Amsterdam University of Applied Sciences

Cool Towns Heat Stress Measurement Protocol

Gideon Spanjar, Luc van Zandbrink,
Debbie Bartlett and Jeroen Kluck

Thermal comfort assessment at street-level scale

Amsterdam University of Applied Sciences
Centre of Expertise Urban Technology
Faculty of Technology

ISBN: 9789492644213

Cover image: City of Breda with AUAS research assistants Erica Caverzam Barbosa and Kylian Postema.

SUMMARY

Weather criteria	Air temperature more than 25 °C and clear sky (forecasted)
Measuring period	Always between 1st of June and 31st of August
Measuring time	Always between 12:00 pm and 4:00 pm local time
Measurement points	Points of interest distributed over the site: at hot and cool spots. Points of interest belonging to existing green, blue or artificial (e.g. shade sails) features or interventions require an associated reference point. At a control point the weather station continuously measures at one place while the measurements are being conducted.
Measurement parameters	Air temperature, globe temperature, PET: Degrees Celsius (°C) Relative humidity: Percentage (%) Wind speed: Meter per second (m/s) Wind direction: 360° N, 90° E, 180° S, 270° W
Measurement units	Metric system
Logging interval	10 seconds or shorter
Sampling period	At least 15 minutes per measurement
Sensor placement	1.1 m above the ground
Interview location	Interviews need to be conducted at the site and at the same time as the measurements.
Interview number	A minimum of 16 per day per site but preferably 25.

CONTENTS

1. Introduction

European cities are confronted with rapidly rising temperatures causing more heatwaves and increasing the duration and frequency of exposure to heat stress conditions. Consequently, it reduces the liveability of cities, and discourages the use of urban open spaces citizens depend on for social interaction. Shopping centres, mobility hubs, and pedestrian areas are examples of vulnerable locations for heat stress with a high intensity of daily use (Spanjar & van Zandbrink, 2020).

The design of the urban fabric is no longer adequate to provide thermally comfortable open urban spaces during hot weather, leaving citizens in general, and vulnerable societal groups (children, older people, and with an illness) in particular, exposed to thermally uncomfortable conditions. The thermally challenging characteristics of the outdoor environment may contribute to our indoor oriented lifestyle. European citizens, on average, already spend approximately 90% of their time indoors leading to health consequences (WHO, 2013).

Decision-makers find it challenging to counteract the negative effects of climate change by finding attractive spatial solutions that mitigate heat stress in their areas. Action is now needed to ensure the development of adaptation capacity to a changing climate, preventing investments at higher costs becoming necessary later (EEA, 2012). The process of climate-proofing urban areas must happen incrementally by developing tactical heat stress interventions on a street-level scale. Installing green walls, placing shade sails, and planting trees are examples of practical and cost-efficient solutions to provide cool spots where most needed whilst delivering many co-benefits. These interventions at street level can also provide opportunities to work on a wide range of societal needs actively promoting human health and wellbeing in cities.

Thermal Comfort Assessments (TCAs) are often conducted at town, city or regional scale to identify potentially vulnerable heat stress locations. The heat stress maps generated are based on a climate comfort model calculated from several meteorological parameters, and informed by geographical characteristics (e.g. Koopmans et al., 2020). These maps are frequently complemented by indicators to identify demographic and socio-economically vulnerable groups. However, the influence of specific local spatial conditions, functions, and dynamics on the thermal comfort experienced by users and the effectiveness of heat stress interventions in different types of urban spaces, remains unanswered.

In the Cool Towns project, European regions, municipalities, universities, and climate adaptation specialist companies, have come together to investigate how to develop effective interventions at street-level to combat heat stress in their urban areas on a fine-grained scale. It is essential to measure the effectiveness of interventions in different countries for providing thermal comfortable outdoor spaces, but, until now, there has been no standardised data collection methodology (Johansson et al., 2014; Elnabawi & Hamza, 2020).

The Cool Towns Heat Stress Measurement Protocol presented here is a standardised methodology to identify the experienced thermal comfort on the fine-grained scale and can provide a robust justification for (future) investments as part of a cost-benefit analysis. It provides basic guidance to conduct a TCA at street-level and enables investigating the extent to which users of urban public open spaces are thermally comfortable during hot summer days, and determining the cooling effects of street-level interventions.

For more information on the Cool Towns Project please visit: cooltowns.eu

1.1 Reading guide

This protocol for conducting Thermal Comfort Assessments (TCAs) at street-level, chronologically describes the process in three phases: 1) developing a measurement plan where all the different measurement locations are identified, 2) conducting the fieldwork and phase 3) the analysis of the data collected (see fig. 3). The protocol starts with providing some theoretical background, explaining the PET-index used to measure thermal comfort, the research design, including why site characterisation and a questionnaire are used, and introduces a case study, the Osdorpplein shopping centre in Amsterdam, that will be used to demonstrate the overall process.
Chapter 2 provides instructions on how to develop a measurement plan that ensures a systematic assessment of the thermal comfort of the users of a site and the effect on this of existing features and installed interventions. It describes how to characterize the site and use the questionnaire, the equipment required and how to pinpoint the different measurement locations on the map.
The next step, conducting fieldwork, is described in Chapter 3. This contains essential information on weather and working conditions, the measurement specifications according to the type of interventions (e.g. row of trees, water features, sails, etc.), and how to document the measurements.
The final chapter demonstrates how to analyse and interpret the results by using the case study Osdorpplein shopping centre.

1.2 Target user groups

This document will be useful to experts directly involved in the implementation of climate adaptation strategies in urban areas, such as urban area development and urban renewal programs. It provides practical support in identifying areas that are now, or could in the future, be affected by heat stress, and for proposing effective measures in (future) plans. For local authorities, developers, spatial designers, including landscape architects and urban planners, it provides practical instructions on how to evaluate and justify in an evidence-based way, different solutions to mitigate heat stress for effective climate proofing of urban areas.

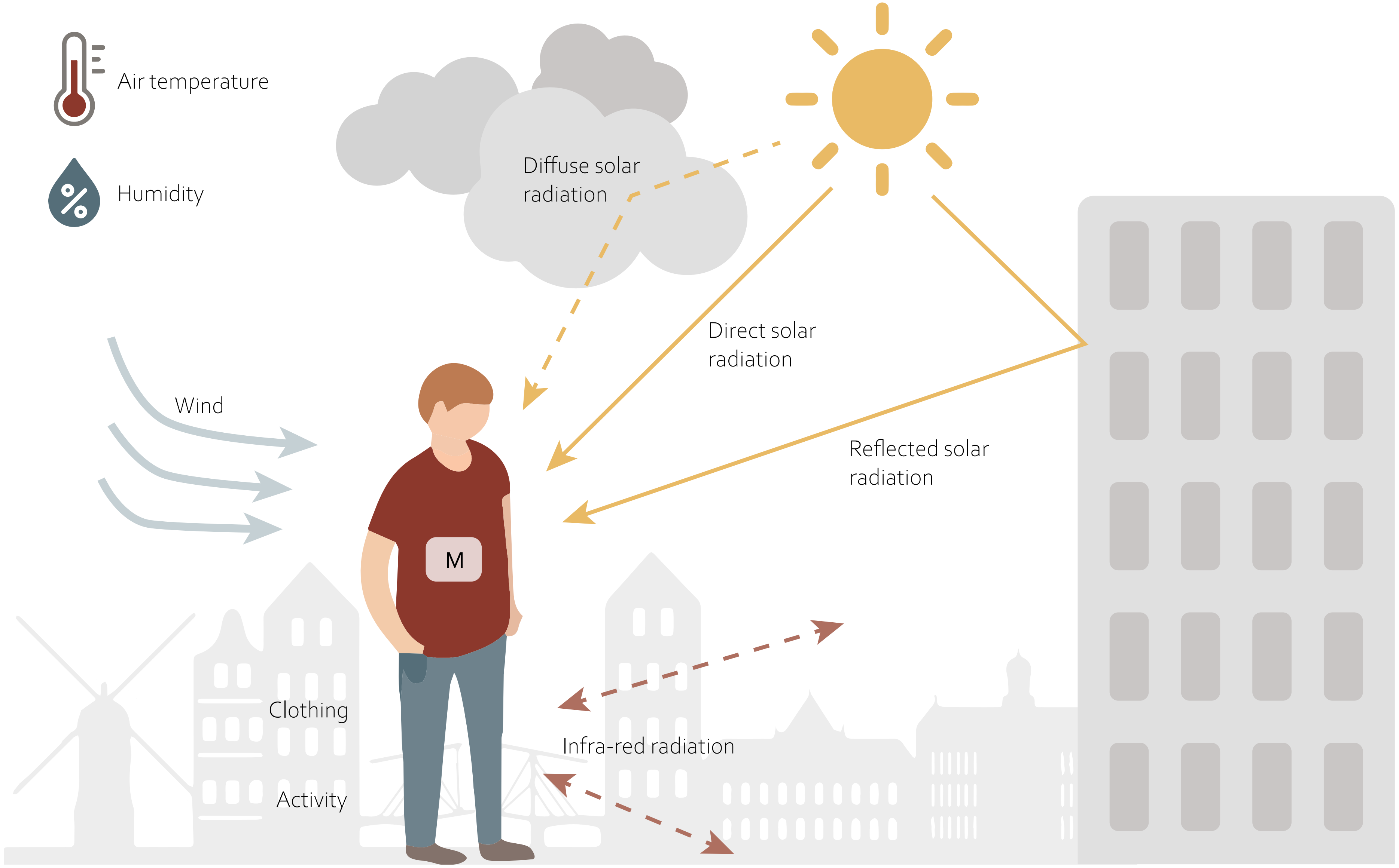


Figure 1: *Schematic representation of the different factors that influence the energy balance of the human body. Air temperature, humidity and wind speed are directly measured by a mobile weather station. The influence of direct, diffuse and reflected solar radiation and infra-red radiation from the environment are combined in the globe temperature measurement. Clothing insulation and activity are recorded by the questionnaire. (M=metabolic heat production). Adapted from Havenith (1999).*

I.3 PET-index

People experience heat stress when too much heat is absorbed by the body (Epstein & Moran, 2006). It can cause a decrease in mental and manual performance, have negative effects on social behaviour, cause heat exhaustion and heat stroke, and may even lead to death (Bell, 1981; Epstein & Moran, 2006; Pilcher et al., 2002). In humans it can be measured by the Physiological Equivalent Temperature (PET) index and this is the most commonly used climate comfort index when measuring outdoors (Coccolo et al., 2016; Matzarakis et al., 2014). The PET-index is expressed in degrees Celsius (°C).

The PET-index is based on the energy balance of the human body by using a similar indoor air temperature experience as reference (Höppe, 1999). If, for example, a person experiences a PET of 50 °C outdoors, based on a combination of different meteorological parameters, the equivalent indoors would be an air temperature of 50 °C, without the wind and solar radiation, but at the same humidity.

PET can be calculated from micrometeorological data recorded by a weather station using the following parameters: air temperature (°C), globe temperature (°C), relative humidity (%), and wind speed (m/s). With a grey or black globe thermometer the mean radiant temperature (T_{mrt}) can be measured (Thorsson et al., 2007). The T_{mrt} is composed of the direct solar radiation and the reflected solar radiation from the surroundings, in combination with the radiant heat exchanged with the surface of buildings and pavement (by so-called infra-red radiation see fig. 1). For example, if the surfaces of pavements in urban open space and/or of adjacent buildings are warmed up by the sun they will emit more infra-red radiation resulting in higher PET values being experienced. If, however, the building or pavement is white (a higher albedo effect) it will warm up less but reflect the solar radiation and consequently, increase the PET value at that particular moment (Erell et al., 2014). Thick clothing affects heat resistance increasing skin and core temperatures and so heightens PET value (Höppe, 1999). A person's level of activity, walking, sports or sitting, may also influence the PET value. There are also minor differences due to gender, age, height, and weight.

Weather stations measure the meteorological parameters via sensors preferably placed at 1.1 m, the average height of the centre of gravity of the standing adult human (Johansson et al., 2014). The PET value (°C) derived corresponds to the physiological stress grades in the figure 2. The higher the grade the greater the risk of heat stress at that particular location. The actual impact varies depending on duration of exposure, health condition, and adaptive capacity (Pilcher et al, 2002).

PET (°C)	Physiological Stress Grade
<18	Slight Cold Stress
18-23	No Thermal Stress
23-29	Slight Heat Stress
29-35	Moderate Heat Stress
35-41	Strong Heat Stress
41-46	Extreme Heat Stress (LV 1)
46-51	Extreme Heat Stress (LV 2)
51-56	Extreme Heat Stress (LV 3)
>56	Extreme Heat Stress (LV 4)

Figure 2: *The different grades of thermal perception and physiological stress on human beings expressed as the Physiological Equivalent Temperature (PET) thermal index. After Nouri et al. (2018), adapted from Matzarakis et al. (1999).*

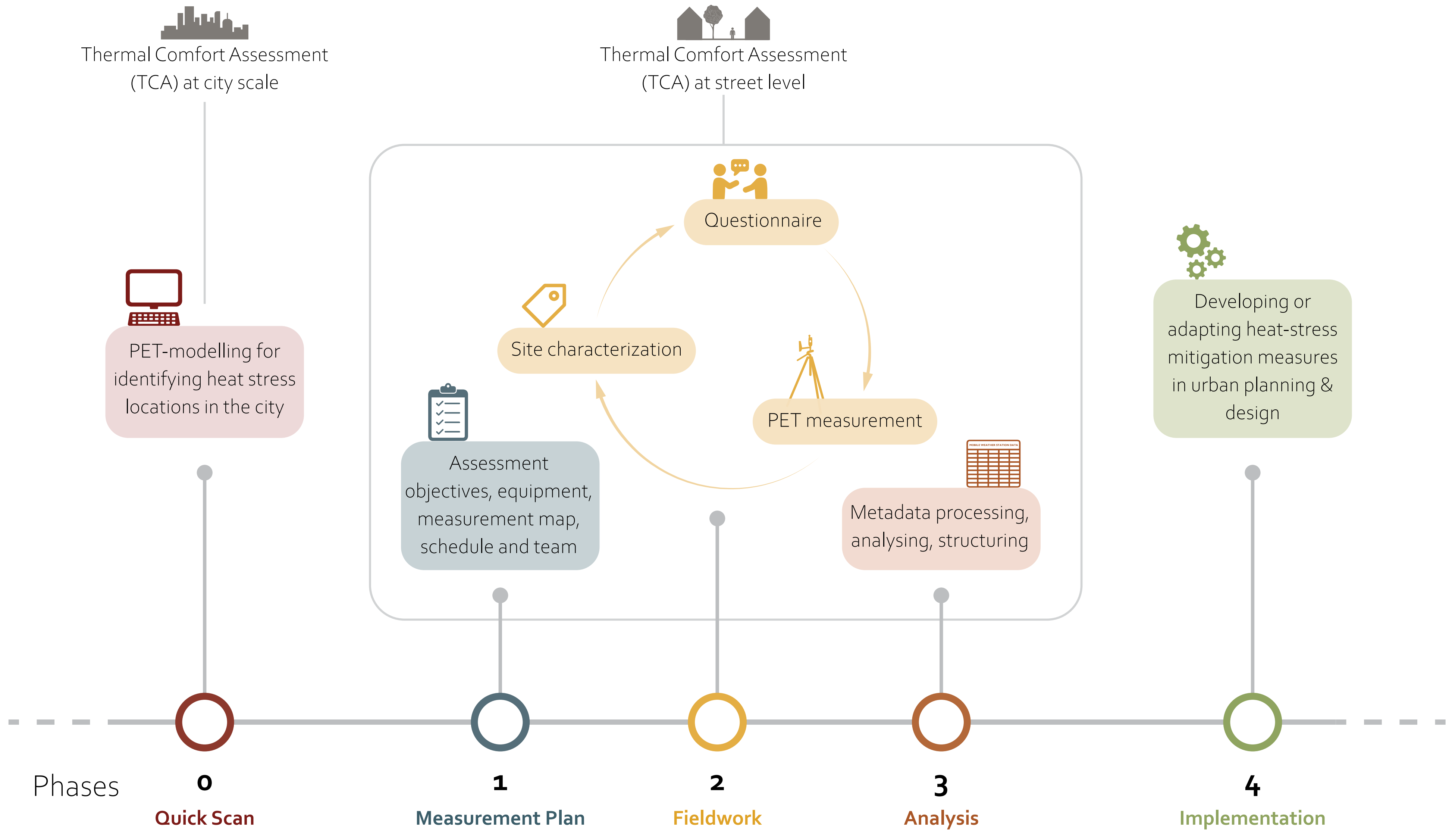


Figure 3: *Schematic representation of the method and steps required to conduct a full Thermal Comfort Assessment (TCA) at street-level.*

1.4 Research design

The Cool Towns Heat Stress Measurement Protocol delivers guidance to determine where in a site heat stress is likely to be experienced. It also determines whether the intervention(s) at the site and existing heat mitigation features reduce heat stress sufficiently as perceived by its users and estimates the number of people benefitting from the interventions at the site. Hence, it contributes to a robust evidence-base on the effectiveness of various heat mitigation features under hot weather conditions, site characteristics, and spatial contexts.

One or more of the aims above can be achieved by conducting the TCA at street-level by investigating the baseline situation, the effect of interventions, or the contribution of existing heat mitigation features. In either one a combination of three complementary methods is recommended: site characterization, a questionnaire, and measurement of PET.

The set of methods can be expanded by using observation techniques to evaluate the users' (adaptive) behaviour of the site and for triangulation of research methods.

1.4.1 Site characterization

The TCA starts with a characterization of the urban geometry, green and blue infrastructure, and finding out how the site is used to analyse whether the existing spatial configuration contributes to, or mitigates, the level of heat stress. The height/width ratio of buildings and street affects the amount of solar radiation entering and the extent to which this heat may be "trapped" between buildings. The type of landcover affects heat loss due to evaporation and how much remains to warm the surface. The type of site and how it is used determines the times that thermal comfort assessment is relevant. The thermal characterization can be visualised by taking photographs, including those taken with a thermal camera and a fisheye lens.

1.4.2 Questionnaire

The calculation of PET makes no differentiation between individuals if clothing and activity (and to a lesser extend gender and age) are assumed as constant values. A questionnaire asking those using the site about their thermal perception provides insight into their individually experienced thermal comfort and how it could be further improved. The questionnaire, developed for this protocol, has been adapted from several outdoor thermal comfort studies (Klok et al. 2019; Johansson et al. 2014; Lenzholzer & van der Wulp 2010) and has been established as a result of pilot studies during shared field experience in The Netherlands, Belgium, The United Kingdom, and France during the Cool Towns project. It has a strong focus on the use, and thermal perception of the urban space combined with user behaviour, as effective mitigation of heat stress depends as much on behavioural and psychological factors as physiological aspects. The use of jargon like 'thermal' has been avoided in the questions and it aligns with the ASHREA Standards for the Assessment of Thermal Environments (ANSI/ASHRAE, 2017).

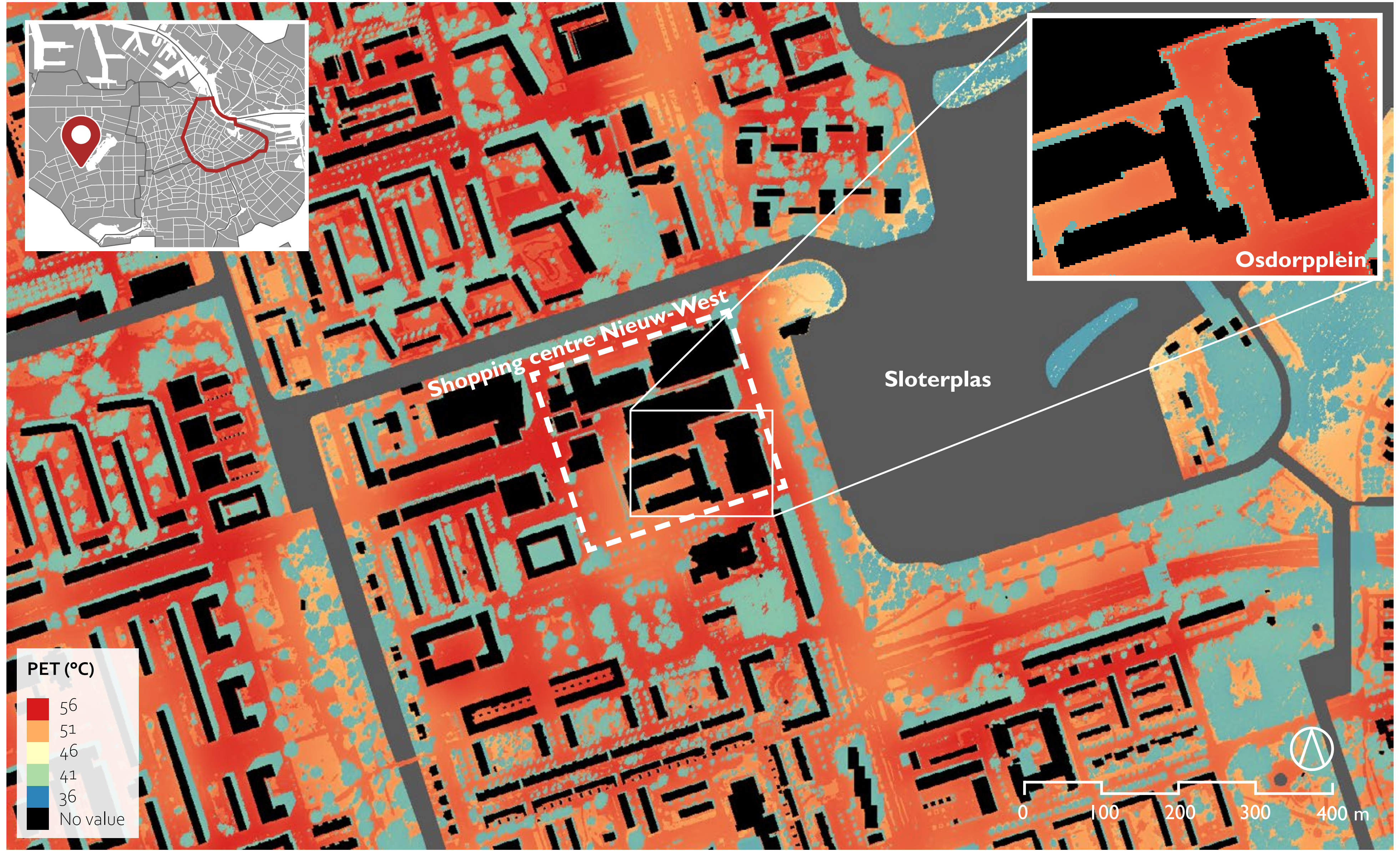


Figure 4: *Nieuw-West shopping centre, Amsterdam, showing the PET-model results for 3:00 pm on the 24th July 2019. According to the methodology described by Koopmans et al. (2020).*

1.4.3 Measuring the PET

To calculate the PET a range of micrometeorological data is measured using two (or more) mobile weather stations: one at a point of interest, another at an associated reference point in the sun. These points are monitored simultaneously to investigate the difference in microclimate, and accordingly, the variety of heat stress levels in the site or the potential cooling effect of an existing green/blue feature or intervention. This enables the PET at the point of interest to be measured and compared to people's perceptions of heat according to questionnaire responses.

Further clarification can be achieved by taking the thermal photographs, fisheye photographs, and regular photographs. If the aim is to assess the cooling effect of future, planned interventions, then measurements of PET need to be conducted prior to installation, to generate a baseline and then repeated after installation.

1.4.4 Osdorpplein case study

To demonstrate the use and application of the Cool Towns Heat Stress Measurement Protocol the 'heat robust shopping centre Osdorpplein' has been used as a case study. A short introduction to the project is given here (for more information see Kuenen, 2020). Osdorpplein is in the Nieuw-West district of the city of Amsterdam. The shopping centre is in the process of redevelopment and has a challenging socio-economic status compared to other Amsterdam districts. A heat stress map, based on a GIS modelling of the Physiological Equivalent Temperature (PET), identified several locations in the shopping centre that seemed to suffer from heat stress (see fig. 4), especially around midday. Osdorpplein is 50 meters long and over 25 meters wide, enclosed by a mix of low and medium-height buildings. The only shade was from a group of small horse chestnut trees in the square.

In the summer of 2019 an intervention, called the Climate Cube, was installed in the centre of the square as a heat stress intervention (see fig. 5). It is a modular temporary construction of raised flowerbeds with a wooden pergola planted with Mediterranean trees, shrubs, and herbs, with benches on each side. It was installed to provide comfortable seating spots during hot days and to intercept part of the water coming from the library roof.

The change in thermal comfort and impact of the intervention were assessed using the methods described in this protocol. Measurements were performed, photographs taken, and questionnaires conducted during a heatwave in July, just before the installation of the Climate Cube, and repeated after installation, during another heatwave in August.

Figure 5: *Heat stress intervention: The Climate Cube at Osdorpplein, Amsterdam.*

2. Measurement Plan

Figure 6: Osdorpplein square, Amsterdam, where the baseline measurements for the existing group of horse chestnut trees and the site of the planned intervention (the Climate Cube) were measured.

This chapter elaborates how to set up a measurement plan and all the preparations that need to be made prior to the fieldwork. First, a TCA objective outlines the different aims to conduct a Thermal Comfort Assessment (TCA). How to carry out the different measurements is explained in the following paragraphs. The equipment and personnel required, the weather conditions and measurement schedule are discussed at the end of this chapter.

2.1 Assessment objectives

There are three objectives for conducting a thermal comfort assessment at street-level; to develop a baseline against which to measure the need for future change, measuring the effectiveness of an installed intervention, or measuring the performances of existing heat stress mitigation features. These are described in the following sections.

2.1.1 Thermal comfort baseline

To develop a thermal comfort baseline, the site characteristics that contribute to heat stress are identified. The baseline consists of measurements of the PET distributed over the site, a questionnaire to interview users on the level of thermal comfort experienced, as well as site characterisation (see subchapter 1.4.1). The baseline measurement will identify the (most) vulnerable locations for heat stress, and so where interventions are required. The baseline measurements can be followed up by a heat stress intervention and measuring its effectiveness to combat heat stress.

2.1.2 Heat stress interventions

Measurement of the effect of an intervention determines if heat stress is reduced sufficiently, especially if users responding to the questionnaire report that thermal comfort has improved. The number of people benefitting from the heat mitigating installation also contributes to quantifying the effectiveness of the intervention. An intervention can be any type of feature in an open urban space that has the potential to reduce heat stress; one site could have several types of interventions. Comparing effectiveness with a baseline measurement, made before installation, provides more reliable results than a standalone one.

2.1.3 Existing heat mitigation features

Measuring the heat mitigation performance of existing features is similar to that for interventions, described above. It provides opportunities to measure, for example, mature trees and settled features that provide optimum mitigation. These features can be used to represent the impact of proposed heat stress interventions, particularly if these are planned in similar spatial settings.

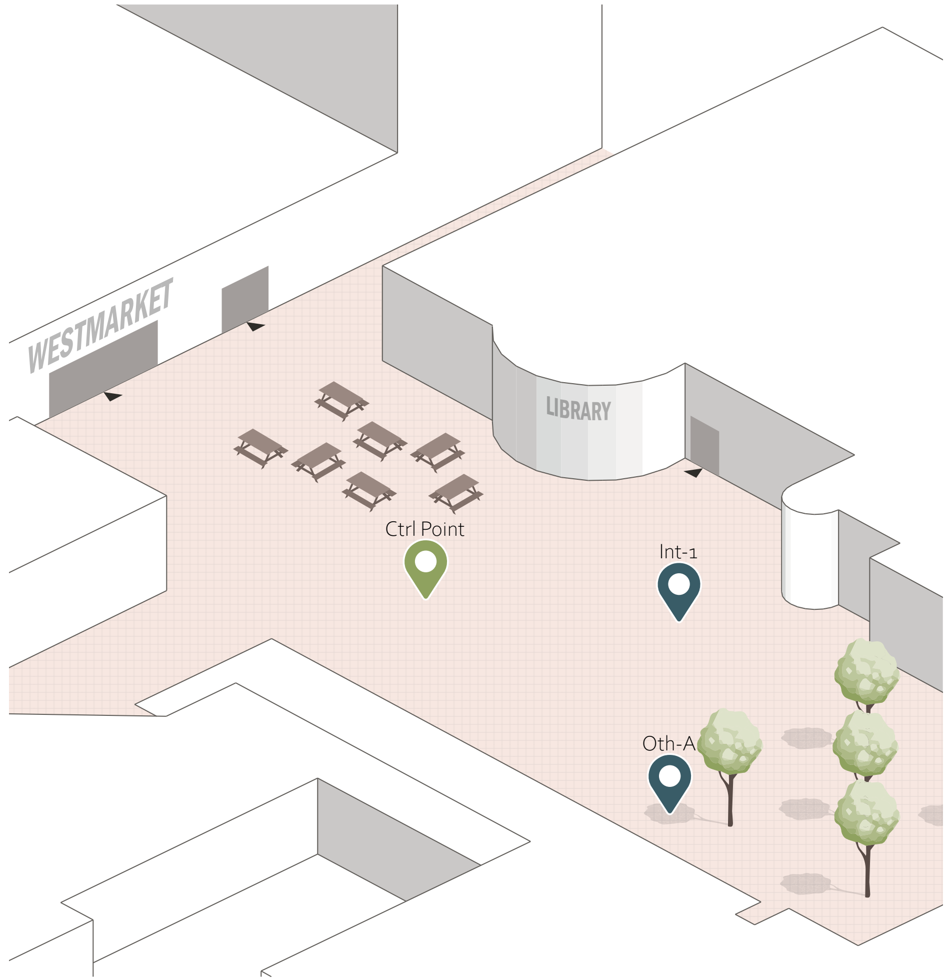


Figure 7: Baseline measurement point locations in Osdorpplein, Amsterdam, shown in blue. Ideally these should be equally distributed over the site. The control point (green) was monitored continuously throughout. The cooling effect of an existing horse chestnut tree was measured.

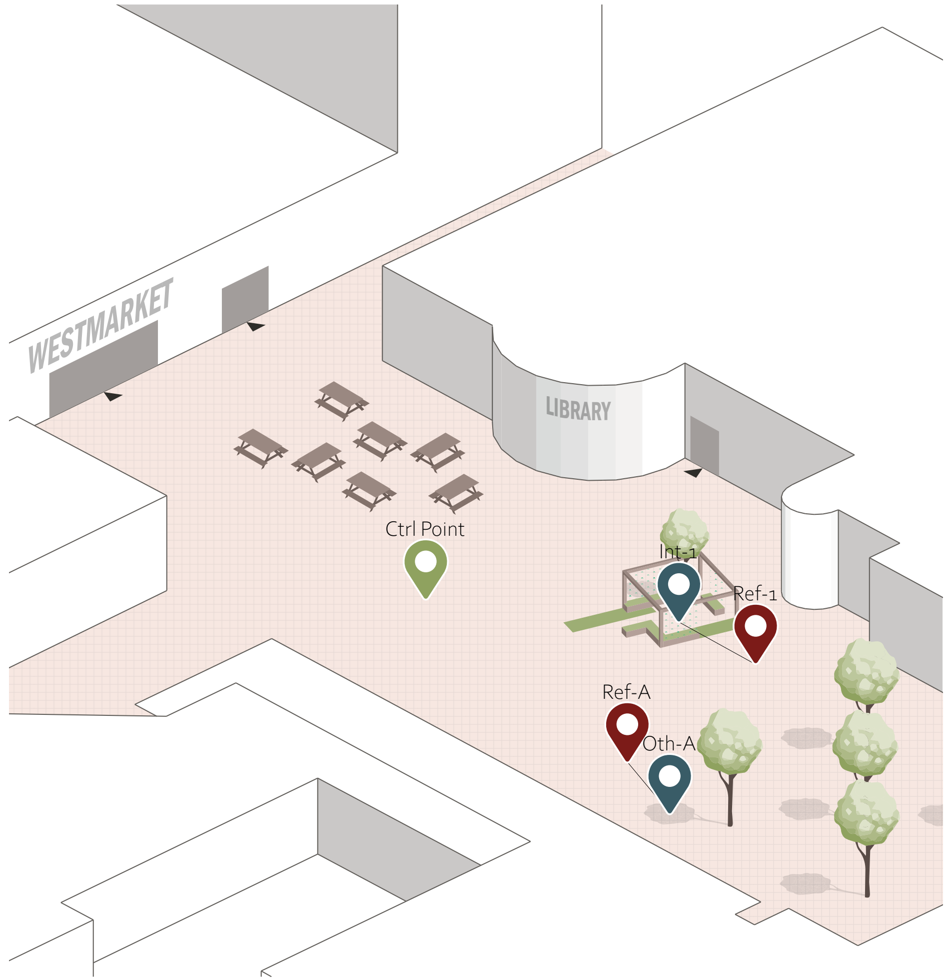


Figure 8: Measuring the effect of interventions in Osdorpplein, Amsterdam: intervention measurement points are shown in blue with those measured simultaneously to provide as reference are in red. The control point (green) is continuously monitored throughout the measurement period.

2.2 Measurement map

A measurement plan comprises a scale map showing the measurement points for the weather stations; the locations of the feature(s) or baseline area and the different PET measurement points (points of interest, associated reference points, or control point). In the baseline measurement, points of interest need to cover the variety of heat stress levels present, including existing heat mitigation features and the hot and cool spots on the site.

The points of interest of existing green, blue or artificial (e.g. shade sails) features or interventions should be selected so as to cover the maximum cooling effect of the entire feature despite the changing position of the sun during the afternoon; the measurement point for shade features must be located in the centre of the shade pattern at all times. If the same type of intervention is repeated, then measurements should be distributed over the site, covering different ground surface types and social areas (entrances, seating area, etc.) as appropriate.

A reference point is required to correspond to every point of interest near an existing feature or intervention. This reference measurement is required to enable its thermal influence to be interpreted. It is important to place it close to the original point of interest, preferably on the same site, but far enough away from it to ensure there is no thermal interference. For a full list of specifications for different types of interventions see p.38-41. If it is not possible to make a reference measurement on the site then a similar site, with the same characteristics, nearby can be used. If, due to unforeseen circumstances the intervention and/or reference points need to be redefined any new locations need to be documented and marked on the map. Importantly the measurements must always be taken simultaneously (see subchapter 2.4).

Using a control point (see fig. 7) enables any variation in the meteorological conditions during the measuring period to be taken into account in the analysis. The weather station used for the control point records continuously in one place, ideally the centre of the site, always in full sun the entire time measurements are being conducted. The control point in the baseline verifies that the variety of heat stress levels found at the points of interest is not a result of the variation over time. A control point in the intervention measurements increases the reliability of the data collected of the cooling effects.

Figure 7 presents the baseline and figure 8 the intervention measurement locations for Osdorpplein. The following labels have been used for the measurement points: 'Ctrl' for the control, 'Int + a number' for the intervention point(s) of interest, 'Oth + a letter' for the points of interest of existing features, and 'Ref + a corresponding number or letter' for the associated reference point. For the baseline measurement (see fig. 7) a control point ('Ctrl'), was placed near the location planned for the installation of the Climate Cube ('Int-1') and in the shade of the existing horse chestnut trees ('Oth-A'). When the effectiveness of the intervention was measured (see fig. 8) the same locations were used for the control point, the point of interest inside the Climate Cube, and in the shade of the horse chestnut trees.

Figure 9: *Setting-up a mobile weather station at the Lijnbaanstraat in the city centre of Ostend.*

Figure 10: *A thermal photograph visually demonstrating the temperature differences across Osdorpplein, Amsterdam.*

Figure 11: *A vertical fisheye photograph provides a view of the sky and geometry of the urban canopy at a measurement point in Osdorpplein, Amsterdam.*

2.3 Equipment requirements

In order to acquire accurate results, it is important to follow these recommendations.

2.3.1 Mobile weather stations

The parameters for the calculation of PET are measured with weather stations. A minimum of two weather measurement stations is needed, as measurement at the intervention and control point or reference point/site must be taken simultaneously. A third weather measurement station is recommended for a control point during heat mitigation measurements.

Weather stations do not measure PET directly but record the range of parameters: wind speed, radiation, humidity, and air temperature required to calculate the PET (e.g. see fig. 9). They are used to measure these in places where people would normally walk or sit. In crowded places weather stations cannot be left unattended as they may obstruct activities or fall victim to vandalism. Mobile weather stations increase the flexible use of resources allowing the measurement of multiple points of interest in one afternoon. The minimum specifications (weather parameter ± measurement accuracy) for a device to calculate PET at 1.1 m above the ground accurately are: air temperature ±0.5 °C (protected from direct sunlight), relative humidity ±2%, or wet-bulb temperature: ±2 °C, globe temperature ±2 °C and wind speed ±2 m/s. Mobile weather station settings may need to be manually set to the above units before conducting the measurement. It is important to know the emissivity value and (equivalent) diameter of the globe temperature, usually provided by the manufacturer.

2.3.2 Regular camera

Taking photographs with a regular camera provides a record of the weather, and spatial and social circumstances under which PET values and thermal perceptions from the questionnaire are obtained. It also provides valuable information about the position of the equipment and the intervention to verify and help interpret the results. A smartphone with a camera should be sufficient for this purpose.

2.3.3 Thermal camera

Thermal photographs (see fig. 10) function as a control of the PET measurement, a means to understand the thermal environment, and a way to communicate why differences in PET values occur. The recommended specification is that the thermal camera should have: accuracy of ±5 °C, field of view (FOV) not smaller than 45° x 34° and thermal resolution of at least 80 x 60 pixels but preferably 160 x 120 pixels.

2.3.4 Fisheye lens camera

Hemispherical photography (see fig. 11) is a technique to characterize the specific urban canopy geometry. These photographs taken with a fisheye lens enable understanding of the overhead spatial configurations controlling the thermal environment at the point of interest and can help explain differences in PET values between locations. Fisheye lenses range from clip-on gadgets for smartphones to professional lenses to mount on a digital camera. A field of view (FOV) not smaller than 180° is recommended.

Figure 12: *A team member conducting a questionnaire. Osdorpplein, Amsterdam.*

2.4 Measurement schedule

It is advisable to conduct the measurements on a summer afternoon when weather forecasts from the local official meteorological source predict an air temperature of 25 °C or more and a clear sky, to ensure the PET values are high enough to measure heat stress levels, account for heat stress conditions and the measurements are not disturbed by clouds that can cause large inconsistencies by intermittent shading.

On a summer afternoon between June 1st and August 31st, measurements should be carried out between 12:00 pm and 4:00 pm local time, the hottest period of the day. This will measure the performance of the intervention(s) when thermal comfort is probably most needed. The thermal conditions can differ in the early and late afternoon depending on microclimatic changes and the type of materials that have been used as paving and in the façade of adjacent buildings. Earlier in the afternoon the sun is at its highest point and later in the afternoon air temperature peaks. The PET at points of interest (and simultaneously the corresponding reference points) should therefore be measured twice in two rounds on the same day, preferably in the same order, but at least one hour apart. The minimum number of participants that can be interviewed depends also on the size of the measurement team, measurement period and number of users on the site. The latter is related to the type of outdoor space. Likely, there are more people at time of conducting interviews in shopping streets than in residential streets. Based on the experiences from the Cool Towns project, during the measurement period the questionnaire should be used to interview a minimum of 16 (but preferable 25) users of the site to develop an understanding of the experienced thermal comfort during a summer day.

The measurement schedule should account for a team member spending on average 15 minutes per questionnaire respondent and 20 minutes per PET measurement at a point of interest. Note that the intervention(s) and a reference point(s)/site(s) need to be measured simultaneously. A control point is continuously monitored on one spot during the entire measurement period. To obtain accurate results it is essential that before and after each day of measurements, the team verifies that all equipment is working properly. Weather stations can be tested, for example, by positioning them closely together in an outdoor environment for 15 minutes; they should all record similar values during the last minutes. All equipment should be fully charged and spare batteries available.

2.5 Measurement team

A minimum of two people is needed although the optimum is four; two to operate the weather stations and two to deliver the questionnaires. As they will be working at locations affected by heat stress, their health, and that of those interviewed, are vitally important. Adequate preparations should be made for extreme working conditions and the team members should be equipped with hats, sunscreen, drinking water, and a parasol to provide shade for questionnaire respondents (see fig. 12).

The fieldwork requires proper preparation and clear documentation. This consists of training the team in using measurement equipment and methods, including site characterisation and the measurement plan prepared for the site. An (on site) briefing on the measurement plan provides an elementary guide to the measurement team.

3. Fieldwork

This chapter covers the instructions for conducting the three investigative methods: site characterization, questionnaire, and measurement of PET. The field work can start when it is the required weather, the team is well-trained and ready with an agreed measurement plan and schedule. The Cool Towns Measurement Checklist (see cooltowns.eu/protocol) can be used to offer step-by-step guidance for the team in the field with instructions on for example, required equipment, instructions for site characterisation, procedure for conducting measurements and interviews.

It is important to take the pre-prepared measurement plan and map(s) of the measurement points to the site, to ensure the locations for the weather stations are correct or revised if necessary (any alterations must be marked on the map and noted in the plan). There may be local policies or regulations regarding privacy and these may apply to taking photographs and conducting the questionnaire. It is important to comply with the local legislation (e.g. General Data Protection Regulation, GDPR, in the EU, or the Algemene Verordening Gegevensbescherming (AVG) in The Netherlands).

Keeping records of fieldwork is important. At the end of each field workday a report should be made, including any updates of the measurement plan or map. For each measurement point, the PET records need to be checked to ensure everything is fully documented with the start and end time of every PET recording, the weather station brand, type, and serial number. A unique identifier (UI, e.g. serial number, name, or colour) is essential for each individual weather station and this must be recorded every time a measurement is made so that data is linked to the correct measurement point. The type of thermal camera used, and the names of the fieldwork team should also be recorded each day.

Left: A Thermal Walk led by AUAS during a Cool Towns partner meeting in Saint Omer.

List of site characteristics

Complete with a tick or a number in empty boxes as appropriate.

Location

Location (tick all that apply) — Documents included:
- ☐ Address
- ☐ Town plan with site marked
- ☐ Aerial view with site marked

Height/width ratio

Width of the site
- ○ <4 m
- ○ >4 m but <12 m
- ○ >12 m but <25 m
- ○ >25 m

Length of the site
- ○ <12 m
- ○ >12 m but <25 m
- ○ >25 m but <50 m
- ○ >50 m

Urban geometry
- ○ High buildings (>2 floors)
- ○ Low buildings (max. 2 floors)
- ○ Mixed

Landcover

Ground surface material
- ___% paved surfaces
- ___% unpaved surfaces

Green infrastructure
- ___ trees present (nr.)
- ___m tree canopy size (average crown diameter)
- ___ m² other green surfaces area
- ___ m² grass area

Blue infrastructure

Type of water feature:
- ○ pond
- ○ stream/river
- ○ swale/SuDS

Size in m² or width/diameter in m:
___ m/m²

Use

Time of use (tick all that apply)
- ☐ Morning
- ☐ Afternoon
- ☐ Lunchtime
- ☐ Evening

Social movement (tick all that apply)
- ☐ Route
- ☐ Place to stick around
- ☐ Mixed
- ☐ Abandoned

Figure 13: *The site characterization sheet (see cooltowns.eu/protocol) that needs to be completed during the site assessment.*

3.1 Site characterization

Start the fieldwork by completing the list of site characteristics (fig. 13). This needs to be accompanied by photographs to provide visual evidence on the spatial configurations (fig. 14), thermal conditions and every feature or intervention measured with a regular and thermal camera. A fisheye lens photograph should be taken above every weather station at a point of interest immediately before the start of each measurement.

3.1.1 List of site characteristics

Complete the list of site characteristics (fig. 13) with a tick or a number in empty boxes as appropriate.

3.1.2 Photographs with a regular camera

Make sure:

- to take pictures of every single feature or intervention that is measured. It can be done before, during, or directly after the measurements;
- photographs are taken from an eye-level perspective and from all directions: north, east, south, and west (see fig. 15);
- to include photographs covering the area of influence of the intervention (for example edges of the warmer/sunny and cooler/shaded surface);
- the reference point is included in one of the photographs. If this is not possible it should be photographed separately;
- if people are included either their permission should be requested and consent recorded or faces should be blurred before use so as to be unrecognizable in the photographs to meet the privacy legislation;
- the photographs are appealing and informative.

3.1.3 Thermal photographs

Make sure:

- the sun is on your back except when photographing a green wall, when the photographer should stand perpendicular (at right angles) to the wall;
- photographs are taken from an eye-level perspective;
- the intervention and edges of the warmer/sunny and cooler/shaded surface are included (see fig. 16);
- the reference point is included in the photograph. If this is impossible, a separate photograph according to the above requirements should be taken.

Figure 14: A good overview photograph showing the environment, microclimate and use of the site (Osdorpplein, Amsterdam).

Figure 15: A good example photograph of an intervention (the Climate Cube, Osdorpplein, Amsterdam).

Figure 16: A good example of a thermal photograph (Osdorpplein, Amsterdam).

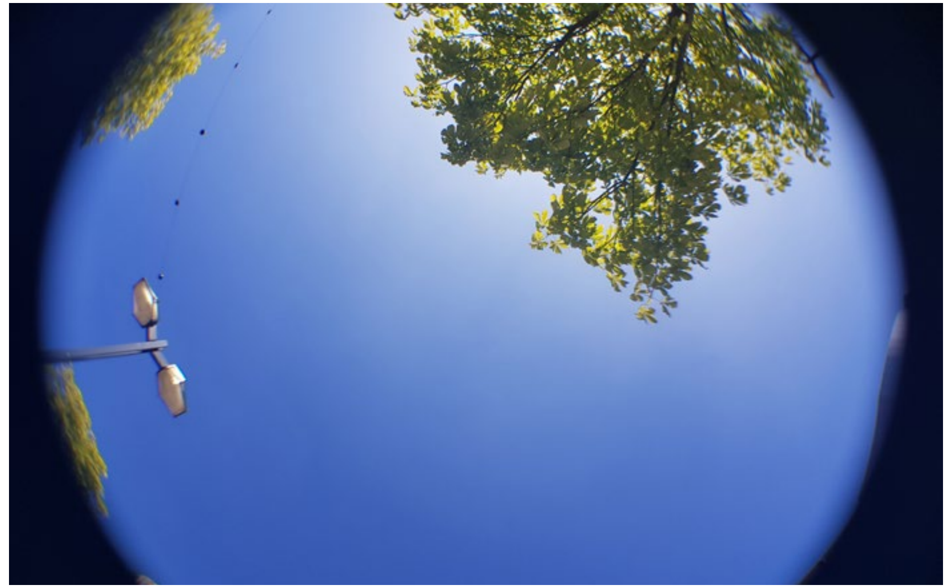


Figure 17: A good example of a fisheye photograph.

3.1.4 Fisheye lens photograph

Refer to fig. 17 and make sure:

- to take the photograph before the start or directly after the end time of the measurement to avoid influencing the sensors and so the measurement;
- to take the photograph just above the sensor (see fig. 18);
- the camera lens is horizontal;
- the photographer is not visible on the photograph (kneel down).

3.2 Questionnaire

This should be carried out at the same time as the weather station measurements by additional team members. The users of the site are questioned (see fig. 19) in both shaded and sunny parts of the site. During the Cool Towns project, it has been found that each questionnaire takes about 15 minutes.
Team members should briefly introduce themselves to the participant, explain the research project and specifically why people are being interviewed about their thermal perception. If appropriate, shade (parasol) can be offered, it can be suggested that they move into the shade or be offered a seat. If there are no people passing-by, for example at a school during holidays, the recommended alternative is to arrange for a group to visit the site so they can be interviewed. This needs more preparation as this can be difficult to arrange on a day that meets the required weather conditions. Please be prepared to provide background information about the research, such as flyers, as people are generally interested in activity that concerns their environment.

Figure 18: Demonstrating how to take a photo with a fisheye lens equipped camera.

After the general introduction the time, location and interviewer should be recorded followed by the subject's clothing and level of activity, as these may influence perception of thermal comfort; they should be told that this is being done. If clothing does not exactly match any of the descriptions the most similar one in the list should be ticked. Some participants may prefer not to answer all questions (e.g. gender or age range), please continue with the questionnaire. Please write down the respondent's answers avoiding any interpretation of their thermal experience. Questions that specifically apply to the site and/or interventions under investigation or relating to local policy issues can be added to the questionnaire as necessary.

Cool Towns Questionnaire

1. General information

a. Time (hh:mm)

___:___

b. Location (in sun or shade)

sun / shade

c. Name of interviewer

....

2. Personal information

a. Age

<10, 10-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70+

b. Write down gender

M / F / X

c. Are you on holiday/free/work day?

holiday / free / work day

d. Why are you here?

I work here / am travelling by / live here /
am shopping here / recreating or relaxing here

e. Clothing

(Tell the respondent what you are writing down.)

I. Upper body

sleeveless / short sleeves / long sleeves / shirtless

II. Lower body

short trousers, skirt or dress / long trousers, skirt or dress

III. Vest or jacket

vest / sweater / jacket / raincoat

IV. Accessories

sunglasses / cap / hat / headscarf / umbrella / face mask

f. Write down the activity level

laying down / sitting / standing / walking / running / cycling

g. Thermal history

I. How long have you been outside?

___ min.

II. How long have you been at this location?

(0 minutes for passers-by)

___ min.

III. How much longer are you intending to stay at this location?

(0 minutes for passers-by)

___ min.

IV. How often do you use/pass this location?

daily / weekly / monthly / seldom

3. Thermal perception at this location

a. How are you feeling now?

cold / cool / slightly cool / neutral / slightly warm / warm / hot

b. How do you perceive this environment (i.e. combination of sun, wind, shade, humidity)?

comfortable / slightly uncomfortable / uncomfortable /
very uncomfortable

c. Would you prefer it to be different?

cooler / no change / warmer

d. Are you comfortable here on warm days?

yes / no

e. Wind: At this moment, would you prefer...

less wind / OK / more wind

f. Sun: At this moment, would you prefer...

less sun / OK / more sun

4. Municipality

a. Has enough effort been done to make this area comfortable on warm days?

too little / sufficient / too much

b. Would you like to see anything changed? [open question]

....

....

5. Other

Do you have any further comments?

....

....

Figure 19: *The Cool Towns Questionnaire (see cooltowns.eu/protocol).*

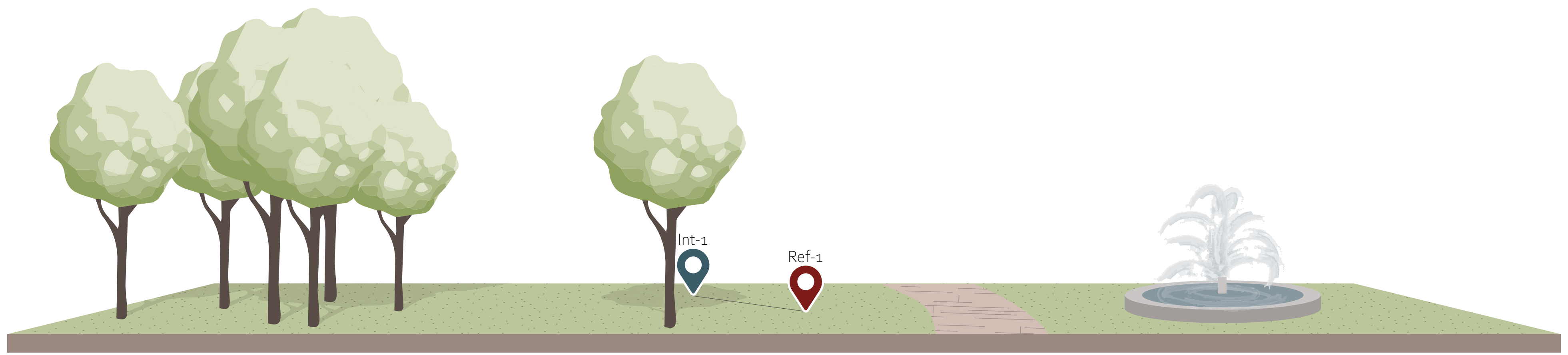


Figure 20: Diagrammatic representation showing the position of the reference point in the sun away from any other influences.

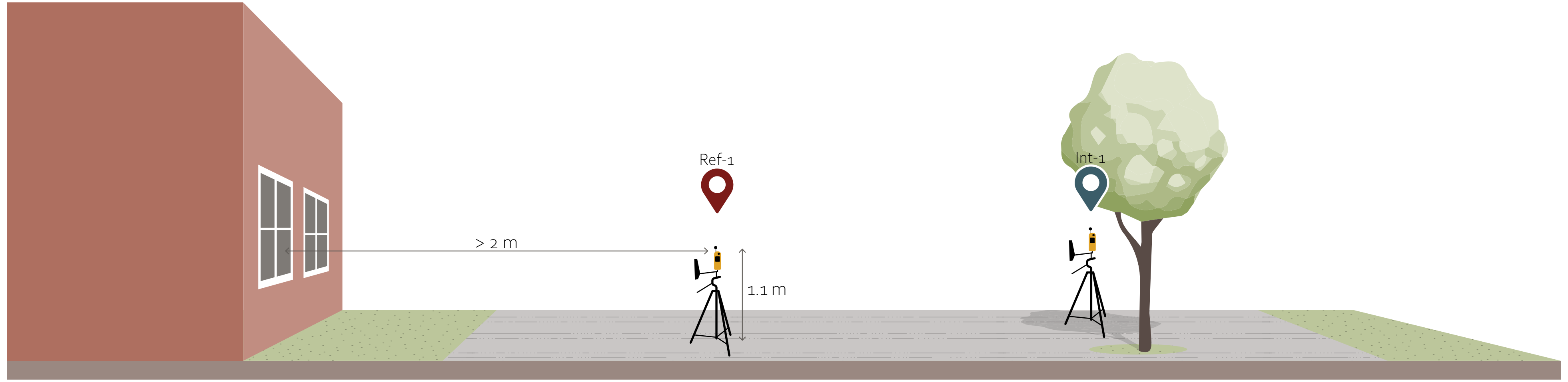
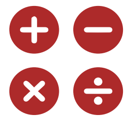


Figure 21: Diagrammatic representation showing the position of the weather station 1.1m above the ground, and the reference point at least 2m away from the intervention measurement point and on the same ground surface.

3.3 Measuring the PET



Two weather stations are used simultaneously: one measuring at the intervention and the other at the reference point. Experience during in the Cool Towns project has revealed three common mistakes that lead to serious consequences for the reliability of the data and analysis. The following are important to ensure that these are avoided:

1. make sure the weather station sensors are 1.1 m above ground level (take a tape measure) and are levelled if necessary;
2. make sure that the temperature and humidity sensors are never exposed to direct sunlight;
3. make sure the wind speed sensor is exposed and facing the direction of the wind or breeze so air can pass over it.

The measurement duration must always be at least 15 minutes per point of interest, (as it takes about 10 minutes for the black globe to equilibrate) with the logging interval set at 10 seconds (or shorter). The start and end time of recordings should be noted. If there is a weather station at the control point, then this should be set up to record constantly during the entire time measurements are being made on the site.

A few general specifications for (almost) all situations follow (see fig. 20 and 21):

- the reference measurement point should always be positioned in the sun and away from the influence of other interventions;
- the weather station for measuring the reference point should be on the same type of surface as the weather station at the intervention measurement point (except when measuring cool surface types);
- all measurement points should be at least 2 meters away from any factors that could influence accuracy (e.g. cars, engines, walls, (except when measuring green walls), air conditioners or any other heat sources;
- if the intervention provides shade it is important to measure in the centre of the shade pattern.

Some interventions may contain different cooling mechanisms, and these must be measured separately. Examples are described below.

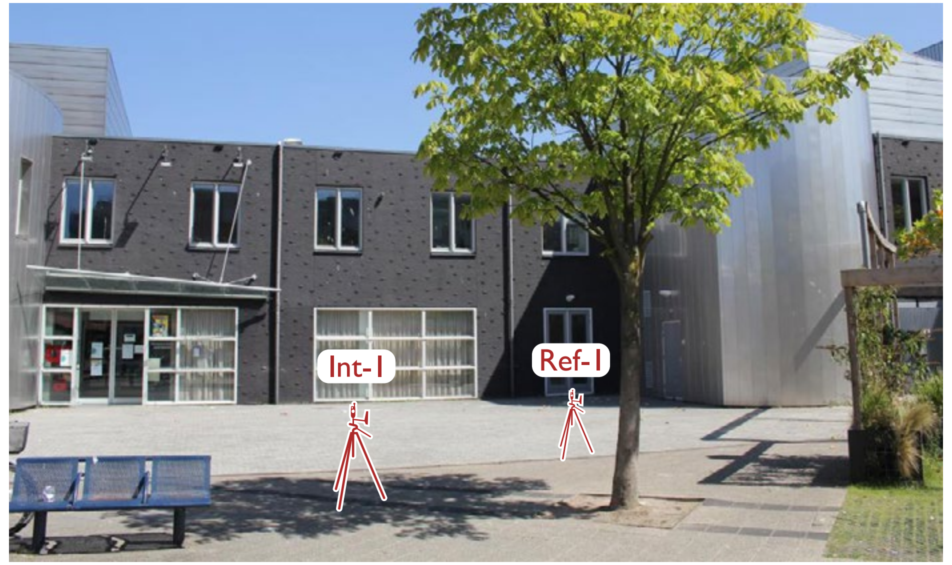


Figure 22: *Example showing how to measure the effect of a solitary tree (Osdorpplein, Amsterdam).*

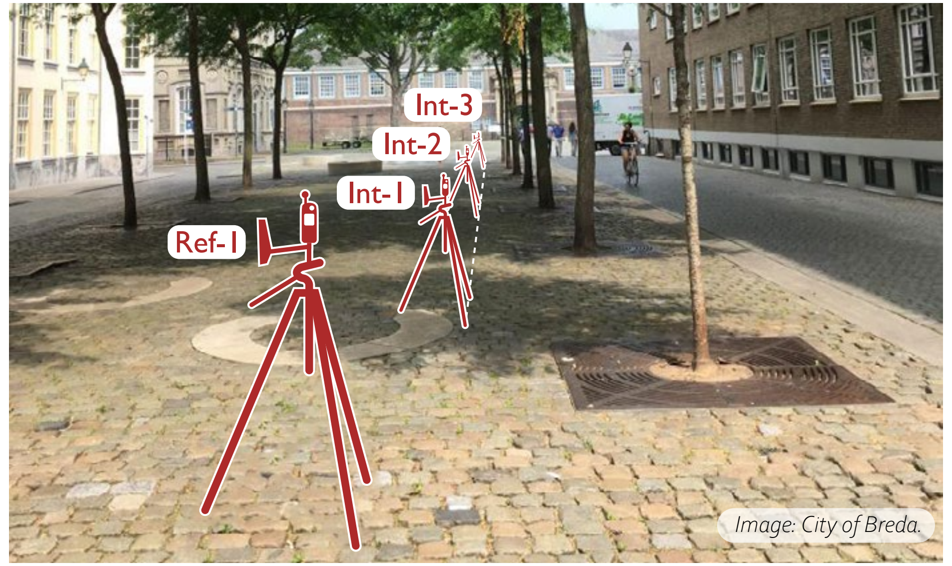


Figure 23: *Example showing how to measure the effect of a row of trees (Kasteelplein, Breda).*

Figure 24: *Example showing how to measure the effect of a shade structure (Zijlstraat, Haarlem). Adjusted image showing possible future shading scenario.*

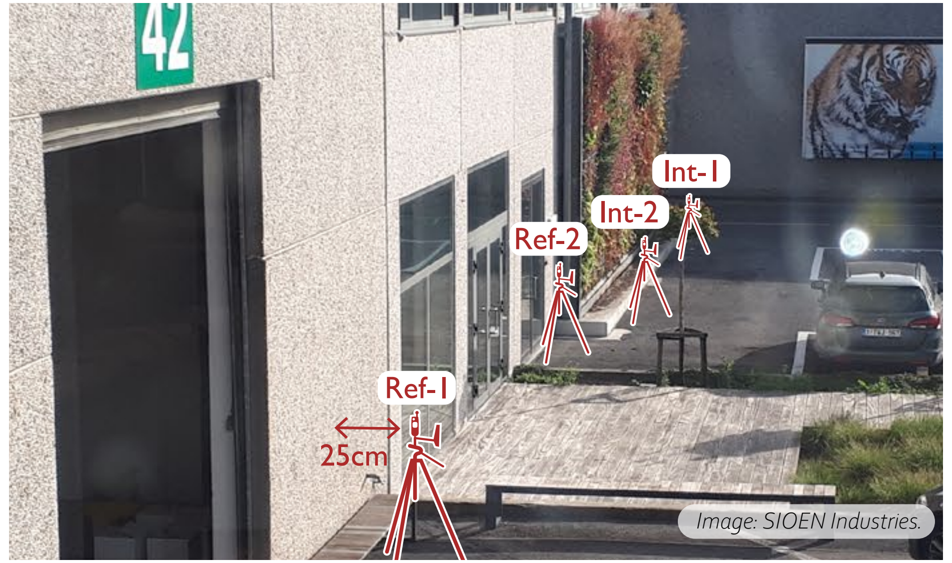


Figure 25: *Example showing how to measure the effect of a green wall system. Point Ref-1 illustrates the distance from the wall required (SIOEN headquarters, Ardooie).*

3.3.1 Additional advice for measuring single trees

Please note down the tree species, the estimated height, shape (e.g. domed, spreading, fastigiate, coppiced, trained) and for espalier or pleached trees, the orientation. The type of surface where the weather station is located should also be recorded (see fig. 22).

3.3.2 Additional advice for rows of trees

- It is important to note the tree species, the estimated height the orientation of the row and the type of surface where the weather station is located (see fig. 23);
- Three measurement points are required, one in the middle and one at each end of the row of trees with a single reference measurement point, preferable in the same line, but in full sun. If this is not possible then this should be placed in same orientation, in a treeless area with similar spatial characteristics such as surface material.

3.3.3 Additional advice for shade structures

Place the weather station at the measurement point in the shade, 2 meters away from any other influences (see fig. 24). It is important to record the estimated height of the structure and the type of ground surface where the measurements are conducted.

3.3.4 Additional advice for green walls

- Different types of green walls, including green facades, are measured in the same way (at 1.1 m above ground level), from at least two places of the area covered with plants, at least 2 meters apart and at least 25 cm from the sides.
- The reference points should be two places on the same wall which is not covered with plants (at least 25 cm aside) and, again, at least 2 meters wide (see fig. 25). If no part of the wall is bare then another can be used as a reference point, this should have the same orientation and surface material as the green wall or façade.
- The weather stations should be positioned so the sensors are 25 cm from the bare wall or plant material, the distance that provides space for rotation of the wind vane or anemometer (see fig. 25);

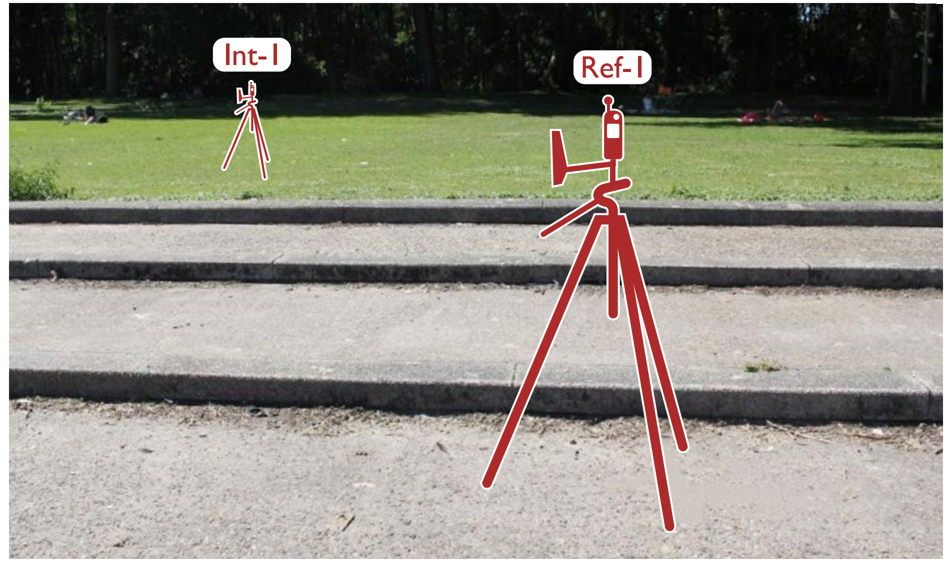


Figure 26: *Example showing how to measure the effect of different ground surfaces (Stadspark Osdorp, Amsterdam).*

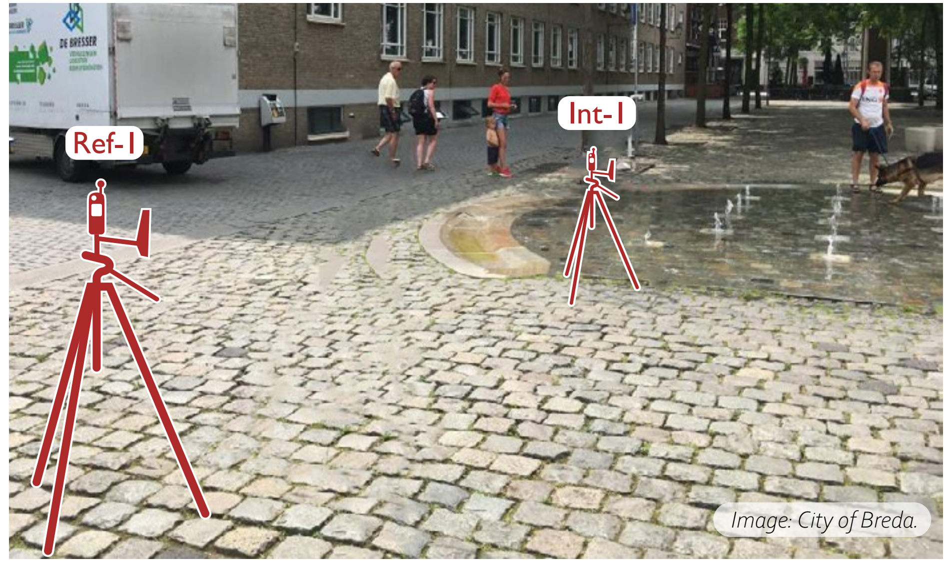


Figure 27: *Example showing how to measure the effect of a water feature (Kasteelplein, Breda).*

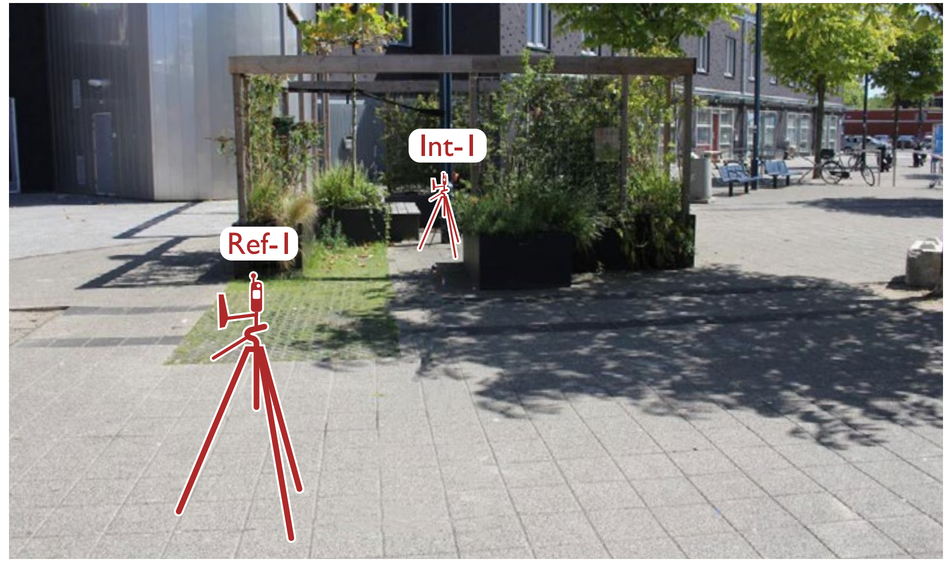


Figure 28: *Example showing how to measure the effect of a temporary, mobile, intervention (the Climate Cube, Osdorpplein, Amsterdam).*

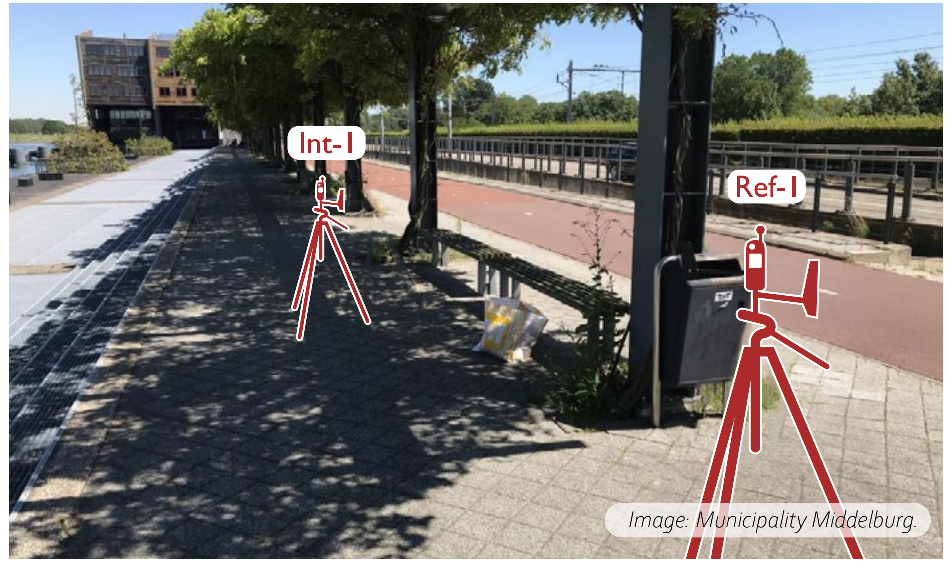


Figure 29: *Example showing how to measure the effect of a mature pergola (Kanaalweg, Middelburg).*

3.3.5 Additional advice for cool surfaces

- The weather station should be located in the middle of the cool ground surface type, such as grass, and this needs to be at least 25 m².
- The reference measurement point should be at least 2.5 meters away from that surface in similar surroundings (see fig. 26).

3.3.6 Additional advice for water features

- Water features (e.g. playground, fountain, wet surface, misting unit or waterbody) should be measured next to the feature, about 25 cm from the water feature's edge (see fig. 27);
- The reference measurement point needs to be at least 8 meters away from the water on the same type of surface and in similar surroundings.

3.3.7 Additional advice for other cooling features

Some potentially cooling features are not currently described in this protocol (see fig. 28 and 29). These should be treated similarly to features described if they have a similar cooling mechanism. For example, a tree espaliered to a south-facing wall is a tree, but with respect to cooling mechanism it functions like a green wall so measure it in the same way.

3.4 Documenting measurements

The measurement form should be completed for each measurement and each installed intervention or existing heat mitigation feature. All the information in figure 30 is necessary as without it, the data cannot be used.

All the points of interest (i.e. where the weather stations are positioned as indicated on the measurement map of the site, see subchapter 2.2) should be described as fully as possible and the associated photographs (regular, thermal and fisheye) carefully saved with filenames that indicate exactly where and when they were taken.

The Cool Towns Heat Stress Measurement Form (see cooltowns.eu/protocol) includes fields to complete with the information in figure 30 and is necessary for processing the data. The descriptive columns (if applicable) need to be filled in about the measured points of interest. The column headers describe "Tree", "Shade Structure", "Green Wall", "Water feature" and "Cool surface". The photograph filenames should be noted according to whether they are regular, thermal, or fisheye.

3.5 Data management

All raw data is stored electronically in separate folders and clearly labelled (for example date\site\point of interest) and should include all the information on the recording form. Accurately document the unique identifiers (UIs) of all mobile weather stations. Remember to ensure people are unrecognizable in photographs - please blur any faces. Make sure you have a backup.

Location	The name of the site where measurements are taken.
Point of interest	The point to be measured to determine the heat mitigation. This could be a tree, a shade structure, a green wall, a water feature, a cool surface, or any other cooling feature.
Name	The team members conducting the measurement
Date	Date of the measurement
Start time	The time (hours and minutes) when all the weather stations are in position and begin measuring.
End time	The exact time (in minutes and seconds) when measurement stops. This must be at least 15 minutes after the start time.
Unique Identifiers	It is essential that each weather station is given a unique identifier (UI). This can be a serial number, name or colour, and enables recording which weather station was used to carry out the measurements at the points of interest, the reference and control points.

Figure 30: Essential information to be completed during fieldwork using the Cool Towns Measurement Form (see cooltowns.eu/protocol).

3.6 The calculation of PET

The calculation of Physiological Equivalent Temperature from the values measured follows Höppe's method (1999) and requires the following steps:

a. The data from each mobile weather stations is linked by a unique identifier to the location and the time period (i.e. the data is labelled to show which weather station it came from and where and when it was recorded).

b. The first 10 minutes of each recording is discarded as this is the time that is needed for the globe temperature to equilibrate.

c. The average for the values recorded in the following 5 (or more) minutes gives the globe temperature, wind speed, air temperature and relative humidity for the next steps.

d. The 'mean radiant temperature' (again for 5 or more -minutes average) using the (equivalent) diameter and colour (i.e. emissivity value) of the globe in the formula determined by Thorsson et al. (2007, equation 3.).

When the globe temperature, air temperature and wind speed are known, the mean radiant temperature (T_{mrt}) can be calculated according to:

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

T_g = globe temperature (°C)
V_a = wind speed (ms^{-1})
T_a = air temperature (°C)
D = globe diameter (m)
ε = globe emissivity (-)

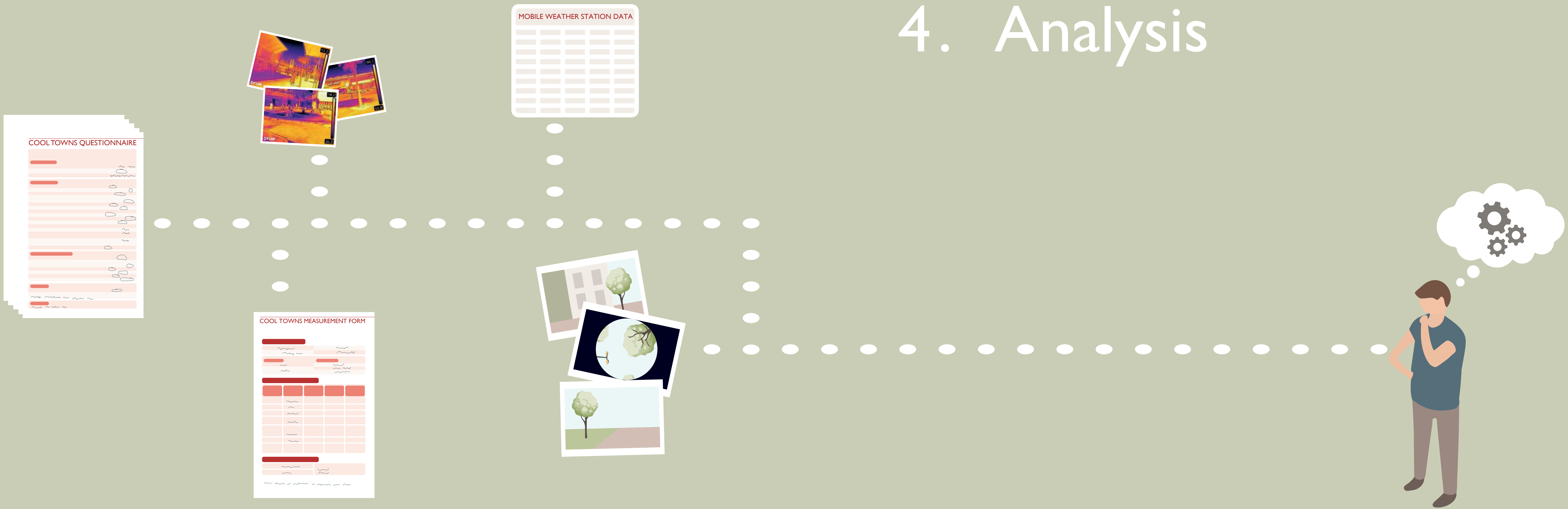
Thorsson et al. (2007) empirically derived parameter 1.10×10^8 and the wind exponent ($V_a{}^{0.6}$) which together represent the globe's mean convection coefficient ($1.10 \times 10^8\, V_a{}^{0.6}$).

e. PET (also as a 5-minute average value) can then be calculated form the the 5-minute averages of air temperature, mean radiant temperature, relative humidity and wind speed using either the RayMan software (Matzarakis et al., 2007) or developing a specific script (see for example, Walther & Goestchel, 2018).

The Cool Towns Heat Stress Measurement Protocol is accompanied by the Cool Towns MS Excel PET Calculation Template (see cooltowns.eu/protocol) to simplify steps c to e. As the columns for air temperature, globe temperature, relative humidity and wind speed are filled in, it calculates the PET values.

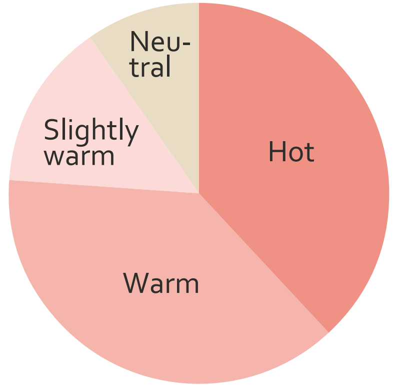
Once the PET values for all measurement locations and time periods have been calculated the data can be analyzed to provide information on the relative heat stress mitigation. This is illustrated in the following case study.

4. Analysis



MOBILE WEATHER STATION DATA
COOL TOWNS QUESTIONNAIRE
COOL TOWNS MEASUREMENT FORM

Figure 31: *Questionnaire results showing how and why respondents were using Osdorpplein on 24th of July 2019.*



PET (°C)	Physiological Stress Grade
<18	Slight Cold Stress
18-23	No Thermal Stress
23-29	Slight Heat Stress
29-35	Moderate Heat Stress
35-41	Strong Heat Stress
41-46	Extreme Heat Stress (LV 1)
46-51	Extreme Heat Stress (LV 2)
51-56	Extreme Heat Stress (LV 3)
>56	Extreme Heat Stress (LV 4)

Figure 32: *Questionnaire results showing the thermal perception of users of Osdorpplein on 24th of July 2019 and the corresponding physiological stress grade.*

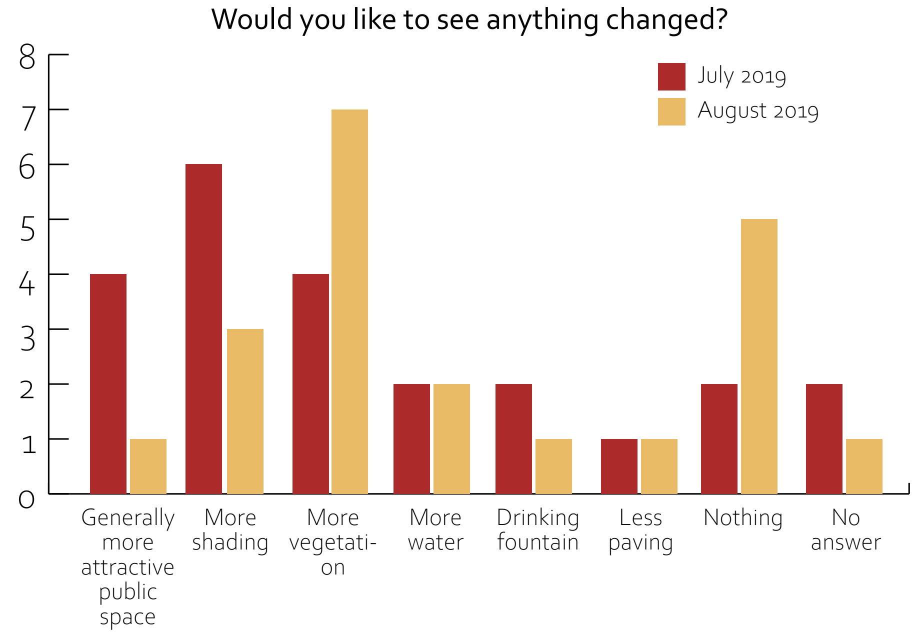


Figure 34: *Questionnaire results showing suggestions for (further) improvements at Osdorpplein.*

ID	PET (°C)	T_{air} (°C)	T_{globe} (°C)	Wind (m/s)	RH (%)
Next to chestnut tree	51,6	35,0	47,5	1,1	35
Under chestnut tree	39,3 (-12,3)	33,9 (-1,1)	37,5 (-10,0)	1,1 (±0,0)	37 (+2,0)

Figure 33: *PET difference measured in the shade of a horse chestnut tree at Osdorpplein.*

Using this Cool Towns Heat Stress Measurement Protocol can provide insight into the full thermal experience of users at the street-level in urban areas. The PET-values calculated from the data recorded by mobile weather stations combined with the questionnaire responses enables heat stress locations to be identified and can demonstrate the heat stress reduction provided by interventions and existing features.

In this chapter the results from investigations conducted using the protocol at the Osdorpplein shopping centre in Amsterdam are briefly discussed to demonstrate how this information can inform planning and design to improve thermal comfort.

4.1 The site characteristics

The measurements at Osdorpplein took place during the two heat waves in the Netherlands in 2019. On Wednesday July 24th, the first measurement day, a maximum temperature of 38.9 °C was recorded by the nearest official weather station (near Schiphol airport). On the second, Monday 26th of August, the maximum temperature was 33.8 °C.

On both measurement days, the square was observed to be empty and only used by passers-by mostly going to Westmarket shops or those in smaller streets nearby (see fig. 31). This was confirmed by the questionnaires, mostly conducted in the shade. On average, users of the square perceived the thermal conditions as warm, but a significant number described it as hot (see fig. 32). Respondents reported that they felt the area currently lacks shade and vegetation (see fig. 34), with the majority finding the square is not a comfortable place to be on a summer's day. It is completely paved with only a few small horse chestnut trees. The photographs show these site-characteristics which are responsible for the challenging thermal conditions and illustrate the lack of use of the square.

4.2 The baseline situation

The thermal experience of the respondents is illustrated by the thermal photographs in fig.16. In this image, the shade created by the canopy of the horse chestnut tree can be seen but this is not sufficient to create a cool spot for users to remain in the square for long. The trees are distributed over the southern part of the square so neither form a large canopy (see overview photo fig. 14 and fisheye photo of fig. 17) or provide a continuous shaded route for crossing the square. There are some fixed benches near these trees, some of which are shaded for short periods, but the larger number of picnic tables scattered in the northern part of the square are exposed to the sun all afternoon which explains lack of use. The measurements carried out have shown that higher PET is experienced in the northern part of Osdorpplein, due to little influence of wind in this relatively enclosed space (see fig. 35).

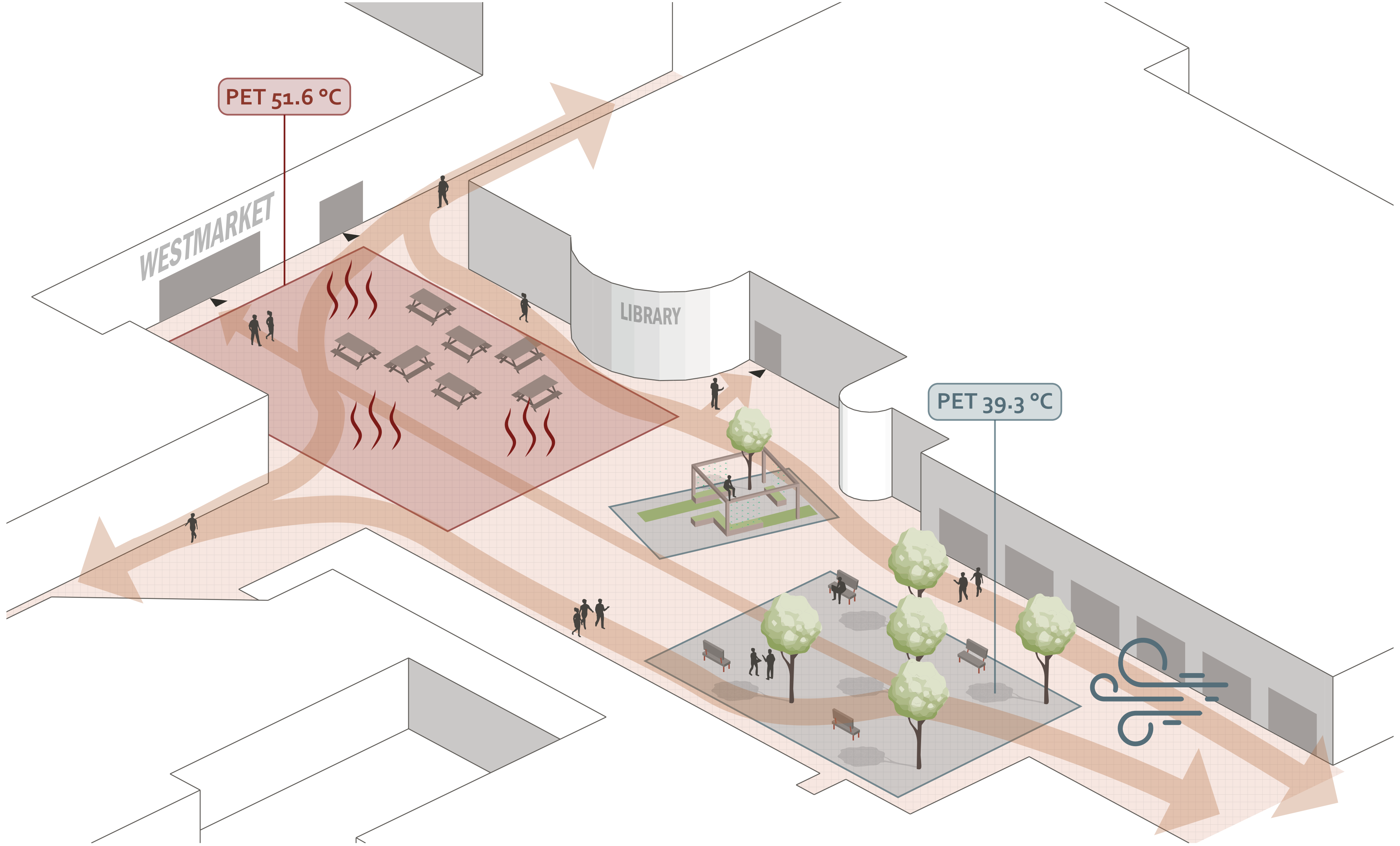
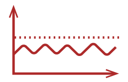


Figure 35: 3D view of Osdorpplein with main pedestrian routes highlighted. The red zone experiences higher PET-values while the blue zones show heat stress mitigation. This illustrates that design modifications could create cooler routes and more comfortable, inviting, places to rest on hot days.

4.3 The potential for intervention



The measurements showed that an individual horse chestnut tree had a cooling effect of 12-13 °C PET, equivalent to two physiological stress grades (see fig. 33). Placing trees to provide more shade strategically along the most used pedestrian routes could extend this cooling effect to maximise the benefit for passers-by while maintaining sunny seating areas for use in colder weather and to cater for individual preference. More trees around some recently placed picnic tables would provide a more balanced mixture of sunny/shaded conditions on summer days and respond to the request from users for a greener environment.

The cooling effect of the newly installed Climate Cube was examined on the 26th of August 2019. The questionnaire showed the thermal preferences of users leaned more towards 'colder' with more remaining, either sitting or standing in the square rather than walking across it compared to the previous situation, before the installation.

The PET-measurement results showed a slight decrease in the heat stress experienced at the Climate Cube. The effect was less than expected but could be explained by the recently planted vegetation that was still small. In future, the London plane tree, in the centre, and the climbing plants growing over the wooden pergola are expected to grow rapidly. In a few years' time this temporary intervention is likely to improve the thermal comfort for users of the square and may encourage introduction of wider heat stress mitigation strategies.

REFERENCES

ANSI/ASHRAE. (2017). Standard 55: 2017, Thermal Environmental Conditions for Human Occupancy. Atlanta, GA, USA: ASHRAE. https://www.ashrae.org/

Bell, P. A. (1981). Physiological, Comfort, Performance, and Social Effects of Heat Stress. *Journal of Social Issues*, 37(1), 71–94. doi: 10.1111/j.1540-4560.1981.tb01058.x

Coccolo, S., Kämpf, J., Scartezzini, J. L., & Pearlmutter, D. (2016). Outdoor Human Comfort and Thermal Stress: A comprehensive review on models and standards. *Urban Climate*, 18, 33–57. doi: 10.1016/j.uclim.2016.08.004

EEA. (2012). Urban Adaptation to Climate Change in Europe: Challenges and opportunities for cities together with supportive national and European policies. EEA Report No 2/2012, 143p. doi: 10.2800/41895

Elnabawi, M. H., & Hamza, N. (2020). Behavioural Perspectives of Outdoor Thermal Comfort in Urban Areas: A Critical Review. *Atmosphere*, 11(1), 51. doi: 10.3390/atmos11010051

Epstein, Y., & Moran, D. S. (2006). Thermal Comfort and the Heat Stress Indices. *Industrial Health*, 44: 388. doi: 10.2486/indhealth.44.388

Erell, E., Pearlmutter, D., Boneh, D., & Kutiel, P. B. (2014). Effect of High-Albedo Materials on Pedestrian Heat Stress in Urban Street Canyons. *Urban Climate*, 10(P2), 367–386. doi: 10.1016/j.uclim.2013.10.005

Havenith, G. (1999). Heat Balance when Wearing Protective Clothing. *Annals of Occupational Hygiene*, 43(5), 289–296. doi: 10.1093/annhyg/43.5.289

Höppe, P. (1999). The Physiological Equivalent Temperature - A universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology*, 43(2): 71-75. doi: 10.1007/s004840050118

Johansson, E., Thorsson, S., Emmanuel, R., & Krüger, E. (2014). Instruments and Methods in Outdoor Thermal Comfort Studies - The need for standardization. *Urban Climate*, 10(P2), 346–366. doi: 10.1016/j.uclim.2013.12.002

Klok, L., Rood, N., Kluck, J., and Kleerekoper, L. (2019). Assessment of Thermally Comfortable Urban Spaces in Amsterdam during Hot Summer Days. *International Journal of Biometeorology*, 63:129-1. doi: 10.1007/s00484-018-1644-x

Koopmans, S., Heusinkveld, B., & Steeneveld, G. (2020). A Standardized Physical Equivalent Temperature Urban Heat Map at 1-m Spatial Resolution to Facilitate Climate Stress Tests in the Netherlands. *Building and Environment*, 181, 106984. doi: 10.1016/j.buildenv.2020.106984

Kuenen, K. (2020). Eerste Bevindingen in Europees Verkoelingsproject Cool Towns. *Vakblad Groen*, 76(02), 30–34. https://stadszaken.nl/

Lenzholzer, S., & van der Wulp, N. Y. (2010). Thermal Experience and Perception of the Built Environment in Dutch Urban Squares. *Journal of Urban Design*, 15(3), 375–401. doi: 10.1080/13574809.2010.488030

Matzarakis, A., Mayer, H., & Iziomon, M. G. (1999). Applications of a Universal Thermal Index: Physiological Equivalent Temperature. *International Journal of Biometeorology*, 43, 76–84. doi: 10.1007/s004840050119

Matzarakis, A., Rutz, F., & Mayer, H. (2007). Modelling Radiation Fluxes in Simple and Complex Environments - Application of the RayMan model. *International Journal of Biometeorology*, 51(4), 323–334. doi: 10.1007/s00484-006-0061-8

Matzarakis, A., Muthers, S., & Rutz, F. (2014). Application and Comparison of UTCI and PET in Temperate Climate Conditions. *Finisterra*, 49(98), 21–31. doi: 10.18055/Finis6453

Nouri, A. S., Lopes, A., Costa, J. P., & Matzarakis, A. (2018). Confronting Potential Future Augmentations of the Physiologically Equivalent Temperature through Public Space Design: The case of Rossio, Lisbon. *Sustainable Cities and Society*, 37, 7–25. doi: 10.1016/j.scs.2017.10.031

Pilcher, J. J., Nadler, E., & Busch, C. (2002). Effects of Hot and Cold Temperature Exposure on Performance: A meta- analytic review. *Ergonomics*, 40(10), 682–699. doi: 10.1080/00140130210158419

Spanjar, G., & Zandbrink, L. van. (2020). Van Risico's voor de Volksgezondheid door Hitte naar een Hittebestendige Inrichting van de Stad. *Rooilijn*, 53(1), 51. https://www.rooilijn.nl

Thorsson, S., Lindberg, F., Eliasson, I., & Holmer, B. (2007). Different Methods for Estimating the Mean Radiant Temperature in an Outdoor Urban Setting. *International Journal of Climatology*, 27(14), 1983–1993. doi: 10.1002/joc.1537

Walther, E., & Goestchel, Q. (2018). The P.E.T. Comfort Index: Questioning the model. *Building and Environment*, 137(April), 1–10. doi: 10.1016/j.buildenv.2018.03.054

WHO (2013). Combined or Multiple Exposure to Health Stressors in Indoor Built Environments. Bonn: World Health Organization Europe. https://www.euro.who.int

CREDITS

Authors
Prof.dr. Gideon Spanjar
Project Leader - Senior Researcher
Amsterdam University of Applied Sciences

Luc van Zandbrink
Junior Researcher Urban Climatologist
Amsterdam University of Applied Sciences

Dr. Debbie Bartlett
Professor Environmental Conservation
University of Greenwich

Dr. Jeroen Kluck
Professor Urban Waters
Amsterdam University of Applied Sciences

With the cooperation of
Vera Wetzels, Junior Researcher Urban Design, AUAS
Kylian Postema, Research Assistant, AUAS
Erica Caverzam Barbosa, Research Assistant, AUAS

Figures
All figures in this document are made by Amsterdam University of Applied Sciences unless noted otherwise.

In collaboration with the Cool Towns Partners
Municipality Middelburg, City of Breda, Province of East-Flanders, City of Ostend, Southend on Sea Borough Council (SBC), University of Greenwich, Kent County Council, University of Picardie Jules Verne (UPJV), GreenBlue Urban, AUD Agency for urban planning and development of the Saint-Omer and Flandre Interieure region, Amsterdam University of Applied Sciences (AUAS), Sioen Industries, Community of the agglomeration of St Omer.

Acknowledgement
Interreg 2 Seas Mers Zeeën for funding the Cool Towns project. Province of North-Holland and Province of Zeeland for co-funding this publication.

More information
Cooltowns.eu

Contact
Gideon Spanjar
G.Spanjar@hva.nl

Date
Thursday the 19th of November 2020

Cities are confronted with more frequent heatwaves of increasing intensity discouraging people from using urban open spaces that are part of their daily lives. Climate proofing cities is an incremental process that should begin where it is needed using the most cost-efficient solutions to mitigate heat stress. However, for this to be achieved the factors that influence the thermal comfort of users, such as the layout of local spaces, their function and the way people use them needs to be identified first. There is currently little evidence available on the effectiveness of heat stress interventions in different types of urban space.

The Cool Towns Heat Stress Measurement Protocol provides basic guidance to enable a full Thermal Comfort Assessment (TCA) to be conducted at street-level. Those involved in implementing climate adaptation strategies in urban areas, such as in redevelopments will find practical support to identify places where heat stress may be an issue and suggestions for effective mitigation measures. For others, such as project developers, and spatial designers such as landscape architects and urban planners it provides practical instructions on how to evaluate and provide evidence-based justification for the selection of different cooling interventions for example trees, water features, and shade sails, for climate proofing urban areas.

Cooltowns.eu