ENER/FP7/609127/"READY"

Resource Efficient Cities Implementing Advanced Smart City Solutions - READY

Deliverable no.: D.3.1.1

Name of deliverable:

Report describing the feasibility of heat recovery from waste water, PVT and heat storage in multi-family buildings and recommendations for demonstration including final design notes

Revision no.: 1

Due date of deliverable: M12
Actual submission date: 21. April 2016

Start date of project: 1. December 2014
Duration: 60 months

Organisation name of lead contractor for this deliverable: COWI
Authors: Reto M. Hummelshøj, Joakim Larsen, Svend Erik Mikkelsen

Project co-funded by the European Commission within the Seventh Framework Programme		
Dissemination level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Scope of deliverable

Report describing the technical feasibility of heat recovery from wastewater, PVT and heat storage in multi-family buildings and recommendations for demonstration including design notes.

Context of deliverable

Task 3.1.1 focusses on heat recovery and energy generation in buildings: wastewater, PVT collectors, and heat storage in multi-family buildings. This task analyse and optimise an advanced system for heat recovery in the multi-storey buildings and on-site energy generation and storage. Taking point of departure in solar and wastewater heat recovery solutions for buildings, developed in WP2, the task focus on system-wide implications of such solutions.

COWI has performed in house calculations of the heat exchanger and expected output as well as POLYSUN simulation of the aggregated thermal network in dynamic level and the impact of different operational strategies (e.g. variation of PVT supply and return temperature, management of distributed storage tanks, variation of heat generation unit's sources)

Perspective of deliverable

The development of the new solution will be tested in demonstrations later stage in the READY project.

Involved partners

COWI et al

Summary

The project objective is to develop a technology for heat recovery from wastewater with use of separation system aimed at existing multi apartment buildings. Recovery of heat loss from wastewater has not been considered much earlier, but energy for production of domestic hot water is often about 25% of the total heating demand for existing buildings in Denmark and Sweden, and about 50% for new build low energy houses (building class 2015) i.e. a significant amount of the added heating energy will leave the building through the wastewater system.

The project is based on a system with a wastewater storage e.g. as a prefabricated wastewater manhole with macerator pump - or the storage is a modification of an existing manhole. In the manhole, a special heat exchanger will be installed and coupled to a heat pump that can pre-heat domestic hot water for a domestic hot water tank. The heat pump can also use the PVT system as heat absorbers to extract heat from the sun and the surroundings. The buffers in the waste water tank and the domestic hot water tank enables the heat pump to be operated independent of the demand and domestic hot water, which introduces flexibility and use of a smart grid ready control strategy.

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1. INTRODUCTION

1.1 Background

This report is a part of the READY-project. READY is an acronym for Resource Efficient cities implementing Advanced smart city solutions. The main priority is to demonstrate optimized energy systems for high performance energy districts. The project include demonstration of residential buildings going through towards zero energy retrofitting, grid balancing/electricity storage solutions for buildings and energy systems, solutions to maximize use of renewable energy, development of energy smart solutions for kitchens, solutions for water efficiency and waste water energy recovery and development and demonstration of new solutions for low temperature district heating. This report describe technical feasibility of heat recovery from wastewater, PVT and heat storage in multi-family buildings as a recommendation for design and demonstration.

1.2 Purpose

"The ignored energy loss"

The heat demand in an average Danish apartment is approximately 120-140 kWh/m² per year, based on figures from Varmeplan Danmark[1]. The heat demand can be divided into four categories: transmission loss, ventilation loss, infiltration and hot water consumption. After a thorough building renovation in accordance to requirements in BR08[2] the demand is expected to drop to 70-80 kWh/m² per year. According to BR15[3] heat demand for new buildings is 40 kWh/m² per year under design parameters. As comfort temperature might be higher than the design temperature of 20°C, actual heat demand might be higher.

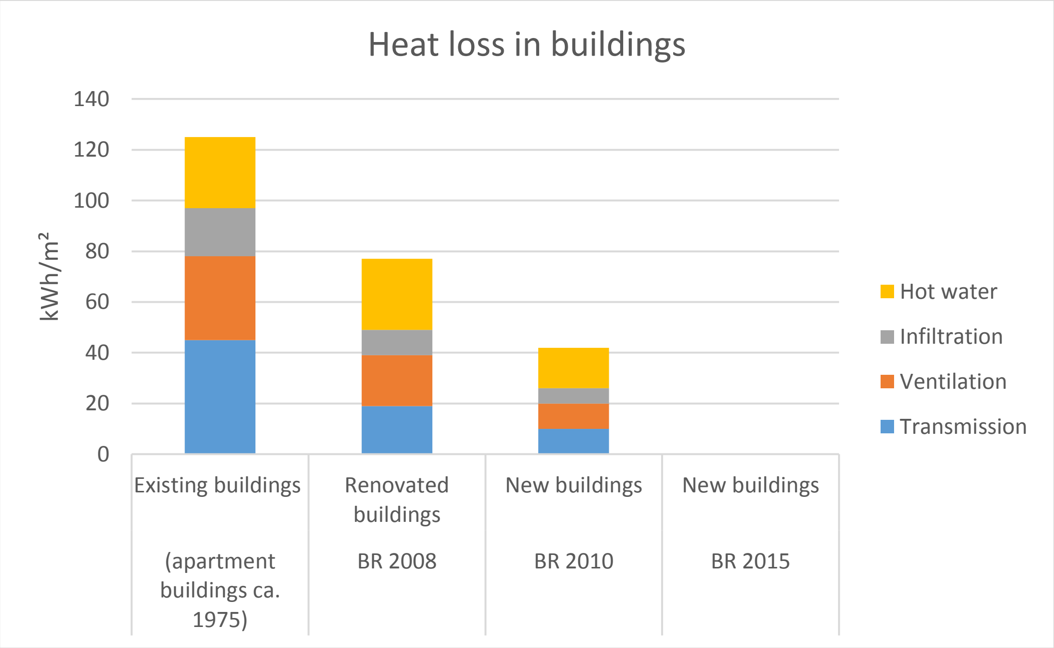

Figure 1-1 : Typical annual heat loss in existing buildings and new buildings according to class 2015.

As illustrated in Figure 1-1, there have been tremendous heat loss reduction in transmission, ventilation as well as infiltration. Hot water consumption has not been particularly reduced.

For new buildings, it is gradually getting more difficult to comply with the regulations by reducing heat transmission and ventilation loss. One solution could be to recycle wastewater heat reduce overall energy consumption.

It is assumed, that approx. 20% of the energy consumption comes from domestic water heating, there would be about six PJ to save in all buildings. If it is assumed that approx. 30% of all apartment blocks would install a heat recovery system, approx. 30,000 systems would be installed in Denmark.
This way the market is of high interest and justifies that that prefabricated solutions are developed. At the same time the potential in the EU is enormous, as apartment blocks are common in all countries and a relatively large part of these buildings are not having district heating supply.

[1] #VarmeplanDanmark.dk
[2] #
[3] #

Consumption of hot water

The water consumption in a Danish household is typically 100-140 l/person/day. According to Statistics Denmark[4], the total water consumption is decreasing, while the hot water consumption over the last 20 years has increased from 10 m^3 per person per year to 15 m^3 per person per year.

Figure 1-2 indicates an approximate division of water consumption on sources.

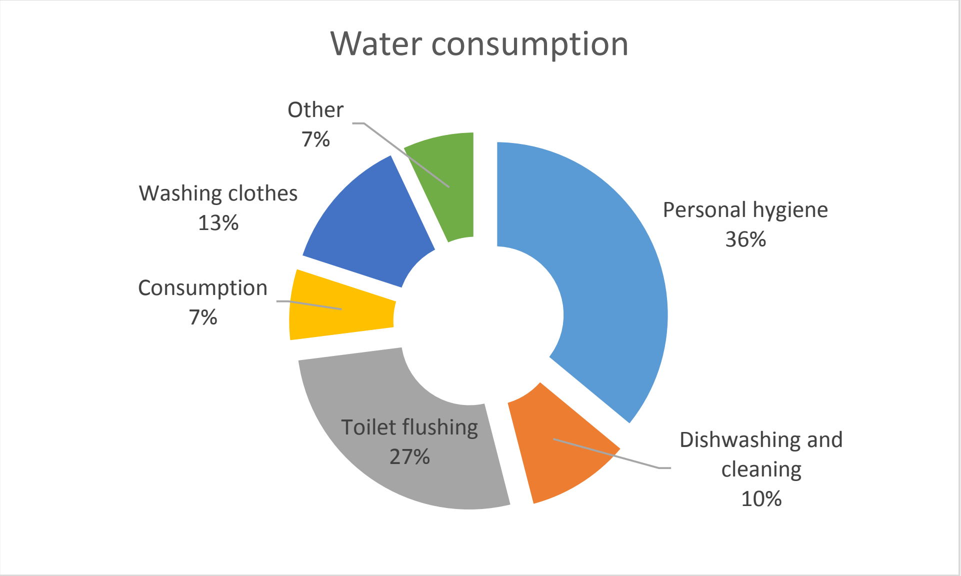

Figure 1-2: *Distribution of hot water in private households. Source:* http://www.energimidt.dk/Privat/El-vand-og-varme/Tips-og-raadgivning/Gode-raad-om-vand/Sider/Gode-raad-om-vand.aspx

Two main sources of utility water, personal hygiene, and dishwashing and cleaning, amount to approximately 46%. As some of this water is cold, the hot utility water is estimated to approximately 40%.

[4] #

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Not all the heat in the hot utility water is wasted. A report from SBI[5] concludes that heat loss from circulation pipes in large buildings counts for approximately 60% of the total heat consumption of hot utility water. Not more than 33% is used for heating of water.

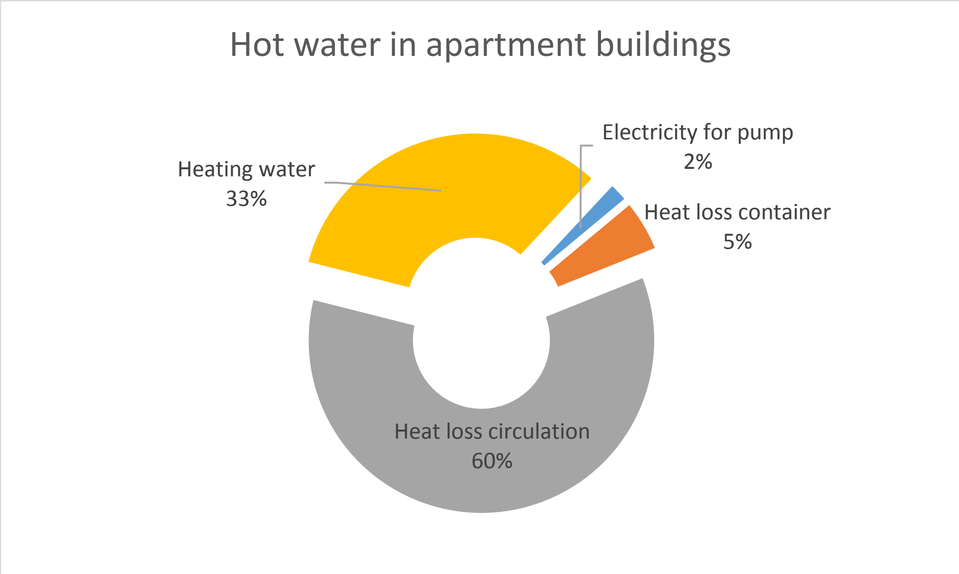

Figure 1-3: Example on the distribution of energy consumption for hot water in apartment houses with a large circulation system.

The daily hot utility water consumption from 10°C to 55°C on approximately 2.4 kWh/day/person. Water heated for cooking, dishwashing and laundry is not included. The hot water is usually sent directly to the wastewater through the drain in the building and the heat is wasted.

1.3 The project presumption

It is the project work presumption, that regaining the energy in the wastewater is a usable technology, when the energy is gained from a heat pump and for instance as pre-heating of the same hot utility water.

If it is possible to separate the bathwater from other wastewater, it is possible to gain a wastewater temperature of approx. 30-33°C close to the source. If it is not possible to split the two wastewater flows (grey and black), temperatures between 10-25˚C is expected[6] but the flow will be higher. The temperature is high close to the source and is influenced by ground temperature outside the building (the winter temperature typically drops to 12-14˚C and the summer temperature rises with a diversity during the day of 3˚C). The temperature is rational according to heat recovery and cooling by use of a heat pump. If the wastewater is mixed with rainwater or melted snow, temperatures are expected to drop.

It is expected that the use of wastewater recovery would make it possible to reach approx. 100% recovery of the amount of energy, which is released through the wastewater. If the wastewater is cooled to e.g. approx. 4-5°C, the potential amount of energy recovered is higher than the energy supplied to the hot domestic water.

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[5] SBI-report 2009:10 "Varmt brugsvand – Måling af forbrug og varmetab fra cirkulationsledninger", http://www.sbi.dk/byggeteknik/installationer/varmt-brugsvand/varmt-brugsvand

[6] "Project Development Guideline", EU-project: "Waste Water Heat", 2006-2007.

2. Heat recovery potential

2.1 Dayly profiles

Volume flow

The estimated volume flow day profiles are based on consumption pattern from found literature. Both idealized drain profiles (tappeprofiler) from e.g. standards and actual measurements from various sources. As far as possible, the use of hot and cold water is distinguished.

Day profiles are found to be able to estimate the energy-related potential in an actual apartment house. Furthermore the day profiles would give an input to the dimensioning of the found components in the project and give an input to the evaluation of the Smart Grid potential.

The result of a measurement series gathered in a report prepared in a EU-founded project in a consortium by partners from Germany, Norway, Sweden and Austria[7] is shown in Figure 2-1. The measurement series is based on measurements from 40 households in Sweden. The figure shows an exact connection between the water consumption and the wastewater disposal.

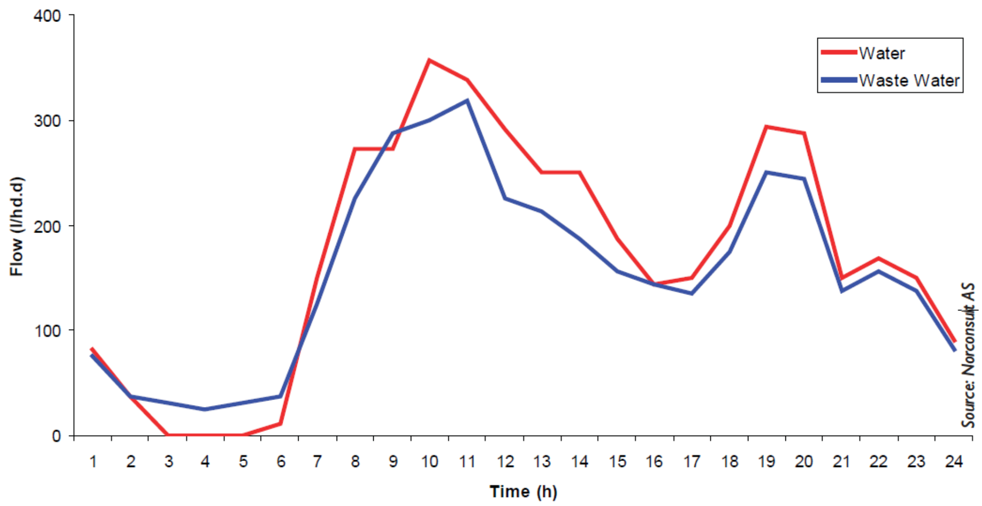

Figure 2-1: Typical daily consumer pattern of water consumption and wastewater release.

The consumption in Sweden is assumed to be a little higher or comparable to the consumption in Denmark, and therefore it is assumed, that there in Denmark is a clear connection between the water consumption and the wastewater.

The season variation for cold and hot water utilization is not included, as the variation is minor. A variation is expected, because of the extent heat emission from the pipes, higher comfort due to hot baths during winter, etc.

The standard EN16147:2011 "*Heat pumps with electrically driven compressors. Testing and requirements for marking of domestic hot water units*" shows drain profiles in the sizes small, medium, large, X-large and XX-large. Large drain profiles corresponds to a daily consumption of approx. 120 litre, which corresponds to the consumption of an average family of 2.7 residents with a daily consumption of hot domestic water of approx. 40-50 litre per

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[7] "Project Development Guideline", EU-projekt: "Waste Water Heat", 2006-2007. Af Norconsult, Grazer ENERGIE Agentur, Berliner Energieagentur, Energikontor Sydost.

person. The drain profile is a result of the European standardization work and shows a representative drain pattern for an average “large” consumption.

Waste water temperature

The temperature of the wastewater have been measured on site. Measurements every ten minutes during the priod 06/10-15 to 19/10-15. The temperature measuremnts span from 15°C to 35°C.

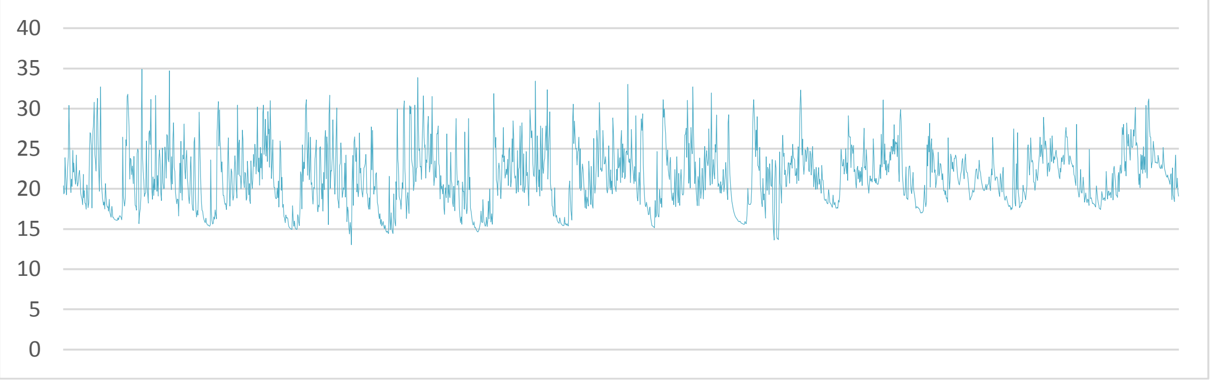

Figure 2-2:

Dayly profiles are present where temperatures drop to around 15°C during the nighttime. When measurements are sorted on each hour of the day the result show a daily profile in Figure 2-3. Average values for each hour span from 17°C to 24°C.

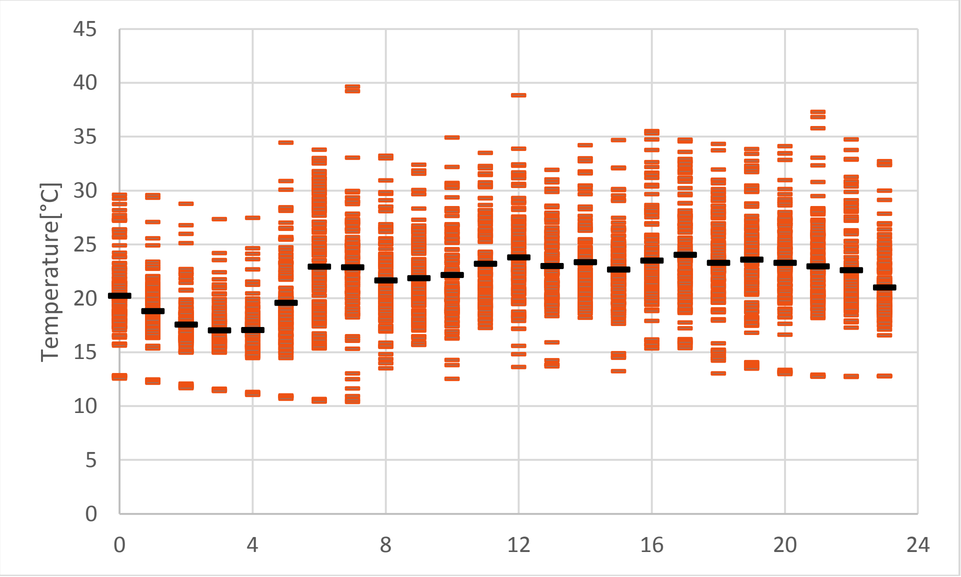

Figure 2-3:

Wastewater energy

In Figure 2-4, results for water consumption in a Swedish investigation from the *Energimyndigheten* for 44 apartments[8] is shown.

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[8] "Mätning av kall- och varmvattenanvändning i 44 hushåll", Delrapport i Energimyndighetens projekt "Förbättrad energistatistik i bebyggelsen och industrin", ER2009:26

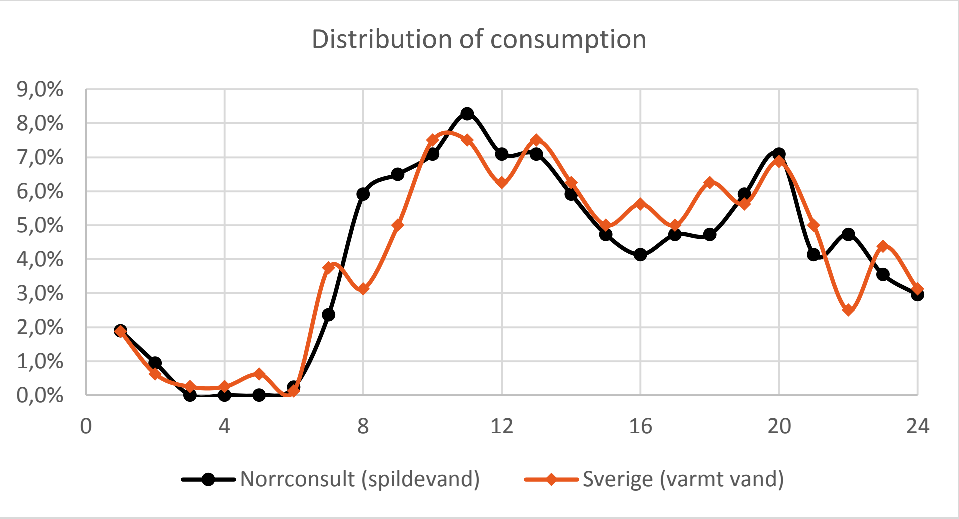

Figure 2-4: *Distribution of wastewater (black) and hot water consumption (orange).*

Measurements from the case specific location show a similar pattern when combined with expected wastewater massflow:

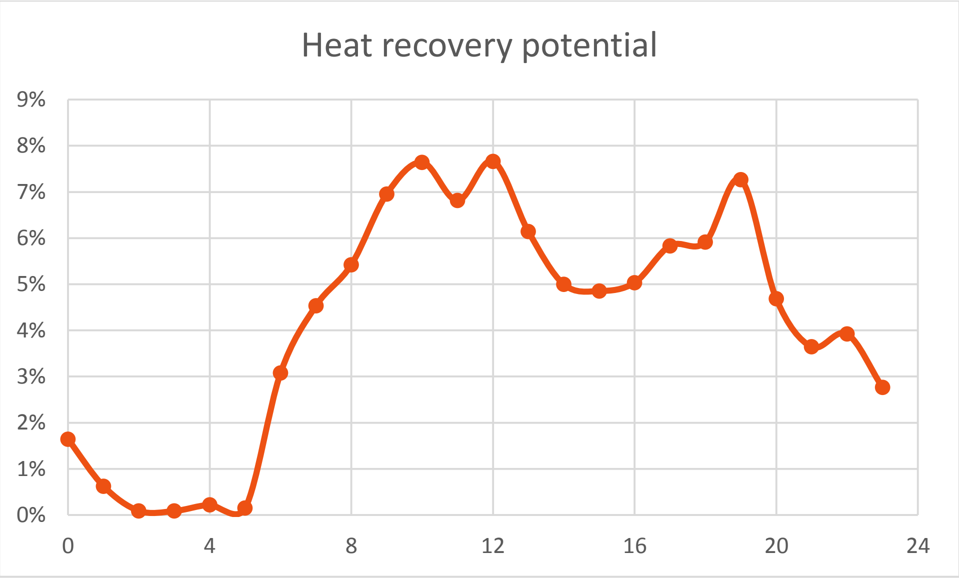

Figure 2-5: *Estimated day heat recovery potential profile.*

2.2 Energy potential

The average heat recovery potential for one household is estimated based on measured wastewater flow and temperature.

Parameter	Unit	Växjö case
Water consumption	Litre/person/day	140
Population	Person/houshold	3.1
Water consumption	Litre/day	434
Average wastewater temperature	°C	22.8
Heat recovery potential	kWh/day	9.8

3. Technologies to wastewater recovery

A literature study has been made aiming at qualifying state-of-the-art within utilization of wastewater heat to reheating hot water and/or room heating.

As written in the following, more activities has been started on European level. In the article "Sewage water: interesting heat source for heat pumps and chillers[9]" (Schmid, 2008) it is described that there are more than 500 plant within the tree areas shown in the figure below.

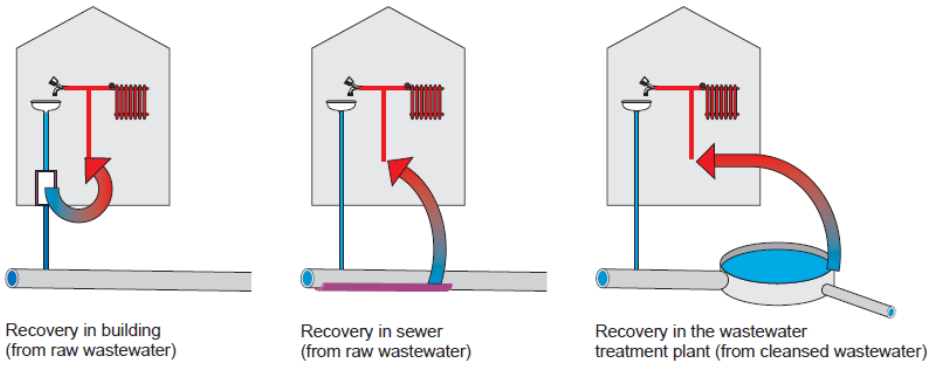

Figure 3-1: Three different methods of utilizing heat from wastewater. Figure from the article "Sewage water: interesting heat source for heat pumps and chillers" (Schmid, 2008)

As shown in Figure 3-1, it is possible to utilize the heat in three fundamentally different ways:

- Recovery directly in the building
- Recovery from common drain
- Recovery after wastewater treatment plant

In the report, the focus is on recovery from common drain.

[9] http://www.bfe.admin.ch/php/modules/publikationen/stream.php?extlang=en&name=en_508290240.pdf

3.1 Decentral heat recovery seen in an overall perspective

The capacity, which is available by the wastewater treatment plant, for most of the year allows that the supply-pipe temperature is lowered. However, a large implementation of the system will require further investigations of the influence of the supply-pipe temperature for the wastewater treatment plant. It is not certain, if the cooling effect of the wastewater from the apartment blocks will increase the sediment from e.g. grease in the drain with following inconvenience. Furthermore, this will take further investigations to implement the system.

Temperature influence on sewage treatment

Substance turnover in the biological processes, involved in the sewage treatment is critical according to the temperature of the wastewater. This is seen on the wastewater treatment plant. Here the return temperature is typically approx. 13-14°C, but varies according to the time of the year to between 19-24°C in the summer. The lowest temperature typically occurs in the winter when snow and ice is melting and involves large amounts of meltwater. Here the temperature is 8-9°C, but this only occurs two days a year. Temperatures for Lynetten, which are below 9-10°C, is a challenge, as the retention time of the wastewater is prolonged because of the reduced speed in the biological processes – the maximal capacity is reached and the plant size is just large enough for the full purification process. In extreme cases, when the temperature is lower and there is a lot of meltwater, the capacity is not enough and the part of the wastewater will be drained through the system untreated.

Heat recovery centrally in the drain system or directly before intake in the wastewater treatment plant, for the wastewater treatment plant would be counterproductive in the winter half-year and at the limit would demand a capacity increase on the wastewater treatment plant. The consequences for heat recovery of wastewater has not yet been analysed for the wastewater treatment plant, but would anyhow depend on the size and topology of the drain system in the service area for a given wastewater treatment plant. Thus, the considerations below are speculative and should be investigated in future. For a wastewater treatment plant with a service area with fewer clients and less density per area (e.g. single-family house area vs. departments), it is expected that there will be a lower average supply temperature. That way the middle temperature of the wastewater intake to the wastewater treatment plant may be 12°C in contrast to 13-14°C in the winter for major cities like Aarhus. Assumed that the average wastewater temperature is between 28-30°C in the household, there will be a considerable heat loss in the pipe system regardless of the character of the surrounding area.

If the wastewater temperature by the source is lowered, the heat loss to the surroundings is also reduced e.g. from the soil, from which heat is radiated upwards. The first assumption is, that there is a lower temperature T_n, which the wastewater temperature by the household can be lowered to, without considerable effect of the supply temperature by the wastewater treatment plant and the biological processes. T_n is firstly a function of, how big a share from the given household drain network, that implement decentral heat recovery, next from the topology of the drain and the soil conditions. This way, calculation of T_n is not a prime issue of this task an clearly go beyond this study.

However, measurements show that the wastewater temperature is affected of the soil temperature and converge against it according to the pipe length, which the wastewater has to pass. This would also mean, that the wastewater can be subcooled decentral in the summer half-year and can still have the wanted inlet temperature by the wastewater treatment plant. By sub cooling of the wastewater the drainpipe to the wastewater treatment plant would work as a heat absorber and the temperature by the wastewater treatment plant would be close to soil temperature even if all wastewater would be subcooled decentral, e.g. 5°C.

Grease separation

Grease is a real problem, which has to be considered, as it is deposited in the drain. Grease separators are installed in places, where the grease content is above the normal level (canteens, restaurants etc.). DS432 "Norms for drain systems" indicates limits for the allowed content of grease and other things in the wastewater. In general, apartments are excluded, but theoretically can be forced to install a grease separator, if the norm for drain installations is not respected. The grease separator is (as basis) installed outdoor and must according to EU legislation be emptied each month. In practice, this is not always the case. It is important, that the grease separator is emptied regularly, as odour problems may arise.

Wastewater from households is to be considered as a heterogenic mix of fluid and dry substance. The liquid phase is primarily watery, but due to fraction, coming from kitchen draining, there will also be a more water-soluble grease/oil fraction. To which extend the grease phase is dissolved depends on the amount of soap in the water and the temperature of the water phase. In general, separation of both grease and saponified grease would increase with decreasing temperatures, and certain grease fractions would change to massive form.

Grease separation on the heat exchanged surfaces will cause reduced heat transmission in the changer described by coefficient:

$$R_f = \frac{d_f}{k_f}$$

Of which d_f is the approximate depth of the grease layer, separated on the changer surface and k_f is the specific thermal conductivity for the grease phase. R_f can be considered a thermal resistance, which has been introduced on the heat exchanger surface, which is increased with the layer depth of grease and decreasing thermal conductivity. Oils typically has a k_f the size of 0.1 – 0.2 W/mK, while stainless steel typically has a k_f the size of 16 -24 W/mK.

In line with the cooling of the water phase in the exchanger system, the grease separation will increase and the heat exchanger effectivity decrease. For a heterogenic system as wastewater, it is assumed, that the problem will increase, as the grease is expected to absorb the suspended dry matter in the liquid phase, when the grease is precipitated on the heat exchanger surfaces. Hereby, a firm matrix on the exchanger surface is build up. It consists of solid material combined with grease, which increases the layer depth radically and hereby R_f. If the heat exchanger surfaces are structured with turbulators to break the laminar fluid flow, then the grease separation will to a certain extend "reduce" this structure and this way reduce the turbulent flow. The heat transfer related laminar flow causes a further decrease in efficiency. But anyhow it is not recommended to use turbulators but rather to "oversize" the heat transmission area of the heat exchanger.

The above description illustrates, that it can be necessary with a mechanical grease separation in decentral heat recovery systems, which rise the question of, which consequences the grease separation would have for the drain system and the wastewater treatment plant. It is possible to separate and removed it with the household refuse, which in practice is cost-intensive. Alternatively, systems are designed, in which the grease is discharged into the drain through a self-cleaning mechanism e.g. surface scimming by raising water level to the outlet and enable the surface of floatation grease to leave the manhole.

Table 1: Approximate melting point for distinctive oils, which are available in housholds. The melting point for animal grease shows large variation, but is generally above room temperature and below 180 ℃. The values are a representative average found on various gastronomical homepages.

Fat / Oil type	Melting point (˚C)
Butter / Margarine	32-36
Oliveoil	-6
Animal fat	40-180
Sunfloweroil	-17
Palmoil	35
Kconutoil	25
Peanutoil	3

4. System design

In the following different ways of system configuration are described.

4.1 Functions

There are a number of functions, which should be installed in a system for the wastewater recovery. They are important for the systems to be prepared:

› Smart-Grid possibility (buffering in heat storage)

› Only hot water or room heating or a combination

› “Simple” or “advanced” system (direct heat recovery connected to a heat pump)

› Connection to other renewable energy technologies as e.g. solar heating / PVT

› Separation of wastewater (is it possible in the building)

The basis is three different system constructions, which are included in this report

1 **The simple system** is build up around direct heat recovery pre-heating the domestic water with the wastewater. In the most simple version through pre-heating of domestic water a heat recovery is installed on the piping – vertical or horizontal. This system can be extended by recovery, of which the heat recovery takes place in a well and the pre-heating takes place in a hot-water tank.

2 **The complicated system** using a heat pump to rise the temperature of the hot domestic water. Here it is necessary with a well and a hot-water tank.

3 The most **advanced solution** using a heat pump to boost the temperature, but apart from producing hot domestic water it also produces room heating.

Limitations by renovation

There are two specific requirements to be considered in any project, in which there is a need for installation of wastewater recovery:

- Available space
- Minimal interference with existing installations

System with directly heat recovery

The obvious advantage by this solution is the simple access and the related savings compared to purchase of a heat pump. One of the main disadvantages is the legionella problem. Drinking water should not be standing or circulating in a heat exchanger; but at a maximum temperature of 25°C the risk is minor. Furthermore, the system can be designed without circulation. Drinking water should not be used as a refrigerant unless a sufficient and continuous flow is ensured. Furthermore, there is risk of cross contamination from wastewater to drinking water, when the pressure in the drinking water is relieved during maintenence. Leakage can cause large water loss. Finally, the efficiency is lower by this kind of heat exchange.

System with heat pump for heating of hot domestic water

The advantages by using a heat pump is the safety barrier, which the refrigerant circuit provide. Furthermore, the degree of utilization considerably higher for a heat pump as the heat can be used at a sufficiently high temperature level. Over time, the heat pump solution also has the possibility to "run backwards" and heat the wastewater during a “cleaning sequence”.

In Figure 4-1, a possible principle diagram for recovery of wastewater is shown. It is based on a system using a heat pump.

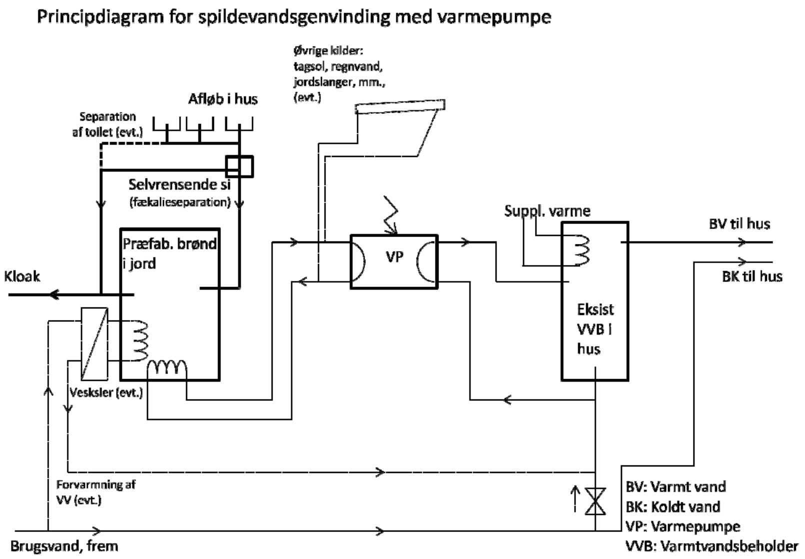

Figure 4-1: Example on principle diagram for solution to recover wastewater

4.2 Design of components

In this part the basic design will be described. Basically, there are some main components in the system, which should be designed separately:

- Prefabricated well with built-in heat exchanger (one for direct exchange in top of the well and one in the bottom for the heat pump)
- Macerator pump (e.g. SEG 40 from Grundfos, Zenit GR Blue or a Staring DSK 10 for small installation)
- Heat pump optimized for the utilization of the existing temperatures and needs
- Hot-water tank preheated by the heat pump and further heating (not shown)
- Additionally piping, valves and e.g. heat exchangers are required

In the project it must be assured, that the elements are optimized and fit each other. This means, that the well is dimensioned to the actual wastewater flow and that the size of the heat pump and hot-water tank is fitted in.

Prefabricated well

The purpose of the prefabricated well / heat exchanger is to catch the wastewater for recovery both directly for preheating of hot domestic water and through a heat pump. It is centrally, that the well must be build up in a way, that it has the same good qualities as a standard well from e.g. Grundfos without heat recovery. This is not only in relation to an uncomplicated installation, but also in relation to self-purification. The well is prepared with overflow to the existing drains, which are used in case of pump stop.

For preheating of domestic water it might be necessary with a secondary circuit to assure that fresh domestic water is not circulated through the well and "ends up to close" to the wastewater.

The dimensioning of the wastewater well is decided on basis of a volume with a minimum of a 10 minutes interval between the pump starts, and that there is room for the components. Furthermore, the pump and the exchanger must be removable from the well for service / replacement.

Heat exchanger

The heat exchanger in the wastewater well might have to be over-dimensioned, as it will quickly have a layer of biological residue (biofilm) from the wastewater. Alternatively, an effectively self-purification must be established. More designs have be considered. Some of the designs are mentioned below:

- Plastic hoses
- Metal exchangers
- Well walls or spiral

The material selection of the heat exchanger surfaces is a compromise between chemical constancy, heat conductivity, fabrication suitability and price. We estimate that plastic surfaces have a low heat transmission coefficient and the needed area is disproportionate large and does not allow a compact design as required. The only applicable metal for wastewater would be Stainless steel in a 304 quality. It secures sufficient chemical resistance over time, but forms a compromise in relation to heat transmission quality, where e.g. copper has a heat conductivity on between 300-400 W/mK unlike 15-25 W/mK for stainless steel.

To counter that the effective heat transmission quality of the heat exchanger surfaces is not dropping to 0.1 W/mK because of plaque (100 W/m^2K by 1 mm fouling), a number of different purifying strategies for removal of delivered grease was investigated.. Basically, different mechanical purification methods, which are typically used in the food process industry be adapted for the purpose. Unlike industrial processes, where the media is well defined, the problem is that the wastewater is an unknown phase, where paper, fibres and textile remains could block almost any mechanical mechanism.

Grease purification of the exchanger surfaces could be made through non-mechanical processes, including a special combination of hosing with water and chemical/physical modified surfaces.

Macerator pumps versus standard pumps

It is preferred that as few changes as possible are being made to the building, by installing the technology. This way it will often not be possible to make a separation of the toilet wastewater. It is therefore necessary to take into account the solid matter in the wastewater, which should be handled, and avoid that it over time will not damage the heat transfer between wastewater and secondary water in the well. This a macerator pump in the bottom of the well will pulverize and it could be removed from the bottom of the well. At the same time the macerator pump secures that the well could be self-purifying or only require minimal maintenance. The pump is placed a little elevated to be kept free from solid matter (e.g. sand), which could layer on the bottom of the well

Heat pumps and hot-water tanks

It is expected that the standard components can be used, maybe with a little modification. The heat pump has its own external domestic water exchanger/tank.

For the hot water tank it might be necessary to have two supply sources, both from the ordinary preheating source and from the heat pump. This is a system which is well-known from solar collectors. For existing tanks the hot water from the heat pump could be supplied together with the circulation pipe.

4.3 Smart Grid

One essential element is the control of the system. The storage time of the wastewater in the well will allow the technology to produce a Smart-Grid effect. As a result, it will be possible to use the well as an external heat storage, where the heat pump is only used during periods when it is possible to purchase environmentally friendly electricity at a low price. In that case, it may be relevant to use an insulated well. However, the disadvantage is that the heat exchanger and heat pump have to be a lot larger compared to a scenario where the heat pump operates continuously. As a result, the system becomes more expensive and currently there is economic incentive for choosing a Smart Grid control solution.

The system should be as standardised as possible to minimise the investment. Therefore, it is envisaged that the system should be constructed in pre-defined, standardised sizes. The size of the system would depend on the dimensions of the existing wastewater well, the size of the housing block, required Smart-Grid flexibility, and other matters. The possibility of utilising the flexibility which the storage of waste water in the wastewater well offers is obvious, however. The graphs of water consumption indicates that after morning showers, etc. there will be a lot of heat available in the waste water, but that some of this heat can be stored until the increased evening consumption. The time when heat is produced from the high discharge amount in the morning can be determined by the electricity price, which varies during the day. Similarly, the increased production of wastewater in the evening can be stored and the heat can be recovered from it during the night when the electricity price is low.

If heat is to be produced independently of when it is consumed, a number of system add-ons to the energy system may be required. On the side of the domestic water, a hot water tank of a suitable size may be necessary. If the wastewater service area covers more houses, the house utilising the heat can also have part of the room heat demand covered, the control thereof can be made Smart-Grid ready. På space heating side a thermal storage can be used (however, a buffer tank has to be very large before it can hold heat demands over a relatively long time). Another possibility is to accept that the room temperature can vary within a certain comfort range. This could be for instance 22ºC+/-2ºC. That will make it possible to accumulate heat passively in the building when the electricity price is low and accept a minor temperature fall when the electricity price is high. However, accumulating strategies must be coordinated with heat in the waste water being available and varying electricity prices.

Integration of Smart Grid does not cause a drop in the consumption of electricity, but rather leads to an increase in consumption because the heat pumps will operate in forced operation at certain times under non-optimum operating conditions. In isolation, there will be an increase in the consumption of electricity for the individual installation. However, the price for electricity will reflect the current consumption of electricity compared with the electricity production. If the electricity is consumed when the electricity price in the future is low, electricity, which would otherwise be sold to other countries or be lost, will be consumed and from a societal point of view the consumption of electricity and production of electricity can be balanced.

4.4 Calculation model

The project has focussed on the development of a simple calculation mode for determination of heat exchanger, buffer tank and economy. The model calculates the effect utilised and the temperature at which the wastewater is cooled down. The model is still at its preliminary stage for in-house use at the end of this project phase.

Focus is exclusively on systems where wastewater is collected in wells.

The model is merely a simple calculation in a spreadsheet, which cannot be used without knowledge of the spreadsheet structure. In this section, the calculation model is explained and the application of the model is illustrated using examples based on the calculation of three cases.

Consumer pattern

An important parameter in the system is the selection of a well compared to the supply of wastewater from consumers. In this respect, it is the consumption pattern which is decisive. Profiles for the daily distribution of supply are applied. This goes for the amount as well as the temperature. In the case calculations, the following data are used**Fejl! Henvisningskilde ikke fundet.**.

Table 2: Based on measured data

Time	Supply	Supply in %	Temperature
Unit	l/h per residential unit	-	°C
00-01	8,2	2%	20,2
01-02	3,4	1%	18,8
02-03	0,5	0%	17,5
03-04	0,5	0%	17,0

04-05	1,4	0%	17,0
05-06	0,8	0%	19,6
06-07	13,3	3%	22,9
07-08	19,6	5%	22,9
08-09	24,9	6%	21,7
09-10	31,6	7%	21,9
10-11	34,2	8%	22,2
11-12	28,9	7%	23,2
12-13	31,6	7%	23,8
13-14	26,4	6%	23,0
14-15	21,1	5%	23,3
15-16	21,2	5%	22,7
16-17	21,1	5%	23,5
17-18	23,8	5%	24,0
18-19	25,0	6%	23,3
19-20	30,3	7%	23,6
20-21	19,8	5%	23,3
21-22	15,7	4%	22,9
22-23	17,2	4%	22,6
23-24	13,2	3%	21,0

Energy balance for well

The model is based on an hourly day and night profile with quasi-stationary conditions in each hour.

The model is developed as specified below, where index i is the time interval.

$$E_i = E_{in,i} + E_{out,i} + E_{vv,i} + E_{i-1}$$

E_{in} is the energy content in the water discharged to the well with waste water

$$E_{in} = \dot{V}_{in} \cdot \rho \cdot c_p \cdot (T_{in} - T_{well})$$

E_{out} is the energy content in the water removed from the well with waste water

$$E_{out} = \dot{V}_{out} \cdot \rho \cdot c_p \cdot (T_{out} - T_{well})$$

E_{vv} is the effect extracted via heat exchange with potable water or via heat pump.

In the first equation, E_i is calculated for one hour. For the following hour, the excess/missing energy from the last hour will be "carried forward" in the calculation.

For input data, the supply of wastewater is used as determined via measurements in Skovgårdsparken or via the consumption pattern described in the previous section.

It is worth noting that the well can be emptied either on a continuous basis – i.e. $V_{out} > 0$ for all hours or it can be emptied instantaneously. It is assumed that the latter will always take place between two timesteps in the calculation and that the pump will only partly empty the reservoir in the manhole. Based on this $E_{i-1} = 0$.

In the practical calculations, a value of E_{vv} is specified to ensure that the temperature in the well is not too cold.

4.5 Calculations

Cases

The following scenarios are calculated:

- 10 apartments with full heating of domestic water
- Apartment building with 30 apartments and full heating of domestic water
- Community with 100 apartments (with pre-heating of domestic water and afterheat from district heating).

Combination of directly working systems and heat pump

Heat recovery has been calculated based on two cases where 10 apartments on the same staircase and a apartment building with 30 apartments supply a 5-metre deep well with a diameter of 0,5 metre. The well is fitted with a 4,5-metre long cape, where heat is exchanges between the cooling circuit in the heat pump and the wastewater. The calculation assumes that the heat transfer is 100 W/m²K and that the inlet temperature of the cooling circuit is 3°C.

5. Results

The important parameters are the heat exchanger's total surface area and heat pump output.

	Apartments	Apartment building	Community
Apartments	10	30	100
Wastewater well	982 liter	982 liter	8.906 liter
Heat exchanger surface	7,1 m²	7,1 m²	24,1 m²
Technology	Heat pump	Heat pump	Heat pump in combination with direct heat excahnger
Heat recovery [%]:			
Heat pump size	Apartments	Apartment building	Community
1 kW	26 %	9 %	10 %
2 kW	49 %	17 %	13 %

5 kW	88 %	36 %	20 %
10 kW	92 %	63 %	33 %
15 kW	92 %	66 %	41 %
50 kW	92 %	67 %	68 %
Heat recovery [kWh/døgn]:			
Heat pump size	Apartments	Apartment building	Community
1 kW	16 kWh	16 kWh	61 kWh
2 kW	30 kWh	32 kWh	77 kWh
5 kW	54 kWh	67 kWh	125 kWh
10 kW	56 kWh	117 kWh	202 kWh
15 kW	56 kWh	123 kWh	250 kWh
50 kW	56 kWh	123 kWh	415 kWh
Hoighest heat pump power	**8,8 kW**	**12,6 kW**	**46,7 kW**

It is essential that the heat exchanger surface area is large enough relative to the amount of wastewater, otherwise, the heat pump can not utilize its full capacity.

6. Polysun simulations for the integration of PVT

This chapter deals with utilization of PVT modules for preparation of domestic hot water and the combination of this with utilization of wastewater heat recovery.

PVT modules are combined solar PV solar thermal panels. PVT modules could be located on the roof of a multiappartment building that contains the installations for preparation of domestic hot water in the basement.

The PVT modules suggested is without an insulation cover on the front and delivers heat at a relatatively low temperature, of maximum 40°C. The cooling of the modules meas that the output of electricity will slightly increase as the output depends on the temperature of the panels.

The principle for operation is shown in Figure 6-1. Preheating of domestic hot tap water takes place in a solar tank that is heated by the PVT panels. Further heating of the domestic hot water is done with a heat pump that takes heat from a heat pump tank that is also heated by the PVT panels. The heat pump uses electricity from the PVT panels. The heat pump tank can in this way be cooled to a very low temperature, perhaps donw to a few degree, which will give a higher thermal output of PVT panels and a further increase in electric output. With low solar insolation, the PVT modules will only deliver heat to the heat pump tank, with higher solar insolation also to the solar tank.

In perids with low solar insolation, the temperature in the heat pump tank will reach the minimum temperature, which may be 5°C. In this situation, the domestic hot water will be heated by district heating in the DWH tank. The other system, that will also be demonstrated, is to use heat from the wastewater heat recovery as a supplementary heat source for the heat pump.

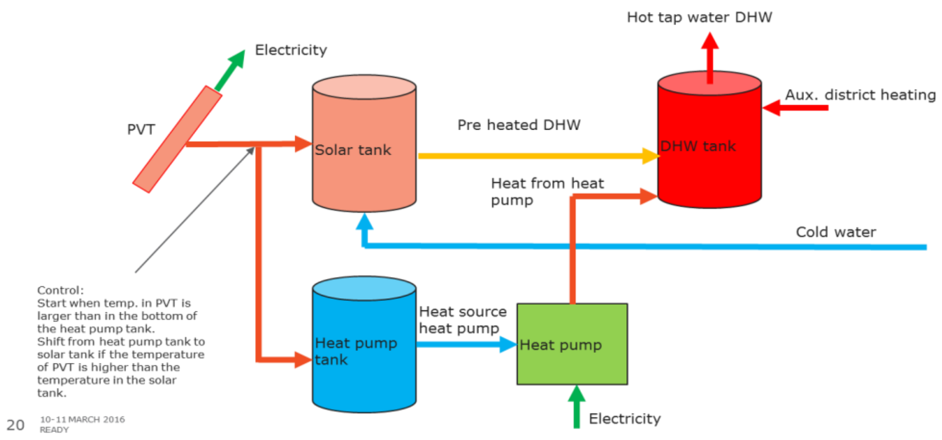

Figure 6-1 Principle diagram for utilization of PVT for preheating of domestic hot water and as as source for domestic hot water heat pump. Wastewater heat recovery will be used as supplementary heat source for the heat pump in block 12.

Based on preliminary analysis it is expected that the thermal output from the PVT panels will be as big as 300 kWh/m² if the PVT area is reduced to half of what is planned for a block of 36 flats i.e. 110 m² PVT see the table below. The output is very dependent on the sizing of components and the control of the system and will be further analysed as part of deliverable 4.1. of the Ready project.

In the actual demonstrations to follow we expect to have approximately 220 m² per block which is oversized thermally as we in this case give priority to power production from the PVT panels. Figure 6-2 show an analysis with Polysun showing the thermal output of the PVT panels as function of the area of PVT and Figure 6-3 an example of temperature fluctuations in the storage tanks for a system with 220 m² of PVT.

The pay-back period of the system is estimed to be in the range of 5-15 years depending on the preconditions at the actual site.

PVT modules for heat pump. Performance as a function of the PVT area. Valid for one block.						
PVT area		m²	220	110	55	27
Solar thermal energy to the system		kWh	34.842	33.767	32.348	29.113
Electricity production		kWh	29.863	16.208	8.061	3.785
Thermal production per m² PVT		kWh/m²	158	307	588	1.078
Electricity production per m² PVT		kWh/m²	136	147	147	140
Balance						
Demand for hot tap water		kWh	47.700	47.700	47.700	47.700
Circulation loss		kWh	6.000	6.000	6.000	6.000
Heat from heat pump			36.100	36.600	37.700	37.100
District heating			11.000	12.500	13.200	15.900
COP			4,1	4,0	4,0	3,9

Figure 6-2 Example of results of analysis of the system described in Figure 6-1.

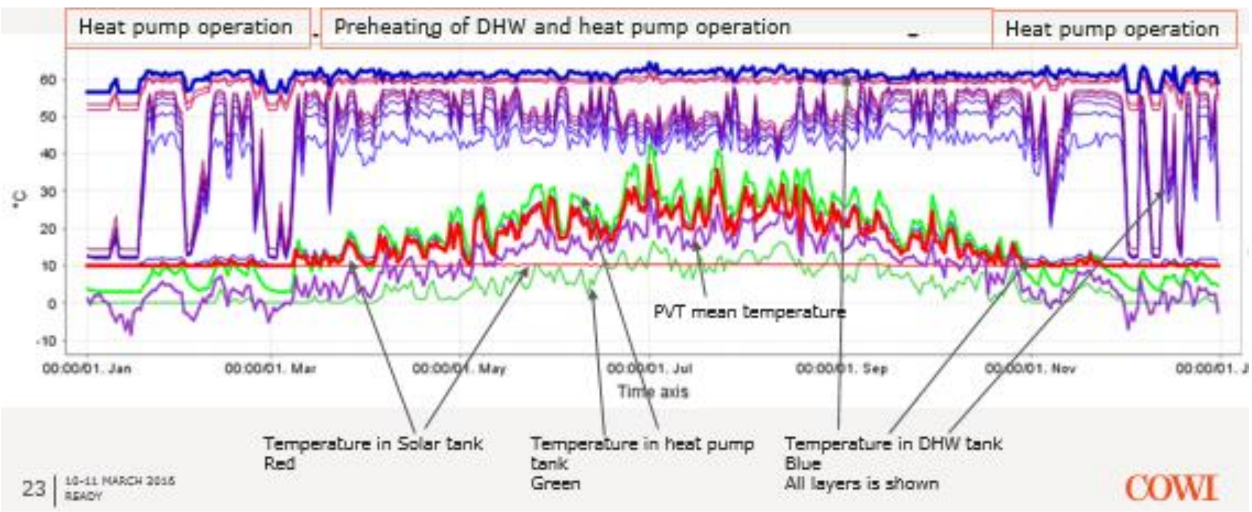

Figure 6-3 Example of temperatures in storage tanks with 220 m² PVT for one block.