
RESHYVENT

Cluster Project on Demand Controlled Hybrid Ventilation in Residential Buildings with Specific Emphasis on the Integration of Renewables

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WP 3 Renewables integration support unit

Report Title:

SPECIFICATIONS OF APPLICABLE RENEWABLE SOURCES FOR INTEGRATION IN POSSIBLE PROTOTYPES
(Deliverable DWP 3.2)

RESHYVENT Working report No:

RESHYVENT-WP3.2

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CONTENT

1 INTRODUCTION

Within the Fifth Framework Programme of the European Commission a research project RESHYVENT has been executed, running from January 2002 until December 2004. The aim of the RESHYVENT project have been to research, develop, and construct demand controlled hybrid ventilation concepts for residential buildings with special emphasis on the feasibility of applying renewable energy.

This report is part of work package 3 (WP3) within the RESHYVENT project. The main objectives of WP3 are to support and guide four different hybrid ventilation consortia's in issues dealing with development, implementation and integration of renewable energy applications.

The integration of renewable energy technologies has focused on solar (Photo voltaic (PV) for electricity supply) and wind (as natural driving force for air movement) applications to substitute fossil fuel in the operation of hybrid ventilation systems. The focus in this deliverable is mainly on the application and integration of PV systems into different components in the different developed hybrid ventilation systems. PV has been chosen as this technology is very flexible and has many implementation possibilities as the PV solution has the possibility to be fully integrated into components and the building.

1.1 Objectives

The objective of this report is, through real examples, to give the reader a feeling of what and how renewable energy is analysed for different hybrid ventilation systems. The report contains some general guidelines and recommendations for using renewable energy applications and also specifications of applicable renewable energy sources for integration in possible prototypes for the concepts of the Industrial Consortia involved in the project. This report is deliverable 3.2 (D3.2) in the project.

1.2 Background

Four climate zones and four industrial consortia have been defined.
They are named as follows:

- Severe climate - Industrial consortium, IC 4 (Norway)
- Cold climate - Industrial consortium, IC1 (Sweden)
- Moderate climate – Industrial consortium, IC2 (The Netherlands)
- Warm and mild climate – Industrial consortium, IC3 (France and Belgium)

Prior to project start the industrial consortia showed interest in the following renewable energy technologies:

Industrial consortia (IC)	**IC4**	**IC1**	**IC2**	**IC3**
Climate	Severe	Cold	Moderate	Warm and Mild
Building type	Single family houses	Apartments	Dwellings, Apartments	Dwellings
Renewable	Wind Heat recovery	PV Wind * With and without heat recovery	PV Wind *	PV

Table 1.1 Renewable energy applications considered before project start. Wind as a renewable application considered in IC1 is thought of as a natural driving force for air movement only, not as electricity production.

For general information and guide to the dimensioning and use of renewable energy applications for a hybrid ventilation system, please refer to the report: “General information on renewable energy application for auxiliary energy – suitable for use in hybrid ventilation systems, (D3.1)” of the Reshyvent project.

2 GENERAL GUIDLINE FOR APPLYING PV IN A VENTILATION SYSTEM

When dealing with renewable energy sources the electricity consumption of the components, which are to be supplied by renewable energy, has to be evaluated in detail in order to determine the feasibility of integrating renewable energy solutions. The major part of the electricity demand of a ventilation system is for the fans. However, controls, sensors, actuators, electrostatic filters, heat recovery with rotating wheels or pump driven water circuit will also contribute to the electricity use of the ventilation system. The two major renewable sources, which can be used to generate electricity are, solar power (PhotoVoltaic, PV) technology and wind technologies. As stated in the limitations of the report the wind application is not analysed in this report.

When dealing with stand-alone PV the following thresholds and target values have been identified:

- Thresholds are space (required area for solar module/-cell integration or installation), energy consumption, orientation (preferably south) and location.
- Target values may be defined as compensation of the extra costs for an advanced ventilation system for the electricity produced for the ventilation system by applying PV. In some cases applying PV may reduce installation costs (e.g. cabling).

2.1. Design parameters to consider before applying PV

From a technical point of view PV technology is relatively simple. However, there are still some crucial steps that must be taken in both the design and installation stage.

In the design stage there are a number of parameters, which needs to be considered. The table below illustrates the design parameters which are necessary to consider when applying PV.

Main Item	**Sub Issues**	**Example**
Geography	Latitude	50° North (Brussels)
	Longitude	5° East
	Orientation	195° - 15° from south
	Tilt angle	90° - Vertical
Load profile	Input voltage range	6-12 Volt DC
	Power needed	2-6 Watts
	Time of consumption	6 Hours
	Period of consumption	Daily during summer, weekends in spring / autumn, none during winter.
	Consumption pattern	6-9 AM, 1-4 PM
Shadowing	Shadows occur	Yes / No
	Time of shadowing	Winter between 8-12 AM
Available area	PV	L_{max} = 900 mm, L_{min} = 400 mm
	Battery	H_{max} = 100 mm, L_{min} = 20 mm, W_{max} = 25 mm
	Control device	H_{max} = 100 mm, L_{min} = 80 mm, W_{max} = 50 mm
Wiring	Distance between battery and consumption	2 m
	Distance between PV location and battery	0,5 m
	Distance between PV location and controller	0,5 m
Weather conditions	Average ambient temperature	Summer +22°C, Winter 2°C
	High / Low ambient temperature	-25°C to +42°C
	IP class needed for battery	IP 23
	IP class needed for controller	IP 65
Feasibility	Cost of kWh	0,13 Euro / kWh
	Price to power the component (AC transformer, cabling and installation cost, battery cost)	14 Euro
	Electrical maintenance cost	5 Euro per year
Integration	Possibility to integrate PV	Yes, front of inlet – 0,36 m^2
	Possibility to integrate battery	Yes, inside inlet – 20 cm^3
	Possibility to integrate controller	No
	Design requirements	“Black PV module look”

Table 2.1. Design parameters for evaluation and integration of PV in a ventilation system.

2.2. How to optimise the energy output

The energy output from a PV system is optimised by installing the PV cells in a perfect location and orientation. The geographic location is important for the environmental conditions (weather related) and for the insulation. The orientation is important in order to achieve the optimal incident angle for the solar radiation and to avoid eventual reductions in the output as a result of shading.

For an optimal PV solar output the following is required:

- South orientation: This is not always possible. East and west orientations may be considered. North orientation should be discouraged.
- An optimal tilt angle: This is almost never possible, as a wall/façade is stationary (vertical), even a sloped roof may have an unfavourable slope.
- Free horizon: Especially when apartment/office buildings are opposing each other along streets this is not possible. Moreover, in a built environment the chance of a 100% free horizon is limited.
- No shading: In a built environment this may be hard to achieve.

2.3. PV cell types

While conventional mono-crystalline cells have an efficiency of 13-17% and poly-crystalline about 12-15%, relatively high efficiencies (about 20%) are achieved by using new mono-crystalline cells with embedded contacts and a grooved surface area.
Amorphous silicon is the least efficient of the commercial silicon based products. Its efficiency is in the 8-10% range when new. Instability of the material though lowers the efficiency to a stabilised efficiency of about 4-7% after a few months exposure to sunlight. Another disadvantage of the amorphous cell is that it requires twice as much surface to generate the same energy as crystalline.

Technology	Commercial efficiency (%)	Commercial size (m^2)	Yield per m^2 (Wp / m^2)	Price pr. Wp (Euro / Wp)
Monocrystalline	13-17	0,5-1,5	160	3.000 – 4.20
Polycrystalline	12-15	0,5-1,5	150	2.80 – 4.00
Amorphous	4-8	0,2-0,8	40	1.80 – 2.50

Table 2.2. List of commercial PV technologies (anno 2004)

2.4. Battery types

For the applications requiring energy at night or during periods of low sunlight, a storage medium must be used to ensure the autonomy of the system. The usual storage equipment used with stand-alone systems is rechargeable batteries.

Technology	Commercial size (cm^3)	Voltage level (Volt)	Rated power (Ah)	Ambient temperature (°C)	Price pr. Wh (Euro / Wh)
Lead Acid – Open	120 – 25.000	2 – 12	6 – 2.000	-20 to +50	0,05 – 0,40
Lead Acid – Closed	120 – 50.000	2 – 12	6 – 2.000	-20 to +50	0,10 – 1,00
NiCd	5 – 50	1,2 – 9,0	0,36 – 2,4	-20 to +50	1,00 – 2,00
Lithium – Ion	10 – 30	3,7 – 9,0	3,7 – 7,4	-20 to +50	2,75 – 3,25

Table 2.3. List of commercial battery technologies (anno 2004)

2.5. Size of the PV panels and battery

The energy consumption of the component and the geographical position, orientation and possible shading determines the required PV size. For example a fan system in De Bilt (NL) will require in the winter season twice the solar surface of the same fan in Nice (FR). The battery capacity of the solar power system in De Bilt (NL) will be twice the size of the same system in Nice (FR). The feasibility of a PV system is therefore better in Southern Europe than in Northern Europe.

2.6. Exterior placement of the PV panels

Provided that the power consumption is within the economic and technical boundaries of PV solar application, roof mounted PV solar powered fans can generally be applied. For wall/façade mounted devices as inlet grilles, even when power consumption is reasonable, there will still be substantial barriers for the application of PV solar, mainly due to shading or unfavourable orientation angles and tilts.

2.7. Interior placement of the PV panels

Controls, sensors and actuators are in principle fit for stand-alone power supply. It would give these devices the flexibility of mounting them in the best position. However, the layout of the internal wiring in houses/buildings may reduce this flexibility if wireless technologies are not used. Integration of PV can reduce cabling to and from the components, but it must be analysed that adequate light intensity is available for the PV cells. This means positioning near windows is preferred, which is not necessarily the best position for the component.

2.8. General approach and options

When electricity demand of the components has been minimized as much as possible the following steps should be followed:

- Select only low consumption DC devices or find/develop low consumption DC alternatives for AC devices.
- For each of the devices the electricity consumption profile must be defined or estimated.

Based on this, the PV solar system requirement can be calculated and physical feasibility (space, orientation and location) and economic feasibility (initial and avoided costs) of PV solar can be determined.

3 INDUSTRIAL CONSORTIUM 1: SWEDEN (COLD CLIMATE)

This chapter exploits the possibility for implementing renewable energy applications in the IC1 hybrid ventilation concept.

3.1 The hybrid ventilation system of IC1

The IC 1 hybrid ventilation system is a two mode system with demand control. The system is characterised by:

- One fan per apartment
- Humidity sensor in bathroom
- Control unit for the user
- Network unit for integration and increased intelligence
- Supply convector for preheating air
- Building integrated monitoring unit

The system layout for the Swedish system is illustrated in Figure 2.1.

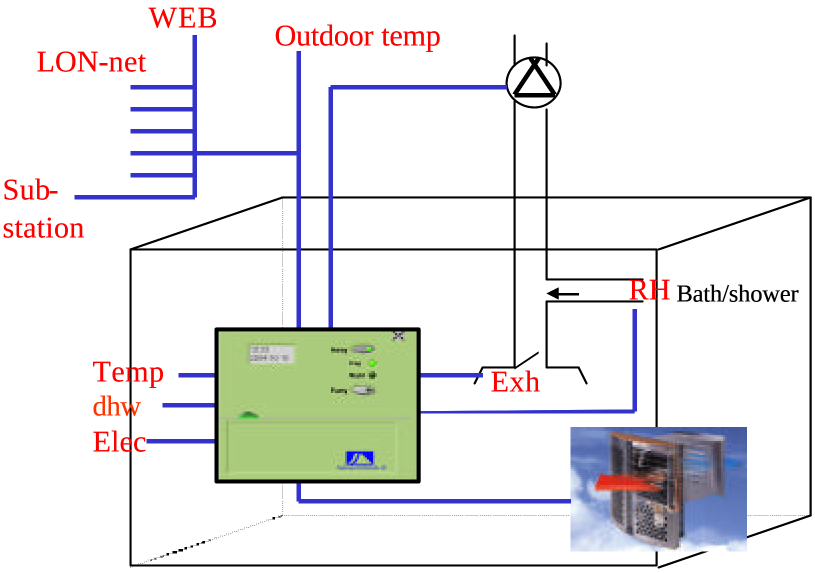

Figure 3.1 Hybrid ventilation layout of IC1.

The system is described in more detail in deliverable D9.1, of the Reshyvent project.

The possibility for integration of renewable energy in IC1 is primarily:

- PV for supply of electricity for components (fans, sensors and actuators).
- Solar air collectors for pre-heating of incoming fresh air.

The integration possibilities, dimensioning and feasibility of these two technologies are analysed in the following.

3.2 Analysis of using stand-alone PV systems for components

The fan, actuators and sensors in the IC1 system have been evaluated for application of a stand alone PV system for supply of electricity for these components.

3.2.1 PV supply for the fan (outlet)

The fan used in the IC1 system, is not optimised for the object (as it is built for higher back pressure), but will be able to self regulate the intended airflows, but not down to the low flows (and pressures) the ventilation system will operate with. As a short term solution the fan has been complemented with a tool that increases back pressure at low flows and at the lowest (not at home mode) the ventilation system will use the fan in intervals. Meanwhile, the IC1 partner, Systemair, will study the opportunities to build a new fan specially aimed for this purpose which can be used in future building objects.

According to measures conducted by Systemair, the fan motor will need:

- 23 Watt at 42 l/s or 0.55 Watt/l/s (21 Watt at 27 Pa and 28 Watt at 80 Pa) and
- 11 Watt at 14 l/s or 0.86 Watt/l/s (10 Watt at 1 Pa and 13 Watt at 48 Pa) minimum air flow.

The internal back pressure includes an extra 40 Pa.
For air flows in the interval of 18 – 30 l/s we assume an electricity need for 0.7 Watt/l/s.

The table below shows an overview of the analysis carried out and the results. The details concerning the analysis are presented in Appendix 1.

The Fan	Description
Voltage level:	220 VAC
Maximum power consumption:	23 W at 42 l/s (Systemair data)
Load profile:	Winter load (October – March): 12-17 W / hour in average, equals 288 – 408 Wh / day.

	Summer load (April – September): 13.6 W / hour in average, equals 326,4 Wh/ day.

PV system:	330 Wp module
	26,4 kWh battery bank
	20 A control system
Documentation:	
Cost price of system:	Euro 3.635 per apartment.
Feasibility:	Not defined, as payback time not defined
Advantages:	Autonomous “Zero Energy” system.
Disadvantages:	Very high cost. Large roofing / addict area needed.
Lessons learned:	Little contribution from Stack effect due to system choice,
	High power consumption to move airflow,
	Low efficiency fan,
Conclusion:	Not possible to apply autonomous PV system design due to season variation and high power consumption of the fan. For flat roofs of apartment buildings a so-called hybrid PV-small wind system with battery back up may be considered.
Suggestions for improvement:	Use central exhaustion system to increase stack effect
	Find other DC fan sources with lower power consumption (like the fan used in IC3)

Table 3.1 Overview of the results of the analysis of a PV system for the fan supply. Details can be viewed in Appendix 1.

3.2.2 PV supply for the actuator (inlet)

The table below shows an overview of the analysis carried out and the results. The details concerning the analysis are presented in Appendix 1.

Actuator	Description
Voltage level:	Low voltage DC (exact value unknown)
Maximum power consumption:	2 W
Load profile:	8 hours, every day, all year 16 Wh / day , every day, all year

PV system:	32 Wp module
	0,01 kWh battery bank
	6 A control system
Documentation:	
Cost price of system:	Euro 190 per apartment.
Feasibility:	Not defined, as payback time not defined
Advantages:	Autonomous “Zero Energy” system.
Disadvantages:	PV has to be placed south and with a “free” horizon to ensure sufficient insolation. Situation apartment buildings causing canyon effect which is disadvantageous for PV systems as it reduces the output of the solar module substantially due to shading of (part of) the solar modules. Size of the solar module too big for integration in the inlet structure itself.
Lessons learned:	Difficult to make economic autonomous PV system design due to season variation and relatively high power consumption..
Suggestions for improvement:	Find less electrical energy consuming actuator. Future thin film PV technology with optimal response to low light intensity may offer a solution.

Table 3.2 Overview of the results of the analysis of a PV system for the actuator supply. Details can be viewed in Appendix 1.

3.2.3 PV supply for the sensor

The table below shows an overview of the analysis carried out and the results. The details concerning the analysis are presented in Appendix 1.

Sensor	Description
Voltage level:	Unknown
Maximum power consumption:	1-3 W
Load profile:	24 hours, every day, all year 24 Wh – 72 Wh per day, every day, all year
PV system:	32-96 Wp module
	0,03-0,08 kWh battery bank
	6 A control system
Documentation:	

Cost price of system:	Euro 190-430 per apartment.
Feasibility:	Not defined, as payback time not defined
Advantages:	Autonomous “Zero Energy” system.
Disadvantages:	PV has to be placed near window facing south to ensure sufficient insolation. . This means that sensors cannot be mounted in optimal locations without cabling.
Lessons learned:	Difficult to make economic autonomous PV system design due to season variation, high power consumption of the sensors and the required indoor location of the sensors...
Suggestions for improvement:	Find less electrical energy consuming sensors. Future thin film PV technology with optimal response to low light intensity may offer an economic solution.

Table 3.3 Overview of the results of the analysis of a PV system for the sensor supply. Details can be viewed in Appendix 1.

3.3 Analysis of using a solar air collector for pre-heating of inlet air

The IC1 system is dimensioned for cold climates and therefore preheating of the inlet air is required in order to obtain a good thermal comfort. The IC1 system operates with at convector to preheat the incoming fresh air. The preheating is delivered by the central heating system (fluid based). However with solar air collectors the incoming air can be pre-heated by using the solar radiation on the facade[1].

The potential for using solar air collectors is analysed using two methods. First a rough method using nomograms from the book “Solar air systems, a design handbook”, and secondly a more detailed analysis using the building simulation program Bsim2002.

The first rough estimation of the energy output of a solar air collector for the IC1 system shows an energy saving of *82 kWh / year per* m^2 collector. Based on this a more detailed model was set up and used to verify the first rough results. The results of the detailed analysis show an energy saving of about *120 kWh/year for 1* m^2 *collector.* Based on this analysis it may be concluded that using this more detailed model shows a significant higher saving potential. The details behind the two methods can be seen in Appendix 1. Both analyses are, however, only theoretical calculations and they must be documented by testing in order to fully verify the results.

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[1] The solar air collector technology is described in more detail in the report WP3.1, General information on renewable application for auxiliary energy – suitable for use in hybrid ventilation systems.

Based on the detailed simulation, the results show an energy saving for a 3 m^2 solar air collector is approximately 360 kWh/year, which is approximately 10% of the heating demand for the IC1 reference system.

The cost of a solar air collector is approximately 700 Euro per m^2 for an Aidtmiljeo collector[2] i.e. for 3 m^2 the cost is 2.100 euro. Over a lifetime of 20 years this results in an energy cost of 0,29 euro per kWh, which is rather high.

The conclusion is that even with a drastic increase of the energy cost over the next years, inserting a solar air collector for this system is not feasible. A major reason for the low effectively of the collector is the low airflows in a hybrid ventilation system as a solar air collector works most efficiently at larger airflows.

3.4 Overall renewable outlook for IC1

PV supply

Supply component	**Fan**	**Actuator**	**Sensor**
PV module	330 Wp (3 m^2)	32 Wp (0,3 m^2)	32-96 Wp (0,3-1 m^2)
Battery bank	26,4 kWh (0,3 m^3)	0,6 kWh (0,01 m^3)	1,5-4,5 kWh (0,03-0,08 m^3)
Control unit	20 A	6 A	6 A
Estimated total cost	3.650 Euro	190 Euro	190-430 Euro

Table 3.4. Simulation results, for location Stockholm Sweden and the IC1 reference system.

Solar air collector

Solar air collector	Collector size	Energy saving kWh/year	Price of collector	
Aidt miljø SV3	0,4 m2	85	376	Euro
Aidt miljø SV7	0,73 m2	108	510	Euro
Aidt miljø SV14	1,4 m2	185	860	Euro

Table 3.5 Simulation results for location Stockholm and the IC 1 reference system

Based on the analyses carried out, the overall renewable energy outlook for IC1 is as follows:

- PV solutions are not feasible with the current electricity demands of the components.
- Solar pre heating is technically possible – but economically not feasible due to the low air flows

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[2] Aidtmiljoe is a Danish solar collector manufacturer, information may be found on the internet at www.aidt.dk

3.5 Suggestions for improvements

The feasibility/potential of the use of PV solar systems is dependant on the energy consumption and the energy consumption pattern of the fan(s) and auxiliary components during the day, the week and the year. For the application of PV solar systems the power consumption should be as low as possible and use DC current. IC1 has plans for the development of low energy devices in order to reduce overall electrical energy consumption when applying ventilation systems, hence increasing the potential for integrating renewable energy solutions. Furthermore, small wind turbines look interesting for future application, eventually in a hybrid system with PV, in case (flat) roof mounted systems can be applied.

4 INDUSTRIAL CONSORTIUM 2: THE NETHERLANDS (MODERATE CLIMATE)

This chapter exploits the possibility for implementing renewable energy applications in the IC2 hybrid ventilation concept.

4.1 The hybrid ventilation system of IC2

The IC 2 hybrid ventilation system is a two mode system with demand control consisting of:

- Self-regulating inlets through the façade, with constant flow
- CO_2 sensors for determination ventilation demand in each room (other sensors possible)
- Low pressure valves
- A fan for mechanical mode (> 2 W for 56 l/s) and a motorized damper for natural mode

A principle sketch of the IC 2 system is illustrated in figure 4.1 below.

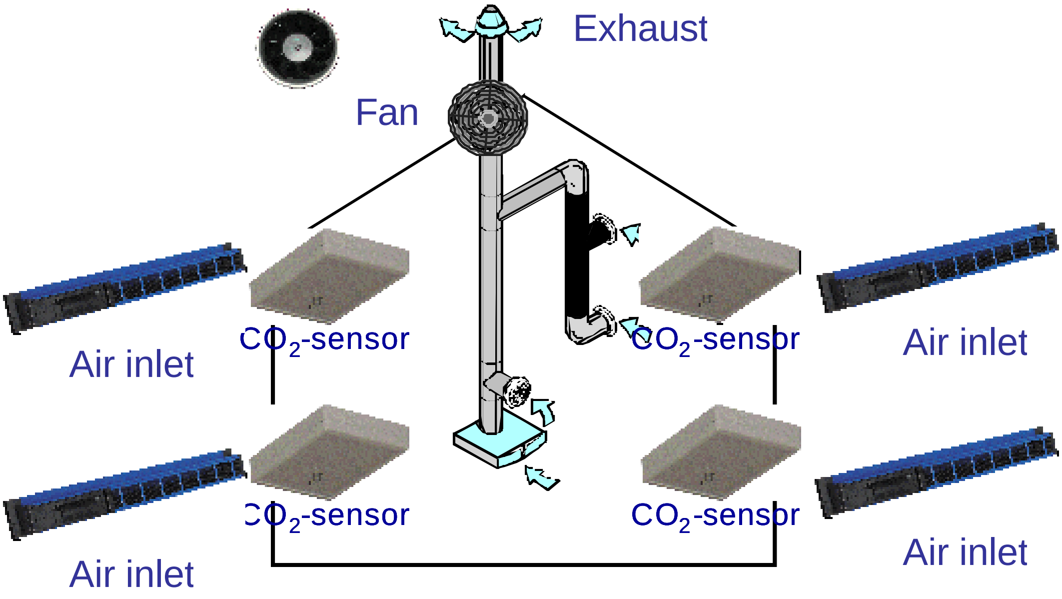

Figure 4.1: Principle sketch of the IC2 hybrid ventilation system

The system is described in more detail in deliverable D9.2, of the Reshyvent project. The analysis for IC2 has been concentrated on the application of PV solar cells.

4.2 Analysis of using stand-alone PV systems for components

In the following applications of PV have been considered and reviewed based on the input obtained from IC2. Analyses of the following components have been carried out:

- Control print
- Flow sensor
- Damper
- Fan
- Inlet grille

4.2.1 Power consumption of the components

- The control print has a power consumption of 2,5 VA and is running constantly (natural and mechanical mode).
- The flow sensor has a power consumption of 1 VA and is running constantly (natural and mechanical mode).
- In the natural mode a damper for controlling the airflow is used. This damper can regulate constantly but it can also be chosen to adjust it once in a period of a quarter. In that case it will consume +/- 1 VA during 30 seconds each quarter of an hour.
- In the mechanical mode the fan is used. At this moment the damper in the mechanical mode throttle the flow in case of low demands. That is due to the fact that the fan is still too powerful.

For calculations of PV possibilities the use of the damper in mechanical mode is not calculated as a solution for the low demands in the fan. Therefore, in the mechanical mode we will have a constant power consumption of the fan of +/- 2 VA. The system is expected to run in natural mode for 70 - 80 % of the time and 20 - 30 % of the time in mechanical mode.

4.2.2 Placement of solar cells

For fan integration, the solar panels were meant to be integrated on top of the exhaust (horizontal on an area with a diameter of 30 cm) and on the round casing (vertical) that has a height of 20 cm.
For the inlet grille, the PV solar cells could be integrated directly on the inlet placed on the facade of the building.

4.2.3 Calculation of Energy Consumption

Calculation based on average monthly energy consumption:

Control print:	24 hr x 2.5 VA (or W)	= 60 Wh/day
Flow sensor:	24 hr x 1.0 VA (or W)	= 24 Wh/day
Fan mechanical mode:	24 hr x 2.0 VA (or W) x 80%	= 38 Wh/day
Damper natural mode:	24 hr x 1.0 VA (or W) x 20% x 0.8 [3]	= 4 Wh/day
Total		= 126 Wh/dag

For De Bilt in The Netherlands this would mean a solar module surface of:

- 23 sqm with solar cells facing North
- 14 sqm with solar cells facing East or West
- 6 sqm with solar cells facing South

The above mentioned sqm solar cells areas are applicable for vertically mounting against a wall. With a tilt angle of 45 degrees the above mentioned surfaces will reduce with approximately 20%. Further, it is assumed that the horizon will be "free". Hence no obstacles like buildings, walls, trees and the like in front of the system. The area available for the solar panels i.e.on the top of the fan, horizontally, or on the casing, vertically is very limited. Hence not possible for integration with the above mentioned required sqm of solar cell area. Separate mounting of solar modules was not favoured by IC2.

4.2.4 Inlet grille

IC2 looked also at the possibility of integrating solar cells on the eventually extended upper part of an inlet grille, (see sketch in figure 4.2) in order to power the damper and sensor.

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[3] 30 sec : 3600 sec x 4 x 24 hr

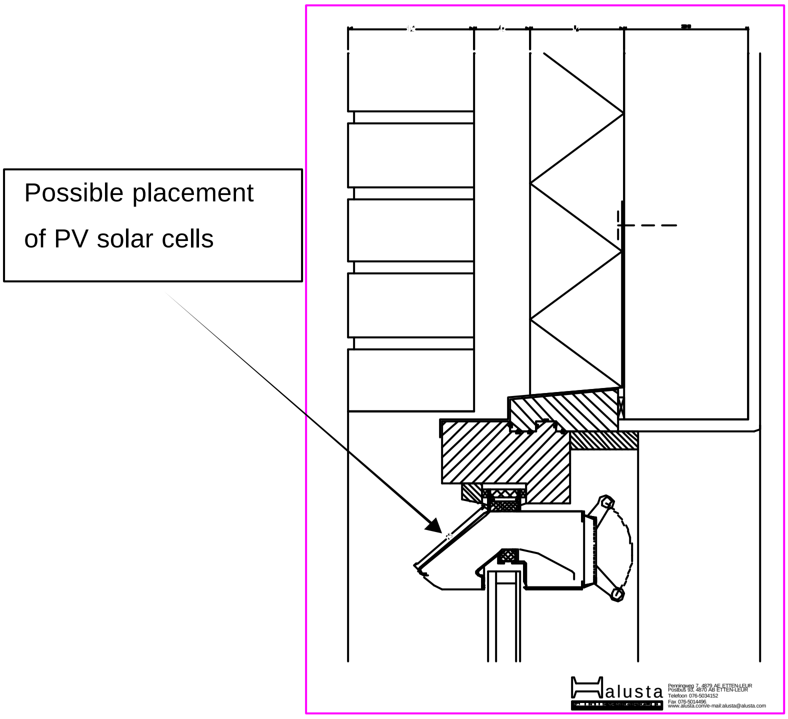


Figure 4.2 Sketch of cross section the IC2 Inlet, where solar cells could possibly be integrated, indicated by thee arrow.

From the drawing of the inlet grille it became clear that with the extreme high power consumption of the control print it will not be possible to integrate PV solar.

Next to the high power requirements the main constraints for this application of PV in the built environment are:

- preferably south orientation required
- DC appliances rather than AC appliances required (in order to avoid conversion-losses from AC to DC)
- free "horizon required for optimal energy output of PV solar cells
- the cover of the inlet grille needs to be extended beyond the overhanging wall
- continuous (high) power consumption of the sensor
- if integrated in the inlet grille the use should be universal; with the above sqm requirements this is not feasible

4.3 Overall outlook for IC2

PV is not a viable option for the IC2 hybrid ventilation configuration.

In summer it would work for all components with a reasonably small size solar module and small battery. However, in winter a large size battery would be required to pass the winter months. In order to recharge the battery after the winter months as quickly as possible extra solar modules will be required. Therefore, PV solutions are not feasible in IC2 with the current electricity demands of the components.

The technical constraints for IC2 are:

- Wish of IC2 for a standard solution for products with integrated solar cells fit for general use, i.e. the system should also work while facing north, which at the moment is not possible as too little energy will be generated in the north orientation.
- Space available on the fan and inlet grille for mounting the solar module(s) is limited
- Slope of the roofs for tilting of the solar module (s) not always optimal.

4.4 Suggestions for improvement

Future use of PV may be possible if:

- Power consumption of the components is reduced substantially
- New PV technologies become available with higher output and lesser area requirements

At present the first small wind engines for integration in the built environment are under test in among others The Netherlands. With this development of small wind engines for application in the built environment, wind energy may offer an option for an economic power supply of some of the components.

The disadvantages of the wind option:

- aesthetcs aspect (no roof integration possible)
- extra structural design on the roof to mount the wind engine
- extra wiring because of need to position the wind engine near the edge of the roof

5 INDUSTRIAL CONSORTIUM 3: FRANCE AND BELGIUM (MILD AND WARM CLIMATE)

This chapter exploits the possibility for implementing renewable energy applications in the IC3 hybrid ventilation concept.

5.1 The hybrid ventilation system of IC3

The IC 3 hybrid ventilation system is a two mode system with demand control based on sensors (presence detection, humidity and temperature). All the ventilation devices are piloted by the system i.e. Inlets / outlets / fan / motorised windows.

The central control unit determines:

- Airflow in each room
- Speed of the fan
- Opening of the windows

There is always a balance between supply and exhaust at the level of the central control unit

A principle sketch of the IC 3 system is illustrated in figure 5.1 below.

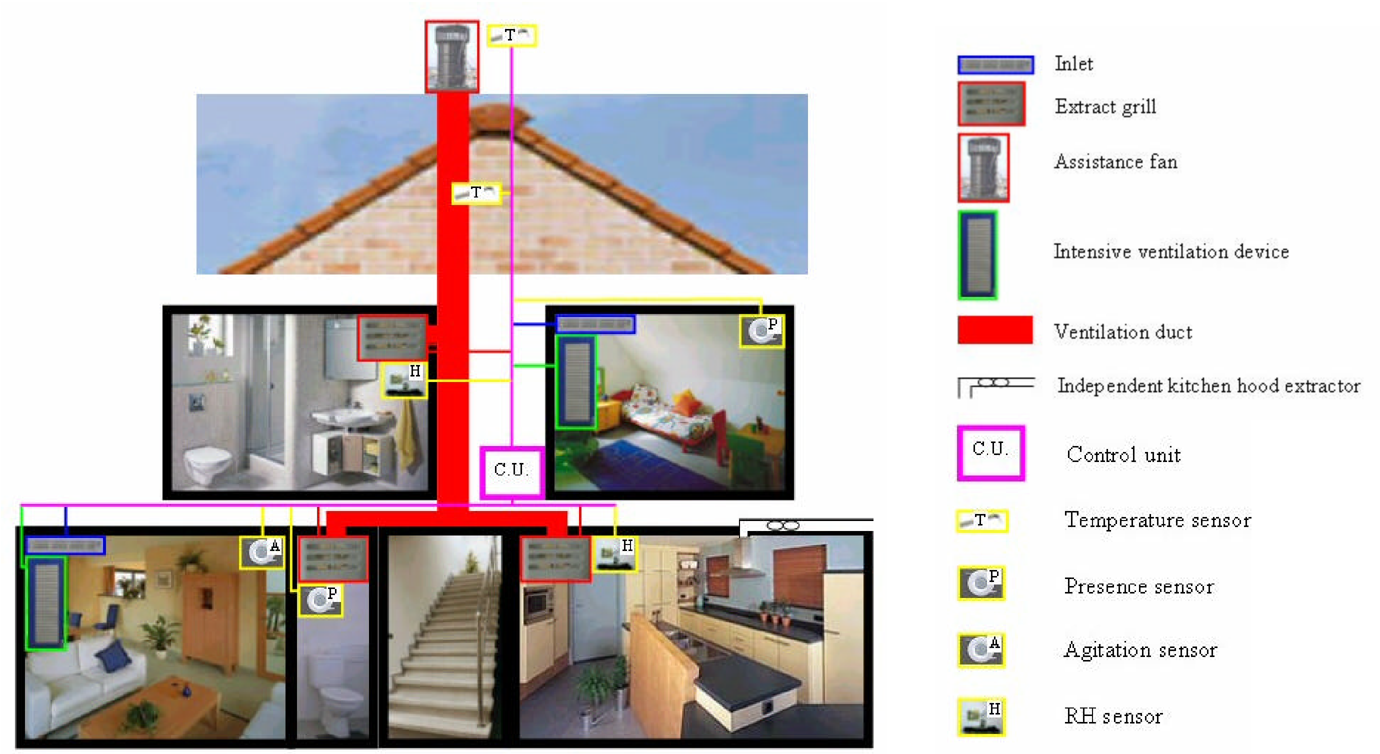


Figure 5.1 Graphic sketch of the IC3 hybrid ventilation system. The system consists of the components listed to the right.

The system is described in more detail in deliverable D9.3, of the Reshyvent project. Only the application of PV solar cells will be analysed for IC3.

5.2 Analysis of using stand-alone PV systems for components

In the following application of PV has been considered and reviewed based on the input obtained from IC3.

The following two components have been considered for application of PV.

- fan
- inlet grille

5.2.1 The fan

In order to determine the more detailed energy consumption of the fan used in the system, distributed over a year, IC3 has conducted monitoring of the energy usage for different locations in France. Figure 4.2 and 4.3 shows average energy use (in Wc and Ah/day) for fans in different locations in France, for the years 1998 and 1999.

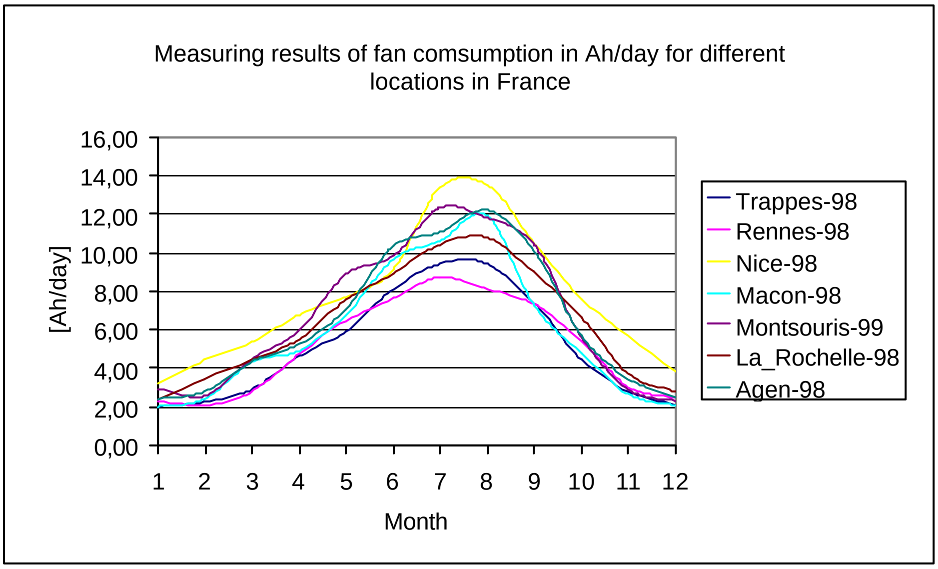


Figure 5.2: Average measuring results of fan consumption in Ah/day for different locations in France

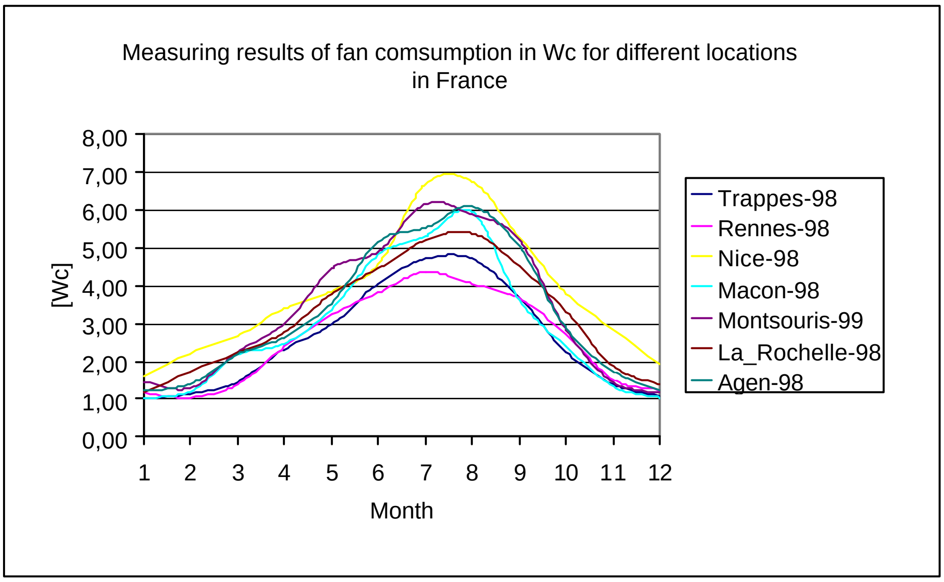


Figure 5.3: Average measuring results of fan consumption in Wc for different locations in France

Figure 4.2 and 4.3 show the (average) monthly power consumption in different regions in France. La Trappes and Montsouris, both near Paris, show a substantial difference in consumption between 1998 and 1999. This proves that it is very important to build in a security in the PV system for periods with low sun (which can be very locally). It is lso important to use a reference year data for the insolation, and not just a random year.

For dimensioning of the PV system the 4W - 1W (plus occasionally 16W) configuration of the ventilation system is used. The different loads (1,4 or 16W) are determined by a correlation between weather data and the system. However, the direct correlation between insolation and load requirement, as is assumed in the consumption calculations, is not finally evaluated by IC3.

A tailor made system for the various sites in France is an option, though not attractive for a standard solution. The difference is in the size of module and battery.

- Module size varies between 35 Wp and 45 Wp.
- Battery size varies between 30 Ah and 45 Ah.

If only the tilt angle and orientation of the solar module is used as parameters for the optimal performance, then one could use for the whole of France (and Belgium) a system composed as follows:

- 1 solar module 45 Wp
- 1 solar battery (lead-acid, gel type, maintenance free) 45 Ah/12V
- 1 charge controller

The above system is currently being tested in a pilot system, set up near Paris, France. The outcome from the trials should provide detailed info for the design and composition of the definite PV system.

The lifetime of the solar module is 20 years plus. The battery has a much shorter lifetime and is thus a replacement component. The choice for the size of battery is made on lifetime expectancy. This is a matter of economics and convenience. With the proposed battery type and size this could be up to 10 years. If a smaller size of battery is chosen, then the lifetime will reduce dramatically.

For the solar module either crystalline cells or thin film (requires more space) can be considered.
For the battery lead acid is the recommended type.
Optionally NiCad or Lithium batteries can be considered. These are expensive though and not environmentally friendly.

5.2.2 Configuration / set-up of the pilot system for the fan

The pilot system is set up in the building of Aereco, located near Paris, in real conditions, and is connected to a "box" equivalent to a house. In this box 1 motorised damper replaces all the usual inlets (between outside and inside the box), and 1 damper replaces all the extract grilles (between the inside box and the duct connected to the fan). A computer simulates needs detections (RH% and presence) and so the strategy designed for IC3 system is applied, so that dampers (and fan) are driven as real "total" grilles.
The box and duct inside pressures are measured and generated airflows are evaluated in order to assess the impact of passive stack effect (and auxiliary parameters as wind on the building) on the expected target airflows. Further, are measured PV panel current, battery voltage, fan used electric power, outdoor temperature, indoor temperature and solar radiation.

The solar system is composed of one solar module of 50 Wp, a sealed lead acid battery of 12V/41Ah and a charge controller. Readily standard available components are used.
The pilot system setup can be viewed in figure 5.4.

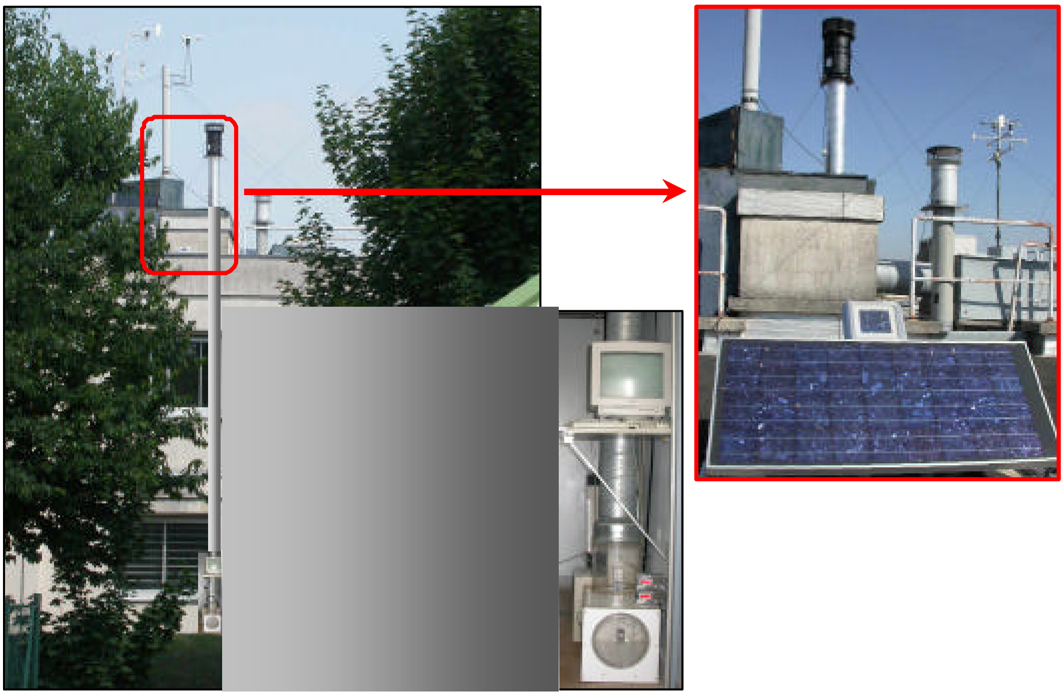


Figure 5.4. Illustration of the IC3 PV power fan set up.

After the monitoring period (1-2 years) the PV system will be customised to the actual power requirements of the fan. Though, there are distinct differences in the performance of the hybrid ventilation system for the North and South of France, which effect the sizing of the PV systems, it may be possible to design a standard PV powered fan for the whole of France.

5.2.3 First monitoring results of PV system for the fan

Before the end of the Reshyvent project some first monitoring results were collected. Figure 5.5 shows the monitoring results for a period of 6 days for a summer and autumn situation.

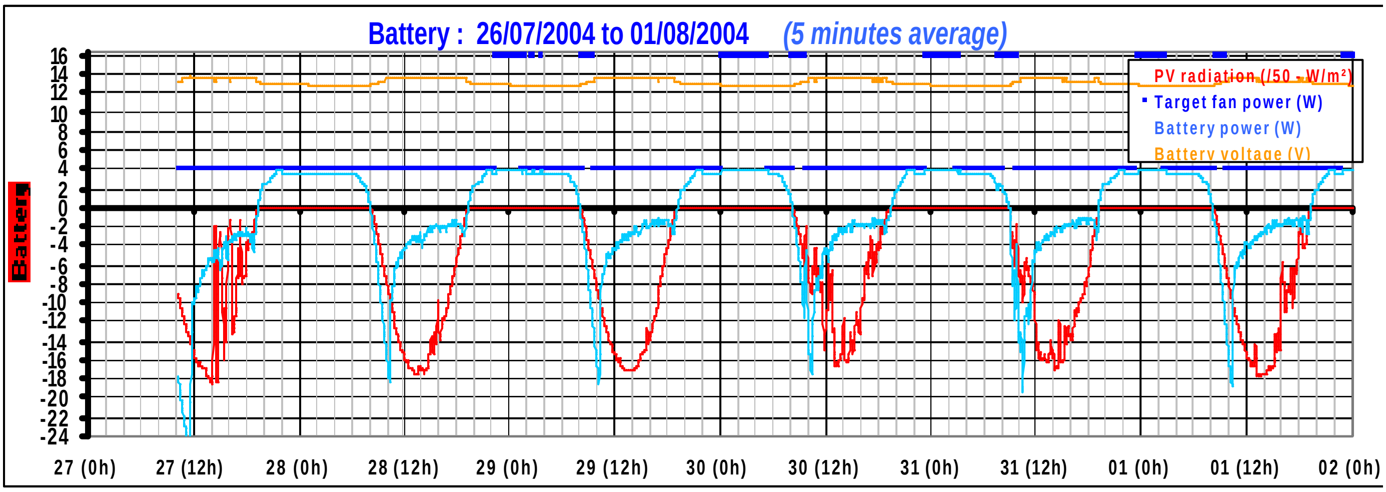


Figure 5.5. First monitoring results of the pilot PV system for the IC3 fan power consumption during late July 2004 (showing a sunny period).

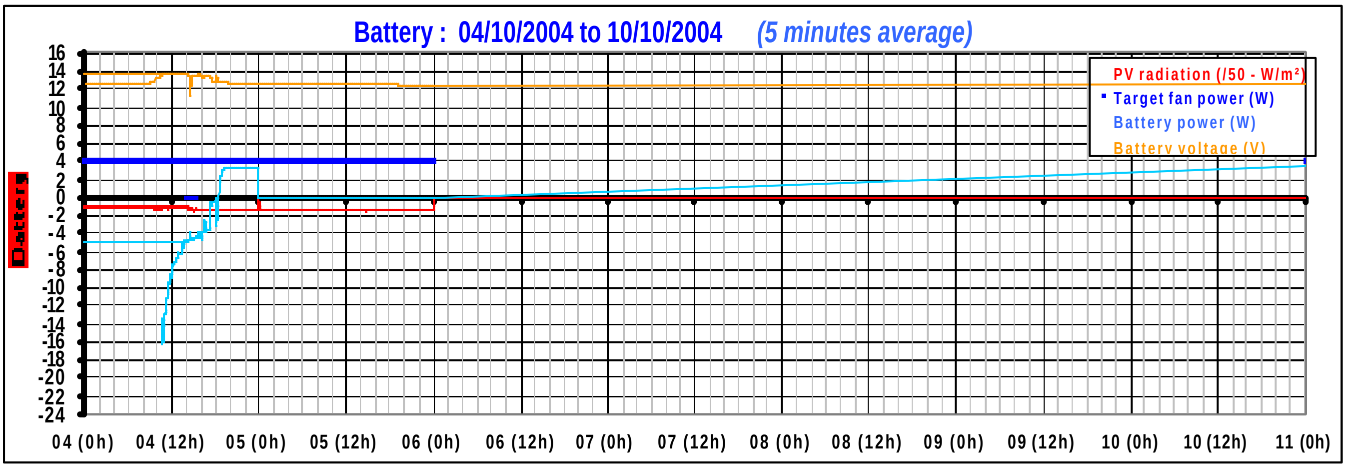


Figure 5.6. First monitoring results of the pilot PV system for the IC3 fan power consumption during beginning of October 2004 (showing a cloudy period).

From these first results it can be seen that the match between the PV panel and battery and the system use is in good correlation, however, a longer monitoring period must be conducted before the system is evaluated and possibly adjusted.

5.2.4 Inlet grille

IC3 looked also at the possibility of integrating solar cells on the front part of an inlet grille. In the case of IC3 it was possible to integrate a strip of solar cells on the vertical (front) part of the inlet grille, as indicated on figure 5.7 below.

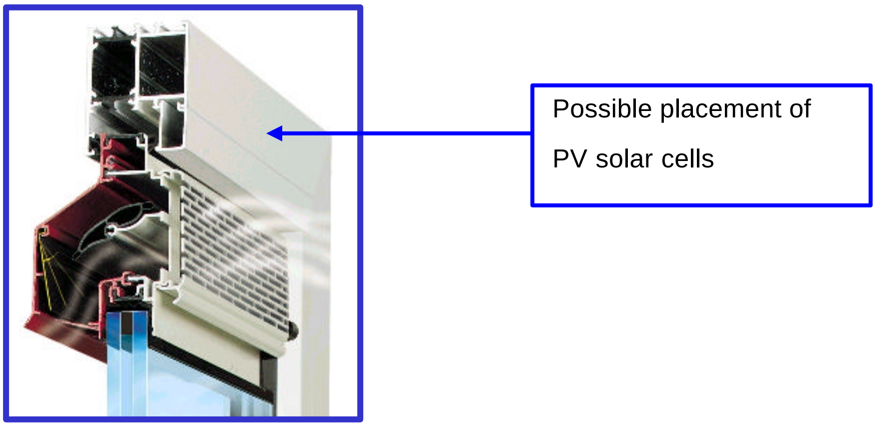

Possible placement of PV solar cells

Figure 5.7. Illustration of placement of possible PV solar cells in IC3 inlet grill

Unfortunately, due to change of design and way of mounting of the inlet grille this option became obsolete during the process of the project.

5.3 Overall outlook for IC3

PV solution is feasible in IC3 with the current electricity demands of the components and can be used as stand-alone power supply for the fan in the IC3 hybrid ventilation configuration.

With small changes PV will also be a viable solution for the inlet grill.

5.4 Suggestions for improvements

A PV system has been dimensioned and monitoring is ongoing. It is assumed that the ventilation requirement is depending on a lot of parameters like temperatures (inside and outside), location/orientation/use/occupation of the building/house, etc. If this is a fixed pattern and as reflected in the data, the solar powered fan will operate all the time as required for this pattern. For patterns that require a higher overall load consumption, it will not. Therefore, accurate data resulting from the monitoring of the trial system(s) will fine-tune the design data for the definite PV system configuration.

An option to consider is to integrate the charge control unit and the battery in the inlet grille unit and a separate strip with solar cells that can be mounted against the wall just above the inlet grille. For the sake of easy installation, connection between solar cells and charge control should be made with a plugs & sockets.

6 INDUSTRIAL CONSORTIUM 4: NORWAY (SEVERE CLIMATE)

This chapter exploits the possibility for implementing renewable energy applications in the IC4 hybrid ventilation concept.

6.1 The hybrid ventilation system of IC4

The IC4 hybrid ventilation system is a two mode system with demand control based on sensors (humidity and CO2) and heat recovery. It is fully automatic with a control of the overflow rate and a spatial distribution of the air. The IC4 system is characterised by the following components:

- IR-sensor motorised damper in living room [Siemens/Belimo]
- Manual dampers in bedrooms (option).
- Efficient EC fan motors
- Regenerative heat exchanger, with electrostatic filter and moisture recovery
- Wind vane on the roof

The IC4 system is illustrated in a sketch on figures 6.1 and 6.2.

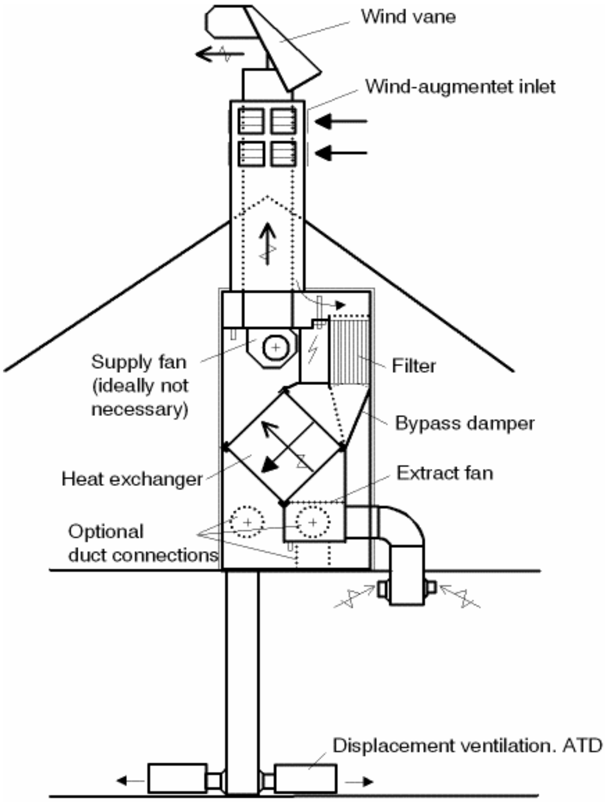


Figure 6.1. Graphic sketch of the IC4 hybrid ventilation system.

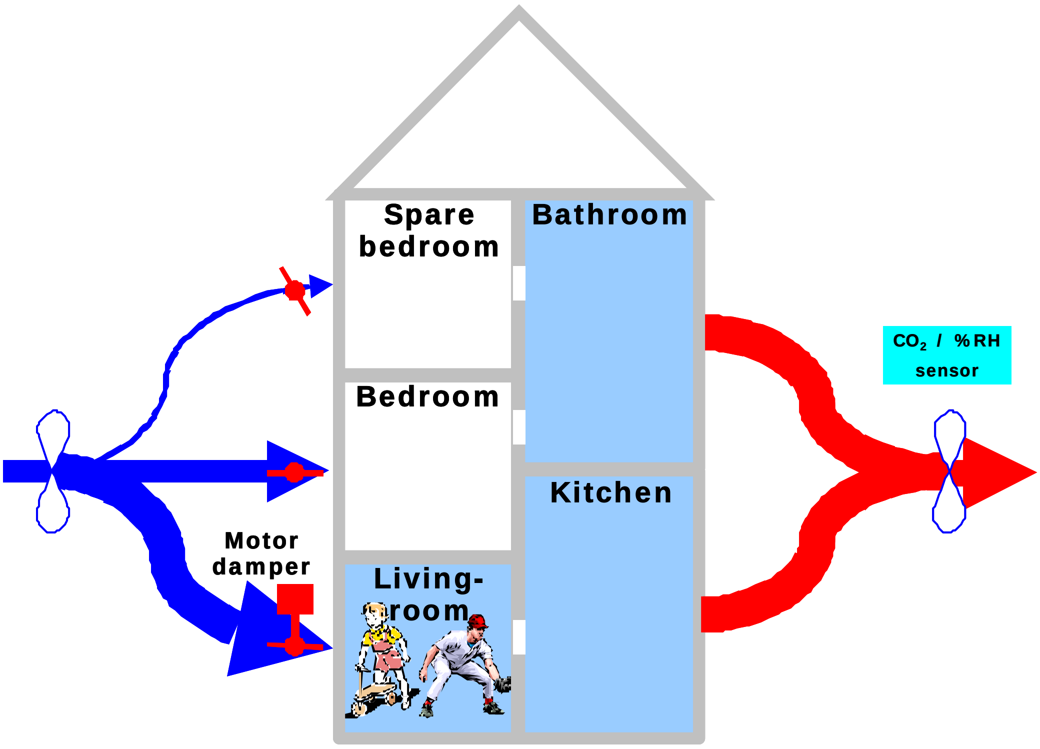


Figure 6.2 Sketch illustration of the air movement in the IC4 system

The system is described in more detail in deliverable D9.4, of the Reshyvent project. Only the possibility for integration of PV has been analysed in this deliverable.

6.2 Analysis of using stand-alone PV systems for components

In the following application of PV has been considered and reviewed based on the input obtained from IC-4. Only application of PV for the fan power has been analysed.

6.2.1 Energy consumption of the fan

The power consumption of the fan consists of three motors:

- A rotary heat exchanger
- A supply fan
- An exhaust fan

The rotary heat exchanger:

Rotation speed of stepper motor is controlled to keep constant supply temperature (depends on outdoor temperature and internal gains).

Motor power consumption: = 0 W when no heat recovery required, up to 18 W at maximum speed.

For simplicity a bimodal on/off operation is assumed i.e. the rotor uses approx. 18 W when the outdoor temperature is below the dwelling's balance point temperature (assume 12°C).

The supply and exhaust fan power:

The fan has an approximated efficiency of 15%. The flow rate required is 0.03 m³/s when the building is occupied and 0.01 m³/s when the building is empty during extended periods (system automatically reduces flow rate).

The period of operation at reduced flow rate is assumed to be 20% of the year, randomly spread throughout year.

The total system pressure drop is 29.5 Pa normally and 5 Pa when the building is unoccupied (natural driving forces will reduce this value.).

Therefore, the total fan power is:

Total fan power = Flow rate [m3/h] x Pressure drop - natural driving forces [Pa]/ Efficiency [-]

The energy consumption based on the above energy calculation is shown in table 5.1.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Wh	15557	15639	15440	14427	8927	4435	3160	4172	9276	14604	15469	14963
Wh/sqm*	550	1140	4500	3450	5060	4350	3720	3645	2300	1230	575	225
Sqm**	28	14	3.5	4.2	1.8	1	0.9	1.2	4	12	27	66

*Wh generated per sqm of solar module

**Sqm = area of solar modules at a tilt angle of 60° (with the horizontal)

Table 6.1 Energy consumption and the corresponding PV area need for the IC4 fan. The calculations are based on the information listed in this section, and the results are the average monthly energy consumptions.

The above calculations results show an anti cyclic pattern i.e. the energy demand is high when the energy supply is low or the energy supply is high when the demand is low.

This could be solved by using a large battery and more solar modules in summer, which would make it a very expensive stand-alone system that would even require a separate battery room.

The conclusion is therefore, that PV is not a viable option for the IC4 hybrid ventilation system. Furthermore, the standby power consumption of the fan control is 35 W, which is high even compared to the energy use of the fan.

6.3 Overall outlook for IC4

Due to the northern climate (less solar radiation is available) and the anti cyclic pattern (higher energy use for the fan during winter) PV solutions are not feasible in IC4 with the current electricity demands of the components. If PV could be applied in IC4, the grid connected PV option would be the option to be considered.

6.4 Suggestions to improvements

The feasibility/potential of the use of PV solar systems is dependent on the energy consumption and the energy consumption pattern of the fan(s) and auxiliary components during the day, the week and the year. The availability of fans and auxiliary devices with DC (Direct Current) operation rather than AC (Alternate Current) operation is an important criterion for the economic and trouble-free application of PV. This would make the PV application for IC4 better. However, as long as the PV power supply and energy demand from the fan are anti cyclic, PV will not be a viable solution for IC4.

Another element for improvement of the IC4 system is reduction of the energy demand. For the application of PV solar systems the power consumption should be as low as possible. This requires highly energy efficient devices. In the case of the IC4 solution the electrical energy consumption is far beyond the economic boundary of PV systems. IC4 may consider developing a low consumption fan (like in IC3) although the power consumption should then be reduced substantially because of, the especially in the winter months, low insolation that results in hardly any output from the solar modules.

7 SUMMARY AND CONCLUSION

The possibilities for applying PV, and for IC1 the possibility for applying solar air heating, have been investigated. A summary of the findings is listed in table 7.1 below.

The Industrial Consortia (IC)	Result of renewable application analysis
IC1 (Sweden)	♦ PV systems (for fan, actuator, sensors) are not feasible due to season variation and high power consumption ♦ Solar thermal applications are not feasible due to season miss-match and the relatively low airflow rate for the ventilation system. ♦ Recommendation for future application for IC1: If power consumption is lowered a (flat) roof mounted PV/small wind hybrid system might be considered.
IC2 (The Netherlands)	♦ PV is not a feasible option with the current power requirements ♦ Recommendation for future application for IC2: Reduction of the power consumption of the components will make PV integration an interesting option
IC3 (France and Belgium)	♦ PV is a viable option as a standalone power supply for the IC3 fan ♦ PV is possible to integrate onto the inlet grille of IC3. However, due to change of design and method of mounting this option had to be disregarded. ♦ Monitoring of test systems is ongoing ♦ Recommendation for future application for IC3: Consider using a separate strip of PV to supply the inlet grille. Mount the strip to the outside wall. Integrate the charge control unit and battery into the inlet grille. Connection with the PV strip could be made with plug and socket units.
IC4 (Norway)	♦ PV systems for fan supply is not a feasible option due to an anti cyclic pattern (energy demand is high when solar radiation is low) and high energy demand. ♦ Recommendation for future application for IC4: Consider the use of small wind applications ♦ If PV is considered, it should be grid connected

Table 7.1. Overview of the results of the analysis for applying renewable energy solutions to the different IC hybrid ventilation systems

7.1 General options and restrictions

In the Reshyvent project four different climate types have been described. This division is geographically defined and has so an impact on the size of the solar systems and consequently the viability of such a system. For example a fan system in De Bilt (NL) will require in winter twice the solar surface of the same fan in Nice (FR). Moreover the battery capacity of the solar power system in De Bilt (NL) will be twice the size of the same system in Nice (FR). This makes it difficult to come with an “of the shelf” solar powered product for a wide variety of geographical locations.

The feasibility/potential of the use of PV solar systems is dependent on the energy consumption and the energy consumption pattern of the fan(s) and auxiliary components during the day, the week and the year. The availability of fans and auxiliary devices with DC (Direct Current) operation rather than AC (Alternate Current) operation is an important criterion for the economic and trouble-free application of PV.

The way of mounting of the PV solar cells is important for eventual reductions in the output as a result of (partially) shading, not optimal orientation (south for northern latitudes) and not optimal tilt angle. IC3 has chosen a stand-alone PV system to power the fan, which facilitates optimal positioning of the PV system and offers a great extent of flexibility.

For an optimal PV solar output for the inlet grille is required:

- South orientation. This is not always possible. East and west orientations may be considered. North orientation should be discouraged.
- An optimal tilt angle. This is hardly feasible on a wall/façade and even a sloped roof.
- Free horizon. Especially when apartment/office buildings are opposing each other along streets this is not possible. Moreover, in a built environment the chance of a free horizon is second to none.
- No shading. In a built environment this is hard to achieve.

The energy output is also technology dependent. Mono-crystalline and poly-crystalline silicon solar cells have the best performances, while amorphous silicon solar cells have the lowest performances. An advantage of amorphous (thin film) over crystalline is its ease of integration in other products. A disadvantage of amorphous is that it requires twice as much surface to generate the same energy as crystalline.

7.2 The use of wind and hybrid PV/wind applications for power supply

At present the first small wind engines for integration in the built environment are under test in among other The Netherlands. With this development of small wind engines for application in the built environment, wind energy may offer an option for an economic power supply of some of the components. In combination with a battery and a small PV system, a so called hybrid wind-PV system may be a solution for powering the fan.

Disadvantages of the wind option:

- visual aspect (no roof integration possible)
- extra structural design on the roof to mount the wind engine
- extra wiring because of the need to position the wind engine near the edge of the roof

7.3 Lessons learned in applying PV in a hybrid ventilation system

Technical constraints are:

- space available on the roof for mounting the solar module(s)
- orientation of the (existing) houses
- slope of the roofs for optimal tilting of the solar module (s)

Future use of PV may be possible if:

- power consumption of the components is reduced substantially
- other PV technologies become available with higher output and lesser area

7.4 Conclusion

PV solar is under very specific and favourable conditions a commercially viable power supply option for electricity consuming devices in hybrid ventilation systems.

In the future new PV solar cell technology with much higher conversion percentages, greater availability of DC appliances and availability of appliances with very low power consumption will increase the potential for use of PV solar power in hybrid ventilation systems.

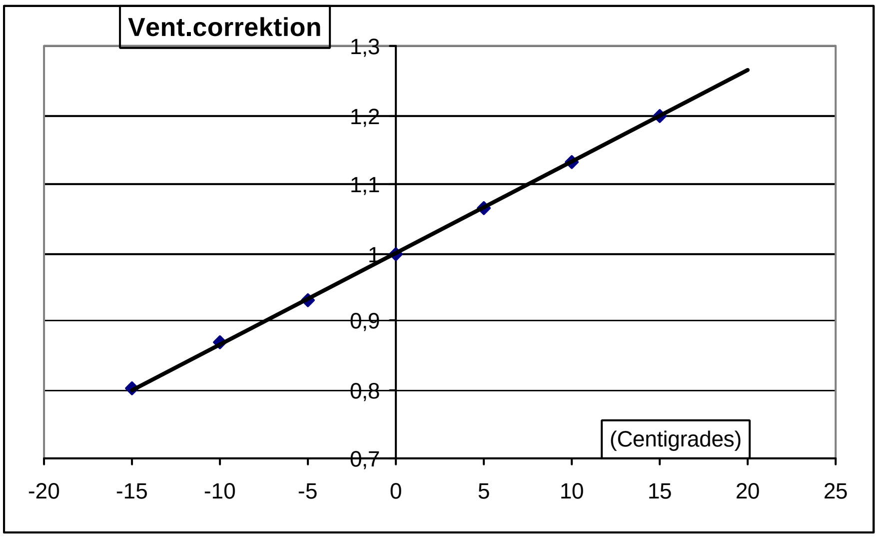
8 APPENDIX 1: IC1 BACKGROUND INFORMATION AND DOCUMENTATION

System description and documentation

The airflow will vary with family size and ventilation mode. With the assumptions as in table 1 the average family size will be 2 persons (Swedish average in new built multifamily houses) and the average airflow will be 16.3 l/s.

No. of apartments	3	2	1	
Person/apartm.	1	2	5	Time share
Base vent.	17	21	35	0,33
Night vent.	13,6	16,8	28	0,33
Out-mode	8	8	8	0,3
Cooking	40	40	40	0,03

With this data and the power need for the fan in each apartment for each period of mode the mean power use will be 12 Watt/apartment.



The airflow will be controlled also according to outdoor temperature. At lowest temperature – 20°C and at high temperature + 20°C (or more). This is of interest, as PV will produce less in winter time. But in December, the darkest month the average temperature is + 0.1°C (Stockholm) and the decrease in ventilation will be zero.

In average the airflow will be at the same level as in 0°C for the whole dark period October to March. In the spring/summer period April – September the airflow will in average be 16% higher. In average for the whole year the airflow increase will be 8%.

In the dark winter period the same power will be needed in average for the day
(12 Watt/apartment) but in the summer period the average power needed will be
13,6 Watt/apartment.

Peak power at winter time
Assuming 50% at peak hour will use forced ventilation at cooking time. Then the power needed at that time will be 17 Watt in winter period.

2010 fan power needs
With a fan that is optimised for low pressure systems and that has a built in self regulation control that keeps the right air flow even with negative pressure opposed on the fan (due to thermal pressure) the theoretical power need will vary between 1 – 3 Watt/apartment. To this power requirement the power requirement for control units has to be added.

For general information on components of a PV system see report WP 3.1 in Reshyvent.

PV module requirements

Consumption	Voltage level	Rated Power	Controller size
Fan	220 VAC	330 Wp	20 A
Actuator		32 Wp	6 A
Sensor		32-96 Wp	6 A

Cost estimations for the integration of PV into a hybrid ventilation system

Estimated cost prices	Fan	Actuator	Sensor
Installation materials	410	15	15-30
Hardware	3.000	150	150-350
Installation	225	25	25-50
Total cost	3.635	190	190-430

Documentation of the analysis of using the nomograms for pre-heating of inlet air

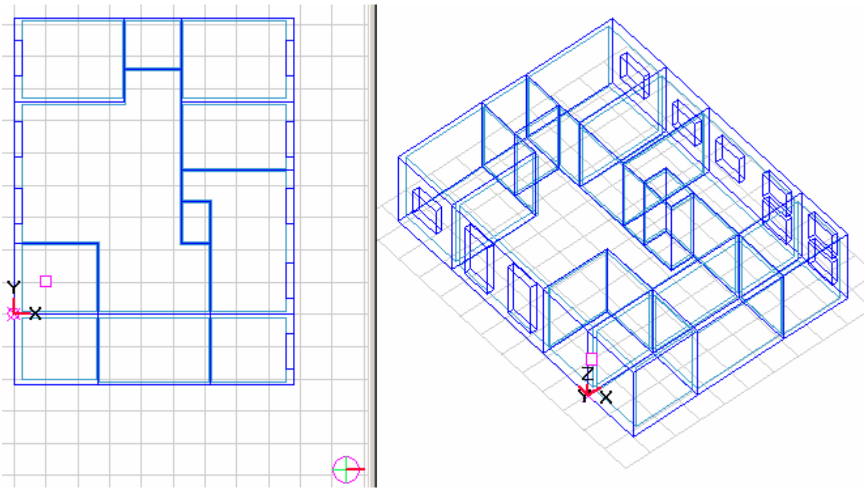
Parameters	
Location	Stockholm , Sweden
Size of apartment	80 m^2
Tilt and orientation	90 ° tilt due South
Collector	3 m^2 i.e. 0,038 m^2/m^2 floor area
Airflow through collector	Approx. 15,12 m^3/h (1/4 th of the average airflow of 16,8 l/s) i.e. 0,2 m^3/h m^2 floor area
Control strategy	Temperature controlled
Space heating demand	4.200 kWh/year i.e. 52,5 kWh/m^2 floor area
U-value of façade	0,22 w/m^2K

Documentation of Bsim2002 simulation

In this appendix the data used to simulate the preheat demands in the IC1 reference apartment is listed. The simulation has been carried out using the Bsim2002 simulation tool.

The model has been kept as simple as possible. Only one thermal zone has been used. The elevator/stairway and technical rooms have not been included in the thermal zone. The model is graphical illustrated in the figure below.

The simulation data:



Area of model and the thermal zone:

The total heated floor area is (including wall thickness’) 80 m^2 (the technical room and the elevator/stairway have a total area of 11 m^2. These are however not heated and therefore not included in the thermal zone of the apartment.)

Weather data:
Design reference year for Stockholm Sweden has been used.

Placement of windows:
The total area of the windows in heated zone is 12 m^2 , divided in 6 each 1,1m x1,1m, and 2 each 1,1 x 2,2 within the thermal zone. Half of the windows is placed facing north and half south.

The components and materials:
The materials used for walls, floors, windows etc. have been inserted according to the detailed information delivered to WP6. (Reshyvent: WP6 model building description – Multifamily house input data)

Heating:
The heating season is defined from September to April, and set at a set point of 22 °C with night cooling at a set point of 18°C. The efficiency of the heating 93%.

Infiltration:
The mean infiltration for the apartment has been calculated from information delivered to WP6 (Reshyvent: WP6 model building description – Multifamily house input data). The infiltration is therefore set to 0,06 per hour constantly.

Venting:
The venting (opening of Windows) is set at a set point of 24 °C or 1000 ppm Co^2 of 2 times per hour.

Equipment:
The equipment load is set at 1,1kW in use in the morning (3 hours) and in the afternoon/evening (5 hours) corresponding to 6 kWh per day, with 73% part to air.

Lighting level:
The lighting level has been set to 0,05 kW task lighting and 0,2 general lighting controlled with a set point of 200 lux in the time in use.

Person load:
The average number of persons in the reference house is two (2). This has therefore been used as a standard in this simulation. The load is set as 73 W per person. The load profile has been defined as follows:

Every day: The load is from 14:00 in the afternoon to 8:00 in the morning. (corresponding to the ventilation schedule given)
Ventilation For now the ventilation is all mechanical (worst case scenario). The ventilation is based on an inlet control regulation. The air flow is regulated following the rough load profile, given:Inlet pressure loss: 4

Pa at 16,8 l/s over convector. Outlet pressure loss: 1 Pa at 16,8 l/s over the fan and ducts. The efficiency of the fan is 2% at 16 l/s.

Preheat of ventilation air

At outdoor temperatures of –12°C and below, the inlet air will be preheated to 18°C and at temperatures of 12 °C the inlet air will be heated to 22 °C.

Schedule for the four (4) ventilation modes:

- Summer mode runs from April to September
- Winter mode runs from September to March
- Base vent. From 14:00 – 18:00 and from 19:00 to 23:00 (8 hours)
- Night vent. From 23:00 – 7:00 (8 hours)
- Out- vent. From 7:00 – 14:00 (7 hours)
- Cooking vent. From 18:00-19:00 (1 hour)

Winter ventilation:

Base vent.	21 l/s
Night vent.	16,8 l/s
Out-mode vent.	8 l/s
Cooking vent.	40 l/s

Summer ventilation (16% higher that the winter situation):

Base vent.	24,4 l/s
Night vent.	19,5 l/s
Out-mode vent.	9,3 l/s
Cooking vent.	46,4 l/s

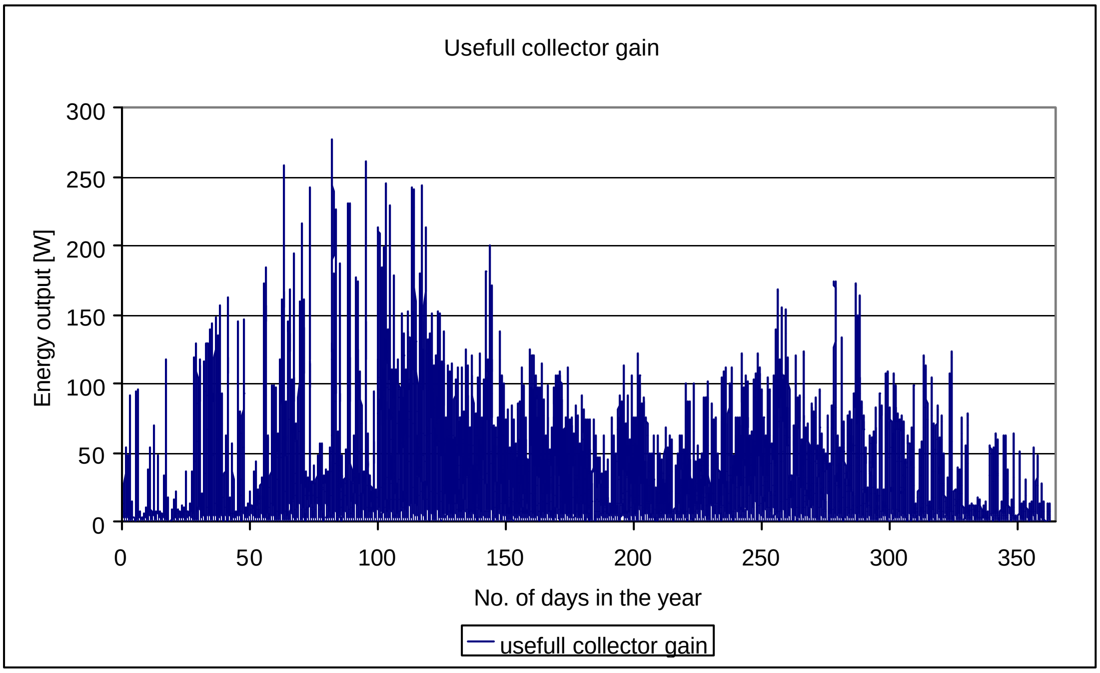
The results

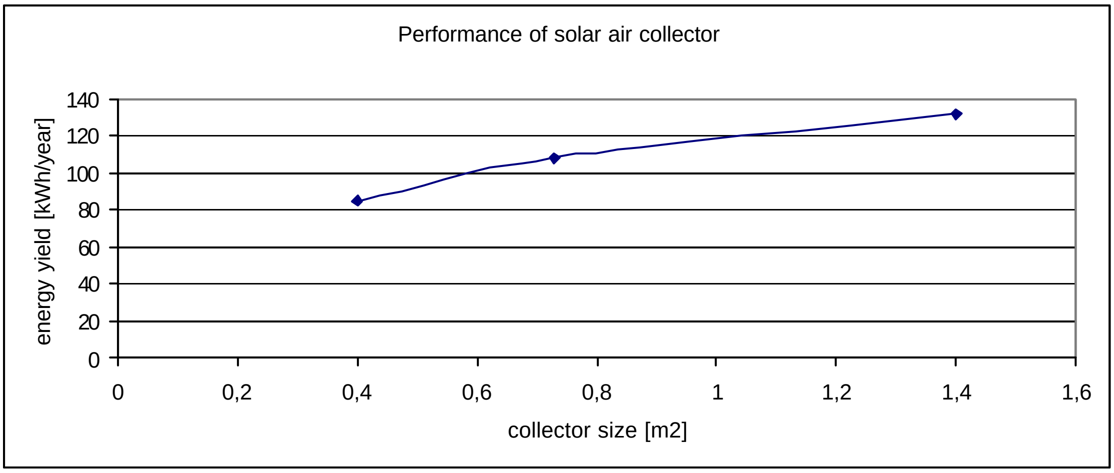
Heating demand:	913 kWh
Preheat demand:	2.076 kWh
Total heating demand:	2.989 kWh (Compared to the 3.400 kWh listed in the document " Information from IC1 to WP3")

The saved energy is calculated as:

- Pre-heat up to 22 °C
- No pre heat from 15 May – 15 Aug

The inlet temperature will be higher than 22 °C at times – i.e. larger savings are possible if this situation is allowed within the IC1 concept. Overall the rough estimations and the detailed calculations match very well.





Feasibility

Solar air collector	Collector size	Energy saving kWh/year	Price of collector	
Aidt miljø SV3	0,4 m2	85	376	Euro
Aidt miljø SV7	0,73 m2	108	510	Euro
Aidt miljø SV14	1,4 m2	185	860	Euro