COST-EFFECTIVE BUILDING INTEGRATED PV-SYSTEMS WITH COMBINED ELECTRICITY AND HEAT PRODUCTION

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Abstract – In 1993, Cenergia received in cooperation with a Danish housing association and the electricity utility in Copenhagen (Copenhagen Energy) support from the EU-Thermie programme for the first EU-supported PV-project in Denmark. Since then a total of 20 kWp of building integrated PV-area have been installed as part of this project. In connection to this 80 m² of crystalline PV-modules, which are also utilised for preheating of ventilation air, have been installed on a south-facing gable. The idea of utilising PV-modules for a combined heat and power production, which has also been dealt with in the EU-Joule project PV-VENT and in the second Danish EU-Thermie supported project INNOPEX, which has been started in 1998. In the INNOPEX project a ventilation tower with a combined solar wall/PV-solution is used to preheat ventilation air. The value of the possible annual saving from crystalline building integrated PV-modules has been calculated in Cenergia. For both facade and roof integration of PV-modules the savings have been calculated for just the PV electricity and also for applications where the PV-modules at the same time are used to preheat ventilation air.

1. INTRODUCTION

In 1993, Cenergia received in cooperation with a Danish housing association (Dansk Boligselskab) and the electricity utility in Copenhagen (Copenhagen Energy) support from the EU-Thermie programme for the first EU-supported PV-project in Denmark.

20 kWp of building integrated PV-area has been installed as part of this project. An example from the project is shown in figure 1, where crystalline PV-modules have been installed on a south-facing gable, and is also utilised for preheating of ventilation air.

Figure 1. 8.6 kWp crystalline PV-modules from the Danish company Gaia Solar placed on a south facing gable at Viktoriagade 10 B, Vesterbro in Copenhagen.

In 1996 based on a long term cooperation with the Danish ventilation company TermoVex Denmark and an interesting retrofit housing project with the Danish housing association, FSB it was in cooperation with the PV-manufacturing company Fortum from Finland decided to make a proposal for an EU-Joule project "PV-VENT", where different prototype systems were tested using typically 1 m² of building integrated PV-area per apartment together with energy efficient ventilation systems with heat recovery for housing ventilation. This project has been supported by the EU and will be finalised in 2000.

The idea of utilising PV-modules for a combined heat and power production was also dealt with in the second Danish EU-Thermie supported project INNOPEX, which has been started in 1998. In the INNOPEX project a ventilation tower with a combined solar wall/PV-solution is used to preheat ventilation air.

2. OBJECTIVES OF THE PV-VENT PROJECT

The objective of the PV-VENT project is to research, develop and test low-cost high efficiency PV-powered ventilation systems for apartment blocks, where PV-modules are integrated in an architectural acceptable way in facades, gables and roofs.

The use of fans with new and reliable DC-motors in TermoVex Denmark's ventilation heat recovery systems makes it possible to use photovoltaic modules or PV modules to cover part of the electricity demand directly, which means that a further reduction of the electricity use can be obtained to reach the future aimed low electricity

use of only 25-40 W per dwelling for ventilation systems with heat recovery. This is equal to an electricity use of only 200-300 kWh per year.

Calculations show that if 3 m² facade integrated amorphous silicon PV-modules, covering 30-50% of the reduced electricity use, are used with a direct link to a shared ventilation system with heat recovery and at the same time utilising the PV-modules for preheating of ventilation air, the extra PV costs per m² facade are today only 1680 DKK (224 ECU), equal to a simple pay-back time in Denmark of 21 years. With an expected 40% reduction of the price of PV-modules in 5 years it should then be possible to reduce the extra PV costs per m² facade to only 668 DKK, (89 ECU) equal to a simple pay-back time of 8 years.

In the PV-VENT project it is aimed to develop and test the following prototypes of innovative economically optimised PV-powered ventilation systems with a considerably reduced electricity use compared to normal.

- An energy efficient shared ventilation system with heat recovery and direct PV-supply to fans with DC-motors.
- Multifunctional solar energy ventilation elements for facade integration with a building integrated heat recovery ventilation system in combination with building integrated PV-modules and preheating of ventilation air.
- An integrated energy efficient shared ventilation system with heat recovery and direct PV-supply to fans with DC-motors as mentioned under item 1 but including grid connection and a larger building integrated PV area per apartment more defined from the available facade area than having an optimised PV area determined by the level of electricity use for the ventilation fans.
- A PV-powered cheap exhaust ventilation system with preheating of ventilation air in the PV-modules.
- An energy efficient shared ventilation system with heat recovery as mentioned under item 1, but with the PV-modules integrated in an air solar collector surface, which can also be used for preheating of domestic hot water in summer through a water to air heat exchanger.

The above mentioned prototype PV-ventilation systems will be tested under realistic operating conditions in actual housing blocks in Denmark, as a complete system test to be able to develop the highest possible reliability in practise both for the PV-systems and the ventilation systems.

The partners of the PV-VENT project are Cenergia Energy Consultants, which is coordinator, the FSB housing association, which is the builder, the ventilation company TermoVex Denmark, Fortum from Finland, NTNU from Norway, Ecofys from Holland, the Danish Solar Energy Laboratory, PA-Energy and the Copenhagen Energy Utility.

3. PV-VENT PROTOTYPE SYSTEMS FOR LUNDEBJERG IN SKOVLUNDE

In connection to the PV-VENT project an architectural competition has been realised aiming at a retrofit project with 513 apartments at Lundebjerg in Skovlunde near Copenhagen, Denmark, administered by the FSB housing association, as basis of a large demonstration of PV powered ventilation systems in practice.

To be able to utilise building integrated PV-systems in connection with optimised ventilation designs it is necessary with a very active involvement of builders and architects in practice. Because of this it was decided to make an architectural competition in connection with the above mentioned retrofit project with 513 apartments, which should utilise energy efficient heat recovery ventilation systems with PV-supply, and to do this before the EU-Joule supported prototype ventilation systems have been installed in the first housing block with 27 apartments.

Five of the best Danish architect companies were pre-qualified for the architectural competition, and introduction material was made and presented to the architect companies prior to the competition at a special one-afternoon seminar at Lundebjerg in Skovlunde.

The results of the architectural competition were indeed very interesting, with many good ideas of how to integrate PV-panels in the building the best way, also ideas that the project team had not thought of before the competition were held.

The entries illustrate two different approaches regarding the integration of the PV elements in the architecture: Four of the entries integrate the PV elements in the east and west orientated facades. The ventilation aggregates are placed above suspended ceilings in the dwelling units and/or in the attic of the building. These east and west orientation results in a need for a somewhat larger PV area than a south orientation would do.

Only one entry orientates the PV elements to the south. This is done by adding new architectural elements, termed ventilation ”chimneys”, to the building and by integrating crystalline PV elements in the southern facades of these. The ”chimneys” do also function as exhaust airshafts.

Based on an evaluation of the five entries the jury found that the entry with the ventilation ”chimneys” from the architectural firm ”Tegnestuen Vandkunsten”, in Copenhagen, to be the best. See figure 2. A at later stage it has been decided to let the number two of the architectural companies “Sunesons Tegnestue” realise the project.

Figure 2. Drawing by the "Vandkunsten" architects of the first housing block to be renovated using PV-VENT prototype ventilation systems with direct PV-supply for the fans.

The retrofit of the first building will be finished during the spring or early summer of 2000 and will also include other PV-integrated solutions, e.g. use of amorphous PV-modules on the gable to the south.

A large part of the PV-area in Lundebjerg is placed on the south facing facades of the 3 ventilation chimneys, which will be installed on the roof. A total of 21 m² of crystalline PV-modules are placed here (approx. 3.6 kWp). Furthermore approx. 3 m² of crystalline PV-modules are placed on the west-facing facade of the building also preheating ventilation air for 3 apartments. And 60 m² amorphous PV-modules are placed on the south facing gable supplying 3 apartments with PV-electricity.

For most of the ventilation systems that are utilised, there is a direct PV-supply to the fans of the ventilation systems via a so-called PV-mixer (a DC/DC converter) which allows PV-electricity to cover as much as it can and then take supplemental electricity from the grid.

For the three apartments near the gable approx. 0.8 kWp PV-electricity will be installed per apartment. In this case the PV-electricity is grid connected, but at the same time supplying electricity for local electricity use in each apartment. In these apartments electricity meters, which can run both ways, will be installed so a "roof top system" function can be realised. In these 3 apartments it is at the same time foreseen to install so-called "Energy guard" electricity and heat consumption displays to ensure a motivation for energy saving user habits.

A total of 4 shared PV-VENT prototype systems, each for 3 apartments, will be installed at Lundebjerg. For all systems a design with preheating of ventilation air in the PV-modules will be utilised.

At Lundebjerg also exhaust ventilation systems with PV-supply will be installed for 9 apartments. For three of these apartments an increased PV-area will as already indicated be built into the gable and will be utilised. In this case with grid coupling of the amorphous PV-modules (2.4 kWp), which are at the same time used to preheat ventilation air in winter and supply natural ventilation in summer.

Furthermore 6 individual PV-VENT ventilation systems for 6 apartments will be installed. For these systems individual user control and moisture control on ventilation rates will be utilised. For 3 of the apartments approx. 1 m² of crystalline PV-area will be installed on the west facing facade, which are going to supply PV-electricity to the individual heat recovery ventilation systems, and at the same time preheat ventilation air.

4. EXAMPLE OF POSIBLE ECONOMY OF THE DEVELOPED PV-VENT SYSTEMS

Calculations show that with PV-VENT systems you can already today in ideal situations have an electric thermal performance ratio of 1:14.7 (electricity use compared to heat saving), a pay- back time of 7 years and a saving of primary energy per housing unit of 4000 kWh per year (calculated as heat).

For conventional HRV systems these figures are 1:2.7 - 8 years and 2080 kWh. When a real market has been created the pay-back time should be reduced to around 4 years even for the HRV systems with PV-supply. (see also figure 3).

5. THE "INNOPEX" EU-THERMIE PROJECT – PV-OPERATED VENTILATION TOWERS WITH ENERGY EFFICIENT HEAT RECOVERY

The "INNOPEX" EU-Thermie project, which received support in 1998, includes PV-demonstration projects as part of retrofit building schemes in Denmark, the Netherlands and Italy

As part of the Danish project, which is being realised at Frederiksberg in Copenhagen in spring 2000, a new type of so-called "ventilation towers" with PV-modules integrated in the top is utilised.

The "ventilation towers" are 600 × 600 mm and made of a perforated metallic plate material, which together with the PV-modules is used to preheat ventilation air. All the ventilation ducts are also placed in the ventilation towers and a ventilation heat recovery unit is placed in the attic.

6. ECONOMY OF BUILDING INTEGRATED PV-MODULES WITH COMBINED ELECTRICITY AND HEAT PRODUCTION – STATUS BY APRIL 2000

In figure 4 and 5 the value of the annual savings is estimated for crystalline building integrated PV-modules. For both facade and roof integration of PV-modules the savings have been estimated for the PV electricity alone and also for applications where the PV-modules at the same time is used to preheat the ventilation air. This can

also increase the electricity yield from the PV-modules. The calculations are based on an electricity price that in principle is equal to the market electricity price in Denmark.

The possible heat saving is based on calculations made in Cenergia and results concerning 1 and 4 m² PV-area per housing unit is presented.

In figure 4, which deals with PV-modules in facades, it can be seen that compared to a situation where you will obtain a yearly saving of 79 DKK/m² PV-module from only using the electricity from the PV-module, you can in principle obtain a saving of 221 DKK/m² PV-module if you only use 1 m² PV-module per apartment, which is at the same time being used to preheat ventilation air, (e.g. using the PV-modules to supply electricity directly to the ventilation fans).

If you use 4 m² PV-modules per apartment you can obtain a saving of 169 DKK/m² PV-module.

In figure 5 the same type of calculations are presented for PV-modules in roofs and here the amounts are 104 DKK in yearly savings per m² PV-area only based on the electricity contribution and 275 and 212 DKK in yearly saving per m² PV-area for 1 and 4 m² PV-area per housing unit respectively.

Figure 6 shows the economy of the PV-modules mentioned in figure 4 and 5 and is based on prices of large orders of the installed PV-modules, to be used both in roofs and new-built or renovated facades.

From figure 6 it can be seen that today the pay-back time of building integrated PV-systems at large purchases is between 44-52 years in Denmark.

If 1 m² of PV-modules per housing unit is used to preheat ventilation air at the same time it is possible to reach a pay-back time between 16-18.5 years, and if a future 40% reduction of the PV-price is obtained the pay-back time will be 8-9 years. This can be compared to 22.5-24 years pay-back time if only the electricity is utilised.

With 4 m² of PV-module per housing unit the pay-back time today will be 20.5 to 24 years and with a future 40% reduction of the PV-price the pay-back time will be 10.5-12 years.

7. CONCLUSIONS

It can be concluded that there seems to be a very interesting area to create a market for cost-effective building integrated PV-modules if you focus on PV-system designs, which are not only used for electricity production but is also used to produce heat, which can e.g. be used for preheating of ventilation air.

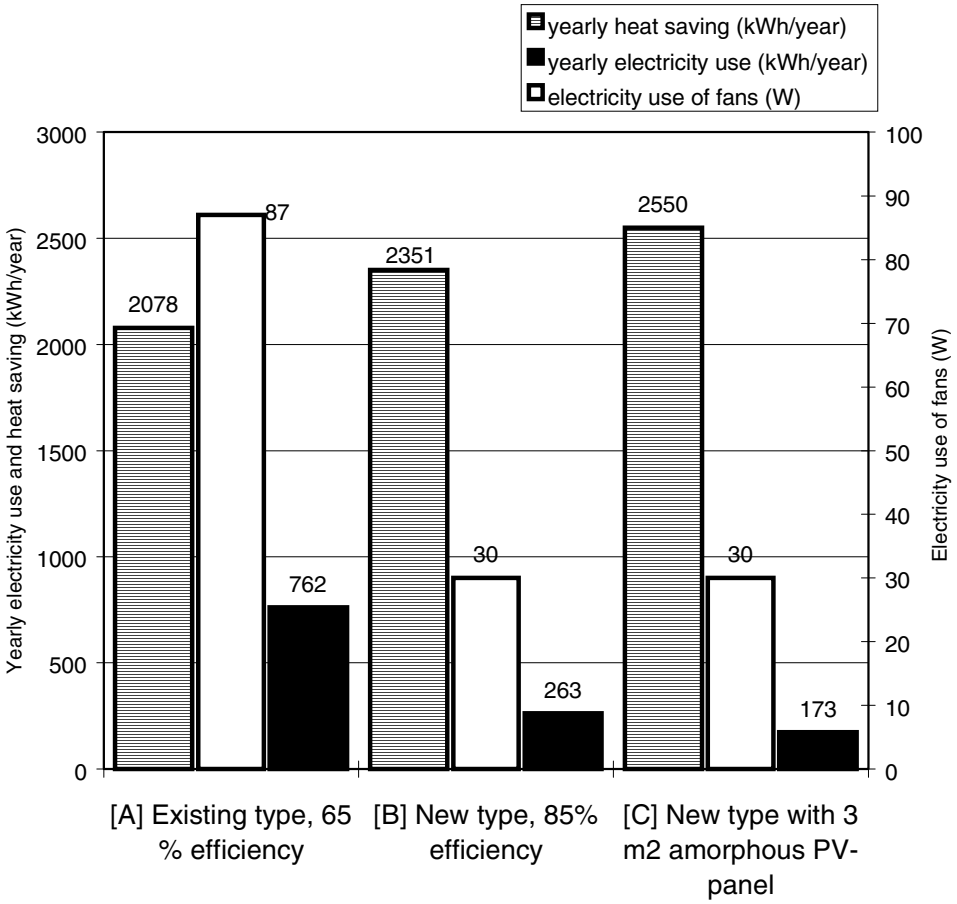
There is a great need for further R&D concerning such concepts as basis of creating system designs with a documented reliable and durable function in practice.

LITERATURE SOURCES

Journal articles:
Peder Vejsig Pedersen (1999) – *European Directory of Sustainable and Energy Efficient Building 1999*, pp 88-92, James & James 1999.

Book:
Peder Vejsig Pedersen (2000) - *Solar Energy Building* (In Danish). Teknisk Forlag, Copenhagen.

Illustration of positive economy of new energy efficient heat recovery ventilation systems with PV-supply.



[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 m² 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 bad	8.9 very good	14.7 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 m³/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.)

Figure 3. Comparison for one housing unit between different types of heat recovery ventilation systems HRV) including systems with PV-supply for the electricity use.

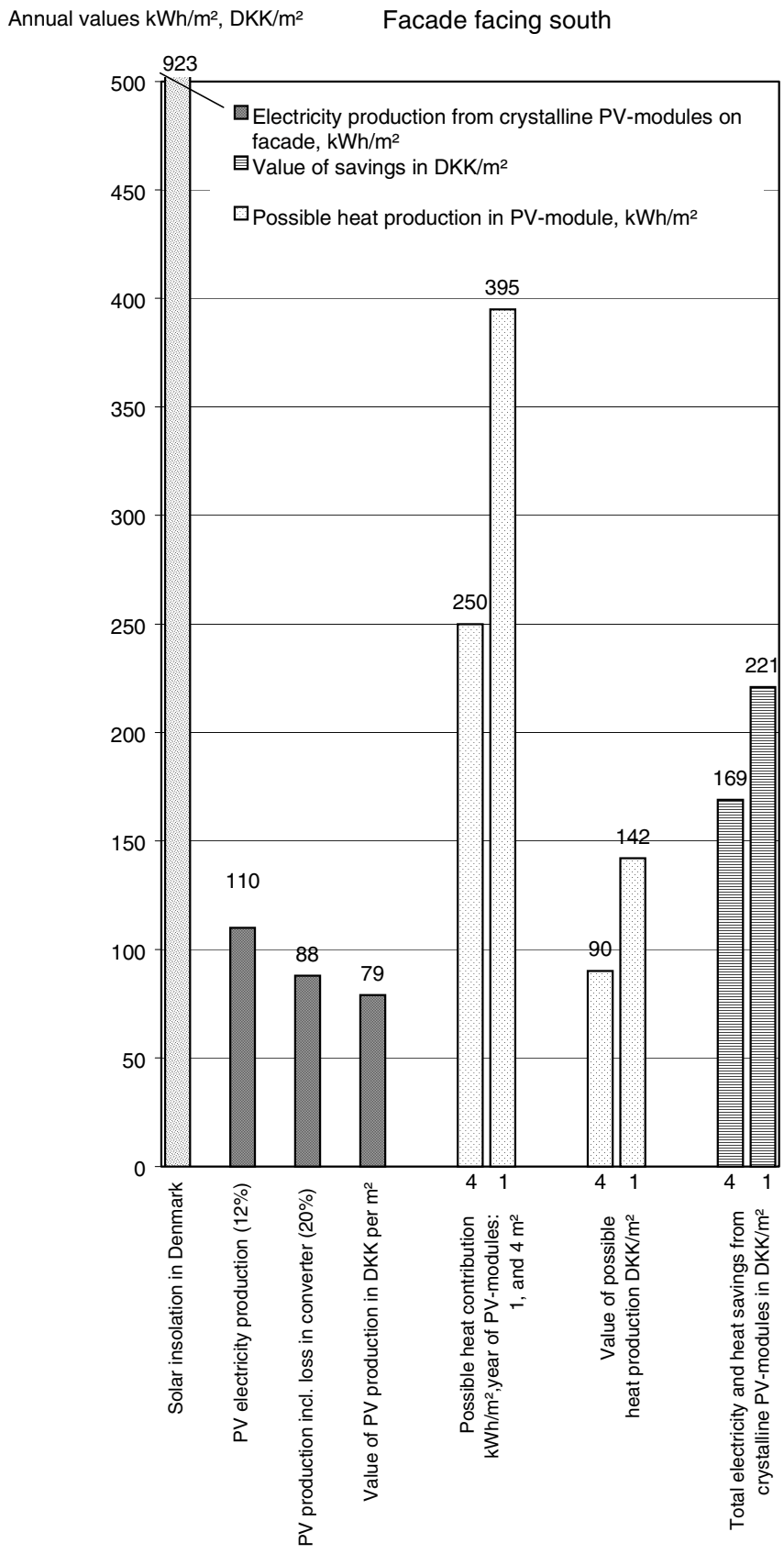

Annual savings for roof and facade integrated PV-modules facing south
Annual values kWh/m², DKK/m²
Facade facing south
Electricity production from crystalline PV-modules on facade, kWh/m²
Value of savings in DKK/m²
Possible heat production in PV-module, kWh/m²
923
110
88
79
250
395
90
142
169
221
500
450
400
350
300
250
200
150
100
50
0
4
1
4
1
4
1
Solar insolation in Denmark
PV electricity production (12%)
PV production incl. loss in converter (20%)
Value of PV production in DKK per m²
Possible heat contribution kWh/m².year of PV-modules: 1, and 4 m²
Value of possible heat production DKK/m²
Total electricity and heat savings from crystalline PV-modules in DKK/m²

Figure 4.

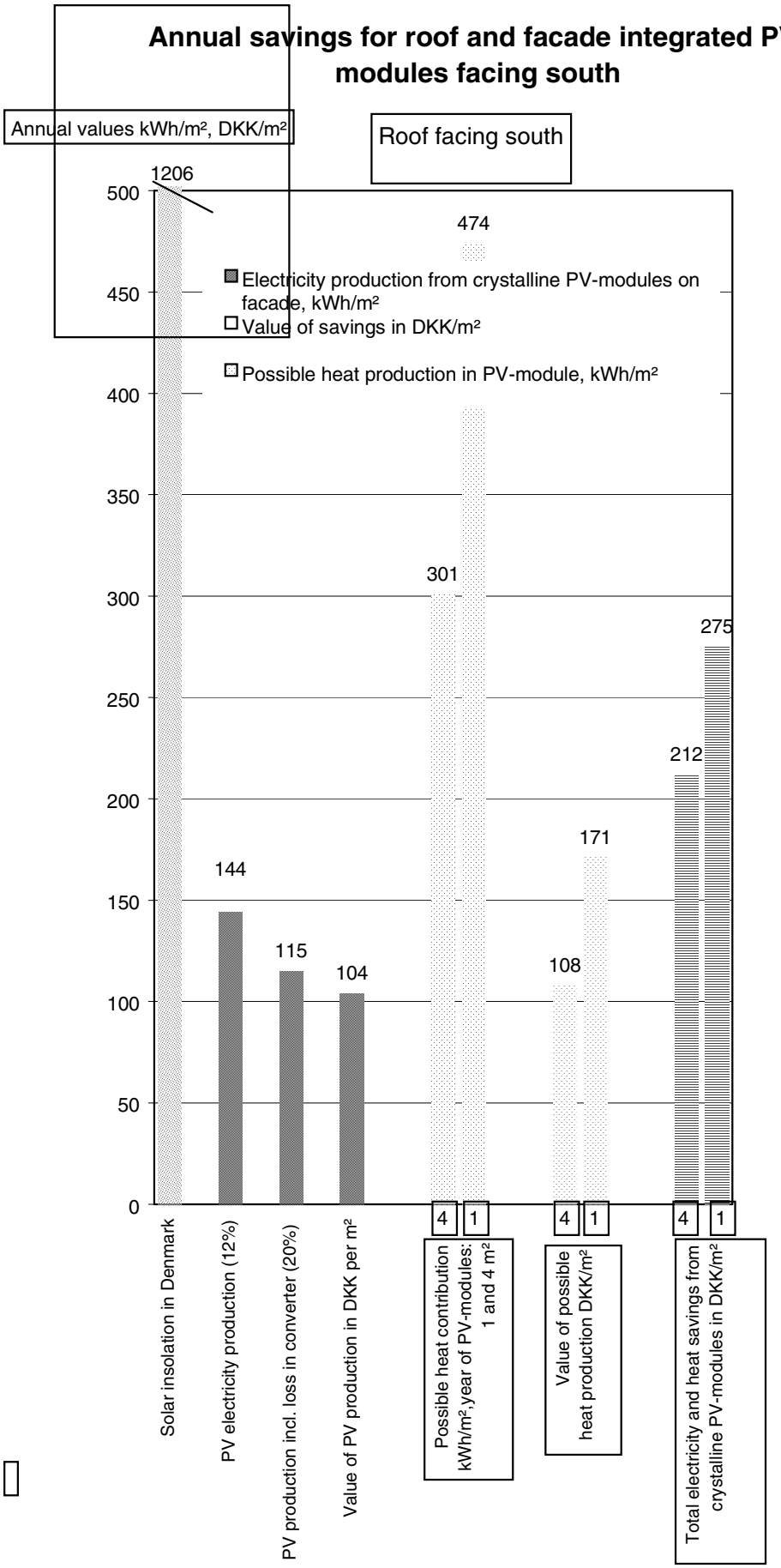

Annual savings for roof and facade integrated PV-modules facing south
Annual values kWh/m², DKK/m²
Roof facing south
1206
474
301
275
212
171
144
115
104
108
500
450
400
350
300
250
200
150
100
50
0
Electricity production from crystalline PV-modules on facade, kWh/m²
Value of savings in DKK/m²
Possible heat production in PV-module, kWh/m²
4
1
4
1
4
1
Solar insolation in Denmark
PV electricity production (12%)
PV production incl. loss in converter (20%)
Value of PV production in DKK per m²
Possible heat contribution kWh/m²,year of PV-modules: 1 and 4 m²
Value of possible heat production DKK/m²
Total electricity and heat savings from crystalline PV-modules in DKK/m²

Figure 5.

ECONOMY FOR BUILDING INTEGRATED PV-MODULES WITH COMBINED ELECTRICITY AND HEAT UTILISATION.

		South facing roof with a 45° slope with crystalline PV-modules *)	**South facing facade with crystalline PV-modules **)**	
		(1)	(2)	(3)
		1999 price by large purchases	1999 price by large purchases	1999 price by large purchases
			(renovation of concrete - facade)	(new-built houses - wall)
1. The price of installed building integtrated PV-modules (DKK/m²), incl. converter and electric installation		4000	4000	4000
2. Total extra costs including design, facade insulation and ventilated solutions with perforated steel plate		5050	5550	5850 (wall in new-built houses with PV-modules)
3. Price of ordinary solution, e.g. with insulation and ordinary covering, incl. design		500	1440	2350
4. Additional expenses for a PV-solution (item 2-3)		4550	4110	3500
5. Simple pay back time (item 4/(saving – 1% of extra investments for maintenance)) (years)	-only electricity combined heat and electricity: 1 m² per housing unit 4 m² per housing unit	44 16.5 21,5	52 18.5 24	44 16 20.5
6. Total price with a 40% cheaper PV-solution		3030	3330	4125
7. Additional expenses for a PV-system with a 40% cheaper PV price (item 6 – item 3)		2530	1890	1775
8. Simple pay back time (item 7/(saving – 1% of the extra investments)) (years)	-only electricity combined heat and electricity: 1 m² per housing unit 4 m² per housing unit	24 9 12	24 8.5 11	22.5 8 10.5

*) Annual saving from PV-module electricity production from a 45° south oriented roof and preheating of ventilation air, excl. maintenance of 1% of the extra investments
A-1: only electricity 104 DKK/m², A-2: 1 m² per housing unit 275 DKK/m², A-3: 4 m² per housing unit 212 DKK/m².
**) Annual saving from PV-module electricity production from a facade towards south and preheating of ventilation air, excl. maintenance of 1% of the extra investments
B-1: only electricity 79 DKK/m², B-2: 1 m² per housing unit 221 DKK/m², B-3: 4 m² per housing unit 169 DKK/m².

Figure 6.