Finding (subsurface) anthropogenic heat sources that influence temperature in the drinking water distribution system

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Abstract. The water temperature in the drinking water distribution system and at the customers' taps approaches the surrounding soil temperature at ca. 1 meter depth. Water temperature is an important determinant of water quality, since it influences physical, chemical and biological processes, such as absorption of chemicals and chlorine decay. In the Netherlands drinking water is distributed without additional residual disinfectant and the temperature of drinking water at the customers' tap is not allowed to exceed 25 ºC. Routine water quality samples at the tap in urban areas have shown locations with relatively high soil temperatures compared to the expected modelled soil temperatures, so called 'underground hot-spots'. In the last decades, the urban sub-surface is getting more occupied with other sub-surface infrastructures and some of which can be heat sources. A few recent studies tackle the anthropogenic sources and their influence on the underground, but at coarse spatial scales. However, little is known about the urban shallow underground heat profile. Our research focuses on developing a method to identify and to localize potential underground hotspots at -1.0 m at a small spatial scale. First a literature study was done to identify possible sources of the underground hot-spots and secondly a method to search for the locations of these hot-spots was determined.

1 Introduction

The temperature of the water at the customers' tap is largely influenced by the soil temperature (T_{soil}) around the distribution pipes. In the Netherlands for drinking water distribution systems (DWDS) at ca. 1 meter depth, it was shown that the water temperature in the DWDS approaches the surrounding T_{soil} (Blokker and Pieterse-Quirijns, 2013). Water temperature is an important determinant of water quality. In the Netherlands drinking water is distributed without additional residual disinfectant and the temperature of drinking water at the customers' tap is not allowed to exceed 25 ºC (Drink Water Directive, 2011). During a warm year, 2006, 0.1% of the routine water quality samples exceeded this maximum value (Versteegh and Dik, 2007). With a rapid increase of the urbanised area, combined with increasing extreme weather events due to climate change, with more local variations due to the urban heat island effect and with increasing anthropogenic heat emissions (Menberg et al., 2013b), more samples may be expected to exceed this threshold.

Although it is clear that there is a relationship between subsurface temperatures and urban development (Grimmond et al., 2010a; Grimmond et al., 2010b), it is difficult to predict these temperatures at a small spatial scale. Currently, thermal remote sensing is used to observe and investigate the surface urban heat island (SUHI), which refers to the relative warmth of urban surfaces. The SUHI intensity is defined as the difference between the urban and rural surface temperatures (Klok et al., 2012). An analysis of the SUHI in the Netherlands showed the influence of different surface materials and soil types on the surface temperature. The daytime SUHI intensity of Rotterdam can be as large as 10 °C, with variations between the different neighbourhoods, creating "hot-spots" within the city. However, these analyses take place at coarse spatial and temporal scales (Agudelo-Vera et al., 2015a). Schwarz and Manceur (2015) concluded that attention needs to be paid to the aims of spatial planning, because mitigating the SUHI might lead to measures that are actually increasing mean temperatures. This can partly be explained by the fact that heat sources are not clearly identified. Mitigation measurements are effective when the heat sources are identified and localized and the magnitude and temporal variations are assessed. Additionally, anthropogenic heat sources are not only above the ground but also underground as shown by a number of German studies focusing on the sub-surface urban heat island (SSUHI) (Menberg et al., 2013a; Menberg et al., 2014; Menberg et al., 2013b; Müller et al., 2014; Benz et al., 2015).

Müller et al. (2014) reported 9 °C SSUHI gradient at 70 cm below ground level based on eight (urban) locations in Oberhausen (Germany) between July 2010 and September 2011. Agudelo-Vera et al. (2015a) reported 7 °C SSUHI based on temperatures at the tap in Rotterdam during the summer of 2012. The results of the temperatures at the tap, suggest that the SSUHI effect varies within the city. Blokker and Pieterse-Quirijns (2013) developed a micrometeorology model to predict T_{soil} at various depths as a function of weather and environmental conditions. Agudelo-Vera et al. (2015a) extended the model adding anthropogenic heat sources using literature values reported by Stewart and Oke (2012). The results for urban areas suggested a large influence of anthropogenic sources on the T_{soil} on locations with high anthropogenic heat sources. Therefore, different areas have a different risk of exceeding the threshold temperature. The average city and the peri-urban neighbourhoods show a low risk of exceeding the temperature limit. However, hot-spots show higher risks in the current situation and in the future. Specifically in urban areas, with concentrated population and diverse underground infrastructure and land cover characteristics, tools are needed to monitor and predict drinking water temperature in the network at small spatial scales.

There is a need to localize and quantify the "anthropogenic" (underground) sources and their influence on T_{soil} to plan site specific mitigation or adaptation measures. This information can also be used during the planning phase for installation/replacement of new pipelines to determine location and depth, considering the existing urban infrastructure and potential increase of temperature due to climate change. Modelling and random sampling are not enough to identify urban underground hot-spots. New methods are needed to localize and assess anthropogenic heat sources that influence the temperature in the DWDS. On-site measurements of T_{soil} are needed to better understand the thermal interactions of the shallow urban underground. Therefore, identifying the location of the hot-spots and quantifying their intensity is crucial to limit the risk of exceeding the temperature limit. This research focuses on developing a method to identify and to localize potential underground hotspots at -1.0 m at a small spatial scale.

2. Method

This article introduces a method to identify subsurface (anthropogenic) heat sources that influence temperature in the DWDS, Figure 1. Various data sources were used, given the complexity of the city, and different methods. Measurements and simulations were combined to beter understand T_{soil} in cities. Modelling offers the flexibility to simulate a range of urban configurations whereas measurements validate the simulated temperatures. Section 3 describes the steps described for a case study in the Netherlands, except for steps 3c–d because the measurements are taking place.

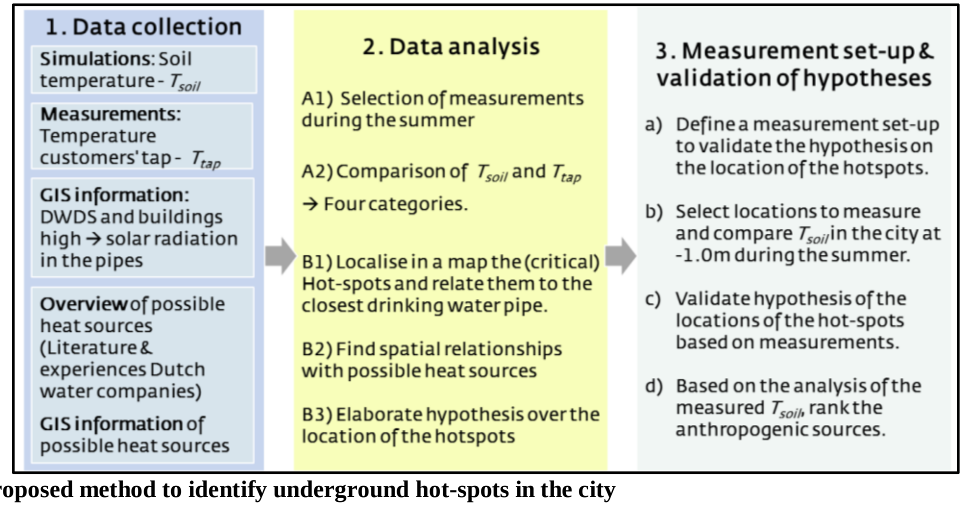

Figure 1 Proposed method to identify underground hot-spots in the city

A part of the city of Rotterdam was used as case study. T_{soil} at -1.0m in the average city and in the hotspots were simulated using the extend soil temperature model (Agudelo-Vera et al., 2015a). The expected maximum daily T_{soil} for the average city ($T_{soil\text{-}av}$), and the maximum expected daily T_{soil} for the hotspots ($T_{soil\text{-}hs}$) were determined from simulations. A period of 16 year was simulated, (2000 – 2015), to identify inter-annual variations. Temperature measurements from 2008 – 2015 at the tap (T_{tap}) during the summer were used. T_{tap} measurements were then classified into four categories, using T_{soil} simulations, as described below and in Figure 2:

1) Non hot-spot: $\mathrm{T_{tap}} < \frac{\mathrm{T_{soil-av}} + \mathrm{T_{soil-hs}}}{2}$

2) Low hot-spot: $\frac{\mathrm{T_{soil-av}} + \mathrm{T_{soil-hs}}}{2} \leq \mathrm{T_{tap}} < \mathrm{T_{soil-hs}}$

3) Hot-spot: $\mathrm{T_{soil-hs}} \leq \mathrm{T_{tap}} \leq \mathrm{T_{soil-hs}} + 2 * (\mathrm{T_{soil-hs}} - \frac{\mathrm{T_{soil-av}} + \mathrm{T_{soil-hs}}}{2})$

4) Critical hot-spot $\mathrm{T_{tap}} > \mathrm{T_{soil-hs}} + 2 * \left(\mathrm{T_{soil-hs}} - \frac{\mathrm{T_{soil-av}} + \mathrm{T_{soil-hs}}}{2}\right)$

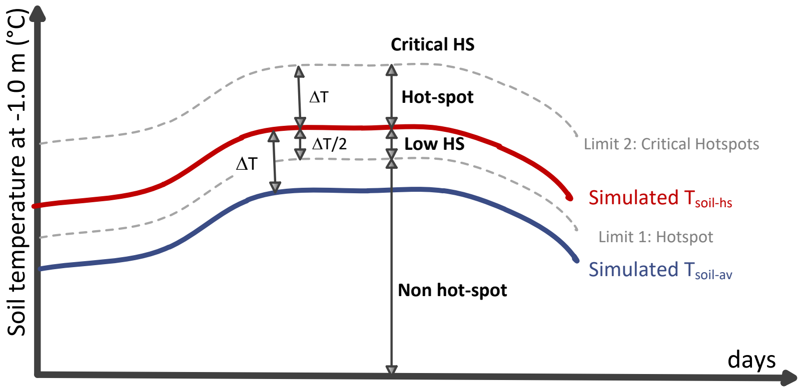

Figure 2: Schematic representation of the hotspots categories

Next, the tap temperatures were plotted and assigned to the closest DWDS pipe segment. Additional spatial information from anthropogenic heat sources (from step 1) in the city was also collected and plotted. Data from the location of the DWDS was analysed together with the information regarding the height of the buildings. Using a GIS tool the solar radiation onto each pipe was determined. Additionally, the hotspots identified from the T_{tap} measurements and the potential heat sources were plotted. Proximity analyses were used to determine the relationship between the heat sources and the four hot-spots categories. Areas with high density of hot-spots were identified to narrow down the search. For these specific locations a measurement set-up was proposed to validate the hypotheses.

3. Results and discussion

3.1 Simulating T_{soil} in the average city and in the hotspots

Figure 3 shows T_{soil} simulated for the months: June, July, Augustus and September for the average city and for the hotspots. The simulations for the average city showed 15 °C $< T_{soil-av} <$ 25 °C, while for the hotspots 17 °C $< T_{soil-hs} <$ 27 °C. The 25°C threshold temperature is approached only in very hot summers in the average city, while it is exceeded in the hot-spots in eight of the 16 simulated years, with a total of 75 days in 16 years, Figure 4. In a cold and wet year, 2011, a maximum $T_{soil-hs}$ of 23 °C was simulated.

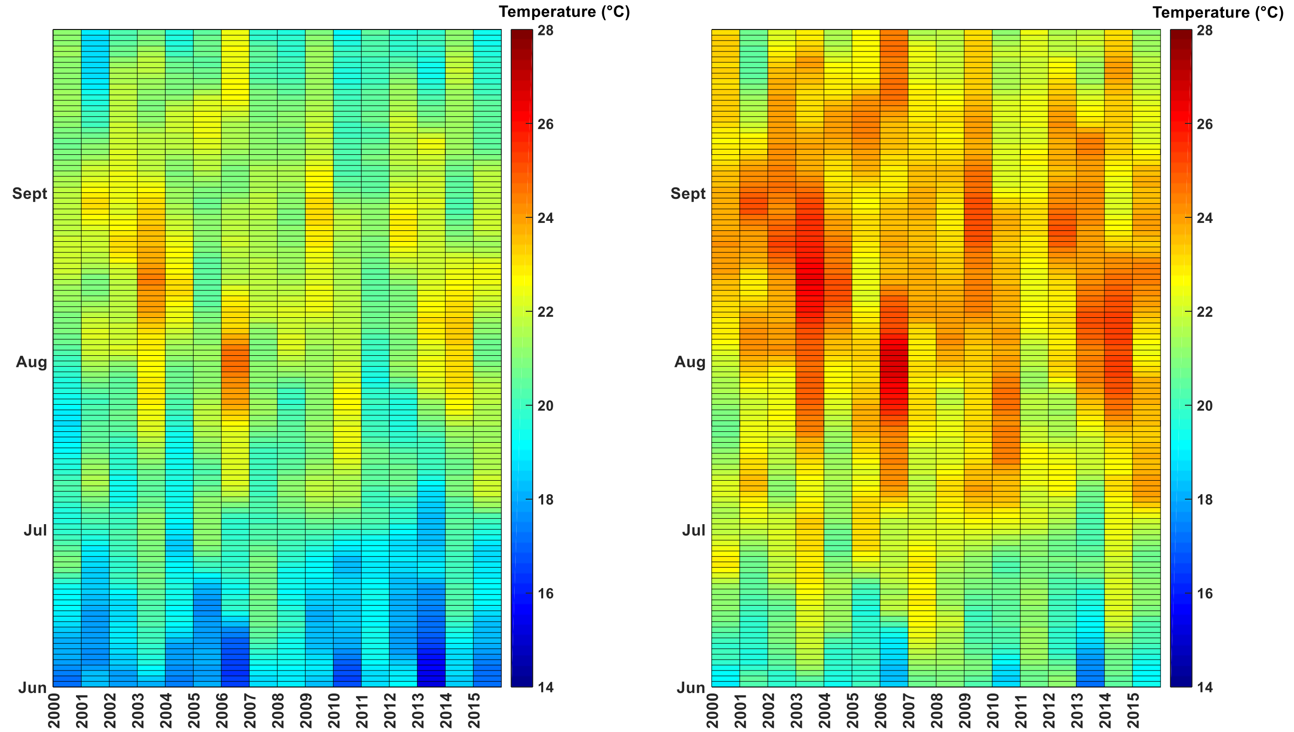

Figure 3: Simulations of T_{soil} at -1.0 meter in the average city (left) and in the hot-spots (right) from 2000 until 2015 during the months: June, July, August and September

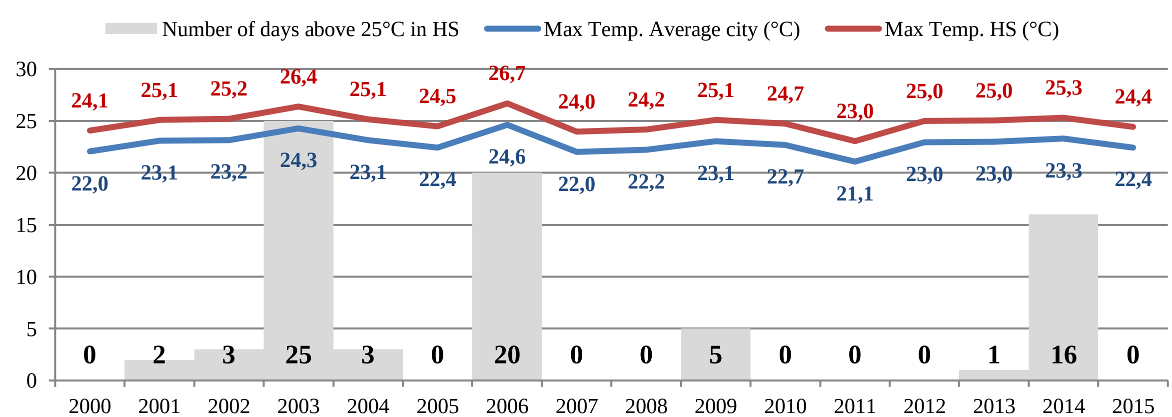

Figure 4: Simulated maximum T_{soil} at -1.0 meter in the average city and in the hot-spots from 2000 until 2015 and estimated number of days exceeding the 25°C in the hot spots.

3.2 Analysis of the measurements of the water temperature at the tap

The measurements of the water temperature at the tap were categorized as: Non hotspot, Low HS, HS and Crit-HS. Figure 5 shows the categorisation of the water temperature measurement at the tap. The number of hotspots is relatively small compared with the number of non-hotspots. It is important to highlight that current sampling of the locations is random and not focused on finding the warmest locations.

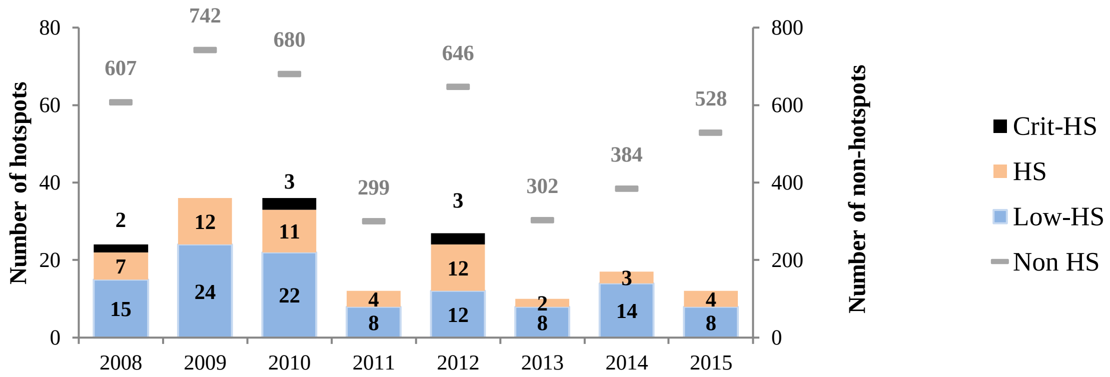

Figure 5: Overview of the categorisation of the measurements of the water temperature at the tap per year

3.3 Identification of the heat sources

Based on literature and experience of representatives of the Dutch drinking water companies 11 potential heat sources were identified. They were categorised between above and under ground, (Table 1).

Table 1 Overview of possible heat sources that influence underground hot-spots in Dutch cities

#	Above ground	#	Under ground
1	None or little shade (sidewalk)	6	(Old) district heating systems
2	None or little shade (asphalt streets)	7	Buried high power cables
3	High density of buildings and/or reflection of buildings facades (glass buildings)	8	Basements / underground parking facilities
4	Waste heat of special buildings (e.g. swimming pools, cooling facilities)	9	Tunnels (Metro infrastructure)
		10	Sewer networks
5	Electrical distribution substations	11	ATES systems & underground heat storage infrastructure

3.4 GIS information to asses solar radiation in the DWDS and potential heat sources

Figure 6 shows a detail of the GIS analysis, where the possible heat sources, shade conditions and the categorised tap samples are plotted. After that, a proximity analysis was performed, however, no direct relationship was found between the heat sources and the hotspots. This is due to the location of most of the T_{tap}, which are randomly selected.

Figure 6: Detail of the GIS analysis for a small area of the case study

3.4 Measurement plan

Based on the GIS analysis and together with the drinking water company, five neighbourhoods were selected to perform T_{soil} measurements for three months (15 July until 15 October 2016). To monitor different heat sources, 44 locations were selected based on the proximity to the possible heat sources identified in Table 1. A characterisation of the locations was done using the information described in Table 2. T_{soil} measurements are being carried out to validate this hypothesis. Therefore, a ranking of the anthropogenic heat sources is not yet included.

Table 2 Overview of the characterisation of the locations

Shade condition		Shade	Partial shade	No shade			
Urban type		Residential	Industrial	Urban square	Park		
Top layer		Tiles	Grass				
Anthropogenic sources	**Above ground**	Hospital	Laundry facilities	Reflection of buildings	Swimming pool	High density of buildings	Electrical distribution substations
	Under ground	Metro	High tension cable	ATES	Parking	District heating systems	

3.4 Outlook and future research

Although today the risk is still low, with climate change, increasing urbanization and increasing pressures on the underground, it is important to be able to anticipate and take measures to avoid the creation of new hotspots and to control the current ones. Greening the cities has been the “strategy” to make “climate change” proof cities, however this might not be always the best strategy. In busy urban areas, congested with underground infrastructures, several heat sources can be buried and be overseen during urban planning strategies to cope with climate change. By mapping the anthropogenic sources, customized measures can be taken based on the heat sources. If anthropogenic sources are not controlled, climate change adaptation measures are likely to fail.

Determining T_{soil} in urban areas is important for different aspects; for instance to predict infrastructure performance, e.g. pavement durability (Diefenderfer et al., 2006) or coupled heat pumps (Garcia Gonzalez et al., 2012), and to determine the drinking water temperature (Blokker and Pieterse-Quirijns, 2013). Managers of a single infrastructure cannot implement the required measurements that often involve urban planning. Collaboration between urban planners and infrastructure managers is crucial to create climate change proof cities. While mitigation measures can reduce the impact of the SSUHI and climatic changes, these measures take time to implement and to have an impact. In the meantime, there is a need to monitor drinking water temperature in the DWDS and prevent drinking water quality problems during heat waves, especially in the high density urban areas.

Although a lot of information comes available from satellite images, underground infrastructure is not visible and often neglected. Nowadays with increasing open/public data and GIS systems combining data of different infrastructure is possible to understand the heat profile of the urban underground.

This research focused on the Netherlands, with a moderate maritime climate with cool summers and mild winters. A similar approach can be used to identify hotspots in other cities worldwide. Earlier research has shown that it is possible to use weather forecast information as an "early warning system" to predict temperature in the DWDS (Agudelo-Vera et al., 2015b). Understanding the spatial distribution of heat sources and using models to simulate soil temperatures, managers will be able to anticipate to extreme weather events, such as heat waves.

4. Conclusion

Underground hot-spots have been overlooked, although their impact on infrastructure and in the urban climate can be significant. This article introduced a method to localize underground hotspots in the city. Given the complexity and heterogeneity of urban soils and the unknown interactions of buried infrastructure and the city, finding these hot-spots needs different approaches, e.g. simulating soil temperatures, using alternative data sources, e.g. temperature at customer's tap and performing GIS analysis. Finally validation of the hypothesis can only be done with measurements in situ.

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