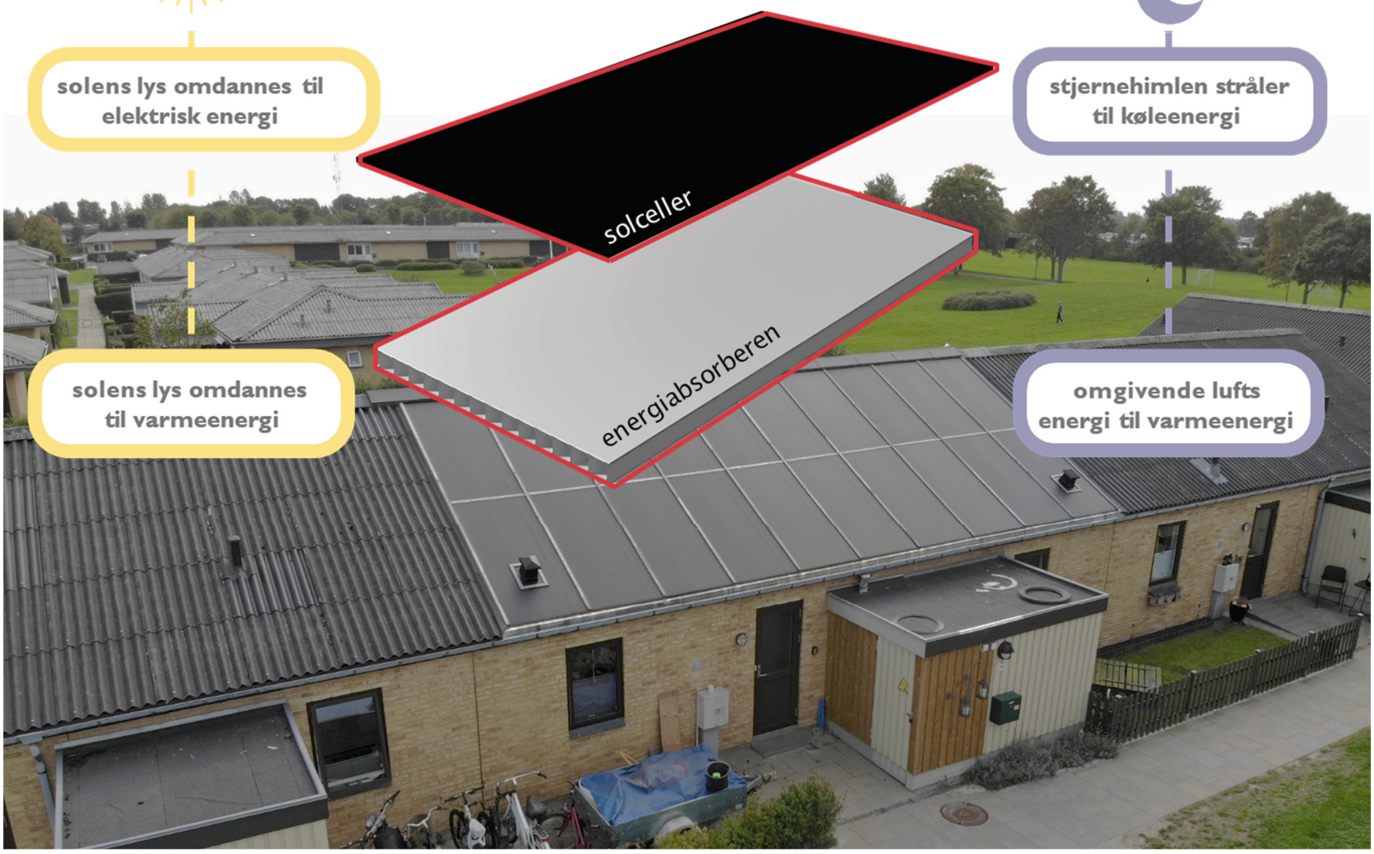
Det Energiteknologiske Udviklings- og Demonstrationsprogram

Solar Smart System

EUDP Slutrapport 2020

Energimodulet



Project Details

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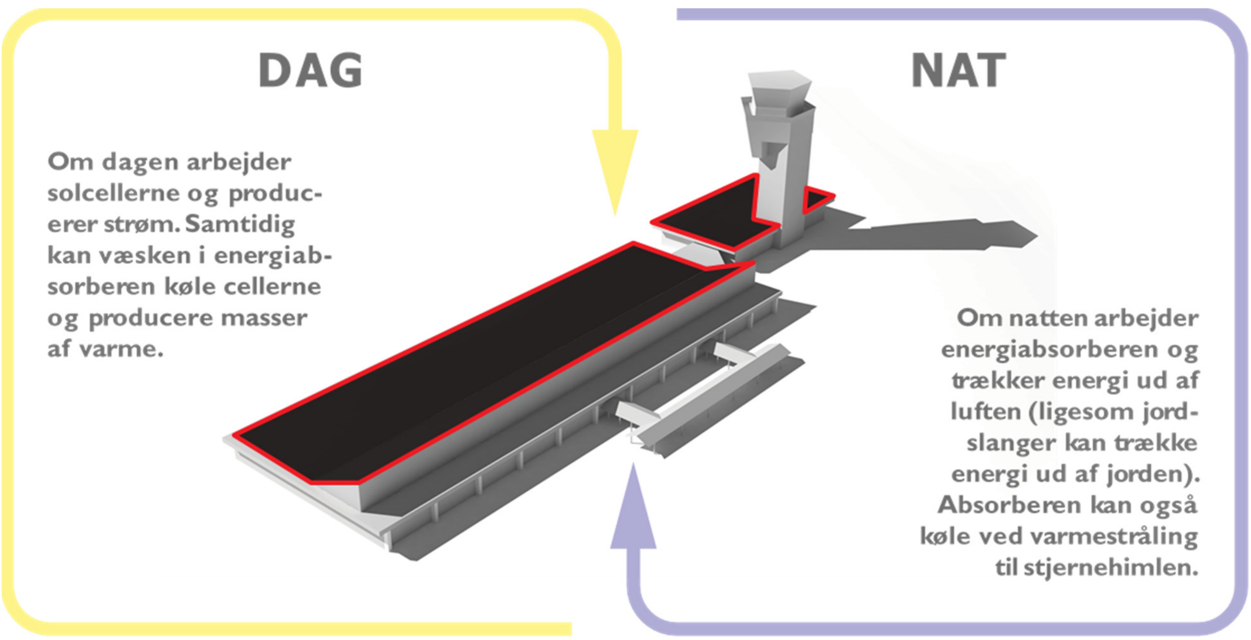

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1. Short description of project objective and results

English

The Project objectives were to develop new innovative PVT technology making it applicable and affordable for single family houses and for commercial buildings. Radical cost-reductions were to be gained by enabling complete replacement of the old roof with the new type of watertight PVT modules.

The concept being developed was to include future integration into both large-scale grid and district heating in combination with heatpumps, storage tanks and battery storage. The technology should prove a future cost-effective alternative to fossil fuels and introduce more flexibility in the grid with reliable PVT heat-, cooling- and electrical supply to the end user day and night all year.

The Smart Solar System project and new PVT technology were successfully developed proving cost effective full self-reliance by PVT energy via a single-family house and two airport buildings.

Danish

Formålene med projektet var at udvikle en ny innovativ PVT teknologi, så den bliver brugbar og økonomisk for enfamiliehuse og til erhvervsbygninger. Kraftige omkostningsbesparelse skulle opnås ved at muliggøre en komplet udskiftning af det gamle tag med den nye type af vandtætte PVT moduler.

Det nyudviklede koncept skulle muliggøre fremtidig integration i både storskala elnet og fjernvarme kombineret med varmepumper, lagertanke og batterilager. Teknologien skulle påvise en fremtidig kosteffektiv alternativ til fossile brændstoffer og introducere ny fleksibilitet i forsyningsnettet med sikker PVT forsyning af varme-, køling- og elektricitet til slutbrugeren dag og nat året rundt.

Smart Solar System projektet med ny PVT teknologi blev succesfyldt udviklet og påviste kosteffektiviteten i anlæg med fuld selvforsyning via PVT energi for et enfamiliehus og for to lufthavnsbygninger.

2. Executive Summary

The Smart Solar System was successfully developed proving self-reliance of energy by the new type of PVT integrated roof. Replacing the roof with watertight self-bearing modules was fully proved. The structure of the PVT module was still too thick, heavy and too costly, but it is expected that further innovation and optimization of the absorber could solve these issues in the near future.

The new PVT technology also successfully proved itself fully feasible for complete self-reliant cooling and heating of control towers and buildings in Rønne and Copenhagen airport. In-order-to develop solutions for extraordinary challenging requirements for of energy supply reliability, airports were chosen.

The integration of PVT modules and the existing roof was developed introducing new features, that made it possible for roof builders to easily attach the large PVT modules on the existing timber construction. The development of the PVT modules resulted in a ground-breaking concept feature where the builders could cut the length of the module and even cut holes into the PVT modules for air outlets when necessary. This could pave the way for future of the shelf standard sized PVT modules for building roofs. Also premanufactured PVT modules with build-in insulation layer were developed and proved easy to mount, stable and preventing moisture condensation.

The main proof of concept of energy self-reliance by combining PVT with local heatpumps and storage tank & battery for single-family houses was successfully achieved and documented fully as proven technology and thus paving the way for large scale integration with existing electrical grid and district heating. The system was able to provide all heating, hot water and electricity for a family of four with a very high energy consumption. The system was tested for more than two years including two very cold winters. As a result of the project, 42 similar semidetached single-family houses will be renovated in 2021 and provided with PVT modules abolishing all the existing gas boilers.

3. Project objectives

3.1 Objectives – Main objectives

The main objective for this project is to develop, demonstrate and provide PVT based Solar Smart Systems. This new concept (phase 1) should be forming the grounds for a forthcoming next nationwide implementation phase (phase 2), where many local residential communities and industrial buildings that are based on fossil fuel and financially cannot be connected to a district heating grid, can transform from fossil fuels to clean energy only utilised from PVT technology via the buildings. By introducing both single house and house clusters solutions, this modular concept could be further developed and used nationally in smaller towns for creating cost effective renewable energy local district heating grids.

3.1.1 Objectives – Vital extra features

Extra vital objectives were to coordinate and develop the concept and planning together both with the individual local house owners, the building association, community, but also with the regional district heating utilities.

In the objectives were several extra features that should be included in the same system in-order-to make the building as self-sufficient as possible and all year round. These features also include (1) intelligent control system ensuring reliable energy supply (2) Cost effective renovation and transformation of the roof into a self-bearing PVT panel roof and to (3) look at the economic impact for the building construction improvements and energy costs from the new PVT based systems.

3.1.2 Objectives – Overcoming technology barriers

In the aim of making the PVT technology competitive when replacing the gas-, oil or other fossil fuel supply for a building, the end user must have a Smart System, so that it is self-controlling, is reliable, has no maintenance and does not require reconstructing any part of the building. All these requirements for the new PVT technology must compete with already well-known off-grid thermal energy supply systems such as geothermal energy, air-to-liquid heat pumps. The benefits from the new Solar Smart System PVT technology should also be developed in order to make it modular when more buildings are coupled into one central system control. So, the main barriers were to develop and demonstrate a smart building integration technology by the physical modules and to develop and prove that the control system is smart.

3.2 Innovative Technology: Develop ▷ Tested ▷ Optimized ▷ Demonstrated

To meet the many ambitious objectives and achieve successful results for Solar Smart System project, new innovations were necessary and needed to be developed, tested and demonstrated. The new innovative technologies seemed realistic, since the PVT module, components and connecting system could utilize some important head-start knowhow provided by former successful RACELL lead EUDP projects: (I) "Self-bearing Roof Hercules PVT elements", (II) "Isolation PVT wall for apartment blocks", (III) "COOL PVT" and (IV) "Solar CHP-C".

3.2.1 Energy Solar Smart CONTROL System

Most of the various objectives were reached, making it possible in the future to start the "phase 2" follow-up project demonstrating the Solar Smart System on a large scale. Development, preparations and engineering and PVT modules were made to demonstrate the system on one house in Arnager on Bornholm, so that many of the other appr. 45 houses in the town of Arnager could have get the PVT Solar Smart System Energy Technology. However, because of missing permissions and delays another house and area was activated. This semidetached house was placed in

Stengården at Ølstykke, 30 kms north of Copenhagen. The Stengården complex consists of 43 houses, which unlike Arnager have one owner, a Social Housing company KAB. A complete system was demonstrated fully in the house that had the highest and worst-case energy consumption. As a result, the Solar Smart System PVT solution is being established on all the 43 houses in Stengården starting in the spring of 2021.

Figure 3.2.1 (I) The house chosen in Stengården at Ølstykke. Notice the two outlets. Holes were cut on site.

The energy solution utilizing the PVT with a smart control system was developed and resolved, so that PVT can be used for several houses in a local area transformed from oil and gas supply to direct electrical and thermal energy directly from the hybrid PVT modules. The Solar Smart System is combined with battery storage and PV modules. The Heatpump component and the forecast smart system to match and optimize the energy consumption and PVT production was partly demonstrated. Some technical barriers and thus parameters were still not developed fully, in particular the Heat pump. Especially with cold clear nights, the Heatpump stops working at -10 degrees. A new PVT oriented Heatpump is being developed by Metrotherm as a result of this project by reaching flexibility and higher COP for PVT down to -25 degrees C. The new heatpump will also be able to have interfaces that can communicate with the other components of the system, such as the flow in the PVT, the inverter, the battery and comfort requirements from the end user. With these interface solutions the Heat Pump will be able to control the other system components and thereby enable a complete Solar Smart System.

The areas without snow are with modules that do not have built-in insulation layer

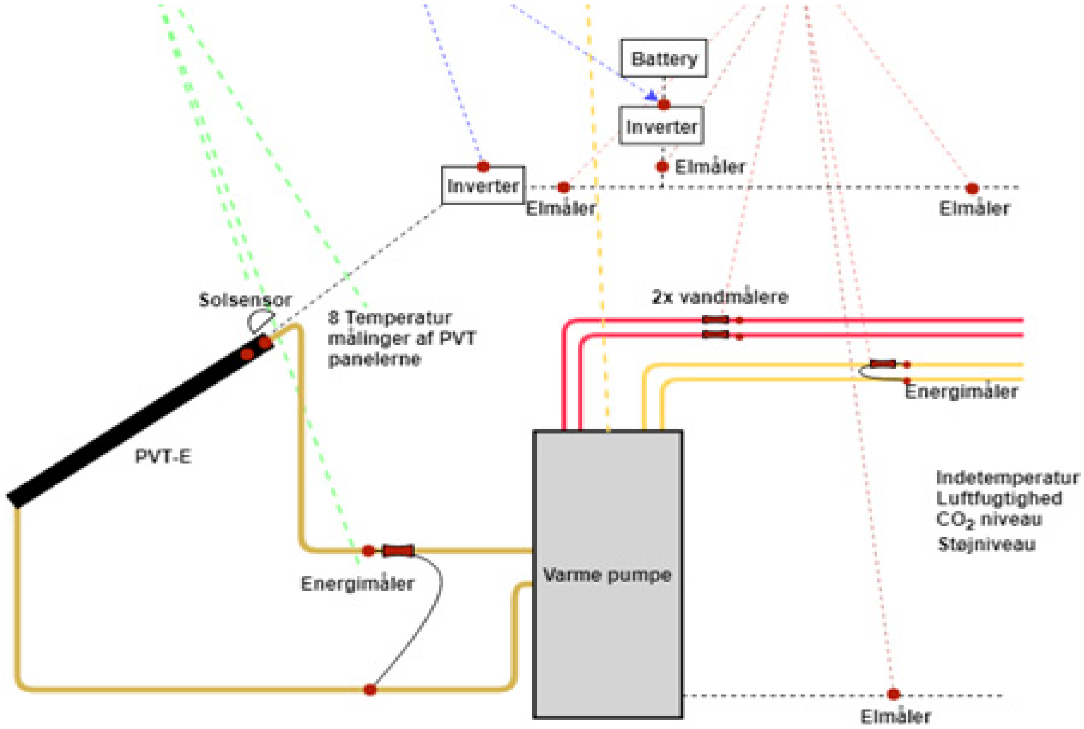


Figure 3.2.1 (II) The system set-up for a single family house with monitoring equipment.

Fejl! Henvisningskilde ikke fundet. figure shows a schematic sketch of the system with the applied measurement equipment. The space heating demand, the domestic hot water consumption, the electricity consumption, the heat and electricity production of the panels, the solar radiation, the outdoor temperature, the indoor climate and system temperatures were measured. In this way, the detailed operation of the system could be followed

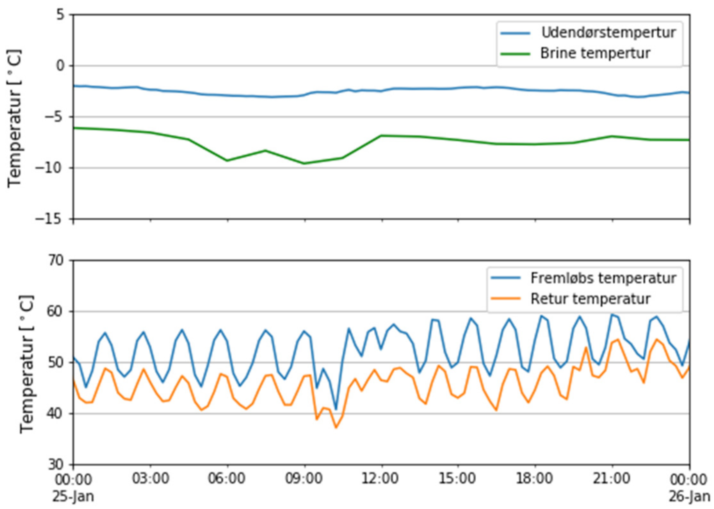


Figure 3.2.1 (III) Testing on a snowy day. The modules without snow have no insulation layer.

From the tests during the project period, it turned out that rather than having a heatpump and battery system for every single house, it was much more energy efficient and economical to have a heatpump, battery system and inverters for a group of houses, either 5 or 10. The energy control system and the physical installations would be much easier to handle and maintain at a low cost. Also, the area used by the system components could be reduced to 1/3 by grouping 5-10 houses to one common control system. The clustering of differentiated energy user profiles can be utilised only if the control system is smart and intelligent, so that it coordinates for the shifting cold and warm days against high consumption houses having 4 residents/100m2 and houses with 1-2 residents/m2. The comfort and supply reliability were extremely important especially in the winter season. As the smart control system still needed optimization, two solutions were implemented: (1) having a back-up electric heating coil in a 100 – 300 liters buffer tank, so that there is always enough hot water and room heating, (2) redundant control system for each major component, so that if the central intelligent and smart system is not functioning, each unit (heatpump, battery system, inverter and valves, can regulate itself.

A spin off from the development of this project resulted in a PVT Solar Smart System for 3 large building blocks, at Trigeparken in Aarhus by the EU project READY. The PVT area covered 750 m2 and supplied 60 flats with electrical and thermal energy. Here it turned out that a new renovation and insolation of the houses was so efficient that room heating was barely needed. Also, the consumption /needs of DHM (Domestic Hot Water) had gone down as new residents moved in. For the Solar Smart System, this meant that the surplus thermal energy from the PVT modules could be efficiently used for focusing on cooling the cells instead and thus generating more electricity.

Figure 3.2.1 (III) the PVT-E system on three building blocks in Århus

The SolarSmartSystem phase 1 test period clearly proved how important the smart control system is. For PVT, contrary to geothermal and to systems with seasonal storage which have a very stable temperature of f.eks. 5 degrees, the temperature of the renewable energy supply is varying according to the weather. Sometimes in minutes varying from less than zero and up to 40 deg. C or more. The extremely large thermal storage tanks are avoided in the Solar Smart System, saving expenses area, thus the control system is the key issue for the system, even if it is only 5 households in one cluster. For typical content of a control system, see also appendix (A).

For the Rønne airport, new PVT control system was designed and installed, one for PVT cooling and heating the flight control tower and another system was designed for providing electricity and thermal heating & cooling for the Rønne terminal building. Simulation results showed that serious energy savings could be reached both by the new Solar Smart control system energy and by the PVT and all fossil fuels consumption for the building could be abolished. However, during the PVT project implementation, the original plans of the airport management of placing a large scale heatpump, was brought back to the general strategy because of the new plans of the ultra large wind energy island project.

An alternative placement for the demonstration was started in Copenhagen airport together with Naviair. The project here was slightly different since the energy control systems are well developed and have a high degree of safety so it can be easily combined with the Solar Smart PVT control System. The focus engineering was started for the new airport Air Control tower. A two-stage installation was decided upon, one for the 50 m2 PVT-E and next stage for 500 m2 PVT-E at the control tower. The control tower already has two identical and redundant fossil fuel energy supply systems. The PVT-E should take over and become the 3rd redundant system but using renewable energy only.

The existing air-cooling system to be replaced by the PVT-E roof Solar Smart System

Part of the 500m2 available roof area upon which the PVT-E modules will be mounted

For the Control tower at Kastrup airport the dimensioning of the test system was as follows:

En case med et PVT areal på 42 m² som altså leverer både varmt brugsvand (kun lidt) samt opvarmning og køling. Der er ingen opvarmning om sommeren, men der er køling hele året fordi der er serverkøling, dog mest køling om sommeren hvor der er komfortkøling. Forbruget for komfortkøling er ikke præcis og derfor p.t. kun et estimat.

Anlægget dækker 43% af forbruget og som det fremgår PVT leverer:

- El. 193 kWh/år/m²
- Varmepumpen trækker 456 kWh/m² energi fra PVT til varmepumpen, det er altså varme leveret af PVT om vinteren hovedsagelig.
- Desuden afleveres der (dumpes) 598 kWh/år pr. m² varme fra PVT, i sommerperioden.

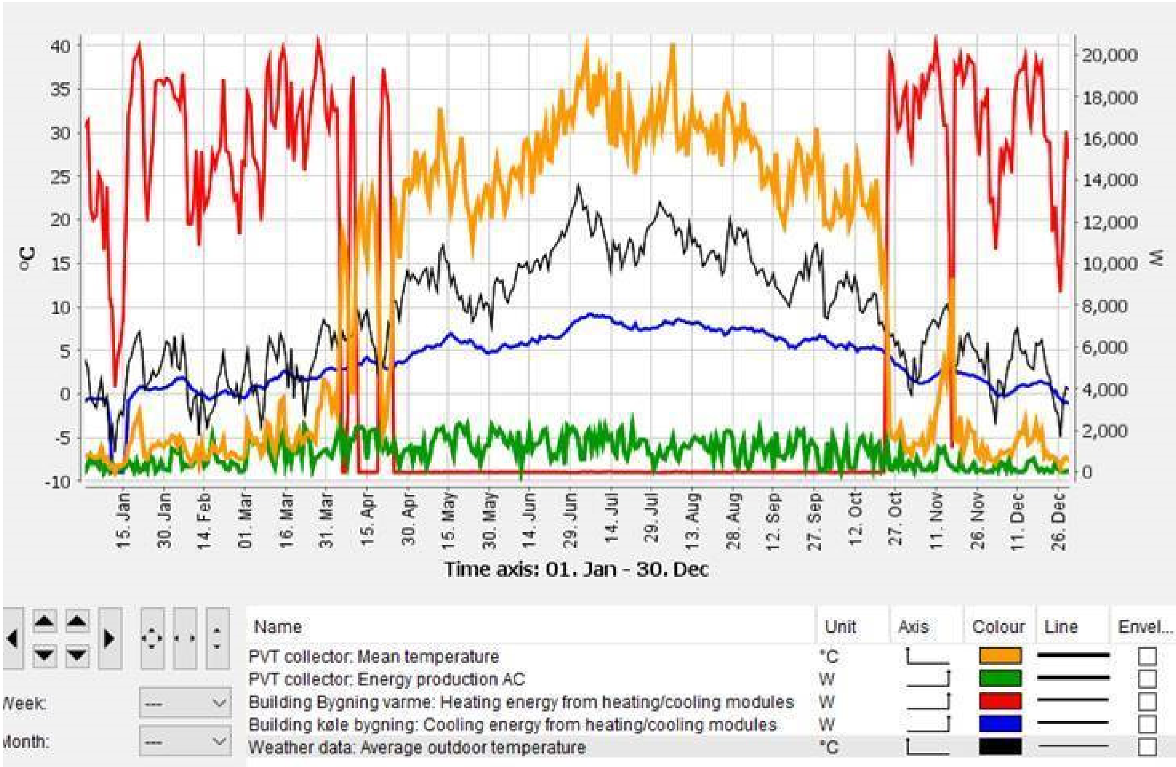
Den samlede COP bliver på 5,1. Altså varmepumpen leverer 5 gange så meget brugbar energi til varme og køl som den selv bruger af el. Af den el som varmepumpen bruger produceres 35% af PVT panelerne. Tages det med bliver COP på 8,0.

Hovedtallene fremgår af følgende tabel.

Anlæg		
PVT areal	m²	42
Varmepumpe		20 kW varme
PVT buffer	l	500
Varmtvandsbeholder	l	300
Buffer til varme	l	500
Buffer til køling	l	600
Varmt brugsvand		
Forbrug VV	l/dag	2,600
Leveret VV	kWh/år	2,550
Varme		
Varme forbrug	kWh/år	133,000
Varme leveret	kWh/år	66,000
Køling		
Køling behov	kWh/år	131,500
Køling leveret	kWh/år	46,700
El forbrug og produktion		
El produceret	kwh/år	8,115
EL brugt af VP	kWh/år	22,600
Beregning		
Energi fra PVT	kWh/år	420
- januar	kWh	6,350
- Sommer, ca pr. md.	kWh	-5,000
Temp af PVT januar, mean/min/r	C	-6/-12/10
Temp. PVT juli, mean/min/max	C	32/10/56
Samlet udnyttet energi	kWh/år	115,250
samlet cop		5.1
cop inkl. PV el		
Samlet dækning af varme og køl	%	43%
Energi hentet i PVT	kWh/år	19,169
Energi dumpet i PVT	kWh/år	-25,096
Ydelse PVT positiv, pr. m²	kWh/m²/år	456
Ydelse PVT negativ , pr. m²	kWh/m²/år	-598
Ydelse af PVT el	kWh/m²/år	193

Nedenstående graf viser levering af varme og køl og el over året, rød, blå og grøn. Temperaturen i PVT er også vist. Det fremgår at i vinterperioden er PVT i gennemsnit koldere end luften og der trækkes varme ud. Om sommeren er PVT varmere end luften og der afgives varme. Det ses at i april måned skifter det frem og tilbage mellem disse.

Det virker altså ret effektivt. En af grundende er at der i vinterperioden er samtidig brug af varme og køling hvilket mindsker belastningen på PVT anlægget fordi noget af varmen til varmepumpen hentes fra kølesiden.



The high expertise of the Naviair teams and control systems is considered to further promote the PVT-E Solar Smart System concept. Two other buildings in Kastrup airport Naviair facilities area were allocated and after the test and demonstration period in 2021, the plans are, to incorporate large scale areas of PVT-E systems to be combined with an existing ATES system and more.

3.2.2 PVT MODULE for the Solar Smart System

The major work in the project, in parallel with the control system, was to develop innovative new PVT modules, that could provide more energy per m2 and at the same time provide vital cost reductions for the future products and systems. The energy output per m2 from the PVT-E modules turned out to be better than expected, even though the heatpump was not designed or optimized for PVT modules.

The ways to achieve the goals were to innovate new PVT module types and structures that could:

(1) replace the existing old roof elements with PVT elements that did not need a space between them for the pipes; that would save a lot of costs for the houseowner

(2) to hide the header pipes and the interconnect pipes; thereby utilizing the full roof area for active energy generating PV cells and thermal absorber providing a high efficiency "Triple Energy" roof with more than 600 W/m2. At the same time this would provide an architectural aesthetic roof.

(3) to mount the PVT elements directly on the existing timber construction without having to establish a new roof underneath the PVT elements; that would save high costs for a new roof and extra weight which might even have to tear down and renew the whole roof construction underneath

(4) to provide ease of mounting; no scaffolding would be needed for several weeks and thus save some extremely high costs for workhours and scaffolding construction.

(5) to make it feasible for cooling the PV and PVT modules without having special and expensive ventilation channels: without this facility the supplementary PV modules for the roof area that does not need PVT, the energy losses would be high because of elevated temperatures in the PV modules

(6) to provide an insulation layer as part of the rear side of the PVT modules; this would add to insulate the loft area, but more importantly it would reduce the chances for forming ice by condensed air from the warm loft

(7) to make light weight PVT element; if the PVT modules are too heavy, the whole supporting timber construction has to be changed.

(8) to avoid many pipes under the PVT roof; normally people want to use the loft for storage and hobbies. All the pipes also need to be insulated so that the pipes do not form ice and thus wet the loft when the ice melts

(9) reduce the production costs for the PVT modules; the main barrier is the construction of the absorber and the header pipes. But also, the heavy and hand-made bearing sandwich profiles are extremely expensive to produce.

All these goals were planned with innovative technologies, but many succeeded only partly:
The objectives (1), (2), (3), (4), (5) and (6) were achieved but at the costs of (7), (8) and (9). The modules har to be made with two thick layers sandwich aluminium layers in-order-to hide the header pipes of the absorber whereby the modules became very heavy. The header pipe in-and outlets had be placed in the rear and thus pointing into the roof and invoking many interconnections with flexible pipes with work underneath and inside the loft area. A new absorber construction idea was not feasible and was neither possible to produce. Risk of leakage from the existing absorber was still an issue so some PVT modules had to be scrapped. As the missing innovative issues were clear, the fully PVT roof could be mounted and functioned successfully and it was considered that in the near future more innovation would provide solutions to points (7), (8) and (9).

Some of the aspects of the energy module technology are illustrated below in the pictures from the project.

Figure 3.2.2 (I) Final PVT-E modules before mounting seen from the rear

Some of the remaining critical issues to be solved are the dimensions of the absorber and resulting PVT-E construction. For cost reductions, reduction of material usage and risk of leakages. A new innovative absorber technology must be found and is being considered.

The present absorber used in the Stengården house solution is constructed as shown in the pictures below.

Presently because of the recent limitations of the MPE absorber technology available and handmade welding, the Racell PVT-E have had to use massive and heavy Aluminium sandwich profiles to contain the main header pipes, see figure 3.2.2 (I) and (II). The thickness is 40mm and the weight extremely high.

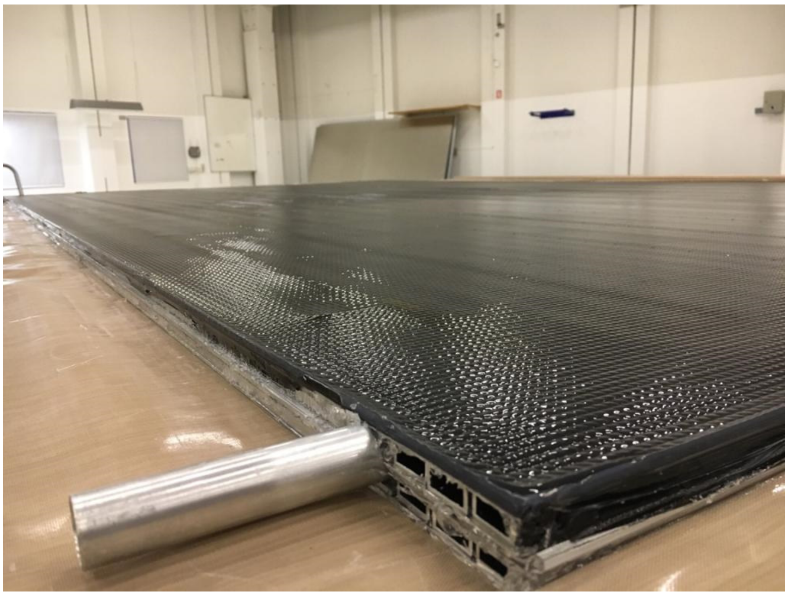


Figure 3.2.2 (II) The header pipe is well hidden, but at the cost of some very heavy hand made aluminum sandwich construction

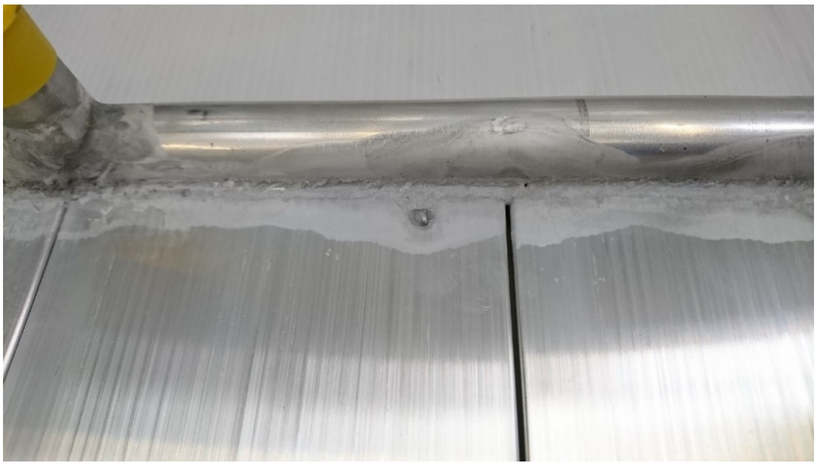


Figure 3.2.2 (III) The critical absorber with flame hand welded MPE profiles. Many failures occur during the hand welding and cause leakages afterwards. Leakage test is adopted, but the quality is questionable for surviving for more than 20 years. The aim is 50 years.

The dream technology, which is considered realistic, is to develop a new welding technology that is controlled carefully and precisely by automated equipment. Several trials have been made by other companies with robots and more, but only if massive use of aluminum is employed it had succeeded. Initial small scale trials by Racell seem to show an innovative way out by laser welding and new designs. The ideas are expected to make a major breakthrough in the PVT industry, but needs to be developed and tested and proven, in the future.

4. Project implementation

4.1 The Project Risks and Evolvement

The project evolved according to the original plans as regard to developing and implementing the innovative energy solutions. Some changes occurred in order to keep the timeline and avoid delays so that tests could be performed in the worst-case situation, which is the winter season.

With the help from the Bornholm Energy & District Heating Utility BEOF, the small town Arnager at the coast was chosen, as it was too expensive to provide district heating to this area. Instead the plan was that the Solar Smart System could be used in Phase 2 of the project, starting with demonstrating the concept in one single family house.

For the one family house, it was difficult to find a family who would take the many potential risks by installing a completely new untried energy system. Risk of completely removing their reliable gas-boiler and family heat source, take the risk of ruining their loft, have engineers and craftsmen in and out of the house over a number of months. And last but not least, a financial risk if the roof is ruined and has to be re-stablished. Also the risks of asbestos from the roof works.

The test house was supposed to be in Arnager in Bornholm and the only test house that could be found in Arnager was a new house extension being built with new materials without professional craftsmen. The project group considered that house to be too risky and it turned out that the house also collapsed completely during construction.

Another house was found in Arnager. Engineering was made and modules were produced, but the house owner wanted the whole roof changed, although well-functioning solar collectors were already installed on an annex. The demonstration value would be lost and also there was no loft underneath the roof, meaning that mounting the PVT roof modules could ruin sleeping chambers and more on the first floor. Although precise engineering and visualisation were made, the many risks for the family were considered far too high. The visualisation is very precise and shows exactly how the roof would look if the PV and PVT modules had been integrated in the roof. Real modules were used for the visualisation shown. With the high risks profile, although aesthetically very appealing, other bad issues for the demonstration in a small and close society and with a yearly summer conference on the Island with all the Danish Politicians attending, would damage this project and give the worst-case publicity if something did go wrong.

Arnager house before BIPVT modules

Arnager house after BIPVT roof modules

The preparations and planning for the Arnager house is described in Appendix (D)

One interesting result that came out was the further development of the PVT module, that provided the roof carpenters to cut through the PVT roof module, so the modules did not need to be custom made. It turned out that it was possible to add an innovative structural change to the PVT and PV modules in order to implement this interesting feature. The cutting of holes in at site is much safer since precise measures are often not available and carpenters are used to regulate by sawing off and adjusting on the building site.

Another house with a risk willing young family was found in Ølstykke north of Copenhagen with a building society providing some risk management safety for the family. Many of the expected risks actually happened and some extra occurred as well. As the craftsmen connecting the cables and the pipes in the roof area where untrained and during the summer holidays new craftsmen took over. This induced many changes to the interconnections on the roof. The mounting of the large PVT modules went well and took only a couple of days. But as the installers of the subcontractor have changed, the original measures also changed. The PVT modules could not be changed in size and the top roof cover was made too short. Thus, rainwater was pouring in until the mistakes were corrected. Fortunately, the PVT modules were water-tight next to each other, so the water problem was created by the carpenters. Actually, Murphy's law was working and amazingly the family kept the spirit high.

The lesson learned was that mainly that new innovative systems should be under extreme strict control during the installation phase and should be done by trained craftsmen only and that the very same craftsmen should finalise the project without changing the persons underway. Installation manuals should also be made with extensive and well visualised drawings. Also, the craftsmen should be trained with a mock-up before they install anything.

The democratic set-up in this particular area created new perspectives as the families living in the neighbouring houses brought new ideas of how to pay for the energy consumed when houses were clustered or not. All the families in the 43 houses voted for this new solution and the project is now being reproduced on all the 43 houses. So the project ended more successful than expected.

After seeing the difficulties in producing light-weight PVT modules from Racell, the families and the building society KAB decided to build a new standard roof, thus not ruining the loft area with many pipes going through as in the test house where the PVT modules formed the actual roof. Unfortunately, Racell had still not been able to invent and produce new light-weight absorbers and PVT modules, so the aesthetic solutions could not be realized, so that the mounting system for the PV and PVT modules will be done on top of a firm roof. The renovation and the new Solar Smart System will be financed by a loan from Landsbyggefonden. It will be very costly, because the whole loft timber structure will be changed completely. If Racell have had a technology for manufacturing the light-weight PVT Energy absorber solution and header pipes that could be interconnected differently and on top of the loft, not inside the loft, it is considered that the project could have been done for half the existing price.

Large area modules being installed in the Stengården house in Ølstykke.
Installation was done within 2 days only.


The PVT modules being installed as the new roof in the house in Ølstykke

4.2 Solar Smart System for large buildings

The project evolved A similar situation as for Arnager for moving the project from one site to another occurred for the project in Rønne airport. Because Racell considered the innovative PVT technology too risky, the delivery was delayed on purpose. On the other hand, in the meantime, though after many months, the airport received permission for this type of modules after proving that no reflections and glare would disturb the pilots.

A sketch of the Rønne airport coverage with black non-reflecting modules is shown on page 2.

One of the major risks is that combining liquid, metal and high voltage, could generate unexpected fire. So, a new type of PVT modules that were slightly thinner and not as heavy and expensive were tested in Aarhus. It turned out that one supplier of materials provided one wrong component that instead of being electrically insulating material, delivered electrically conductive materials. All the modules were repaired, and the small component was changed. For an airport project this kind of fault would have been disastrous, not because of the impact, but because of the rumours such an incident would create. Therefore again, rather than hurrying to deliver because of pressure from the end users or partner, it is vital to do the correct and full quality control tests and worst-case experiments.

After solving the safety issues the PVT project for the airport was started in Kastrup Airport in Copenhagen.

With the new Energy Island with wind energy supplying Bornholm and more, the airport authorities decided to drop the PVT project. This political decision was final. Also, the utility and partner in the project lost interest because of the delays for the PVT modules and because of the new Energy Island concept.

The new PVT-E technology has created a new interest from airport authorities and Racell has also been invited to supply specialised modules for a new airport in Australia. Therefor the demonstration of the concept is vital for new commercial projects in the future.

4.3 Implementation and Milestones

The main Milestones for the project and their implementation were developed as expected, except for the withdrawal of Rønne Airport.

M1: Start up workshop with all interested parties made and reported
Medium interest from house owners, but major interest from the utility

M2: Dimensioneringsmodel for PVT-E anlæg til enfamiliehuse og til erhvervsformål.
Succesfully developed

M3: Attrativ (BI)PVT-E finanseringspakke præsenteres for beboerne i Arnager
The financial model was theoretically interesting, but had to be proven after implementation

M4: Samlede potentiale frem mod 2025 og beskrivelse af samfundsøkonomien

BIPVT-E teknologi en særlig mulighed for oliefyrs-konvertering

Som led i projektet Solar Smart System Bornholm er der med beregningsværktøjet PVT-BAT gennemført analyser af brugerøkonomien ved at udskifte eksisterende oliefyr med et BIPVT-E-anlæg med PVT-moduler, batteri, varmepumpe og supplerende udstyr. Disse beregninger supplerer analyser, som med projektstøtte fra Dansk Energis ELFORSK-program er udført på boliger, der opvarmes med individuelle naturgasfyr.

PVT-BAT er et værktøj, som COWI har udviklet med projektstøtte fra ELFORSK, og som benyttes ved dimensionering af hybridanlæg med solceller og batterier, suppleret med PVT-moduler og varmepumper. Værktøjet er fleksibelt, så ændrede rammevilkår i form af prisudvikling, renteniveau, støtteordninger og politisk fastsatte rammevilkår hurtigt kan integreres som beregningsparametre.

Positiv beboerøkonomi ved konvertering fra oliefyr
Under SSSB-projektet er der på dette grundlag udført følsomhedsanalyser for effekten af bl.a. en ændring af gældende straks-nettoafregning til en ordning med garanterede afregningspriser for salg af overskydende elproduktion, effekten af lavere elvarmeafgift samt reduktion af elafgift. Sådanne ændringer kan forskyde det beboerøkonomiske resultat af konvertering fra oliefyr til BIPVT-E, men ser ikke ud til at gøre denne type konverteringsprojekter urentable. Der er ikke indregnet effekt af de aktuelle tilskudspuljer til skrotning af olie- og naturgasfyr og installering af varmepumper, da disse tilskudspuljer indeholder nogle restriktioner, der kan ramme BIPVT-E projekter.

Som led i SSSB-projektets screening af potentialet for husstandsanlæg på Bornholm er der udvalgt to ejerboliger i landsbyen Arnager, hvortil det ikke er samfunds- eller selskabsøkonomisk rentabelt at udbygge fjernvarmen:
En bolig på 164 m^2 skønnes at skulle investere ca. 325.000 kr. inkl. moms for et BIPVT-E anlæg, der kan producere ca. 10.400 kWh i et år med normal solindstråling. Med et fastforrentet 30-årigt realkreditlån vil et sådant konverteringsprojekt give et årligt beboerøkonomisk overskud på ca. 11.900 kr. Reduceres låneperioden til 20 år, mindskes det beboerøkonomiske overskud til ca. 6.600 kr.

En bolig på 136 m^2 med et noget lavere olieforbrug skønnes at skulle investere godt 200.000 kr. i et BIPVT-E anlæg. Anlægget har en beregnet årlig elproduktion på 5.667 kWh og vil med et 30-årigt fastforrentet realkreditlån få et beboerøkonomisk overskud på ca. 9.600 kr. om året. Supplerende beregninger viser, at adgangen til at sælge overskydende el til elnettet mod vederlag kun påvirker beboerøkonomien marginalt.

For at belyse BIPVT-E teknologiens mere generelle potentiale på det danske hjemmemarked er der udført yderligere beboerøkonomiske beregninger af to standard ejerboliger på hhv. 90 m^2 og 140 m^2. Her viser beregningerne, at disse boliger vil have et betydeligt behov for supplerende elindkøb, fordi elforbruget til anlæggets varmepumpe overstiger den beregnede elproduktion fra PVT-E modulerne. Men i kraft af boligernes konvertering fra oliefyr til eldrevne varmepumper kan boligerne BBR-registreres som elopvarmede og dermed få adgang til elvarmerabat for den del af det samlede elforbrug, der overstiger 4.000 kWh om året. I kombination med det aktuelle lave renteniveau medfører det, at der i begge typer ejerboliger vil være et beboerøkonomisk overskud på hhv. ca. 8.600 kr. (90 m^2) og 13.425 kr. (140 m^2) om året.

For de mere detaljerede beregninger henvises til de tre tabeller med beregningsresultater.

Stort CO_2-reduktions potentiale i konvertering fra oliefyr til BIPVT-E
Der er ikke alene et gunstigt beboerøkonomisk potentiale i at konvertere olieopvarmede ejerboliger til BIPVT-E teknologien – jo større olieforbrug, jo bedre bliver beboerøkonomien – men også et klimapolitisk potentiale. Forskellige kortlægninger af eksisterende helårsboliger med oliefyrs-opvarmning vidner om, at der stadig er ca. 80.000 boliger, der primært opvarmes med oliefyr. Langt de fleste af disse boliger er placeret uden for de eksisterende eller planlagte fjernvarmeområder, og BIPVT-E er derfor – sammen med installering af eldrevne varmepumper – den bedste vej til grøn omstilling af disse boliger.

BIPVT-E anlæg har betydeligt højere omkostninger end f.eks. en luft-vand varmepumpe. Til gengæld vil BIPVT-E drevne boliger ikke medføre samme belastning af de lokale distributionsnet som rene varmepumpeanlæg. BIPVT-E anlæggets batterilager giver boligen et mere fleksibelt elforbrug end en varmepumpe alene, idet varmepumpen kan forsynes med el fra batteriet i de timer, hvor belastningen i distributionsnettet er stærkest.

I sommerhalvåret kan overskydende elproduktion fra de mest solproduktive dagtimer lagres i batteriet og bruges, når der opstår behov for varmt brugsvand, når familierne vender tilbage til boligen sidst på eftermiddagen. I vinterhalvåret kan batteriet benyttes til at lagre elindkøb fra de tidlige eftermiddagstimer, hvor belastningen af elnettet er lavere end i spidslasten kl. 17-20, så der bliver mindre behov for elindkøb i disse kritiske timer. Disse hensyn ventes at få stadig større betydning i takt med de kommende års udrulning af elbiler.

Foreløbige beregninger af de samfundsøkonomiske effekter af anlæg med solenergi og batterilager vidner om, at et mindsket behov for udbygning af elproduktionskapaciteten og for forstærkning af distributionsnet har en meget gunstig effekt på det samfundsøkonomiske resultat af BIPVT-E teknologien.

Som nævnt er de resterende oliefyrs-opvarmede boliger i overvejende grad placeret uden for eksisterende og planlagte fjernvarmeområder. Nationalt Center for Miljø og Energi (DCE) har med afsæt i data fra Skorstensfejerlauget kortlagt antal og type af små fyringsanlæg for Miljøstyrelsen (januar 2018). Det fremgår af denne kortlægning, at der i ø-kommuner som Bornholm og Langeland er relativt mange oliefyrs-opvarmede boliger. Men også kommuner som Faxe, Faaborg-Midtfyn, Guldborgsund og Lolland samt i Vestsjælland er der et forholdsvis stort potentiale for konvertering af oliefyr til BIPVT-E.

For mange boligejere i disse områder kan det være forbundet med udfordringer at opnå adgang til en fordelagtig realkreditfinansiering af deres konverteringsprojekter, fordi boligernes geografiske placering betyder, at realkreditinstitutterne vil være mere tilbageholdende med at yde finansiering pga. af disse boligers lange liggetider ved salg. Det bør derfor overvejes, om der som supplement til de nyligt indførte skrotningspræmier og andre tilskudspuljer til konvertering af olie- og natrugasfyr til varmepumper kan etableres en form for tredjeparts garanti for boligejernes realkreditlån eller anden form for støtte til disse boligejeres finansieringsbehov.

Der er et samlet potentiale for reduktion af CO_2 på ca. 400.000 tons, hvis det lykkes at få alle 80.000 oliefyrs-opvarmede boliger konverteret til varmepumper og BIPVT-E anlæg. Herudover er der et endnu større CO_2-reduktionspotentiale i konvertering af naturgasfyr til varmepumper og BIPVT-E, idet der skønnes at være 300.000-350.000 naturgasopvarmede boliger.

Det pilotanlæg, som RACELL har opført i en almen boligafdeling i Stenløse, viser, at der i den type konverteringsprojekter er større behov for ekstern finansiering end ved konvertering fra oliefyr. I projektet i Stenløse bliver der i et opfølgende fuldskalaanlæg, der omfatter 43 boliger i en innovativ teknologisk løsning som "nærvarme"-anlæg givet et betydeligt tilskud i form af ydelsesstøtte fra Landsbyggefonden. Men dette projekt har også vist, at det med PVT-E moduler i kombination med traditionelle solceller er muligt helt at dække naturgasopvarmede boligers varmebehov fra solenergi, samtidig med at boligafdelingen bliver en betydelig nettoeksportør af CO_2-fri el på årsbasis.

M5: 2 pilotanlæg idriftsat

Planlagte anlæg til kontroltårnet i Rønne

M6: Afrapportering af det første ½ års resultater fra de 2 pilotanlæg

M7: Seminar om erfaringer fra simuleret "drift" af virtuelt PVT-E kraftvært

Milestones blev gennemført enkelte med 6 måneders forsinkelser men alle målinger blev gennemført.

M8: EUDP-ansøgning til etablering af 35 stk. BIPVT-E husanlæg samt 2.000 m² PVT-E demo anlæg udarbejdes - hvis behov for anlægsstøtte. (mar. 2019)

Milestone 8 blev ikke ansøgt og ikke gennemført i Arnager, men blev til gengæld overhalet af virkeligheden, således at der i stedet både blev vedtaget etablering af 43 PVT anlæg i Ølstykke, 750 m2 PVT er opsat på 3 boligblokke i Århus og planer om PVTE anlæg i stor skala implementeres i 2021 i Kastrup Lufthavn.

Non-expected issues in the project were the success of the single-family house system and the interest from the airports. On the other hand, other technologies were competing such as more efficient air-to-liquid heatpumps for one-family houses and large scale heatpumps for large buildings. Furthermore, the new expectations for huge Energy Islands at sea and Power-to-X, so that for a while the Solar Smart System was losing momentum.

However, the loss of interest from the utility seems to be changing in 2020, because of the very high and flexible triple energy efficiency available from the PVT-E and Solar Smart System. It is very modular and could become the next generation local district heating solution for small communities outside the district heating grid.

For the private housing, the PVT-E must thus prove itself as a simpler and more cost-effective roof replacement solution and the technology must be further developed in-order to keep the momentum and the wide interest that it has started among residential houses.

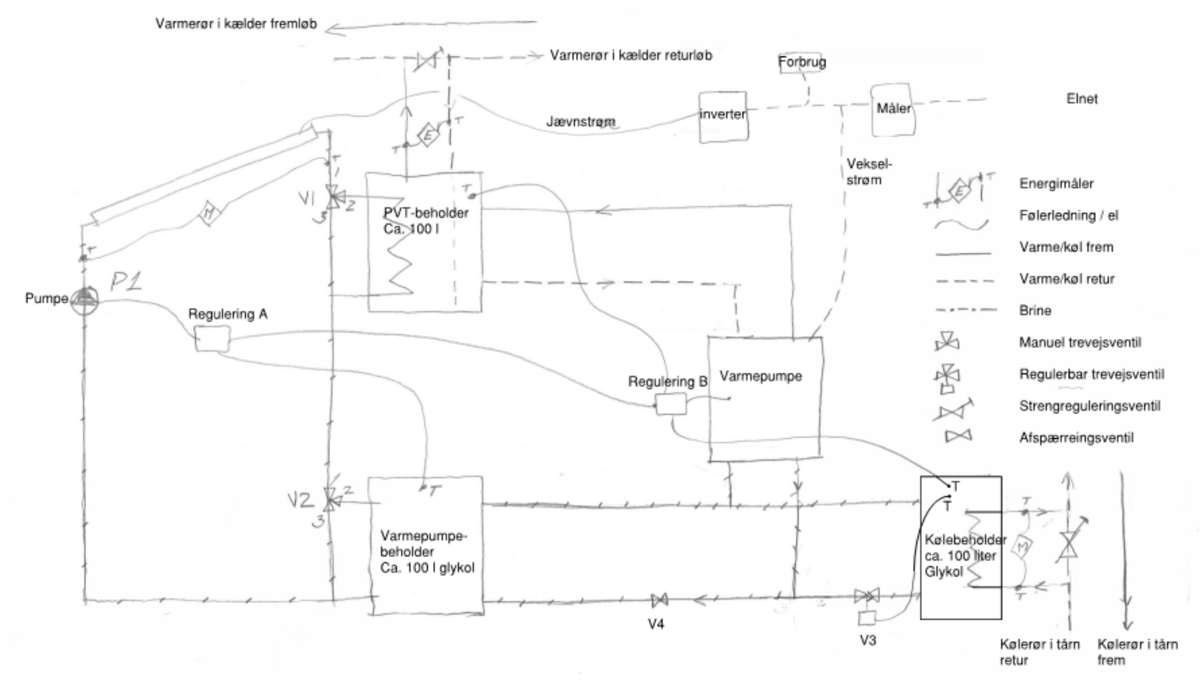
5. Project results

5.1 Project results and obstacles

The objectives of the project were fully obtained. The demonstration had to be moved from Bornholm to another island, Sjælland, and the impact of the technology tests seem to attract wide attention.

The project design for the Rønne airport is described here and in appendix 3.

Principdiagram for PVT-E pilotanlæg til Bornholms Lufthavn - version 15 april 2019



The intelligent control system was developed both for Rønne Airport and for the private house but needs more adjustments and flexibility and interfaces to other emerging systems such as heatpumps and battery and storage systems.

The concept for single family houses and residential housing blocks was proven after installation and optimization. Financially the missing part was a further technology development of the absorber and integration in the PVT module. This is though expected to be solved within the next couple of years with new innovations.

A complete test report for the single-family house is given in appendix (E). It is showing the losses by the heatpump, because of the missing insulation and because of the wrong dimensioning of the heatpump.

5.2 Technological results

The test period proved that the PVT-E system produced more energy than expected from the theoretical models. The actual absorber based solar hybrid modules, although heavy and with "clumsy" piping, is now a proved concept and for the first time ever showing that it is possible to produce large scale PVT modules that can easily become the actual roof since mounting is done within a day or two.

An important need for a new type of heatpump for the PVT with a non-toxic brine system that is flexible in viscosity and can be active also if the temperature reaches minus 20 degrees C.

Failures originating from the welding in the production of the aluminium absorber unit and design issues having to deal with the large header pipes from the absorber were the greatest technology barriers for the project.

New ways of standardizing the PVT modules were invented during the project, so that the modules can be changed by actually sawing holes in then at the building site.

5.3 Commercial results

After the testing period for the single house system in Ølstykke and for the residential blocks in Århus, many new customers have been contacting Racell asking for built-in roof PVT Smart Solar System.

The interest is coming without any advertising and at one point 2-3 house owners were contacting per day. Also customers from the EU, USA and Canada are calling. The pressure is high for developing some standardised systems.

For the residential blocks the interest is also very high, but here more references are asked for and pricing is only competitive, the building is outside the district heating area and that the PVT modules constitute the actual new renovated roof. Otherwise, the easy solution is to buy cheap Chinese PV modules and mount them on top of the roof.

The ROI is by no doubt better for the PVT Solar Smart System, but financial institutions also need references, whereas simple PV solar is already well known and can generate whatever loans are necessary.

For "oil villages" and rural districts without district heating, or for the export market south of Denmark where cooling is needed, the Solar Smart System is highly competitive and just needs to be introduced. The missing links are (1) a simpler and cost-effective absorber, (2) heatpumps allocated for PVT and (3) standardised PVT-E modules and related HVAC components.

For the commercial or large-scale buildings, the system seems very attractive. A fast breakthrough for Airport solutions seems underway, just because of the initial small systems introduced at Rønne and at Kastrup airport.

5.4 Commercial target groups

As soon as the absorber is further developed and costing thus is dramatically reduced, the markets and customer groups are several.

In Scandinavia the most attractive market would be for renovation projects of residential building blocks. In the near future, as also well described in the EU Horizon READY project, the smart city buildings would be provided with low temperature heating that would fit nicely with local temperature boosting and with interacting with the low temperature energy supply from the PVT-E roofs and facades.

In Southern Europe self-reliant energy for single family houses and for large scale buildings will be a large market, since solar electricity and cooling 24/7 from PVT-E is the most cost-effective solution. In order to avoid time consuming, custom made solutions for every building, it is vital that standardised PVT-E modules and HVAC components are available.

Another expected target group would be district heating companies that want to transform from fossil fuels to renewable energy. These companies could benefit from the triple energy concept, so the get 3 times as much energy per m2 than just from solar cells, and they can deliver both direct electricity, heating and cooling from the same energy source.

Also, public, and institutional buildings, such as schools, hospitals and more, could become a target group for the Solar Smart System. However, the legal obstacles can be complicated in these cases, so that it remains to be seen in which regions and countries this market is probable.
Finally, an obvious market and target group are shopping malls and supermarkets. They require large scale energy consumption and need much electricity but in particular cooling (and in Scandinavia also heating). The main benefit is that the PVT-E Solar Smart System is easy and fast to install, does not need much space and does not need to

interfere with the existing HVAC installations. It can just be "hooked-on" because the control system will provide whatever the energy consumption requires from the users in the building.

The market for new build and high-rise buildings is also interesting, but since these projects require several years and since there are many restrictions and complex contracts, this segment of the renewable energy market is only optional. In combination with the architectural solutions that Racell already has, the Solar Smart System could be the DGNB and energy issue that makes the competition easier to win in the big international Tenders.

6. Utilisation of project results

THE PROJECT PARTICIPANTS UTILIZING RESULTS

During the project a close collaboration between the participants has been developed and the knowledge obtained for the new concept is gradually developing through the networks into requests and inquiries for new orders. An example is Danfoss which finds the concept suitable for their products reg. control of indoor climate comfort. Although Danfoss has sold off its own production line of Heat Pumps, a collaboration has started together with the Danish producer MetroTherm, Racell, Danfoss, COWI and Li- Balance for developing a commercial Solar Smart System for commercial buildings, building blocks and for one family houses.

From the results of this project, we are considering the Solar Smart System to become a true game changer. This has led to a close collaboration between Racell, Danfoss, Metrotherm, Rockwool, COWI, NCC, Building Societies, Kemp & Lauritzen and more, for developing new standards for the building industry.

THE NEW COMMERCIAL ACTIVITIES AND PRODUCTS

The well proven good results from the new Solar Smart System technology for the residential and commercial buildings, has opened up with new customers contacting in particular Racell, asking for offers for specific buildings, both for renovation. The new PVT-E module is to become a new product line, as the ROI and NOI and the idea of self-reliance by renewable energy gets known. Whereas before it was mostly the aesthetics that formed the attraction, today it is first of all the financial benefit that attracts the building owners, secondly it is the independence of energy supply from outside. Total energy self-reliance is new phenomena which is also used by companies to show their sustainability and green marketing.

From the discovery of how little an area is actually needed for PVT-E to provide cooling for large scale shopping malls (even 100.000 m2 or more), the product has started to attract also the PV solar park providers. Instead of providing "only" 2 MWp per Hectare of electricity, the PV park developer can 6 MWp on the same area an sell the surplus costly 4 MWP cooling-energy for local district cooling. This new economy of scale has now been implemented in the Racell activities and new business plans. It can be implemented on large area buildings, like data centers or shopping malls or as ground based Solar Smart System parks. The market potential is overwhelming, especially for cooling purposes and thus partnerships with other Danish companies that are operating on the international markets (Danfoss, Metrotherm, Rockwool, 3XN, Arkitema, Henning Larsen, COWI, European Energy and more) will become important partners for the future market penetration.

Racell has hired more people in the company, the turnover has doubled and only the major R&D efforts has been holding the company back from the exponential growth.

The competition is starting to grow as other companies are trying to copy the concepts from the EUDP projects performed by Racell and patents by Racell. However, with further development of a new absorber type and optimization of the large area PVT-E module combined with Smart Solar System controls no other PVT company can meet the energy and technology benefits by the Racell PVT-E products.

The major competition are large heat pumps combined with the low-cost PV modules. But since the SCOP for the Solar Smart System is very high the investment costs low, the competition is only dependent on having more reference projects, that can prove that this "too-good-to-be-true" actually exists and works.

Some new competitors, when considering large scale renewable energy systems, are the Power-to-X and Energy Islands. But actually, the PVT-E could become a part of the Power-to-X energy supplier. On the other hand, the enormous transmission lines needed for these ultra-large-scale projects can be saved when using the PVT-E Solar Smart System, since the energy elements ARE building blocks in the actual building and the energy is used locally by the building and does not have to be transmitted. In the case of district heating companies operating in the cities, the Solar Smart System should not be competing with these, but rather be a supplementary energy source.

New PVT manufacturers are having success but can only produce small PV modules and the costs for mounting and pipe interconnections are very high. The lifetime of the modules from the competitors is limited, because unlike the Racell technology, they have serious problems by the mismatch of the expansion coefficient between metal and glass. Almost all PVT manufacturers are buying the cheap PV modules and are pressing or gluing them with a metal absorber. The price is thus low, but with the mounting and many pipe connections, the total costs are high.

The popular air-to-liquid heatpumps for one family hoses is also a major competitor, but since the heatpumps need maintenance, need electricity and are noisy, the PVT-E solution is more viable and has a faster ROI. In particular since the PVT-E also produces the electrical energy for the liquid-to-liquid heatpump. The best solution and by far the most cost-effective solution, is when the absorber technology has been further developed and the PVT-E modules form the actual roof. The savings for a new roof and the aesthetics that have been kindly promoted by Elon Musk, is rising the value of the house and financing becomes easy. Also knowing that the PVT-E roof makes the building self-reliant on electricity, heating and cooling, a building component that provides free energy for 50 years, is a major attraction. No other company today can match the large module sizes that Racell is able to produce and fit any roof. After standardization of the PVT-E Smart Solar System, the company and partners will grow extremely fast.

THE CONTRIBUTIONS TO REALIZING ENERGY POLICIES AND TO DISSIMINATION

As a gamechanger within renewable energy, it is obvious that the future contributions from this project will be important both in the building industry and in the utility sector. The association C40 is an example of where the Solar Smart System PVT-E might change the rules as a game changer, once the large cities realize the existence of this flexible and area intense energy technology.

It is well known that in 2020 parties across the aisle passed a law committing Denmark to reduce greenhouse gas emissions by 70% from 1990 levels, or around 20 million tons of CO_2 equivalent, within 10 years.

The Danish government estimated that the annual cost of implementing the shift to greener technologies would rise to 16-24 billion Danish crowns ($2.5-$3.7 billion) by 2030 - or 0.7%-1.0% of gross domestic product.

For the national Danish policies of Climate Change Program reducing the CO_2 emissions by 70%, the residential buildings in Denmark using fossil fuels account for more than 400.000 households. The PVT-E Solar Smart System can provide a major contribution to the 70% reduction. From preliminary calculations 3% reduction nationally could easily be achieved by the new Solar Smart System technology. The major hurdle, apart from the optimization of the absorber, is how to manage the logistics, infra structure for an exponential growth of the company. This issue is being handled by forming close relationship to companies in the building sector and also by initiating negotiations with potential Scandinavian investors.

7. Project conclusion and perspective

The Solar Smart System project has proven that the newly developed and demonstrated technology, especially when based upon the newly developed PVT-E modules, has now become a proven concept with proven technology for changing the way we think about energy production in our cities.

It is well known that the energy consumption in the cities around the world, is the single and most dominant factor in our ever-growing energy consuming mankind. The climate warnings are well-known, and the role of the urban areas on large are well described below:

From "UN HABITAT for a Better Urban Future" :

> **UN-Habitat is the United Nations programme working towards a better urban future. Its mission is to promote socially and environmentally sustainable human settlements development and the achievement of adequate shelter for all.**
>
> *Regardless of the source, energy is a major factor for development. It is needed for transport, industrial and commercial activities, buildings and infrastructure, water distribution, and food production. Most of these activities take place in or around cities, which are on average responsible for more than 75 per cent of a country's Gross Domestic Product (GDP) and therefore the main engines of global economic growth. To run their activities, cities require an uninterrupted supply of energy. They consume about 75 per cent of global primary energy and emit between 50 and 60 per cent of the world's total greenhouse gases.*
>
> *A sustainable urban energy system will need low carbon technologies on the supply side, and efficient distribution infrastructure as well as lowered consumption on the end-user side. Cities therefore need to shift from the current unsustainable fossil fuel energy generation towards using renewable energy sources, not only because of looming resource depletion but also to curb the negative externalities such as pollution and greenhouse gas emissions. At the same time, energy consumption must be reduced by changing consumption patterns and adopting energy saving techniques.*
>
> *To tackle intermittency, several renewable energy sources should be combined to overcome source-specific shortages, such as solar at night, or wind during doldrums. Solutions can also come from waste and heat recovery technologies that can be used to bridge supply gaps.*

From NREL & DOE report 2016:

> *Building energy use—primarily electricity and natural gas consumption—accounts for about 40% of U.S. greenhouse gas emissions (EPA 2015). Cities can reduce building-related emissions through the implementation of new building energy codes or through measures to maximize energy savings from existing building energy codes. Our analysis finds that city building energy code actions can reduce building-related carbon emissions by about 60-120 MMT CO2/year by 2035, representing about 0.9%-1.9% of 2013 U.S. greenhouse gas emissions. It is important to note that the short-term carbon abatement potential of building energy codes is limited by the long life and slow turnover of building stock; however, the longer-term carbon abatement potential may be significantly greater (Schwartz et al. 2016).*

This EUDP project was intending to prove that the combination of PVT supportive supply of both electricity and thermal energy would be a supplementary to the Smart City approach with energy efficiency savings enabling the reduction of energy consumption in buildings. The Solar Smart System is also expected to assist in reducing the peak load demand for the grid on thermal and electrical energy via coordination with the existing grid. That overall objective has been reached.

Technically the project managed to prove that it is possible to integrate the PVT-E Smart Solar System and to produce reliable and controllable renewable energy for different building types and energy users in different climates and predict the energy production match to the energy consumption of the building.

The impact is influencing the whole energy sector: suddenly the PVT-E combined with the Solar Smart System components makes the building the energy source for all energies: electricity, heating, cooling, domestic hot water. Masses of noisy Air-Condition units hanging all the buildings are no longer needed. Energy is available also when there is no sun. The city buildings are generating energy day and night and do not need massive district heating and district cooling networks. All energy is produced locally by the buildings themselves.

International investors have recently started to become active by getting involved with direct contacts and are seriously looking forward to supporting the forthcoming breakthrough of this new Gamechanger in the global energy market, the Solar Smart System concept. It is indeed with the support from the Danish EUDP support program that this new energy adventure has been lifted up from ideas and small-scale tests to a forthcoming massive sustainable energy revolution.

8. Appendices

- Appendix (A)__Measurement and solar smart control system.pdf
- Appendix (B)__Specifikationer_af_leverancen_til_Rønne_lufthavn_2019.pdf
- Appendix (C)__Notat om Bornholm lufthavn feb 18.pdf
- Appendix (D)__Arnager hus illustration bolig, skitser fra Racell 2018.pdf
- Appendix (E)__DTU Stengården test measurements report.pdf