THERMAL WALK IN PRACTICE - MARINETERREIN JUNE 18, 2019

Conclusions & interpretations

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Amsterdam, 13 March 2020

Hogeschool van Amsterdam

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1. Introduction

The thermal walk investigates the influence of urban design on the thermal experience of pedestrians moving through a certain urban area. Thermal walks are often used by scientists to understand how residents experience heat in urban environments. However, thermal walks can also be beneficial to urban professionals working at local governments that need to adapt urban areas to rising temperatures. Thermal walks can answer their questions such as: How hot is a shopping street, a residential area, a specific walking route through the city or a station area? Which adjustments are needed to create cool spaces? Which factors determine whether the outdoor space is hot or cool and which of these factors can be included in a heat-resilient design? A thermal walk reveals and lets participants experience which urban designs are hottest, coolest or most pleasant, and which factors play a role. Therefore, thermal walks can help urban professionals by:

- Mapping the heat resilience of a specific area and understanding which adjustments can help to create cooler areas; and
- Teaching them the phenomenon of urban heat and the factors that lead to a heat resilient design.

On the 18th of June 2019, during the 'We make the city' festival, we used the thermal walk to investigate the heat resilience of the walking route on a former historic naval base in the city of Amsterdam, the Marineterrein. In addition, the thermal walk was accompanied by mini-lectures in order to teach the participants about the phenomenon of urban heat. The weather on this day was characterized by air temperatures above 25°C and the large presence of intermittent clouds, which were in fact not optimal conditions for the measurements.

The participants examined the thermal situation at four different locations: along the water, in a shady park, under a street tree, and in a paved sunlit environment. Among the participants were policy advisors and urban designers. The research questions that we tried to answer, were:

1) How heat resilient is the walking route on the Marineterrein?
2) Which factors influence the thermal experience of the walking route on the Marineterrein?
3) In what way can the microclimate of the Marineterrein be set up more attractively for pedestrians during hot days?

Next to this, we used this thermal walk to reflect on how it can be used and improved to help professionals in their work and as a tool to educate professionals. In this report, we first analyse the results of the thermal walk with respect to the three research questions. Subsequently, we briefly discuss the thermal walk as an education tool and how it helps urban professionals by mapping the heat-resilience of an area. The analyses and visuals in this report might be inspiring for future thermal walks.

2. Methods

2.1. Thermal walk set up

The thermal walk is a systematic approach to analyse the way people experience the urban outdoor space. The approach is derived from the sense walking method in which various experiences such as sound or smell can be mapped. The thermal walk helps to understand how different factors influence the perceived temperature. The methodology has been developed by researchers from England (Vasilikou & Nikolopoulou, 2013 and Vasilikou & Nikolopoulou, 2015). During a thermal walk, the participants of the walk visit a number of locations in a certain area and investigate the thermal situation at these locations on the basis of meteorological measurements and questionnaires.

Our thermal walk was planned on an early summer day with air temperatures above 25°C and the large presence of intermittent clouds. Such weather conditions are not optimal, as the presence of clouds reduces the incidence

of solar radiation and may affect the perceived temperature and the thermal perception of the participants. The walk was organized on the Marineterrein, a former historic naval base in the city of Amsterdam.

The thermal walk took place in two rounds, each with two groups. Each group consisted of 10 participants guided by one HvA urban climate researcher, Lisette or Anna (see Figure 1). At each location, the participants needed to write how they experience the microclimate with the help of a questionnaire.

The questionnaire consisted of both objective and open questions (see Appendix I). Questions asked were:

- How warm does it feel? Answer in °C.
- How do you feel at this location? Cold, fresh, neutral, warm, hot?
- How do you experience this environment thermally? Comfortable, uncomfortable, very uncomfortable?
- Which factors influence your thermal experience of the environment?

Figure 1: Thermal walk rounds. Left: Lisette's group in the park. Right: Anna's group at the 'tree' location.

Next to this, data was collected at a 1-minute interval using two Kestrel 5400 Heat Stress stations. The parameters analysed were: globe temperature (°C), air temperature (°C), wind speed (m/s), and relative humidity (%). The Kestrels were coupled with a vane mount and positioned at an approximate height of 1.1 m (centre of gravity of a human body). From these measurements, an index for the perceived temperature was calculated. For this, we used the PET-index (the Physiological Equivalent Temperature; Matzarakis et al., 1999).

Each thermal walk had a duration of 1 hour and consisted of 4 locations (see Figure 2): a park, an area below a tree, a street, and a waterfront location. The park is (naturally) a green area, with grass and surrounded by trees that provide shade for the entire space. The 'tree' location is in the middle of a large street surrounded by buildings on one side and by the park on the other side. This area is characterized by impervious pavement and the presence of a large tree, creating a large shaded area. The street location is at the corner of a line of buildings. This area is characterized by the presence of impervious surfaces and buildings, and no green or water features are present. The waterfront is at a pier, in the middle of a large water body with no shading features.

Each group started at the same time, but walked in opposite directions (see Table 1), to allow the investigation of the thermal walking history on the thermal experience of the participants. With a duration of approximately 10 minutes for each location, the participants had enough time to fill in the surveys and discuss the perceived microclimate conditions. This time was tight but sufficient for the measurements, as the black globe of the Kestrel needs a minimum of 7-10 minutes to adjust to true atmospheric conditions according to the website of the manufacturer.

Besides the measurements in the investigated areas, one Kestrel was also installed at a reference location to collect data for the entire period of the thermal walk. The reference location was at the entrance of the AMS Institute (see start; Figure 2) and is characterized by impervious pavement and without any shade. The heat resilience of the walking route was assessed through the comparison between the simultaneous measurements in the investigated areas and the reference location.

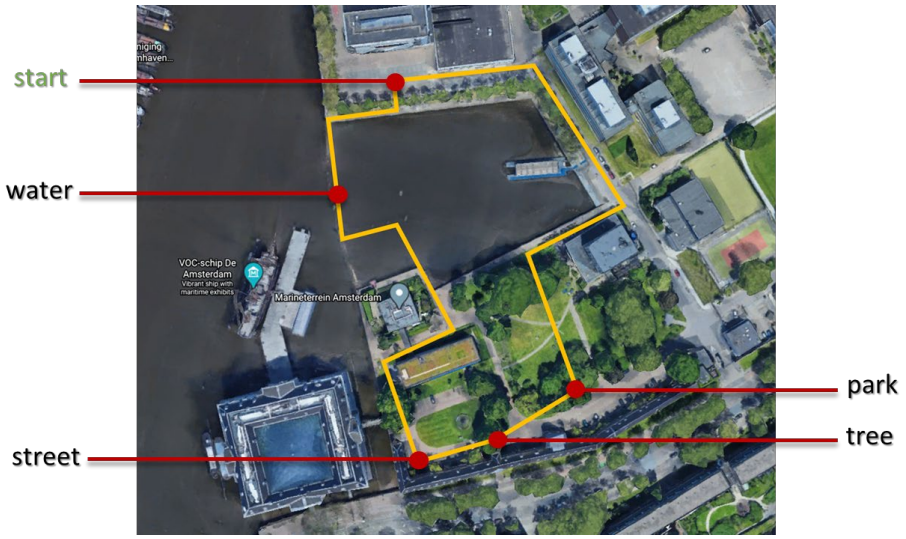

Figure 2: Locations of the thermal walk in the Marineterrein.

Table 1: Thermal walk routes and their time schedule.

Round	HvA researcher	Begin time	End time	Location
1st	Lisette	14:18	14:28	park
		14:31	14:41	tree
		14:42	14:52	street
		14:55	15:06	water
1st	Anna	14:15	14:25	water
		14:29	14:39	street
		14:41	14:51	tree
		14:54	15:04	park
2nd	Lisette	15:45	15:55	park
		15:56	16:06	tree
		16:07	16:17	street
		16:20	16:30	water
2nd	Anna	15:41	15:51	water
		15:55	16:05	street
		16:07	16:17	tree
		16:18	16:28	park

2.2. Data analysis

The parameters analysed were: globe temperature (°C), air temperature (°C), wind speed (m/s), and relative humidity (%). The mean radiant temperature (T_{mrt},°C) was calculated according to the equation proposed by Thorsson et al. (2007) (3.1). Each parameter used in the equation consisted of the average of the last 5 minutes of each walk measurement. As such, we obtained one value of T_{mrt} for each location point.

$$(3.1)\quad T_{mrt} = \left[\left(T_g + 273.15\right)^4 + \frac{1.1 \times 10^8 V_a^{0.6}}{\varepsilon D^{0.4}} \times \left(T_g - T_a\right)\right]^{\frac{1}{4}} - 273.15$$

Where:
T_g = (5-minutes average) globe temperature (°C)
V_a= (5-minutes average) wind speed (m/s)
T_a = (5-minutes average) air temperature (°C)
D = globe diameter (m)
ε = globe emissivity

The Kestrel 5400 Heat Stress has a black globe with a diameter of 1 inch (0.0254 m). According to the website of Kestrel, the temperature inside a 1-inch black powder-coated copper globe is converted to T_g equivalent for a standard 6 inches (0.15 m) globe. The calculation of the T_{mrt} also depends on the globe's mean convection coefficient, which is an empirically derived parameter. In equation 3.1, this is represented by $1.1 \times 10^8 V_a^{0.6}$, which is the globe's mean convection coefficient for a black globe.

With the T_{mrt} values, we calculated the the PET-index. The PET was calculated with the software Rayman version 1.2. The personal data, clothing, and activity were kept as default: male, 35 years, 75 kg, 1.75 m, 0.9 clo, and 80 W, as a light activity. The input for the program consisted of the average of the last 5 minutes of each walk measurement of air temperature (°C), relative humidity (%), wind speed (m/s) and the mean radiant temperature (°C). As for all the other parameters, we obtained one PET value representative of each location during the walk.

The data from the interviews was plotted in graphs and analysed both individually but also in combination with the measurement data. This way, we could compare the thermal experience of the environment and the measured thermal conditions.

3. Results

3.1. Meteorological data

3.1.1. Air temperature

Figure 3 shows the 1-minute interval data of the measured air temperatures during the thermal walks and Table 2 provides the average air temperature for every location along the walking route. The first aspect to be noticed is that the air temperature is very similar for all the instruments before the beginning of the first thermal walk, supporting the accuracy of the sensors given by the manufacturer (see Figure 3). During the period between the first and the second walk (15:15 – 15:30), however, the air temperature differences among the sensors are higher than the accuracy provided by the manufacturer.

Table 2 shows that nearly all investigated areas are cooler than the reference location. The differences are small: up to 2.2°C in the first measurement round and 1.9°C in the second one. Such differences in air temperature may reflect the real temperature differences between the locations, but can also be the result of the warming up of the Kestrel's air temperature sensor. The Kestrel's casing is not properly shielded and the sensor is not

actively ventilated. As a result, the casing may warm up if exposed to long periods in the sun, affecting the air temperature readings of the sensor. As the reference Kestrel was always in the sun, this might have affected the results. This effect can also explain the larger differences among the sensors observed during the time in between the two thermal walks.

Despite the temperatures above 25°C, the measurement day was not really hot and had the presence of intermittent clouds. This makes it difficult to determine which locations are heat resilient. However, we can observe that in 3 out of 4 walks, the park and the tree were the coolest places, whilst the water and the street were the hottest places. When comparing to the reference location, the park was the coolest one and the street and water share equally the position as the hottest spots. These results suggest that the green areas are cooler than the other locations and that the results are linked to environmental characteristics rather than weather fluctuations.

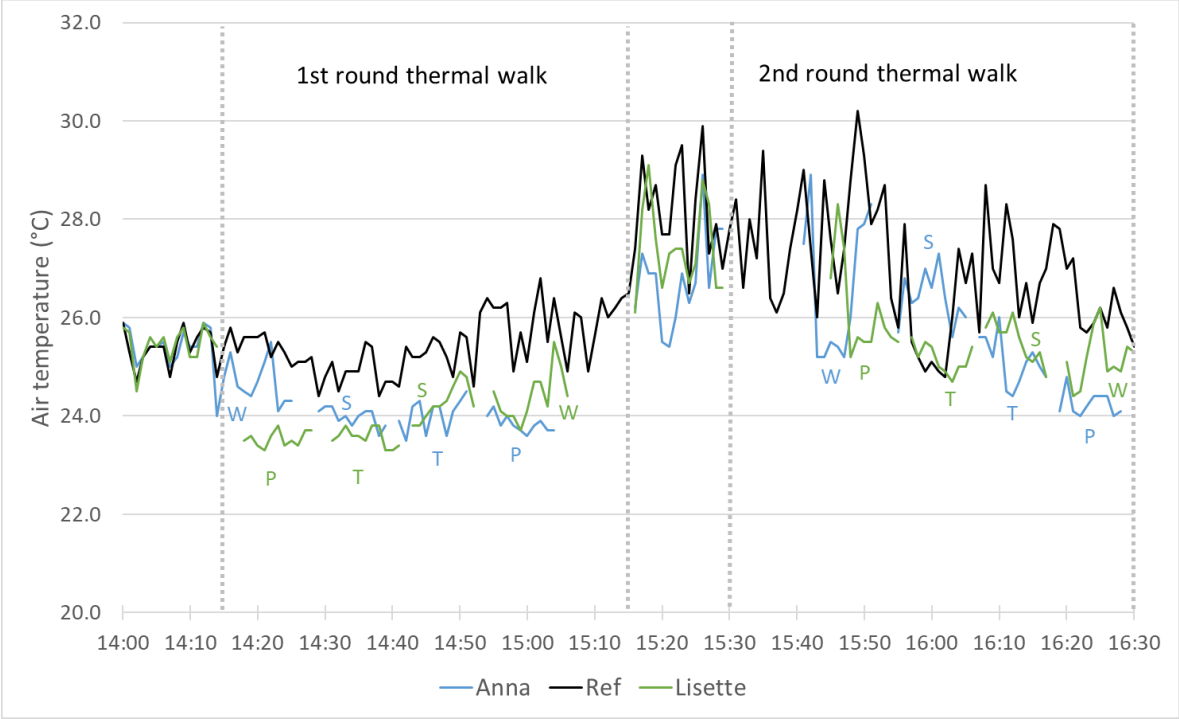

Figure 3: Air temperature (1-minute interval) of the 3 Kestrels during the entire period of the thermal walk.

Table 2: Average air temperature for every location of the thermal walk. The arrows indicate the walking direction and the colours indicate the hottest areas (red) and the coolest ones (blue).

1ST ROUND – AVERAGE AIR TEMPERATURE

	Anna	Δ (Anna-Ref)	Lisette	Δ (Lisette-Ref)
WATER	24.7°C	-0.7°C	24.8°C	-1.1°C
STREET	23.9°C	-1.1°C	24.6°C	-0.6°C
TREE	24.1°C	-1.2°C	23.5°C	-1.2°C
PARK	23.7°C	-2.2°C	23.5°C	-1.6°C

2ND ROUND – AVERAGE AIR TEMPERATURE

	Anna	Δ (Anna-Ref)	Lisette	Δ (Lisette-Ref)
WATER	27.0°C	-1.7°C	25.1°C	-0.8°C
STREET	26.3°C	0.3°C	25.2°C	-1.3°C
TREE	25.0°C	-1.5°C	25.0°C	-1.4°C
PARK	24.3°C	-1.9°C	25.7°C	-1.7°C

Walking route

3.1.2. Relative humidity

The relative humidity (see Figure 4) follows an inverse pattern of air temperature. This is an expected result, as the capacity of air for containing water vapor is almost an exclusive function of its temperature, with warm air having a much larger capacity than cold air (Bencloski, 1982). The relative humidity at all investigated areas was mostly larger than at the reference location. The differences achieved a maximum of 7.1% (see Table 3). In 3 out of 4 walks, the relative humidity was the lowest at the waterfront and the highest at the park. Interestingly, this is the opposite of what most people think. When comparing the investigated areas with the reference location, the street, and the park are the places with the lowest and the highest relative humidity, respectively.

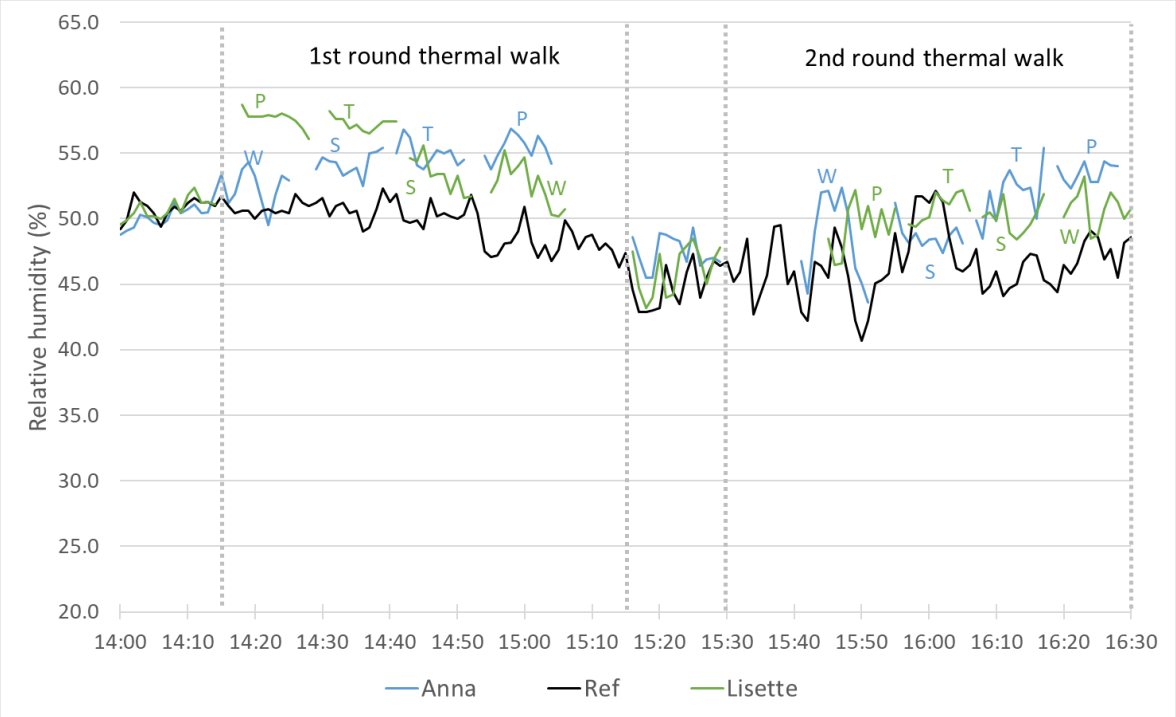

Figure 4: Relative humidity (1-minute interval) of the 3 Kestrels during the entire period of the thermal walk.

Table 3: Average relative humidity for every location of the thermal walk. The arrows indicate the walking direction and the colours indicate the areas with the lowest (red) and the highest (blue) relative humidity.

1ST ROUND – AVERAGE RELATIVE HUMIDITY

	Anna	Δ (Anna-Ref)	Lisette	Δ (Lisette-Ref)
WATER	51.8%	1.2%	51.3%	3.4%
STREET	54.4%	4.0%	52.4%	1.8%
TREE	54.8%	4.6%	57.1%	6.0%
PARK	55.3%	7.1%	57.3%	6.2%

2ND ROUND – AVERAGE RELATIVE HUMIDITY

	Anna	Δ (Anna-Ref)	Lisette	Δ (Lisette-Ref)
WATER	47.5%	3.8%	51.0%	3.6%
STREET	48.4%	-0.4%	49.9%	3.6%
TREE	52.5%	6.2%	51.5%	3.7%
PARK	53.6%	6.1%	50.0%	4.5%

Walking route

3.1.3. Wind speed

As expected, the wind speed was highly variable (see Figure 5). In 3 out of 4 walks, the average wind speed was the highest and the lowest at the waterfront and the tree location, respectively. In general, the wind speed at the study area was relatively low everywhere with most of the readings below 1.5 m/s. In comparison with the reference location, differences were variable and small (<1 m/s) (see Table 4).

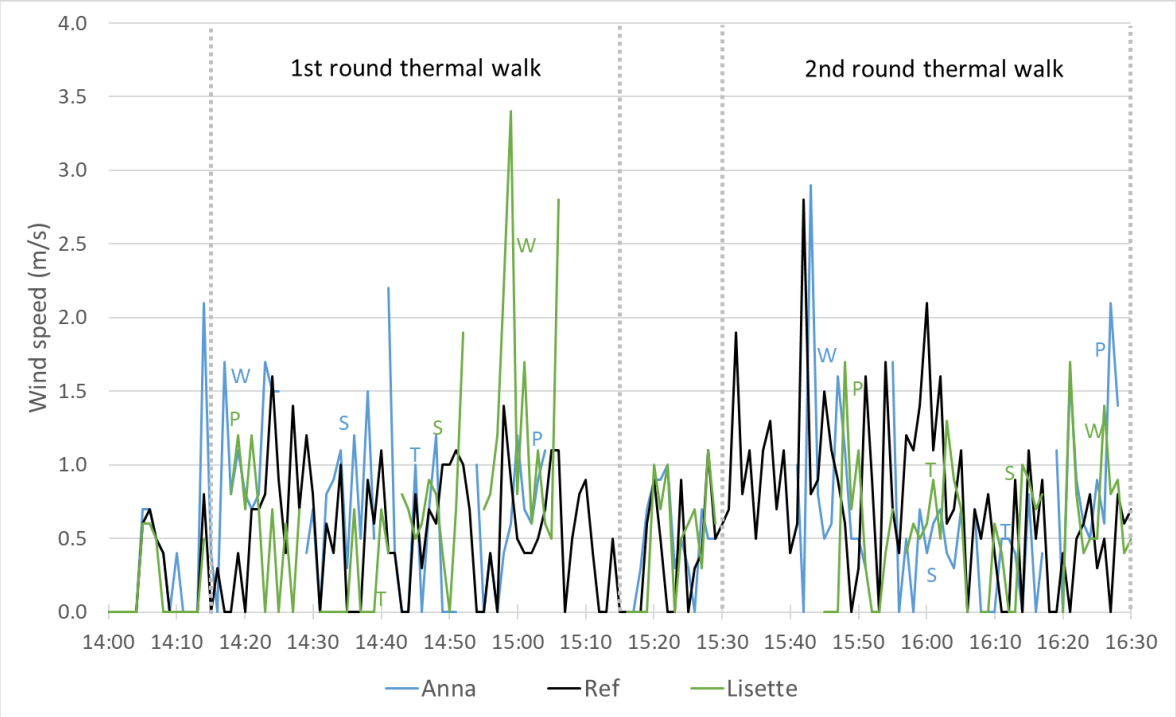

Figure 5: Wind speed (1-minute interval) of the 3 Kestrels during the entire period of the thermal walk.

Table 4: Average wind speed for every location of the thermal walk. The arrows indicate the walking direction and the colours indicate the areas with the lowest (red) and the highest (blue) wind speed.

1ST ROUND – AVERAGE WIND SPEED

	Anna	Δ (Anna-Ref)	Lisette	Δ (Lisette-Ref)
WATER	1.2 m/s	0.3 m/s	1.1 m/s	0.4 m/s
STREET	0.8 m/s	0.5 m/s	0.8 m/s	-0.2 m/s
TREE	0.4 m/s	-0.5 m/s	0.2 m/s	-0.4 m/s
PARK	0.9 m/s	0.4 m/s	0.4 m/s	-0.6 m/s

2ND ROUND – AVERAGE WIND SPEED

	Anna	Δ (Anna-Ref)	Lisette	Δ (Lisette-Ref)
WATER	0.8 m/s	0.1 m/s	0.8 m/s	0.3 m/s
STREET	0.5 m/s	-0.5 m/s	0.7 m/s	0.0 m/s
TREE	0.3 m/s	-0.4 m/s	0.7 m/s	-0.1 m/s
PARK	1.1 m/s	0.6 m/s	0.3 m/s	-0.7 m/s

Walking route

3.1.4. Globe temperature

Before the beginning of the thermal walk, all the Kestrels showed a very similar globe temperature, supporting the accuracy of the sensors (see Figure 6). In all the walks, the globe temperature was the highest at the waterfront and the lowest in the park and under the tree. This shows the importance of shadow by trees in reducing the incoming solar radiation. The globe temperature was higher at the reference location compared to any of the other investigated areas. In this case, the waterfront and the street are the ones with the smallest

differences compared to the reference, whereas the park and the tree locations are the locations with the highest differences reaching up to 15.8 °C.

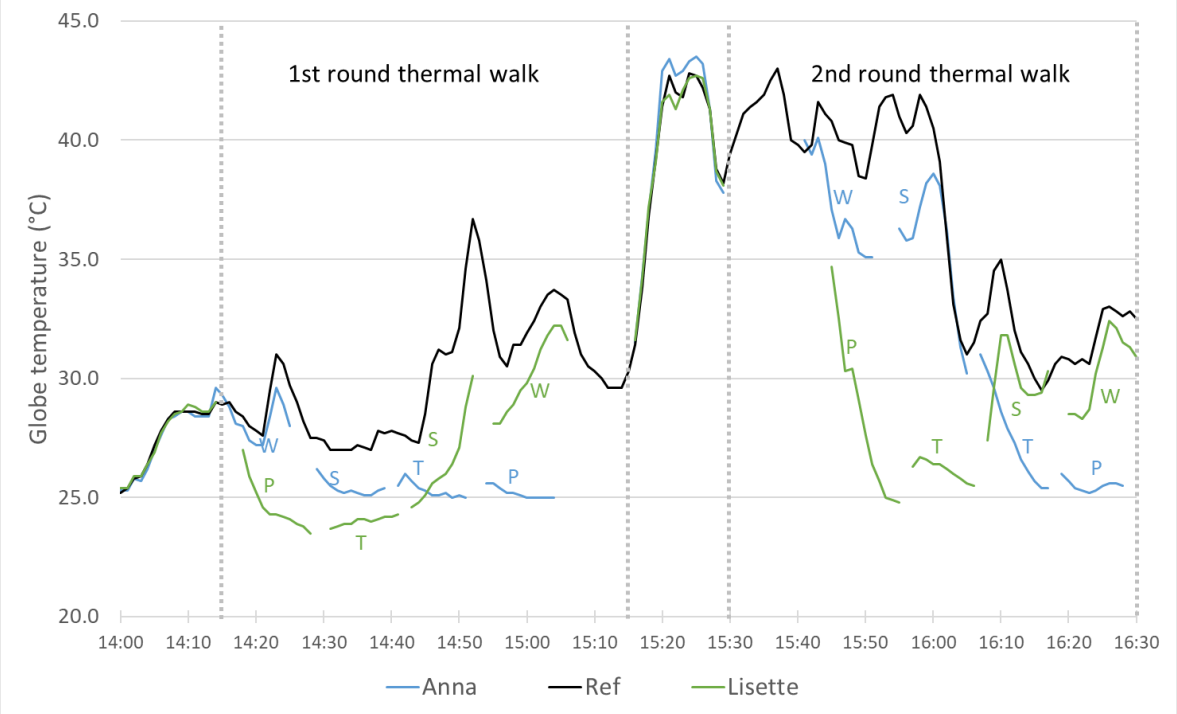

Figure 6: Globe temperature (1-minute interval) of the 3 Kestrels during the entire period of the thermal walk.

Table 5: Average globe temperature for every location of the thermal walk. The arrows indicate the walking direction and the colours indicate the areas with the lowest (red) and the highest (blue) globe temperature .

1ST ROUND – AVERAGE GLOBE TEMPERATURE					
	Anna	Δ (Anna-Ref)	Lisette		Δ (Lisette-Ref)
WATER	28.4°C	-1.3°C	31.8°C		-1.6°C
STREET	25.2°C	-2.1°C	27.7°C		-5.4°C
TREE	25.1°C	-6.9°C	24.2°C		-3.4°C
PARK	25.0°C	-7.9°C	23.9°C		-5.1°C
2ND ROUND – AVERAGE GLOBE TEMPERATURE					
	Anna	Δ (Anna-Ref)	Lisette		Δ (Lisette-Ref)
WATER	35.7°C	-3.6°C	31.6°C		-1.1°C
STREET	33.8°C	-0.3°C	29.6°C		-0.6°C
TREE	25.8°C	-4.4°C	25.8°C		-6.8°C
PARK	25.5°C	-7.1°C	25.4°C		-15.8°C

Walking route

3.1.5. PET

The highest PET values were estimated for the waterfront and the lowest for the park (3 out of 4 walks) (see Table 6 and Figures 7 and 8). Similar to the globe temperature, the PET was higher at the reference location compared to any of the investigated areas. In this case, the park is the location with the highest differences, whereas the waterfront and the street are the ones with the highest ones. This difference was more evident when comparing it to the park, with values up to 18.5 °C. In general, the wind speed at the Marineterrein was low everywhere and hence differences in PET were mostly influenced by solar radiation. As the waterfront and the reference location were the most open spaces, the PET-index in these areas was also highest. It is important to mention that there were intermittent clouds during the measurements. As a consequence, the differences

between the locations can be explained by both environmental characteristics but also by weather fluctuations. At the reference point, where environmental characteristics are constant, we could see a large variation in PET values (see Figure 9). This can be explained by the presence of local clouds and also by the radiation error on the temperature sensor as explained in paragraph 3.1.1.

Based on the PET values classification (Matzarakis et al., 1999), none of the investigated areas can be classified as comfortable (see Figure 9). At the park and tree location, PET values are close to the upper limit for "comfortable", but still classified as "slightly warm". In 3 out of 4 walks, the PET values of the street also fall in the category of "slightly warm" and in 1 walk, it is classified as "warm". The waterfront is the only location to be classified as "hot" in one of the walks. In the others, it is classified as "slightly warm" (1 walk) and "warm" (2 walks).

Table 6: PET values for every location of the thermal walk. The arrows indicate the walking direction and the colours indicate the areas with the lowest (red) and the highest (blue) PET.

1ST ROUND – PET					
	Anna	Δ (Anna-Ref)	Lisette		Δ (Lisette-Ref)
WATER	27.3°C	-1.7°C	31.8°C		-1.5°C
STREET	23.5°C	-3.3°C	26.5°C		-6.9°C
TREE	24.1°C	-7.7°C	23.8°C		-2.8°C
PARK	23.1°C	-9.6°C	22.9°C		-5.1°C
2ND ROUND – PET				Walking route	
	Anna	Δ (Anna-Ref)	Lisette		Δ (Lisette-Ref)
WATER	36.3°C	-3.9°C	31.4°C		-1.1°C
STREET	33.9°C	-0.8°C	28.8°C		-0.8°C
TREE	25.3°C	-4.3°C	24.4°C		-8.1°C
PARK	23.5°C	-8.7°C	24.8°C		-18.5°C

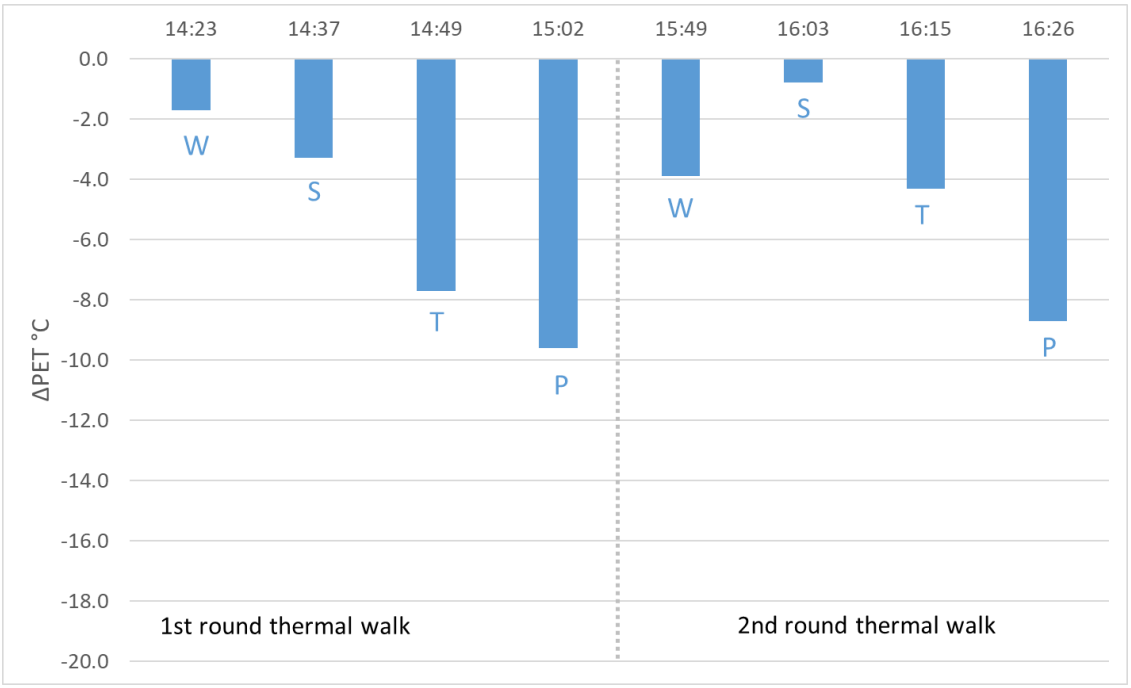

Figure 7: PET differences between Anna's kestrel and the reference.

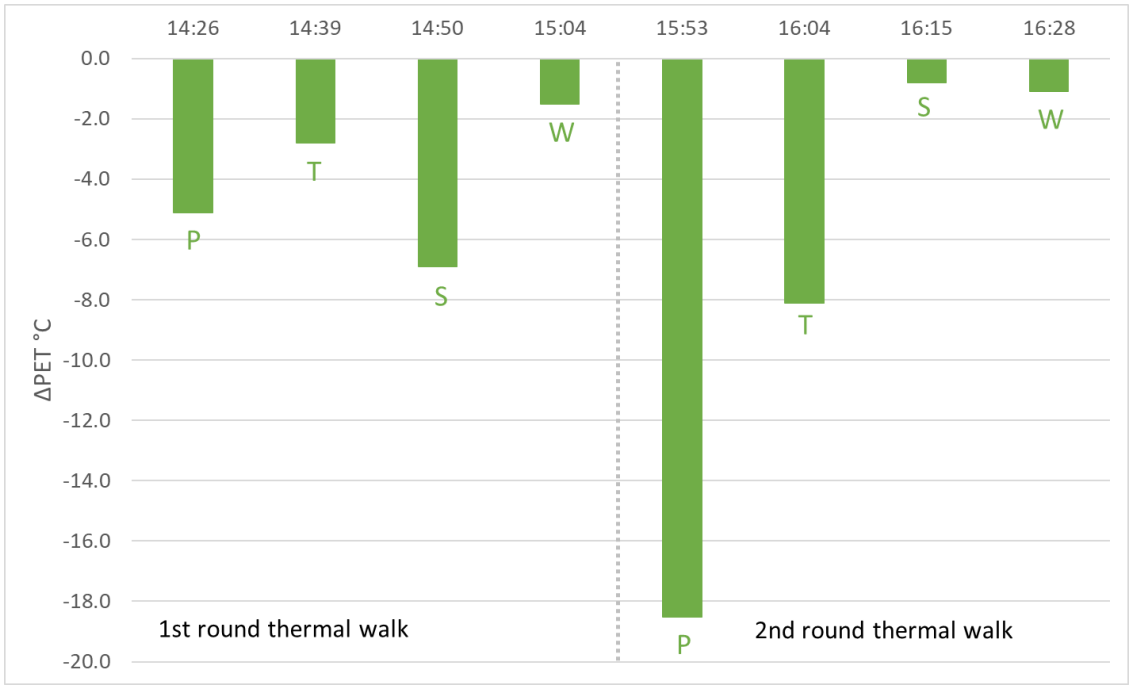

Figure 8: PET differences between Lisette's kestrel and the reference.

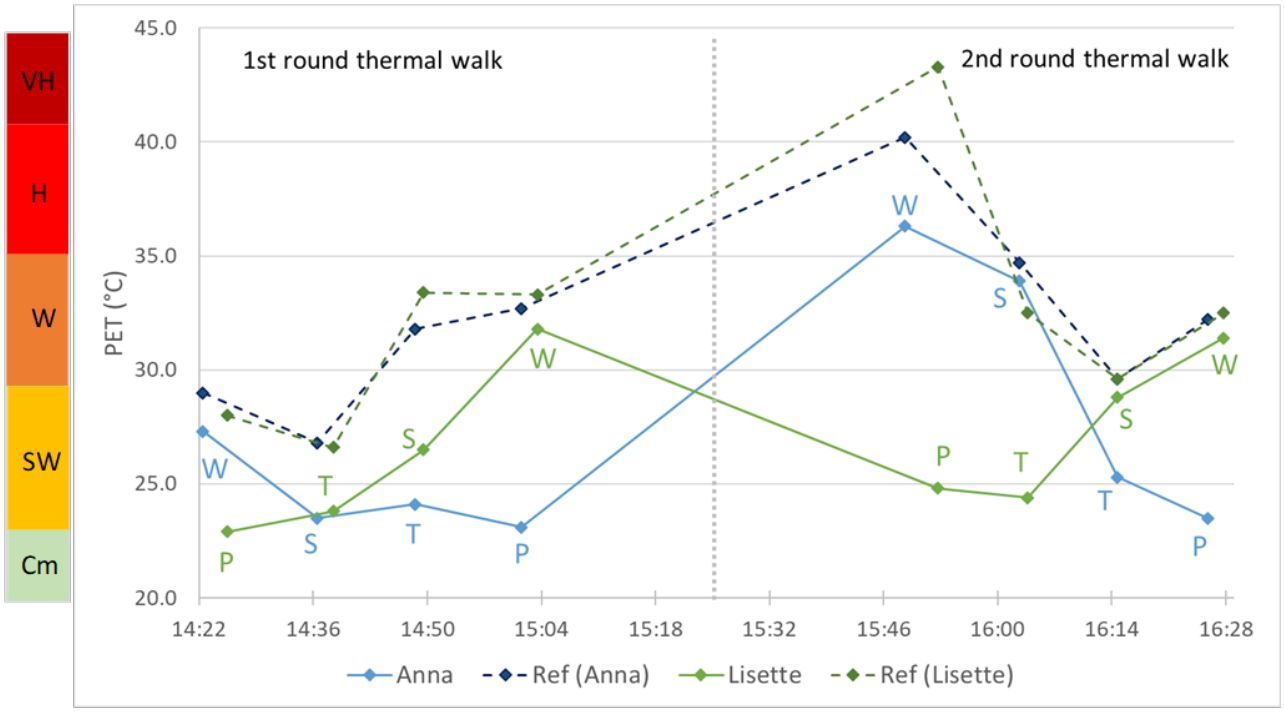

Figure 9: PET values for Anna's and Lisette's groups and their correspondent reference PET values. The bar on the left represents part of the PET scale (from up to down): Hot (41-35°C), Warm (35-29°C), Slightly Warm (29-23°C), Comfortable (23-18°C), and Slightly Cool (18-13°C) (Matzarakis et al., 1999).

3.2. Interviews

3.2.1. Air temperature (measured) versus air temperature (perceived)

The participants were asked to guess the air temperature at each location (the perceived temperature). Figures 10 and 11 show the measured air temperature and perceived temperature as filled out by the participants of the thermal walk. The graph of the perceived values contains error bars, which represent the standard deviation of the average temperature values described by the participants. Most of the time, people perceived the air temperature lower than it actually was. For Anna's groups, this difference averaged up to 3.3°C (3.4°C in the 1st round and 3.3°C in the 2nd). For Lisette's groups, the average difference was 1.7°C (2.0°C in the 1st round and 1.3°C in the 2nd).

In 3 out of 4 walks, the park was the location with the highest difference between the measured and perceived air temperature. During all walks, the street was perceived warmest, with the smallest differences from the measured air temperature. This can be explained by the psychological effect of the environment on people; people might consider green areas cooler than areas without vegetation.

3.2.2. PET (measured) versus air temperature (perceived)

Figures 10 and 11 also depict the comparison between the measured PET values and the perceived air temperature. In all cases, the perceived air temperature is lower than the actual PET values. The largest differences are found at the waterfront. This suggests that water has a psychological effect on people's perception of heat. People tend to think that an area surrounded by water is cooler, which is not always the case. At the Marineterrein, the waterfront had very little wind and was very exposed to sunlight, which resulted in high PET values. The perceived temperatures evaluated at the park and tree locations were closest to the measured PET-values.

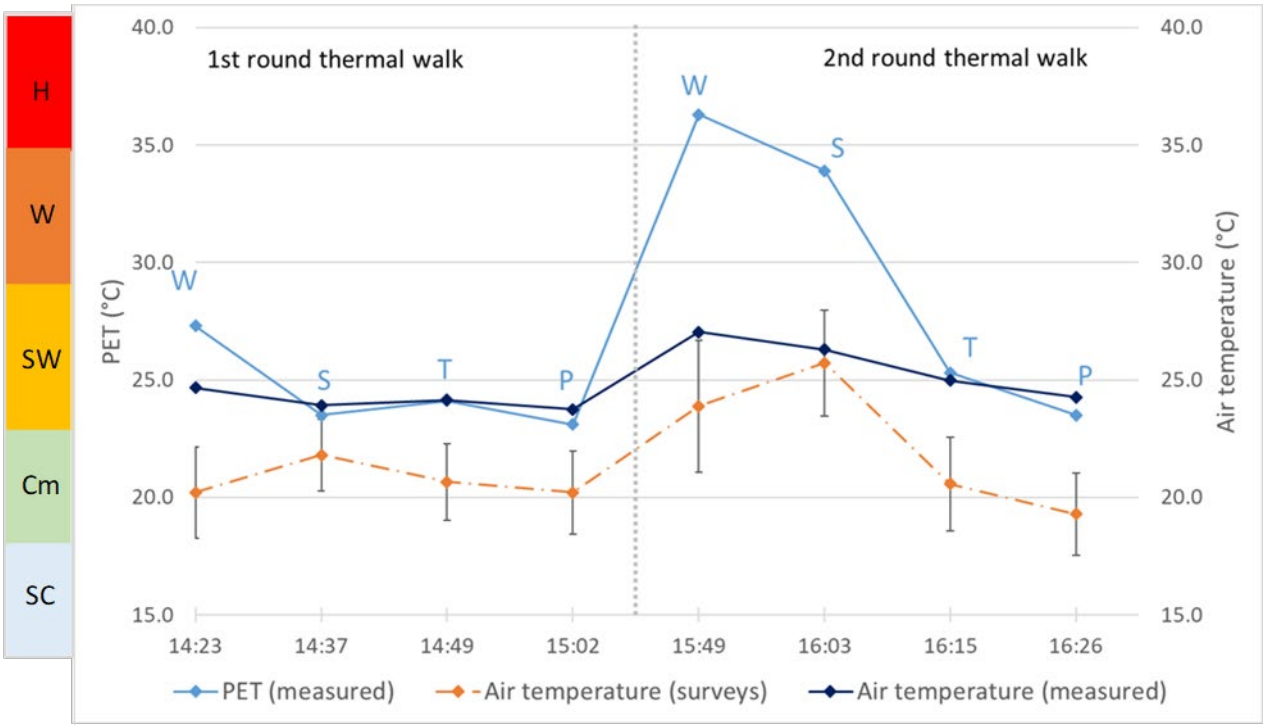

Figure 10: Comparison between the measured air temperature, the measured PET, and the average air temperature as perceived by the participants of the walk, for Anna's group. The error bars represent the standard deviation of the average temperature values described by the participants. The bar on the left represents part of the PET scale (from up to down): Hot (41-35°C), Warm (35-29°C), Slightly Warm (29-23°C), Comfortable (23-18°C), and Slightly Cool (18-13°C) (Matzarakis et al., 1999).

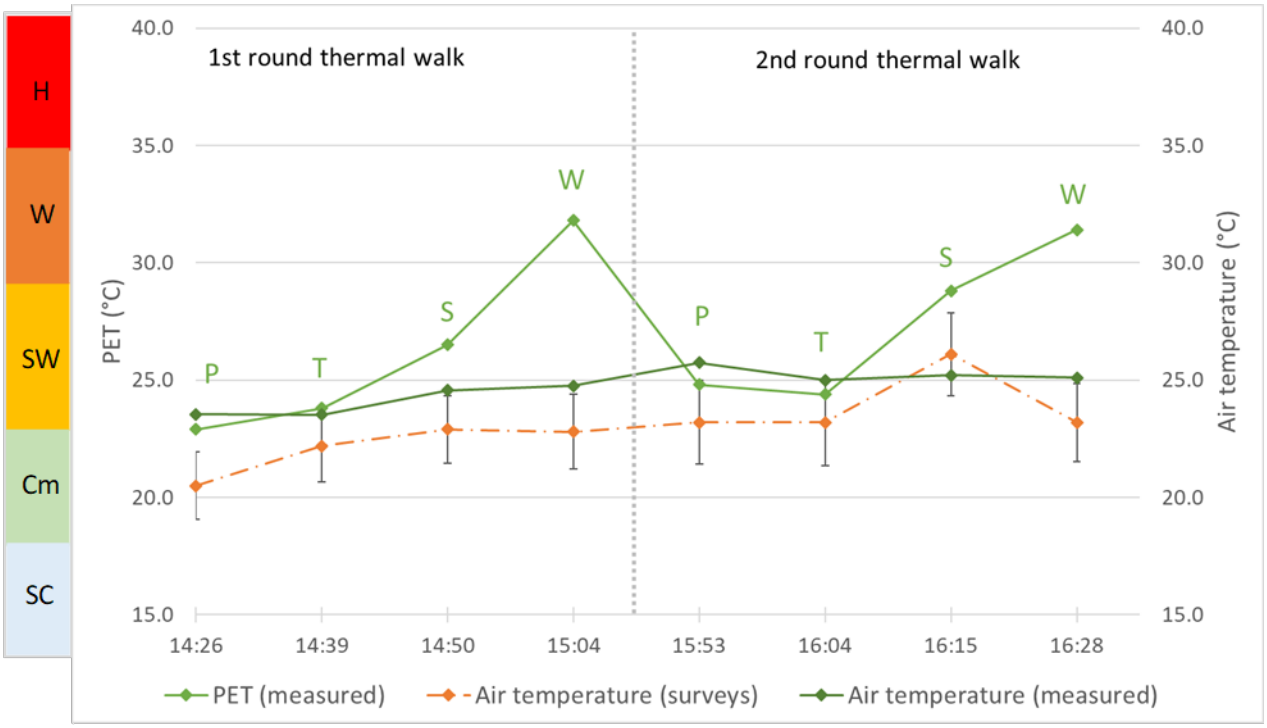

Figure 11: Comparison between the measured air temperature, the measured PET, and the average air temperature as perceived by the participants of the walk, for Lisette's group. The error bars represent the standard deviation of the average temperature values described by the participants. The bar on the left represents part of the PET scale (from up to down): Warm (35-29°C), and Slightly Warm (29-23°C), and Comfortable (23-18°C) (Matzarakis et al., 1999).

3.2.3. Thermal comfort

The participants rated the thermal comfort of each location as: comfortable, slightly uncomfortable, uncomfortable, and very uncomfortable. Most of the locations were classified as comfortable (see Figures 12 and 13), with exception to the street in both second walks. This matches with the measurements: the street is the place with the lowest PET differences in relation to the reference location (see Figures 8 and 9). The fact that people rated most of the locations as pleasant is an expected outcome if we take into account that the thermal walk occurred with mild temperatures. So, it was relatively pleasant everywhere.

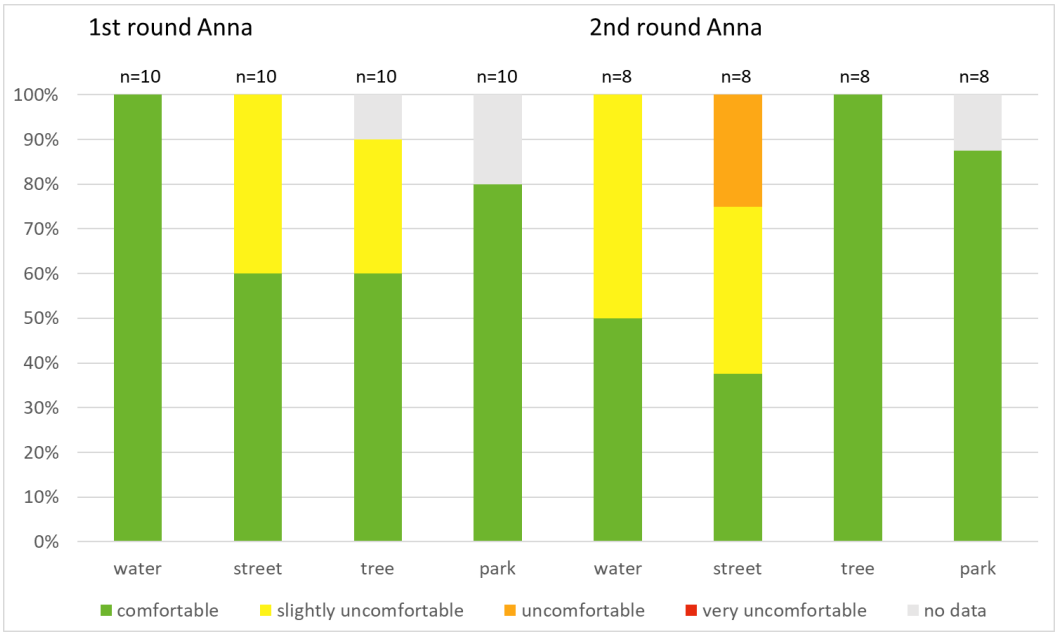

Figure 12: Thermal comfort rated by the participants of the thermal walk led by Anna.

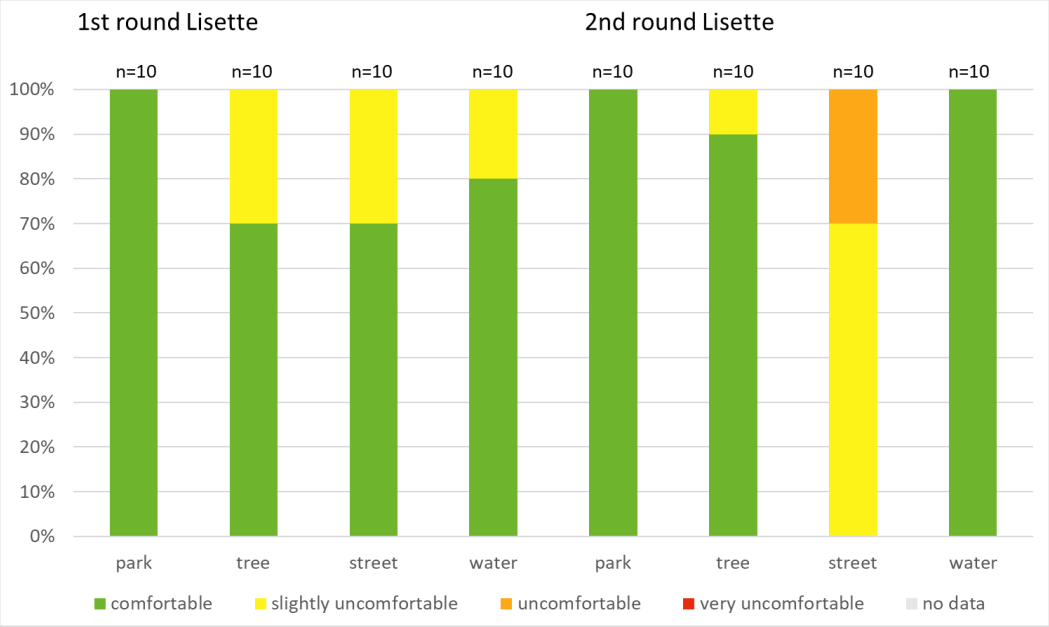

Figure 13: Thermal comfort rated by the participants of the thermal walk led by Lisette.

3.2.4. Thermal perception

The thermal perception was assessed based on 7 different levels of heat: cold, fresh, slightly fresh, neutral, warm, slightly warm, and hot. Figures 14 and 15 show the results in a graph and Table 7 provides a numerical overview of the thermal perception. We classified the thermal perception categories from 1 to 7: 1 being cold and 7 being hot. The numbers shown on the table are the average values computed with this numerical scale.

The results show that the street was perceived in all the walks as the warmest area, whilst the park was considered the coolest location (3 out of 4 walks). The thermal perception also changed between the two walks; people found the locations warmer in the second walk. Interestingly, the participants guided by Lisette assessed almost all locations warmer than the ones guided by Anna.

Table 7: Thermal perception results based on a scale of values from 1 to 7 with cold being 1 and hot being 7. The colours indicate the areas perceived as the warmest (red) and coolest (blue).

1ST ROUND – THERMAL PERCEPTION

	Anna	Lisette
WATER	3.7	4.1
STREET	4.2	4.6
TREE	3.9	4.3
PARK	3.5	3.9

2ND ROUND – THERMAL PERCEPTION

	Anna	Lisette
WATER	5.0	4.2
STREET	5.8	5.7
TREE	4.1	4.4
PARK	3.3	4.4

Walking route

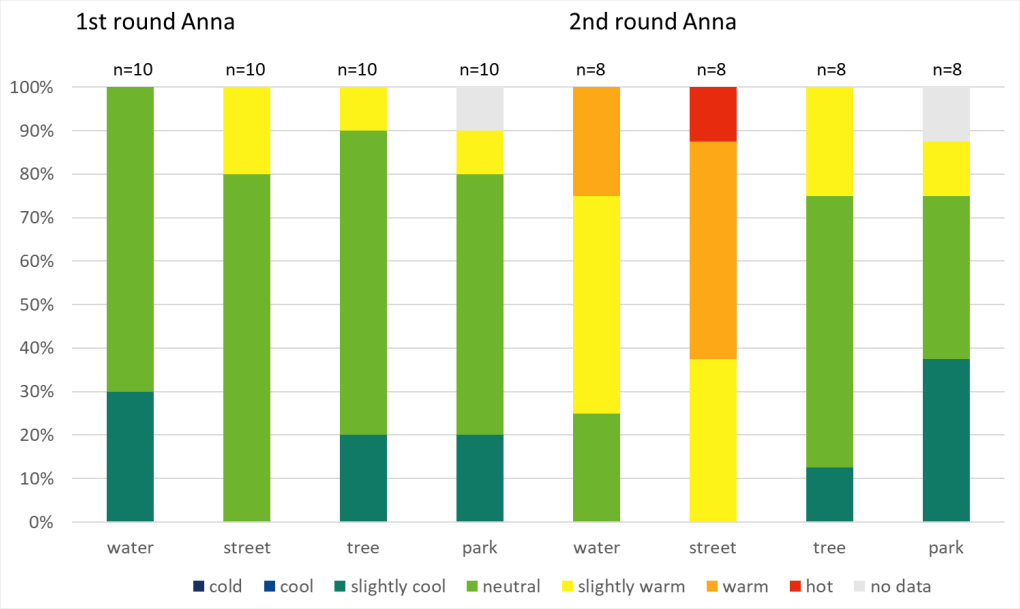

Figure 14: Thermal perception rated by the participants of the thermal walk guided by Anna.

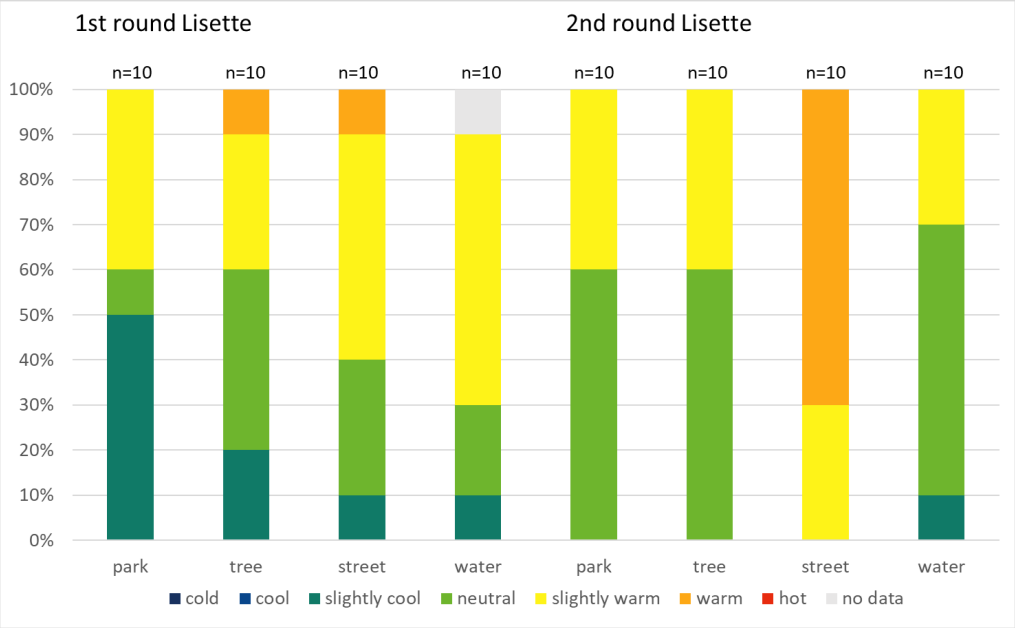

Figure 15: Thermal perception rated by the participants of the thermal walk guided by Lisette.

3.2.5. Thermal differences between the locations

The participants were also asked to assess if the location they were visiting was cooler, warmer or the same as the previous location. Figures 16 and 17 show the results, which are somewhat difficult to interpret. In words we can conclude for the four walks (where TS is the evaluated thermal situation):

- Anna:
  - 1st round: $TS_{reference} > TS_{water} < TS_{street} > TS_{tree} > TS_{park}$
  - 2nd round: $TS_{reference} > TS_{water} < TS_{street} > TS_{tree} \approx TS_{park}$
- Lisette:
  - 1st round: $TS_{reference} > TS_{park} \approx TS_{tree} < TS_{street} \approx TS_{water}$
  - 2nd round: $TS_{reference} > TS_{park} \approx TS_{tree} < TS_{street} > TS_{water}$

For Anna's first thermal walk, this reads: the thermal situation at the reference location was evaluated warmer than at the waterfront, the waterfront was evaluated cooler than at the street, etc.

The results indicate that the park and tree locations were rated similar, while the street was rated warmer than the water and the tree locations. This shows that people tend to feel less comfortable in spaces with little or no green. As the waterfront was either the first or last location, we cannot compare it with the green areas (park and tree).

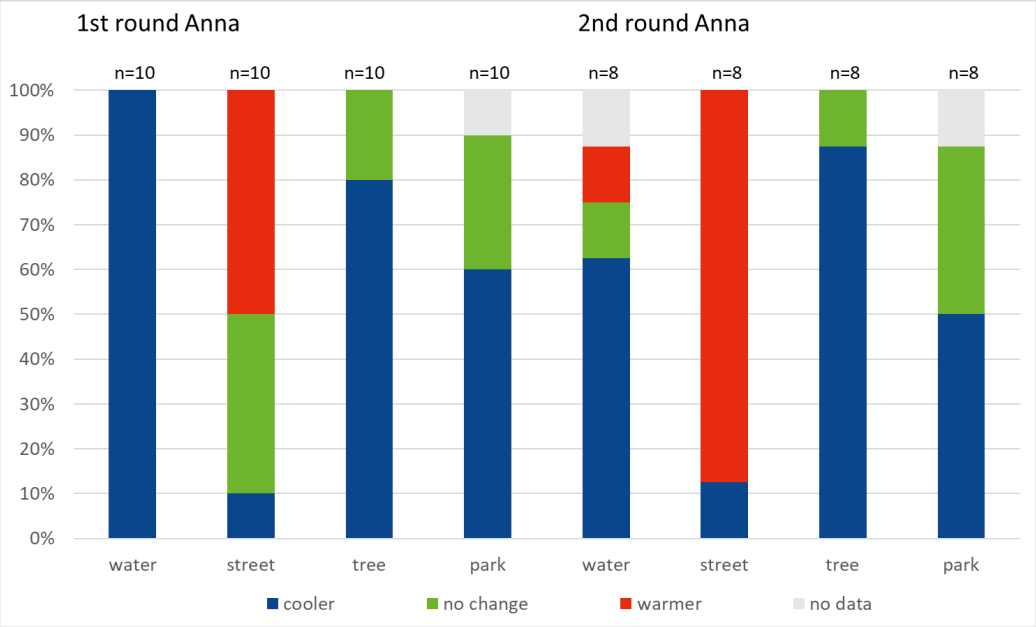

Figure 16: Thermal differences between the locations determined by participants of the thermal walk led by Anna.

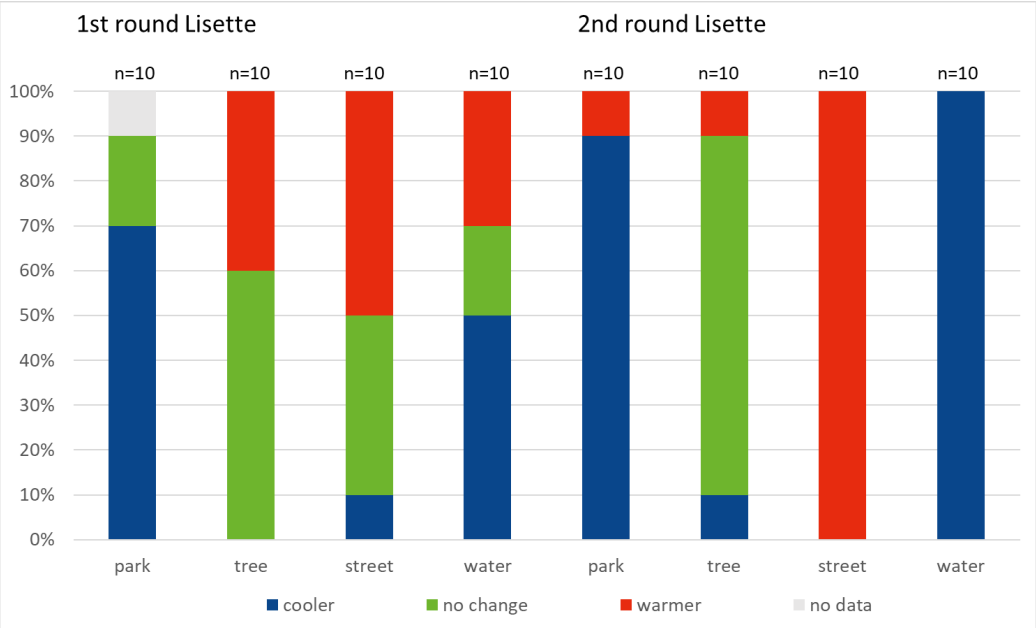

Figure 17: Thermal differences between the locations determined by participants of the thermal walk led by Lisette.

3.2.6. Thermal choice

The participants were asked if the area they were visiting should be cooler, warmer or if no changes in the temperature were necessary. The answers showed that people generally did not prefer a cooler or a warmer spot (see Figures 18 and 19). The only exceptions occurred in the second round of the thermal walk when participants of both groups determined that the street location needed to be cooler. Anna's group also considered that the waterfront needed to be cooler.

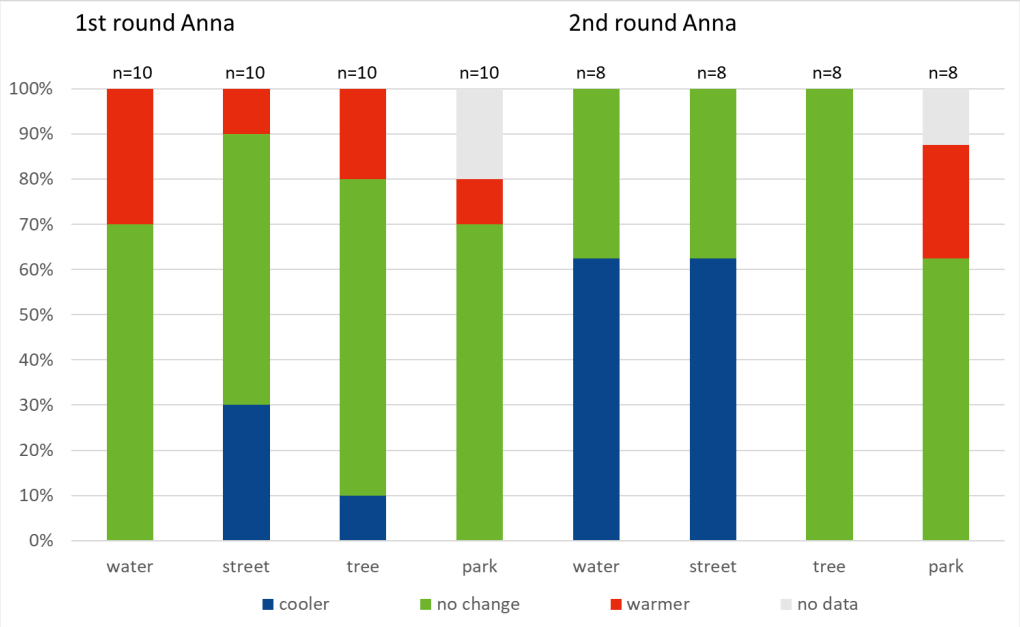

Figure 18: Thermal choice of the participants of Anna's group.

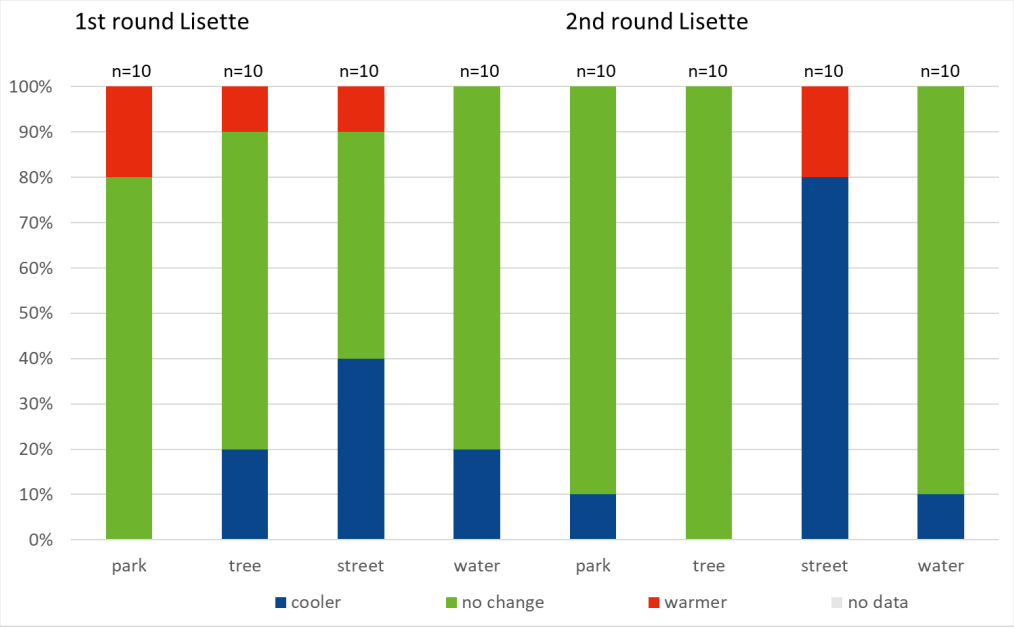

Figure 19: Thermal choice of the participants of Lisette's group.

3.2.7. Note on the questions that we did not analyse

Questions regarding the personal information of the participants, such as gender, age, etc., were not analysed. These questions are relevant for understanding how the perception of heat changes according to personal conditions. However, this type of research is outside the scope of the thermal walk. Besides, the number of interviewed people is not large enough to provide significant results for this type of analysis.

The participants were also asked if they considered the amount of wind and sun at a certain location as being too little, ok, or too much. We concluded that the answers to these questions do not add relevant information to the research at this moment and we decided to not analyse them.

3.2.8. Open questions

The final part of the interview consisted of open questions. The questions asked were:

1. How heat resilient is the walking route on the Marineterrein?

The answers provided were classified into 3 groups: good, reasonable (depends on the location), and mediocre (Figure 20). The results are shown in Figure 20. The majority of participants in Anna's group considered the walking route well heat resilient, while most of Lisette's group thought the walking route was heat resilient depending on location. In the second round, Anna's group had a more divided opinion with about 25% of the people considering the route not heat resilient. The main comments in the 1st round were: (1) many options between sunny and shaded areas, (2) park and tree locations are heat resilient, and (3) waterfront and street locations are less heat resilient. In the second round, most of the people considered the walking route well heat resilient. The main comments of the 2nd round were: (1) park and tree locations are heat resilient, (2) the waterfront is warm/not heat resilient, and (3) more shade is necessary in the walking route.

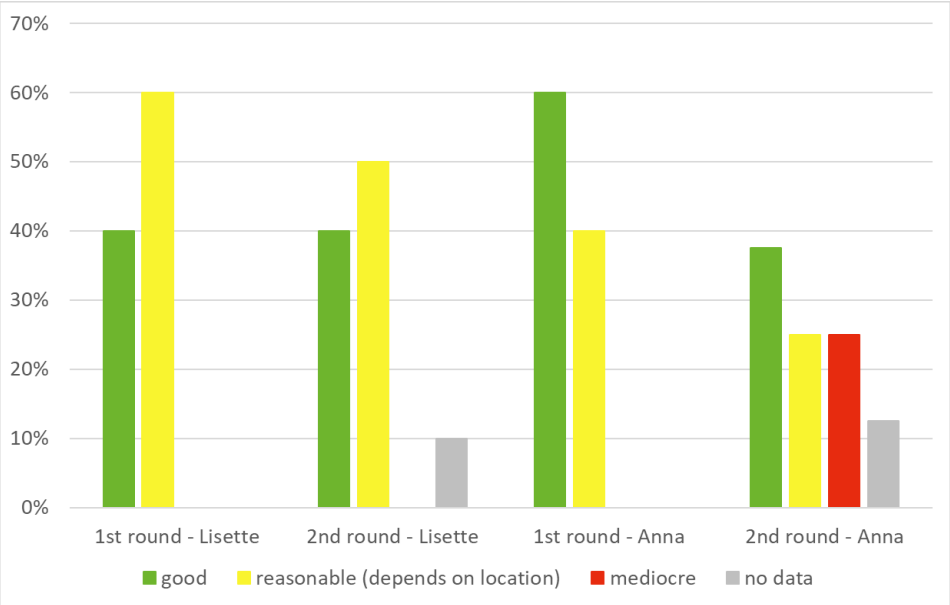

Figure 20: Results of the open question: "How heat resilient is the walking route in the Marineterrein?".

2. Which factors influence the thermal experience of the walking route?

The answers provided for this question were classified into shade, water, wind, green, hard surfaces, and others. Usually, each participant answered one or more factors. The results are in Figure 21. Based on this outcome, shade and wind seem to be the most influential factors affecting the thermal experience of the walking route. Green became in the third place, followed by water. Some of the participants mentioned the openness of the space and walking history as other factors that influence the thermal experience of the walking route.

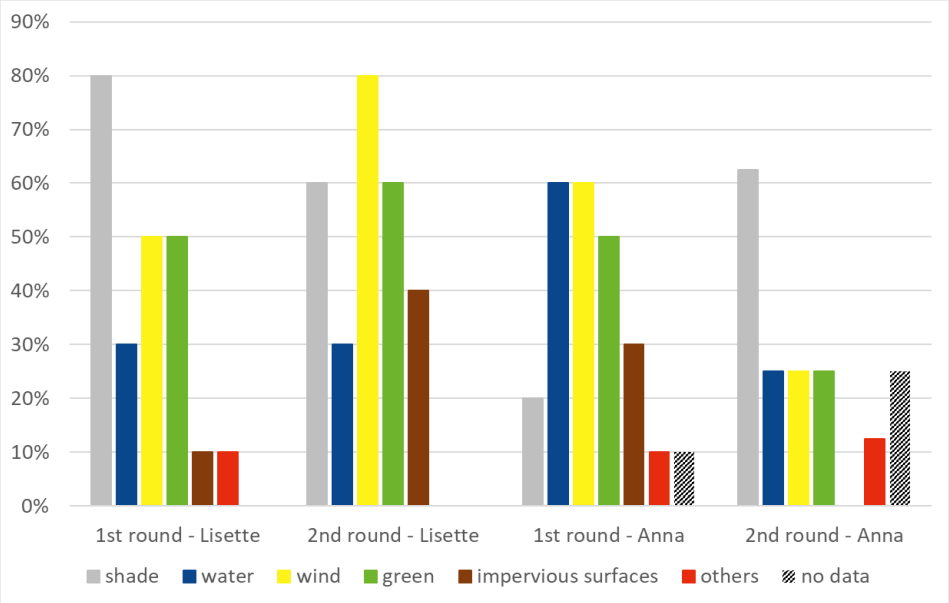

Figure 21: Results of the open question: "Which factors influence the thermal experience of the walking route?".

3. How can the microclimate be more attractive for pedestrians (during hot days)?

The answers were classified into: more shade, more water places, more wind, more green, less hard surfaces, no change, and others. The results are in Figure 22. According to the interviewed people, the three main options to make the microclimate of the walking route more attractive for pedestrians are (in the following order): more shade, more green, and more water areas. Other comments included the provision of artificial shade and more variations in the city, from warm to cool places.

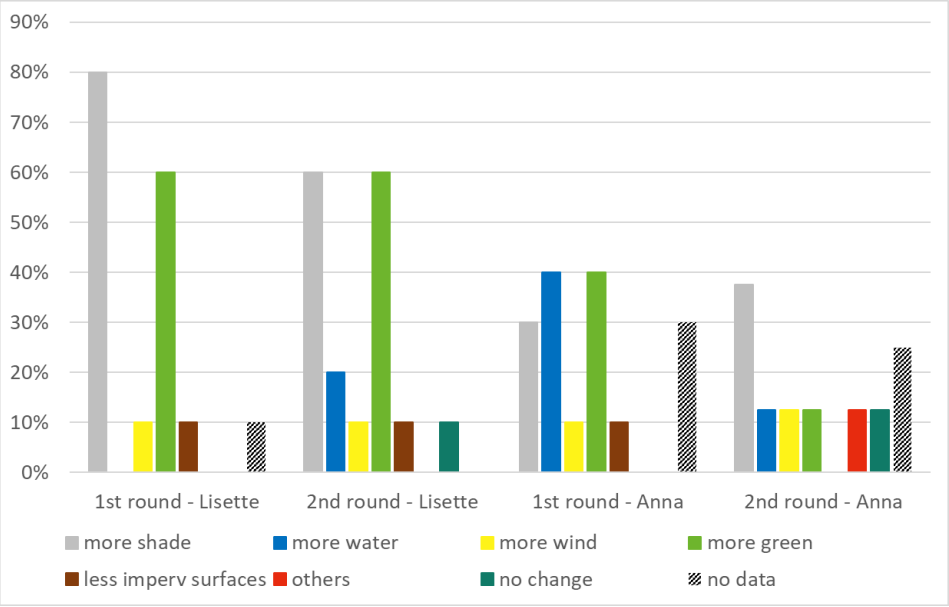

Figure 22: Results of the open question: "How can the microclimate be more attractive for pedestrians (during hot days)?"

4. Discussion and conclusions

4.1. How heat resilient is the walking route on the Marineterrein?

To answer this question we need to combine the meteorological data with the answers of the interviews. Despite the interesting results from the measurements and interviews, we cannot conclude if the thermal route on the Marineterrein is heat resilient, because the thermal walk was conducted on a day on which weather conditions were influenced by the presence of intermittent clouds and mild temperatures. The presence of clouds reduced solar radiation, affecting the measurements and the thermal perception of the participants. Areas that are normally not heat resilient during hot days might have been rated as comfortable in such conditions. Still, the results suggest:

- Park and waterfront were the locations with the lowest and the highest air temperatures, respectively. This is most likely the result of the impact of shading, which was provided by the trees in the park and was absent at the waterfront. However, the measured differences can also be the result of the warming up of the Kestrel's air temperature sensor as explained in section 3.1.1.
- PET values along the walking route were mainly affected by solar radiation. Wind speed was not high anywhere along the walking route and relative humidity varied very little among the locations. The PET was lowest in the park and highest at the waterfront. This shows the positive impact of greenery on the perceived temperature.
- Based on the PET classification (Matzarakis et al., 1999), none of the investigated areas was classified as "comfortable". Despite the low PET values, the park and tree areas were classified as "slightly warm". The street was also mostly "slightly warm". The waterfront was the only one to be classified mostly as "warm" and during one walk as "hot".
- At all locations, the air temperature was considered cooler by the participants than it actually was. The largest differences were at the park and the waterfront. These results suggest that the presence of blue and green areas has a psychological effect on people's thermal perception and makes the area feel cooler. On the other hand, people might have understood the survey question "How warm is it?" as a sort of challenge to guess the correct air temperature. This might have limited the answers, as no one would like to look silly to say it felt like 30°C whilst the real temperature was around 25°C. To better assess the participant's perception of the environment, the question "Which is the perceived temperature?" could be included in a next thermal walk.
- Regarding the thermal comfort, people considered most of the investigated areas as "comfortable", except at the street location. The street was also considered the warmest location in the thermal perception assessment and the only location that needed to be cooler, according to the thermal choice assessment. According to the measurements, however, the street was the second warmest location. The warmest, as said before, was the waterfront.
- The participant's opinion was divided concerning the heat resilience of the walking route: some people found the route well heat resilient and others found it reasonably resilient, depending on the location. In general, people commented that there was plenty of choice between sunny and shaded locations and that the park and tree areas are heat resilient, while the waterfront and the street are not. It is also worth to mention that the answers were sometimes vague, such as "Yes", "Reasonably", "Yes, in some places". For future thermal walks, the question may be reformulated to "Is the route heat resilient?" and "Which areas are more and less heat-resilient and why?" An alternative would be to add the question: "How heat resilient is this location?" and ask this for each investigated area, offering a classification of 1 to 10 (or good to bad).

4.2. Which factors influence the thermal experience of the walking route on the Marineterrein?

Unfortunately, we cannot investigate the effect of the walking history on the thermal experience properly, as the weather conditions were not stable during the thermal walk. Still, the results suggest that:

- Areas with more shade were thermally more comfortable than the open ones and showed lowest PET values.
- The participants of the walk determined that shade, wind, green and water (in this order) are the most influential factors on the thermal experience of the walking route.
- Other answers provided in the survey were the openness of the space and walking history.

4.3. In what way can the microclimate of the Marineterrein be set up more attractively for pedestrians during hot days?

Because the question was not specific to each visited location, the answers were general and somewhat vague. For future thermal walks, the question may be accompanied by a map on which the participants can draw their design suggestions for a more heat-resilient and attractive area. Still the results suggest that:

- More shade was the most commented measure to improve the microclimate at the Marineterrein. This option was followed by more green and water places. Less hard surfaces was also a measure that was mentioned.
- One person mentioned that it is necessary to create more variation between hot and cool places accessible to anyone, so people can choose depending on their comfort wish. This somehow contradicts some of the answers provided in the first open question, in which the participants said that the walking route was heat resilient because it has plenty of choice between hot and cool spots.

4.4. What did urban professionals learn from the thermal walk?

The thermal walk also had the educational purpose to give the participants insight into the phenomenon of urban heat. The thermal walk conducted at the Marineterrein was successful in informing the participants about the basic principles of the urban heat phenomenon, about the differences between air temperature, perceived temperature and thermal experience and about the factors that play a role. The reactions of the participants showed that the thermal walk is useful for urban designers to explore and experience the influence of greenery, water, and space on air temperature, perceived temperature and thermal experience. Eye openers among the participants were that the measured air temperatures at the various locations did not differ and that shadow reduces the perceived temperature to a large extent. The participants were surprised that water was not measured and experienced as the coolest place.

4.5. How can the thermal walk be improved to be useful for urban professionals?

In the previous sections, we already mentioned some improvements to the thermal walk: The question “How warm is it?” can be replaced by “Which is the perceived temperature?” And for a better evaluation of the heat resilience of the different locations, the questions “Is the route heat resilient?” and “Which places are more and less heat resilient and why?” can be added to the survey. An alternative would be to ask “How heat resilient is this location?” and offer a classification from 1 to 10 (or good to bad).

Additionally, the question in the survey regarding how the microclimate of the Marineterrein can be set up more attractively resulted in somewhat vague answers. We, therefore, recommend asking this question for each location of the walking route, instead of the route as a whole. This would result in more consistent answers, which are more helpful for urban professionals in understanding the best strategies to improve the heat-resilient design of the route. The question if the walking route overall is heat-resilient can be valuable in case the overall perception of the area is evaluated. For future thermal walks, the survey may also be accompanied by a map on which the participants can indicate their design suggestions for a more heat-resilient and attractive area.

Residents preferably also participate in a thermal walk, especially if the thermal walk is used to assess the heat resilience of a residential street or area. It is primarily the residents for whom a residential area must be sufficiently heat resilient. Moreover, residents probably know better from experience which locations are comfortable during hot days and what improvement are needed. Their experiences and ideas for solutions are a valuable contribution to the heat resilient design of public spaces. This makes the thermal walk a nice method of resident participation.

We also advise to perform the thermal walk under optimal weather conditions with temperatures above 25°C and clear sky. During our thermal walk, weather conditions were not optimal and therefore we could not answer all research questions properly.

For future thermal walks, we as well advise to investigate the accuracy of the air temperature measurements of the Kestrel sensors in more detail. The Kestrel's casing is not properly shielded and the sensor is not actively ventilated. As a result, the casing may warm up if exposed to long periods in the sun, affecting the air temperature readings of the sensor.

5. References

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Appendix I Survey of the thermal walk

Persoonlijke gegevens	
Naam	
Leeftijd	0-9 / 10-19 / 20-29 / 30-39 / 40-49 / 50-59 / 60-69 / 70+
Geslacht	m / v
Kleding	
i. Bovenlichaam	mouwloos / korte mouwen / lange mouwen / shirtloos
ii. Onderlichaam	korte broek of rok / lange broek of rok
iii. Vest of jas	vest / sweater / jack / regenjas
iii. Accessoires	zonnebril / pet / hoed / paraplu
Culturele achtergrond	
i. Woon je in Nederland?	ja / nee
ii. Wat is je geboorteland?	
iii. Hoe lang ben je al in Nederland?	…… jaar

Hoe hittebestendig is deze looproute op het Marineterrein?	
Welke factoren beïnvloeden de thermische beleving van de looproute?	
Op welke manier kan het microklimaat aantrekkelijker (koeler) worden ingericht voor voetgangers (tijdens hete dagen)?	

		Voorbeeld	Locatie 1	Locatie 2	Locatie 3	Locatie 4
Naam locatie		*Dorpsplein*				
Tijdstip	uu:mm	10:35				
Hoe ervaar je het type locatie? (meerdere antwoorden mogelijk)	groen					
	waterrijk					
	versteend	*x*				
Zon/schaduw	z/s	*z*				
Hoe warm voelt het aan?	°C	***24***				
Hoe voel je je nu op deze locatie?	koud					
	fris					
	beetje fris					
	neutraal					
	beetje warm	*x*				
	warm					
	heet					
Voel je een thermisch verschil met de vorige locatie? Het is nu….	Kouder					
	Hetzelfde					
	Warmer	*x*				
Waardoor wordt dit thermische verschil veroorzaakt?		*Door meer verharding*				
Hoe ervaar je deze omgeving thermisch gezien?	aangenaam	*x*				
	beetje onaangenaam					
	onaangenaam					
	heel erg onaangenaam					
Wat zou je voorkeur nu zijn?	kouder					
	geen verandering	*x*				
	warmer					
Hoe ervaar je de wind op deze plek?	te weinig wind					
	ok	*x*				
	te veel wind					
Hoe ervaar je de zon op deze plek?	te weinig zon					
	ok					
	te veel zon	*x*				
Gemeten luchttemperatuur	°C	***20***				
Gemeten globetemperatuur	°C	***36***				
Gemeten hitte-index	°C	***23***				
Gemeten luchtvochtigheid	%	*55*				
Gemeten windsnelheid	m/s	*2*				
Gemeten windrichting	°	*200*				

Noteer de temperatuurwaarden in de grafiek
Hoe de temperatuur aanvoelt
Gemeten luchttemperatuur
Gemeten globetemperatuur
Gemeten hitte-index