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Moerman, Andreas; van Bel, Nikki; Oesterholt, Frank; de Laat, Vincent; Blokker, Mirjam

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Thermal Energy Recovery from Drinking Water Systems: Assessing Water Quality and Downstream Temperature Effects

Andreas Moerman, Nikki van Bel, Frank Oesterholt, Vincent de Laat, and Mirjam Blokker

Abstract

Climate change demands for sustainable options for heating and cooling of buildings. Low-temperature thermal energy can be abstracted from the drinking water distribution system (DWDS); this is called thermal energy from drinking water (TED). The possible use of TED as a secondary function of the DWDS raises the question whether this secondary function can exist alongside the primary function (supplying safe and reliable drinking water) and, if so, under what conditions. Using various cases, the potential downstream effects of TED related to drinking water temperature (and hence, downstream increase of cost and CO_2emissions for water heating) and microbiological drinking water quality were studied.

Keywords

Thermal energy • Sustainability • Water quality • Drinking water distribution

1 Introduction

Under the Paris Agreement, countries agreed to reduce total CO_2 emissions, and thus prevent global warming from averaging more than 2 °C in the coming decades, which demands a huge energy transition. One major part of this transition is sustainable heating and cooling for the building environment. One of the challenges while creating sustainable systems for heating and cooling is the transport of thermal energy and, thus, the potential loss during transport. The infrastructure required for this is expensive to construct and difficult to finance because of a relatively long payback time.

The drinking water distribution system (DWDS) is an already available infrastructure through which drinking water flows, with the primary aim of providing safe and reliable drinking water. During transportation from the pumping station to the end user, the drinking water exchanges thermal energy with the surrounding soil, as a result of which the pipeline network can also be regarded as a collector of sustainable (soil) thermal energy (Blokker and Pieterse-Quirijns 2013; Hubeck-Graudal et al. 2020; Pasquale et al. 2017). Because the water flows through the pipeline network, heat is transported through the drinking water. This "low-temperature heat" can be extracted from the drinking water by using a heat exchanger. This is called thermal energy from drinking water (TED). By using an (electric) heat pump, the low-temperature heat can be converted locally to useful temperature level for floor heating. Assuming the heat pump is driven by sustainable electrical energy, TED is a "green" option for heating and cooling buildings. Combining TED with aquifer thermal energy storage (ATES) creates the ability to abstract heat from the DWDS during the summer season for heating purposes in the winter season. During the summer season, the temperature increase of the drinking water in the DWDS is maximal (and so is the potential for thermal energy), since the drinking water temperature is dependent on the soil and thus atmospheric temperature (Blokker and Pieterse-Quirijns 2013; Agudelo-Vera, et al. 2020). Vice versa, the combination of TED and ATES offers the possibility to use the lower drinking water temperatures in winter for cooling houses in summer.

Depending on the pipe flow, the application of TED can save substantial amounts of CO_2 emissions, against good financial conditions (Hoek et al. 2018).

A. Moerman (✉) · N. van Bel · F. Oesterholt · M. Blokker
KWR Water Research Institute, Groningenhaven 7,
3433 PE Nieuwegein, The Netherlands
e-mail: andreas.moerman@kwrwater.nl

V. de Laat
Brabant Water, Magistratenlaan 200, 5223 MA,
's-Hertogenbosch, The Netherlands

M. Blokker
Department of Civil Engineering and Geoscience, Technical
University Delft, Stevinweg 1, 2628 CN Delft, The Netherlands

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The possible use of TED as a secondary function of the DWDS raises the question of whether this secondary function can exist alongside the primary function (supplying safe and reliable drinking water) and, if so, under which conditions. In cooperation with several partners, KWR Water Research Institute studied the (potential) effects of energy abstraction in the DWDS. These studies were elaborated along two research questions:

1. What would be the downstream effect range of an induced temperature change and what does this mean for the energy consumption (for heating drinking water to washing water) of downstream customers in terms of costs and extra CO_2 emissions?
2. What would be the microbiological water quality risks at the site of the TED installation (particularly, within the heat exchanger).

2 Cases

Four pilot and operational cases were studied in three different research projects, from which three cases are in operation (Table 1).

3 Methods

3.1 Determination Range of Temperature Change

The downstream range of an induced temperature decrease (question 1) was studied for the cases A and D using a temperature model (Blokker and Pieterse-Quirijns 2013) in combination with a hydraulic network model (EPANET) including a water quality solver (EPANET-MSX (Shang et al. 2011)). Temperature results per demand node were converted to extra cost per household and extra CO_2 emissions (due to heating of drinking water, for e.g., showering). In Fig. 1, the calculation process is shown; steps one and two were introduced to minimize calculation time.

3.2 Water Quality Measurements

For cases A to C, water samples were taken during the summer and winter seasons (both three times) to assess the water quality, e.g., presence of opportunistic pathogens, before and after the heat exchanger. Biofilm samples were taken to study the presence of opportunistic pathogens in the biofilm. For case A, the biofilm was swabbed six times using removable pipe sections before and after the heat exchanger. For case B, the biofilm was swabbed one time before and after the heat exchanger and inside the heat exchanger by detaching plates from three different locations within the heat exchanger. All biological and chemical parameters which were measured are listed in Table 2. Every parameter was measured both in water and biofilm using common standards (as far as available).

Next to the parameters listed in Table 2, the biofilm potential of the materials used in the heat exchanger was assessed in a laboratory environment using the biofilm production potential (BPP) method as described in the NEN-EN16421 standard.

4 Results

4.1 Range of Temperature Change

Results show that the range of temperature change strongly depends on the flow conditions. After temperature decreases in the heat exchanger, the drinking water can heat up again in interaction with the surrounding soil. This mitigating influence of the soil on the temperature change in the DWDS mainly depends on the residence time of the water and the pipe's diameter (and, thus, the volume of water per length unit).

Table 1 Cases for research on the effect of thermal energy from drinking water (TED)

Case	Status	ΔT^a (°C)	Power^b (kW)	Customer(s)
A	In operation	−2	45	School
B	In operation	−4	590	192 houses, eight commercial buildings
C	In operation	−2/0.5	140/35	Three utility buildings
D	Pre-design	−1	185	Multi-utility building

(a) ΔT = the designed temperature change of the total flow downstream of the heat exchanger. Negative value: abstraction of heat; drinking water temperature decreases, positive value: addition of heat; drinking water temperature increases cases A, B, and D make use of aquifer thermal energy storage (ATES) which enables heat abstraction during summer and heat storage for use in winter season. For these cases, the heat abstraction takes place in the approximate period of June-October. For case C, it is the opposite (heat abstraction in winter and heat addition in summer)

(b) Thermal power generated by heat exchange (design value)

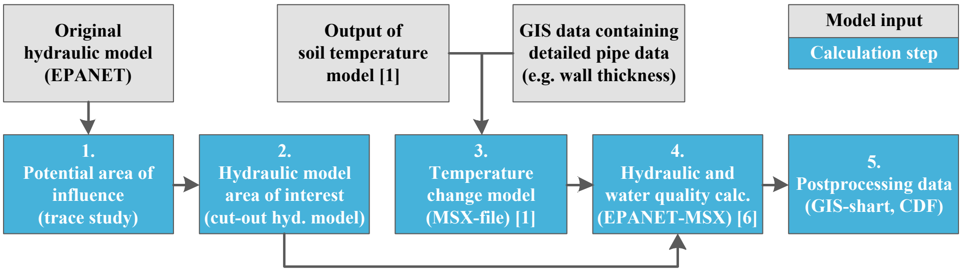

Fig. 1 Calculation steps to assess temperature changes per household connection

Table 2 Microbial and chemical analyses to assess water quality and biofilm

Parameter (B = biological, C = chemical)	Detection method	Standard
HPC (B)	Plate count	NEN-EN-ISO 6222
Aeromonas (B)	Plate count	NEN-ISO 6263
Legionella spp. (B)	Plate count	NEN-ISO 6265
Pseudomonas aeruginosa (B)	Plate count	NEN-ISO 16266
Aspergillus fumigatus (B)	qPCR	n/a
Pseudomonas aeruginosa (B)	qPCR	n/a
Legionella pneumophila (B)	qPCR	n/a
Stenotrophomonas maltophilia (B)	qPCR	n/a
Acanthamoeba spp. (B)	qPCR	n/a
ATP (B)	Enzyme detection	NEN-EN 16,421:2014
Ammonium (NH_4) (C)	Spectrophotometry	

Larger diameters (which usually have a transport function) conserve the temperature change (to a certain extent), as shown in Fig. 2, where the blue marked lines indicate transport infrastructure (either one 200 mm pipe or double parallel pipes of at least 160 mm). Figure 2 also shows that the induced temperature change rapidly decreases when the cooler water enters the tertiary network (east and west of the blue marked lines) which consists of smaller diameters ($\leq$ 110 mm) and longer residence times. The latter results in almost total mitigation (soil influence) of the initial

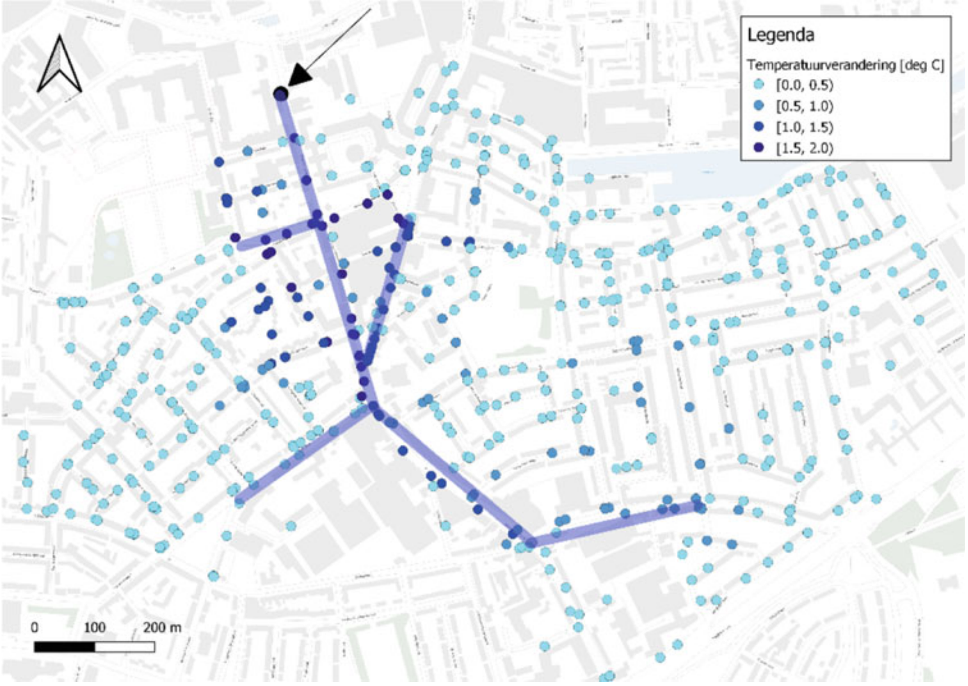

Fig. 2 Range of temperature change downstream of TED-installation (location indicated by the arrow) at average flow conditions (10 m^3/h) for case A (Moerman et al. 2019). The initial temperature change equals 2 °C. The nodes represent (non-zero demand) customer points

temperature change for most of the downstream customers ($\leq$ 95%).

4.2 Water Quality

Results of water quality and biofilm analyses show, for cases B and C, that concentrations of typical indicators for microbial activity (HPC and ATP) are lower downstream of the heat exchanger, in case of heat abstraction (Bel et al. 2017). Gaskets (made of synthetic rubbers; EPDM) used in the plate heat exchangers have a biofilm production potential (BPP) of 1925 pg/cm^2 (Moerman et al. 2019), which is almost twice the statutory limit for pipe materials. However, there were no indications that, given the occurring temperatures (10–18 °C), the biofilm within the heat exchanger or in the downstream pipe functioned as a growth place for opportunistic pathogens (like *Pseudomnonas aeruginosa*, *Legionella,* and *Acanthamoeba*). The BPP value for the material used for the heat exchanger plates (stainless steel) was almost equal to zero.

5 Conclusions

Based on various case studies, it was concluded that:

- Based on modeling, a very small part (< 5%) of downstream customers are expected to face a substantial temperature change at service point (location of connection to the DWDS), leading (on average) to a small cost surplus for individual households $\leq$ 1 €/year (research question 1).
- The extra CO_2 emissions generated by downstream customers for heating drinking water (showering, etc.) is 5% of the CO_2 emissions, which are saved by using the DWDS as a source for low-temperature thermal energy (research question 1). This was also found in an earlier case study based on the same principles (Blokker et al. 2013).
- The use of a TED has very limited or no adverse effects on the microbiological quality of drinking water in situations where the temperature is below 15 ºC (research question 2).
- Lowering the temperature through heat abstraction (using TED) has a demonstrably positive effect on water quality (monitored by HPC and ATP) (research question 2).

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