven by PV-modules or PV-VENT systems has been created, it will then be possible to get a pay-back time as low as 4 years.

In addition to the placing of the heat recovery unit, there is also going to be space for the necessary ducts with a dimension of 100-600 mm, to secure exhaust from both kitchen and bathroom on 72 and 54 m³/h respectively and with at least two air supply ducts in other rooms, e.g. the living room and a sleeping room. The easiest way to hide the necessary ducts is to hide them behind false ceilings in the kitchen, bathroom or hall or by moving a dividing wall. The cooker hood in the kitchen can also be connected to the heat recovery unit but this requires improved filters and more frequent change of these. As an alternative the connection can be made after the recovery unit before the exhaust air is sent out of the flat. The exhaust air is going to be let out above the roof, either via a shaft or via a ventilation tower on the outside of the facade.

Common ventilation systems

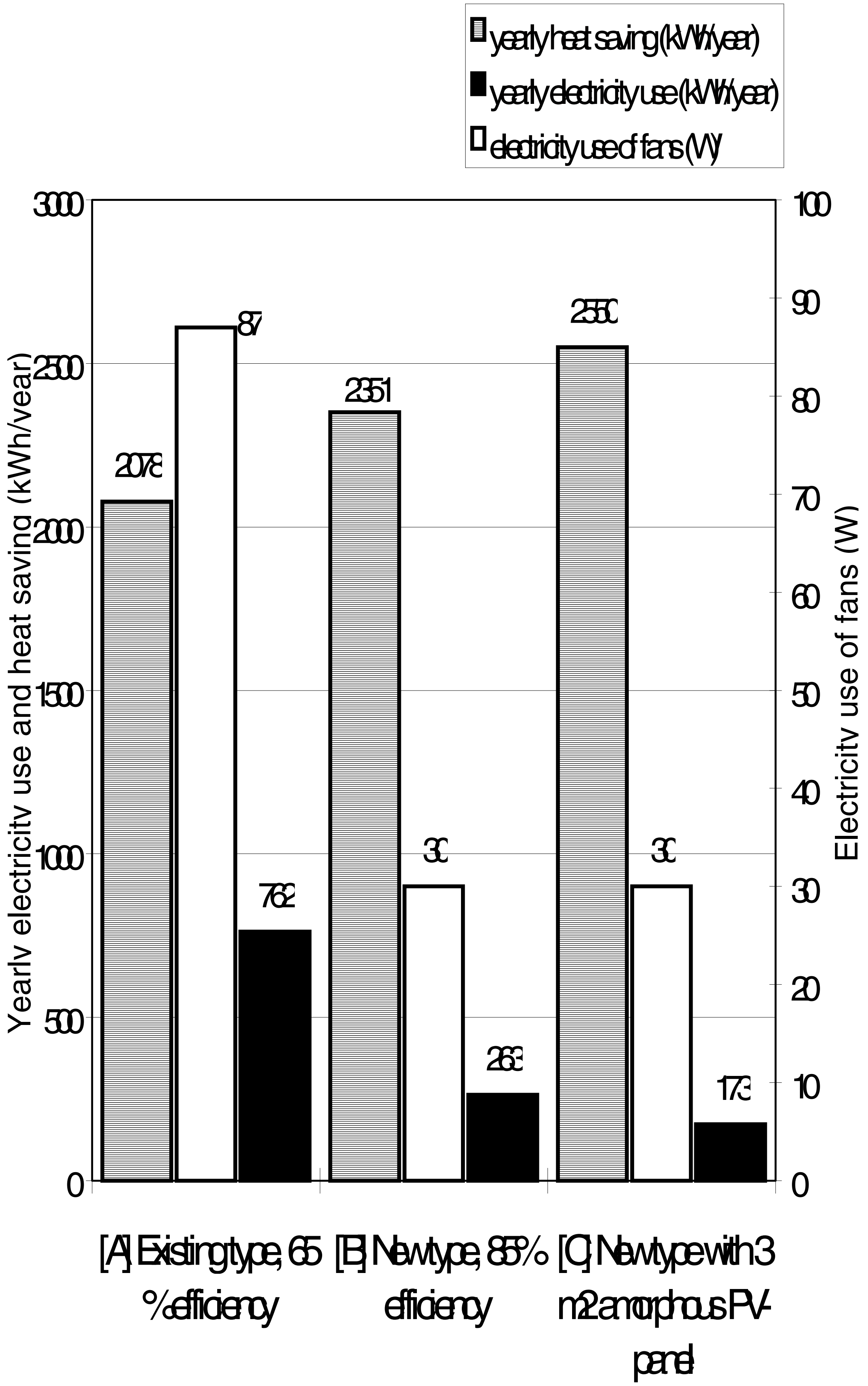
Also common systems are available, e.g. for three flats above each other at a time. However, work has to be done to reduce the heat loss from the heat recovery unit and from the ducts when they are placed in a cold attic. The heat loss can even with an optimisation of this easily be 10-20% of the heat saving. By use of common systems there is going to be a shaft through the flats with space for exhaust and air supply ducts. The distribution of the ducts in the flats is the same as for individual systems.

Economy of PV-modules

The economy of use of PV-modules will still be very overextended but, however, not impossible. In section 2.6 there is an illustration of the expected positive development.

Figure 2.8.9. Economy of a PV-VENT system.

As mentioned above there is a detailed illustration in figure 2.23 of the economy of the new efficient ventilation system with counterflow heat recovery and with PV-operation of the ventilation system as a PV-VENT system. In the following there is an analysis of these things.



yearly heat saving (kWh/year)
yearly electricity use (kWh/year)
electricity use of fans (W)
Yearly electricity use and heat saving (kWh/year)
Electricity use of fans (W)
0
500
1000
1500
2000
2500
3000
0
10
20
30
40
50
60
70
80
90
100
2078
87
762
2351
30
263
2550
30
173
[A] Existing type, 65 % efficiency
[B] New type, 85% efficiency
[C] New type with 3 m2 amorphous PV-panel

Figure 2.23. Illustration of the economy of a PV-VENT system. Here is shown the annual energy consumption and heat savings of three types of heat recovery ventilation systems for houses.
[A] Existing type heat recovery ventilation system (HRV), (cross flow) 65% efficiency, 87 W electricity use according to new Danish Building Regulation (BR95).
[B] New type of counter flow HRV, 85% efficiency, low pressure loss and good fans with only 30 W electricity use.
[C] As [B] but with 3 m^2 amorphous PV-panel for preheating of ventilation air and supplying electricity use for fans.

Relation between:	**[A]**	**[B]**	**[C]**	
Yearly heat saving/electricity use:		2.7	8.9	14.7
	bad	very good	extremely good	
Saved primary energy use:	2078	3598	4023	
Pay-back time today (years)**(***:	7.7	4.0	7.2	
Pay-back time when there is a market (years)**(****:	-	2.4	4.0	

Extra costs for HRV ventilation including saving on installed heating effect (5.000 DKK). Type A extra costs: 5.000 DKK., type B extra costs: 5.000 DKK., type C extra costs: 10.000 DKK. Yearly maintenance is 1% of extra investment.
(*: heat price(HP): 0.36 DKK./kWh, electricity price(EP): 1.04 DKK./kWh, yearly heat saving (HS) includes 50% of electricity converted into heat, yearly electricity use (EU), pay-back= investment costs /((HS*HP)+(762-EU)*EP). Primary energy use of electricity is 2.5*yearly electricity use (EU). Yearly heat demand in low energy housing for ventilation is calculated to be 2610 kWh at 126 m^3/h ventilation rate (35 litre per second).
(**: 20% expected savings when there is a market in investment costs of heat recovery ventilation and 50% expected savings on PV-panels in 5-10 years.)