Final report

1.1 Project details

Project title	Energy renovation with PVT, Smart Grid control and energy storage. Energirenovering med PVT, Smart Grid styring og energilagring – ERPSGEL
Project identification (program abbrev. and file)	EUDP-2016 I Journalnr.: 64016-0076
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	Kuben Management A/S, Ellebjergvej 52, 2450 København SV
Project partners	Ballerup Kommune, Schneider Electric DK og SBi/AAU
CVR (central business register)	28693036
Date for submission	February 27, 2020

Contents

1.2 Short description of project objective and results

English

The objective of this project was to develop and demonstrate a combined energy renovation of a public building, which integrates SMART GRID / SMART ENERGY and energy storage.

In the project a swimming hall was energy renovated and in relation to this renovation a photovoltaic solar cell (PV) system and a heat-pump was installed. When the PV-elements produce electricity this can be used to run the air to water heat-pump that cools the ambient air and delivers heat to one or two heat storages in the swimming hall – the swim basin or the hot water basin. The heat-pump can also produce energy for heating the basins based on electricity from the grid, when the relationship between the price of electricity and that of district heating is lower than the efficiency factor of the heat pump. The first monitoring shows that the system works according to the expectations and payback from the investments are in the order of 8-10 years. The experiences will be of importance to the future development of the "Flexible Energy system of Denmark", one of the key areas for the new Energy Commission established by the Danish Minister for Energy, supply and climate.

Danish

Formålet med projektet var at udvikle og demonstrere en samlet energirenovering af en offentlig bygning, der integrerer SMART GRID / SMART ENERGY og energilagring.

I projektet energirenoveredes en svømmehal og i kombination hermed installeredes et solcelle (PV) system og en varmepumpe. Når PV-elementerne producerer strøm benyttes denne til at drive luft-til-vand varmepumpen, som køler udeluften og afleverer varmen i et af to varmelagre i svømmehallen – enten i svømmebassinet eller i varmtvandsbassinet. Varmepumpen kan også producere varme til bassinerne på strøm fra nettet, når de aktuelle el- og varmepriser sammenholdt med varmepumpens effektivitet viser, at det er økonomisk fordelagtigt. De første målinger viser, at systemet fungerer efter hensigten med en forventet tilbagebetalingstid på 8-10 år. Erfaringerne fra projektet vil bl.a. være et vigtigt bidrag til den kommende udvikling af Danmarks fleksible energisystem, der er et af nøgleområderne for den nye Energikommission, nedsat af Klima-, Energi- og Forsyningsministeren.

1.3 Executive summary

In the project a swimming hall was energy renovated with new roof cassettes, insulation in general and a new efficient lighting system. In relation to this renovation a photovoltaic solar cell (PV) system (515 m² and 96 kWp) and a heat-pump (55 kW heating effect) was installed.

Additional energy meters were also installed and the heating consumptions for the different heating requirements within the swim hall was analysed. Based on this analysis it was decided that the heating produced by the heat pump should be used to heat the two basins: the swim basin and the hot water basin.

When the PV-elements produce electricity this or part of this can be used to run the air to water heat-pump, which cools the ambient air and delivers heat to one or both of the two of the above basins. The heat-pump can also produce energy for heating the basins based on electricity from the grid, when the relationship between the price of electricity and that of district heating is lower than the efficiency factor of the heat pump. In both cases the free or cheaper heating from the heat pump can be stored in the swim basin after this has reached its set point temperature of 27 °C by increasing this temperature by 0.5 °C thereby using the basin as a storage tank.

The first monitoring results show that the system works according to the expectations. The calculations based on that show that the heat pump will produce 170 MWh/year and besides the PV-system will produce around 50 MWh/year. The system will result in a total CO_2-reduction of about 80 tons/year. Even when producing heating on bought electricity from the grid the heat pump does it with half the CO_2-emission as that of the district heating network supplying the swim bath.

The payback from the investments are according to the calculations in the order of 10 years. Ballerup had some extra costs, which might not apply to the next implementation in another municipality, so the payback time may be reduced to 8 years.

The results from this project can be used in similar projects in Denmark and as such the experiences will be of importance to the future development of the "Flexible Energy system of Denmark", one of the key areas for the new Energy Commission established by the Danish Minister for Energy, supply and climate.

1.4 Project objectives

1.4.1 Objectives

The objective of this project was to develop and demonstrate a combined energy renovation and SMART ENERGY supply system - based on PV and heat pump - with energy storage on a public swim bath in Ballerup.

1.4.2 Implementation of the project

The implementation of the project followed a number of tracks:

- The energy renovation of the building,
- Dispensation for the requirement to form a company for the PV system
- Determination of type and location of PV-system.
- Analysis of measured energy consumption data.
- The determination of the type and size of heat pump, its selection and installation.
- The development of the control algorithms.

1.4.2.1 Energy renovation

The energy renovation of the building were carried out according to the plan. The existing Teflon-plastic roof was replaced by new roof cassettes, which improved the insulation of the roof considerably. The existing halogen lamps were replaced by a new LED lighting system. And the water treatment system was renovated.

1.4.2.2 Avoidance of company formation (selskabsdannelse) and application for "nettoafregning"

One of the prerequisites for the municipality to accept the installation of a PV-system was to be able to avoid the otherwise required company formation (selskabsdannelse). This requirement could be avoided if an energy frame calculation of the energy renovated building with the PV-system and a heat pump could be shown to equal that of a new building with the same use. This was done and an application sent forward to Energinet in March 2017. The dispensation was received in August 2017.

After this dispensation was received the municipality applied for "nettoafregning" and got received approval about that in December 2017.

1.4.2.3 Determination and location of PV-system

A number of issues had to be dealt with for the determination of the type and location of the PV-system. The original idea was to use PVT-modules and place them directly on the roof cassettes. A screening of the market revealed that the prices of PVT-modules were prohibitive. It would be more meaningful to use standard PV-cells and use an air-liquid heat pump instead of a liquid-liquid heat pump.

A load bearing evaluation of the roof cassettes showed that they could not carry the weight of standard PV-cells. Then the idea was to mount a scaffold for the solar cells. However, it turned out that the roof cassettes were constructed with a hygrodiode for moisture control and the functioning of this would be ruined by the shading from the PV-cells on the scaffold.

A new load bearing evaluation of the roof cassettes showed that they could carry the weight of thin film PV with a maximum weight of 4.5 kg/m². A tender was written, sent out and two offers received. Because of the lower efficiency of the thin film PV-cells the needed KWp could not be achieved on the available roof area. At the same time the cost of the PV-systems offered were too high. In this process also an idea of mounting façade-PV-panels on the southern façade of the swimming hall was born. But due to cost and to small useful area this idea was not taken further.

In conclusion it was decided to choose standard PV-cells and look for another location. Fortunately, the neighbouring buildings, the TopDanmark hall and the changing rooms building for that, were located on the same cadastral (matrikel) number as the East Kilbride swim bath, which meant that the PV-system could also be placed on one of these buildings. In the end it turned out that the location on the changing rooms building was the only possible, because only its roof could carry the additional weight of the solar cells.

A total of 515 m² of solar cells with a peak effect of 99 kWp was installed on the roof. The inverters installed had a total peak effect of 80 kWp. The installed PV cells are shown on figure 1.

Fig. 1 The PV-system installed on the roof of the changing room building for TOPDanmark hallen.

The electricity supply to the changing room building came from the East Kilbride swim bath building. However, the cable did not have the sufficient capacity to carry the produced electricity from the PV-system, so a new cable had to be drawn and installed.

1.4.2.4 Analysis of the measured data and final design of the system

Originally, only the total heating energy consumption of the swim bath was known. Therefore, a number of meters were installed to allow for an analysis of the heating demand of the individual heating energy consumers: The swim bath basin, the hot water basin, the heat exchanger in the ventilation system and the hot water preparation for the changing rooms.

The results of the analyses of these individual heating consumption data was:

1. The heating energy use of the hot water preparation for the changing rooms were quite small and therefore not worth the cost of the installation of additional connections and control to let it be supplied by the solar driven heat pump.
2. On the other hand the heating energy consumption of the heat exchanger in the ventilation system was continuously so high that if supplied by the heat pump there would be no surplus to store in the basin. At the same time the technical difficulties in connection this heat exchanger to the heat pump supply was quite high, so this was also not connected.
3. The heating energy consumption of the swim basin and the hot water basin were on the average of such a level that both could be supplied by the heat pump, if required, and if only one of them require heating it is possible to supply that and store some surplus heat generated by the solar driven heat pump.

Based on these results the final design of the system was formed as shown on figure 2.

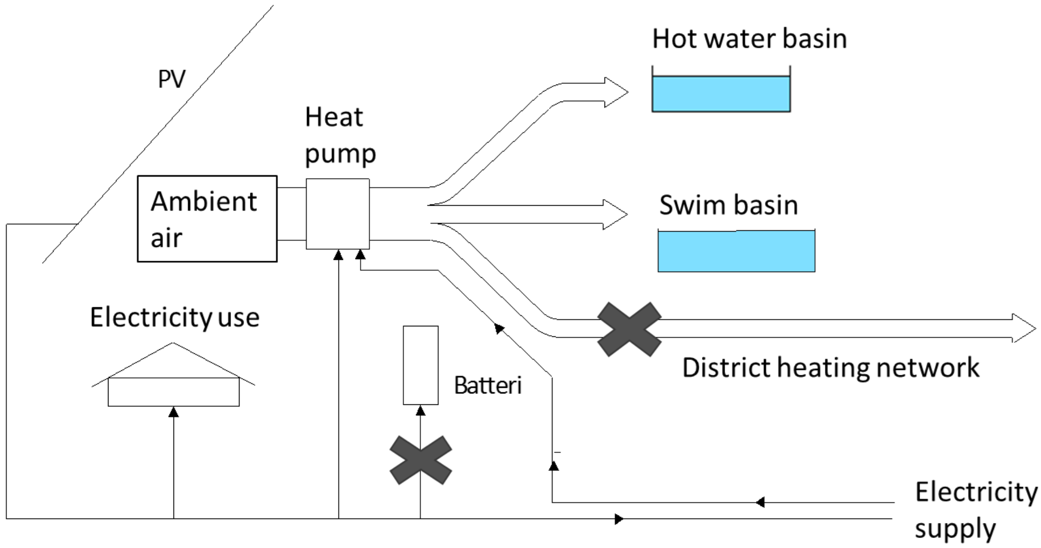


Fig. 2. A sketch of the final system design.

1.4.2.5 The determination of the type and size of heat pump, its selection and installation.

At the same time as opting out of the PVT elements, it was decided to investigate alternatives to the thermal part of the PVT solution. The first alternative was Icopal's energy roof (which can be connected to a liquid-water heat pump), but it also proved to be too expensive and also inappropriate due to the cooling in the roof, which can create condensation in the ceiling of the swimming pool. The other alternative was to install ground tubes (also for a liquid-water heat pump), but it was also considered to be too expensive, since the expected higher efficiency of the ground heat pump would not be as pronounced as usual, because most of the solar-generated heat production will take place when the air temperature is at or above the ground temperature. An air-water heat pump was therefore selected.

During 2018, meetings were held with several potential heat pump suppliers – e.g. representing the brands Viessmann, Weishaupt and Danfoss. None of these had satisfactory solutions. Then contact was made to the company Klimadan, which has several references on innovative, slightly advanced heat pump solutions and the company also had a good offer for a solution for the EK swimming pool. The choice fell on an air-water HP of the Carrier brand.

<u>Sizing of heat pump</u>

The original energy frame calculations were repeated with the now known size and location (direction and slope) of the solar cells, the measured energy consumption for the swimming pool and the hot water pool and a 55 kW HP. The calculations showed that the energy frame calculations still held - both when using primary energy factors from Building Regulations 2015 and for Building Regulations 2018. It was therefore decided to install a 55 kW heat pump

1.4.2.6 The development of the control algorithms.

For the control, a CTS system from Schneider-Electric DK was installed. This provides the opportunity to control the supply of heat from the HP on one of the following options in relation to district heating (DH): Only HP or only DH, or HP in addition to DH. The connection allows to supply heat from the HP to one basin, to the other, or to both.

Figure 3 shows the two heat exchangers before the renovation - and the new pipe installation around the exchangers, which allows hot water to be supplied from the heat pump instead of or together with the district heating.

Fig. 3: Left photo: Heat exchangers for swimming pool (front) and hot water pool (rear) in the old installation. Right photo: New exchanger on the district heating supply and pipe installation for introducing heat from the heat pump.

<u>Alignment of the existing installation</u>
As the installation was originally, the DH supplied the heat directly into the EK swim hall with a pressure of up to 10 bar. This is a pressure that the HP can work with. However, for a while there had been talks that Vestforbrænding might start delivering heat directly and that could result in significantly higher pressure. So one question had been whether an exchanger should be put into the DH delivery to be prepared for this. This was decided, since many of the other components of the heating system are also not to be exposed to high pressures.

As the first measurements of temperature levels in the installation when heating the two basins came into the CTS system, it became clear that the heat exchanger for the hot water basin was laid out to the relatively high temperatures provided by the district heating. Temperatures in excess of 68 °C were required for heating the basin. As such high temperatures would ruin the operation of the heat pump, it was necessary to investigate whether the heat transfer in the heat exchanger could be increased. Fortunately, this was possible as the exchanger can be expanded with extra plates. These were ordered and then installed.

<u>Management strategy / function description of CTS</u>

The CTS system must primarily control the heating of the two basins, respectively from district heating or heat pump or a combination of these. The control of the heat supply of the basins is designed so that when the solar cell production is above a certain level and there is simultaneously a heat demand in one of the basins, the heat pump is started and the heat demand in the basins is supplied with heat from the heat pump. If there is no current heat demand, the water treatment system is requested to raise the desired temperature in the swimming pool by 0,5 °C, after which the heat pump can use this pool as heat storage and thus increase the yield from the solar-powered heat production. Along the way, the control unit must ensure that the heat pump has a minimum operating period of half an hour to prevent it from commuting unnecessarily.

Furthermore, the control provides an opportunity to control according to the COP of the heat pump in relation to energy prices. The municipality of Ballerup pays the following heating and electricity prices (2019): DKK 482,62/MWh for district heating and DKK 1,86/kWh for electricity. Both prices are excl. VAT. This means that when the heat pump's COP is above 3,854 (3,9) - it is worthwhile to run with the heat pump on power purchased from the grid. With a flow temperature of 45 °C, the HP can on this basis run for outdoor temperatures above approx. 8 °C.

The CTS system can also monitor the system's energy meters, motor valves, pumps and temperatures and display the status on a screen as well as log this data from the energy meters. It will always be possible to calculate the energy production from the heat pump and the supply of the two basins from the measurements as well as information on the temperature levels with which heat is supplied from the VP.

Figure 4 shows the system diagram as shown on the CTS system and Figure 5 shows the screen for changing control parameters.

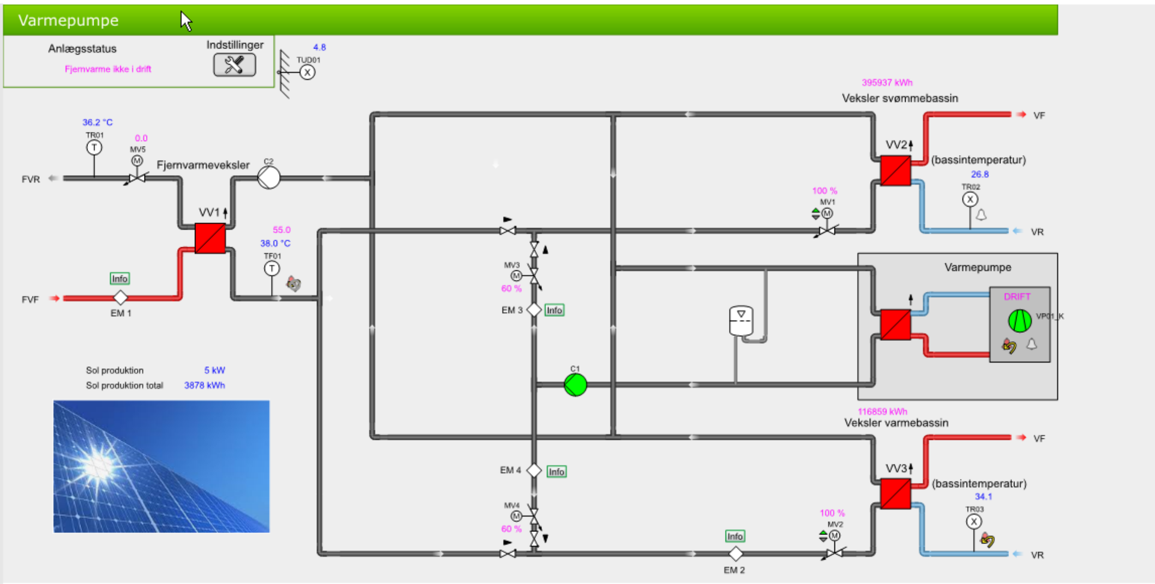


Fig. 4 The system diagram as depicted on the CTS screen.

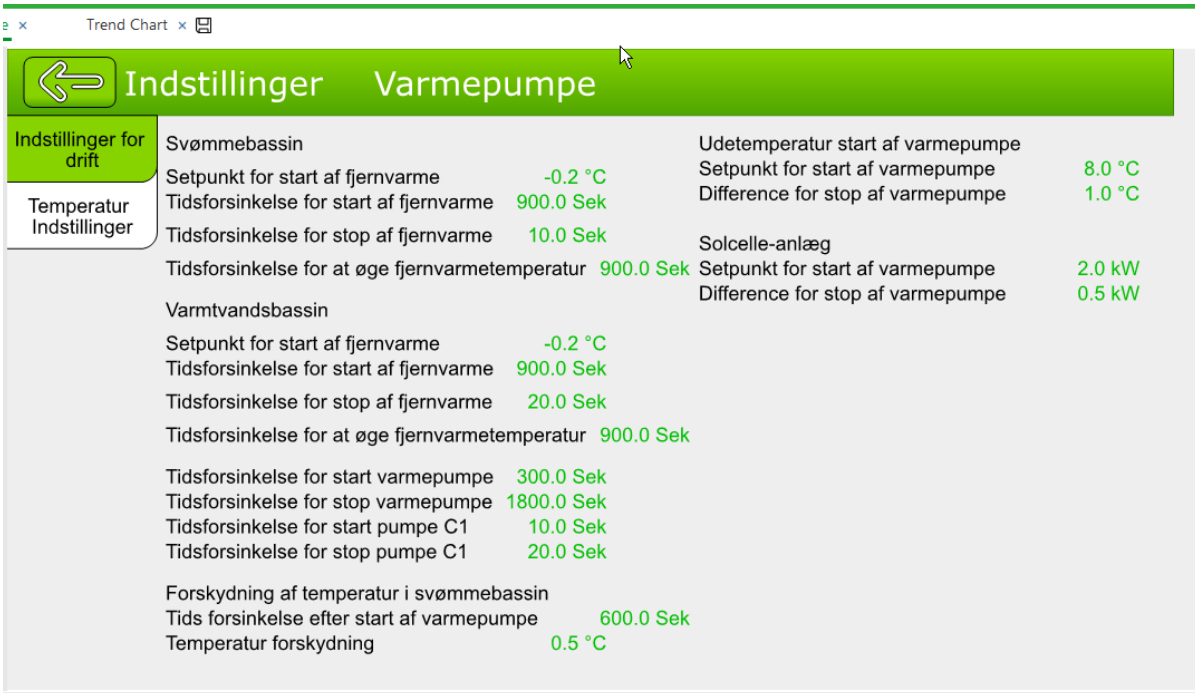


Fig. 5 CTS screen for changing control parameters.

One of lessons learned from this work was that when working with Smart Building principles including the installation and integration of different systems, it is important to make sure that the different components can 'talk together'. In the East Kilbride project, it appeared that the integrated solutions consisting of solar cells, heat pump and water treatment system had different forms of IT communication. Therefore, a central part of the project was to gather communication and distribution of data in the open CTS platform. In future projects it is therefore recommended to investigate how the communication protocols of the individual components can be integrated into a single platform to allow SMART control.

As it appear from the above the project implementation did not develop as foreseen and according to milestones first agreed upon. First the application procedure for the solar cells system took almost a year, thereafter the investigations of type and location of solar cells also took much longer than expected. Next step identifying the heat pump and its installation and finally, solving the IT-system interaction between the different system took additional months. Underway, the project was extended more than a year. Luckily all the efforts were worth it and we ended up with a well-functioning system.

1.5 Project results and dissemination of results

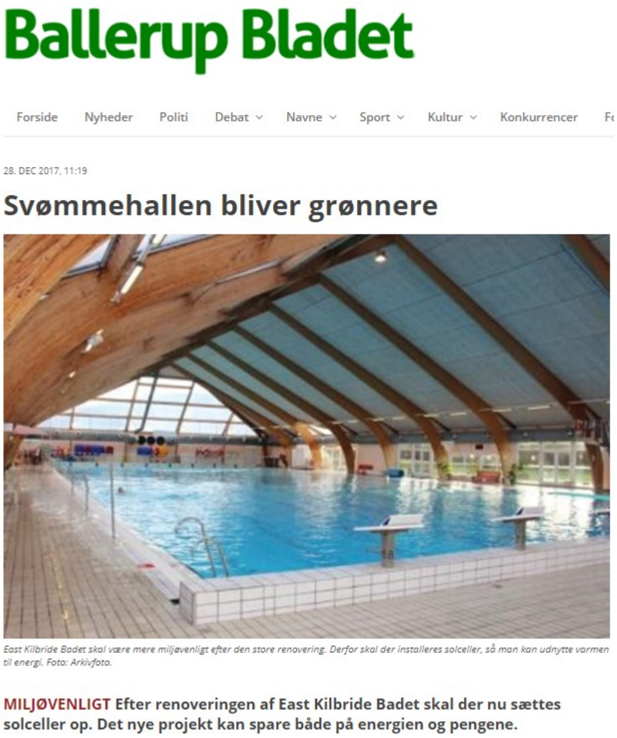
As it appear from the above chapters the project succeeded in demonstrating a successful combination of an energy renovation with an implementation of a SMART GRID / SMART ENERGY system and energy storage. Because of the long process caused by many difficulties as described above it has only been possible to monitor the system for little over a months, where we originally has planned for 12 months. However, these first monitoring results show that the system is functioning according to the expectations. This is further documented in a project report on Danish – se Annex 1. Based on that calculations show that the system performs according to the plan and results in economical savings of app. 180.000 DKK a year and CO_2-reductions of 80 tons a year. So, the project objectives were met. The challenges of the integration of the different IT-systems of heat pump, PV-system and water treatment system were handled and the developed CTS-system is able to control the heat pump in a SMART way depending on the load of the basins, the output of the PV-system and the outdoor temperatures.

The project has so far not resulted in increased turnover, exports or employment for the partners and they do not expect any immediate increase in these areas. However, due to the project the partners have gained knowledge and expertise in designing and implementing this type of system and in the long run at least two of the partners – Kuben Management and Schneider-Electric expect further work for consulting or implementing such systems.

The project results has been disseminated through a number of channels:

1. First an article in the local newspaper in Ballerup:

https://ballerupbladet.dk/node/45491


Ballerup Bladet

Forside | Nyheder | Politi | Debat | Navne | Sport | Kultur | Konkurrencer | Fo

28. DEC 2017, 11:19

Svømmehallen bliver grønnere

East Kilbride Badet skal være mere miljøvenligt efter den store renovering. Derfor skal der installeres solceller, så man kan udnytte varmen til energi. Foto: Arkivfoto.

MILJØVENLIGT Efter renoveringen af East Kilbride Badet skal der nu sættes solceller op. Det nye projekt kan spare både på energien og pengene.

2. A report in Danish published on February 18, 2020 – see Annex 1.
3. A press release – see annex 3 - was sent to the following media:
    - electronic-supply.dk
    - building-supply.dk
    - energy-supply.dk
    - Licitationen.dk
    - elfokus.dk
    - HVACfokus.dk
    - tekniskfokus.dk
    - Installatør.dk
    - Dagens Byggeri
    - Ingeniøren
    - Energy-watch
    - Energiforum Danmark
    - DANVAK
    - Byggetidende.dk

And was accepted by a good part of these:

https://www.building-
sup-
ply.dk/announcement/view/120846/east_kilbride_badet_oger_smartness_efter_
renovering

http://www.dagensbyggeri.dk/artikel/109181-smart-building-giver-energi-
gevinst-for-ballerup-kommune

https://www.elfokus.dk/blogs/east-kilbride-badet-i-ballerup-kommune-oeger-
smartness-efter-renovering/

https://installator.dk/east-kilbride-badet-i-ballerup-kommune-%C3%B8ger-
%E2%80%99smartness%E2%80%99-efter-renovering

https://www.tekniskfokus.dk/blogs/east-kilbride-badet-i-ballerup-kommune-
oeger-smartness-efter-renovering/

https://www.byggetidende.dk/east-kilbride-badet-oeger-smartness-efter-
renovering/

4. Posts on social media:

Kuben Management:
https://www.linkedin.com/posts/kuben-management-a-s_east-kilbride-badet-i-
ballerup-kommune-%C3%B8ger-activity-6635818600601051137-CYHK

https://l.facebook.com/l.php?u=https%3A%2F%2Fkubenman.dk%2Fkuben-
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Ballerup:

https://www.linkedin.com/feed/update/urn:li:activity:6635881506361364480

www.Ballerup.dk:

https://ballerup.dk/borger/east-kilbride-badet-oeger-smartness-efter-
renovering

The "East Kilbride Badet" also intends to share this information via their info-channels.

Build (SBi)/AAU:
https://www.linkedin.com/feed/update/urn:li:activity:6636551996469985281

1.6 Utilization of project results

Ballerup Municipality can directly use the results from the project in implementing similar systems in other public buildings in the municipality. Two of the partners have plans to use the results commercially. Kuben Management can use knowledge and experience gained in its consulting work towards other municipalities and building owners in general and Schneider-Electric DK can offer CTS-systems to similar SMART BUILDING / SMART GRID applications based on their gained experience in this project. The marketing of these services has primarily been done through a press release on the results of the project followed by posts on the social media. The market potential in Denmark is quite significant: There are about. 1700 larger sports halls and swimming pools in Denmark. However, the developed and demonstrated technique will also be applicable to public buildings.

There has been and will not be taken any patents based on the project. Results have not been transferred to other institutions and a Ph.D. student has not been involved.

The project does contribute to realize energy policy objectives in reducing CO_2 and SMART heat storage of electricity from e.g. PV-systems and wind turbines and can help to increase the energy grid flexibility in the consumption and production of electricity.

1.7 Project conclusion and perspective

Does it pay off? Ballerup Municipality has invested in solar cells, heat pumps, CTS system and various necessary extra electrical installations for approx. 1.85 million DKK. The calculated savings from solar cell electricity and heat production are approx. 183.000 DKK. The repayment period is thus approx. 10 years. At the same time, the plant will reduce CO_2 emissions by approx. 80 tonnes per year.

The use of heat pumps in the heat supply becomes more and more relevant as the electricity supply charges (probably) are reduced over the coming years and CO_2 emissions are reduced. Preliminary figures from Energinet show that the average CO_2 emission from electricity generation in 2019 was 150 g per kWh. In comparison, Vestforbrænding states on its website that the fossil fuel share of district heating production emits approx. 85 g CO_2 per kWh. When using heat pumps, approx. 4 kWh of heat out of each kWh of electricity will thus be less than half the CO_2 emission from the district heating plant.

The energy grid needs flexibility in the consumption and production of electricity when the power system needs to be balanced. This need increases as the share of fluctuating renewable energy production increases. Already today there are times over a year when Energinet is challenged to get the amount of production and consumption to vote. SMART heat storage of electricity from e.g. wind turbines can help solve this problem.

There are about. 1700 larger sports halls and swimming pools in Denmark. However, the developed and demonstrated technique will also be applicable to public buildings. The overall market potential in Denmark is thus very significant.

Annex

Annex 1

The project results and report in Danish on the NEWS of the website of Kuben Management: https://kubenman.dk/kuben-management/nyheder/?article=east-kilbride-badet-i-ballerup-kommune-oeger-smartness-efter-renovering and on the intranet of the company.

Annex 2

Projekt report in Danish "Solcelledrevet varmepumpe og smart energilagring på energirenoveret svømmehal" published on the website of Kuben Management: https://kubenman.dk/media/3391374/solcelledrevet-varmepumpe-og-smart-energilagring-paa-energirenoveret-svoemmehal.pdf

Annex 3

Pressemeddelelse udsendt som beskrevet under 1.5.

Pressemeddelelse

East Kilbride Badet i Ballerup Kommune øger 'smartness' efter renovering

Den planlagte energirenovering af East Kilbride Badet fik et smart element, da Ballerup Kommune i samarbejde med Kuben Management, Build AAU og Schneider Electric DK valgte at afprøve principper om Smart Buildings ved samme lejlighed. De beregnede resultater lyder på reduceret CO2-udledning – ca. 80 ton om året, mere end 180.000 kr. i energibesparelser og en energiramme svarende til en ny svømmehal bygget efter BR18. Projektet er støttet af EUDP-midler bevilget af Energistyrelsen og udmønter sig bl.a. i en ny rapport, der detaljeret beskriver processen fra projektets første systemidé til den endelige udformning af anlægget. Find link til rapporten nedenfor. En kortere beskrivelse af projekt og resultater kommer i en artikel i HVAC-bladet d. 10. marts.

Smart Building

Smart Building tankegangen blev realiseret ved, at East Kilbride Badet fik installeret solceller på TopDanmark hallen og en luft-vand varmepumpe ved svømmehallen. Disse komponenter bliver på smart vis styret af CTS-anlægget. Ove Christen Mørck fra Kuben Management fortæller:

"Solcellerne producerer strøm til at drive varmepumpen, som derefter afleverer varmen til forskellige varmebehov i East Kilbride svømmebad, dvs. enten svømmebassin, varmtvandsbassin, eller begge. Ved at styre varmepumpen intelligent får man det bedst mulige udbytte af systemet."

En intelligent styring af East Kilbride Badet opfanger varmebehovet i bassinerne og styrer opvarmning af vandet enten med varme fra varmepumpe eller fjernvarme. Når solcelleproduktionen er over et vist niveau, opvarmes bassinerne af varmen fra varmepumpen. Når begge bassiner har opnået den ønskede temperatur, øges denne i svømmebassinet med 0.5 °C, således at bassinet fungerer som varmelager. Når solcellernes produktion ikke er tilstrækkelig til at

drive varmepumpen skiftes der til fjernvarme.

Figur 1. Svømmehallen set indefra før renoveringen (tv) og efter renoveringen (th).

Hvis man arbejder med Smart Building principper herunder installation og integration af forskellige systemer, er det vigtigt at have for øje at de forskellige komponenter kan 'snakke sammen'. I East Kilbride projektet blev det erfaret, at de integrerede løsninger bestående af solceller, varmepumpe og vandbehandlingssystem havde forskellige former for IT-kommunikation. Derfor var en central del af projektet at samle kommunikation og distribution af data i den åbne CTS-platform. I fremtidige projekter anbefales det derfor at undersøge, hvordan de enkelte komponenters kommunikationsprotokoller kan integreres i én samlet platform og tillade en SMART styring.

Fremtidsperspektiverne for at benytte sig af varmepumper i varmeforsyningen er relevant i takt med stigende afgifter og krav til CO_2-reduktion.

I Danmark er der ca. 1.700 større idrætshaller og svømmehaller, som kan benytte sig af den demonstrerede løsning. På den baggrund er det samlede potentiale for reduktion af klimapåvirkning til at få øje på.

Ny rapport beskriver processen for implementering af Smart Building-principper i svømmehallen:

Rapporten SOLCELLEDREVET VARMEPUMPE OG SMART ENERGILAGRING PÅ ENERGIRENOVERET SVØMMEHAL beskriver processen fra den oprindelige systemidé for installation af solceller og varmepumpe i forbindelse med energirenovering af East Kilbride Badet i Ballerup – herunder dispensationsansøgning vedrørende selskabsudskillelse for solcelleanlægget og ansøgning om nettoafregning af solcellestrøm – til den endelige udformning og de første målinger på anlægget.

Hent rapporten hér:

https://kubenman.dk/media/3391374/solcelledrevet-varmepumpe-og-smart-energilagring-paa-energirenoveret-svoemmehal.pdf

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Annex 4

HVAC ARTIKEL. The article ”Solcelledrevet varmepumpe og smart energilagring på energirenoveret svømmehal” is in the March 2020 issue of the journal: “HVAC bladet”.

Artiklen er bilagt som selvstændig .pdf-fil.