Amsterdam University of Applied Sciences

Cool Towns Intervention Catalogue

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Proven solutions to mitigate heat stress at street-level

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Bart Tommelein, Mayor City of Ostend

Foreword

Climate change confronts us with very big challenges. Most people - especially in cities at the seafront - think of flood risk but the opposite, periods of extreme drought, are also possible. Heat stress, a particular issue in cities, is currently underestimated with the impact on daily life, nature, health and the economy much bigger than we think.

The European project Cool Towns, a cooperation between 14 partners; various local governments, knowledge institutions and private partners, have worked intensively on this issue for the last 4 years. This publication, the Cool Towns Intervention Catalogue, shows policy makers and related professionals, such as city planners and architects, specific examples of what can be done to mitigate heat stress. It will help us to understand how to make a livable city that feels pleasant and refreshing even during periods of very high temperatures.

The tools, such as planting trees, integrating water elements, construction of green walls and shade sails, are described and the advantages of each option analysed. Local authorities also received training and guidance from the universities regarding the choice of location in the city to prioritise for intervention by identifying the places most likely to suffer from heat stress (see Spanjar et al., 2022).

A unique aspect of this publication is the robust scientific basis. The effectiveness of all the interventions have been measured on pilot sites across the participating cities and municipalities. This has resulted in a "full evidence-based" design guide so that the best decisions can be made.

This catalogue of interventions provides an overview of which type of intervention works best for which type of outdoor space, use and purpose, providing very useful information that we will integrate into our climate adaptation plan, currently in preparation for the City of Ostend.
In addition to its role as a useful working document, this publication is also an excellent example of effective cooperation between cities, universities, and private businesses.

Let's continue the spirit of this European project and tackle climate challenges together!

Bart Tommelein,
Mayor City of Ostend


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1. Introduction

Built environments are particularly vulnerable to the impacts of climate change. Most European towns and cities have developed horizontally over time but are currently in the process of further densification (Cortinovis et al., 2022). High-rise developments are being built within city boundaries at an unprecedented rate to accommodate a growing urban population. The densification contributes to the Urban Heat island phenomenon and can increase the frequency of extreme heat events locally, extending the duration and decreasing relief from heat exposure (Schatz & Kucharik, 2015). These new build-up areas have one thing in common with historic centres; they consist of solid surfaces and often lack open urban spaces covered with green vegetation.

The current amount of vegetation is inadequate to prevent the city heating up. Thermal radiation from conventional construction materials, whether these are stone, or the modern alternative forms of concrete, combined with roads and pavements, causes cities to be warmer than the surrounding countryside and can bring great discomfort for citizens.

The urban geometry – the way buildings and streets are laid out - influences which areas within the city are sunny or shady, windy, or still. Outdoor spaces flanked with buildings affect local thermal conditions so it is possible for urban spaces close to each other to have very different microclimates. Urban areas which people depend on in their daily life such as shopping areas, residential streets, mobility hubs, playgrounds and walking and cycling routes, are under threat of rising temperatures (see Spanjar et al., 2022). It is here, at street level, that creating tactical cooling capacity can significantly increase the thermal comfort for residents and ensure the accessibility of the most vital parts of cities and towns during warm periods of the year.

In the Cool Towns project, municipalities collaborated with universities, and companies specialising in climate adaptation, to install and measure the effectiveness of a range of heat stress interventions on sites with different characteristics – from streets that also experience surface water flooding, to town squares, school playgrounds, parks and multi-purpose green spaces. Over four years in Belgium, England, The Netherlands, and France, a large number of features installed during the project and existing urban green and blue infrastructure was assessed regarding cooling capacity during warm summer days when the air temperature was above 25 degrees Celsius.

This publication brings together the latest available evidence on the effectiveness of a wide array of different street-level interventions in improving the thermal comfort for citizens and provides factsheets with important information on the advantages and disadvantages associated with each one.

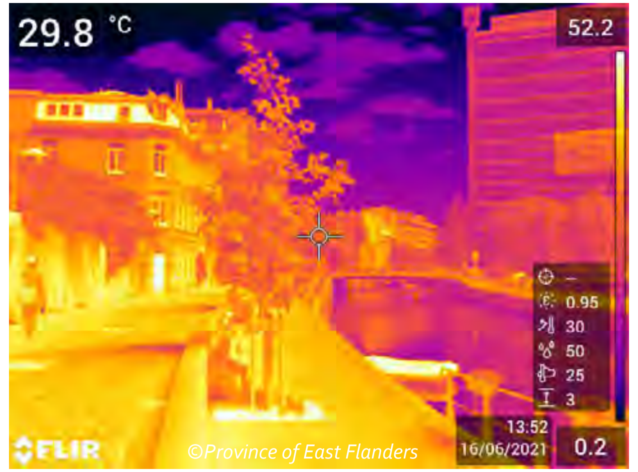

Figure 1: Thermal photograph of Bisdomkaai, Ghent, Belgium, on a hot June afternoon showing surface temperatures and indicating the intensity of infrared radiation experienced when walking along the canal or sitting at its edge.

1.1 Reading guide

The aim of The Cool Towns Intervention Catalogue is to provide the reader with technical information on the range of interventions that can be implemented to mitigate heat stress in the urban environment.

The first chapter provides an introduction and is followed by the second, discussing the variety of assessed street-level interventions to mitigate heat stress. The following chapters provide technical information on the advantages and potential drawbacks of each intervention type to enable the reader to make an informed decision about which one is most likely to suit their needs. At the end of the document, in the eighth chapter, you will find a comparative analysis of the different types of interventions to provide thermal comfort for people, the conclusions and the tips and tricks for measuring and implementing heat stress interventions.

1.2 Target audience

This publication has been designed as a resource for decision makers, urban planners, landscape architects, environmental consultants, elected members and anyone else who is considering how to mitigate heat stress in urban areas. This may be as part of a refurbishment or improvement plan for a street, square, park, playground or neighbourhood or as part of a new development.

In order to help those involved in taking decisions to make an informed choice and achieve the best possible result the different options are presented, along with information about the particular benefits associated with each of them, so that the most appropriate for the specific spatial situation can be identified.

Figure 2: *The European Cool Towns partners in the Interreg Two Seas Region.*

1.3 The Cool Towns project

The Cool Towns project is a partnership of 14 European partners located in the two seas region (see fig.2). The project brings together leading European academic institutions, local governmental organisations and industries from the climate change adaptation domains and ran from 2018 to 2022. The partnership aimed to counteract the negative effects of climate change and find attractive solutions that make cities more climate robust and provide municipalities with the knowledge and tools to become heat-resistant.

The Cool Towns Intervention Catalogue is the third in the series of publications produced by this project and it discusses the effectiveness of a wide range of intervention types - from different tree species to water features and green walls - in reducing the Physiological Equivalent Temperature (PET) to increase thermal comfort for users of public open space. The interventions mentioned in this publication have all been measured by mobile weather stations on the ground generating quantitative information regarding the reduction in PET and this is combined with qualitative information, from questionnaires conducted at the same time, to explore the thermal experiences of those nearby .

The Cool Towns Intervention Catalogue is the follow-up to the The Urban Heat Atlas (see fig.3 and Spanjar et al., 2022) that provides an introduction to the identification of places likely to suffer from heat stress to enable decision-makers to set priority locations for action. The second publication, entitled the Cool Towns Heat Stress Measurement Protocol, is a standardised methodology to identify the thermal comfort experienced at fine-grained, local, scale and can provide a robust justification for future investment, as part of a cost-benefit analysis. It provides guidance to enable a full Thermal Comfort Assessment (TCA) at street-level to be undertaken, enabling quantitative information to be generated on PET reduction and, using a questionnaire, the thermal perceptions of users (qualitative information) to be produced.

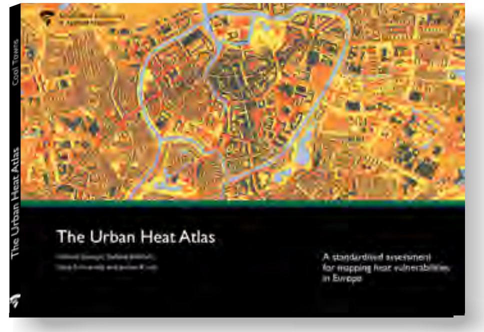

Figure 3: *(1) The Urban Heat Atlas demonstrates how to conduct a Thermal Comfort Assessment (TCA) systematically to identify heat vulnerabilities and cooling capacity in cities to enable decision-makers to set priorities for action.*

(2) The Cool Towns Heat Stress Measurement Protocol provides basic guidance on how to conduct a TCA at street-level and how heat stress and cool spots can be measured.

(3) The Cool Towns Intervention Catalogue provides an overview of the effectiveness of heat stress interventions to gain insight into the cooling capacity and application.

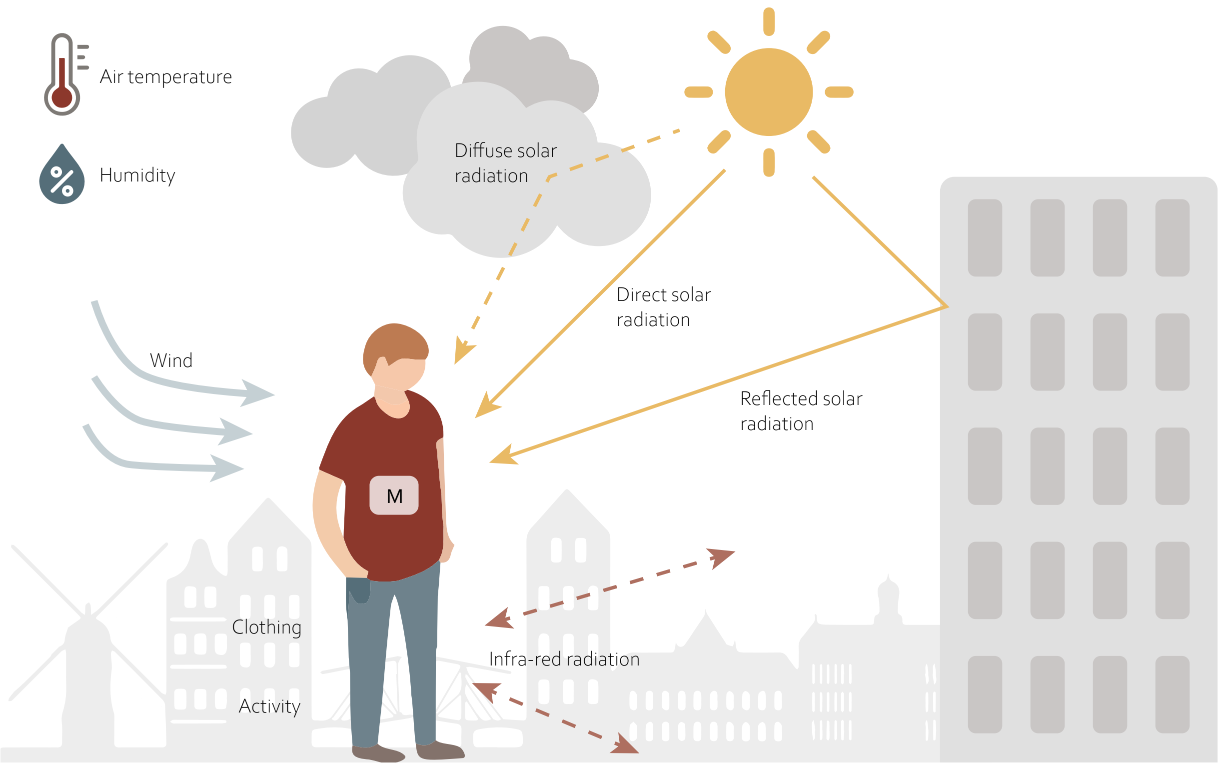

Figure 4: *Schematic representation of the different factors that influence the energy balance of the human body and on which the Physiological Equivalent Temperature (PET) is based. The air temperature, humidity, and wind speed can be directly measured by a mobile weather station (or the data can be sourced from a meteorological station nearby) and are then combined with spatial data. Insulation from clothing and activity are recorded using a questionnaire at the same time as PET is measured. If PET is modelled a fixed value for clothing factor and walking is the activity used (Adapted from Havenith, 1999).*

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 (LV1)
46-51	Extreme Heat Stress (LV2)
51-56	Extreme Heat Stress (LV3)
>56	Extreme Heat Stress (LV4)

Figure 5: *The different grades of thermal perception and physiological stress on human beings expressed as the Physiological Equivalent Temperature (PET) index. After Nouri et al., 2018, p. 13 and adapted from Matzarakis et al., 1999.*

1.4 Thermal comfort

People experience heat stress and become thermally uncomfortable when too much heat is absorbed by the body (Epstein & Moran, 2006). The way heat stress is built up and experienced by people is the result of the interaction of many factors, not just the air temperature, which is the figure usually given in weather reports. It is also a function of the intensity of the sun's radiation, humidity, and wind speed. Thus, the parameters required when assessing heat stress are: air temperature (°C), globe temperature (°C), relative humidity (%), and wind speed (m/s) and mean radiant temperature (Tmrt) (see also Thorsson et al., 2007). These parameters together form the Physiological Equivalent Temperature (PET) the most common thermal comfort index (see fig.4) for outdoor spaces (Coccolo et al., 2016; Matzarakis et al., 2014). The PET is expressed in degrees Celsius (°C) and based on the energy balance of the human body using 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.

The Tmrt comprises the direct solar radiation and the reflected solar radiation from the surroundings, in combination with the radiant heat exchanged with building and pavement surfaces (by so-called infra-red radiation see fig.4). For example, if pavement surfaces in urban open space and/or adjacent buildings are warmed by the sun they will emit more infrared radiation, resulting in higher PET values. The PET value (°C) measured in outdoor spaces, including the PET reduction value of heat stress interventions in this publication, corresponds to the Physiological stress grades in Figure 5. The higher the grade the greater the risk of heat stress, although impact varies according to length of exposure, whether the subject has any underlying health condition, and their adaptive capacity. This means that the same person will have different experiences of the temperature at different locations in the city even when the weather conditions are the same. In direct sunlight it will feel much hotter than under either deep or dappled shade and the presence of nearby vegetation, whether trees or bushes, will have a cooling effect as plants use energy during a process called evapotranspiration. Buildings create barriers to the movement of air, and this affects the thermal comfort people experience.

Street orientation is also a factor with the direction affecting where there is shade and this changes as the sun moves across the sky from dawn to dusk. How people feel in hot weather varies from person to person and with clothing and level of activity. Thick clothing for example, affects heat resistance, increasing skin and core temperature, so heightening PET value (Höppe, 1999). Level of activity, for example, walking, undertaking sports or sitting down, may also influence the PET value; there are also minor differences due to gender, age, height, and weight.

Hence, there are many factors to consider when thinking about how to mitigate heat stress. This publication mainly focuses on how to improve the thermal comfort of outdoor urban spaces during the day.

1.5 Measuring cooling interventions

The thermal comfort of outdoor public spaces in cities can be evaluated by conducting a Thermal Comfort Assessment (TCA). It helps to identify potential heat risks at regional, city, and local scale. Often the TCA is based

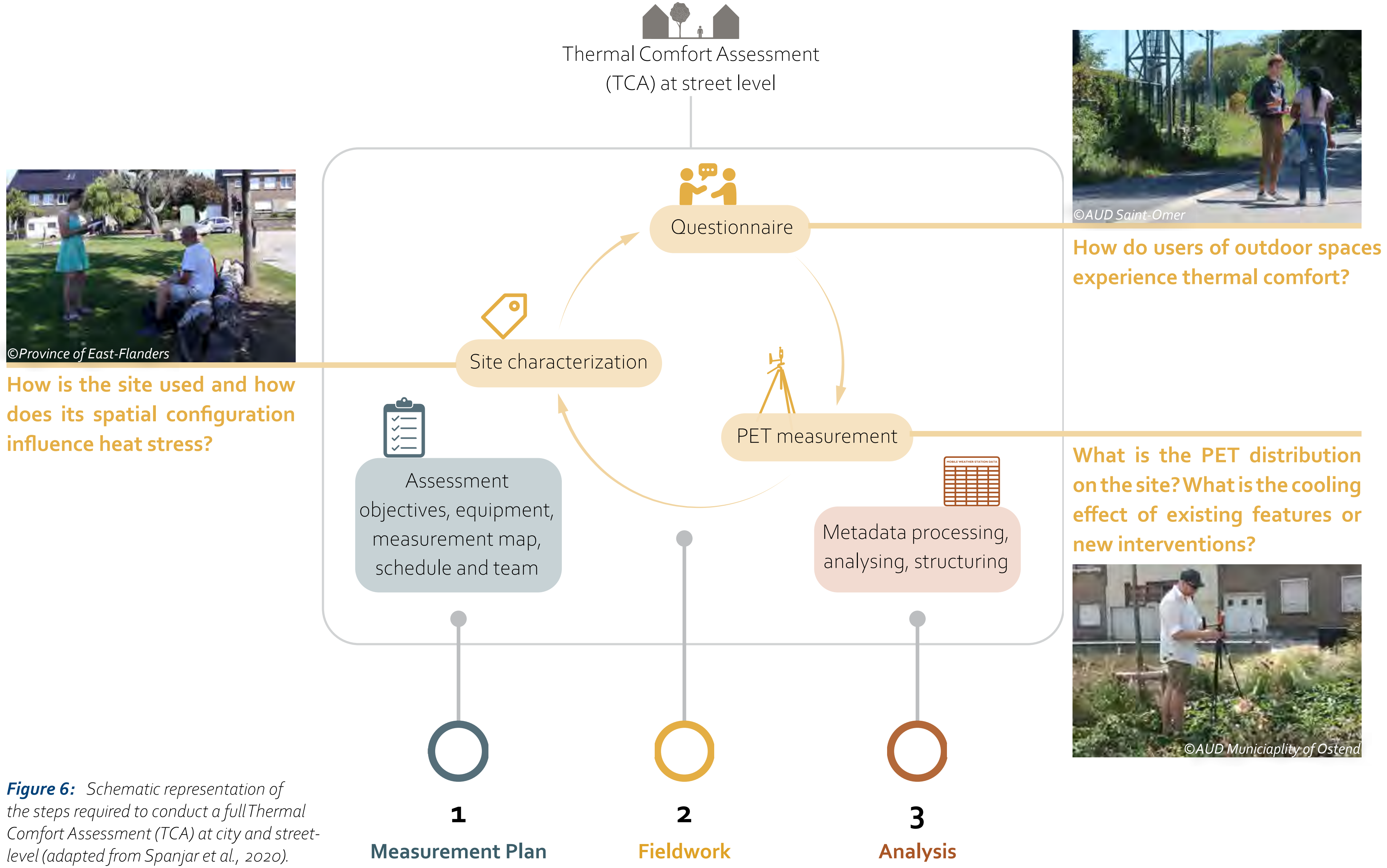

Figure 6: *Schematic representation of the steps required to conduct a full Thermal Comfort Assessment (TCA) at city and street-level (adapted from Spanjar et al., 2020).*

on integrating meteorological and spatial geographical data for modelling the PET of urban areas. However, it is limited in including local conditions, functions, and dynamics on a local scale (Koopmans et al., 2020). This is important for assessing the thermal comfort of users of specific outdoor spaces and the effectiveness of heat stress interventions. The Cool Towns TCA approach developed (see fig.6) operates effectively at both city and street-level scales.

At city-scale the TCA follows two Thermal City Life scenarios that reflect the conditions often observed in Northwestern Europe. These scenarios cover the differences in the use of outdoor public spaces depending on the time of the day and are accompanied by vulnerability mapping to get a deeper understanding of the physical, socio-economic, and demographic heat stress vulnerabilities. Taking in wider socio-environmental aspects, such as pedestrian and cycle routes, urban functions, and use by specific groups, into account will enable priorities for action to be set as a solid basis for further action. The methodology and maps derived from it are discussed in The Urban Heat Atlas (see Spanjar et al., 2022).

The initial quick scan can be followed up by the full Cool Towns TCA at street-level which aims to analyse the potential locations where heat stress is likely to be experienced based on the modelled PET. It can also be used to evaluate, as has been done in this publication, how existing cooling structures, or recently developed interventions, mitigate heat stress. The TCA at street-level consists of three important objectives and steps. (1) Site characterisation to analyse how the urban geometry and existing green-blue infrastructure present at the study site influences the PET-values and how this affects the thermal comfort for the users. Infrared cameras are used to determine thermal conductivity of building materials, with the visualisations enabling comparison between impervious surfaces and vegetation, and so enhance the PET measurements. (2) Questionnaires show how users of the site experience the microclimate. (3) PET measurements with small mobile weather stations placed to measure the cooling effect of an intervention (referred to as the 'point of interest') in close relationship to a reference point in full sun but without the influence of the intervention. In the 'Cool Towns' project Kestrel 5400 Heat Stress mini weather stations were used.

Each intervention type requires a different approach to measuring the heat stress mitigation effects. For example, to know the cooling capacity of a tree the mobile weather station at the point of interest needs to be placed in the centre of the shadow cast by the tree, while for a green facade or water feature the weather station needs to be placed 25 cm from it. For more information about the standardised methodology to conduct a TCA at street-level and how to measure the whole range of intervention types see the Cool Towns Heat Stress Measurement Protocol for guidance (see Spanjar et al., 2020).

Measurements made by CoolTowns project partners using this protocol have been included to underpin the evidence in this catalogue of interventions. This will help decision makers to decide which intervention would be most appropriate for a specific situation. The factsheets on the different heat stress interventions, discussed later in this publication, are a combination of the site characterisation, questionnaires, and PET measurements. When existing artificial, green and blue structures were assessed the focus was on the site characterisation and PET measurements to maximise the number and variety of example interventions.


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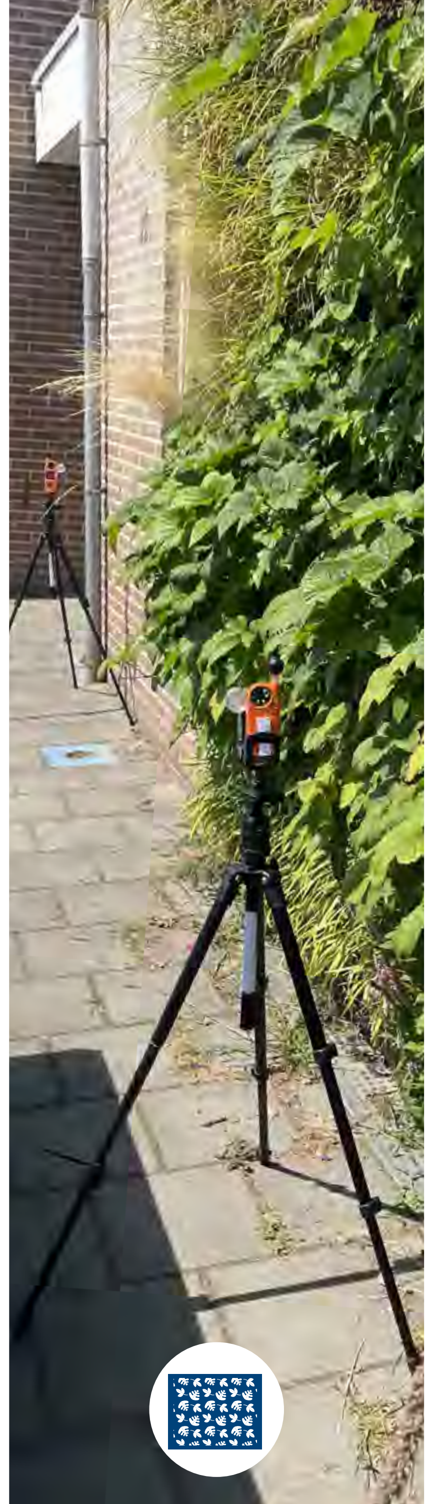
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2. Intervention typologies

While there are many different ways heat stress can be reduced, the Cool Towns project has focused on those that are relatively simple and inexpensive to install and have significant additional benefits when used in the urban environment. There are two important cooling mechanisms important for mitigating heat stress at street level: (1) reducing the solar radiation by providing shade, and (2) the process of evaporation from plants and water.

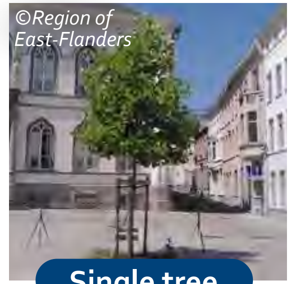
Trees are effective cooling measures primarily because they create shaded areas. This is an important and effective mechanism for reducing the temperature to a comfortable level. How effective the shade is depends on the size, shape, and density of the crown. The other trees cool the environment is the process of evapotranspiration. This keeps trees relatively cool during hot days, although the extent of this depends on the type and health of the tree, as well as soil moisture levels. Pergola constructions overgrown by climbing plants are the only other cooling intervention that provides both cooling mechanisms. Shade sails are an artificial alternative to providing shade as they can obstruct the solar radiation and reflect it by their white colour to improve the thermal comfort underneath. Conversely, depending on the material used for the shade sail, they may also reduce airflow beneath and so increase thermal discomfort by trapping the heat.

Greenery attached to walls only provides cooling by evapotranspiration, although freestanding green screens or benches may provide occasional shade if positioned well. Cool Surfaces such as lawns only provide some cooling capacity by evapotranspiration. Evaporation from the water surface is expected to be effective if the water is moving or if people touch the water, which gives a direct cooling effect by reducing the core body temperature.

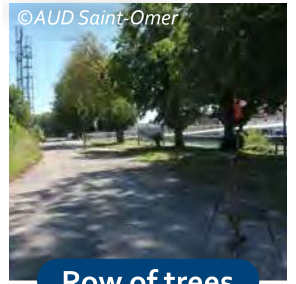
Thus, multiple factors have to be taken into account in every design project. Although there is increasing awareness and concern regarding heat stress, it is just one of many factors that need to be considered in urban design. Green and blue infrastructure has many additional benefits, for example for health (see Interreg Europe 2017a), and biodiversity (Interreg Europe 2017b) The aim is to provide evidence-based information for decision makers to enable effective solutions for tackling heat stress. A short definition for each of these interventions is given below.

2.1 Trees

Trees are perennial woody plants with many secondary branches supported clear of the ground on a single main stem or trunk, although they may be pruned – or coppiced – to create multiple stems emerging from ground level. For heat stress measurement purposes the Cool Towns project differentiates freestanding or **single trees**, **row of trees** and **group of trees**.



Single tree



Row of trees

Group of trees

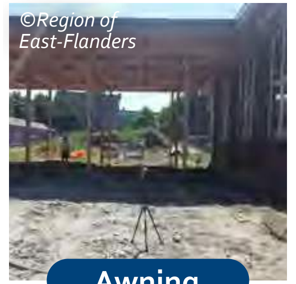
Intervention characteristics

- *Species*
- *Height*
- *Crown diameter*
- *Orientation*
- *Condition*
- *Shape*

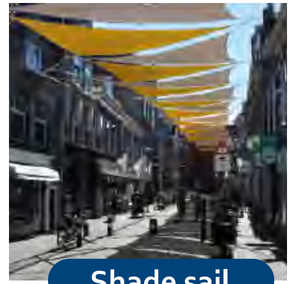
2.2 Shelter canopies

Awnings may be shading devices made of textile material and attached to buildings so they can be rolled out when required, or they may be a permanent built construction creating a roof above openair spaces. **Shade sails** are similar to textile awnings but secured at their corner to free standing posts or hooks on other vertical structures. **Pergolas** are shaded walkways or sitting areas with vertical posts supporting cross beams and are often covered with climbing plants.

Pergola



Awning


Shade sail

Intervention characteristics

- *Height*
- *Size*
- *Material / Species*
- *Transparency (%)*

2.3 Green walls

Green walls come in multiple types based on how they support the plants on them. Plants may grow in the ground or in a planter box and climb up the building wall forming a **direct green facade**. If a lightweight structure, usually wood or metal, is secured to the building wall to support the climbing plant, it is called an **indirect green facade**. Alternatively, plants may be planted into pocket-like structures attached to the wall forming a **living wall system**. If a climbing plant grows on a supporting structure but not directly adjacent to a building wall, it is called a **freestanding green screen**.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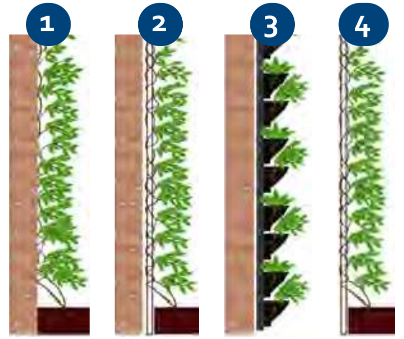
1: Direct green façade
2: Indirect green façade
3: Living wall system
4: Freestanding green screen



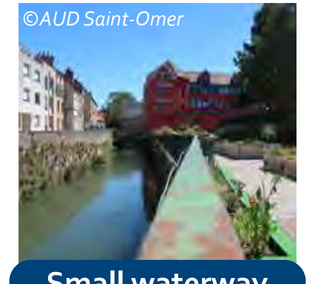
©Adapted from Bustami et al., 2018

Intervention characteristics

- *Height*
- *Width*
- *Orientation*
- *Condition*
- *Wall coverage (%)*

2.4 Water features

Water features come in many common forms, such ponds or rivers. The Cool Towns project included three small-scale urban forms. **Small waterways** are linear bodies of moving water, such as urban canals, which are usually narrower and slower flowing than rivers. **Fountains** are often ornamental constructions with a rising stream of water. They may encourage children to play in them and be referred to as water playgrounds. **Misting** is the spraying of fine water mist into the air or onto the ground.


©AUD Saint-Omer
Small waterway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Fountain


Misting

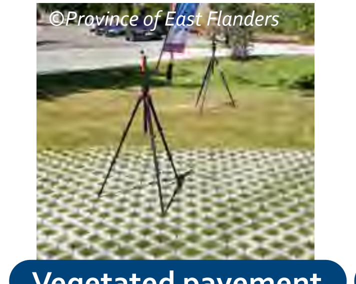
Intervention characteristics

- *Wet area*
- *Misted area*
- *Movement*

2.5 Cool surfaces

Cool surfaces can either be hard landscaped, for example paved areas made of specific cool or reflective materials, or be vegetated, with either grass or other low growing plants. The Cool Towns project included three types of cool surfaces; **grass** and **vegetated pavement**, which consists of a water permeable surface with low growing plants between its elements, and **damped pavement**, a hard surface moistened with water.


Municipality of Breda
Grass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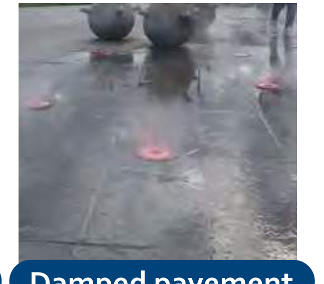
Vegetated pavement


Damped pavement

Intervention characteristics

- *Width*
- *Area*
- *Condition*
- *Moisture level*

3. Trees

Lessons learnt

1. *Trees are effective in addressing heat stress by reducing PET up to 20°C but the level of cooling capacity greatly depends on foliage cover.*

2. *This intervention is effective in reducing PET in public spaces for children to play, people to rest, or carry out physical activities. Generally, people also appreciate the cooling from trees, particularly when this is accompanied with benches in the shade which help to improve thermal comfort while resting.*

3. *A row of trees can be placed along main cycle and pedestrian paths to provide a cool corridor to vital places of the city.*

4. *In decision making it is important to consider how the cooling capacity of the tree needs to evolve over time. According to the urgency of the need for foliage cover to provide shade, the species with the required growth rate should be selected and specimens of appropriate size planted.*

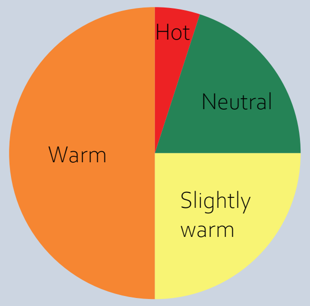
5. *Trees provide numerous important co-benefits, such as biodiversity, water retention and air filtration.*

<18 PET Slight Cold Stress
18-23 PET No Thermal Stress
23-29 PET Slight Heat Stress
29-35 PET Moderate Heat Stress
35-41 PET Strong Heat Stress
41-46 PET Extreme Heat Stress (LV1)
46-51 PET Extreme Heat Stress (LV2)
51-56 PET Extreme Heat Stress (LV3)
>56 PET Extreme Heat Stress (LV4)

15 out of 20 respondents perceived the environment ***comfortable*** *(i.e. combination of sun, wind, shade, humidity), 5 perceived it as slightly* ***uncomfortable****.*

Users spend on average around ***three quarters of an hour*** *at Merelbeke centrum. Some visitors only walk through while others take their time.*

Figure 7: *Thermal comfort: How are you feeling now?*



Interviewees mentioned the need for ***more shadow, less concrete*** *and some* ***nice places to sit****.*

Questionnaire results

Spatial characteristics

349 Hundelgemsesteenweg, Merelbeke, BE

Spatial typology	City centre
Urban geometry	Mixed with mostly low buildings
Social use	Place to linger in the morning, lunchtime & afternoon

Single lime tree on a town square, *Merelbeke, Belgium*

This tree, a lime (*Tilia Cordata*), is an isolated feature in Merelbeke's town centre. It has been planted in a large open area paved with cobbles, although there is a small area of grass immediately surrounding the tree trunk, permitting infiltration of rainwater. This tree is young, just 8m high and with a narrow crown.

The effectiveness of this tree in mitigating heat stress was measured around lunchtime in late June when the air temperature was just below 25 °C (24,6 °C). This is outside the date and temperature range stipulated in the Measurement Protocol, but marginally; all other conditions were met. A reduction in PET of 14,7 °C was measured between the shade of the trees and the reference point; both these points were on the cobbled paved area.

Those who use the area do so when visiting the centre nearby, with some passing through quickly while others linger. 15 of the questionnaire respondents reported feeling comfortable in the vicinity of the tree, while five perceived the environment (i.e. the combination of sun, wind, shade, humidity) as "slightly uncomfortable". Suggestions for improvement included providing more shade, less paving and some pleasant areas for sitting down.

Single tree

Date	23 June 2020
Time	13:00
dPET	14,7 °C PET reduction

Intervention characteristics

Species	*Tilia Cordata*
Height	8 m
Crown Ø	2 m
Orientation	na
Ground	Cobblestone
Condition	Healthy
Shape	Oval

	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**28,8**	24,6	29,1	41,8	1,6	44,6
Reference	**43,5**	24,7	39,8	72,6	1,4	45,3
Difference	**-14,7**	-0,1	-10,7	-30,8	0,2	-0,7
Int. grade	Moderate Heat Stress					
Ref. grade	Extreme heat stress: Level 1					

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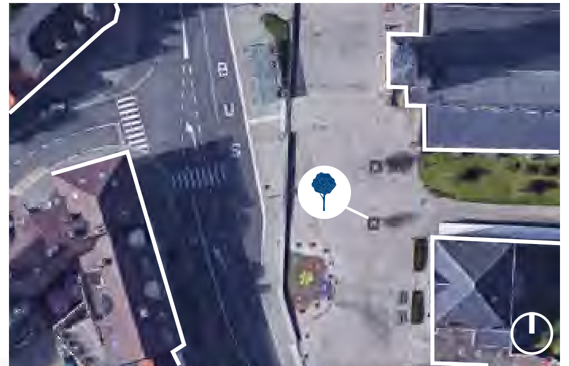
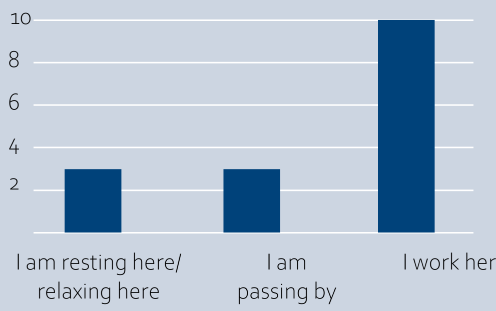

Imagery ©2022 Maxar Technologies, Map data ©2022

Measurements conducted by Oost-Vlaanderen

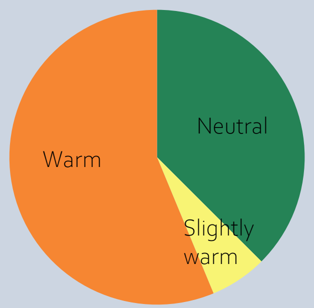
- <18 PET — Slight cold stress
- 18-23 PET — No thermal stress
- 23-29 PET — Slight heat stress
- 29-35 PET — Moderate heat stress
- 35-41 PET — Strong heat stress
- 41-46 PET — Extreme heat stress (LV1)
- 46-51 PET — Extreme heat stress (LV2)
- 51-56 PET — Extreme heat stress (LV3)
- >56 PET — Extreme heat stress (LV4)

Figure 9: *Why visitors spent time in the area*



5 out of 6 interviewees mentioned the need for benches and some emphasized ***seating areas in the shade.***

Figure 8: *Thermal comfort: How are you feeling now?*



9 out of 16 respondents come to the area ***daily****, while 5 said they visit the site* ***weekly****. The others visit it less frequently.*

10 out of 16 respondents feel ***comfortable*** *in the area on warm days.*

Questionnaire results

Spatial characteristics

Sociaal Huis Eeklo, Zuidmoerstraat, Eeklo, BE

Spatial typology	School yard
Urban geometry	Courtyard character surrounded by low buildings, width: >50m, length: >100m
Social use	A place to stay around during the entire day

Single lime tree in a community courtyard, *Eeklo, Belgium*

This site is part of a large courtyard, part of a community centre, in Eeklo, East Flanders, Belgium. It has an area of around 50 x 100 metres and it is surrounded by low buildings. Part of the courtyard is paved but this tree stands alone on grass next to a row of picnic benches.

The effectiveness of this tree in mitigating heat stress was measured in the afternoon, in the middle of June when the air temperature was 27 °C. The same day and close to the same time the effect of the nearby group of beech trees was measured (see factsheet on pg. 40). A reduction in PET of 13,5 °C was measured between the shade of the trees and the reference point located on the grass. It is worth noting that the row of beech trees had a greater effect, with a reduction of 19,5 °C.

Most of the site users interviewed said that they worked on the site so visited it daily or weekly. Ten of the sixteen respondents felt comfortable around these trees on hot days. It was suggested that some benches or other seating would be an improvement, especially if these were in the shade.

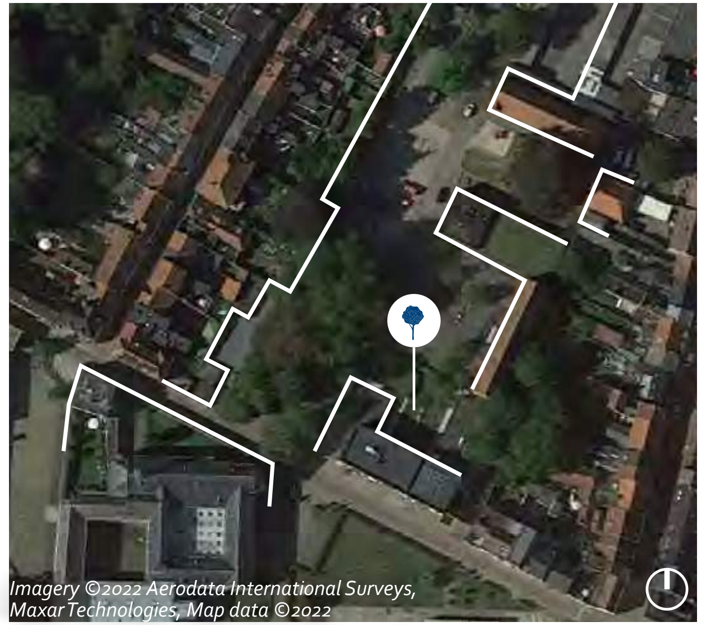
Single tree

Date	14 June 2021
Time	14:51
dPET	13,5 °C PET reduction

Intervention characteristics

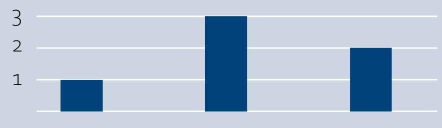
Species	*Tilia x europaea* 'Euchlora'
Height	4 m
Crown Ø	3 m
Orientation	na
Ground	Grass
Condition	Healthy
Shape	Domed

	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**32,7**	29,1	32,2	35	0,3	35,4
Reference	**46,2**	29,5	45,3	61	0,2	34,7
Difference	**-13,5**	-0,4	-13,1	-26	-0,1	0,7
Int. grade	Moderate heat stress					
Ref. grade	Extreme heat stress: Level 2					



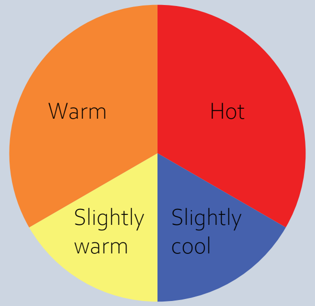
- <18 PET — Slight Cold Stress
- 18-23 PET — No Thermal Stress
- 23-29 PET — Slight Heat Stress
- 29-35 PET — Moderate Heat Stress
- 35-41 PET — Strong Heat Stress
- 41-46 PET — Extreme Heat Stress (LV1)
- 46-51 PET — Extreme Heat Stress (LV2)
- 51-56 PET — Extreme Heat Stress (LV3)
- >56 PET — Extreme Heat Stress (LV4)

Figure 11: *Why the 6 interviewees spent time in on Garrard Avenue, Maynard Avenue, and in George V park. One person living in the area also works there.*



One person standing on Garrard Avenue lives there and visits it ***daily****, while the other interviewee was walking by and visits it* ***seldom****.*

Figure 10: *Thermal comfort in Margate: How are you feeling now?*



Both interviewees on Garrard Avenue ***felt hot*** *which one of them found uncomfortable while the other slightly uncomfortable. They both would have like the place to be* ***cooler*** *but thought that there has been* ***sufficient efforts*** *to make the avenue comfortable on warm days.*

Questionnaire results

Spatial characteristics

43 Garrard Avenue, Kent, UK

Spatial typology	Residential area
Urban geometry	Low 2-storey buildings
Landcover	90% sealed surfaces, 10% grass
Social use	Pedestrian route during the entire day

Single Norway maple tree in a residential street, *Margate, England*

This tree, a Norway maple (*Acer platanoides* 'Deborah') is one of a mixed species row of trees planted in a grass strip between the pavement and the road in a residential area of the coastal town of Margate, in Kent, England.

The effectiveness of this tree in mitigating heat stress was measured around midday in early September, when the air temperature was just above 25 °C. A reduction in PET of 12,8 °C was measured between the shade of the trees and the reference point, on the same strip of grass.

Those interviewed were all from the local area, except one who was an infrequent visitor, two live on this street, the others close by. While all reported feeling warm, with one describing the heat as uncomfortable, they all felt that there has been sufficient effort made to make the street comfortable on warm days.

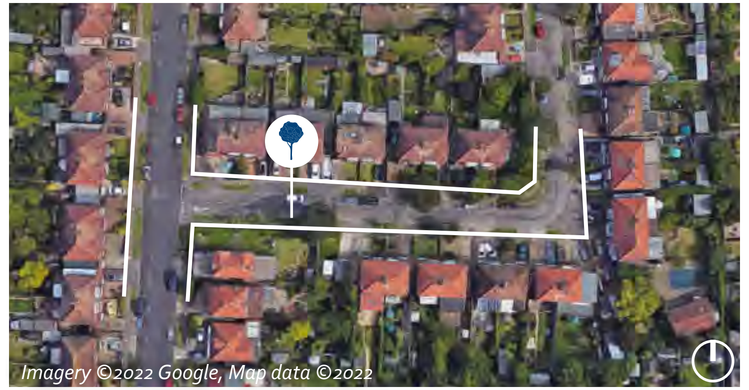
Single tree

Date	7 September 2021
Time	12:46
dPET	12,8 °C PET reduction

Intervention characteristics

Species	*Acer platanoides* 'Deborah'
Height	3,2 m
Crown Ø	1,5 m
Orientation	na
Ground	Asphalt
Condition	Healthy
Shape	Spreading

	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**29,5**	25,4	29,2	40,3	1,7	47,9
Reference	**42,3**	26,1	38,7	68,9	1,7	46,5
Difference	**-12,8**	-0,7	-9,5	-28,6	0	1,4
Int. grade	Moderate Heat Stress					
Ref. grade	Extreme heat stress: Level 1					



Measurements conducted by Kent County Council

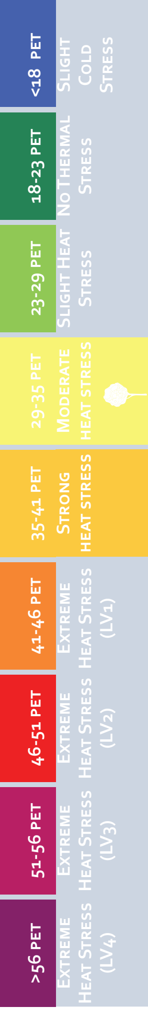


Figure 13: *Why the 10 interviewees spent time near York Road*

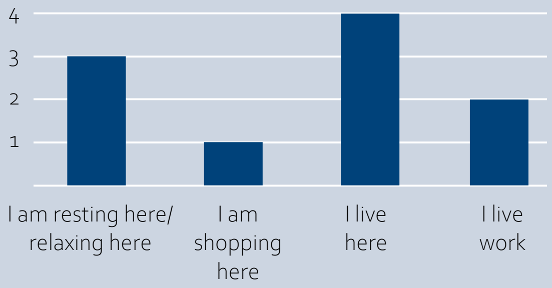
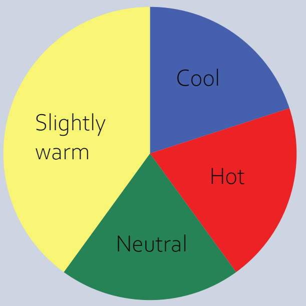


Figure 12: *Thermal comfort near York Road: How are you feeling now?*



*1 interviewee would like **more places like this** near the High Street.*

*Respondents would like to have more **shade, trees, benches or a water fountain.***

Questionnaire results

Spatial characteristics

19 York Road, Southend, UK

Spatial typology	City centre / Shopping area
Urban geometry	Mixed, 2 and 3-storey buildings
Landcover	100% sealed surfaces
Social use	Walking route and place to stay during the day

Single sumac tree in a shopping street, *Southend, England*

This multi-stemmed tree is set in a raised bed surrounded by seating in the city centre area of Southend. It is surrounded by paving in the middle of a street with two and three storey buildings to either side. This tree has spectacular autumn leaf colour but is deciduous, so the leaves fall in autumn leaving bare branches over the winter period. The street is well used, by both residents, shoppers, and those using it as a route to access other parts of the city. The questionnaire respondents were a mixture of these and most felt cool or slightly warm.

The effectiveness of this structure in reducing heat stress was measured in late afternoon in mid-July. The shade cast by the tree reduced PET for those sitting beneath the tree by 9,5 °C compared to the paved areas.

When asked what would improve the area respondents suggested more shade, trees, benches, or a water fountain, with one simply making a request for more places like this.

Single tree

Date	21 July 2021
Time	16:13
dPET	9,5 °C PET reduction

Intervention characteristics

Species	*Rhus Typhinia*
Height	5 m
Crown Ø	3 m
Orientation	na
Ground	Concrete paving slabs
Condition	Healthy
Shape	Spreading

	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**30,6**	27	30,2	40,5	2	48,6
Reference	**40,1**	27,5	37	65,2	2,3	49,4
Difference	**-9,5**	-0,5	-6,8	-24,7	-0,3	-0,8
Int. grade	Moderate Heat Stress					
Ref. grade	Strong Heat Stress					

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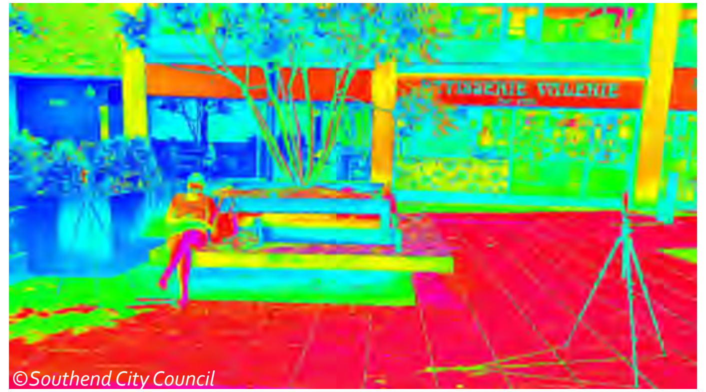
©Southend City Council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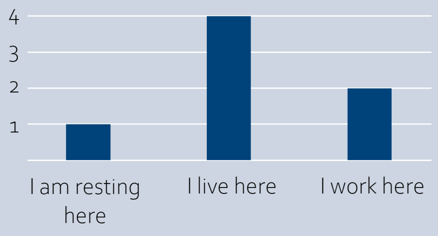
Measurements conducted by southend onsea

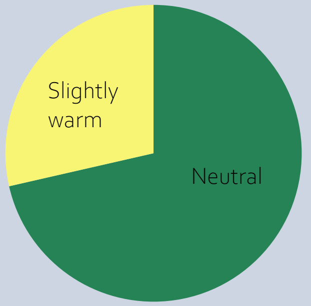
<18 PET	Slight cold stress
18-23 PET	No thermal stress
23-29 PET	Slight heat stress
29-35 PET	Moderate heat stress
35-41 PET	Strong heat stress
41-46 PET	Extreme heat stress (LV1)
46-51 PET	Extreme heat stress (LV2)
51-56 PET	Extreme heat stress (LV3)
>56 PET	Extreme heat stress (LV4)

Figure 14: *Most visitors interviewed on the promenade live in the area, some work nearby and one who lives nearby was relaxing.*



3 interviewees use the area daily while others visit it weekly, monthly or seldom.

Figure 15: *Thermal comfort: How are you feeling now?*



3 out of 7 respondents would like to have ***benches*** *on the promenade, others mentions facilities that would invite them to* ***stay longer****, such as fishing or BBQ facilities.*

Questionnaire results

Spatial characteristics

91 Allée des Marronniers, Saint-Omer, FR

Spatial typology	Mobility hub (path in a park in the vicinity)
Urban geometry	Open site with no nearby buildings
Social use	The promenade is an important pedestrian connection between the train station and the city centre throughout the day.

Row of chestnut trees near a walking route, *Saint-Omer, France*

This site has a row of mature sweet chestnut (*Castanea sativa*) trees planted in a grass strip between the road that passes in front of the railway station and the canal. A footpath runs beneath the trees, and this is a popular walking route that leads from the industrialised station area into Saint-Omer's historic town centre. The effectiveness of these trees in reducing heat stress was measured in the early afternoon on a cloudless day in August when the sun was high in the sky and radiation intense. The shade cast by the trees was found to reduce the PET by 18,1 °C meaning that those in the shade of the trees suffered only slight, rather than extreme heat stress, at the time of the measurements, when the air temperature was over 26 °C .

Most of the questionnaire respondents lived locally with some using the path daily, others less frequently. Around a quarter of those interviewed reported feeling slightly warm in the shade while the others felt comfortable, neither hot or cold. When asked what would improve the site and encourage them to stay longer three out of the seven responded that they would like to have benches along the path, while others mentioned fishing places and barbeque grills would improve the recreational facilities.

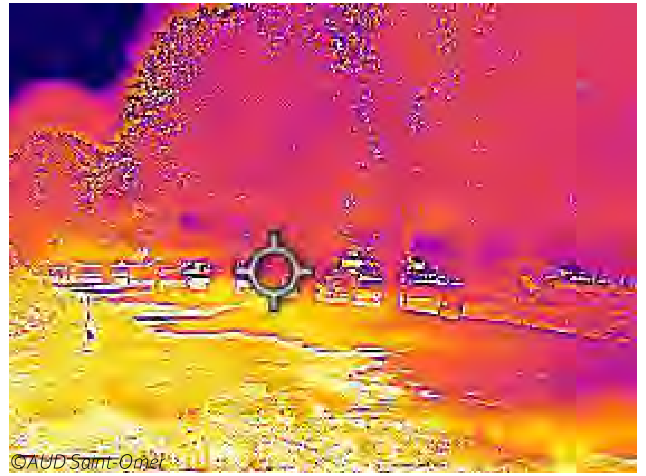
Row of trees

Date	5 August 2020
Time	13:37
dPET	18,1 °C PET reduction

Intervention characteristics

Species	*Castanea sativa*
Height	20 m
Crown Ø	12 m
Orientation	Northwest-Southeast
Ground	Asphalt
Condition	Healthy
Shape	Oval

	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**25,1**	25,9	27,4	33,0	2,6	35,2
Reference	**43,2**	26,5	39,1	74,2	2,3	34,5
Difference	**-18,1**	-0,6	-11,7	-41,2	0,3	0,7
Int. grade	Slight heat stress					
Ref. grade	Extreme heat stress: Level 1					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Measurements conducted by Pays de Saint-Omer Flandre Intérieure

<18 PET	Slight Cold Stress
18-23 PET	No Thermal Stress
23-29 PET	Slight Heat Stress
29-35 PET	Moderate Heat Stress
35-41 PET	Strong Heat Stress
41-46 PET	Extreme Heat Stress (LV1)
46-51 PET	Extreme Heat Stress (LV2)
51-56 PET	Extreme Heat Stress (LV3)
>56 PET	Extreme Heat Stress (LV4)

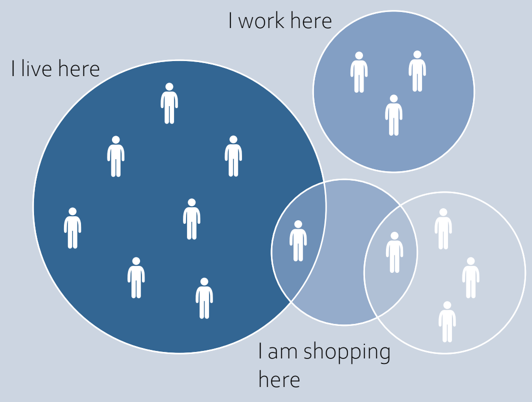
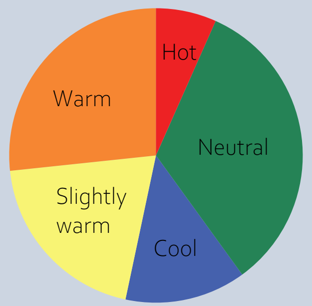


Figure 16: *Why respondents were using Mauritssingel*

Figure 17: *Thermal comfort: How are you feeling now?*



13 out 15 respondents perceived the environment (i.e. combination of sun, wind, shade, humidity) as ***comfortable*** *and only two found it uncomfortable.*

Users of the site mentioned the need for ***water taps****, more* ***green****,* ***shade*** *and* ***benches****, a closer* ***contact with the water*** *and less* ***cars****.*

Questionnaire results

Spatial characteristics

15 Mauritssingel, Breda, NL

Spatial typology	Residential area
Blue-green infr.	20 mature trees, 150 m² grass, canal
Social use	Pedestrian and cycle route in use throughout the day

Row of silver lime trees lining a pedestrian path, *Breda, the Netherlands*

This site has a double row of 20 mature silver lime trees (*Tilia tomentosa*) forming an avenue along the waterside with a pedestrian pathway between them. The Mauritssingel is part of the historical blue-green ring that encloses Breda's city centre. They are planted in grass and follow the southern side of the road. There are trees on the other side of the road, which has traffic during the day, and the area is residential.

The effectiveness of these trees in mitigating heat stress was measured in mid-afternoon in early September when the air temperature was just above 25 °C. A reduction in PET of 14,8 °C was measured between the shade of the trees and the reference point.

15 users of the area responded to the questionnaire and all but two of these reported perceiving the environment (i.e. the combination of sun, wind, shade, humidity) as "comfortable" while the remaining two disagreed. When asked what would improve the area, they proposed installing drinking water points, more greenery, shade and benches, as well as closer contact with the water and less traffic.

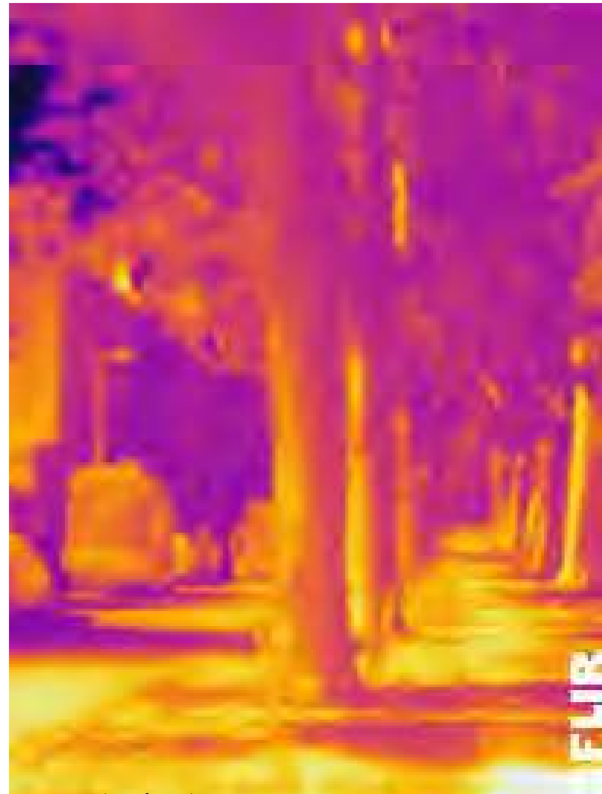
Row of trees

Date	7 September 2021
Time	14:29
dPET	14,8 °C PET reduction

Intervention characteristics

Species	*Tilia tomentosa*
Height	20 m
Crown Ø	15 m
Orientation	East-West
Ground	Grass
Condition	Healthy
Shape	Spreading

©Municipality of Breda


©Municipality of Breda

	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**29,5**	26,2	29,2	37,3	1,5	45,8
Reference	**44,3**	26,7	40,5	71,1	1,4	47
Difference	**-14,8**	-0,5	-11,3	-33,8	-0,04	-1,2
Int. grade	Moderate heat stress					
Ref. grade	Extreme heat stress: Level 1					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<18 PET	Slight Cold Stress
18-23 PET	No Thermal Stress
23-29 PET	Moderate Heat Stress
29-35 PET	Moderate Heat Stress
35-41 PET	Strong Heat Stress
41-46 PET	Extreme Heat Stress (LV1)
46-51 PET	Extreme Heat Stress (LV2)
51-56 PET	Extreme Heat Stress (LV3)
>56 PET	Extreme Heat Stress (LV4)

Row of honey locust trees on an inner city square, *Middelburg, the Netherlands*

This large, open square in the historic city centre of Middelburg has a row of widely spaced, mature, honey locust (*Gleditsia triacanthos*) trees along its south western boundary. The area is paved and enclosed by buildings, most of which are tall, with three storeys. As well as contributing to the character and local distinctiveness of this historic place these trees with their feathery leaves cast a light shade and turn yellow in autumn before they fall.

The effectiveness of this row of trees in mitigating heat stress was measured in the early afternoon, in early September. A reduction in PET of 14,5 °C was measured between the shade of the trees and the reference point on the paving. No questionnaire responses have been received.

Spatial characteristics

Grote Markt, Middelburg, NL

Spatial typology	Historic city centre
Urban geometry	Open site surrounded by 3-storey buildings
Social use	Pedestrian and cycle route and a place to linger and relax throughout the day

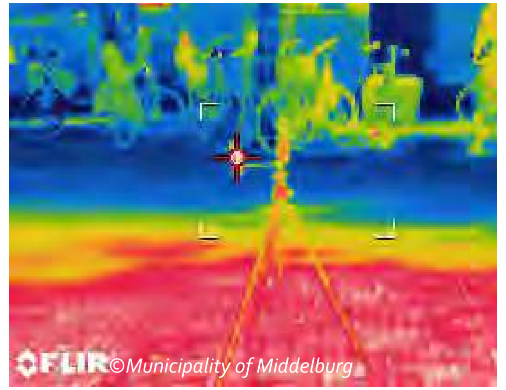
Row of trees

Date	7 September 2021
Time	13:51
dPET	14,5 °C PET reduction

Intervention characteristics

Species	*Gleditsia triacanthos*
Height	7 m
Crown Ø	5 m
Orientation	Northwest - Southeast
Ground	Brick
Condition	Healthy
Shape	Domed

	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**27**	26,3	27,3	29,3	0,8	44,1
Reference	**41,5**	28,3	39,3	57,4	0,8	42,2
Difference	**-14,5**	-2,0	-12,0	-28,1	0	1,9
Int. grade	Slight heat stress					
Ref. grade	Extreme heat stress: Level 1					



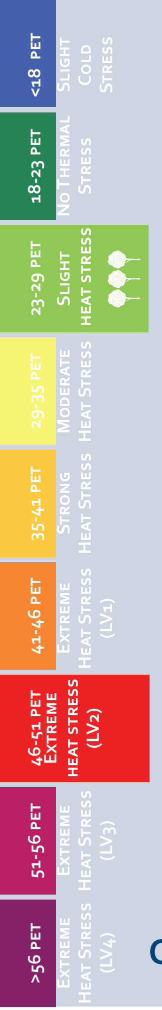
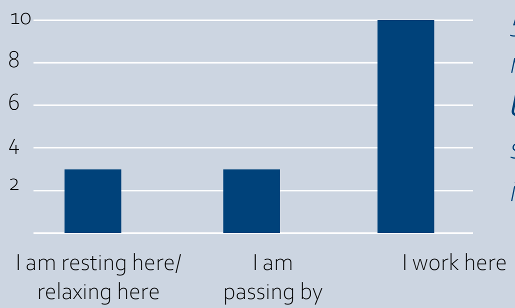
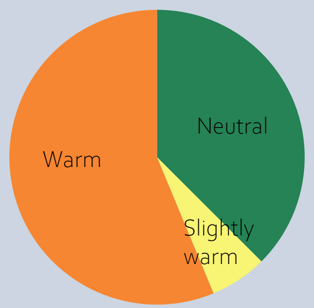


Figure 19: *Why visitors spent time in the area*



*5 out of 6 interviewees mentioned the need for **benches and sitting places**, some emphasize sitting places in the shade.*

Figure 18: *Thermal comfort: How are you feeling now?*



*9 out of 16 respondents come to the area **daily**, while 5 said they visit the site **weekly**. The others frequent it less often.*

*10 out of 16 respondents feel **comfortable** in the area on warm days.*

Questionnaire results

Spatial characteristics

Sociaal Huis Eeklo, Zuidmoerstraat, Eeklo, BE

Spatial typology	School yard
Urban geometry	Courtyard character surrounded by low buildings, width: >50m, length: >100m
Social use	A place to stay around during the entire day

Group of beech trees in a community courtyard, *Eeklo, Belgium*

This site is part of a community centre's large courtyard in Eeklo. Belgium. It has an area of around 50 x 100 metres and is surrounded by low buildings. Part of the courtyard is paved but to the south western corner there is a group of beech (*Fagus sylvatica*) trees planted in rough (unmown) grass. The trees vary in size but there is good canopy cover.

The effectiveness of this group of trees in mitigating heat stress was measured in the afternoon in the middle of June when the air temperature was 27 °C. A reduction in PET of 19,9 °C was measured between the shade of the trees and the reference point located on the paved area.

Most of those interviewed said that they worked on the site and visited it daily or weekly. Ten of the sixteen respondents felt comfortable around these trees on hot days. It was suggested that some benches or other seating would be an improvement, especially if these were in the shade of the trees.

Group of trees

Date	14 June 2021
Time	14:42
dPET	19,9 °C PET reduction

Intervention characteristics

Species	*Fagus spp*
Height	10 m
Crown Ø	10 m
Orientation	na
Ground	Grass
Condition	Healthy
Shape	Domed

	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**27,3**	27	27,8	29,5	0,8	35,9
Reference	**47,2**	29,7	45,4	63,9	0,5	34
Difference	**-19,9**	-2,7	-17,6	-34,4	0,3	1,9
Int. grade	Slight heat stress					
Ref. grade	Extreme heat stress: Level 2					

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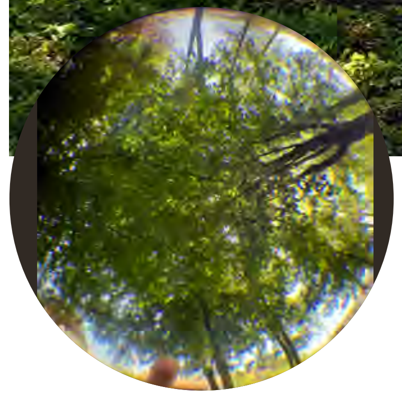


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Measurements conducted by Oost-Vlaanderen


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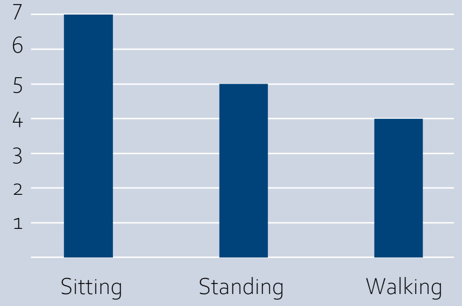
4. Shelter canopies

Lessons learnt

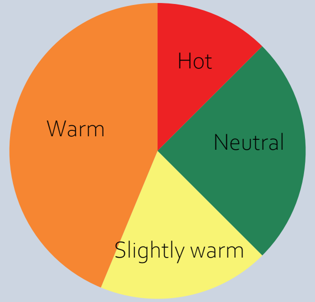
1. *These are effective in reducing the PET as they protect from direct solar radiation.*
2. *Easily implemented in narrow streets with lack of space in city centres.*
3. *Provides an immediate solution to protect vulnerable groups such as children and elderly.*
4. *Can be used as a temporary intervention during extremely hot situations for example at festivals and other events held in the open.*
5. *Pergolas covered with climbing plants take time to grow but are effective in creating well-shaded and aesthetically pleasing cool routes and rest areas.*

Figure 20: *Interviewees were using the school yard in diverse ways, sitting, standing or walking through.*



*All 16 interviewees were using the school yard because they **work** at the school.*

Figure 21: *Thermal comfort: How are you feeling now?*



*13 out of 16 interviees found the environmnet **comfortable***

*Most intervieews mention the need for more **shelter and greenery.***

Questionnaire results

Spatial characteristics

Leegstraat 2, Zelzate, BE

Spatial typology	School yard
Urban geometry	Tall buildings
Green infrastructure	More than 30 trees with an average canopy diamter of 3 m and 750 m² grass cover.

Shade tent at the De Reigers school, *Zelzate, Belgium*

This textile canopy with open sides is situated on grass in the grounds of the De Reigers school which is in a residential area of Zelzate, surrounded by tall buildings. There is some greenery in the neighbourhood but there is little shade in this area which is used by children in their breaks and during outdoor study. The effectiveness of this structure in reducing heat stress was measured in mid-afternoon on a hot day in early June.

The tent structure, made from canvas material, was found to reduce the PET by 15 °C for those in its shade.

Those responding to the questionnaire all worked at the school. About half were sitting when questioned with the others either walking or standing; all felt comfortable with the temperature they were experiencing. They all would like to see more shade to shelter children from the effects of the sun, and more greenery.

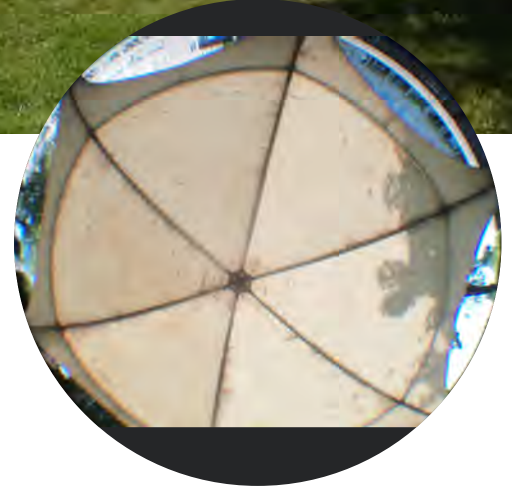
Shade sail

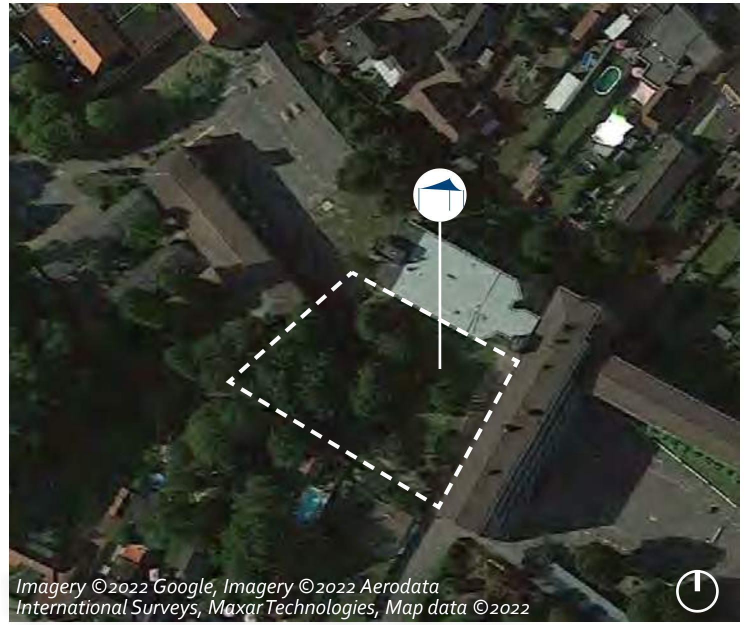
Date	2 June 2021
Time	14:43
dPET	15,0 °C PET reduction

Intervention characteristics

Height	4 m
Shade size	28 m²
Ground	Grass
Material	Canvas
Transparency	0 %

	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**31,9**	28,0	31,5	38,8	0,9	30,1
Reference	**46,9**	27,7	43,3	71,8	1,1	30,9
Difference	**-15,0**	0,3	-11,8	-33,0	-0,2	-0,8
Int. grade	Moderate heat stress					
Ref. grade	Extreme heat stress: Level 2					





Measurements conducted by Provincie Oost-Vlaanderen

<18 PET Slight Cold Stress
18-23 PET No Thermal Stress
23-29 PET Slight Heat Stress
29-35 PET Moderate Heat Stress
35-41 PET Strong Heat Stress
41-46 PET Extreme Heat Stress (LV1)
46-51 PET Extreme Heat Stress (LV2)
51-56 PET Extreme Heat Stress (LV3)
>56 PET Extreme Heat Stress (LV4)

Figure 23: *Why are you here?*

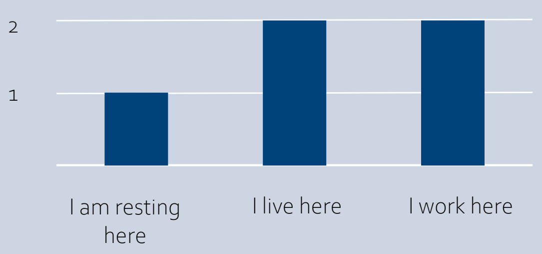
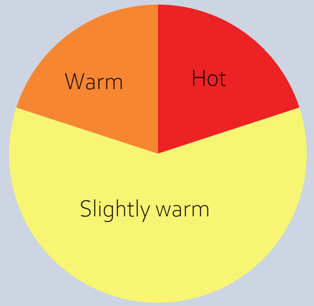


Figure 22: *Thermal comfort: How are you feeling now?*



Respondents mentioned the need for more ***greenery, shade, trees and benches.***

Out of 5 interviewees, 3 respondents were ***sitting*** *and 2 respondents were* ***walking*** *at the time of the interview.*

Questionnaire results

Spatial characteristics

26-36 Kanaalweg, Middelburg, NL

Spatial typology	Mobility hub nearby (about 200m)
Urban geometry	Open site with one high building at each short end of the linear pergola structure
Social use	Place to stay and sit on the benches, cycle route runs next to the site

Pergola structure near the train station, *Middelburg, The Netherlands*

This 50m long metal pergola is located on an important walking and cycling route to the central train station area in Middelburg. It runs parallel to the Canal of Walcheren and is set on an open site. Tall buildings are located on both ends of the structure to a height of 20-25 metres, potentially blocking the wind that might otherwise sweep along the open canal. The pergola is covered with *Wisteria* creating continuous shade in summer. The purple flowers make the pergola especially attractive in late spring.

The pergola's effectiveness in reducing heat stress was measured in late afternoon, when the sun was no longer at its highest intensity and when building facades and concrete tiles, that have already been warmed, radiate heat. Although air temperature was reduced by less than 1 °C thermal comfort was improved with a reduction in PET of 13 °C in the shade.

Residents living, recreating, or working in the area appreciated the pergola for walking along and resting beneath. Interviewees sitting or walking under the shade felt only slightly warm, while those in the sun reported feeling warm or hot.

Pergola

Date	31 July 2020
Time	15:46
dPET	13,1 °C PET reduction

Intervention characteristics

Species	*Wisteria*
Height	3 m
Shade size	100 m²
Ground	Concrete paving slabs
Material	Metal pergola structure
Transparency	85%

	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**36,6**	33,5	35,5	42,1	2,2	26,4
Reference	**49,7**	34	44,7	10,7	2,2	26,3
Difference	**-13,1**	-0,6	-9,2	-31,4	0,02	0,06
Int. grade	Strong heat stress					
Ref. grade	Extreme heat stress: Level 2					

Measurements conducted by

©Municipality of Middelburg

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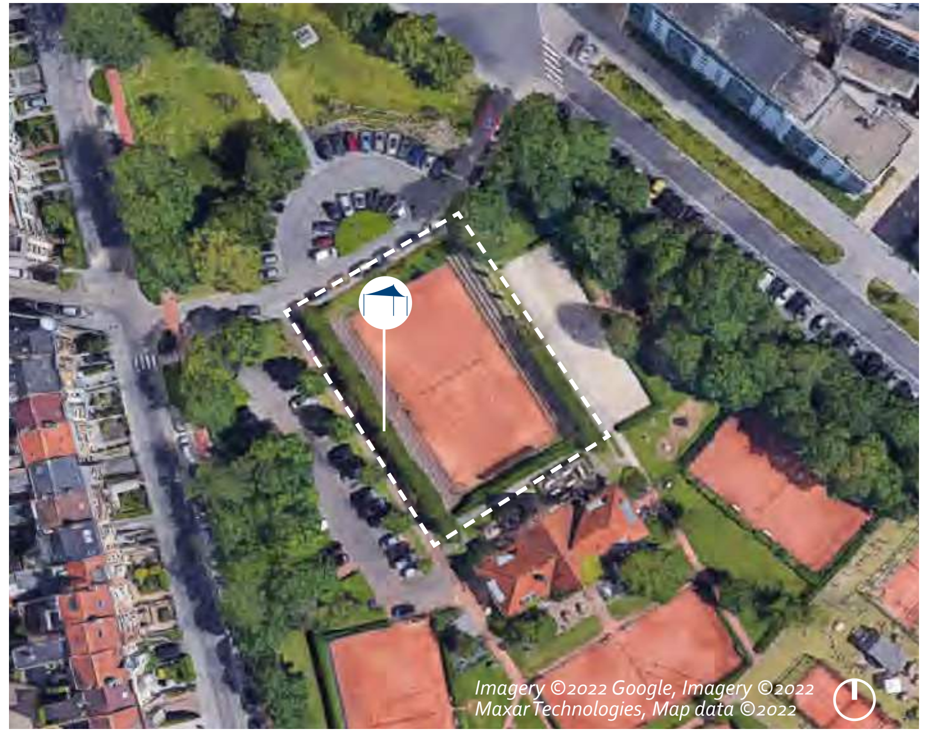
Fisheye photo above the reference point

Imagery ©2022 Google, Imagery ©2022 Aerodata International Surveys, Maxar Technologies, Map data ©2022

<18 PET	Slight Cold Stress
18-23 PET	No Thermal Stress
23-29 PET	Slight Heat Stress
29-35 PET	Moderate Heat Stress
35-41 PET	Strong Heat Stress
41-46 PET	Extreme Heat Stress (LV1)
46-51 PET	Extreme Heat Stress (LV2)
51-56 PET	Extreme Heat Stress (LV3)
>56 PET	Extreme Heat Stress (LV4)



Spatial characteristics

Ostend Tennis Club, Koninginnelaan 83, Ostend, BE

Spatial typology	Residential area, park with tennis club
Urban geometry	Open site surrounded by green infrastructure and parking, nearby high buildings (> 2 floors)
Social use	Place to remain in during the entire day

Pergola structure at a tennis club, *Ostend, Belgium*

The site, in Ostend's residential inner city, has a single line of wooden pillars with a cross bar forming a pergola supporting the climber, Russian vine (*Fallopia baldschuanica* or *Polygonum baldschuanicum*). It acts as the backdrop to staged seating on the south westerly side of the tennis courts belonging to the Ostend Tennis Club. This makes a decorative feature in an otherwise open area with a large expanse of hard surfaces with no vegetation; the 'red clay' courts are made from crushed brick material. There is a grass strip to one side of the structure while to the other there is a paved area, providing a base for the seating. The effectiveness of this vegetated structure in mitigating heat stress was measured in mid-afternoon in early September when the air temperature was just above 25 °C.

A reduction in PET of 8,6 °C was measured between the shade of the vegetated structure and the reference point. However, it should be noted that the ground cover material beneath these measuring points were different, under the pergola the ground was paved while the reference point was on the porous crushed brick tennis court. No questionnaire responses have been received.

Pergola

Date	6 September 2021
Time	15:25
dPET	8,6 °C PET reduction

Intervention characteristics

Species	*Fallopia baldschuanica* or *Polygonum baldschuanicum*
Height	3 m
Shade size	300 m²
Ground	Concrete paving slabs
Material	Wood pergola structure
Transparency	75%

	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**25,7**	23,3	26,4	35,4	1,6	56,9
Reference	**34,3**	25,3	33,1	45,30	0,7	52,2
Difference	**-8,6**	-2,0	-6,7	-9,9	0,9	4,7
Int. grade	Slight heat stress					
Ref. grade	Moderate heat stress					

Measurements conducted by Oostende


©Amsterdam University of Applied Sciences

5. Green walls

Lessons learnt

1. *The modest cooling effect of green walls is only experienced by those walking or sitting right next to them.*
2. *They are space efficient solutions to create cool walking routes and waiting areas.*
3. *When placed close to the terraces of restaurants with people seated close to them green walls can be an effective and attractive intervention.*
4. *They can deliver co-benefits, for example contributing to biodiversity by providing habitat for birds, pollinators, and other insects, especially when native species are used.*

<18 PET Slight cold stress
18-23 PET No thermal stress
23-29 PET Slight heat stress
29-35 PET Moderate heat stress
35-41 PET Strong heat stress
41-46 PET Extreme heat stress (Lv1)
46-51 PET Extreme heat stress (Lv2)
51-56 PET Extreme heat stress (Lv3)
>56 PET Extreme heat stress (Lv4)

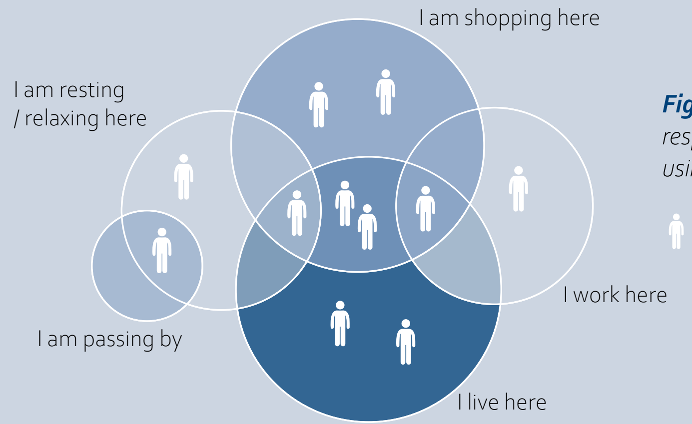
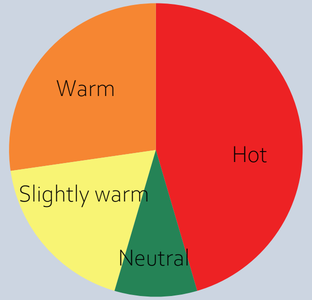


Figure 24: *Why respondents were using London Road*

Figure 25: *Thermal comfort: How are you feeling now?*



*4 out of 11 respondents would like to see **more greenery or more trees**, and another 4 respondents would like **more shade** on London Road.*

*1 interviewee would like to have a **water fountain**.*

Questionnaire results

Spatial characteristics

45 London Rd, Southend-on-Sea, UK

Spatial typology	City centre / Shopping area
Urban geometry	Low buildings
Social use	Mixed use throughout the day: a route and a place to stay

Freestanding green screen near a shopping area, *Southend, England*

In the city centre shopping area of Southend a bench combined with a green screen, covered with ivy (*Hedera helix*) to provide shade is located. It is well used during the day by passers-by, and by those wanting to rest a while. It is situated on paving and surrounded by low buildings. There is no other shade or greenery nearby.

The effectiveness of this structure in reducing heat stress was measured close to midday in mid-July when the sun was high in the sky. The effect of the screen was measured in the shade and this was found to reduce PET by 6,5 °C compared to the concrete paving slabs exposed to direct sunlight.

The questionnaire respondents were using this location in different ways, with some passing through, others shopping or working nearby, or simply relaxing on the bench. Questionnaire respondents wanted more shade and greenery to enhance this central area of the city. One suggested that a water fountain would make the area more pleasant.

Freestanding Green Screen

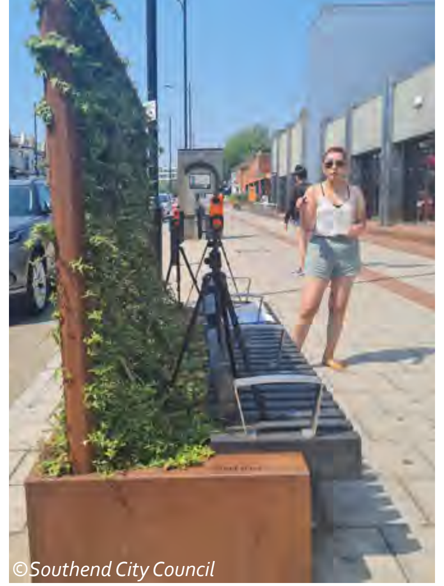
Date	21 July 2021
Time	12:29
dPET	6,5 °C PET reduction

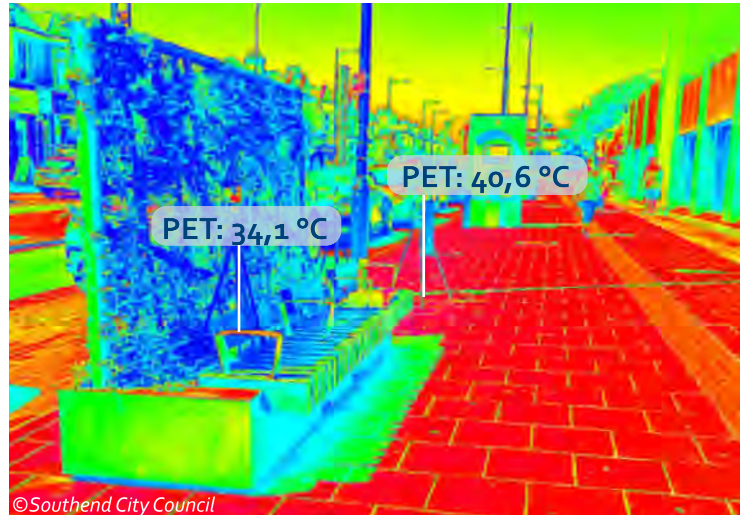
Intervention characteristics

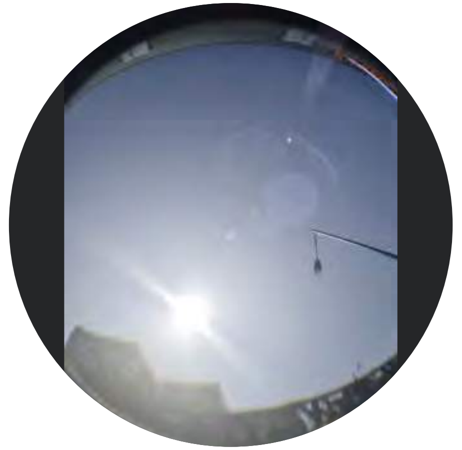
Species	*Hedera helix*
Height	2m
Width	3m
Orientation	North-South
Ground	Concrete paving slabs
Condition	Good
Coverage	50%

	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**34,1**	28,4	33	41,9	0,9	50,4
Reference	**40,6**	27,3	38	61	1,3	53,5
Difference	**-6,5**	1,1	-5	-19,1	-0,4	-3,1
Int. grade	Moderate heat stress					
Ref. grade	Strong heat stress					

Measurements conducted by southend on sea borough council







<18 PET Slight Cold Stress
18-23 PET No Thermal Stress
23-29 PET Slight Heat Stress
29-35 PET Moderate Heat Stress
35-41 PET Strong Heat Stress
41-46 PET Extreme Heat Stress (LV1)
46-51 PET Extreme Heat Stress (LV2)
51-56 PET Extreme Heat Stress (LV3)
>56 PET Extreme Heat Stress (LV4)

Spatial characteristics

4 Arendstraat, Ghent, BE

Spatial typology	Residential area in the centre
Urban geometry	Mixed with one to three storeys
Land cover	~ 100% paved surfaces
Social use	Route

Direct green facade in a residential street, *Ghent, Belgium*

This green wall (or façade) is made up of *Parthenocissus quinquefolia* (also known as Virginia creeper) planted at the base of the wall of the building and climbing up it. This vigorous, self-clinging, climbing plant will cover a large area quickly with a thick layer of glossy green leaves. This plant is deciduous and the leaves turn red before they are shed in the autumn, creating a visually attractive feature for the greater part of the year.

The green wall stands in a mixed use area of Ghent, with both residential and commercial buildings. In the immediate surroundings are hard surfaces, in both the horizontal (pedestrian pavement alongside a road with parked cars) and vertical (the building) planes, making this area of vegetation, which extends over 24m², particularly important.

The effectiveness of this green wall in mitigating heat stress was measured in the early afternoon in early August when the air temperature was just above 25 °C. A reduction in PET of 1,5 °C was measured between the sensors placed 25 centimetres from the vegetation surface of the green wall and the reference point, which was in the middle of the parking area. No questionnaire responses have been received.

Direct green facade

Date	8 August 2020
Time	13:30
dPET	1,5 °C PET reduction

Intervention characteristics

Species	*Parthenocissus quinquefolia*
Height	4 m
Width	6 m
Orientation	South/ slightly Southwest
Ground	Concrete paving slabs
Condition	Good
Coverage	100%

	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**45,5**	35,4	45,8	51,8	0,1	34,0
Reference	**47**	34,3	45,8	57,3	0,3	33,7
Difference	**-1,5**	1,1	0	-5,5	-0,2	0,3
Int. grade	Extreme heat stress: Level 1					
Ref. grade	Extreme heat stress: Level 2					

Measurements conducted by Oost-Vlaanderen


©Province of East Flanders

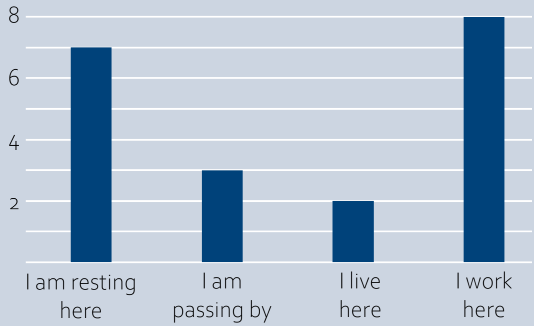
6. Water features

Lessons learnt

1. *Wind direction influences water vapour spread and thereby the cooling effect of fountains and this should be taken into consideration when selecting the position, the type of fountain and seating/play area.*
2. *Co-benefits for recreation and biodiversity often outweigh the actual PET reduction benefits.*
3. *PET reduction is low even close to the water feature however making physical contact with the water has an immediate cooling effect.*
4. *Effective solutions for outdoor public spaces where people spend time and, for example, in shopping streets where green interventions, such as trees, would sometimes be difficult to implement.*
5. *For children, water features with fountains can provide a safe play area for use on hot summer days.*

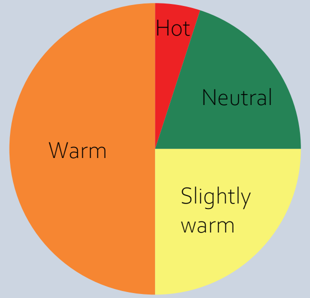
<18 PET	Slight Cold Stress
18-23 PET	No Thermal Stress
23-29 PET	Slight Heat Stress
29-35 PET	Moderate Heat Stress
35-41 PET	Strong Heat Stress
41-46 PET	Extreme Heat Stress (LV1)
46-51 PET	Extreme Heat Stress (LV2)
51-56 PET	Extreme Heat Stress (LV3)
>56 PET	Extreme Heat Stress (LV4)

Figure 27: *Why are you here?*



*Interviewees mentioned the need for more **shade**, less concrete and some nice **places to sit**.*

Figure 26: *Thermal comfort: How are you feeling now?*



*11 out of 20 respondents would like to see more **greenery** at the square, such as **trees**.*

Questionnaire results

Spatial characteristics

349 Hundelgemsesteenweg, Merelbeke, BE

Spatial typology	City centre
Urban geometry	Mixed with mostly low buildings
Social use	Place to stay around in the morning, lunchtime & afternoon

Fountain on a town square, *Merelbeke, Belgium*

This is a water feature with several jets situated on the western side of a large, open, paved area in the town centre of Merelbeke, East Flanders, Belgium. The wet area is unobstructed allowing easy access for children to play with the water. The site is surrounded by buildings and there are some seats located on the opposite side of the square where there is some vegetation.

The effectiveness of this water feature in mitigating heat stress was measured in mid-afternoon in June, when the air temperature was almost 27 °C. A reduction in PET of 1,6 °C was measured between the splash zone of the fountain and the reference point, also on cobbles.

Although there is some seating on the eastern side of the square and this is near to some shrubs, trees and a small green area, over half of those interviewed said they would like to see more trees, greenery and nice shady places to sit. Those interviewed were mostly either working nearby or relaxing in the square; one lived there, and three were just passing through.

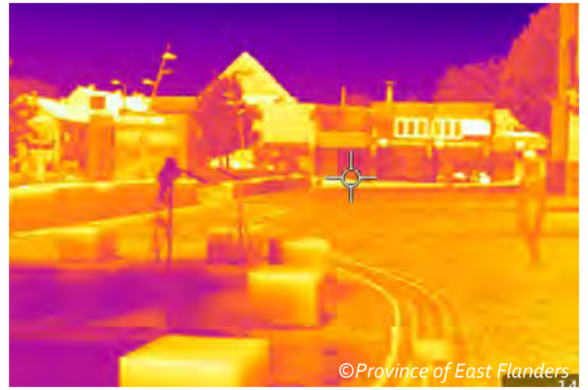
Fountain

Date	23 June 2020
Time	14:37
dPET	1,6 °C PET reduction

Intervention characteristics

Wet Area	48m²
Misted Area	15m²
Ground	Cobble stones
Movement	Active

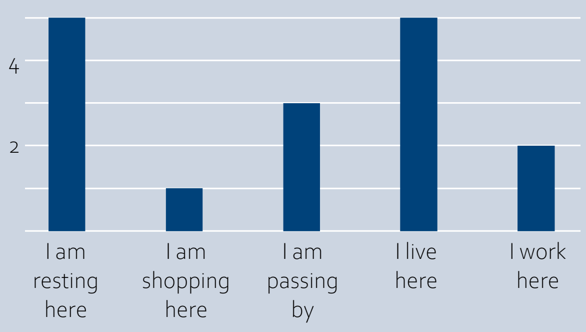
	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**45,5**	26,9	42,4	68,4	1	42,8
Reference	**47,1**	27,1	43,2	73,3	1,2	40
Difference	**-1,6**	-0,2	-0,8	-4,9	-0,2	2,8
Int. grade	Extreme heat stress: Level 1					
Ref. grade	Extreme heat stress: Level 2					



Measurements conducted by Oost-Vlaanderen

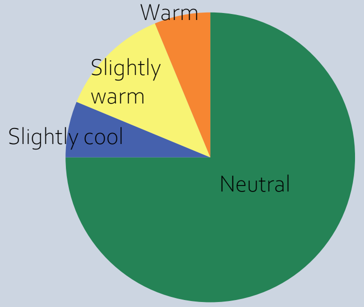
<15 PET Slight cold stress | 18-23 PET No thermal stress | 23-29 PET Slight heat stress | 29-35 PET Moderate heat stress | 35-41 PET Strong heat stress | 41-46 PET Extreme heat stress (LV1) | 46-51 PET Extreme heat stress (LV2) | 51-56 PET Extreme heat stress (LV3) | >56 PET Extreme heat stress (LV4)

Figure 29: *Why are you here?*



*8 out of 16 respondents pass by the location **daily** and 4 pass it **weekly**.*

Figure 28: *Thermal comfort: How are you feeling now?*



*4 out of 16 respondents mentioned the need for more **shade** and 3 would like to see a **fountain** in the area.*

Questionnaire results

Spatial characteristics

Franciscanessenplein, Breda, NL

Spatial typology	City centre
Urban geometry	High buildings (5 to 9 floors)
Social use	The site lies at the edge of the centre with a moderate pedestrian traffic throughout the day. The square doesn't function as a place to stay.

Small waterway in the historic centre, *Breda, the Netherlands*

This waterway is in an area dominated by high buildings, near to the city centre and is part of Breda's historic canal system. It is bordered by paving and an adjacent road with low level but regular bicycle, pedestrian, and vehicular traffic. It is a routeway rather than an area where users are likely to linger.

The effectiveness of this waterway in mitigating heat stress was measured in mid-afternoon in late June when the air temperature recorded on the paved area was just above 25 °C. A reduction in PET of 1,7 °C was recorded close to the waterway.

Two thirds of the respondents to the questionnaire stated that they used this route daily, with the remainder using it every week. Four of the 16 said they felt more shade would improve the area with a further three wanting to see a fountain here.

Date	28 June 2019
Time	15:15
dPET	1,7 °C PET reduction

Intervention characteristics

Wet Area	2000 m² (width: 18 m, part of the historic canal system of Breda)
Misted Area	Not applicable
Ground	Concrete
Movement	No movement

	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**39,5**	24,1	36,4	67,8	1,8	46,2
Reference	**41,2**	25,8	38,6	62,9	1,1	42,7
Difference	**-1,7**	-1,7	-2,2	4,9	0,7	3,5
Int. grade	Strong heat stress					
Ref. grade	Extreme heat stress: Level 1					

Measurements conducted by Gemeente Breda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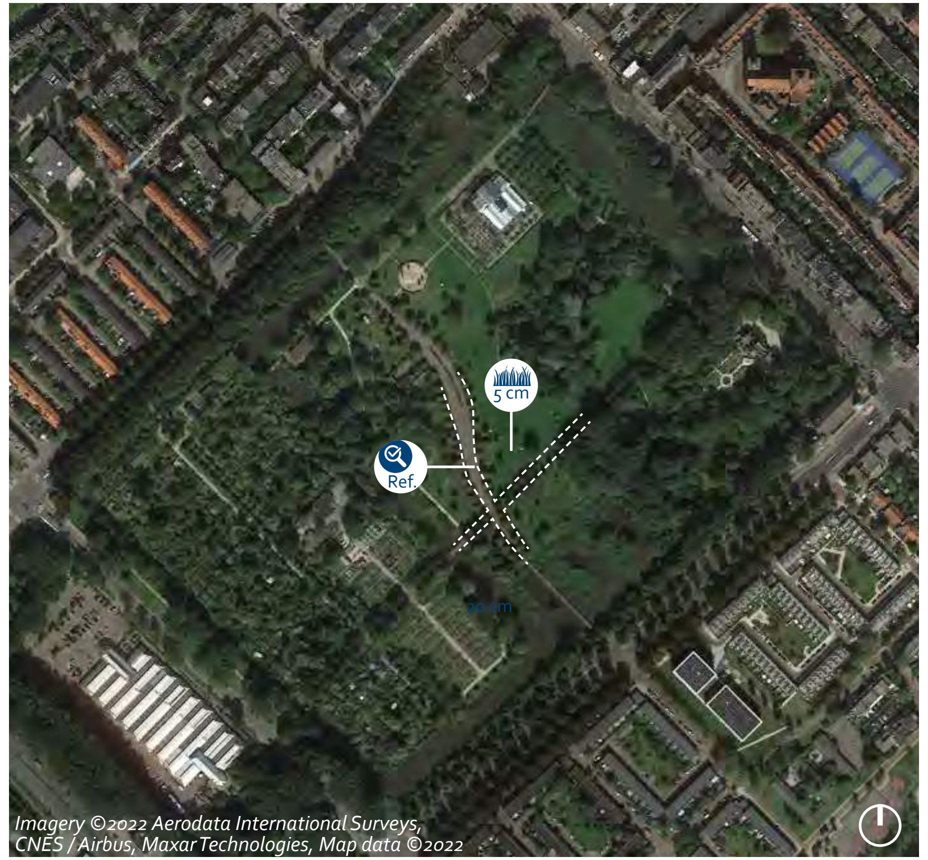
7. Cool surfaces

Lessons learnt

1. *It is challenging to measure the effect on PET using mobile weather stations as a large enough surface area and scope for the required distance between weather stations is necessary.*
2. *While effect on daytime PET reduction at 1.1 metre height is limited these are more efficient in mitigating the urban heat island effect.*
3. *Cool surfaces such as lawns can be complementary to other, larger, interventions, such as trees.*
4. *Lying down on grass, for example in a park, can be a cooling experience.*
5. *Suitable for play areas since children are closer to the ground than adults and particularly vulnerable to heat.*

<18 PET Slight Cold Stress
18-23 PET No Thermal Stress
23-29 PET Slight Heat Stress
29-35 PET Moderate Heat Stress
35-41 PET Strong Heat Stress
41-46 PET Extreme Heat Stress (LV1)
46-51 PET Extreme Heat Stress (LV2)
51-56 PET Extreme Heat Stress (LV3)
>56 PET Extreme Heat Stress (LV4)



Spatial characteristics

Park Frankendael, Amsterdam, NL

Spatial typology	Public park
Ground surface	~ 5% paved and ~ 95% vegetated surfaces
Social use	The site is a public park extensively used throughout the entire day.

Mown grass in an inner-city park
Amsterdam, The Netherlands

This is a large, open surface with 5cm tall mown grass located in the Frankendael park in Amsterdam. Its effectiveness in mitigating heat stress was measured at lunchtime in August when the air temperature reached almost 30 °C.

A reduction of 2,7 °C PET was measured at 1,1m height, and a reduction of 0,7 °C PET was measured at 0,6m height compared to the reference points at corresponding heights. The difference between the PET values at the two intervention points was a negligible 0,3 °C PET. These results show that as a cool surface on its own this is not effective in mitigating daytime heat stress. The effect of evaporative cooling and the lower infrared radiation from grass, compared to hard surfaces, may be better experienced when sitting or lying on it, or by small children.

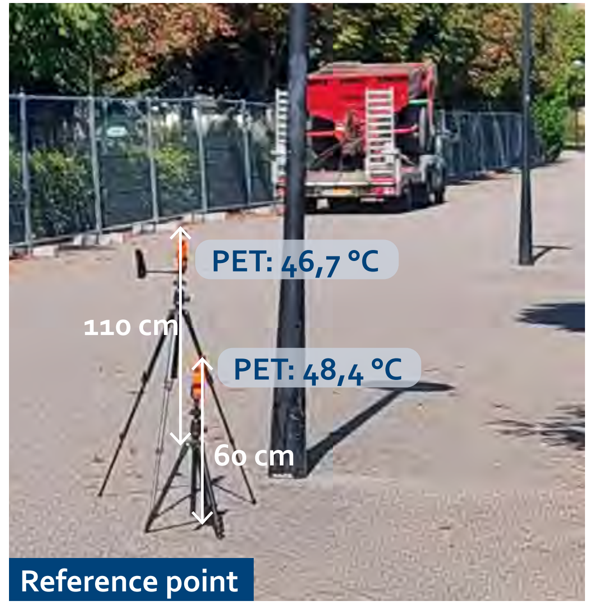
Cool surfaces are challenging to assess due to their marginal cooling capacity. To measure their cooling effect, the surface should be at least 25 m2, wider than 2,5m, and the reference point needs to be at least 2,5m from the edge of the cool surface (see Spanjar et al., 2020). These conditions are not often met in dense inner city areas.

The city park where the measurement took place lies in a former 17th century estate and occupies almost 3 hectares. Important pedestrian and cycling routes lead through it connecting the surrounding residential neighbourhoods. The park offers many opportunities for people to relax such as restaurants, a school garden, community allotments and open meadows for picnics or sports.

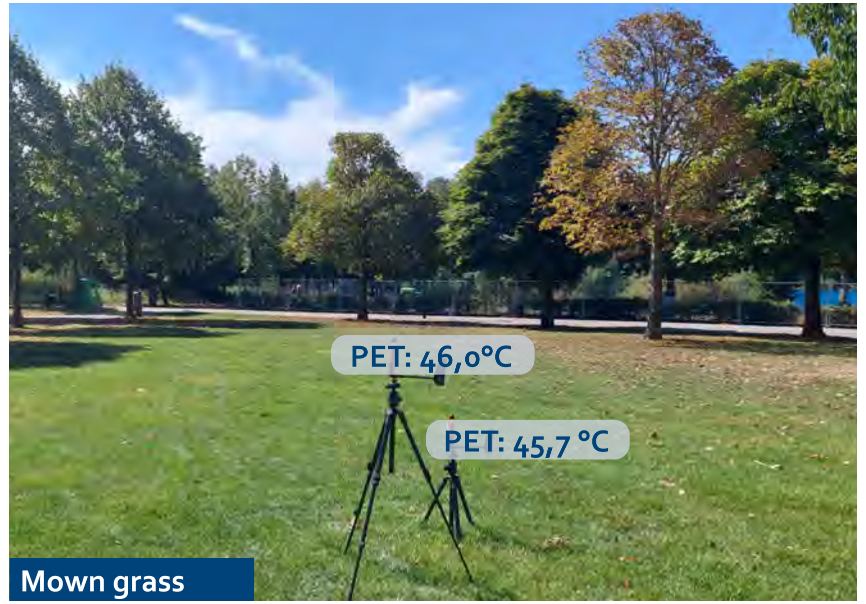
Mown grass

Date	24 August 2022
Time	13:00
PET	0,7 °C PET red. at 110 cm 2,7 °C PET red. at 60 cm
Intervention characteristics	
Height	5 cm
Condition	Healthy
Width	100 m
Area	40.000 m²

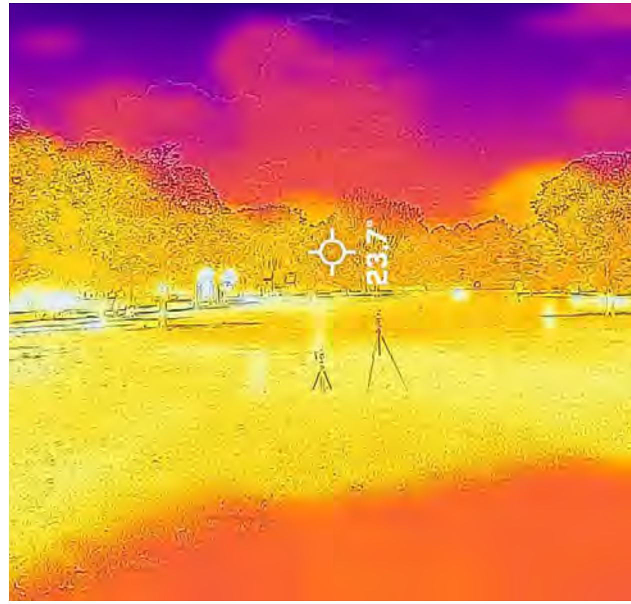
	Measured at 110 cm height						Measured at 60 cm height					
	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)	PET (°C)	T_{air} (°C)	T_g (°C)	MRT (°C)	Wind (m/s)	RH (%)
Intervention	**46,0**	29,5	43,0	67,9	1,1	55,9	**45,7**	29,9	43,2	65,0	0,9	56,0
Reference	**46,7**	30,8	44,2	65,7	0,9	51,3	**48,4**	29,8	45,4	70,4	0,9	54,7
Difference	**-0,7**	-1,3	-1,2	2,2	0,2	4,6	**-2,7**	0,1	-2,2	-5,4	0	1,3
Int. grade	Extreme heat stress: Level 1						Extreme heat stress: Level 1					
Ref. grade	Extreme heat stress: Level 2						Extreme heat stress: Level 2					



Reference point



Mown grass



Measurements conducted by Amsterdam University of Applied Sciences

8. Interventions compared

Tree(s)

Green walls

Water features

Shelter canopies

Cool surfaces

Tree(s)	Shelter canopies	Green walls	Water features	Cool surfaces
Measured PET reduction range				
4-20 °C PET	9-15°C PET	1-7 °C PET*	0-6 °C PET	0-2 °C PET*
		*high PET only when shade of the wall is included		*when lying or sitting on a cool surface
Intervention best suited for				
• *Squares* • *Cycling and pedestrian routes* • *Playgrounds* • *Residential areas*	• *Squares* • *Narrow streets* • *Playgrounds*	• *Squares* • *Pedestrian routes* • *Playgrounds* • *Mobility hubs*	• *Squares* • *Playgrounds* • *Mobility hubs* • *Residential areas*	• *Squares* • *Parks* • *Playgrounds* • *Residential areas*

Figure 30: *Heat stress mitigation achieved by the five intervention types, based on Cool Towns measurements conducted between 2019-2022.*

8.1 Comparative analysis

The results of the Thermal Comfort Assessment underline that the livability of urban areas in Western Europe is under threat from climate change (see also Spanjar et al., 2022). The rising global temperatures are worsened by the current design of our densely built cities. The convention of using hard impervious materials for their durable properties undermines people's thermal comfort. The historical blue-green infrastructure with fully grown trees, often situated around the city centre, city edges and particularly larger parks, act as an important first line of defence to cope with extremely hot conditions. However, large cool areas such as parks, where people can escape the heat, are insufficient on their own to safeguard comfortable urban conditions for those living in this changing climate.

Vital outdoor public spaces that people depend on in their daily lives can become unpleasant to use during hot days. Shopping areas, mobility hubs, parks, schools, and the cycling and walking routes connecting these, frequently experience severe heat stress. Shopping areas, for example, with limited greenery and hard surfaces, effectively heat the built environment and make shops and community facilities difficult to reach. Children at playgrounds, the elderly in retirement homes, and those who are unwell and using health care facilities are especially vulnerable to heat exposure and the associated severe health risks. The Intergovernmental Panel on Climate Change forecasts a dramatic rise in temperatures in Western Europe (IPCC 2022; IPCC 2021) which will further reduce thermal comfort during summers in urban areas, and stresses the importance of immediate action.

The Cool Towns Intervention Catalogue discusses the effectiveness of a variety of street-level interventions to mitigate heat stress in different types of public outdoor space. The intervention types evaluated consist of trees, shelter canopies, green walls, water features and cool surfaces (see fig.30).

In general, trees are the most effective solution to reduce PET. Depending on the foliage cover, the foliage density, and climatic conditions, trees can make up to 20 °C PET difference compared to a location fully exposed to the sun (see the group of beech trees in Eeklo, p. 40). A row of large trees is effective to create cool corridors along major pedestrian and cycle routes in the city (e.g. 18,1 °C PET reduction by the sweet chestnut trees in Saint-Omer, p. 34). Even a small, recently planted, single tree can make a substantial difference to PET (e.g. 13,5 °C PET reduction of linden tree in Eeklo, p.28) but when newly planted the spread of the crown is still limited and may be insufficient to provide enough cooling capacity. The effectiveness of trees depends on the layers of leaves in the crown and the overall leaf area that provides shade, and the process of evaporation that provides cooling when it is not too hot.

Shade sails protect from direct solar radiation and can provide a convenient,and if necessary temporary, solution (e.g. 15 °C PET reduction, p. 44) at places where there is limited underground space to enable tree planting or where immediate cooling is required. For example, shade sails are especially useful in narrow shopping streets, at festival grounds, and children's playgrounds where they can protect one of the most vulnerable groups from heat.

While water features offer only a few degrees of PET reduction if the person is close to the water (e.g. 1,6 °C PET in Merelbeke, p. 58), it does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not mean they are not effective. When people make contact with the water it can cool down their body instantly. Thus, making existing urban water features, such as canals or ponds, accessible and safe for water recreation can provide cooling benefits for a large urban population. Water features with jets, the so-called water playgrounds, are especially effective in mitigating heat stress by allowing children to play even during warm summer days, since making contact with the water instantly lowers the body core temperature. If these features are accompanied by trees, they provide a safe thermal environment to spend time in.

A row of large trees can be effective to create cool corridors for major pedestrian and cycle routes in the city (e.g. 14,8 °C PET reduction by silver lime trees in Breda, p. 36). For shorter but intensively used walking routes, pergolas can create an attractive shaded pathway or resting area, such as near the train station in Middelburg (e.g. 13,1 °C PET reduction of wisteria, p. 46).

At some locations it is not easy to implement heat stress interventions. Due to limited space it may not be possible to install trees, pergola structures or shade sails. Green walls along intensively used walking routes or resting areas can slightly increase the thermal comfort of users (e.g. 1,5 °C PET reduction in Ghent, see p. 54). The cooling capacity of green walls depends on many factors, for example, the species selected, how healthy and moist the vegetation is, and the depth and density of the green cover. Green walls can also offer important co-benefits for biodiversity and thermal comfort indoors.

Cool surfaces, such as lawns or permeable pavements, are not very effective in reducing heat stress for people standing on them. Mown grass can give a PET reduction of 0,7 °C (measured in Amsterdam, see p. 64) but if a person lies down on the grass, or a child (whose centre of gravity is closer to the ground) plays on it, the grassy surface provides a higher cooling benefit. Green walls and green surfaces prevent the absorption of heat and its subsequent release at night so are an effective means of reducing the urban heat island effect.

8.2 Conclusions

Trees are, in general, the most effective intervention type for heat stress mitigation. However, focusing solely on those interventions with the greatest potential to reduce PET is an oversimplification and excludes other alternatives with cooling benefits from the decision making process. Each intervention type comes with its own advantages and disadvantages, and all require careful consideration of all aspects, including the costs, co-benefits, spatial configuration, and the way the public space is used, before making an informed choice.

For full heat resilience, it is recommended that a suite of interventions are combined and integrated to maximise the mitigation of heat stress in public outdoor spaces. Planting trees, creating cool surfaces, and installing green facades, while simultaneously addressing other urban climate related challenges, such as drought and flooding, in a single space, can be the most cost effective way to improve thermal comfort. The Cool Towns consortium of cities, knowledge institutions and companies specialising in climate adaptation, hope that this publication will help decision-makers, and those in related disciplines, create evidence-based designs and strategies to promote urban heat-resilience.

8.3 Tips & Tricks

1. Foster Natural Capital

Pruning the top of trees and creating artificial shelter with sun shades, for example, is not always the most effective use of resources. A quick win is to improve the growing conditions of trees to increase cooling capacity. Taking out the pavement around the tree and improving the soil conditions can help to promote root growth.

2. Water your plants

Trees, pergolas and green walls require a planting and watering strategy particularly in the early, establishment, phase. Multiple Cool Towns pilots, for example Saint-Omer, East-Flanders, and Middelburg, required replacement planting either due to drought, or the faulty green wall irrigation system. Green interventions need regular health monitoring following implementation at least in the first year but especially during the first dry period.

3. Timing is everything

Installing direct green facades on existing buildings is often met with resistance from the owners'. Climbing plants may cause structural damage and complicate property maintenance. These risks are often balanced by the aesthetic benefits of green walls's contributing to an increase in property value. The direct green facades at Ostend's pilot site only gained owners' support after the public space transformation demonstrated potential monetary gains in rental and real estate revenue.

4. Boost biodiversity

Many cooling interventions can function as nature-based solutions, such as trees, pergolas, green walls, and water features. Involve urban ecologists in the design process at an early stage to ensure that the intervention, where possible, supports native plant species and provides food and shelter for a range of birds, beetles, bees and other insects.

5. Support the local economy

Intervening in dense inner cities often results in the loss of parking places, which is met with opposition. Retail owners are often concerned about the inconvenience caused by public works, such as disruption in the delivery of goods. Once a parking area is transformed into a lush vegetated courtyard or a parklet, as demonstrated by the pilots in Southend and Ostend, this encourages new shops and restaurants with open terraces, real estate values rise, and benefits for the local economy become apparent.

6. Think below ground

Utilities with cables and pipes often complicate installation of interventions, particularly those involving plants that need space to grow in the soil. Pedestrianised streets in city centres may lend themselves better to installation of shade sails, while planting trees such as in Kent's residential pilot site or historic city areas with archaeology, need to navigate and respect underground services.

7. Raise awareness

Organise measurements in the presence of residents, for example by conducting a guided 'Thermal Walk', involving participants directly in experiencing differences in thermal comfort in their local area. Another effective method would be, inviting children to take part in opening a pilot site, for example by planting in the pockets of a green wall system, as demonstrated in a school in Middelburg. These events provide educational opportunities and raise public support for investing in climate resilience.

8. Aim for co-benefits

Use co-benefits to engage stakeholders and achieve consensus that action is required. Heat stress interventions are important and often undervalued, but this is just one among the many urban challenges currently experienced in cities. Integrating cooling interventions in local action plans, as has been done at the Breda, Saint-Omer, and East-Flanders pilot sites, and ensuring interventions have tangible co-benefits, such as for biodiversity, mobility, or amenity value, increases project feasibility, general appeal, and scalability increasing the likelihood of similar projects in other places experiencing heat stress.

9. Design for all seasons

Choose cooling interventions that respect all types of weather. Think of where, and how urgently, cool capacity is needed. Deciduous trees allow sunlight to penetrate in winter but in some specific situations the shade cast may cause unwanted, excessive, shadow, in the cool of early autumn and late spring. Shade sails provide immediate and flexible solutions for playgrounds or inner city streets, but can lend themselves better to local cooling although these lack the additional co-benefits associated with vegetation.

10. Towards heat resilient strategy

The discussed creation of cool spots are all important street-level interventions where short term heat relief is urgently required. However, an integrated heat resilient strategy requires systemic change. It asks for an evaluation of the existing green infrastructure on the cooling potential together with the other benefits this delivers. Replacing existing shrubs by trees, or small trees for larger ones for example, increases the cooling capacity and needs to be considered for future proofing cities.

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Built environments are increasingly vulnerable to the impacts of climate change. Most European towns and cities have developed horizontally over time but are currently in the process of further densification. High-rise developments are being built within city boundaries at an unprecedented rate to accommodate a growing urban population. This densification contributes to the Urban Heat Island phenomenon and can increase the frequency and duration of extreme heat events locally. These new build-up areas, in common with historic city centres, consist mainly of solid surfaces often lacking open green urban spaces.

The Intervention Catalogue is the third publication in a series produced by the Cool Towns project and has been designed as a resource for decision makers, urban planners, landscape architects, environmental consultants, elected members and anyone else considering how to mitigate heat stress and increase thermal comfort in urban areas. Technical information on the effectiveness of the full array of intervention types from trees to water features, shading sails to green walls, has been assessed for their heat stress mitigation properties, expressed in Physiological Equivalent Temperature (PET). The results shown in factsheets will help the process of making an informed, evidence based, choice so that the most appropriate intervention for the specific spatial situation can be identified.

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