Integration of energy networks and the water cycle with surface water energy as connecting element

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Abstract

1 Introduction

The surface water energy concept (SWE concept) is defined as the concept of energy generation form surface water by means of heat exchange between surface water and a building service system with a heat pump. There are some typical advantages in utilizing surface water energy: the overall efficiency of the heating/cooling system can be optimized and the water quality can be improved [1]. The focus in this research is on local networks with SWE.

2 Methodology

In this research a test has been performed by defining and analyzing one test case, demonstrating the added value of the integration of energy networks and the water cycle with SWE as connecting element.

3 Research results

The added value can be found in the following performance indicators:

- Energy saving;
- CO_2 emission reduction;
- Application of renewable energy sources;
- System optimization;
- Sustainability of the urban environment.

4 Societal importance for stakeholders

This research showed that SWE can effectively contribute to objectives on energy saving and CO_2 emission next to objectives on sustainability of the urban environment. The integrated networks can incorporate additional energy sources from the environment next to energy from the water cycle. System optimization is essential for integrated systems in general. In this specific case there is an additional need for system optimization because of the low exergy value of the energy from the water cycle that is used.

Keywords: Innovation and R&D; Smart grids/energy

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1. Introduction

The surface water energy concept (SWE concept) is defined as the concept of energy generation form surface water by means of heat exchange between surface water and a building service system with a heat pump. There are some typical advantages in utilizing surface water energy: the overall efficiency of the heating/cooling system can be optimized and the water quality can be improved [1].
According to Hakvoort [2] future energy systems will consist of large scale network infrastructures in combination with local sub-systems. This combination can lead to a higher overall efficiency in comparison with current large scale (centralized) infrastructures. For electricity supply this is an obvious development. Whether other energy forms like heating and cooling will be integrated in these energy networks is still unclear. This depends on the innovations that have to take place and the willingness of actors on the market to deal with this and to generate the additional benefits of the integration of sub-systems. In the Netherlands water boards are responsible for water management; they are important actors in this perspective. One of the key aspects in this perspective is the “water cycle”. According to Fokké et al. [3] we should see the water cycle as the anthropogenic part of the water system and in this way, it must contribute to the quality of life of people living, working and spending their leisure time in the built environment. The Water boards will always assess new developments by looking to the impact on their “water cycle”. Van der Hoek [4] looks at the water cycle from the perspective of a water company responsible for the closed cycle of production and distribution of drinking water and collection and treatments of waste water. Van der Hoek [4] defines energy from the water cycle as thermal energy from surface water, waste water, ground water and drinking water, and chemical energy from waste water.

The development of combined large scale network infrastructures and local sub-systems will lead to changing roles of the actors in the energy market [2]. Consumers can take part in the supply, new services are needed and advanced control systems have to be developed in order to align the complex demand and supply patterns.
The focus in this research is on local energy networks with SWE in the Netherlands. In deploying energy from the water cycle two domains coincide:

1. The world of energy and associated infrastructure;
2. The world of surface water and spatial planning.

This results in the formulation of two propositions:

1. The integration of energy networks and the water cycle can provide substantial added value;
2. The SWE concept can function as a connecting element in the integration of energy networks and the water cycle.

The integration of energy networks and the water cycle is not without conditions, due to the complexity of this integrated system, there are many conditions to be met. This leads to the following research objective:
The research objective is to determine the added value of the integration of energy networks and the water cycle with SWE as connecting element, and the associated conditions that have to be met.

This objective will be pursued by a study into the possibilities of SWE in relation to other systems. The outcome is an assessment of a SWE system by means of a test case. This research focuses on the regulatory context of the Netherlands.

2 Research Framework

Koppenjan and Groenewegen [5] focus on institutional design for complex technological systems. In their research, they distinguish between technological design, institutional design and process design. They argue that process design assumes that designs are created in interactive processes between stakeholders instead of through an intellectual process by a designer. Their process design is focused on improving the interactive process between stakeholders: “designing the design process”. Their research framework was used to specify the added value and conditions to be met. The added value of the integration of energy networks and the water cycle is established by means of literature study and a model based on energy and mass balances, followed by an assessment of a SWE system by means of a test case. In this way, this study contributes to “designing the design process” of the integration of energy networks and the water cycle with SWE as connecting element.

3 Goals and Constraints

Climate change mitigation, renewable energy generation, energy saving and improving the efficiency of energy generation appear to be closely interconnected. There are some typical goals and constraints in each category but overall, we must focus on the combined performance of energy saving measures and generation of renewable energy.

The energy demand of new buildings in the Netherlands is laid down in the energy performance standard EPG. According to the EPG standard, new buildings have to be energy neutral by 2020. The Dutch government decided to define “energy neutral” instead of “zero-energy” allowing for generation of renewable energy from sources in the environment.

Cities have to become more resilient to tackle the many challenges associated with nowadays developments in the urban environment. The challenge is to find an overview of the possibilities with associated assessment of these measures to ensure that the various measures are not counterproductive. The multi-layer approach has proven to be effective [6]. The multi-layer approach distinguishes between underground layer, network layer and occupation layer. The distinctive goals and constraints in these layers are:

Underground layer
Prevention of soil degradation by limiting the unbalance of ground energy storage systems within a bandwidth of 10-15%.
Network layer
Prevention of loss of energy due to interference between systems and regulatory constraints laid down in the Heat law, for example the mandatory permit for systems lager then 10.000 GJ.
Occupation layer
Water

- The water quality must be guaranteed and the temperature changes must be within constraints specified by the CIW assessment methodology [7];
- Increasing the discharge capacity and absorption capacity of water in cities;
- Increasing the retention capacity of regional water systems;
- Improvement of the water quality.

Spatial planning

- Avoiding heat island effect in cities;
- Construction of recreational areas;
- Climate-resistant design of buildings and infrastructure;
- Improving wildlife migration connections.

4 Design Space and design variables

According to Bots and van Daalen [8], we must distinguish between the

- physical process;
- decision making process.

The combination of these two processes features the actual development of the system.

Stremke and Koh [9] identify and discuss five ecological concepts with relevance to energy-conscious spatial planning and design, two off which are relevant to this study:

1. system size;
2. sources and sinks,

ad 1: System size has to do with the spatial extend of the geographical location in which the necessary resources can be found. The question is, where we can identify elements in the geographical location that support the availability of local resources? In this perspective, we will focus on:

- The water structure and the possible connections that can be made to neighbouring water structures;
- The green structure and its contribution to the sustainability of the geographical location;
- Surface water as solar heat collector and storage, as winter cold collector and storage.

ad 2: Sources and sinks are the system components determining the direction of energy flow and associated efficiency. In terms of geographical location, one can distinguish between source areas and sink areas. This corresponds with the concept of system size and associated energy availability. The availability of energy in ecosystems is determined by the seasons. A typical ecosystem solution to cope with shortages, is storage of energy. The question is, where we can identify elements in the geographical location that could function as sources and sinks and associated storage capacity? In this perspective, we will focus on:

- surface water as source, sink and storage capacity;
- other elements in the area acting as source, sink and storage capacity.

The elements in the area acting as source, sink and storage capacity can be characterized by many variables. One of the most influential variables in this perspective is the temperature level of sources and sinks.
The efficiency of heating and cooling systems are determined by the temperature levels of the various components in the system. In general, it is good practice to match various system components according to their optimal temperature levels. In the SWE concept energy is generated from surface water with a temperature between 10 and 20 ˚C. This temperature level is quite close to the required temperature of the heated space in winter time. The heat pump raises the temperature level to the required temperature in the building service system.

In most existing collective heating systems, the heat is generated in centralized heat generators and distributed at high temperature to the distributed heat demand. In case of heating by means of heat pumps this is possible as well. However, in this case there is another option for energy distribution. Instead of distributing the energy at high temperature directly to the energy demand, the energy is distributed at low temperature to the heat pumps. There are some typical benefits associated to this alternative:

- A low temperature distribution system is relatively simple, depending on the temperature the system can do without insulation. In any collective system, an upfront investment in the network is required. This must then be passed on to the individual end users. Particularly in case of phased construction of a residential area, this is a problem. In the starting phase of the area, the upfront investment in the collective system can only be passed on to a limited number of end users.
- A low temperature energy network features distributed generation from additional renewable energy sources from the water cycle and from the environment next to SWE;
- Only the energy input to the heat pumps must be distributed. This corresponds with 77% of the amount of distributed energy in centralized heat generation network systems (for a Coefficient of Performance COP=4,3);
- The supply temperature in the distribution system matches with the cooling demand in domestic applications. Because of this the cooling can be realized by means of heat exchange in the distribution system itself.

The decision-making process is determined by agreements about definitions and system boundaries regarding energy sources and the energy systems. We can distinguish between:

1. Standards and regulations regarding renewable energy sources;
2. Standards and regulations regarding the energy performance of the heat demand (the sink);
3. The trade-off between renewable energy generation and energy saving measures in the development towards energy neutrality.

ad 1: Standards and regulations regarding renewable energy sources.
Most of the calculation methods are based on the substitution method. The main assumption of the substitution method is the idea that any renewable energy source is a substitute for a certain conventional (fossil based) reference energy source. In the substitution method, the renewable energy source must be compared with the

reference. Any contribution made by a renewable resource in the substitution method is therefore converted to the theoretical energy content of the replaced conventional source. This is the avoided consumption of fossil primary energy. The substitution method allows for comparing various energy sources like heat, electricity and gas.
ad 2: Standards and regulations in the Netherlands regarding the energy performance of the heat demand (the sink).
The regulations distinguish between heat demand in case of individual and collective heat supply:

- NEN 2720 EPG for individual heat supply;
- NEN 7125 EMG for collective heat supply.

In general, individual heat supply acts as the reference technology and collective heat supply acts as the substitute. The main component of the individual heat supply is the HR107 natural gas fired boiler, typically for the Dutch situation with its natural gas infrastructure.
ad 3: The trade-off between renewable energy generation and energy saving measures in the development towards energy neutrality.
For the collective energy system, the Energy Performance Coefficient (EPC) for individual buildings must be calculated as a combined performance of the building and the infrastructure. This results in a shift from energy saving measures in individual dwellings to measures in the external infrastructure; in the current situation, the EPC=0,4 is lifted to EPC=0,53. The intention is that the final energy demand is equal in both cases. The consequence of this is that the energy demand of the reference and substitute are not the same; we start with two different concepts (with different energy demands) and we end up with one and the same final energy demand. This study, however seeks the added value of SWE which is an element in a collective energy supply system. Because of this the only logical comparison between energy systems in this study should be comparing two collective energy systems with and without application of SWE. The consequence is that this comparison leads to the amount of primary energy in both cases instead of the amount of avoided primary energy in comparison with a reference technology.
In the future situation, the EPC will be further strengthened resulting in a further reduction of the energy demand. Rovers, [8] argues that the trade-off between energy saving measures and renewable energy generation will lead to paradigm shift in assessment: the embodied energy in the materials will be the crucial factor. This will result in an additional shift from energy saving measures to renewable energy infrastructure. Experiences in the renovation sector indicate that measures with a focus on installations perform better in comparison with measures with a focus on energy saving [10].

The decision-making process is determined by the organisational model.
The local energy supply can be organized in many different ways, depending on the needs of the participating parties, their characteristics and the available energy sources. There is no single best organisational form. Hakvoort [2] presents two models for initiating and exploitation of local energy networks. In the development of these models the principles of a free market, free network access and adequate transport capacity are (partially) released. In addition, the conceptual models focus on integrating local, sustainable production, provoking flexibility and matching demand and supply:

1. The main emphasis in the services model is on the development of Energy Service Companies (ESCOs). These ESCOs are a new group of service providers, in which many features to the user come together;
2. The coordination model in which the separation of production, distribution and use of energy at a local level is lifted. This results in a demand for local planning and coordination. The premise is that the participating parties jointly exploit the supply and that they all participate.

The most suitable organisational model in this perspective, aiming at optimizing the overall efficiency, is the coordination model because this allows for an optimal development and exploitation of a local energy infrastructure. The coordinated actions could take place in the form of public private partnerships, in which all stakeholders take part in the investments, capital expenses and operating costs. In the coordination model, the interaction between the energy generation, storage, supply and the energy network takes place by means of mutual coordination. Because of the integration between the world of energy and infrastructure and the world of surface water and spatial planning, cross-sectional coordination is conditional. In accordance with European legislation, the stakeholders shall be free to leave the system. When they do so, however, this has consequences for the other stakeholders in the system. If the size of the energy supply in the system is limited to 10.000 GJ the prohibition for a licence laid down in the Heat law, is lifted.

Network approach
The combined technological artefact can be described as the integrated system of an energy network and the

water cycle, with SWE functioning as connecting element. It consists of heat exchangers, pipelines and control devises and associated control systems. We can distinguish between three layers in this network [6]:

1. Occupation layer in which the energy demand and energy sources from the environment can be found;
2. Network layer in which energy distribution and energy exchange between sources and sinks takes place;
3. Underground layer in which ground water can be found acting as energy source and storage capacity. In this study an Aquifer Thermal Energy Storage (ATES) is adopted.

The complete overview of possibilities is visualized in figure 1.

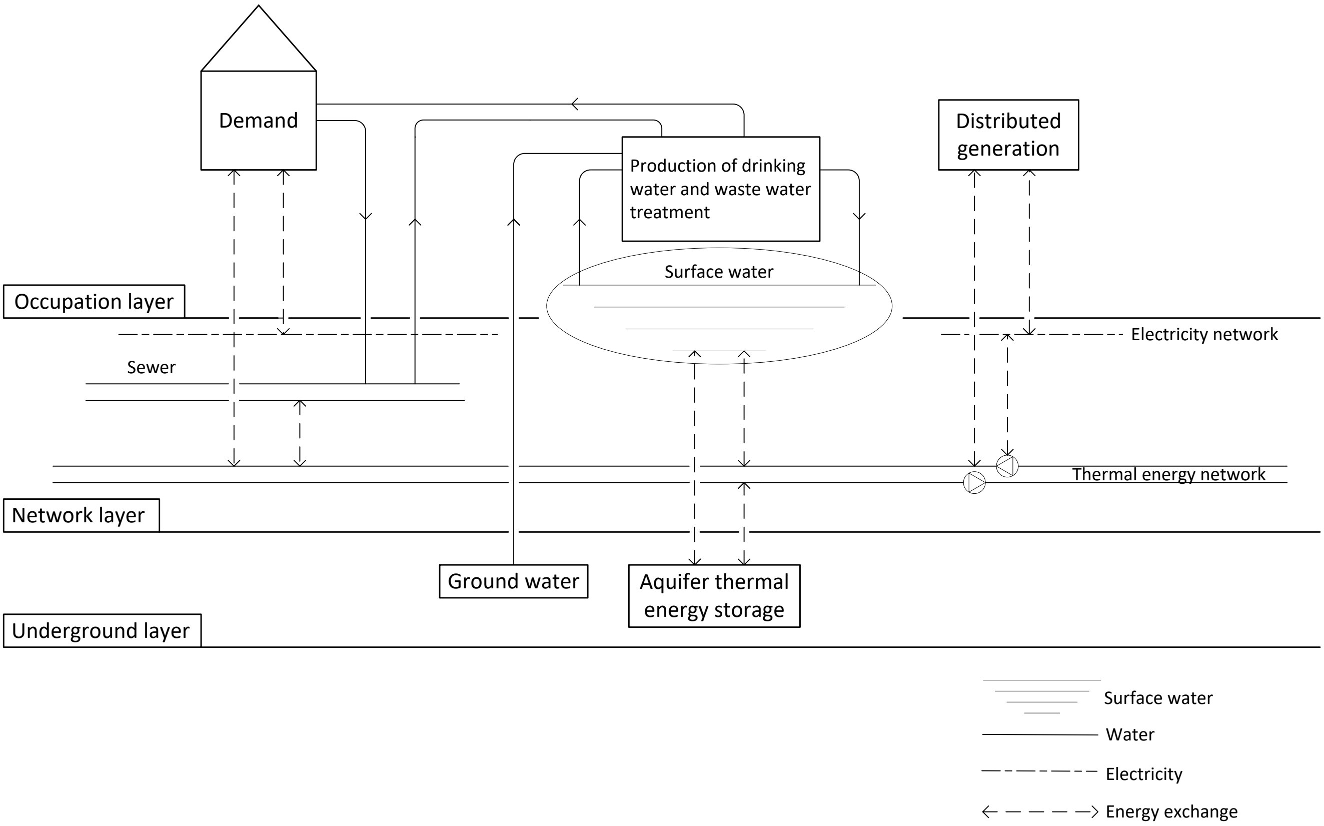

Figure 1 Conceptual model of the integration of energy networks and the water cycle with energy from surface water as connecting element.

The combination of EPG and EMG standard leads to a shift from energy saving measures in individual dwellings to measures in the external infrastructure. In case of a collective heat supply system, the EPC value can be lifted to 0,53. Researching the added value of SWE we can distinguish between two alternatives; with and without the application of SWE. For both alternatives, there is a need for regeneration capacity. In case of any network with SWE the regeneration energy can be generated from surface water. For the alternative regeneration capacity in the form of Solar Water Heaters (SWH) has been defined. This result in the following baseline in the comparison:

1. Energy network with SWE;
2. Energy network with SWH.

SWE model:

The calculation starts with the energy demand specified in the right column in figure 2. Followed by energy conversion steps from right to left in figure 2, concluding with the primary energy demand, based on the standardized efficiency of the electricity generation in the Netherlands, which is based on the current energy mix and technology for generation, transport and distribution. All conversion steps in this model are based on design variables from the standard calculation model “Uniforme Maatlat” [11] in which a comparison can be made between a reference technology and collective heat supply, according to the substitution method. In this case the substitution method itself is not used, as explained before.

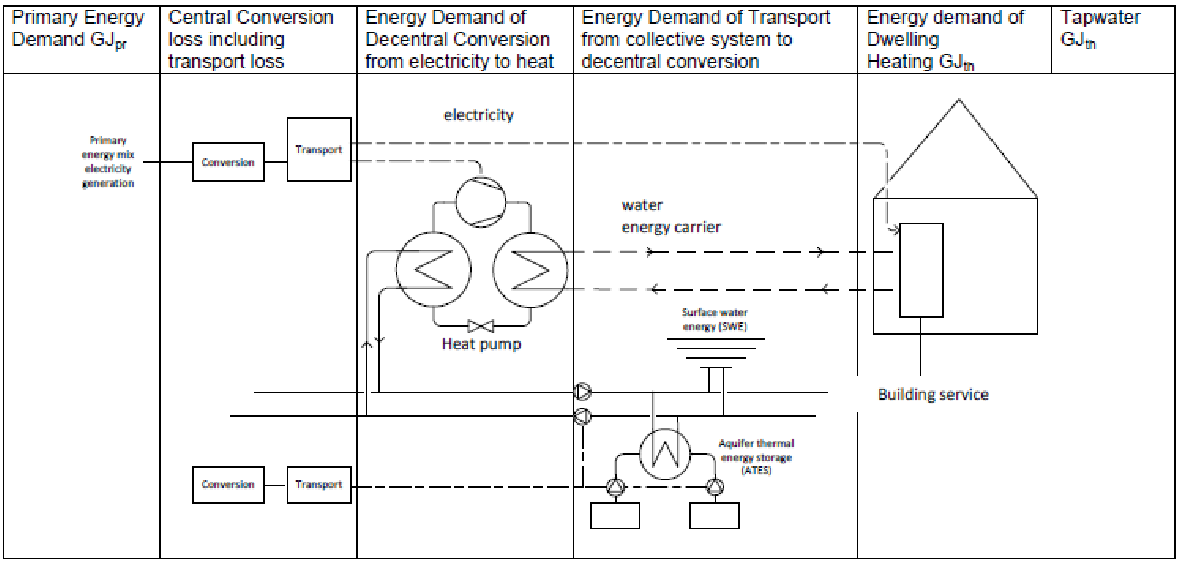

Figure 2 Process diagram and energy conversion steps of the SWE model.

SWH model:
The calculation follows the same procedure as model SWE. The calculation starts with the energy demand specified in the right column in figure 2. Followed by energy conversion steps from right to left in figure 2. The only difference is that the SWE is replaced by SWH.

5 Performance indicators

The energy system can be split up into sub-systems. The goals and constraints, that were found in literature, are matched with these sub systems, leading to the performance indicators in table 1.

Table 1 Split up into sub-systems and associated performance indicators

Integrated system	Sub system	Sub system	Performance indicators
Energy Infrastructure			
	Electricity network; Thermal energy network; Heat pumps; Energy demand		Energy demand for heating and cooling (GJ_{th}) Energy supply of energy network to end users (GJ_{th}) Primary energy demand of energy system (GJ_{pr}) Energy efficiency of the energy system (-) CO_2 emission energy system (kg CO_2) Renewable energy generation (GJ)
Environment			
	ATES		
		Energy source and sink; Regeneration capacity	Energy balance heat extraction versus heat regeneration (GJ_{th}/a) Energy storage water displacement (m^3/a) Productivity of heat supply from ATES (GJ/m^3) Capital Expenditures (CAPEX) regeneration capacity with SWE (Euro) CAPEX regeneration capacity with SWH (Euro)
	Water cycle		
		Surface water system (SWE);	Surface water temperature decrease in heat exchanger (ºC) Surface water displacement (m^3) Productivity of heat supply form SWE (GJ/m^3)

Integrated system	Sub system	Sub system	Performance indicators
		Other elements of the water cycle	Exchanged energy SWE per m^2 surface water area (GJ/m^2) Exchanged thermal power SWE per m^2 surface area (kW/m^2)
	Green and blue environmental elements		Increase the discharge capacity and absorption capacity of water in cities; Increasing the retention capacity of regional water systems; Improvement of the water quality; Avoiding heat island effect in cities; Construction of recreational areas; Climate-resistant design of buildings and infrastructure; Improving migration connections.

6 Test case

Given the preceding analysis with the performance criteria the aim is to test the implementation of a local energy network in an environment with Green and Blue environmental demands. In the test case, a comparison is made between the options with and without SWE; with SWE and SWH.

The test focuses on the residential area of the new development of "TNO-Zuidpolder" business park which is part of the area Delft Zuidoost. The municipality of Delft and the water board of Delfland analysed the water system in this area [12]. This analysis resulted in the conclusion that the water system should be improved to cope with heavy rainfall. The following measures where defined:

- Additional water retention;
- Slowing storm water by disconnecting the sewer and discharge to surface water;
- Improvement of the drainage and flow by connecting watercourses.

In the existing situation, individual water course in this area are connected to the water structure of the Zuidpolder in which Delft Zuidoost is situated. By connecting individual water courses and by extending water retention an integral water structure can be realized. The aim is to realize these measures in an integral approach by which the water quantity as well as the water quality will be improved. In this area are several construction plans, both new residential areas as well as extension of existing utility infrastructure. The associated environmental impact study resulted in the conclusion that the planned development in the area is possible provided that the municipal policy on water, ecology and sustainability for this area is put into practice by the project developers [13]. An obvious step in this perspective would be to combine spatial planning and energy by generating energy for the new buildings with the help of SWE.

"TNO-Zuipolder" is an existing business park that needs to be restructured. The municipality distinguishes several new functions in the area: Businesses, Education, Dwellings and Short-stay facilities. The area is positioned in the centre of the TU Delft campus. It covers 29 hectares of land and 3 hectares of surface water. In the plan space is reserved for 350 new dwellings, both individual family homes as well as apartments. In this test case, it is assumed that the total number is split up in the following types:

- Two apartment buildings: 2x60 =120 apartments;
- 120 terraced homes;
- 80 corner homes;
- 30 semidetached homes.

The surface water area in TNO-Zuidpolder area equals 3 hectares. This results in 86 m^2/dwelling.

The TNO-Zuidpolder case was entered into the SWE-model and the SWH-model, described in Chapter 4 Design space and design variables.

The energy calculations are presented in table 2.

Table 2 Energy demands of specified new buildings in TNO-Zuidpolder according to the SWE model and SWH model.

	Primary Energy Demand (GJ_{pr})	Conversion loss from primary energy to electricity including transport loss (GJ_{el})	Energy demand storage and distribution system (GJ_{el})	Energy demand heating and cooling systems (GJ_{el})	Energy demand of dwellings EPC=0,53 with collective heat supply (GJ_{th})		
					Heating	Cooling	Tapwater
SWE-model	5973	3405	652	1916	3459	608	2668
SWH-model	6439	3670	1043	1916	3459	608	2668

The ATES calculation resulted in the following calculation results:

- The storage water displacement:
  - with SWE: $56 \cdot 10^3$ m^3/year
  - without SWE: $100 \cdot 10^3$ m^3/year
- The productivity of the heat supply from ATES:
  - with SWE: 0,05 GJ/m^3
  - without SWE: 0,04 GJ/m^3
- The CAPEX for regeneration capacity:
  - with SWE: 125.000 euro
  - with SWH: 750.000 euro

The SWE calculation resulted in the following calculation results (no other elements of the water cycle incorporated in this model):

- The surface water displacement: $151 \cdot 10^3$ m^3/year
- The productivity heat supply: 0,03-0,07 GJ/m^3 (depending on the period in the year)
- The temperature decrease:
  - in heat exchanger: ≤ 7 ˚C
  - of the water system: ≤ 1,5 ˚C

A sensitivity analysis has been performed with regard to energy demand and energy supply.
Energy demand:
A critical variable in the models is the energy demand and associated distribution between the three categories; space heating, cooling and tap water demand. The ratio between space heating and tap water demand is critical because the heat pump efficiency strongly depends on the temperature level of the energy demand. If we focus on energy networks for residential areas, we can distinguish between three situations leading to different energy demands:

1. Extension of the energy network to neighbouring business parks. In this case the energy demand for both heating and cooling increases because of the additional connections to the network. It is expected that the ratio between space heating and tap water demand changes in favour of space heating, resulting in an increase in energy efficiency. Additional to this, the cooling demand can be realized by means of heat exchange in the distribution system itself, resulting in an additional increase of the energy efficiency;
2. Renovation projects characterized by relatively high energy demand in the existing situation. Because of the lack of standards determining the energy performance of the buildings, the trade-off between energy saving measures and renewable energy generation is critical in this situation;
3. Future new construction projects characterized by relatively low energy demand. Because of the further strengthening of the EPC the future energy demand will decrease. The trade-off between energy saving measures and renewable energy generation is, in this case governed by the EPG and EMG standards.

Energy supply:
The renewable energy generation in these models is limited to regeneration energy form SWE respectively SWH. The layout of these two alternatives excludes other options for renewable energy generation in order to answer the research question. Other energy potentials from the environment can contribute to a system with distributed energy generation. It is expected that distributed energy generation will improve the efficiency of the integrated system. In the last conversion step in the model the amount of primary energy is calculated based on

the standardized efficiency of the electricity generation in the Netherlands, which is based on the current energy mix and technology for generation, transport and distribution. The energy transition aiming at an energy mix in which the share of renewable energy increases, results in another conversion factor with associated smaller amount of primary energy.

7 Conclusion

In the test case a comparison between a model with and without SWE has been made. The model without SWE is equipped with solar water heaters (SWH). The test case has shown that in a specific area with Green and Blue environmental demands in combination with construction plans, the application of SWE can be very effective, both in terms of energy efficiency as in cost effectiveness of environmental measures. Renewable energy generation in both models is limited to regeneration energy from SWE respectively SWH. The layout of these two alternatives excludes other options for renewable energy generation in order to answer the research question. The comparison is based on the identified performance indicators from table 1.

The performance indicators have shown that the added value of SWE in an energy network can be found in an improvement of the efficiency of the system and in a reduction of CAPEX for the generation capacity. Additional to this, the ATES capacity is reduced significantly, the storage water displacement, which is an important indicator for the efficiency of the ATES is reduced by 44% in comparison with the SWH-alternative.

The Green and blue elements are subject to the following conditions in the design of the test case:

- The extension of blue and green structures in Delft Zuidoost is part of the planned development in the area. The expenses are passed on to the project developers in either case with or without the application of SWE.
    - with SWE:
        - the cross-sectional approach enhances the mutual objectives;
        - lowering the temperature of the water system contributes to the improvement of the water quality and the mitigation of the heat island effect;
        - litter is captured by the filter system.

SWE functions as a connecting element in the energy network itself and between the energy network and the water cycle:

- it is closely connected to the ATES function at a corresponding temperature level;
- it can be complemented with other elements from the water cycle;
- it can be complemented with other renewable energy sources from the environment;
- in case of complementary energy sources, the energy system can easily be extended to additional energy demand, for example to a neighbouring business park.

The conditions to be met in the integration of energy networks and the water cycle can be found in organizational and technical aspects:

- the literature study showed that the most suitable organisational model for a local energy network with SWE is the coordination model, in which mutual coordination is conditional, in this case this means that cross-sectional cooperation is necessary;
- in the coordination model, all stakeholders take part in the investments, capital expenses and operating costs. In accordance with European legislation, the stakeholders shall be free to leave the system. When they do so, however, this has consequences for the other stakeholders in the system. It is likely that this has negative consequences for the performance of the system. In the design of the system one has to deal with the possibility of leaving the system and associated consequences;
- The water quality must be guaranteed and the temperature decrease must be within constraints specified by the CIW assessment methodology.

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