A review on potential use of low-temperature water in the urban environment as a thermal-energy source

J Laanearu¹, A Borodinecs², M Rimeika³ and B Palm⁴

¹Department of Civil Engineering and Architecture, School of Engineering, Tallinn University of Technology, Tallinn, 19086, Estonia
²Institute of Heat, Gas and Water Technology, Faculty of Civil Engineering, Riga Technical University, Riga, LV-1658, Latvia
³Department of Water Engineering, Faculty of Environmental Engineering, Vilnius Gediminas Technical University, Vilnius, 10223, Lithuania
⁴Division of Applied Thermodynamics and Refrigeration, Department of Energy Technology, KTH Royal Institute of Technology, Stockholm, SE-100 44, Sweden

E-mail: janek.laanearu@ttu.ee

Abstract. The thermal-energy potential of urban water sources is largely unused to accomplish the up-to-date requirements of the buildings energy demands in the cities of Baltic Sea Region. A reason is that the natural and excess-heat water sources have a low temperature and heat that should be upgraded before usage. The demand for space cooling should increase in near future with thermal insulation of buildings. There are a number of options to recover heat also from wastewater. It is proposed that a network of heat extraction and insertion including the thermal-energy recovery schemes has potential to be broadly implemented in the region with seasonally alternating temperature. The mapping of local conditions is essential in finding the suitable regions (hot spots) for future application of a heat recovery schemes by combining information about demands with information about available sources. The low-temperature water in the urban environment is viewed as a potential thermal-energy source. To recover thermal energy efficiently, it is also essential to ensure that it is used locally, and adverse effects on environment and industrial processes are avoided. Some characteristics reflecting the energy usage are discussed in respect of possible improvements of energy efficiency.

1. Introduction

There are a number of low-temperature water sources in the urban areas, which may be integrated with the water and energy supply networks in the cities having seasonally alternative temperature. The heat extracted from the urban water sources can be used for different purposes e.g. heating or cooling of spaces, pre-heating of domestic water, etc. ([1], [2]). Nowadays requirements for the building’s performance are regulated by several EU initiatives to reduce the energy consumption of buildings, e.g. Energy Performance of Buildings Directive (EPBD). The heat recovery is one of major part in modern energy efficient house [3]. Nevertheless, when the space heating demand for the European Union is thoroughly studied, then the space cooling demand in the Member States of the European Union is recently studied [4]. The heating and cooling loads are the measures of energy needed to be added or removed from a space by the HVAC system to provide the desired level of comfort. The energy load calculations have direct impact on first construction costs along with the operating efficiency, occupant...
comfort, indoor air quality, etc. However, the building’s energy demands within the EU member states differ due to different climate conditions, various habits concerning comfort levels and possible alterations in thermal characteristics of the buildings [5].

The increasing awareness of climate change has resulted in a strong drive to implement novel solutions in the management of economic problems in a different level of governance. Thus, innovations in the building, water, and heating and cooling sectors have to be considered in the context of the regional, national and municipal levels. Practises around the Baltic Sea Region (BSR) differ greatly between countries and also within a municipalities of national level, which are well reflected in difference usage of the primary and renewable energy (Heat Roadmap EUROPE 2050).

Saving energy through energy efficiency improvements provides multiple economic and environmental benefits associated with reduction of the energy consumptions in different type buildings, and also balancing the generation, transmission and distribution of energy from power plants. Energy efficiency improvements can be related to reduction of air pollution and carbon dioxide emissions, improvement of energy security and independence, and creation of new employments (cf. [6]).

Recently the European Commission published a plan in which EU countries have agreed on a new 2030 Framework for climate and energy, including EU-wide targets and policy objectives for the period between 2020 and 2030 (2030 Energy Strategy). This includes the establishment of targets to reduce the greenhouse gas emissions by 40% compared to 1990, the increase of the renewable energy share to 27%, and the realization of 30% energy savings. Following the Directive 2010/31/ES of the European Parliament, the member states shall ensure that by the end of 2020, all new buildings are nearly zero-energy buildings. Achievement of these targets require a holistic approach in modernization of the sectors of building, energy and transport. Despite the fact that the district heating (DH) accomplish an essential part of the heat demands in the cities they serve (e.g. the share of citizens served by DH in Latvia, Denmark, Estonia, Lithuania, Poland, Sweden and Finland is over 50%, cf. [7]), the standalone solutions such as renovations of buildings, local renewable energy sources (geothermal, biomass, solar, etc.) are increasingly used. According to European Heat Roadmap 2050 the DH systems in the year 2012 covered 12% of the European heat market for buildings of the residential and service sector, while occupying dominating national heat market shares between 40% – 60% in some Scandinavian and Baltic member states. It is apparent that establishment of the EU climate and energy targets are challenging under strongly variable climate conditions. A reason is that the solutions used to improve the energy efficiency in the warm and cold climates alone are not straightforwardly appropriate in the climate zone with of the seasonally alternating temperature.

The urban areas include multiple water and energy supply networks, which distribute the thermal energy between different locations, and are associated with the diffusive heat transfer with surroundings. For instance, according to a report of the Ministry of Economic Affairs and Communications of Estonia [8] the annual generation of heat in Estonia is about 9 000 GWh, 89% of which reaches the consumers and 11% of which represents losses in the heat networks. This indicates that the distribution of diffusive heat sources can be managed in the BSR cities. Increasing urbanization is an important issue that should be addressed for better representation of the impacts of climate change itself, as well as energy storage and smart grid solutions. Imperviousness in the urban areas is a critical indicator for analysing impacts of climate change in the Baltic Sea Region. The mapping of local conditions is essential for management of the harvested and drained waters carrying unused heat from the city areas into nearby water bodies. Also there is a need of knowledge of financial approaches to make thermal energy recovery from Urban Water Cycle (UWC) more attractive and competitive within other renewables.

In this management study the low-temperature water in the urban areas is viewed as a potential thermal-energy source for buildings’ heating and cooling purposes in the cities having seasonally alternating temperature. The low-temperature water sources such as surface water, storm-water, wastewater etc. are under focus from the perspective to increase a multi-functionality of the existing infrastructure in the BSR cities. Some characteristics are discussed in respect of the possible improvements of energy efficiency. Finally, different aspects are outlined to support the concept of a network of heat extraction and insertion including the thermal-energy recovery schemes.
2. Low-temperature water sources

Strong seasonal variations lead to alternating water, heating and cooling demands in the cities. Therefore it is important to outline and map synergy opportunities, which will support the use of alternative thermal-energy sources in the BSR urban areas. An objective is combining data on available low-temperature water sources with the heating and cooling demands of different type buildings (such as residential, business, commercial), hereby identifying the thermal-energy usage "hot spots" for further analysis and evaluation. Specific challenges are associated with the local mapping of low temperature heat demands, and feasibility analysis of the heat recovery schemes for heating and cooling of spaces, pre-heating of domestic water, etc. The thermal energy storage has a potential to increase energy saving in the urban areas, and due to smart-grid solutions apparently will allow the Baltic Sea Region to become more climate neutral region.

2.1. Surface water sources

Usage of thermal energy of shallow lakes, rivers and coastal seas is an option to replace conventional air-air cooling systems during warm period of year for the cooling of buildings that consume a lot of electric energy. A reason is that the water temperature is more stable compared to air temperature in the warm seasons, especially when peak cooling loads are required for a large commercial building such as shopping centre. In operating the building’s cooling system, the low-temperature water enters into of building where it is used for cooling, and the warmer water goes back to a reservoir. The outside surface water follows the seasonal variations, and may be not available during entire year. The water for cooling should be subtracted from the bottom of a reservoir, and the warm water should be directed into the surface layer of a reservoir (cf. [9]). It is found that the energy consumption for cooling in the building compared to individual cooling units can be reduced considerably (see [1]). However, a heating of a small-scale natural water body may be unfavourable due to the threat of eutrophication. Therefore it is suggested to improve the water quality in the cooling systems e.g. by removing the nutrients and hazardous substances. At present main energy needs in buildings are due to heating and/or cooling, the consumption of which depends on local climatic conditions and type of building. The building’s required energy can be achieved from variable sources such as electric grid, district heating or cooling network, or even produced locally from different renewable sources (geothermal, solar, etc.). For instance the DH accomplish over 50% of heating demands in the BSR cities (cf. [7]). There are more comprehensive experiences in the field of district cooling (DC) in Scandinavian countries. For instance, the first district cooling plant and network in Estonia was opened in Tartu in 2016.

2.2. Storm-water system

A modification of the land cover in the urban areas is usually associated with an increase in storm-water runoff. In addition the climate change caused increasing rain-water volume is becoming more and more a global problem, and is a driver to find new applications in taking use this low-temperature water sources. A growing urbanisation causes inevitably increase in storm-water volume, and thus, novel solutions are needed for mitigation of floods accompanying severe weather rainfalls. At present the Sustainable Urban Drainage Systems (SUDS), storage tanks, combined collectors etc. are extensively used for reducing loads on storm-water systems in the BSR cities. The rainwater harvesting is also increasingly used in the buildings to reduce the consumption of building’s drinking water. More than fifty per cent of the volume of water used in commercial and public buildings does not have to meet the requirements for clean drinking water quality. However, the rainwater volume and temperature follow the seasonal weather conditions, and thus may by not available during entire year.

The storm-water heat represents an additional on-site available renewable energy. The usage of low-temperature water locally increases multi-functionality in the urban infrastructure that until now is essentially used to mitigate impacts from extreme climate events. The functioning of an integrated system for domestic hot water production depends on (i) the heat extraction technology; (ii) the meteorological conditions, such as the frequency of rain events at a catchment, and (iii) the need for heat at a location, e.g. due to seasonally restricted district heating. In complex systems, it is important
that there is no need to seek a large number of combinations to obtain the optimal solutions. Therefore the storm-water heat usage for domestic hot water production in different type buildings (e.g. commercial, public or residential) constitutes a multifunctional optimisation task [2]. Within many possible solutions the storm-water volume in storage tank and rainwater catchment area need to be determined that correspond to the precipitation statistics of the local rainy season and the hot water consumptions of the buildings. The availability of storm water depends in turn significantly on water flow in the storm-water system and on purification e.g. sand and oil removal (cf. [10]). For effective heat transfer from a storage tank it is necessary to simulate temperature-stratified flow. However, it is not possible to solve the task only by using the flow hydraulics formulae, which is why the Computational Fluid Dynamics (CFD) simulations are needed. The water temperature above 4°C allows operation of heat pumps in extracting heat from the storm-water tank and "pumping" it to nearby building’s water system (essentially commercial building according to [2]).

2.3. Wastewater sources
Existing studies [11, 12] highlight importance of wastewater energy balance at city scale. According to these data up to 40% of the used heat is wasted to the sewage system in residential buildings.

There are a number of options to recover heat from wastewater, and use it for hot water in building, including showers, tubs, sinks, dishwashers, and clothes washers. Drain water heat recovery systems is also known as drain-line or gravity-film heat exchanger, which capture the thermal-energy from black- or grey-water parts to use it for preheating of building’s water supplied. This design is a vertical, counter-flow heat exchanger that extracts heat out of drain-water (usually warm) and applies it to preheat the cold water entering the building. Also municipal sewage contains thermal energy, which is characterized with temperature range 10°C and 20°C, during entire year. One of City of Riga lighthouse projects evaluated in scope of EU FP7 projects Strategies Towards Energy Performance and Urban Planning (STEP UP) is wastewater heat recovery in the student hostel of the Riga Technical University (figure 1). However, the temperature range 10°C…20°C allows economical operation of heat pumps for recovering heat to nearby buildings. The heat pumps are a reliable for extracting heat from the sewage, but a problem is contamination of the heat-transfer surfaces [1].

![figure 1](image)

**Figure 1.** Temperature in sewage collector a) Saturday/Sunday and b) the wastewater heat retrieval system implemented in 2013, which allows reduce the heat used for hot water preparation system by about 50 %. (It should be noted that temperature measurements in same sewage collector confirmed that during mid-week Tuesday/Wednesday the temperature was also between 13.5°C and 16.2°C.)

GIS modelling tools may be used to identify suitable locations for heat recovery. The amount of heat that can be recovered from the sewer network is limited by the Waste Water Treatment Plant (WWTP) technology. This is because the biochemical reactions in WWTP are influenced by the temperature of the influent. When the temperature is below 10°C then the biological reactions are not as efficient as
needed to obtain a good water quality of the effluent. To recover heat efficiently, it is also essential to ensure that it is used locally, and adverse effects on industrial processes are avoided.

Measurements done by [13] shows that wastewater temperature varies about 20.9°C to 13.5°C in October and December, respectively. Research data [14] has shown combination of wastewater heat recovery and a heat pump yields up 41% electricity savings for hot water preheating in passive multi-apartment buildings. The use of heat pump also is recommended by research [11], where during the 3 year of test period the efficiency fixed-inverter hybrid heat pump system were proved to be to 15.04% better on part loads than the single inverter operation.

In the BSR cities a large amounts of thermal-energy is released into the urban wastewater drainage system and it also reaches to WWTP. There are a number of studies dealing with determination of the heat recovery potential from untreated wastewater in the common sewer line upstream from a wastewater treatment plant. However, the temperature differences are not large enough to recover thermal energy by heat exchanger, and therefore a heat pump solution should be used. The wastewater treatment process in many WWTP in the Baltic Sea Region is using temperature dependant biological treatment for denitrifying the wastewater before it is disposed to the Baltic Sea. The theoretically available heat in the BSR cities wastewater drainage system is comparatively large, but, the practical heat recovery potential is very limited due to socio-economic reasons.

A sustainable solutions for growing cities include the district heating and cooling networks, and power plants. At present the thermal energy storage to increase energy saving in the urban areas is not common. In the Baltic Sea Region, the heat demand in the DH network has annual variations. Heat for the hot water is produced constantly during entire year, but the major part of heat is needed during the shorter heating season, which includes peaks loads during very cold periods in the winter. District cooling is a way to provide cooling for the users during the summer. The "cooling" season in the Baltic Sea Region usually lasts from a mid-spring to a mid-autumn, when the outside temperature is above 0°C. Standards of the district heating and cooling systems in the Baltic Sea Region differ greatly between countries and municipalities, and the application of technologies differs as well. Open networks for heating and cooling, which should be made assessable also for the thermal-energy sources of low-temperature water and other renewables may be a future solution.

However, the low-temperature water usage as the thermal-energy source has also some innovative applications. For instance, the demand for data-center space cooling is increasing, this to meet requirements for the functioning of Information Technology Equipment (ITE). Data centres are huge electrical heaters, this because they are consuming electrical energy and almost all this is converted to thermal energy, which heats up the indoor air. Thus a purpose of data centre cooling technology is to maintain indoor environmental conditions. Achieving this goal requires removing heat produced by the data centres and transferring that heat to sink. In a large data centres, the operators expect the cooling system to operate continuously (during entire year). Data centres operating in direct free cooling mode release the thermal energy as warm air with temperature range 25°C to 40°C. When comparing water cooling versus air cooling techniques in data centres, it can be find that air cooling is more spread nowadays. As data centre equipment has increased in density, the use of large fans is complicated because of a lack of space. It is well known that the refrigerant or chilled water can remove the heat from the space efficiently. With its much higher heat capacity than air, the seawater is useful option to remove the heat from the spaces of data centre. Coastal water is used to cool the data centres in the Baltic Sea region (cf. [15]). There are a number of alternative options to use heat produced in data centre.

3. Energy efficiency
At present exists a need to improve the energy efficiency of water and energy supply networks according to its economic potential, and also for a security reasons. This includes questions on to what extent urban planning through the energy efficiency measures can contribute to saving energy in the medium and long term in the Baltic Sea Region. The mapping of heating and cooling temporal demands in the BSR cities and locating available low-temperature water sources i.e. water ponds, watercourses, stormwater
According to [16], a common climatic indicator for characterizing the building’s heating and cooling demand in particular area is the degree day, which is a measure of the average temperature departure from a set base temperature. Similar to Heating Degree Day (HDD), which is a measure to quantify the demand for energy needed for heating of a building, there is defined Cooling Degree Day (CDD) that can be used to quantify the demand for energy needed for cooling of a building. In most cases the accepted base temperature is 18°C. Following [4], the lowest mean CDD (or highest mean HDD) annual values were calculated for Northern and North-western Europe as well as European mountainous areas. However, comparatively large variability of mean CDD annual values in [16] was found in the Baltic Sea Region, where this number was in range 3 to 104. This indicates that the building’s energy demands due to local climate conditions are less predictable in the BSR countries as compared to the countries located in the warmer region of Europe.

Specific challenge is solve the energy efficiency problems related to implementation of the heat recovery schemes, to support sustainable solutions for water, heating and cooling supplies in the BSR cities. For a productive end-use, three essential components are required: 1) accessible excess-heat source, 2) heat distribution and transfer technology, and 3) user of low-temperature water produced energy.

Essentially two types of energy efficiency measures are needed in dealing with the thermal energy of low-temperature water sources: {1} measure that determine the energy transfer with water flow and {2} measure that determine the energy transfer in heat exchange. These two measures allow assess the energy efficiency of heat transfer process in the integrated systems for water and energy. Distribution losses, representing the energy-efficiency measure of type {1}, are a very important factor in district heating and cooling systems. By optimizing the losses in such a system, both economical and environmental aspects can be fulfilled. In the case of low-temperature water piping, the heat losses between the source and end user may be insignificant. This is also an important argument in the 4th-generation DH system, where the distribution losses are reduced due to supply temperature reduction. Nevertheless, when the district heating systems for the European Union is thoroughly studied (see Heat Roadmap EUROPE 2050), then there is few information regarding losses for DC systems. It was mentioned above that the temperature differences in the case of low-temperature water sources are not large enough to recover thermal energy by heat exchanger, and therefore heat can be extracted more efficiently by a heat pump (cf. [17]). Thus the Coefficient of Performance (COP), which is a measure of heat pump performance, can be used in the first approximation to assess the energy-efficiency measure of type {2}.

However, the trends observed for long-term energy usage, especially for building’s heating or cooling are very irregular, which results in strong fluctuations in the measure, that are difficult to understand as energy efficiency progress should normally change smoothly (incremental technical change). Such fluctuations can be linked to various factors: imperfect climatic corrections, especially with warm winters in the Baltic Sea Region, behavioural factors, influence of business cycles, imperfection of statistics, especially for the last year, etc. The energy efficiency problems related to implementation of the unused urban thermal-energy schemes can be managed by using the planning tool, which takes into consideration different aspect due to the energy efficiency (see an example in [7], where the planning tool is based on the mathematically described heat energy production, distribution and consumption processes within one district heating system, and allows determine a number of efficiency and balance indicators of simulated DH system development scenarios).

4. Concluding remarks
In creating a network of heat extraction and insertion including the thermal-energy recovery schemes, it is essential to identify the possibilities that help meet the challenges due to climate change and increasing urbanization. The knowledge gained on unused thermal-energy potential in the Baltic Sea Region is
essential to accomplish the EU strategies for optimizing resources and creating more emission neutral regions. Therefore a strong involvement of the public and private actors in regional, national and municipal levels concerning on the energy efficiency improvements are needed. However, the proposed network can provide more ambitious energy efficiency measures, and also economic benefits due to cost-optimal solutions increasing energy efficiency, based on enhanced capacity of public and private actors. The low-temperature water usage as thermal-energy source in the BSR cities is well related to the several EU regulation acts. The specific directives are examples of the EU regulatory framework to promote usage of "green" energy instead the fossil fuels. Following the Energy Efficiency Directive, EU has adopted a number of measures to improve energy efficiency, e.g. requiring an annual reduction of 1.5% in national energy sales. The reduction of energy use, and also responsibility for maintaining the requirements to supply drinking water and treat wastewater to protect the environment should be considered in order to comply with the Water Framework Directive. A holistic approach allows establishing balances between heating and cooling temporal demands of a different type buildings and usage of available thermal-energy potential of the low-temperature water sources, this to complement an existing water and energy supply networks.

Identifying the gaps in development of a network of heat extraction and insertion including the thermal-energy schemes, the following points can be outlined:

- Mapping of information on demands (local heating and cooling demands in residential, service and industrial sectors) and sources (low-temperature water streams, ponds, stormwater tanks, etc.) in the BSR cities. For this purpose the GIS-based approach can be used to identify "hot spots" on basis of the nationally and transnationally available data sources.
- Synergy options for the proposed network should be considered from adopting multiple sources: water reservoir, storm-water tank, domestic water line, sewage pipe, data centre, etc. For a positive change towards a new perspective on the emission-free energy usage it is important to implement climatologically sustainable solutions, and help to remove barriers due to transnational, organizational, financial, trust and technical reasons.
- Possible investments for planning, realization, monitoring and evaluation of the particular unused thermal-energy schemes. The energy efficiency measures of applications can be worked out on basis of the industrial case studies. Practical examples in the form of demonstration pilots promote to overcome all kinds of barriers that restrict an implementation of novel energy-transfer technology.
- Development of the urban area thermal-energy usage optimisation and management tool. The tool can be based on the collection and synthetization of information on available data and models that quantify energy and power of the low-temperature water sources. The tool also should allow permit a geospatial assessment of the proposed network. The genetic algorithm (GA), as an optimization method, can be applied as a search technique to determine an optimal solutions. The particular measures can be used to formulate the optimization target functions in establishing cost-effective solutions.
- The guidelines for thermal-energy usage and recovery in the Baltic Sea Region may be worked out on basis of the industrial case studies, including the optimisation and management tool spreadsheet examples. The guidelines can provide different measures to estimate the energy effect in taking use the thermal-energy potential of low-temperature water sources. The cross-border knowledge on practical applications of already implemented low-temperature water sources usage is essential.

A many positive changes associated with realization of a network of heat extraction and insertion including the thermal-energy recovery schemes can be gained. Promotion of usage of the locally proven thermal-energy usage solutions help remove the gaps in taking use the low-temperature water in the Baltic Sea Region. Also the transnational information and implementation of the thermal-energy usage schemes will strongly support the implementation of EU-wide energy efficiency strategy anchored by
several legislation acts. The reduction of primary energy consumption and carbon dioxide emissions by decarbonising the energy sector and enhancing security in water and heat supply are feasible outcomes of the proposed network. In any future study it is important to demonstrate reliability of the low-temperature water source as a useful thermal-energy potential in the BSR urban areas.

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