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Modeling the influence of district heating systems on drinking water temperatures in domestic drinking water systems within domestic properties

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ABSTRACT

In this research we investigated the influence of the heating of drinking water in the connection pipe under the influence of nearby district heating and the effect this has on water temperatures throughout the Domestic Drinking Water System (DDWS) of a typical Dutch domestic property. We found that stagnant water in the connection pipe warms up fast, reaching the surrounding ground temperature in about 15 minutes and these temperatures can be found throughout the house at taps such as the shower and the kitchen tap. Flowing water in the connection pipe is also, depending on the pipe length, heated up several degrees. The prevention of high temperatures in the soil around the connection pipe is the best measure to prevent high drinking water temperatures at the taps.

INTRODUCTION

The Paris accords to reduce CO_2 emissions have resulted in plans for a rapid energy transition within the Netherlands. Currently, the vast majority of houses are heated with gas using boilers; the future is heating without natural gas. One alternative heating system for houses is district heating. Depending on the type of district heating the hot water in the connection pipe can be anywhere between 40 and 70 ^oC and it shares the limited space to the property with the drinking water connection pipe.

To prevent Legionella growth in the pipes within the DDWS the Dutch Drinking Water Act requires that the temperature of drinking water does not exceed 25 ^oC at the tap. The influence of the district heating pipes on the drinking water was investigated before by van der Zwan et al. (2020). This study investigates the risks of a district heating system affecting the drinking water temperature in the connection pipe and which parameters of the DDWS in- or decrease this risk.

METHODS

Setup of the model

The model describes the DDWS of a typical Dutch domestic property. The model consists of three submodels which are linked together. A water demand pattern model, a temperature model and a hydraulic model. The water demand pattern model describes the patterns at the individual tap units. The temperature model describes the heating and cooling of the drinking water in the pipes due to influence of surrounding temperatures and the hydraulic model describes the water transport throughout the DDWS. The three submodels are described in more detail in the following sections.

Hydraulic model

For the hydraulic calculations we used EPANET. The EPANET model for a typical Dutch DDWS was taken from Moerman (2013). For each individual pipe the heat transfer equations are solved. Then the hydraulics are calculated using EPANET with the individual tap patterns of SIMDEUM on all individual tap units. Calculations were done for 24 hours using a 10 second time step for the hydraulic and water quality calculations as well as the input patterns.

Water demand pattern model

For the water demand pattern model we use SIMDEUM (Blokker 2010). SIMDEUM is a stochastic water demand model in which patterns for individual taps are created. Tap demand is based on Dutch statistics about frequency and duration of water appliance use (shower, toilet, etc) and statistics about the presence during the day of the inhabitants. SIMDEUM also includes the technical details of appliances, such as for instance the water flow of a shower or the typical flush volume of a toilet. The resulting usages per appliance thus vary in duration.

Temperature model

To solve the heat transfer equations we used EPANET-MSX using a method described, and validated, by Moerman (2013) and Zlatanovic et al. (2017). Water within the DDWS may be heated up, depending on the scenario, in the connection pipe between the drinking water distribution pipe and the house. When heated up, water will cool down in all other pipes within the property. Fixed temperatures are set on the outside of all pipes (T_{GROUND} for the connection pipe and T_{HOUSE} for all other pipes, described in detail below) and for the water entering the connection pipe (T_{DWIN} , described in detail below). The actual values of these temperatures may differ per scenario.

Scenario's

This research focusses on the possible influence of 9 different variables of which 5 are independent. The remaining parameters depend either on the type of district heating or on the season. A detailed overview is given in Table 1 This has resulted in 128 different scenario's including reference scenario's where no district heating is present.

This research focusses mainly on the differences between scenario's rather than the absolute values of the results.

Table 1: Overview of the different variables. In bold are the values for the reference scenario's in which there is no district heating.

Variable	**Meaning**	**Season**		**District heating**	**Independent variable**
		Summer	**Winter**		
T_{DWIN} (dependent on season)	Temperature of the dringwater from the distribution net	20 ^{o}C	10 ^{o}C		
T_{GROUND} (dependent on season and type of district heating)	Temperature of the ground surrounding the connection pipe	**23 ^{o}C**	**3 ^{o}C**	30 ^{o}C	
$L_{CONNECTION}$	length connetion pipe				2 m / 10 m
$L_{KITCHEN}$	Length pipe from water meter to kitchen tap				5 m / 20 m
T_{HOUSE} (dependent on season)	Temperature in the house	**23 ^{o}C**	**20 ^{o}C**		

$D_{CONNECTION}$	Diameter connection pipe				25 mm / 32 mm
$M_{CONNECTION}$	Pipe material connection pipe				copper / PE
M_{HOUSE}	Pipe material DDWS				copper / PE

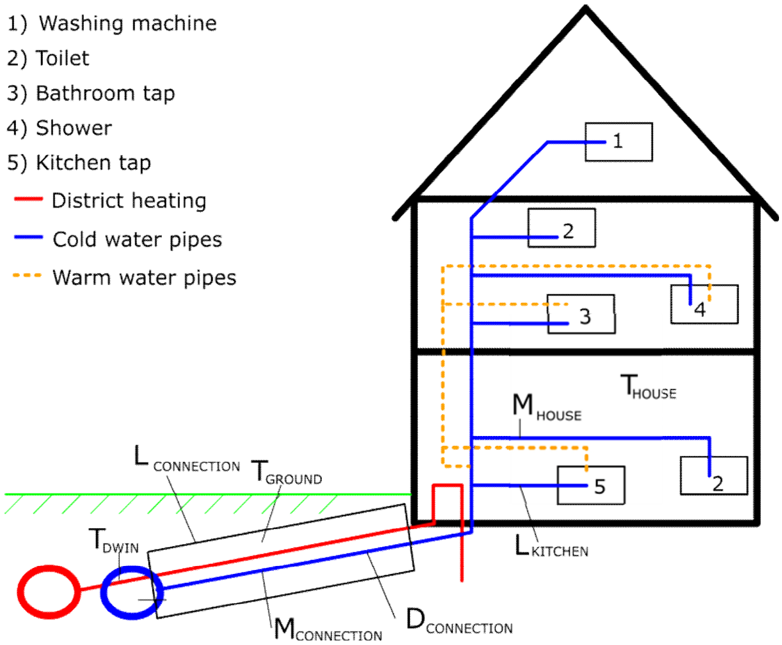

Figure 1: overview picture of all variables

RESULTS

For this research we have looked at the temperature at the cold water tap at three appliances: the kitchen tap, the bathroom tap and the shower. We looked at the maximum, minimum and average temperature (during tapping) during the 24 hours of model time. This means that, when a maximum temperature of X is reported, the temperature at that tap reached X at least once during the 24 hours.

In general the temperature at any tap in situations where district heating is present will follow a similar pattern when a tap is being used:

1) First the water which was present in the pipes from the water meter (directly after the connection pipe) to the tap will arrive. This water generally has the same temperature as the ambient temperature of the house.
2) If we leave the tap running long enough water from the connection pipe will now follow. If the previous tap (at any tap in the entire house) was sufficiently long ago, this water will be of the temperature T_{GROUND} or slightly below due to cooling in the pipes towards the tap point. Generally this cooling is rather limited.
3) If the tap is still running after this, water will follow from the distribution net. The temperature of this water will be slightly over T_{DWIN} . The time it takes to travel the connection pipe is too short to be heated up significantly there.
4) All temperatures at the taps are influenced by all the other taps. If, for instance, the bathroom tap is opened immediately after the shower was, the water present in the

pipes within the house as well as in the connection pipe will not have had sufficient resident time to be heated up significantly and the temperature at the tap will reflect the temperature in the distribution net more closely. This also illustrates the importance to model with realistic tap patterns for all taps.

The maximum temperature (point 2 above) is of short duration (it can only be equal to the volume present in the connection pipe). This typical pattern is reflected by the shower pattern of Figure 4. When we refer to a tap unit (for instance the kitchen tap) we always mean the cold water connection of this particular tap.

Warming up in the connection pipe

Figure 2 shows the temperature of the water within the connection pipe when there is no water being drawn and the water is therefore still. The important note here is that irrespective of material and season (different water temperature coming from the distribution net) after about 15 minutes the water will have reached its maximum temperature. Drinking water in the pipe is thus heated up fast.

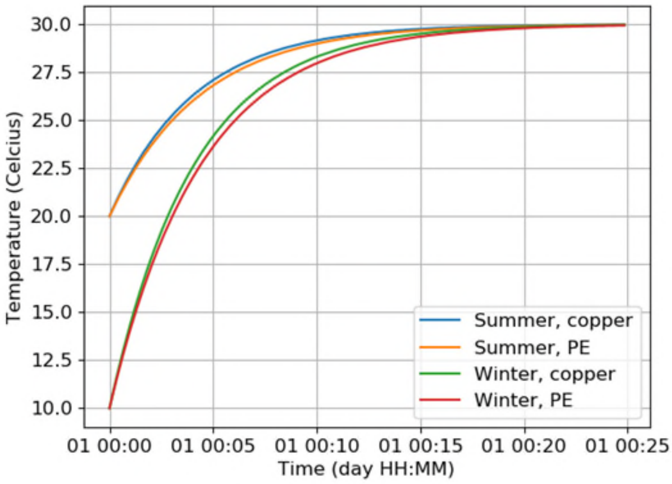

Figure 2: Warming up of the water within the connection pipe and or the pipe in the utilities closet

Temperatures at the tap

Results of the drinking water temperature at the kitchen tap during tapping are presented in Table 2

Table 2: Summary of differences in maximum, minimum and average water temperature at the kitchen tap. Reported are the variables with the highest impact

Variable	**Δ maximum water temperature**	**Δ average water temperature**	**Δ minimum water temperature**
T_{GROUND}	~25 °C (winter)	~3-5 °C (winter)	~15 °C (in winter)
Season	negligible	~3 °C	~7°C
$L_{CONNECTION}$	negligible	~1 °C	~3°C
M_{INSIDE}	~0,5°C	negligible	~1 °C

We can see that for the maximum temperature T_{GROUND} is the determining factor. Other variables have little to no effect. For the minimum temperatures T_{DWIN} (dependent on season) also has a considerable influence.

Temperature profiles during tapping

We analyzed the temperatures at the kitchen tap, bathroom tap and shower during tapping for different models. Figure 3 shows the temperature profiles during tapping for one of these models. Here we can see that temperatures at the bathroom tap never reach higher temperatures then about 20 ^{o}C. Temperatures at the kitchen tap occasionally reach over 20 ^{o}C with a maximum of about 27 ^{o}C. The temperatures at the shower reach to about 27 ^{o}C both times it is being used. The absolute maximum temperature can be found at the kitchen tap. This tap is closest to the connection pipe and water has thus less time to cool down in the DDWS. The bathroom tap is further away and never turned on long enough for heated up water from the connection pipe to reach the tap. The shower is, of course, turned on long enough both times and a detailed profile in Figure 4 shows the arrival of water from the DDWS first (at T_{HOUSE} of 20 ^{o}C) followed by a pocket of heated up water, followed by water from the distribution net which entered the connection pipe at 10 ^{o}C and is thus heated up by 3 ^{o}C along its way to the shower in either the connection pipe, the DDWS or both.

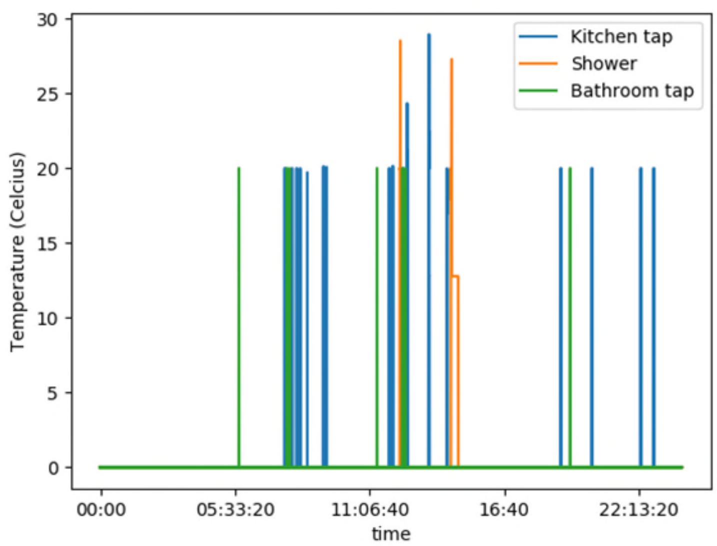

Figure 3: temperature during tapping (otherwise zero) for the shower, kitchen tap and bathroom tap for a model with district heating during winter time

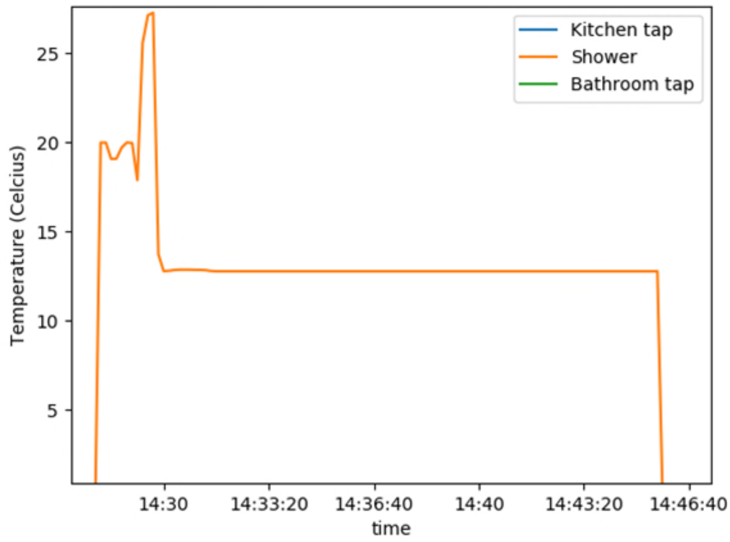

Figure 4: detail of a shower temperature profile

Figure 6 shows this heating of the water from the distribution net while flowing through the connection pipe and DDWS in more detail. Shown is the temperature of the water at the water meter (directly behind the connection pipe) and at the shower while the shower is flowing. Again we see the water at room temperature arrive at the shower first followed by the heated up pocket of water from the connection pipe. It takes this pocket of water from the connection pipe about 1 – 1.5 minute to arrive at the shower and during that time it cooled about 1 ^{o}C. This water is followed by water directly from the distribution net which is set to 10 ^{o}C in winter time. It heated up to about 13 ^{o}C while flowing through the connection pipe (of 10 meters in this particular scenario) and a final 1.5 ^{o}C in the rest of the DDWS. Figure 5 shows that for a shorter connection pipe water is not heated up as much.

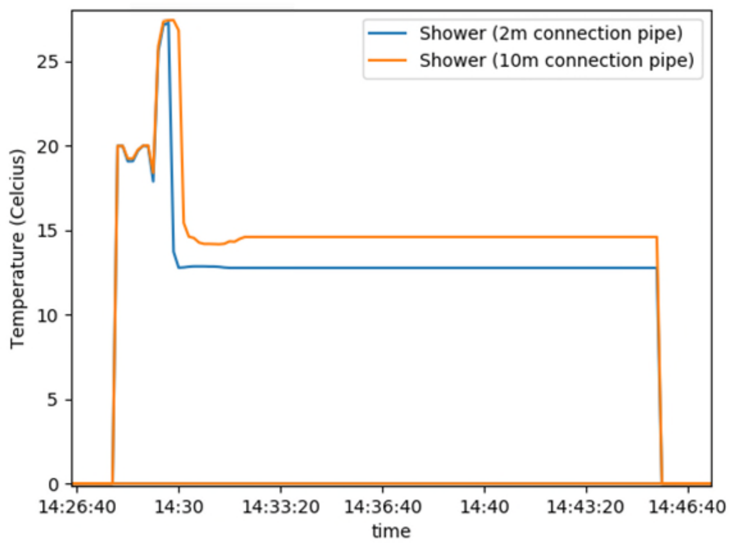

Figure 5: shower temperature profile for a model with district heating during winter time with a short and a long connection pipe

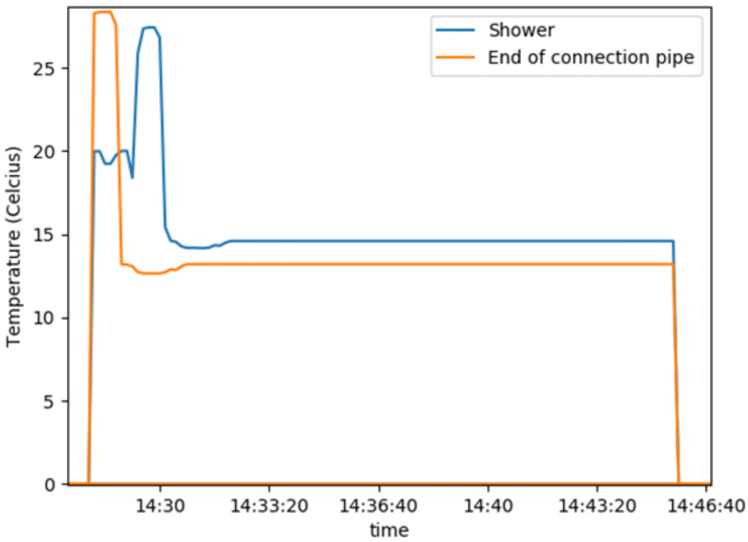

Figure 6: Temperature profile during tapping of shower at the shower and at the node directly behind the connection pipe for a model with district heating during winter time

DISCUSSION AND CONCLUSION

From all the variables we investigated the maximum temperature reached is almost solely determined by the presence or absence of district heating. The length of the connection pipe has an influence on the heating up of water which flows through it.. For all investigated connection pipes water is heated up to its maximum in about 15 minutes meaning that whenever in the entire house no tap is running for 15 minutes water will be fully heated up. A situation which will occur often in a normal domestic property. There is some cooling in the DDWS during flow and the size of the pocket of heated up water is of course dependent on the volume (diameter and length) of the connection pipe.

Because water, when standing still, heats up to T_{GROUND} fast (15 minutes) in the connection pipe and water can be expected to stand still in the connection pipe for 15 minutes many times during the day and even up to for instance several hours during the night isolation of the water pipe would need to be very extensive to make sure that water does not reach T_{GROUND}. A better solution would be to reduce T_{GROUND} (temperature of the ground directly around the connection pipe). This is probably possible by increasing the distance between the connection pipe and the district heating connection pipe.

Water tap patterns are important in this study. If for instance the bathroom tap would be left open for a longer period, temperatures would reach higher than they do in our models. It shows that modelling using realistic tap patterns is important in order to obtain all the nuances of the model.

When we would measure temperatures at the tap in real situations these results can help us understand what we are exactly measuring. According to our models the hottest water comes from the connection pipe and we thus need to leave the tap running long enough for it to reach the tap. Also the volume of the heated up water is limited to the volume of the connection pipe. This would have to be taken into account when measuring temperatures at the tap.

We showed that our model gives information on temperatures over the pipe length and over time, with water heating up and cooling down all the time. This information is not acquired when taking a sample at the kitchen tap. When studying water quality aspects in the drinking water installation we highly recommend to include this type of temperature modelling.

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