The Urban Heat Atlas

A standardised assessment for mapping heat vulnerabilities in Europe

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Gideon Spanjar, Debbie Bartlett,
Sába Schramkó and Jeroen Kluck

A standardised assessment for mapping heat vulnerabilities in Europe

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

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Cover image: Heat map of Breda


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CONTENTS

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1. Introduction

The climate is rapidly changing, the effects are in particular being felt in urban areas and urgent action is required (see fig.1). The Intergovernmental Panel on Climate Change (IPCC) have issued increasingly stark warnings. In August 2021 the report, Climate Change 2021: the Physical Science Basis (IPPC, 2021) stated "Climate change is widespread, rapid and intensifying". This was followed by Climate Change 2022: Impacts, Adaption and Vulnerabilities (IPPC, 2022) with a risk framework for "understanding the increasingly severe, interconnected and often irreversible impacts of climate change on ecosystems, biodiversity, and human systems".

The situation is serious and requires a response. There are three basic strategies available, reducing any further emissions with potential to increase climate change, actively removing carbon from the atmosphere, and taking action to adapt by mitigating the effects felt by communities. The Paris Agreement, adopted by many of the World's leaders in 2015 (United Nations, 2015), followed by the annual Conferences of the Parties or COPs, most recently COP26 (United Nations, 2021). At national level legislation and policies are put in place to limit further emissions as well as strategies to increase carbon drawdown, such as limiting deforestation and providing incentives for tree planting. The third option, adaptation to the consequences of climate change, is something that has to be actioned at local scale.

As well as long-term increasing average temperatures the effects of climate change include extreme weather events such as heavy rain showers, dry periods, and predicted increase in intensity and frequency of heatwaves. The need to mitigate heat stress has only recently come onto the agenda as the potential impact on health and productivity, has become apparent. How heat stress in urban areas impairs vital functions, hits the local economy, and brings risks to citizens' well-being remains unquantified.

The Cool Towns project, funded under the INTERREG 2 Seas programme was initiated in response to these growing concerns about the impacts of climate change, and particularly hot weather, on the liveability of small towns and cities in Northern Europe.

The Urban Heat Atlas is the result of four years of collaborative research to investigate liveability of European urban areas during warmer periods of the year. It contains a collection of heat maps covering more than 40.000 hectares of urban areas in ten municipalities in England, Belgium, The Netherlands, and France. The maps demonstrate how to systematically conduct a Thermal Comfort Assessment (TCA) to identify heat vulnerabilities and cooling potential in cities to enable decision-makers to set priorities for action. The comparative analyses of the collated maps provide also a first overview of the current heat resilience state of cities in North-Western Europe.

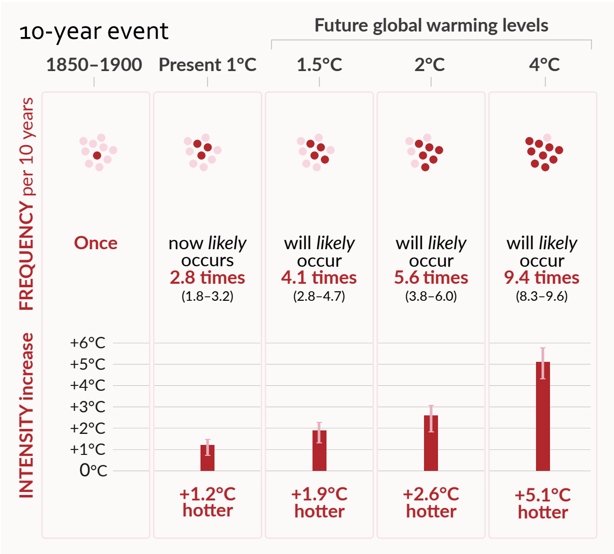

Figure 1: *Projected changes in the intensity and frequency of hot temperature extremes over land (source: IPCC: Summary for Policymakers, 2021, p.19).*

1.1 Reading guide

The *Urban Heat Atlas* describes first how the design of the urban fabric contributes to heat island effects and the creation of uncomfortable thermal outdoor spaces with potentially severe consequences for mobility, local economy, and human health and well-being. Chapter 2 provides basic instructions on how to conduct a Thermal Comfort Assessment at the city and neighbourhood scale. It starts with describing the model developed based on the Physiological Equivalent Temperature (PET) index and operationalized by several meteorological scenarios, complemented by key social and environmental indicators to show heat vulnerabilities. The maps derived by employing this method are discussed, city by city in chapters 3-11. In Chapter 12 a comparative heat resilience analysis is made based on the collection of different types of maps of the assessed municipalities. The emerging heat patterns and priority urban areas are discussed here. The solutions for the short term for combating heat stress where it is urgently needed and pathways for more systemic changes to ensure heat resilience in the long term are presented in the final chapter.

1.2 Target audience

This publication is aimed to help decision makers, urban planners, landscape architects, environmental consultants and related professionals – through to elected community representatives to begin to develop heat resilient strategies. It will guide readers through the first step in developing resilience, which is to identify the areas in the city that are most likely to be affected in hot weather. This will enable priorities to be set based on the proximity of the most vulnerable inhabitants and where the greatest risk is likely to be experienced. The results provide important information for urban development and urban renewal projects to select concerning also other requirements, the most appropriate option for heat mitigation depending on the specific characteristics of the site.

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

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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, governmental organisations, and industries from the climate change adaptation domains and it ran from 2018 to 2022. The partnership aimed to counteract the negative effects of climate change on cities by providing municipalities with the necessary knowledge and tools to implement effective and attractive solutions to enable their cities to become more heat-resilient. The Urban Heat Atlas, the first publication in a series produced by the Cool Towns project (see fig. 3), 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 level of thermal comfort experienced by users at a fine-grained scale and can provide a robust justification for future investment as part of a cost-benefit analysis. It provides guidance to conduct a Thermal Comfort Assessment (TCA) at street-level, to analyse how thermally comfortable urban public open spaces are during hot summer days, and measuring the cooling effects of street-level interventions.

The *Cool Towns Intervention Catalogue* is the third publication and discusses the results of TCAs. It evidences the effectiveness of a wide range of intervention types from different tree species, water features, shading sails and green walls, in reducing the Physiological Equivalent Temperature (PET) to increase thermal comfort of users. The interventions discussed have all been measured by mobile weather stations, enabling quantitative information to be generated for the PET reduction, and this is combined with a questionnaire exploring the thermal perceptions of users, qualitative information.

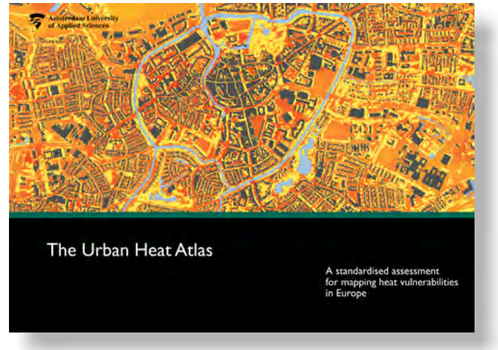


Figure 3: ***(1)*** *The Urban Heat Atlas demonstrates how to conduct a Thermal Comfort Assessment (TCA) systematically to identify heat vulnerabilities and cooling capacity in cities to enable decision-makers to set priorities for action.*

(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.*

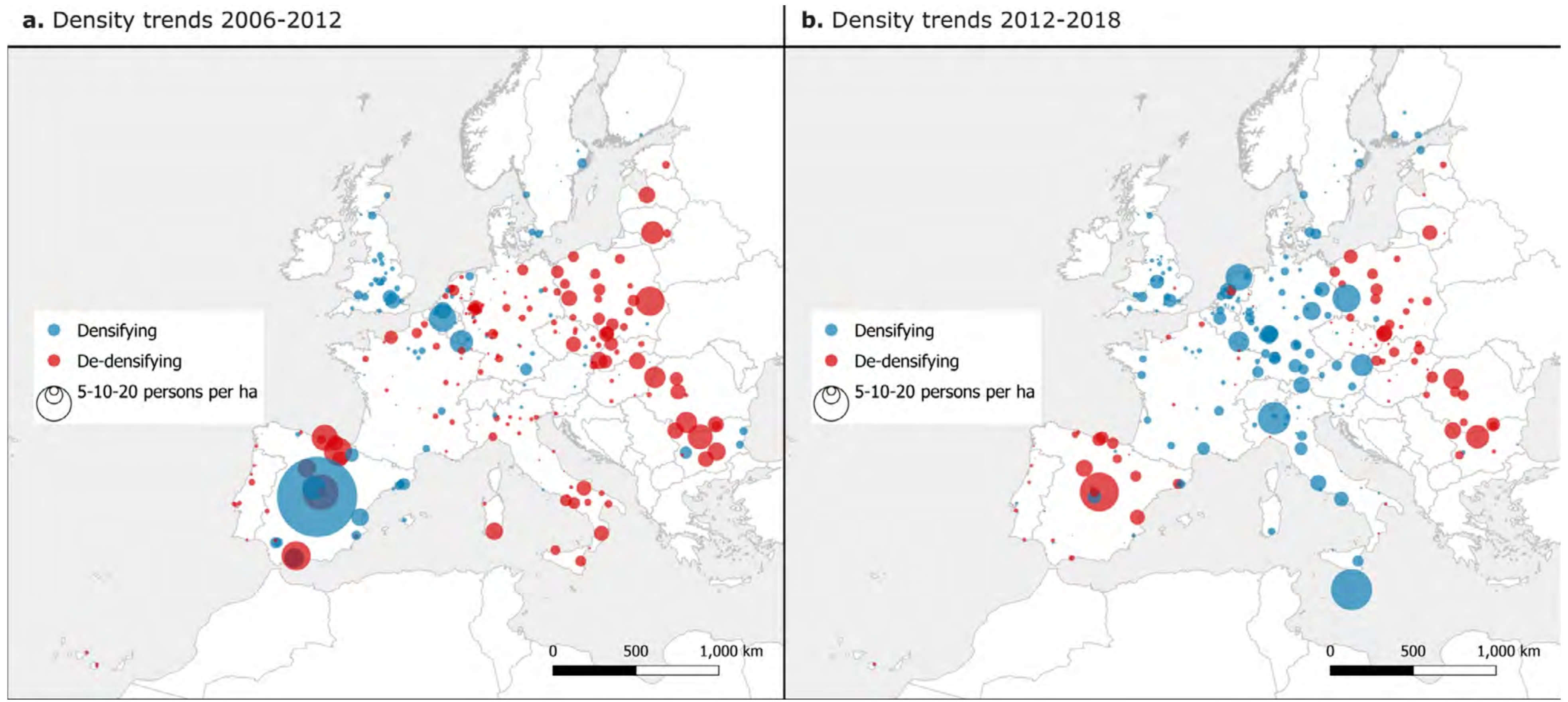


Figure 4: *Density trends in residential areas in Europe, and refer to the period 2006-2012 (a) and 2012-2018 (b) (source: Cortinovis et al., 2022, p. 19).*

1.4 Heat and urban form

Ongoing urbanisation coupled with the predicted frequency, duration, and intensity of heatwaves, requires understanding the way the urban climate is influenced by urban design and development. European cities have turned away from the period of de-densification seen between 2006-2012 to a strategy of increasing density (see fig.4 and Cortinovis et al., 2022). This increase is especially high, for example in the Netherlands, and this has contributed to the Urban Heat Island (UHI) phenomenon (ibid.). The UHI effect can increase the frequency of extreme heat events locally, extending the duration and decreasing relief from heat exposure (Schatz & Kucharik, 2015) bringing great discomfort for citizens. The UHI effect is when an urban area is significantly warmer than its rural surroundings.

The UHI is caused by a change in land use and cover by replacing vegetation with impervious surfaces (e.g. concrete and stones) that have a high thermal conductivity which heats the built environment (heat absorption). Narrow open spaces (street canyons) worsen the situation and trapping solar radiation with slow irradiation loss of heat through even the night (Chapman et al., 2019); in Lisbon, Portugal, this was been observed to increase temperatures by up to 6.3 °C (Nouri et al. 2018). UHI intensity is directly related to density (Li et al., 2020) and strongly influenced by the size and compactness of the city (Zhou et al., 2017). The extreme urban intensification that can be observed in many major European cities with high-rise developments, may resolve some local heat stress by the shade from the buildings although higher wind speed (Zhou & Chen 2018) can also negatively influence thermal comfort for the users of open public spaces. Small, dispersed, and extensive cities experience less UHI.

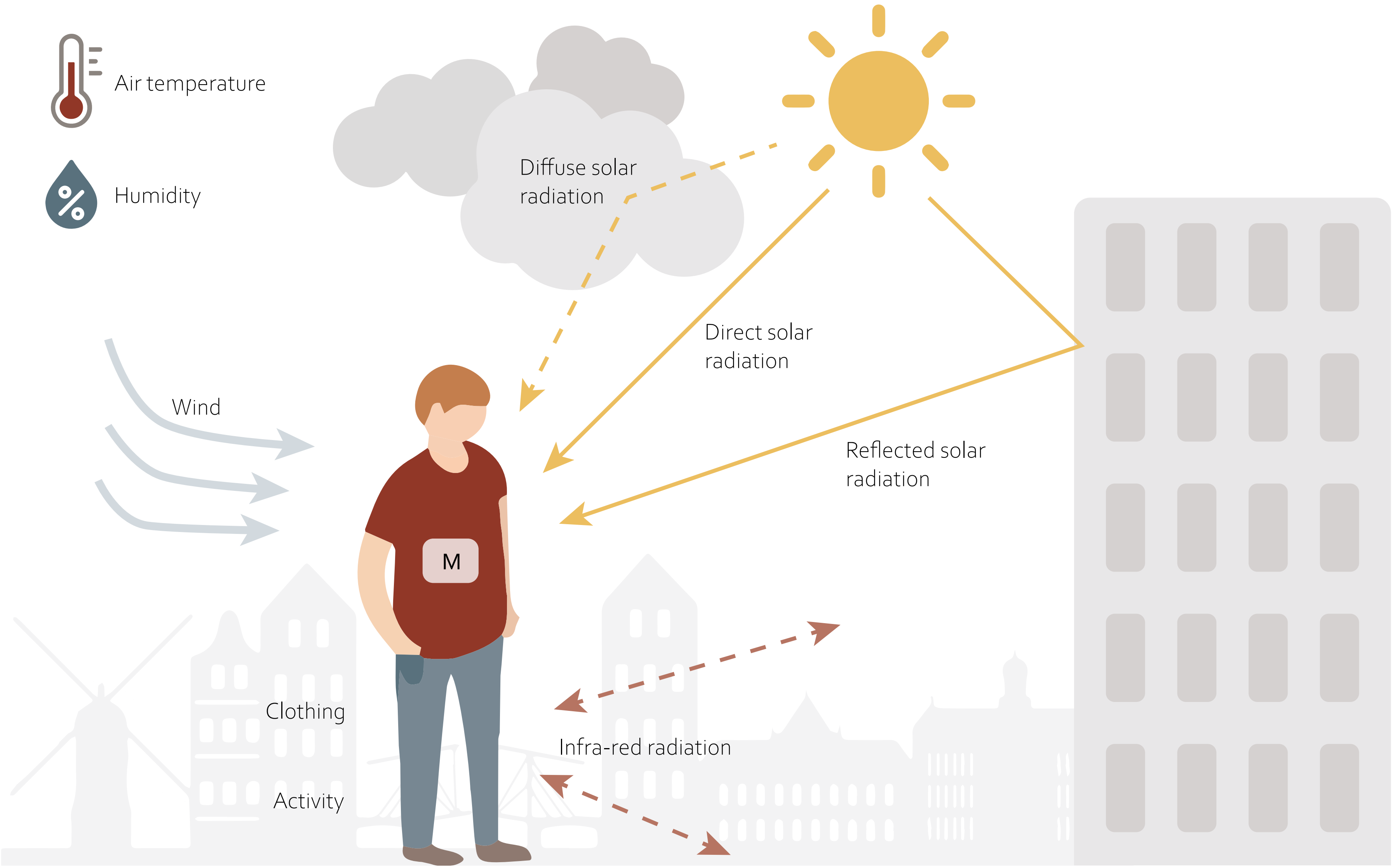


Figure 5: Schematic representation of the different factors that influence the energy balance of the human body and on which the Physiological Equivalent Temperature (PET) is based. The air temperature, humidity and wind speed can be directly measured by a mobile weather station (or the data can be sourced from a meteorological station nearby) and are then combined with spatial data. Clothing insulation and activity are recorded using a questionnaire when PET is measured; when PET is modelled a fixed clothing factor is used and the activity of walking are used (Adapted from Havenith, 1999).

Thermal comfort

People experience heat stress when too much heat is absorbed by the body (Epstein & Moran, 2006). The urban morphology and use of conventional materials can increase heat stress with impact on health and wellbeing as well as the local economy as people are less willing to leave their homes. Thermal comfort is most commonly measured by the Physiological Equivalent Temperature (PET) index, especially when research is conducted outdoors (Coccolo et al., 2016; Matzarakis et al., 2014). It is expressed in degrees Celsius (°C).

The PET-index is 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.

PET can be calculated from micrometeorological data, recorded by a weather station (see Spanjar et al., 2020 for guidance), The parameters required 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). 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.5). 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. If, however, the building or pavement is white (a higher albedo effect) it will warm less reflecting solar radiation and so increasing PET value at that particular moment (Erell et al., 2014). This data is analysed and modelled, with respect to existing meteorological and spatial data. Thick clothing 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.

The PET value (°C) calculated corresponds to the Physiological stress grades in Figure 6. 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 adaptive capacity is described in the next paragraph.

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 6: 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.

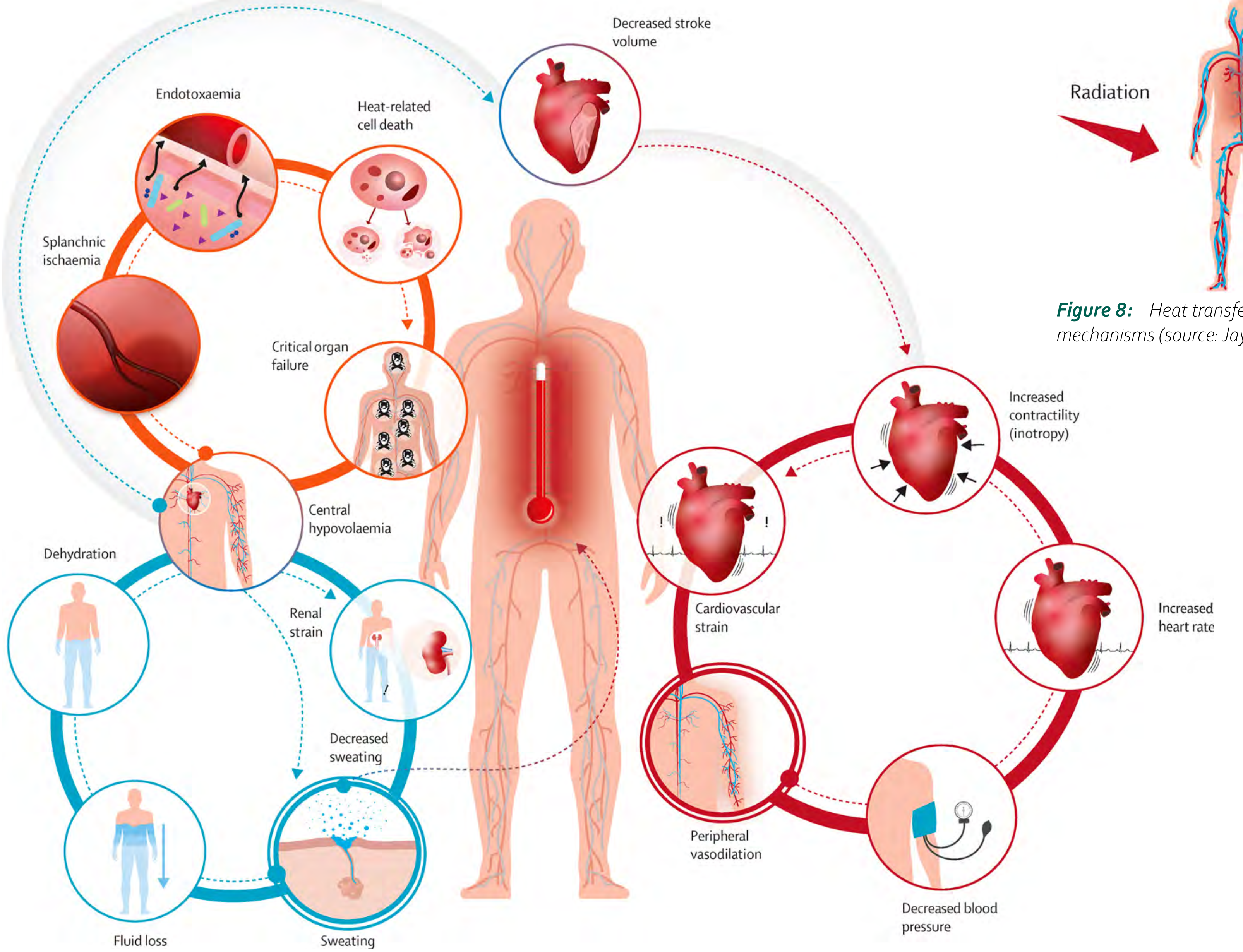


Figure 7: *Physiological paths of human heat stress (source: Ebi et al. 2021, p. 700).*

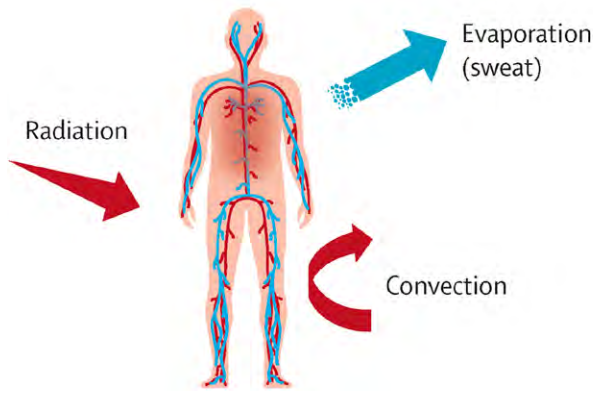


Figure 8: *Heat transfer and two physiological cooling mechanisms (source: Jay et al., 2021, p. 711).*

Impact of heat on health

On a hot day, the heat load of urban areas is transferred to the individual. The principle of this heat cascade is that heat moves from hot surfaces to cooler ones and this can be accelerated with increasing air speeds, and decreased by high ambient humidity (Jay et al., 2021). Humans release body heat by increasing the rate of blood circulation to the skin surface tissues by dilating blood vessels (peripheral/skin vasodilation see fig.7) and increasing heart rate. If this is not sufficient to reduce heat, humans start to sweat. This is an effective cooling mechanism for heat production caused by physical activities such as sports (see fig.8).

However, on days with high air temperature with exposure to high solar-, reflected and infra-red radiation, with no wind, high humidity levels, and if skin is covered with layers of clothing, these cooling mechanisms may not be enough to protect against heat stress. This is particularly true when physical activity in outdoor spaces such as running creates changes in metabolic heat production. The most common heat-related illnesses are:

- Heat rash, if sweat is trapped on the skin and this may itch. Symptoms are inflamed lumps and small blisters.

- Heat cramps are the mildest form of heat related illness. During or after intense exercise muscle cramps and spasms can occur especially in the legs.

- Heat exhaustion is caused when the body is unable to regulate body heat and becomes dehydrated, as there is no fluid and salt replacement. Symptoms range from pale and moist skin, and headache, to fever, and becoming unconscious.

- Heat stroke is a severe heat- related illness and is a life-threatening emergency. If not addressed in time it can progress to heat stroke with high fever, rapid heart rate, lethargy and dry skin (due to inability to sweat) important symptoms

In Europe over 25,000 heat-related deaths are believed to occur every year, with the death toll peaking at over 70,000 in summer 2003 (Robine et al., 2008). In that year the elderly appeared to be the main victims with 82% heat-related excess mortality in France observed in subjects over 75 years of age (Belmin et al., 2007; see also Daanen et al., 2010). The age-related reduction in heat loss response (sweating and skin vasodilation) and intake of prescription of drugs makes those over 60 less able to respond to increases in ambient air temperature (Dufour & Candas, 2007) so they have increased risk of heat-related morbidity (e.g. heat stroke) and mortality (Kaltsatou et al., 2018). More heat-related morbidity and mortality are likely to occur with the predicted longer and more intense heat waves (IPCC, 2022).

People with chronic diseases and in particular those who suffer from obesity, cardiovascular disease, respiratory disease, or diabetes are particularly vulnerable to heat (Kenny et al., 2010). Children (when playing or taking part in sports) adjust more slowly than adults to heat and have lower sweat rates relative to their body surface area (Leyk et al., 2019). The direct physiological impact of heat also affects their learning capacity with cumulative heat exposure inhibiting cognitive skill development in children (Goodman et al., 2019).

Figure 9: *The empty High Street in Margate, England, on a hot summer day.*

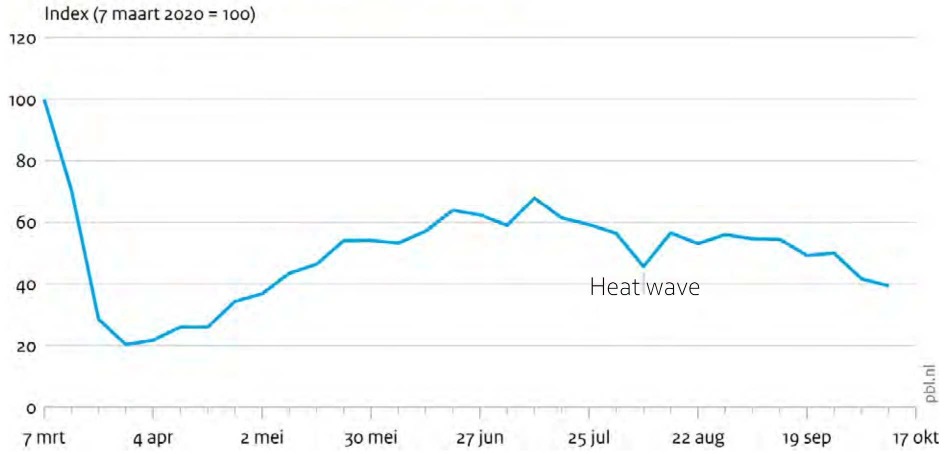


Figure 10: *Number of visitors in the main shopping streets of 53 city centres on Saturdays, 2020 (source: Evers et al., 2020).*

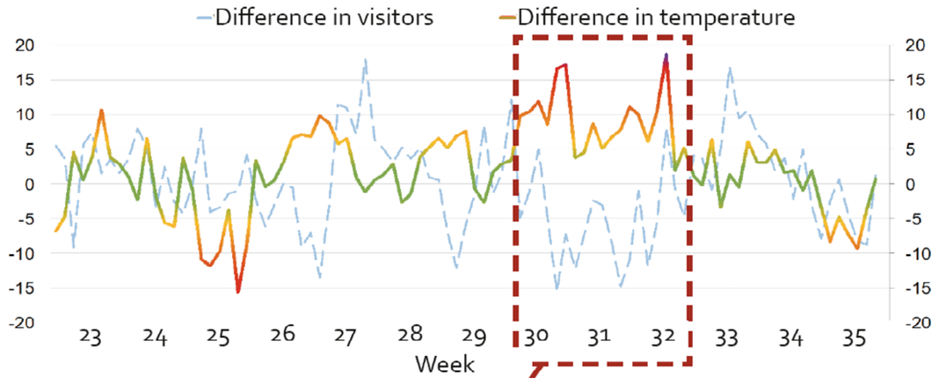


Figure 11: *AUAS research study on daily visitors to Breda city centre related to maximum air temperature in 2018. The average visitor numbers were 10% lower in July 2018 than in July 2017, when air temperatures were 5°C higher.*

Impact of heat on the local economy

The effect of rising temperature on economic growth is substantial. Extreme heat harms the productivity of workers due to biophysical and cognitive constraints (see for example the systematic review and meta-analysis of Flouris et al., 2018). Heatwaves in 2003, 2010, 2015, and 2018 damaged the European economy between 0.3-0.5 % of the European gross domestic product (GDP) and by 2060 the impact may increase by a factor of almost five compared to 1981-2010 (García-León et al., 2021).

This is absent from the climate change adaptation agenda but hot days can also have a direct effect on the local economy of cities (see fig.9). The influence of sunshine and hot temperature can negatively affect retail sales in hot months as people are less willing to go shopping with clothing and footwear sales particularly sensitive to extreme conditions (Agnew and Palutikof, 1999). The fruit and vegetable sales are less sensitive and may increase during hot periods (see fig.12 and ibid.).

Visitor numbers in main shopping streets have been found to decrease during heat waves see Figure 10 (Evers et al., 2020). There is a strong relationship between city centre visitor numbers and maximum temperature; we observed 10% fewer visitors in the centre of Breda during extreme hot weather conditions see Figure 11. Parsons (2001) confirmed the potential loss of 10% on a holiday Friday, and up to 26% compared to a normal Sunday. When the temperature increases, the traffic decreases.

In the research carried out for the Cool Towns project relative humidity and sunshine hours had no significant effect on the decision to go shopping or not. This may be influenced by the spatial configuration of the areas studied. These were frequently located in city centres where open space is scarce and designed for solely social traffic. The challenging thermal characteristics of these areas tend to increase thermal discomfort for visitors and influence their behaviour. The types of shops in daily use by many, such as grocery stores and important amenities such as pharmacies and schools are often located where the potentially vulnerable groups depending on them find them difficult to reach during hot days.

Figure 12: *Clothing and footwear sales are sensitive to hot weather, while fruit and vegetable sales may increase.*

"Of all transport modes, cycling appears to be the most sensitive to weather"
Böcker and Thorsson 2014

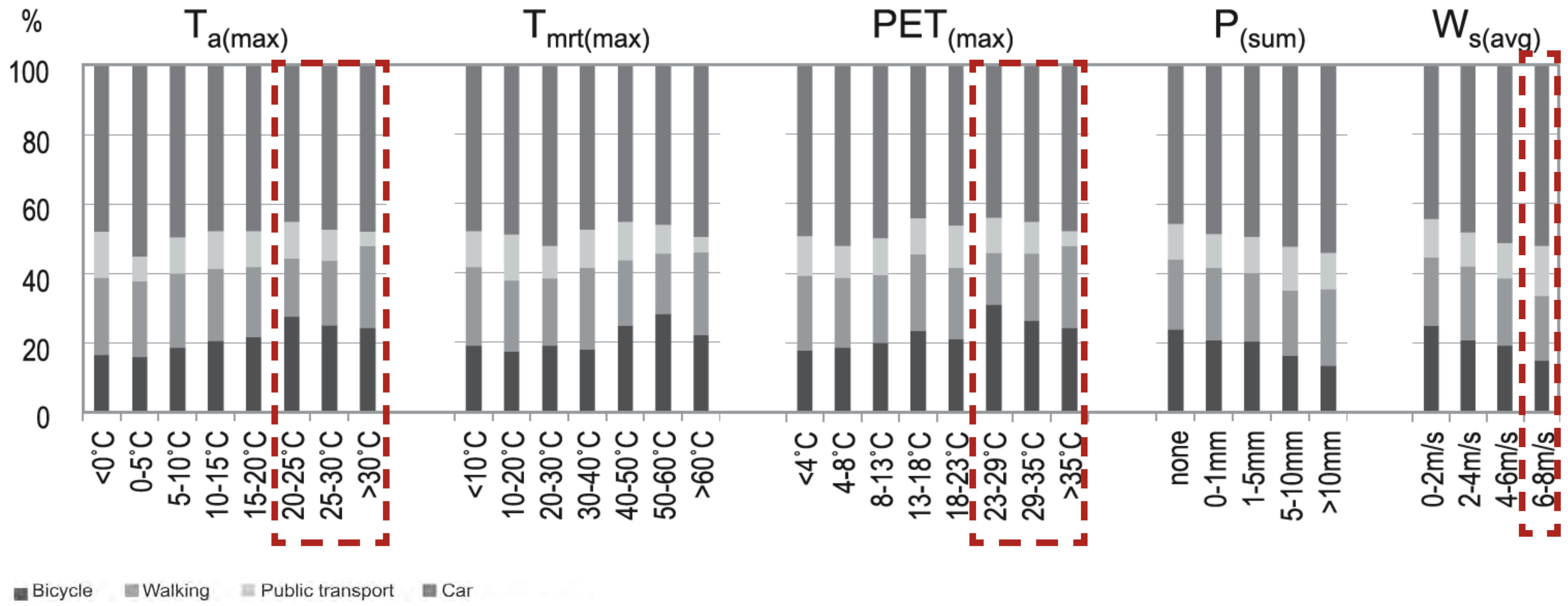


Figure 13: *Different components of weather effects Ta(max) = maximum daily air temperature; Tmrt(max) = maximum daily mean radiant temperature; PET(max) = maximum daily physiological equivalent temperature; Ws(avg) = daily average wind speed; P(sum) = daily precipitation summed (source: Böcker and Thorsson, 2014)*

Impact of heat on mobility

Strategies to reduce CO_2 emissions focus on the need for transition in modes of mobility with European municipalities having ambitions to develop bicycle and pedestrian-friendly cities, often without factoring in thermal comfort. A large body of literature shows that cycling and walking are sensitive to changes in weather (see Pazdan, 2020 for a review of 33 papers). The optimum temperature for cycling differs between regions. In Portland air temperature of above 24°C (Ahmed et al., 2012), 28°C in Montreal (Miranda-Moreno & Nosal, 2011), and 32.2°C in Boulder, Colorado (Lewin, 2011) all discouraged this activity.

A study conducted in the Netherlands shows that highest frequency and duration of cycle rides occur on days with maximum air temperature around 24°C and maximum PET around 31°C (Böcker & Thorsson, 2014). On windy days people's cycle trips are shorter but this appears to have little effect on pedestrians. Interestingly, for walking inclination seemed to decline between 20-25°C maximum air temperature and 23-29°C maximum PET (see fig.13 and ibid.). Thus, where cycling peaks, a dip in car use, and to a lesser extent walking, can be observed, but public transport is not affected. The graph also shows that under extremely hot daytime conditions, above 30°C air and 35°C PET temperature, people prefer to go walking instead of using public transport or cycling.

Changes in spatial settings and PET values among different types of open space and between neighbourhoods were not investigated in these studies but these may affect the decision making; urban morphology is important with higher housing density, more bus stops, and shorter distance from home to the train station all found to be positively related to cycling duration in the Netherlands (Gao et al., 2018). It could be that the home situation (e.g. thermal comfort indoors) purpose (e.g. shopping), PET value at destination (e.g. city centre), and financial affordability (e.g. walking or public transport) could all influence results.

There is some evidence that lower socio-economic and ethnic minority groups are likely to live in warmer neighbourhoods and have fewer social and material resources to cope with extreme heat (Harlan et al., 2006). These groups often live in homes constructed from low-cost materials with poor thermal properties and their mobility is often limited. Cyclists and walkers (commuting and recreational) and people experiencing socio-economic challenges can be considered as important heat vulnerable groups.

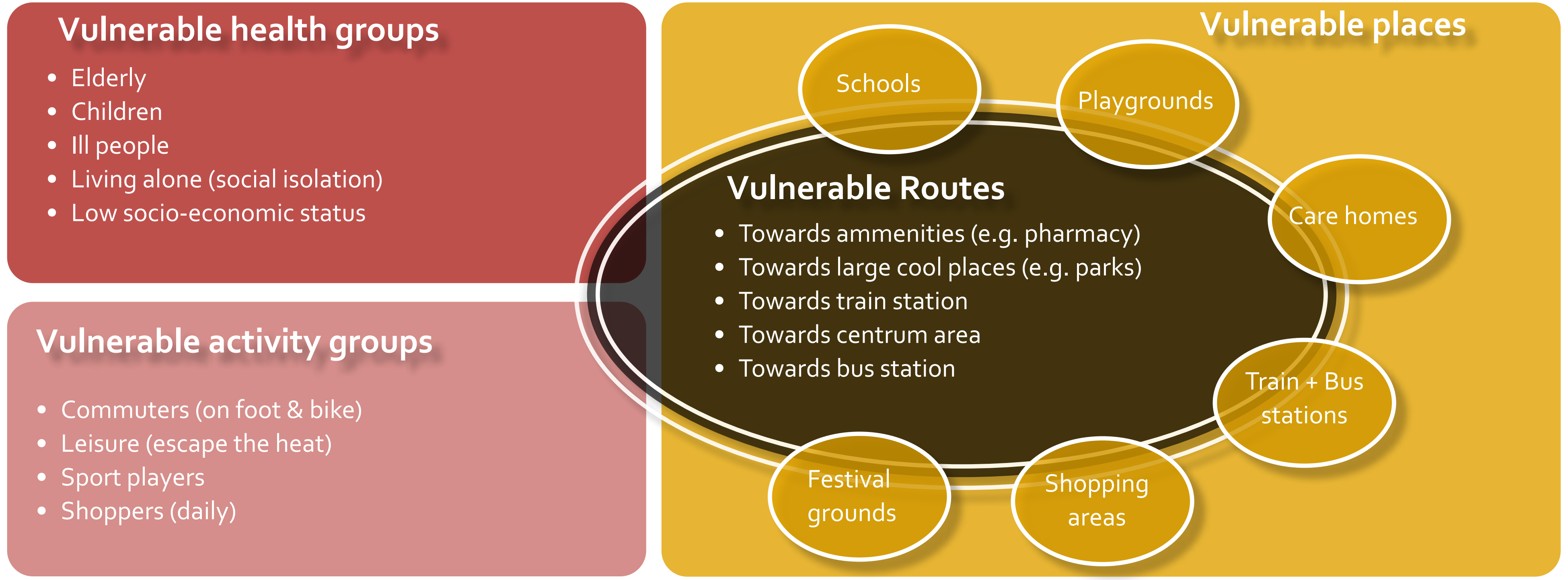


Figure 14: *Heat effects on the liveability of cities are not limited to the well-known vulnerable groups, such as children and elderly, but also important activities citizens conduct, the places with vital amenities and functions they use and the thermal comfort of pedestrian and cycle routes to and from these places.*

Vulnerable groups, places & routes

In the previous paragraphs, the most important heat vulnerable groups were discussed. In summary there are traditionally vulnerable groups with potentially severe health consequences and these overlap with those who undertake an activity that makes them sensitive to warm weather (see fig. 14). The key-question at European level is how accessible are vital amenities for these groups during warm days. Children still have to go to school in the summertime and spend time outdoors playing for their development, so how is heat distributed and what are the thermal dynamics of playgrounds? What are the heat conditions at mobility hubs and shopping areas? Is it still inviting to go to work by public transport and to do routine shopping during warmer periods? Is it possible for those experiencing poor health and older people to go to health care centres and pharmacies when it is hot?

Not only the location itself but, as has been made clear, the thermal comfort of the cycle and walking routes to these places influences their accessibility and this needs to be assessed. The proximity and availability of cool areas, particularly for those in socio-economically challenged neighbourhoods, where these spaces are relied on to keep cool should be assessed.

In this publication, we investigate the liveability of European urban areas during warmer periods of the year and aim to answer the questions posed above. We look at local functional networks, how cool spaces are distributed, and how heat can influence accessibility.

Figure 15: *Upper image of children who are vulnerable to heat cooling off in the water at Brusselplein in Utrecht. Image above people cycling in a park. This (social) activity is sensitive to hot weather conditions.*

2. Methodology

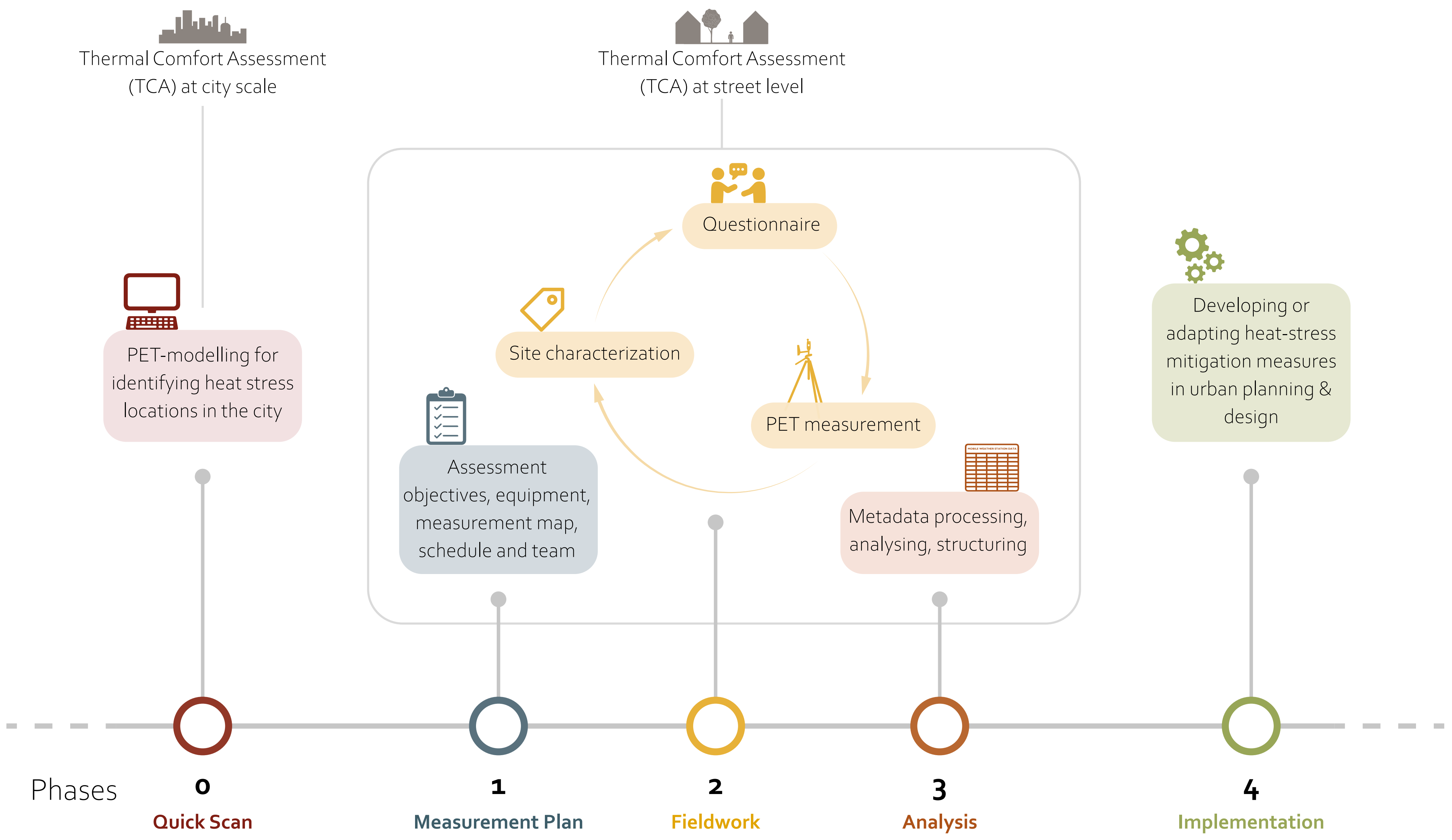


Figure 16: *Schematic representation of the steps required to conduct a full Thermal Comfort Assessment (TCA) at city and street-level (source: Spanjar et al., 2020).*

2.1 Full thermal comfort assessment

A Thermal Comfort Assessment (TCA) is a tool that helps to identify potential heat risk at regional, city and local scale. Previously this assessment was based on generating maps derived from thermal comfort modelling, integrating meteorological and spatial geographical data. This approach, however, often lacks sensitivity to local conditions, functions, and dynamics (Koopmans et al., 2020) important for assessing the thermal comfort experienced by humans, and the effectiveness of heat-stress interventions. Therefore, the Cool Towns TCA approach (see fig.16) consists of a more comprehensive analysis including both city scale TCA (PET-modelling) and a street-level TCA with PET measurements evaluating the thermal comfort at a site. On both scales the TCA is completed by using triangulated techniques to fully integrate the social dimension.

City-scale TCA

The TCA at city scale comprises a PET model based on that developed by the Dutch National Institute of Public Health and Environment (RIVM, 2020; Koopmans et al., 2019) and trained by the human energy balance model (Matzarakis et al., 2010). The PET four meteorological variables (air temperature, radiation, humidity level, wind speed) are weighted for a 'typical' man, 35 years old, 1.75 m high, weighing 75 kg with a fixed clothing factor, and walking at a speed of 4 km/hour. The model combines information on meteorological data and geographical characteristics (e.g., land use & urban geometry) in order to compute the spatial distribution of PET for all urban areas assessed. This ensures the production of high-resolution output maps to serve the following objectives:

1. Forming a baseline for the municipality to identify the distribution of heat-stress vulnerable and thermally comfortable locations in their territory.
2. Providing a tool that enables authorities to identify locations which could benefit from effective interventions.
3. Enabling advanced heat stress vulnerability maps to be produced so priority can be given to places which are particularly sensitive in terms of public function, user groups or socio-economical settings.

Street-level TCA

The TCA at street-level aims to analyse the potential heat stress that has been detected by the PET-model for further investigation into thermal characteristics and user experiences. It can also be used to evaluate how existing structures, or recently developed interventions, mitigate heat-stress. Hence, the TCA at street-level consists of three objectives and steps:

1. Site characterisation to describe the spatial context in which measurements were taken and the thermal (dis)comfort of users. The site characterisation identifies the urban geometry and existing green-blue infrastructure present at the study site. Infrared cameras are used to determine thermal conductivity of building materials, enabling comparison between impervious surfaces and vegetation to be measured and visualised.
2. Questionnaires reveal how users of the site experience the temperature. These different aspects combined enable the

effectiveness of heat-stress intervention to be evaluated and provide information on how thermal comfort can be optimised.

3. PET measurements with small mobile weather stations placed so as to measure the effect of an intervention (the point of interest) in relationship to a reference point in full sun. In other words, to determine the thermal comfort of someone close to the intervention compared to that of someone in full sun, without the influence of the intervention. These measurements provide important input for validation, by comparing actual PET measurements with those modelled for the location.

4. The street-level TCA can be enhanced by taking structured observations on the site to find out how heat stress and cooling structures affects user choices and how these influence their behaviour and perception.

2.2 Modelling urban heat

Thermal climate indices

In recent investigating the thermal comfort of places has resulted in the formulation of many indices (Nouri & Matzarakis, 2019). The three most commonly used are Physiological Equivalent Temperature (PET), Predicted Mean Vote (PMV) and Universal Thermal Climate Index (UTCI); all are suitable for both cold and hot environments (Potchter et al., 2018). They share characteristics but since 2012 it is PET that has become the "dominant index" in use (ibid.). PET combines air temperature and humidity, with non-temperature variables, such as solar radiation, wind speed, and thermo-physiological factors (e.g. clothing and body core temperature). It is therefore the best method to describe how people experience thermal comfort at 1.1. m height, referring to the relationship between meteorological conditions and the heat exchange between the human body and the environment, known as the human energy balance (Höppe, 1984; 1999).

PET has the advantage over, for example, PMV which is also based on the human energy balance, as it is expressed in degrees Celsius (°C). For policymakers and urban planners, unfamiliar with more complex human-biometeorological units, it is easier to interpret the output data. Other thermal climate indices have disadvantages compared to PET, for example the Wet Bulb Globe Temperature (WBGT) is based on single parameters (air temperature, solar radiation, humidity, and wind speed) and does not include the human energy balance. Similarly, the Universal Thermal Climate Index (UTCI) does not consider the effect of clothing (Elnabawi & Hamza, 2020) but can be adjusted based on specific local conditions where PET uses standard clothing.

The further reason for using PET for this study rather than any other is that it is the national standard for three of the partner countries: the Netherlands, England and France. Fortunately, several comparison studies have shown a strong correlation between PET and UTCI (Zare et al., 2018; Matzarakis et al., 2014).

Heat stress-test

The heat maps generated show the PET distribution in each Cool Towns partner city. Each is based on a combination of hourly meteorological and spatial data to compute morphological indicators for heat stress. The maps therefore estimate hourly influence of (extreme) weather conditions such as solar radiation levels on the urban geometry (i.e. trees, buildings, and waterbodies) and of green and hard surfaces. They include the effect of shadows cast by objects and spatial air temperature differences. Only days with a clear sky are considered to prevent clouds disrupting the average radiation intensity for the hour required.

This means that at city level the maps identify public spaces that are exposed to heat stress and at what time of the day this is experienced, showing the PET-value and heat distribution dynamics within particular places in each Cool Towns partners' urban area. The model output particularly shows the effect of shade cast by trees and buildings, with a smaller effect for locations with green surfaces without shadow. At neighbourhood-level building density determines the cooling effect caused by wind, with higher density reducing this resulting in a higher PET. All together these maps provide a clear 'stress-test' for a typical hot day, particularly during lunch time and rush hour when the outdoor built environment is used intensively and in different ways They may help to quickly identify locations that need intervention as well as the existing locations with good cooling capacity people can benefit from.

Input data sets

Both spatial- and meteorological data were used (see fig.17). Meteorological data was calculated for two predefined scenarios: 'lunchtime' and 'rush hour' with each dataset including the following parameters: wind direction (°), wind speed (m/s), air temperature (°C), global irradiation (W/m2), and relative humidity (%). For calibration purposes the Urban Heat Island Effect (UHI), which is based on land use data combined with hourly data from a weather station close to the designated urban area but in the countryside outside, was calculated.

The Normalised Difference Vegetation Index (NDVI), to determine the density of greenery, was generated from land use data combined with colour-infrared orthophotos. This, viewed with a Digital Terrain Model (DTM) or Digital Surface Model (DSM), gives comprehensive insight into the relative proportion of trees, buildings, and water surfaces on the study site. Building and tree height, needed to calculate the effect of shade on the wind and the effect of obstacles, was estimated by converting this from the surface elevation data. The Sky View Factor (SVF) generated gives insight into the ratio of building height and street width where the proportion of sky hemisphere is visible from the ground, not obstructed by buildings or trees. The processed and calculated data generated a PET map with an one-metre spatial resolution.

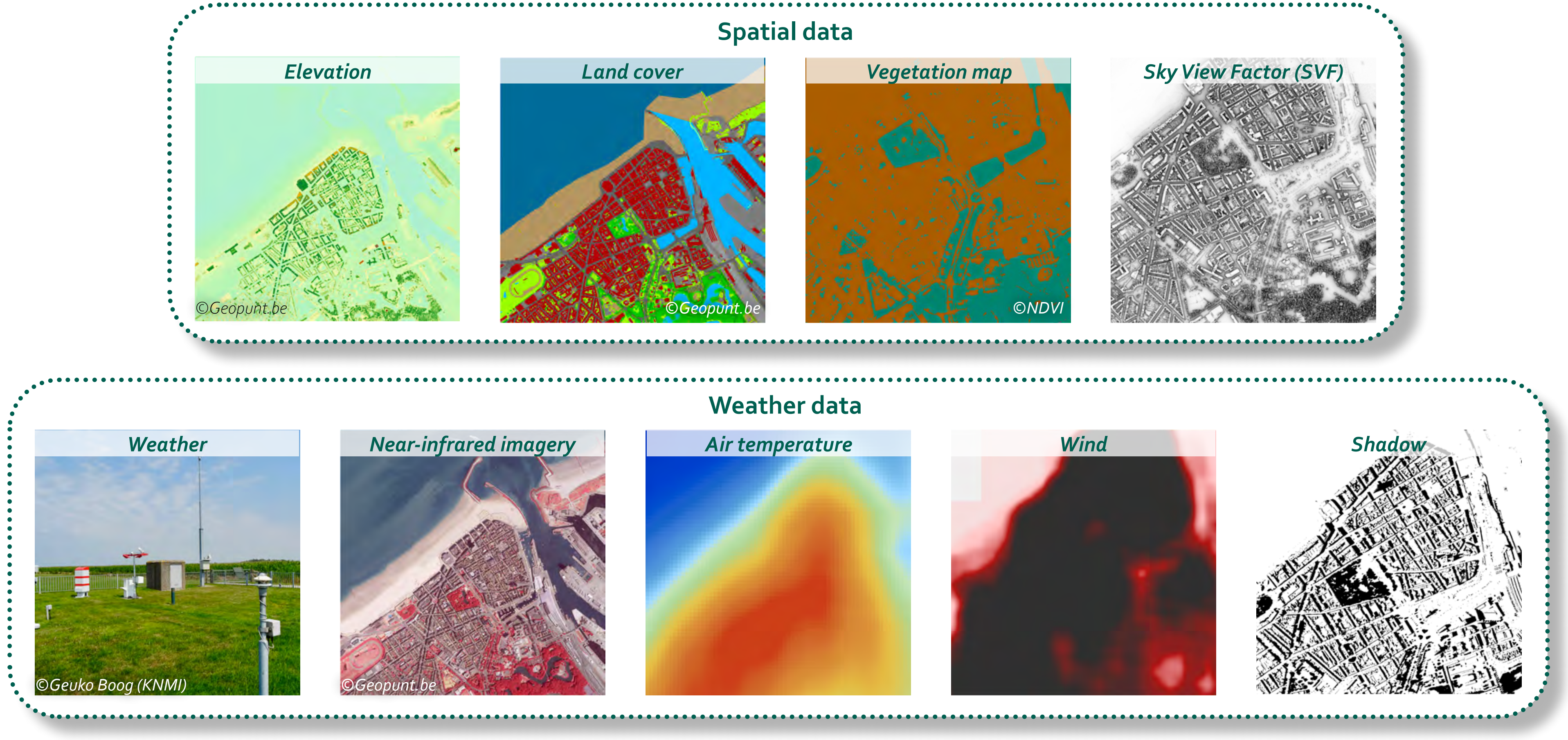


Figure 17: *To model the Lunchtime and Rush Hour Scenario's a combination of spatial and meteorological data sets were used.*

Developing a standardised Thermal Comfort Assessment (TCA) for mapping heat vulnerabilities in different European countries has been challenging because of different data infrastructure, availability, format type, and accessibility between different countries. In England for example, there appears to be an inherent fragmentation in public data supply. This limits the potential for using geospatial data to formulate effective climate change adaptation strategies. Each data supplier has its own methods for providing access to the data, which results in a range of formats, under licensing terms (Geospatial Commission, 2022). When asking for example, an English data supplier for clarification as to whether the data could be converted and then published online, the request was rejected despite the offer of payment under their standard licence. This was resolved by purchasing several orthophotos for the English partner cities from different sources and merging these to provide a single orthophoto (see fig.18).

Due to the spatial dependence of microclimate computations (e.g. wind behaviour), an input data extent of a 1.1 km buffer around each Cool Towns partner study site was required. In France, the geo-location of trees in the designated urban areas was not available. This was resolved by creating a manual inventory of all trees and this was then digitised by the local partners. Thus, datasets were sometimes transformed, merged, or even generated specifically for this project.

Figure 18: *The area with a black line represents Margate City limit; the red line the extent of spatial input data; the blue line the extent of spatial output data (PET). The area within the green line, a total of 3323 ha, marks the extent of spatial output data, excluding sea cover. The small dot-patterned area shows the area for which elevation data had to be purchased from a different supplier.*

Thermal City Life scenarios

Heat maps are frequently developed for policymakers and decision makers giving an average PET value for a large area based on a single historic hot day. This highlights urban open spaces, such as large squares with a high height/width ratio, as severe heat spots and disregards the cooling capacity of places during specific times of day. There are not many users who spend the entire day in one outdoor location. To capture the full heat dynamics of urban areas reflecting the rhythm of cities, hourly data is more appropriate.

The urban areas within the Cool Towns 2 Seas region experience a strong variability in the influence of the coastal microclimate. When local weather station data are used as the meteorological input this poses challenges when comparing model outputs. To counteract this, two contrasting heat-stress scenarios were developed, representing specific meteorological conditions affecting all the urban study sites in the four Cool Towns partner countries. In other words, the two Thermal City Life scenarios reflect the common 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 make it also easier to 'read' the heat maps.

The two TCL- scenarios are based on a period of persistent heat: three consecutive days with an average day temperature of > 20 oC (Huizinga & Kolen 2019). For corresponding meteorological input that matches this condition, thirty-year datasets from four KNMI meteorological stations in the Netherlands (Vlissingen, Westdorpe, Wilheminadorp, and Gilze-Rijen) were analysed.

The PET-maps display a specific time frame on the second day with different thermal conditions and regarding specific social activities that often occur in Northwestern Europe. The two scenarios and derived PET-maps together, delivers deep insight into the thermal comfort of outdoor spaces during hot periods and can be perceived as a heat stress test for urban areas. The following two important periods for the social use of the city during this time were identified by the Cool Towns partners for scenario analysis (see fig.19 for the parameters' values):

'Lunchtime' scenario, see fig.20: this refers to the time of the day when children play outside (e.g. school playgrounds), people go outside for a lunch break, or are generally active in the public space, for example, shopping in city centres. It represents the time when the sun is highest and radiation greatest (12:00 UTC). There is relatively low wind speed and at an air temperature of 28 °C; people are still cycling (see section 1.4). Output generally results in lower than 29 °C PET in the shade, with a thermal perception of 'warm', ideal for cycling (duration 31°C and frequency 33°C), and PET values of 42-44 °C in the sun, which is thermally perceived as very hot (for grades see Matzarakis et al., 1999).

'Rush hour' scenario, see fig.21: this refers to the time of the day when people leave work and travel home, and when children play outside after school. The urban context plays even a more important role in this scenario than in the lunch-break scenario, as heat stress is built up by infrared radiation emitted by buildings and hard surfaces during the afternoon (15 UTC). There is a higher air temperature of 33 °C, slightly more wind from the east, and less solar radiation. The model output resulted in PET values lower than 35°C in the shade (thermally perceived as hot), and PET values of 39-47 °C in the sun (thermally perceived as very hot with risk of extreme heat stress exposure (for grades see Matzarakis et al., 1999). In

these extremely hot conditions people prefer walking rather than cycling and shopping is limited to necessities (see section 1.4). People are also more likely to spend time in large parks and water bodies both within and outside the city in search of heat relief.

Scenario	Hour	Air temperature	Wind direction	Wind strength	Solar radiation	Humidity
Lunchtime	12:00 UTC (14 CEST)	28	0 ° (almost no wind)	1.0 m/s	750 W/m2	49 %
Evening rush hour	15:00 UTC (17 CEST)	33	90 ° (east wind)	4.0 m/s	600 W/m2	29 %

Figure 19: *The two contrasting Thermal City Life scenarios: lunchtime and rush hour each with their specific meteorological conditions reflecting those commonly observed in Northwestern Europe. They cover the differences in outdoor public space use depending on time of the day.*

Figure 20: *Breda demonstrating the lunchtime scenario, Time: 12:00 UTC (14 CEST), Tair: 28 °C.*

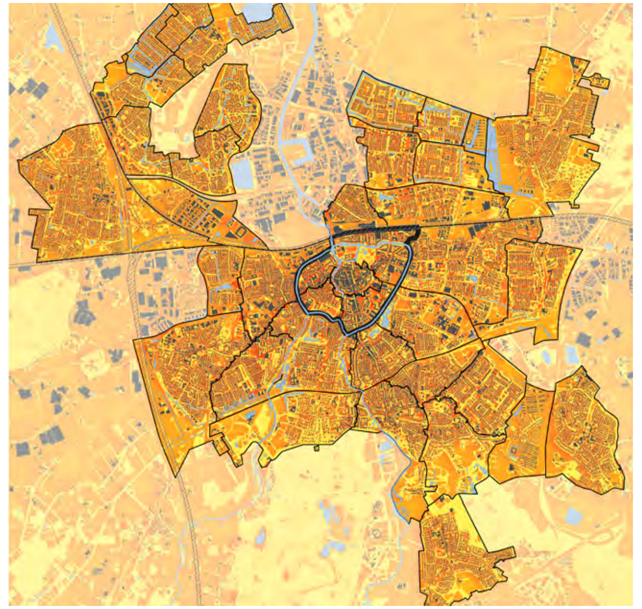


Figure 21: *Breda demonstrating the rush hour scenario, Time: 15:00 UTC (17 CEST), Tair: 33 °C.*

PET-Model validation

The validation carried out aimed to examine the accuracy of the model by comparing the modelled PET-value with actual PET measurements, taken on the ground using mobile weather stations. In the comparative analysis, the difference between PET values were analysed using the measurements collected in four different partner municipalities. Models ran on the same date and at the same time as the on the grounds measurements were performed; these do not use any scenario- based meteorological data, but use data from the nearest automatic weather station such as the ones held by the Royal Netherlands Meteorological Institute (KNMI) for the Dutch cities to ensure that it corresponds to meteorological conditions at the time the street-level TCA was conducted.

The comparative analysis between modelled and measured PET values shows that, on average, modelled PET values are 4 °C degrees lower than the measurements undertaken by partners, implying that the model gives a generally good, but slightly lower PET than measured values. Areas that provide shade (e.g. trees) generally show the most accurate results, whereas baseline measurements (exposed to full sun) show the least correlation. For instance, at the 'Zusterplein' in Middelburg, where only baseline measurements were conducted, the highest PET difference was found. Similarly, the baseline measurements at 'Zelzate' showed a relatively large PET difference, (see Figure 22, the two most northern measurement locations).

The PET differences at the 'Zusterplein' and 'Zelzate' could be explained by the stony surfaces which cause relatively high emission of longwave radiation (infrared). The 'Zusterplein' is a square enclosed by buildings and has no vegetation, and the two measurements at 'Zelzate' were taken near a stone wall; it is also enclosed by buildings. Within the model solar radiation is only determined by two surface factors (vegetation or non-vegetation) which possibly lowers the actual radiative emissivity of certain surface types, thus reducing the PET. Also, the wind is not always accurately represented in the model and can be overestimated, reducing the PET. This is a particular issue in (partly) enclosed squares such as the 'Zusterplein' that may have higher modelled windspeed than when measured.

Hence, the validated maps provided in the Thermal Comfort Assessment (TCA) are a good indication of where, at a large scale, possible heat stress locations are and of the distribution of large cooling structures provided by existing green and blue infrastructure. On a fine grained scale the model is limited in taking up the local nuances regarding the thermal characteristics and use of spaces as described above.

Figure 22: The accuracy of the model has been tested by comparing the modelled (M) PET-value with the observed PET measurements (O) in Middelburg, Merelbeke and Zelzate, using mobile weather stations. The modelled PET values are based on meteorological data from the nearest automatic weather station for days PET measurements were conducted.

2.3 Modelling heat stress vulnerability

To identify vulnerable heat-stress locations suitable for intervention, thermal comfort models, similar to the Cool Towns heat stress model discussed above, are applied. These models are often used as stand alones disregarding vulnerabilities related to user intensity, and specific vulnerable user groups. In a co-creation process the Cool Towns partners identified and emphasised that taking such socio-environmental vulnerabilities into account is crucial for policy and decision-makers, to allocate funds and prioritise areas for climate adaptation.

The vulnerability maps visualise physical, socio-economic and demographic heat stress vulnerabilities by neighbourhood and are based on the literature review discussed in see chapter 1. They provide insight into the underlying causes of heat stress and the potential risk. Examples of the dominant physical characteristics are the high PET values, the vegetated land cover and the amount of available cool ground-level area per inhabitant. Potential heat stress risks for residents are explained by the socio-economic score (SES), population density and age distribution sections. These socio-economic and demographic characteristics are indicators that refer to the presence of certain vulnerable groups and functions in each neighbourhood. For instance, the percentage of children or elderly in a certain neighbourhood may indicate a higher number of elderly homes, schools, and childcare facilities, all groups particularly vulnerable to heat stress so needing heat stress mitigation.

The four vulnerability maps complement the Cool Towns PET maps in assisting decision-makers in identifying focus areas for heat resilient interventions in the city. The following sections explain in more detail how each map was created.

Vegetated land cover

The vegetated land cover is calculated from the Normalised Difference Vegetation Index (NDVI). Each pixel (i.e. square metre as seen from above) in a colour-infrared aerial photograph is assessed to be 'green' if it has a value above 0.16 and 'not green' if below that value (see fig.23). More 'green' pixels indicate a higher vegetated percentage.

The NDVI analysis was based on the colour-infrared orthophotos already provided for the spatial PET model input and means that grasslands, trees, shrubs, and other vegetation types are all taken into account and contribute to the vegetated percentage. While a higher vegetated percentage may mean more trees that can provide shade, it is important to remember that other vegetation types, that do not give shade, are also included.

Vegetation is important to combat the Urban Heat Island Effect (UHI). The vegetated percentage is an indication of transpiration, a cooling mechanism caused by plants which prevents the tendency for grey infrastructure to heat up. A large percentage vegetation cover in urban areas contributes to comfortable night temperatures. Night-time heat stress exacerbates the impact of daytime heat on the human body. The more transpiring vegetation the less a neighbourhood stores solar radiation that raises night-time temperatures. Hence, this is the simplest indicator for the mitigation capacity of night-time heat stress.

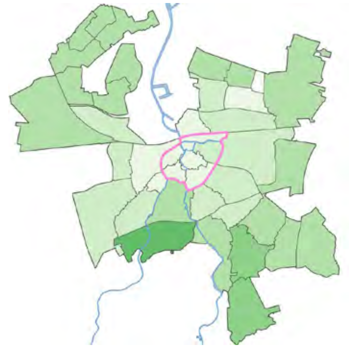


Figure 23: Example of a vegetated land cover map indicating heat stress vulnerability.

Population density & age distribution

The population density and age distribution map represents two demographic neighbourhood characteristics: population density (purple shades) and age distribution (pie charts) see Figure 24. Population density is visualised as the number of square metres per inhabitant per neighbourhood, with higher density indicating more residents could benefit from heat adaptive measures there. People living in dense urban environments often have smaller homes and limited private cool space. Higher population densities also mean more people sharing public parks and outdoor spaces where they can potentially escape the heat. A denser urban context also implies more anthropogenic heat from cars and air conditioning systems, further increasing heat stress.

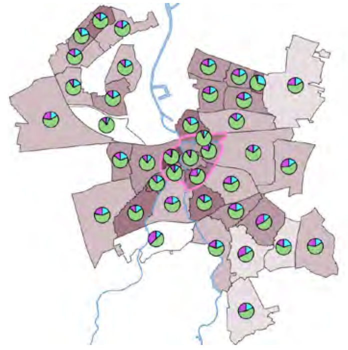


Figure 24: Example of a population density and age distribution map indicating heat stress vulnerability.

The age distribution is visualised per neighbourhood and is subdivided into three age groups: i) children (0 -17 years) who are often less aware of the risks of heat stress and whose centre of gravity is closer to the ground, exposing them to more reflected infrared radiation; ii) adults (18-64 years) who, if healthy, are physiologically the least vulnerable group but nevertheless can be strongly affected by heat stress, particularly in the choices they make regarding activity in outdoor spaces; and iii) the elderly (> 65 years) who suffer more from heat-stress due to generally poorer medical condition and a lower ability to sweat (see also section 1.4). Age distribution can also indicate the number of vulnerable functions in the area related to the elderly (e.g. elderly homes and pharmacies) or children (e.g. schools, childcare facilities, and playgrounds).

Population density and age distribution are assessed based on data from government funded organisations: Centraal Bureau voor de Statistiek (Breda, Middelburg); de provincie in cijfers – databank province (East-Flanders); Institute Nation de la Statistique (Saint-Omer) and the Office of National Statistics (Southend and Kent). Each dataset is converted to an average per neighbourhood.

Socio-economic score & PET

The socio-economic score (SES) map (see fig.25) shows in purple and orange shades per neighbourhood, and the percentage of PET class as pie charts based on the Physiological stress grade classes from Nouri et al., (2018).

SES scores are composed of three frequently used socio-economic indicators: i) low income; ii) low education and iii) unemployment. The different SES grades are derived from the city average scores which also indicate the ability of residents to cope with heat stress. Neighbourhoods with a low SES score seemed to be more vulnerable to heat-stress as, for example, residents may live in poorly insulated homes with limited budget available to cool their homes. They may spend extended periods indoors and have limited options to travel to city parks and nature reserves further away (see section 1.4 for further reference).

PET grades, presented in the pie-charts on the map, indicate the average heat stress by neighbourhood, based on the 'rush hour' scenario. Each part of the pie-chart displays a class of the Physiological stress grade index. This makes it easier to detect which neighbourhoods are more likely to suffer from heat-stress than others, and which of these experience the compounding effects of low SES scores and high heat stress levels.

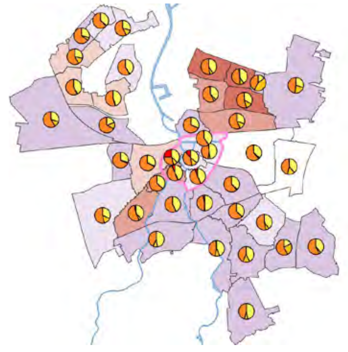


Figure 25: *Example of a socioeconomic status (SES) and heat stress levels (PET) map indicating heat stress vulnerability.*

Cool outdoor ground-level

The Cool Outdoor Ground-level map (see fig.26) shows the number of square metres (m2) per inhabitant that fall below the Physiological 'Strong Heat Stress' (< 35°C) grade, as defined by Nouri et al., (2018), based on the PET value in the 'Rush hour' (hot) scenario PET values. The map takes both public and private outdoor ground-level spaces into account; both public parks and private gardens can contribute to available cool space but areas located above ground level, such as balconies, roof gardens, or rooftops, are not included.

A high amount of cool ground-level outdoor space per inhabitant indicates that the PET values and/or the population density in the neighbourhood are low and so there is a high probability of cool spots being available locally that residents can rely on during periods of extreme heat. Conversely, a low cool area per inhabitant indicates a densely populated neighbourhood and/or PET values are high. These maps do not indicate either the quality or accessibility of these cool spots, their usability, or whether they contribute to cool routes through the neighbourhood. A low amount of cool outdoor space per inhabitant may indicate there is not enough to benefit everyone but could also indicate that opportunities are not evenly distributed. These insights can help decision-makers to prioritise neighbourhoods where the maximum number of people could benefit from heat adaptation measures.

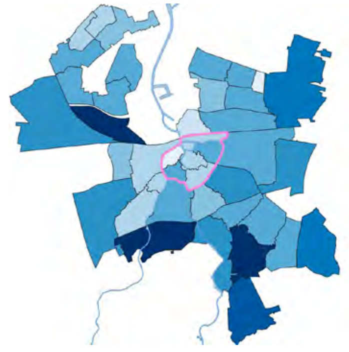


Figure 26: *Example of a cool outdoor ground level area per inhabitant map indicating heat stress vulnerability.*

2.4 Advancing heat vulnerability mapping

Heat stress models often lack integration with other measures of vulnerability such as community facilities, slow traffic routes, urban functions, or use by specific groups. Taking such wider socio-environmental aspects into account is crucial for policy and decision-makers to ensure appropriate allocation of funds for climate adaptation

The city-scale heat and vulnerability maps combined highlight where heat stress is found in the urban areas studied and where socio-environmental vulnerabilities might contribute to an increased risk of heat stress. Cool Towns partners have collaborated to produce these city-scale maps, together with local urban planning and climate adaptation agendas (see fig.27 on the next page), and these have provided the basis for prioritising neighbourhoods for the development of advanced heat vulnerability maps. Once a specific neighbourhood was selected in each partner city, a spatial user network analysis was carried out to reveal heat risk for a particular health group, activity and/or route(s). These maps relate (see fig.28) to Thermal City Life scenarios, with community amenities and slow traffic routes, assisting in identifying potential focus areas.

The maps highlight spatial typologies that fulfil vital urban functions in the city while also being potentially vulnerable to heat stress. Examples are historic city centres, with an abundance of cultural and shopping amenities, suburban shopping centres, mobility hubs, principal bicycle and pedestrian routes and school playgrounds. They also identify parks and recreational areas within the study area that are potential cool places. Whether or not it is actually sufficiently cool can be verified by conducting the Thermal

Figure 27: *Heat stress vulnerability work session with Breda, Middelburg, East Flanders, GGD Noord-Brabant (regional health service) and students.*

Comfort Assessment (TCA) at street-level and is further discussed in the Cool Towns Intervention Catalogue publication (Spanjar et al., 2022).

A combination of open-source, partner-provided data, and Cool Towns generated geospatial data was used although access to datasets varied widely between partner municipalities. An attempt was made to standardise the content and methodology to make interpretation easier and provide comparative results. The study areas varied in size, some were busy shopping streets, while others were entire neighbourhoods. They tended to be defined by political or natural boundaries, such as water bodies, while others included key vulnerable locations. The advanced heat vulnerability maps comprise a series of layers, overlayed on top of each other, to give an indication of possible locations for prioritisation. The descriptions and data sources of the layers are set out indicated below.

These advanced heat vulnerability maps do not only have a single purpose. They can contribute to city-scale heat stress and vulnerability maps to prioritise urban areas for immediate action and strategically integrate with municipal and regional climate adaptation agendas. The maps are currently already used by partner municipalities and a wide network of involved professionals.

In the next chapters, the Thermal City Life scenarios and heat vulnerability maps, generated as part of the standardised Thermal Comfort Assessment (TCA) at city and neighbourhood scale, are discussed by municipality in order to develop effective heat stress intervention(s) at street level (see fig.28).

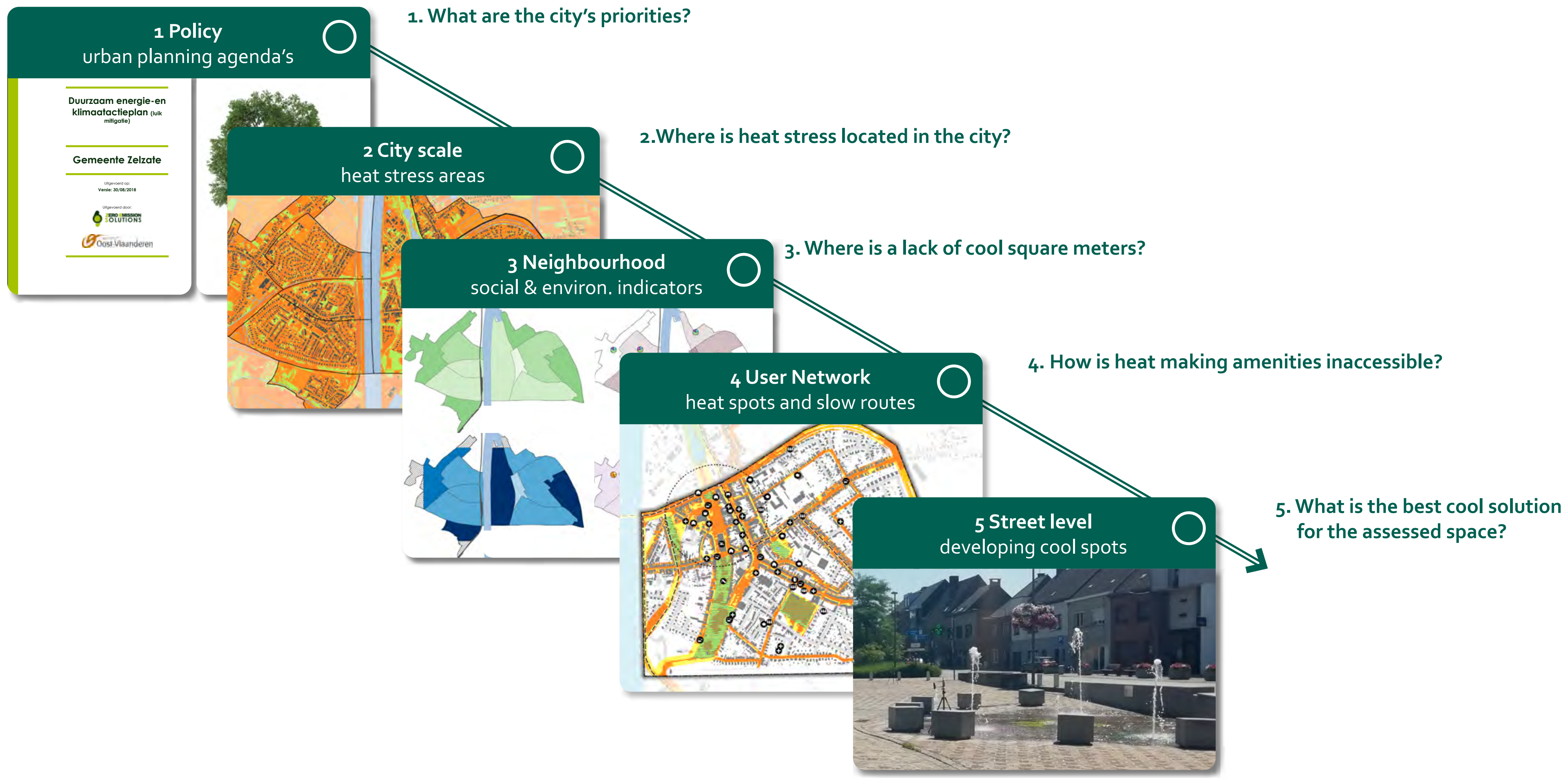
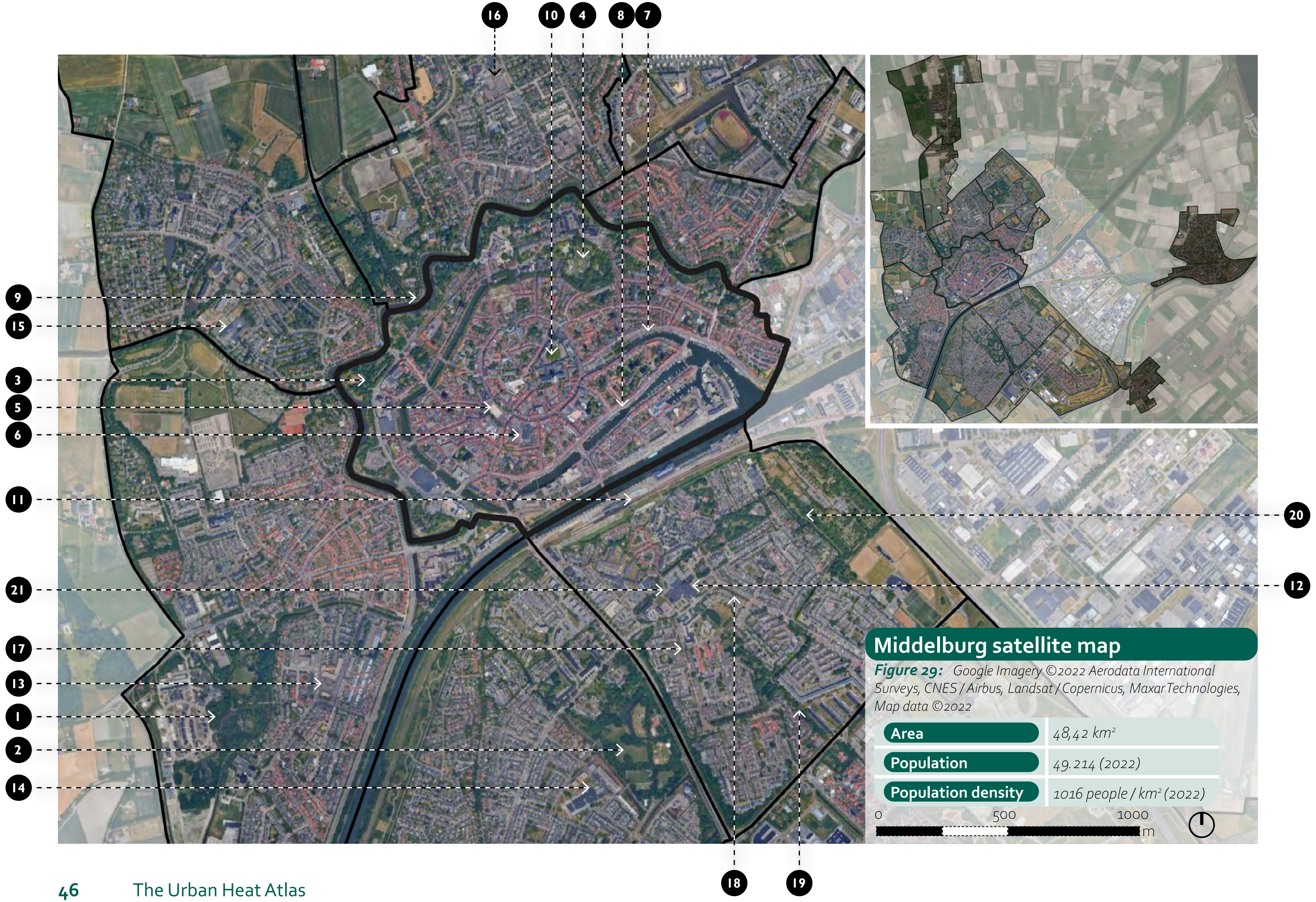


Figure 28: *Identifying and prioritising vital urban areas vulnerable to heat stress using a multi-level assessment to develop the most effective heat stress interventions at street-level.*

3. Middelburg, The Netherlands



Middelburg satellite map

Figure 29: *Google Imagery ©2022 Aerodata International Surveys, CNES / Airbus, Landsat / Copernicus, Maxar Technologies, Map data ©2022*

Area	*48,42 km²*
Population	*49.214 (2022)*
Population density	*1016 people / km² (2022)*

Middelburg

Middelburg is a city in the Netherlands, located in the province of Zeeland on the former island of Walcheren (see fig.29). Middelburg's climate adaptation agenda follows the provincial strategy of gradual adaptation instead of focusing on large-scale interventions. It envisages an integrated approach focused on the key themes of heat resilience, drought, and flood prevention coupled with the city wide objectives such as the Vision for a Climate-proof Middelburg 2018-2050 (Gemeente Midddelburg, 2019). The city recognises the need for mapping the effects of extreme heat as part of the spatial adaptation strategy and recognises the positive effect of breaking up hard surfaces by adding greenery (Zeeuwse overheden & Maatschappelijke organisaties, 2021).

3 De bolwerken, Middelburg

City — *Neighbourhood* — *User Network*

1 Toorenvliedt park, Middelburg

Middelburg lunchtime TCL scenario

The PET maps specifically developed for the municipality of Middelburg contribute the first steps towards heat adaptation by showing where extreme urban heat is found and how this changes during the day. In the lunchtime scenario, with an air temperature of 33°C, urban and peri-urban areas are under Strong or Level 1 Extreme Heat Stress (see fig. 30). Green fields around the city heat up almost as much as urban areas in the absence of trees whereas large city parks stand out as areas with only Slight Heat Stress, providing a refuge, but not all of these are equally effective. For example, the densely forested Toorenvliedt park (1) provides significant cooling capacity, while in Het Meiveld park (2) only the tree-lined paths provide cooling with the open areas exposed to extreme heat. In the historic town centre there is a four kilometre long star shaped park (De Bolwerken), along the former fortifications (3) which serves as

Lunchtime TCL scenario

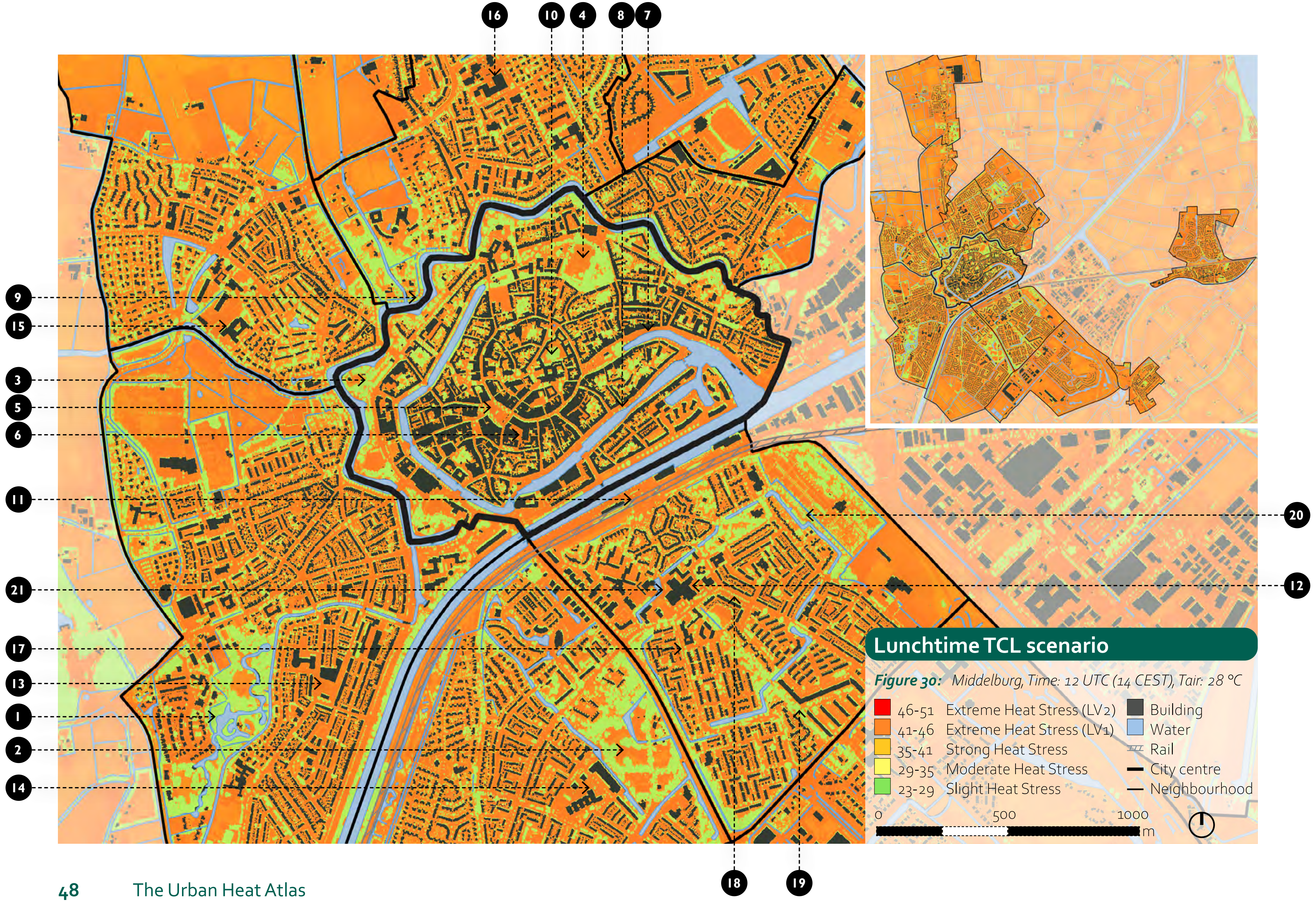
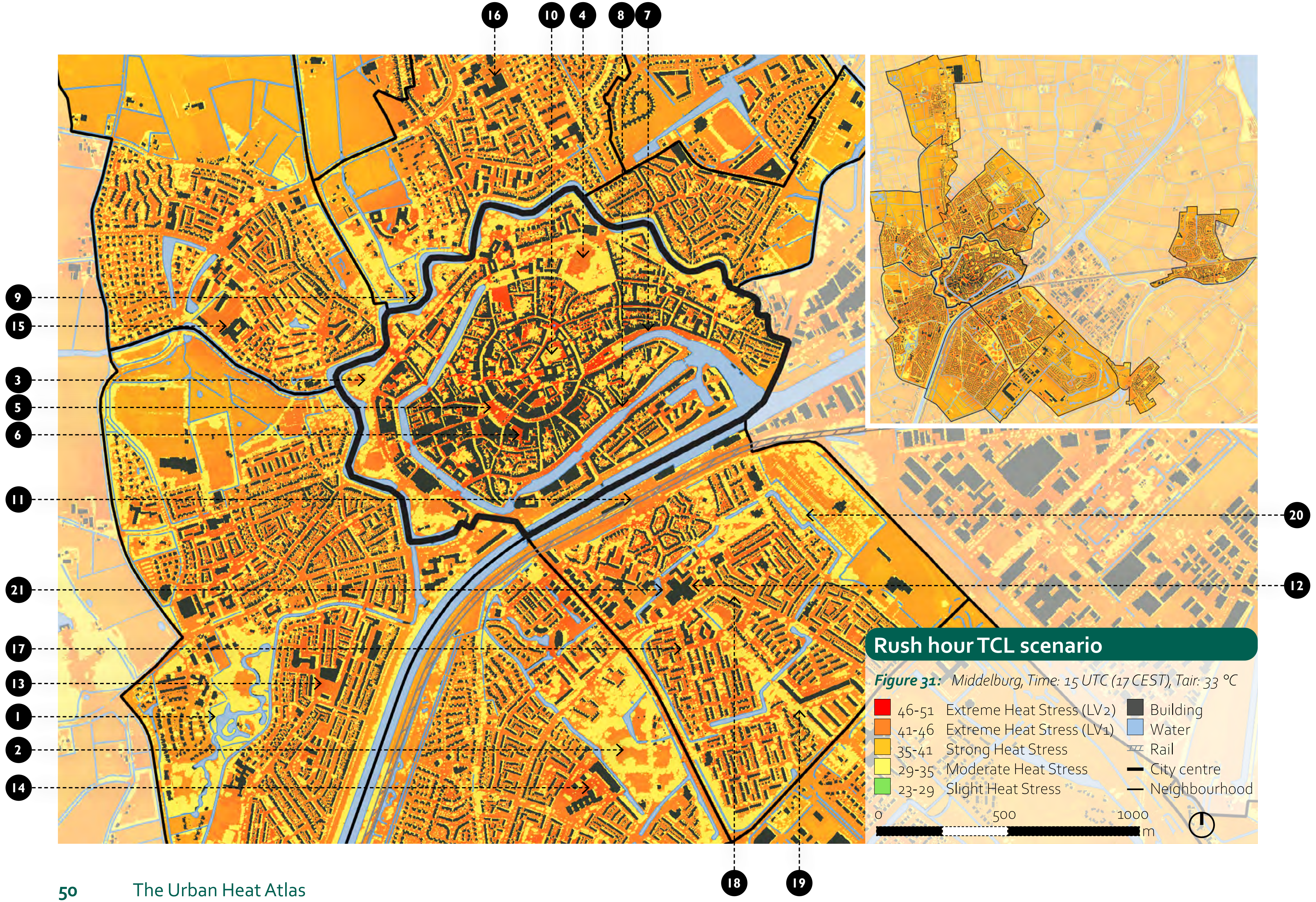


Figure 30: *Middelburg, Time: 12 UTC (14 CEST), Tair: 28 °C*

an important green oasis for escaping from the heat. This park is one of the longest in The Netherlands and was created in 1845 when, as in many other historical fortified cities, this defence was no longer needed. The park has large old trees including catalpas (Catalpa bignonioides) and turkey oaks (Quercus cerris) providing a pleasant, shaded, recreational route that can be used during extreme hot conditions by visitors to the city shopping centre and residents of the town to benefit both physical and mental health. Since creating the TCL scenario maps, Park Molenwater (4), the largest public park in the inner city, has been re-designed with a stormwater management system as part of the Water Resilient Cities Interreg project (Water Resilient Cities, 2020). The new design features a central clearing, with potentially High to Extreme Heat Stress Levels in the lunchtime scenario during hot weather conditions. At the same time, the historical double row of trees in the park still provide shaded routes and increasing water infiltration and retention in the soil means healthier and faster-growing vegetation potentially resulting in additional shading.

4 *Park Molenwater (above & below), Middelburg*

City ---- Neighbourhood ---- User Network



Rush hour TCL scenario

Figure 31: *Middelburg, Time: 15 UTC (17 CEST), Tair: 33 °C*

46-51 Extreme Heat Stress (LV2)	Building
41-46 Extreme Heat Stress (LV1)	Water
35-41 Strong Heat Stress	Rail
29-35 Moderate Heat Stress	City centre
23-29 Slight Heat Stress	Neighbourhood

Middelburg rush hour TCL scenario

In the rush hour scenario (see fig.31), heat in the dense urban areas is exacerbated by impervious surfaces due to heat absorption by infrared from the ground and solar radiation, with slow irradiation loss compared to the surrounding agricultural fields, which begin to cool off. Much of the public space in the mediaeval city centre experiences Level 2 Extreme Heat Stress. Historic squares and parking areas, such as the market square (5), stand out as hot areas. In the Zusterplein parking (6), a green parking area, with permeable paving, will be created in line with the climate adaptation ambition of removing hard surfaces. The rush hour scenario also shows, in agreement with PET measurements on the ground, that proximity to water alone, without sufficient wind to disperse water vapour, does not significantly reduce heat stress. Therefore the northern banks of the Prins Hendrikdok (7, dock) and the Binnenhaven (8, harbour) lack cooling capacity and can experience Level 1 to 2 Extreme Heat Stress. The municipality has intervened by planting trees along these routes, but these are still too small to provide sufficient cooling. In comparison, the mature trees along the outer edge of the historic moat, for example on Seissingel (9), create a continuous cool route, and the trees in the mediaeval monastery courtyard (10) provide a large cool enclosed space.

9 *Seissingel, Middelburg*

5 *Market square, Middelburg*

8 *Binnenhaven, Middelburg*

City *Neighbourhood* *User Network*

11 *Train and bus station (above & below), Middelburg*

Outside the inner city, Middelburg's train and bus station (11) is another location deserving special attention due to its essential function as the main mobility hub. It is one of the Cool Towns pilot sites where the municipality has reduced hard surfaces to provide better growing conditions for the existing London plane trees (Plantanus x hispanica); a species known for its high cooling capacity (see Spanjar et. al., 2022). The city will also plant more trees and install some green walls. In the next few years the Kanaalweg, the road between the station and the canal, may become a thermally comfortable cycle and pedestrian route.

Middelburg heat vulnerability maps

The heat vulnerability maps for Middelburg complement the TCL-scenarios with social, spatial and economic dimensions to highlight the neighbourhoods with thermally unpleasant conditions and/or with residents vulnerable to heat exposure. On the vegetated land cover map (see fig.32), the southern part of the historic centre stands out as having little greenery while most outer neighbourhoods have less than 40% of the surface vegetated. In these areas, residents might struggle with thermally uncomfortable conditions in daytime and relatively warm conditions at night caused by the Urban Heat Island effect. Removing hard surfaces and greening these neighbourhoods would contribute to Middelburg's climate adaptation agenda and promote resident wellbeing. Klarenbeek I, Dauwendaele I, and Damplein are the most densely inhabited areas of the city and in the latter, the high share of elderly residents contribute to increased neighbourhood vulnerability to heat. These three neighbourhoods also stand out on the cool outdoor ground level area per inhabitant map (see fig.35) and emphasise the correlation between population density and the availability of cool outdoor space (see fig.33) where residents feel refreshed. However, this map includes private gardens and estates, as well as publicly accessible areas, similarly to the Prooijenspark neighbourhood.

The map depicting socio-economic status (see fig.34) directs attention to Dauwendaele. The socio-economic score, significantly below city average, indicates that residents might struggle to adapt to times of extreme heat. These therefore have a high need for cool, cycle and pedestrian routes to reach essential facilities, for example, supermarkets, educational and health care facilities. Socio-economically disadvantaged neighbourhoods also require cool spots such as parks, playgrounds and sports fields to escape extreme heat without travelling far. The majority of homes here were built between 1950 to 1990, and are potentially under-insulated, posing severe health risks for residents in socio-economically challenging situations that need to cope with high outdoor and indoor temperatures (as discussed in section 1.4).

Middelburg advanced heat vulnerability map

The TCL-scenarios and heat vulnerability maps together show where, and for whom, heat stress is likely to pose most difficulties. A collaborative analysis with municipal experts enabled integration of the maps generated by the Cool Towns project with municipal ambitions and ongoing development plans to identify target neighbourhoods and investigate how residents could benefit from heat adaptive measures. The post-war Dauwendaele neighbourhood was selected for advanced heat vulnerability mapping as it has the city's lowest socio-economic status, a high population density, low amount of cool outdoor space and low vegetated land cover. Additionally, the municipality had existing redevelopment plans for the local shopping centre and to encourage healthier lifestyles by promoting outdoor activity for residents. The advanced heat vulnerability map (see fig.36) focuses on the visitor user group highlighting important places and routes leading to the shopping centre and other essential facilities residents may use during the rush hour.

The Dauwendaele shopping centre (12) is a cluster of important amenities, such as a pharmacy and a church. Trees shade cars in the nearby car parks but there is no cool route to protect visitors from direct sunlight. The paved surfaces intensify infrared radiation and contribute to the Level 1 Extreme Heat Stress. Reviewing the Thermal City Life (TCL) maps (see fig.30 and fig.31), Westerscheldeplein (13), the areas surrounding the Cypressenhof school (14), the CSW Van De Perre school (15), and the CSW Toorop school

City — *Neighbourhood* — *User Network*

Middelburg heat vulnerability maps

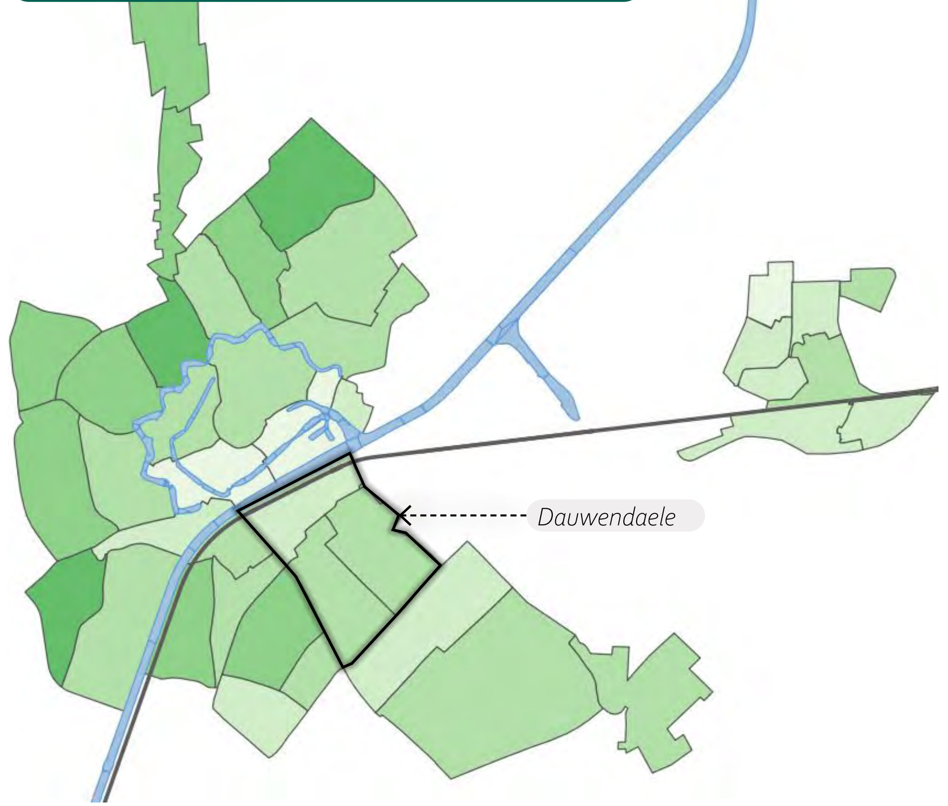


Figure 32: Vegetated land cover

- 0-10%
- 0-20%
- 20-30%
- 30-40%
- 40-50%

- 0-10%
- 0-20%
- 20-30%
- 30-40%
- 40-50%

- Train track

Figure 33: Population density and age distribution

Population density

- 0-50 m² per inhabitant
- 50-100 m² per inhabitant
- 100-150 m² per inhabitant
- 150-200 m² per inhabitant
- 200-350 m² per inhabitant
- 350-500 m² per inhabitant
- >500 m² per inhabitant

Age distribution

- > 65
- 18 - 64
- 0 - 17

- Water
- Train track

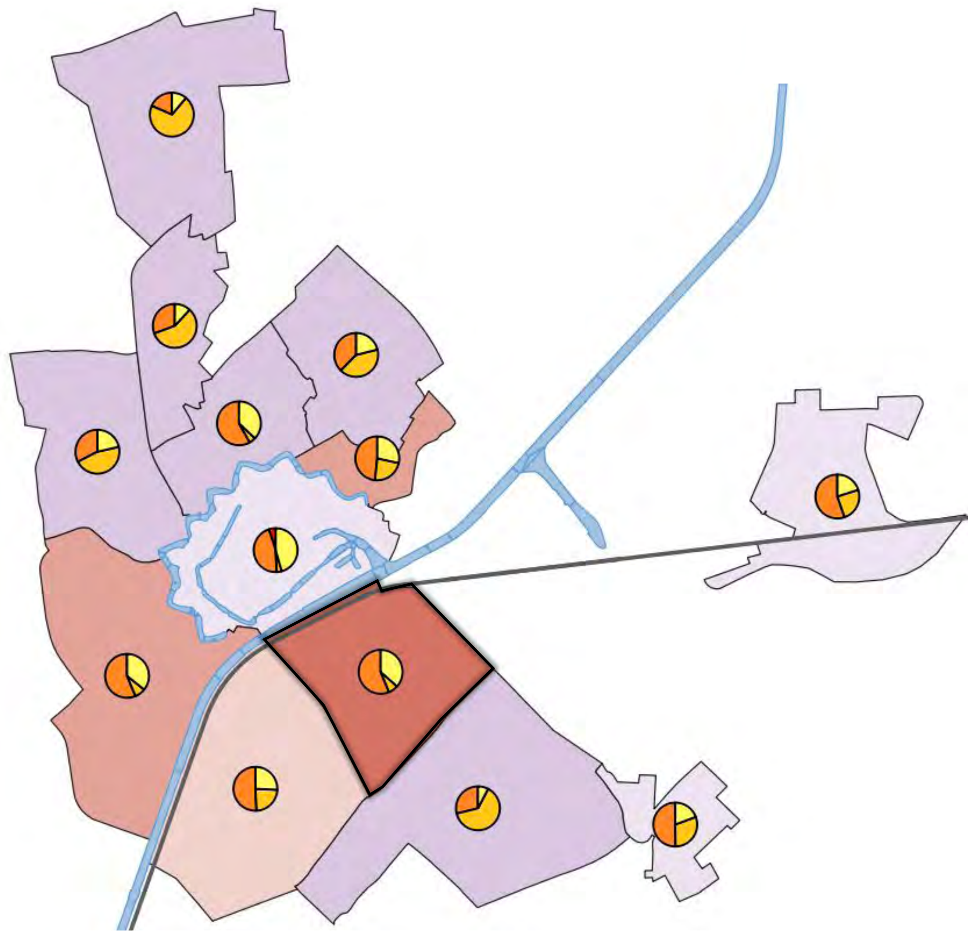


Figure 34: Socioeconomic status (SES) and heat stress levels (PET)

Socioeconomic status

- Extremely below city average
- Strongly below city average
- Moderately below city average
- Slightly below city average
- Slightly above city average
- Moderately above city average
- Strongly above city average

Heat stress levels

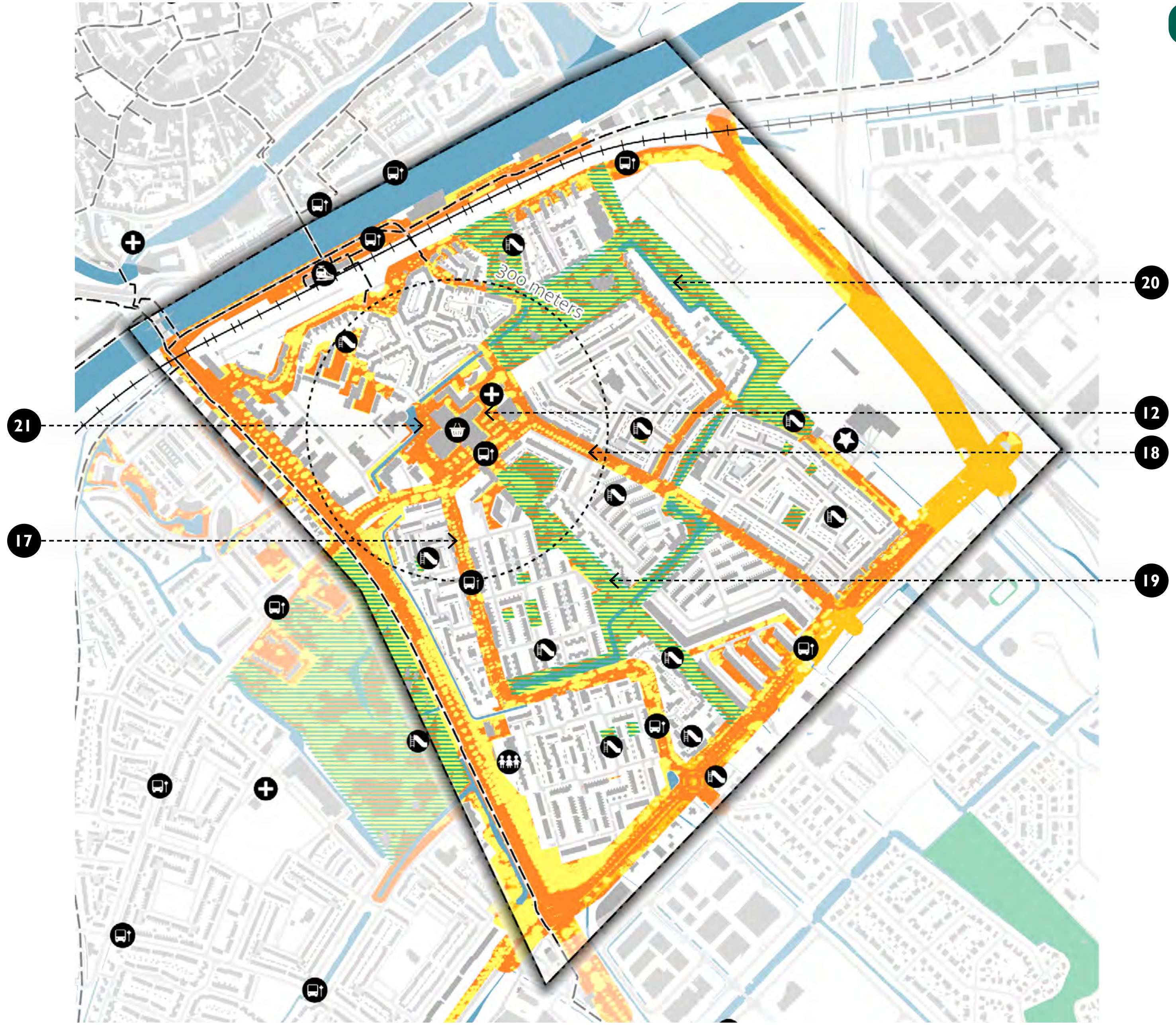
- 46-51 Extreme Heat Stress (LV2)
- 41-46 Extreme Heat Stress (LV1)
- 35-41 Strong Heat Stress
- 29-35 Moderate Heat Stress
- 23-29 Slight Heat Stress

- Water
- Train track

Figure 35: Cool outdoor ground level area per inhabitant

- 0-10 m² [PET < 35 °C] / inhabitant
- 10-20 m² [PET < 35 °C] / inhabitant
- 20-30 m² [PET < 35 °C] / inhabitant
- 30-40 m² [PET < 35 °C] / inhabitant
- 40-50 m² [PET < 35 °C] / inhabitant
- 50-75 m² [PET < 35 °C] / inhabitant
- 75-100 m² [PET < 35 °C] / inhabitant
- 100-125 m² [PET < 35 °C] / inhabitant
- 125-150 m² [PET < 35 °C] / inhabitant
- >500 m² [PET < 35 °C] / inhabitant

- Water
- Train track



Advanced heat vulnerability map

Figure 36: *The Dauwendaele neighbourhood in Middelburg analysed during the rush hourTCL scenario to identify locations vulnerable to heat for visitors.*

Research area: Middelburg - Dauwendaele
User group: visitors
Bus stop
Healthcare related facility
Community Center
Childcare
Train station
Playground
Supermarket
Rail
Regional cycling and walking routes
300 meter walking distance
Potential cool place
Park or recreation area
Water
Road
Building

PET values - Rush hour scenario
46 - 51 Extreme heat stress (LV2)
41 - 46 Extreme heat stress (LV1)
35 - 41 Strong heat stress
29 - 35 Moderate heat stress

0 250 500 m

12 *Dauwendaele shopping centre, Middelburg*

(16), all show similar spatial characteristics and heat dynamics to the Dauwendaele shopping centre. These clusters all have the potential to act as neighbourhood centres for the local community. A more pedestrian-friendly redevelopment would provide an opportunity to introduce heat stress mitigation interventions, such as shade sails, green walls or water features.

Revisiting the Dauwendaele, many primary pedestrian and cycling routes in the neighbourhood are accompanied by rows of trees. For example at the Dauwendaelselaan (17), the Roozenburglaan (18) and several routes towards the train station these trees provide shade. However, several street sections without trees are exposed to Level 1 Extreme Heat Stress and are opportunities for establishing cool corridors by planting trees. An exception is a linear park structure called 'De Overloper' (19) which cuts through the southern half of the neighbourhood, and provides thermal comfort for pedestrians and cyclists during extreme weather conditions. This narrow park has been recently improved with a Sustainable Urban Drainage system (SUDS) which stores excess rainwater allowing it to gradually infiltrate into the ground (Water Resilient Cities, 2020b). Better water supply and management may also contribute to improved cooling capacity through healthier trees and higher evaporative cooling. Other green zones running along the neighbourhood's ring canal may, in future, be developed into a circular park. Currently, some sections, for example by the side of the cemetery, create a green oasis (20), while other sections, such as the canal next to the shopping centre (21), remain as urban locations exposed to extreme heat.

19 *De Overloper, Middelburg*

4. Eeklo, Belgium

Eeklo satellite Mmap

Figure 37: Google, Imagery ©2022 Aerodata International Surveys, CNES / Airbus, Maxar Technologies, Map data ©2022

Area	30,45 km²
Population	21.775 (2022)
Population density	715 people / km² (2022)

0 500 1000 m

Eeklo

Eeklo is a town in Belgium, in the province of East-Flanders (see fig.37), with a local climate adaptation plan (Meert, et al., 2020) that follows a 5-step approach using Copenhagen (in Denmark) as an example. The first step maps the impact of climate change at the local level, and serves as a basis for formulating climate adaptation projects. In the subsequent steps the town aims to prioritise, implement, and monitor these projects. The climate adaptation plan recognises that more intense and frequent heat waves will cause greater thermal discomfort to people, plants and animals.

7 *Market square, Eeklo* ©Province of East Flanders

City Neighbourhood User Network

To address this the plan outlines measures for adapting to a hotter climate, such as greening dense urban areas, planting heat resistant species and introducing water features. The Cool Towns PET and the advanced heat vulnerability maps presented in this chapter contribute to the first two steps of Eeklo's climate adaptation plan highlighting where heat stress is likely to be experienced. This helps to identify the most vulnerable neighbourhoods and groups and to select the locations where heat stress interventions would provide greatest benefit.

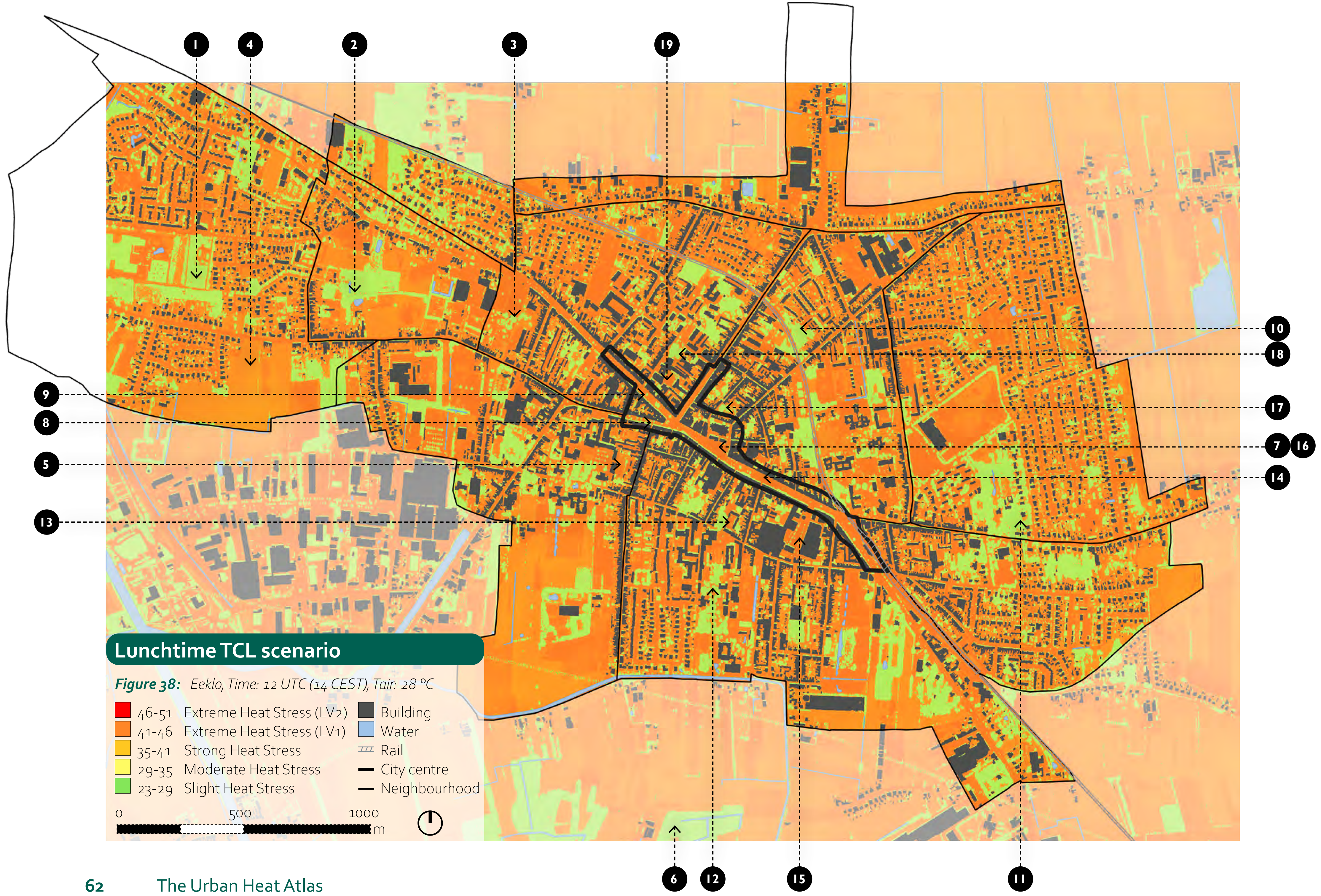


Figure 38: *Eeklo, Time: 12 UTC (14 CEST), Tair: 28 °C*

Eeklo lunchtime TCL scenario

In the Thermal City Life lunchtime scenario, almost the entire town suffers from Level 1 Extreme Heat Stress, including the surrounding agricultural fields (see fig.38) which, although vegetated, have no trees protecting them from direct solar radiation. The bright green areas, indicating Slight Heat Stress, stand out on the map. These are the places where trees and buildings provide shading on the ground. Eeklo aims to create three green axes connecting the surrounding landscape and forests to the city centre. The Raverschootbos forest (1), the Galgenhof urban forest (2) and Eeklo's cemetery (3) will form one axis beginning from the canal west of Eeklo (Evr-Architecten, 2015). The lunchtime scenario map shows that these two forests already function as cool green oases where residents can find relief. The green fields south of the Raverschootstraat and north of Eeklo's industrial zone (4), which currently lack shade, will form the core of the second western axis. The new Hartwijk development (5), on the site of the former hospital, will connect the fields to the centre through a linear city park (ibid.). The third green axis will link the large Het Leen forest (6) south of the town to the historic centre. These new blue and green connections operating at a large scale, present an opportunity to establish cool corridors across the town.

1 **Raverschootbos, Eeklo** ©Province of East Flanders, Natuurbeheerplan Stadsbos Galgenhof te Eeklo (2016)

2 **Galgenhof, Eeklo** ©Dienst communicatie Eeklo

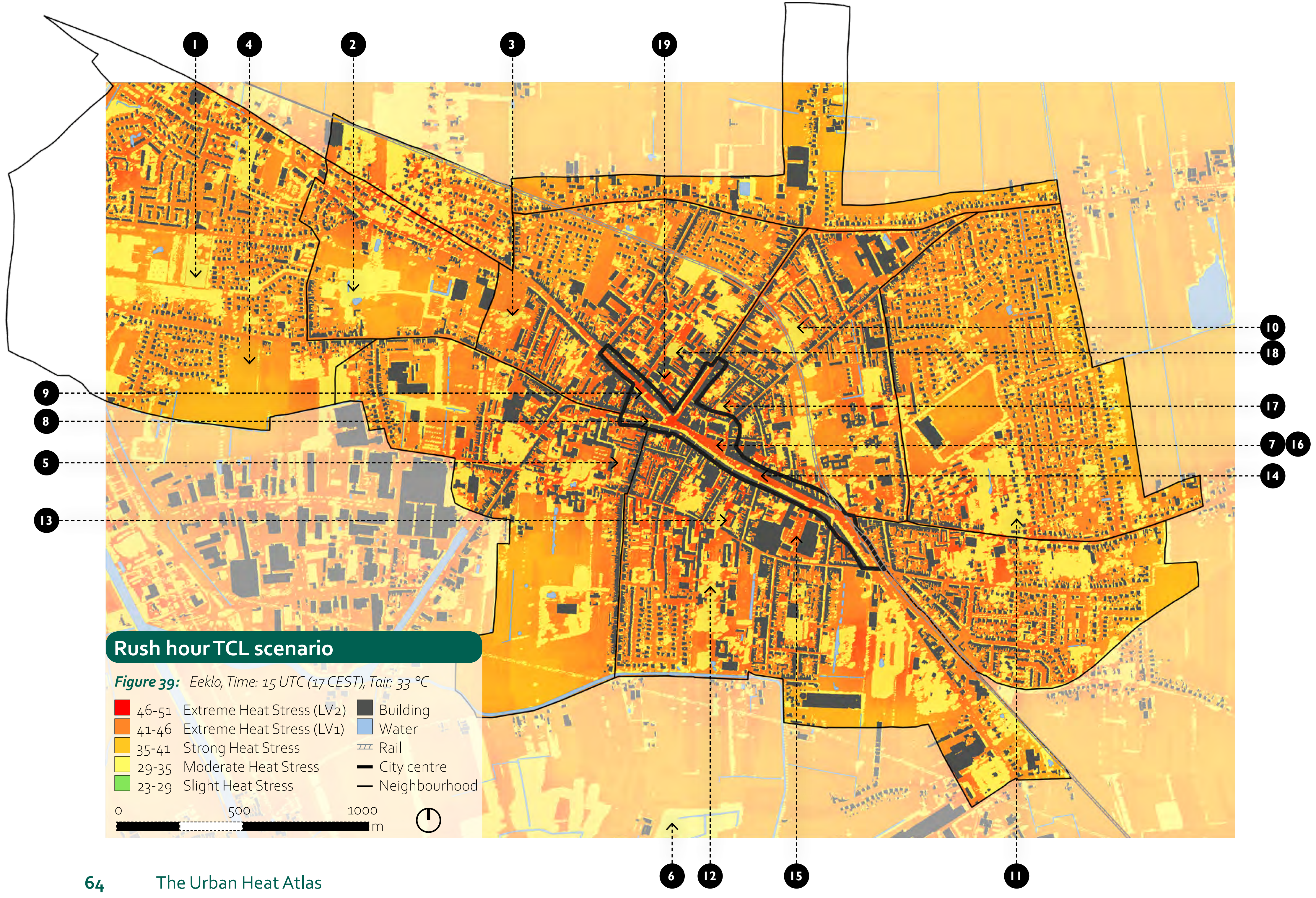
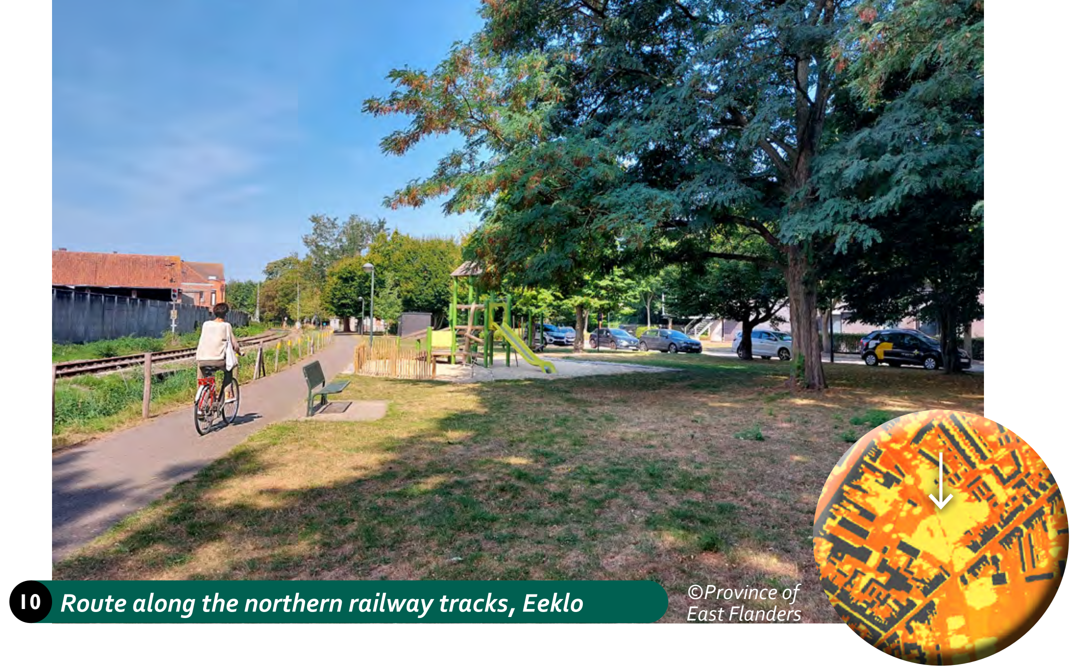


Figure 39: *Eeklo, Time: 15 UTC (17 CEST), Tair: 33 °C*

Eeklo rush hour TCL scenario

During the Thermal City Life rush hour scenario (see fig.39), the historic centre with the market square (7) stands out as a red area, indicating Level 2 Extreme Heat Stress. This is a densely packed urban quarter with predominantly hard surfaces. The lighter yellow colour highlights places where buildings and trees provide some shade on the street. On the Koning Albertstraat (8), for example, honey locust (Gleditsia triacanthos) trees provide scattered shade although these are too far apart to create a continuous cool route. On the Molenstraat (9) mature trees create cool spots but only in the middle section of the road where pedestrians and cyclists cannot benefit from their shade. In line with the lunchtime scenario map, forested areas stand out as places with Moderate Heat Stress. A green strip with mature trees along the northern railway tracks (10) creates a cool route for pedestrians towards the neighbourhoods north of the centre. In addition to the green axes, Eeklo is also developing parks, such as the Heldenpark (11), to provide a large green cool space where people can spend time for recreational purposes on hot summer afternoons.



10 *Route along the northern railway tracks, Eeklo* *©Province of East Flanders*

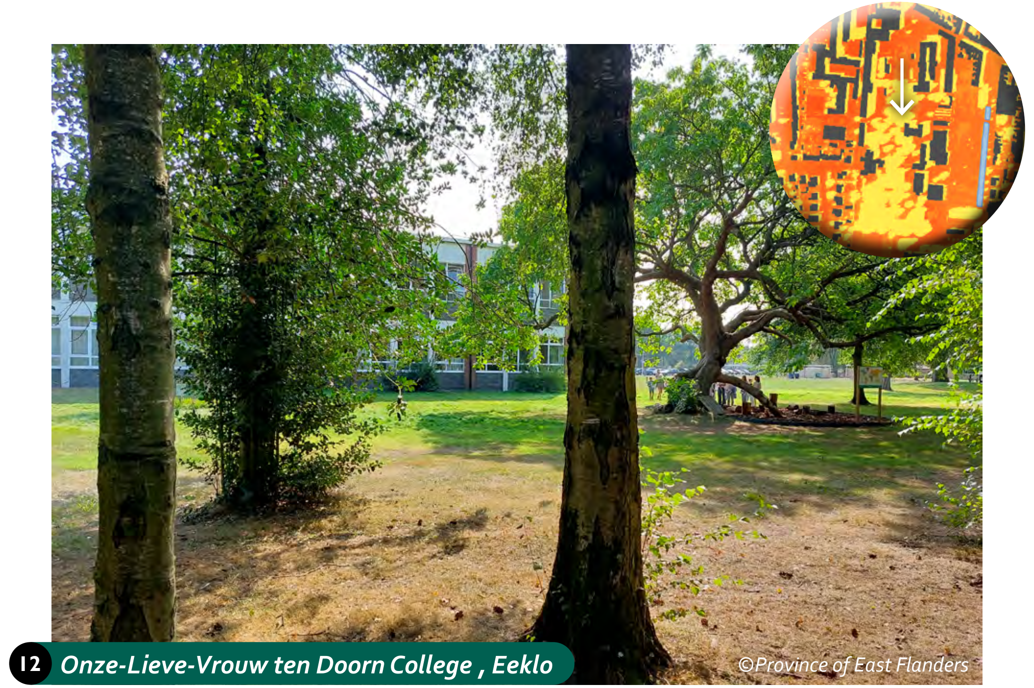
8 *Koning Albertstraat, Eeklo* *©Province of East Flanders*

14 *Stationsstraat in front of the market square, Eeklo* *©Province of East Flanders*

City *Neighbourhood* *User Network*

Eeklo's heat adaptation strategy also aims to green school playgrounds. The Onze-Lieve-Vrouw ten Doorn College (12) is an example of a 'school in a park' (for the masterplan see SMAK Architects, 2020) with the campus located in the grounds of a former monastery and extending from the historic centre to the rural edges of the town. It is clearly visible on the rush hour scenario map as a green cool oasis in contrast to the hard surfaced school playgrounds often found in cities. Eeklo's heat adaptive Cool Towns pilot site is a communal area used by the school and others, De Zuidkaai welfare campus (13). This is the social centre of Eeklo that the town envisions as being a green lung after redevelopment (Seymortier, 2019) During the rush hour scenario, the site suffers from extreme heat stress. The new design will soften the concrete parking area, create designated picnic zones, and plant trees to create a more pleasant green campus.

13 *De Zuidkaai (above) with picnic zone (below), Eeklo* ©Province of East Flanders



12 *Onze-Lieve-Vrouw ten Doorn College , Eeklo* ©Province of East Flanders

©Province of East Flanders

Eeklo heat vulnerability maps

Analysing the four heat vulnerability maps (see fig.40 - fig.43) for Eeklo, the central area stands out compared to other neighbourhoods. The historic centre has the least vegetation, highest population density and the lowest area of cool outdoor space per inhabitant. Looking at the age distribution, there is also the highest percentage of elderly inhabitants living here and the socio-economic status is slightly below the city average. Looking at Eeklo as a whole three large areas can be identified. The northern neighbourhoods, on the urban periphery, are better off, while the Warme Landen neighbourhood, to the west, is the most disadvantaged. The remaining neighbourhoods all have average socio-economic status revealing a three-way division of the town.

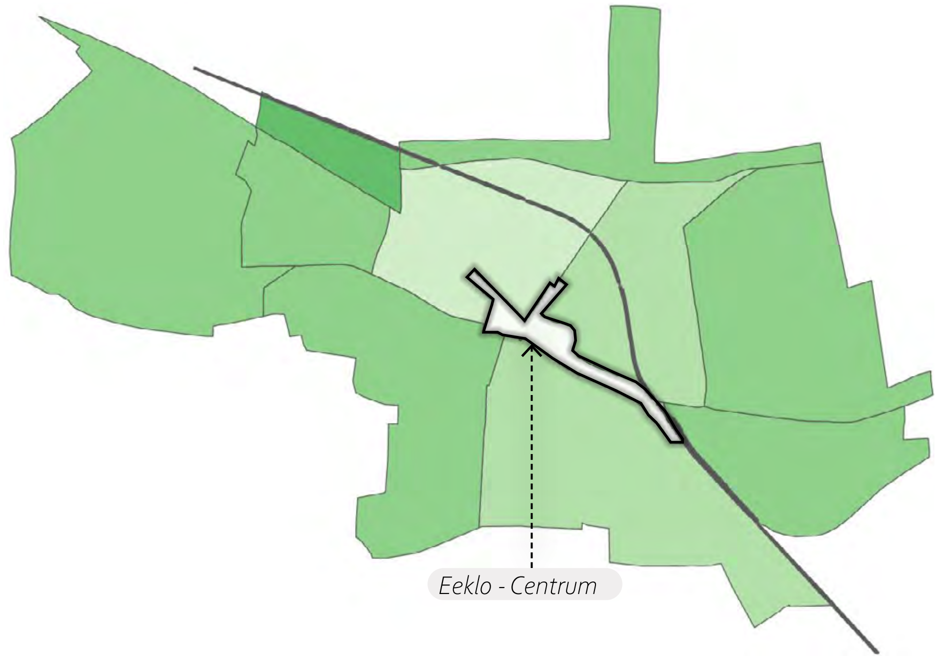
Residents living in neighbourhoods with a low socio-economic status often need cool recreational areas close-by as they have limited ability to travel and their homes may be old and not well insulated exposing them to high indoor temperatures. The presence of large forested areas and agricultural fields in western Eeklo, combined with a low population density, means residents in the Warme Landen neighbourhood benefit from a relatively large cool area to escape the heat. At the same time, Eeklo is a small town, so residents either commute to other cities or towns for work or travel locally as work opportunities are concentrated in particular areas. Establishing cool pedestrian and cycling routes to the train station, the business park in the south-west and through the centre is therefore essential.

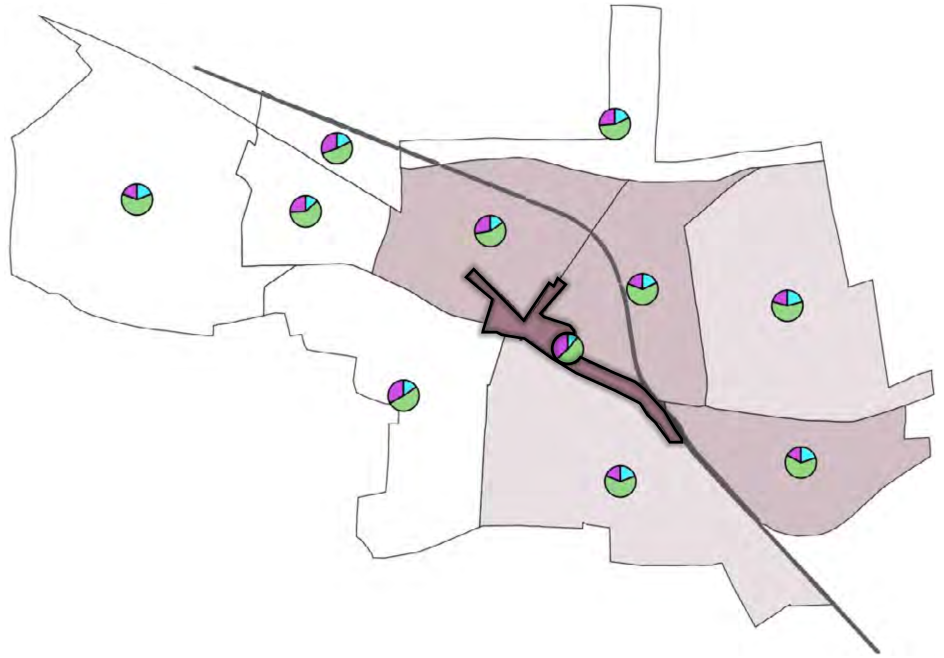
Eeklo advanced heat vulnerability map

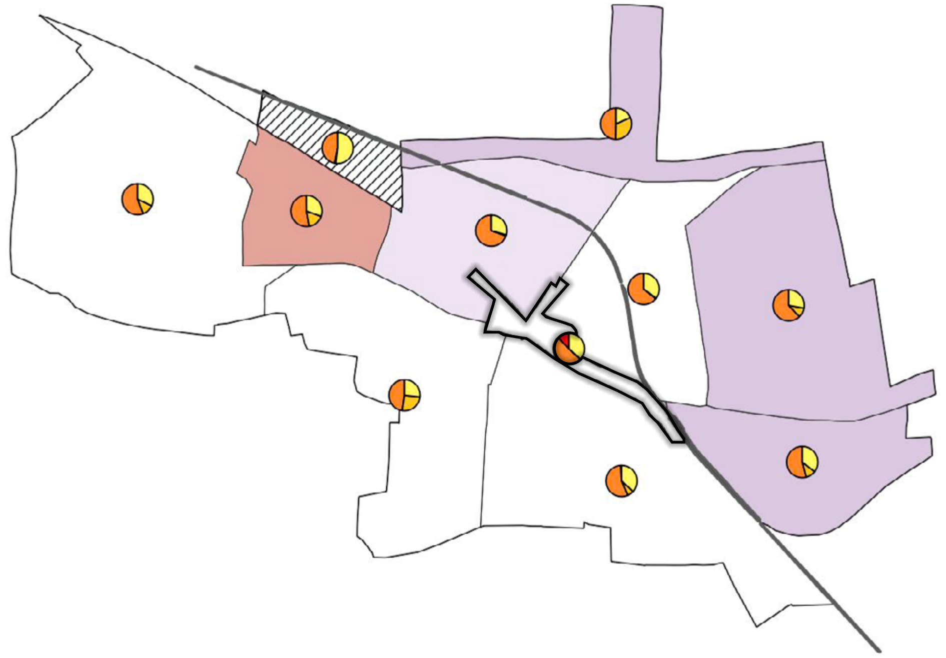
The Thermal City Life scenarios and heat vulnerability maps for Eeklo have identified the centre as the area most vulnerable to heat stress. Collaborative analysis with municipality experts revealed that this is a priority for both immediate and long term urban development in Eeklo's climate adaptation strategy (Meert et al., 2020). Even though the majority of the inhabitants here are elderly it is an important venue for a much more diverse group as most shops, cultural facilities and the town's bus and train hubs are located here. The advanced heat vulnerability map makes clear that Eeklo's central access route, the Stationsstraat (14), suffers from extreme heat. Buildings on the southern side provide some shading but the rest of the street is exposed to solar radiation. The line of lime trees (Tilia ssp.) near the market square are still too small to create a continuous cool route and near the station trees are planted in the middle leaving pedestrian and cycle routes exposed to the sun.

14 *Stationsstraat, Eeklo* ©Province of East Flanders

Eeklo heat vulnerability maps







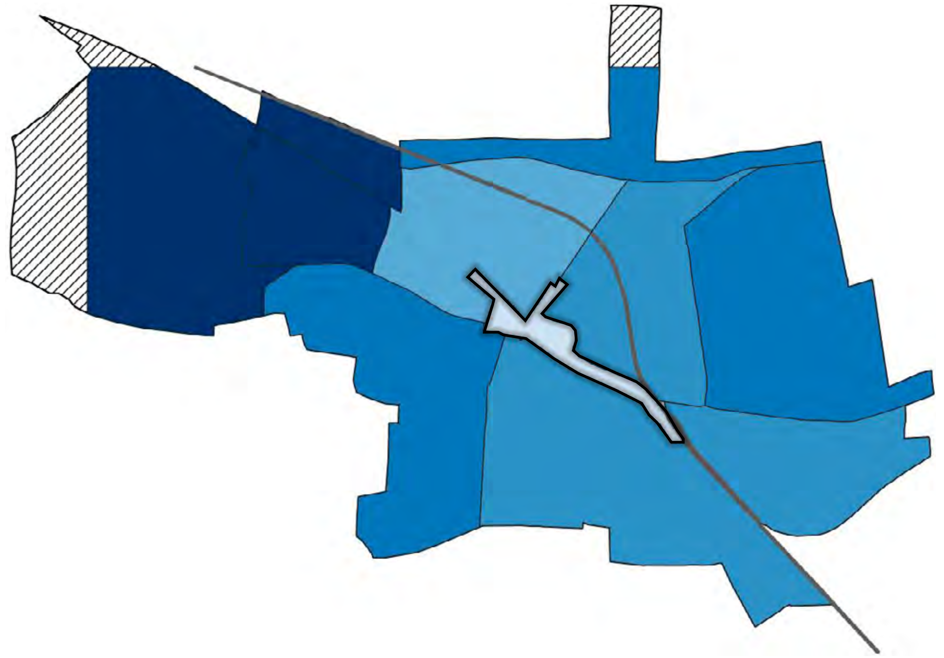


Figure 40: *Vegetated land cover*

- 0-10%
- 0-20%
- 20-30%
- 30-40%
- 40-50%

- 0-10%
- 0-20%
- 20-30%
- 30-40%
- 40-50%
- Train track
- —

Figure 41: *Population density and age distribution*

Population density

- 0-50 m^2 per inhabitant
- 50-100 m^2 per inhabitant
- 100-150 m^2 per inhabitant
- 150-200 m^2 per inhabitant
- 200-350 m^2 per inhabitant
- 350-500 m^2 per inhabitant
- >500 m^2 per inhabitant

Age distribution

- > 65
- 18 - 64
- 0 - 17
- Water
- Train track

Figure 42: *Socioeconomic status (SES) and heat stress levels (PET)*

Socioeconomic status

- Extremely below city average
- Strongly below city average
- Moderately below city average
- Slightly below city average
- Slightly above city average
- Moderately above city average
- Strongly above city average

Heat stress levels

- 46-51 Extreme Heat Stress (LV2)
- 41-46 Extreme Heat Stress (LV1)
- 35-41 Strong Heat Stress
- 29-35 Moderate Heat Stress
- 23-29 Slight Heat Stress
- Water
- Train track

Figure 43: *Cool outdoor ground level area per inhabitant*

- 0-10 m^2 [PET < 35 °C] / inhabitant
- 10-20 m^2 [PET < 35 °C] / inhabitant
- 20-30 m^2 [PET < 35 °C] / inhabitant
- 30-40 m^2 [PET < 35 °C] / inhabitant
- 40-50 m^2 [PET < 35 °C] / inhabitant
- 50-75 m^2 [PET < 35 °C] / inhabitant
- 75-100 m^2 [PET < 35 °C] / inhabitant
- 100-125 m^2 [PET < 35 °C] / inhabitant
- 125-150 m^2 [PET < 35 °C] / inhabitant
- >500 m^2 [PET < 35 °C] / inhabitant

- Water
- Train track
- No data

Advanced heat vulnerability map

Figure 44: The Centrum neighbourhood in Eeklo analysed during the rush hour TCL scenario to identify locations vulnerable to heat for visitors.vulnerable to heat for visitors.

Research area: Eeklo - Centrum
User group: visitors

- Library
- Hotel
- Education
- Childcare
- Market
- Supermarket
- Cultural institution
- Healthcare related facility
- Shopping centre or mall
- Train station
- Bus stop
- Regional cycling and walking routes
- Rail
- Road
- 300 meter walking distance
- Park and recreational area
- Potential cool place
- Building

PET values - Rush hour scenario

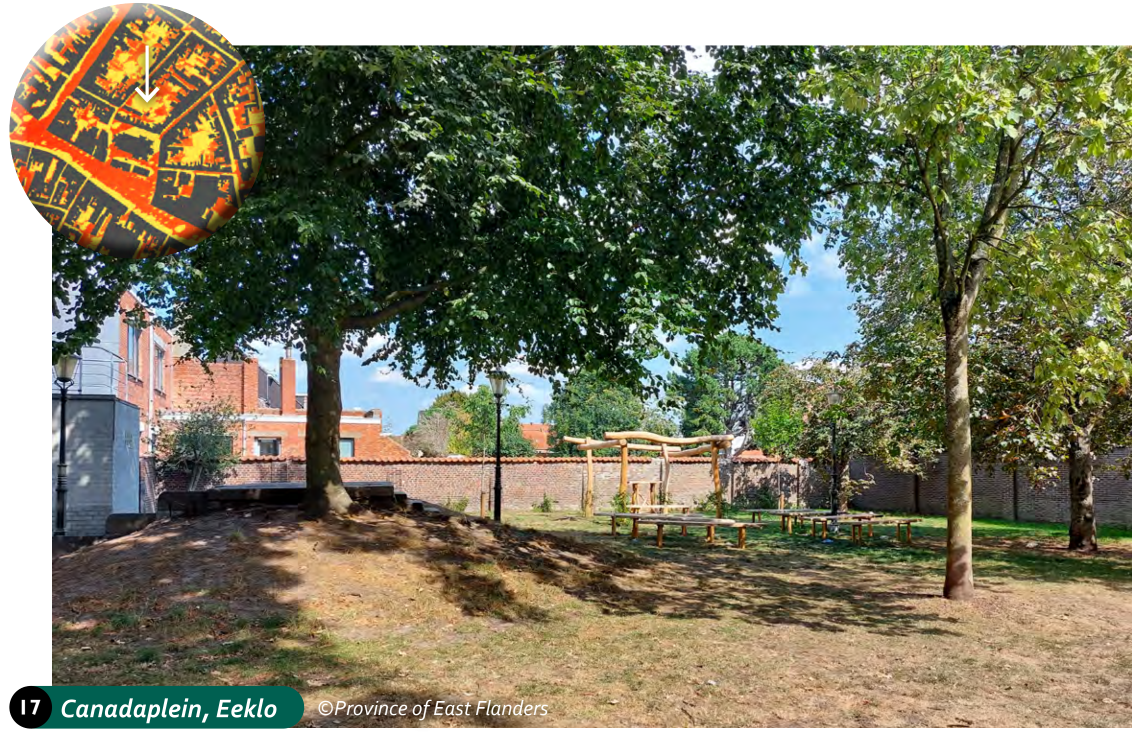
- 46 - 51 Extreme heat stress (LV2)
- 41 - 46 Extreme heat stress (LV1)
- 35 - 41 Strong heat stress
- 29 - 35 Moderate heat stress

0 250 500 m

The municipality has long established plans to create a ring road around the town, and construction will begin in 2022 (Agentschap Wegen & Verkeer, 2022). The Ringlaan (R43) from Nieuwendorpe will connect to Gentsesteenweg (N9) thereby passing traffic around the southern periphery of the town. This major development will drastically decrease through traffic and allow the wide, 4-lane, Stationsstraat to be redeveloped as a tree-lined promenade designed principally for pedestrians and cyclists. In addition to cool corridors for pedestrians and cyclists, creating cool spots is also important for visitors to rest and escape the heat. The outdoor space in front of the Krüger shopping centre (15) is dedicated to parking and suffers from extreme heat. Trees make the parking aesthetically more pleasing but there is no place for pedestrians to rest and feel refreshed. The advanced heat vulnerability map (see fig.44) highlights the opportunity to climate proof the area and create a social place for visitors.

The historic market square (7) is a culturally and symbolically significant place where the weekly Thursday market takes place. It suffers from extreme heat stress. The existing lime trees (Tilia spp.) in the square (16) have been topped, greatly reducing cooling capacity; this has been counteracted by installing artificial sun shades to keep restaurant and retail visitors cool. The fountain on the square (7) might refresh those standing next to it, or children playing in the water, but water features generally have limited effect in reducing PET. The closest cool spot to the market square is Canadaplein (17) where a group of mature trees create a small green oasis. A similar pocket park is the Remi Van Brabantpark (18) close to Eeklo's cultural centre, De Herbakker. It has a courtyard (19) which is also exposed to high heat stress. The nearby small public courtyard garden behind Eeklo's library is a well-known lunch spot among locals and provides some relief from the heat.

16 *Lime trees on the market square with sun shade, Eeklo* ©Dienst communicatie Eeklo



17 *Canadaplein, Eeklo* ©Province of East Flanders

City - Neighbourhood - User Network

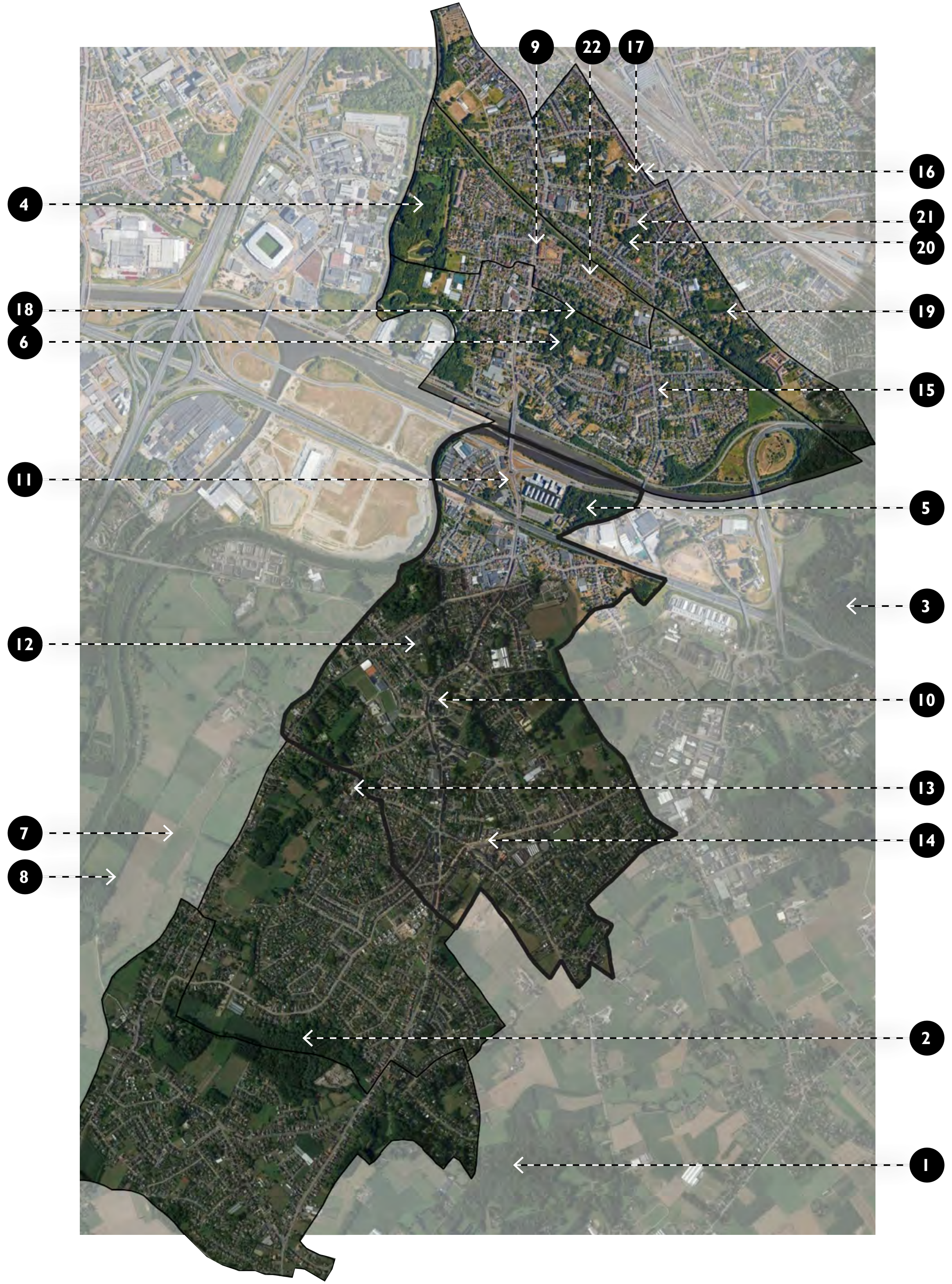
5. Merelbeke, Belgium

Merelbeke satellite map

Figure 45: *Google, Imagery ©2022 CNES / Airbus, Landsat / Copernicus, Maxar Technologies, Map data ©2022*

Area	37 km²
Population	24.886 (2022)
Population density	673 people / km² (2022)

0 500 1000 m



Merelbeke

Merelbeke is a mid-size municipality south of Ghent, Belgium, near protected landscapes, such as the Upper Scheldt Valley to its western border (see fig.45). The municipality recognises the importance of good spatial planning in addressing heat stress and puts great emphasis on creating blue-green networks to tackle multiple climate challenges in an integrated way (Gemeente Merelbeke & OCMW-bestuur Merelbeke, 2020-2025; Nieuwenhuyze et al., 2018). The municipality aims to mitigate heat stress through a combination of social, architectural and spatial measures, such as by breaking up hard surfaces and planting vegetation, creating shade and wind corridors in the urban fabric and giving more space to water.

Even though water infrastructure alone often has limited capacity to reduce heat stress when you are not in the water or close by, the urban water system is fundamental to addressing flooding and drought. Green elements, especially recently planted vegetation relies on sufficient water resources for establishment and so this is vital to the making of an attractive living environment and adequate cooling capacity. The municipality's climate adaptation strategy (Nieuwenhuyze et al., 2018) also mentions controlling heat absorption through reflective surfaces. The location where this is implemented needs careful consideration to ensure the urban heat island effect is reduced and any increase in outdoor thermal discomfort by reflection of solar and infrared radiation back to site users is avoided. Inspired by the Climate Resilient Neighbourhood research project Klimaatbestendige Wijk (Kluck et al., 2017) by the Amsterdam University of Applied Sciences, Merelbeke wishes to extend city-wide tree cover and create numerous small parks to ensure residents have nearby access to cool spots (Nieuwenhuyze et al., 2018).

City - Neighbourhood - User Network

4 Liedermeerspark, Merelbeke *©Province of East Flanders*

Merelbeke lunchtime TCL scenario

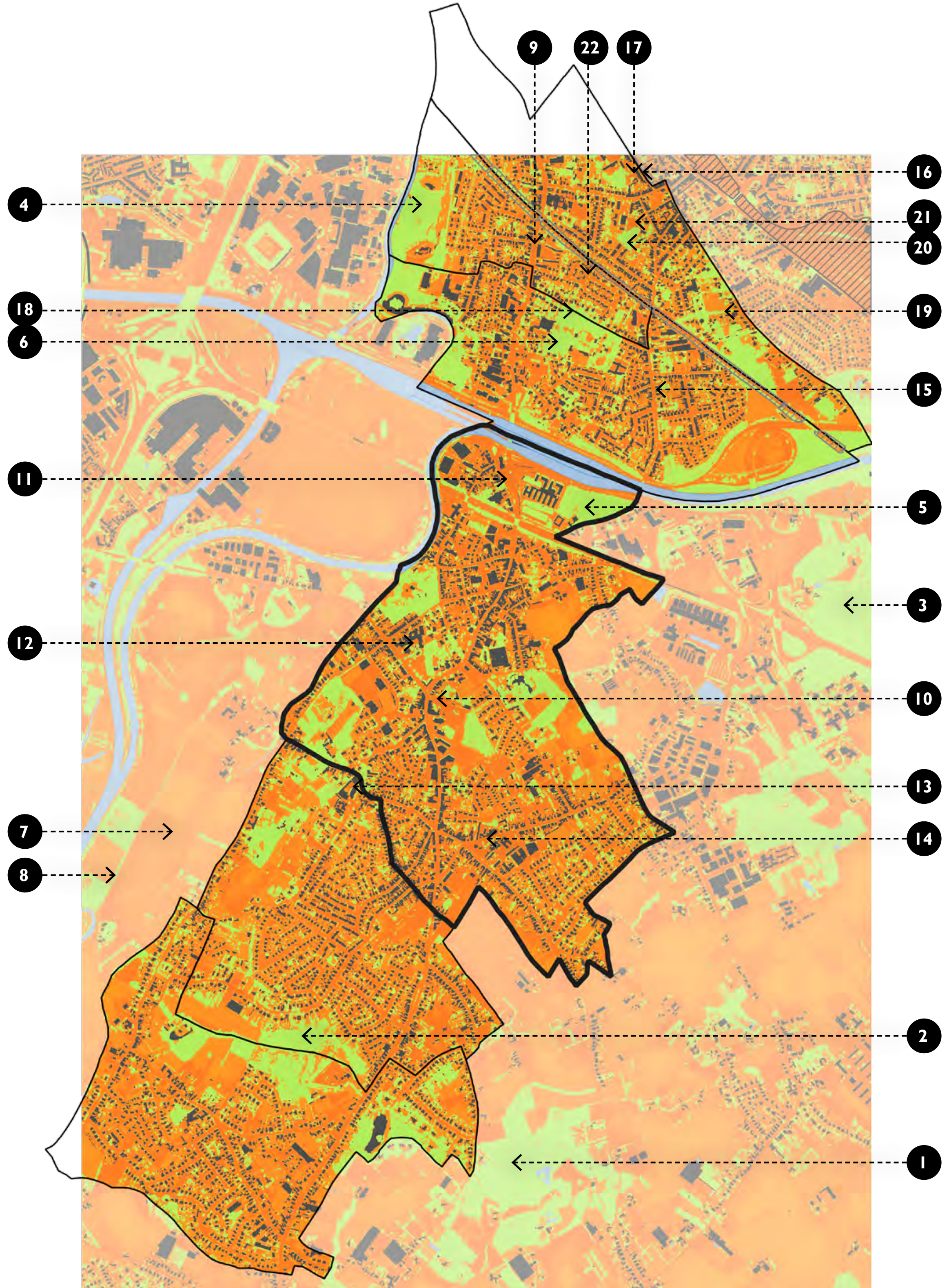
These heat adaptation intentions can be implemented most effectively for Merelbeke once there is a clear picture of where heat stress and cool areas are located, at what time of the day and who might be affected. Looking at the Thermal City Life lunchtime scenario (see fig.46), forested parks such as the Gentbos (1), Rotary-bos (2), Ter Dennen Bos (3), Liedermeerspark (4), and Guldensporenpark (5) stand out. These parks are densely packed with mature trees that provide substantial cooling, lowering heat stress levels by three PET-grades, Slight Heat Stress instead of Level 1 Extreme as seen in the rest of the municipality. For example, the Ten Berg forest (6) in the northern part of the municipality, is the remnant of a castle park with 100-years-old trees; part is private property although there is a plan to increase accessibility to benefit the entire neighbourhood (Gemeente

Lunchtime TCL scenario

Figure 46: *Merelbeke, Time: 12 UTC (14 CEST), Tair: 28 °C*

46-51	Extreme Heat Stress (LV2)		Building
41-46	Extreme Heat Stress (LV1)		Water
35-41	Strong Heat Stress		Rail
29-35	Moderate Heat Stress		City centre
23-29	Slight Heat Stress		Neighbourhood

0 500 1000 m



Merelbeke, 2022). The lunchtime scenario also indicates that not all green areas are equally effective in reducing heat stress; the availability of shade plays a crucial role. Most of the Scheld valley natural reserve (7) consists of open green fields suffering from Level 1 Extreme Heat stress. In contrast, the tree-lined Oude Pontweg (8) cycling route through this reserve is a strategic cool corridor with only Slight Heat Stress.

The PET-map also shows that almost all urban areas in Merelbeke suffer from high heat stress around lunch time making it challenging to identify priorities among the affected areas. A user network analysis could provide guidelines to help with this. For example, walking and cycling routes to supermarkets or schools are often used around lunchtime by working people, children or the elderly. Hundelgemsesteenweg (9) is the main road of the city and has connected Merelbeke to Ghent and the southern towns for centuries. It also provides access to most of the supermarkets of the city. This important road and its many junctions all lack shading. There is limited space to plant trees in most sections but an analysis of what is possible to create a cool route for pedestrians and cyclists should be undertaken to conforms with Merelbeke's Climate Adaptation Strategy which aims to systematically green wide streets by planting rows of trees (Nieuwenhuyze et al., 2018). Part of Merelbeke's adaptation agenda work is already underway softening surfaces and adding greening at Tramstelplaats (10), while the nearby nodes of Hundelgemsesteenweg, Poelstraat and Cornelis Sneyssenslaan are still to be addressed.

8 *Oude Pontweg, Merelbeke* ©Onroerend Erfgoed, Geert Van der Linden, 229254, beeldbank.onroerenderfgoed.be

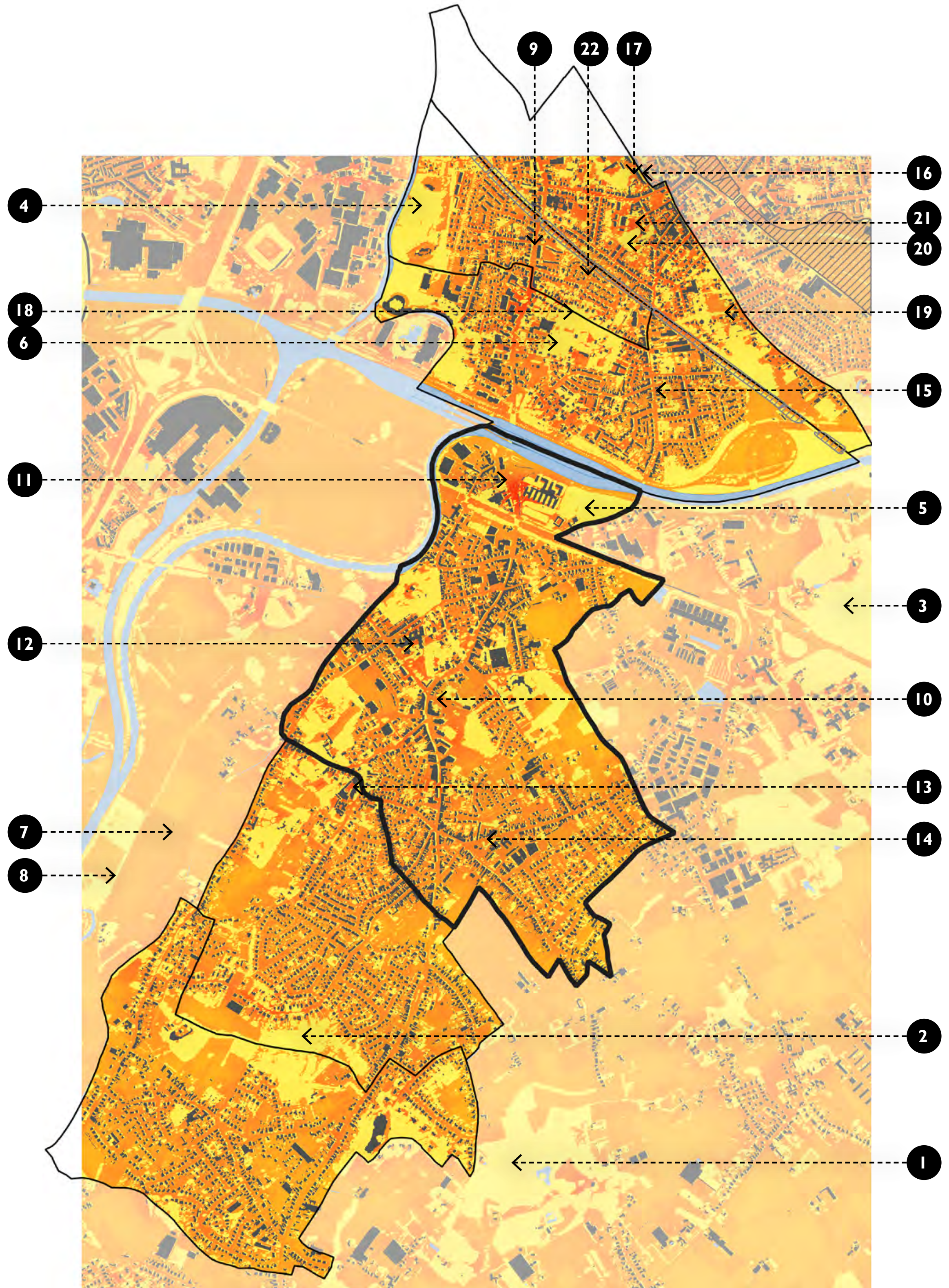
9 *Hundelgemsesteenweg, Merelbeke* ©Province of East Flanders

Rush hour TCL scenario

Figure 47: Merelbeke, Time: 15 UTC (17 CEST), Tair: 33 °C

46-51 Extreme Heat Stress (LV2)	Building
41-46 Extreme Heat Stress (LV1)	Water
35-41 Strong Heat Stress	Rail
29-35 Moderate Heat Stress	City centre
23-29 Slight Heat Stress	Neighbourhood

0 500 1000 m



Merelbeke rush hour TCL scenario

Heat often intensifies during the afternoon. Some places suffer high Heat Stress levels. The junction where the Hundelgemsesteenweg crosses the ring canal (11) suffers from Level 2 Extreme Heat Stress at rush hour and the focus is on motor vehicles and it is not inviting to pedestrians or cyclists (see fig.47). Many school playgrounds also suffer from the heat during the afternoon, for example the Popelin Lyceum (12), the Technical Atheneum (13) and the adjacent BSGO! primary school are dominated by impervious hard surfaces that exacerbate heat build-up through the day. The playground of the municipal Gilko primary school also suffers from Level 1 Extreme Heat Stress, but the street in front of it, Kloosterstraat (14), has been recently redesigned with greenery and trees, also to the benefit of the adjacent residential care centre. The municipality also aims to provide cool shaded play areas in line with the adaptation strategy (Nieuwenhuyze et al., 2018).

©Province of East Flanders

11 *Hundelgemsesteenweg crossing Ringvaart, Merelbeke* ©Province of East Flanders

14 *Kloosterstraat (above & below), Merelbeke* ©Province of East Flanders

City — *Neighbourhood* — *User Network*

Merelbeke vulnerability maps

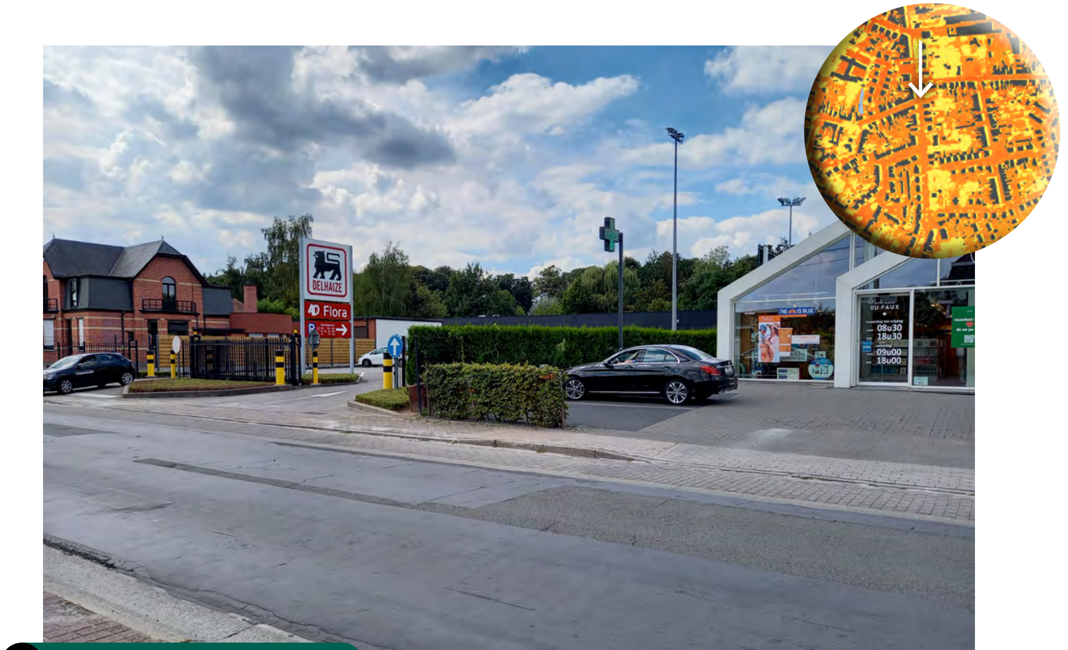
Heat stress in school playgrounds affects children, a group especially vulnerable to heat stress. In addition to primary, secondary and higher education institutions, Merelbeke also has a number of care centres, hospitals and nursing homes where vulnerable elderly or ill residents reside. Additionally Merelbeke's climate adaptation plan recognises that heat stress affects the health and wellbeing of all residents, for example in their productivity or quality of sleep (Nieuwenhuyze et al., 2018, p. 33). The municipality has a balanced age distribution with a slightly lower percentage of elderly living in the northern Flora neighbourhood (see fig. 49). This and the central area are also the most densely populated with the Flora neighbourhood also having a socio-economic status just below the city average (see fig.50).

The map showing vegetated land cover (see fig.48) revealed little difference in green areas across neighbourhoods. Housing types are similar across the entire municipality with most houses having gardens. To the south of Merelbeke, Ketenhoek and Centrum-Bergwijk neighbourhoods have more abundant greenery. These two areas share the Rotary-bos national forest (2) and include agricultural fields. To the north, the Liedermeers park (4) forms a significant part of the Verloren Brood neighbourhood contributing to its higher vegetated percentage (see fig.48). The cool area per inhabitant map (see fig.51) reflects the trend in vegetated land cover. The Centrum and Centrum-Bergwijk neighbourhoods have slightly less cool areas.

Merelbeke advanced heat vulnerability map

Merelbeke's central area and the Flora neighbourhood are identified from the analysis of the PET and heat vulnerability maps as priority areas for heat adaptation. In recent years, the municipality has realised multiple renewal and greening projects in the centre; Flora will be the next focus. The advanced heat vulnerability map of Flora focuses on children, as a vulnerable group highlighting relevant amenities, heat stress locations, and potential cool spots during the rush hour scenario, when children finish school and may play with their friends or family outside (see fig.52) .

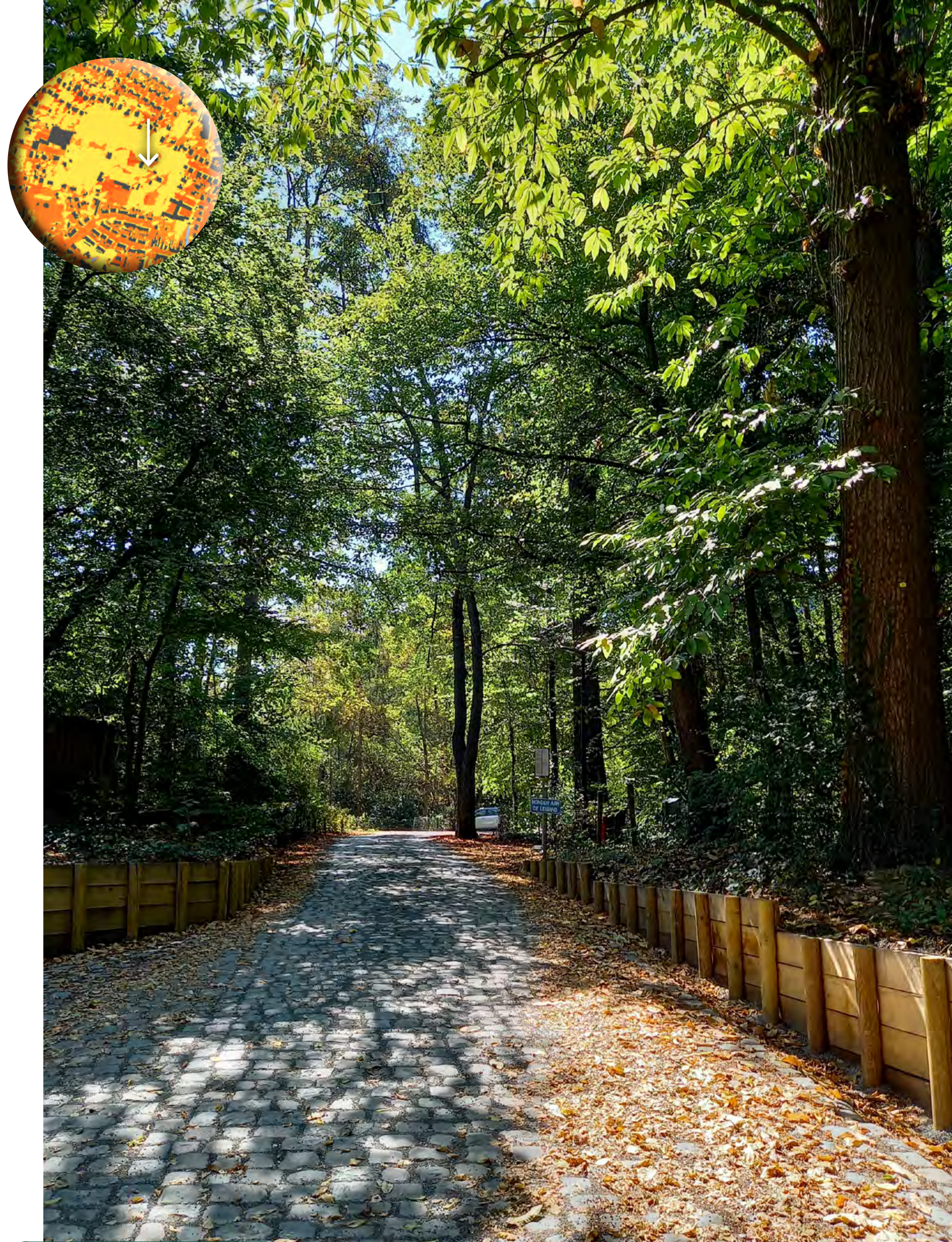
Both the Hundelgemsesteenweg (9) and Fraterstraat (15) are primary routes and, as most of Flora's secondary routes, suffer from Level 1 to 2



15 *Fraterstraat, Merelbeke* ©Province of East Flanders

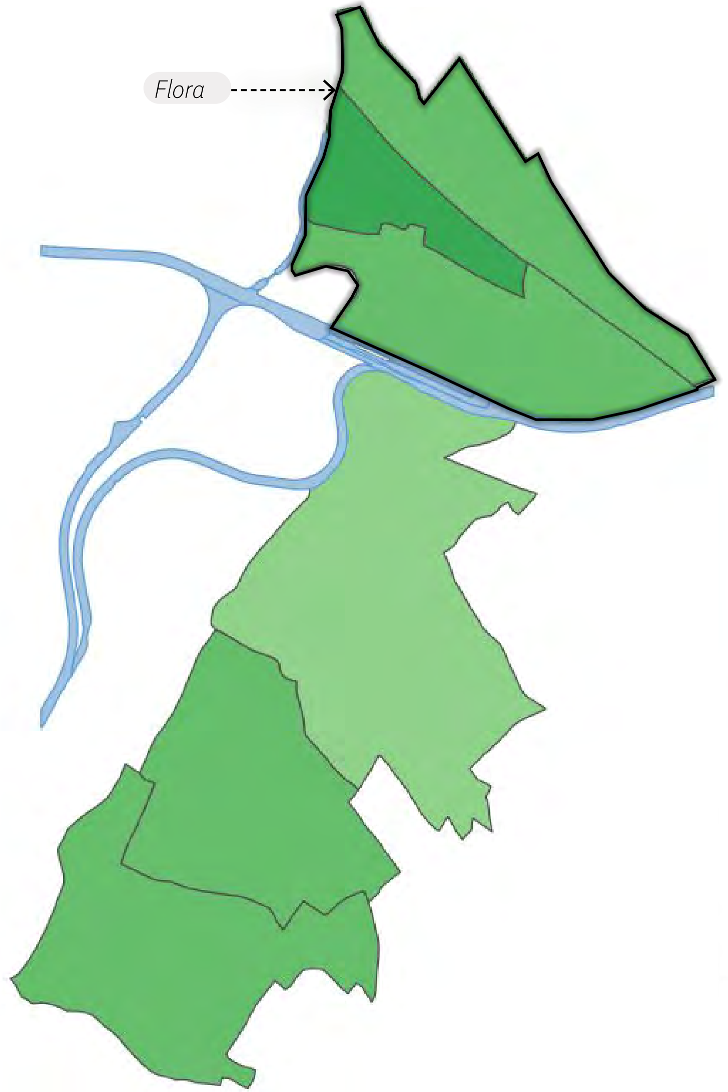
17 *Back of the gardens on Hendrik Consciencestraat, Merelbeke* ©Province of East Flanders

Extreme Heat Stress, mostly due to the structure of the urban fabric. Close to the station area, the street profile lacks greenery and homes are densely packed, forming closed facades. The Hendrik Consciencestraat (16) where a primary school is located is a good example of this. The municipality sees an opportunity to create a parallel walking and cycling route at the back of the gardens (17) with publicly accessible green space that will not only benefit neighbourhood children playing outside during the afternoon but also pupils during school hours. In the vicinity of the Ring canal, the plots become more spacious, the street profile wider and there are more trees (Gemeente Merelbeke, 2022). The Bergstraat (18) and Tertzweildreef (19) streets show how densely planted mature trees can moderate even extreme heat stress and create cool routes.



18 *Bergstraat, Merelbeke* ©Province of East Flanders

Merelbeke heat vulnerability maps



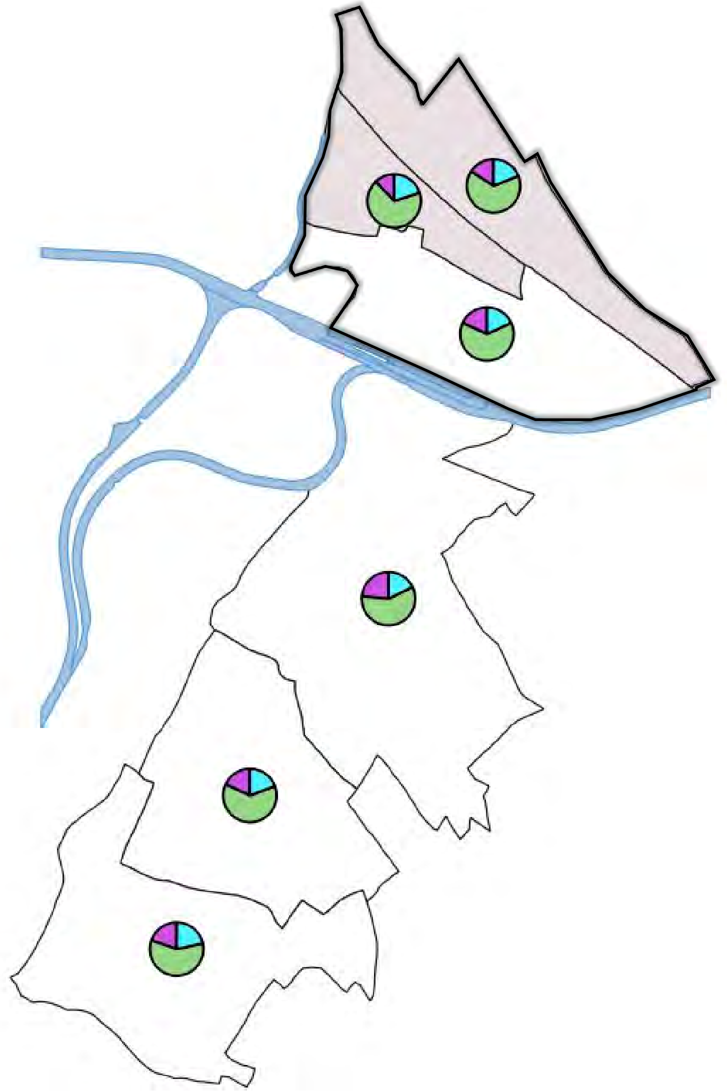


Figure 48: *Left: Vegetated land cover*

0-10%	0-10%
0-20%	0-20%
20-30%	20-30%
30-40%	30-40%
40-50%	40-50%

Figure 49: *Right: Population density and age distribution*

Population density

- 0-50 m^2 per inhabitant
- 50-100 m^2 per inhabitant
- 100-150 m^2 per inhabitant
- 150-200 m^2 per inhabitant
- 200-350 m^2 per inhabitant
- 350-500 m^2 per inhabitant
- >500 m^2 per inhabitant

Age distribution

- > 65
- 18 - 64
- 0 - 17

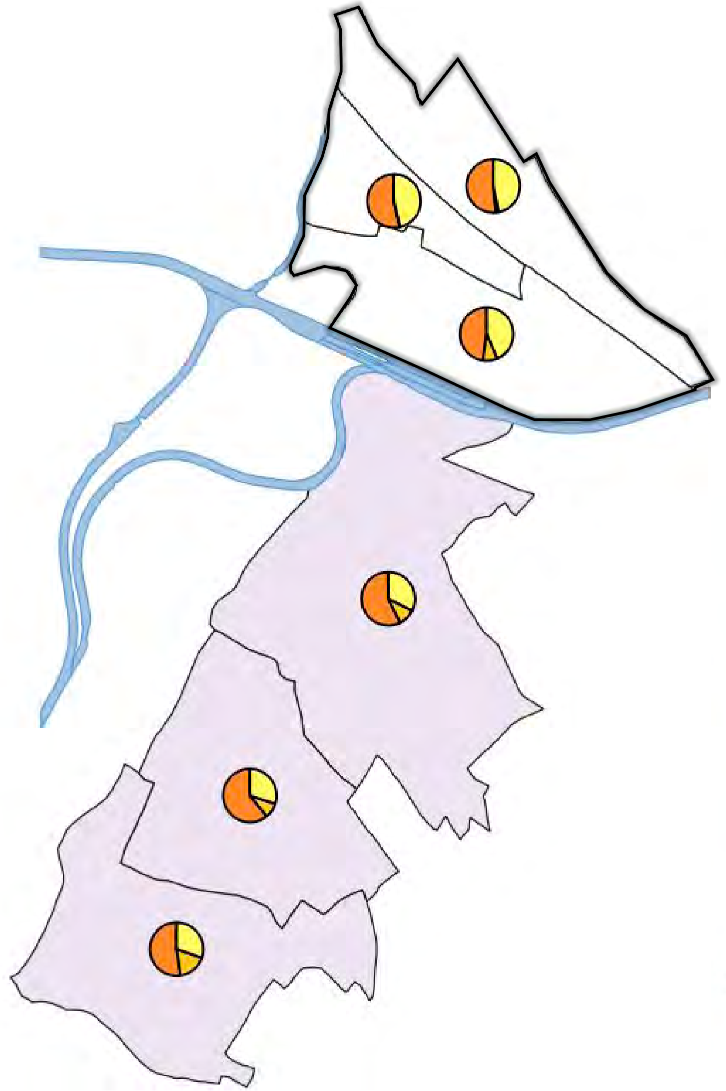


Figure 50: *Left: Socio-economic status (SES) and heat stress levels (PET)*

Socioeconomic status

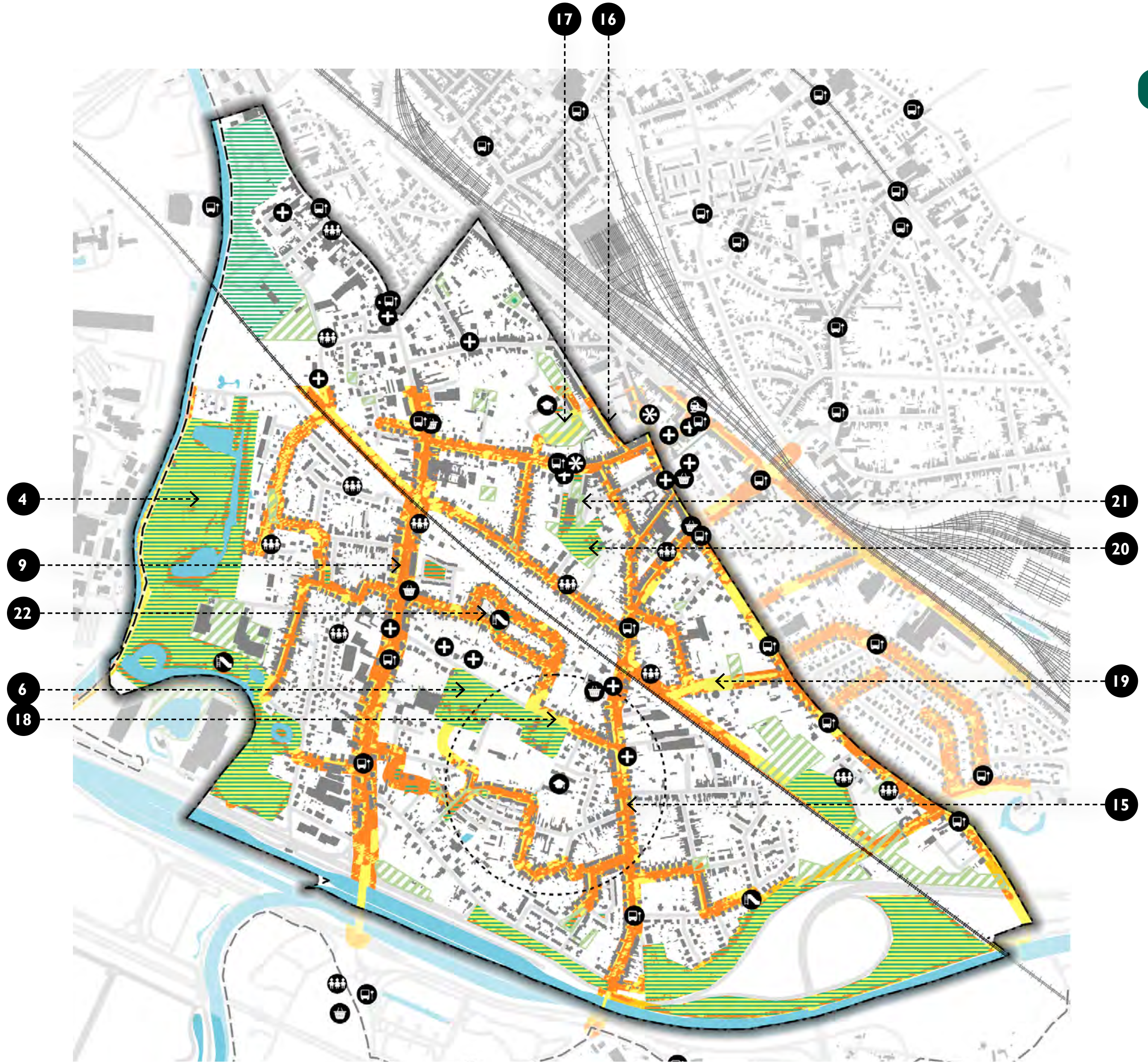
- Extremely below city average
- Strongly below city average
- Moderately below city average
- Slightly below city average
- Slightly above city average
- Moderately above city average
- Strongly above city average

Heat stress levels

- 46-51 Extreme Heat Stress (LV2)
- 41-46 Extreme Heat Stress (LV1)
- 35-41 Strong Heat Stress
- 29-35 Moderate Heat Stress
- 23-29 Slight Heat Stress

Figure 51: *Right: Cool outdoor ground level area per inhabitant*

- 0-10 m^2 [PET < 35 °C] / inhabitant
- 10-20 m^2 [PET < 35 °C] / inhabitant
- 20-30 m^2 [PET < 35 °C] / inhabitant
- 30-40 m^2 [PET < 35 °C] / inhabitant
- 40-50 m^2 [PET < 35 °C] / inhabitant
- 50-75 m^2 [PET < 35 °C] / inhabitant
- 75-100 m^2 [PET < 35 °C] / inhabitant
- 100-125 m^2 [PET < 35 °C] / inhabitant
- 125-150 m^2 [PET < 35 °C] / inhabitant
- >500 m^2 [PET < 35 °C] / inhabitant



Advanced heat vulnerability map

Figure 52: The Flora neighbourhood in Merelbeke analysed during the rush hour TCL scenario to identify locations vulnerable to heat for children.

Research area: Merlbeke - Flora
User group: children
Cultural facility
Playground
Supermarket
Train station
Bus stop
Education
Childcare
Regional cycling and walking route
Rail
Road
300 meter walking distance
Potential cool place
Potential or future park
Park or recreation area
Water
Building
PET values - Rush hour scenario
46 - 51 Extreme heat stress (LV2)
41 - 46 Extreme heat stress (LV1)
35 - 41 Strong heat stress
29 - 35 Moderate heat stress
0 400 800
m

Liedermeerspark (4) and Anthospark (20) are important green oases in the Flora district where residents can escape scorching heat and children can play even on hot days. Merelbeke aims to make many other green areas publicly accessible and develop the pedestrian and cycling network in the neighbourhood, in this way the Ten Berg forest (6), adjacent to two primary schools, can become a secondary play area for children. The station area also lacks accessible green space. Potential green areas include transforming the stony squares around the church (21) that currently suffer from Level 2 Extreme Heat Stress and connecting these to the Anthospark (20) (ibid.).

An effective way to increase greenery takes advantage of Flora's characteristic housing typology reminiscent of a garden city with a network of secondary streets, featuring large street islands with access for cars to every house. In the Cool Towns project, Merelbeke's pilot site in the Tuinwijk Jan Verhaegen street (22) was a new neighbourhood park with a swale, permeable paving and honey locust trees (Gleditsia trianthansos) to complement existing oaks (Quercus spp.) and maples (Acer spp.). In the shade of the 4-metre tall young honey locust trees East Flanders measured 3-6 degrees lower PET than in the sun (see also Spanjar et al., 2022 for the specific factsheet). Based on these measurements, 7-8 metre tall healthy honey locust trees (Gleditsia trianthansos) could deliver 10-15 °C PET heat stress reduction. Flora's green development plan (Gemeente Merelbeke, 2022) envisages more similar street islands and street intersections transformed into pocket parks with water infiltration measures and small playgrounds.

22 Tuinwijk Jan Verhaegen, Merelbeke

©Province of East Flanders

21 Stony areas around Flora's church, Merelbeke

©Province of East Flanders

City — Neighbourhood — User Network

6. Zelzate, Belgium

Zelzate satellite map

Figure 53: *Google, Imagery ©2022 Aerodata International Surveys, CNES / Airbus, Landsat / Copernicus, Maxar Technologies, Map data ©2022*

Area	*13,77 km²*
Population	*13.298 (2022)*
Population density	*966 people / km² (2022)*

Zelzate

In the province of East Flanders lies Zelzate; a Belgian town next to the Belgian-Dutch border with Gent the largest city nearby (see fig.53). Zelzate's Sustainable Energy and Climate Action Plan from 2018 (Zero Emission Solutions & Provincie Oost-Vlaanderen, 2018) recognises the challenge of mitigating heat stress, especially in urban environments, and the multiple consequences for people, plants and animals. The town's Vision for Trees (Gemeente Zelzate, n.d.) builds on the motto "the right tree in the right place" and emphasises the importance of trees in adapting to heat, providing ecosystem services, and contributing to health and the quality of life. It also calls for planning ahead and allowing time for trees to grow while prioritising indigenous species with a long life span.

©Pascal Meyvaert/Lokaal bestuur Zelzate

1 *Zelzate Park, Zelzate*

City — Neighbourhood — User Network

3 *Visvijver, Zelzate*

©Province of East Flanders

Lunchtime TCL scenario

Figure 54: *Zelzate, Time: 12 UTC (14 CEST), Tair: 28 °C*

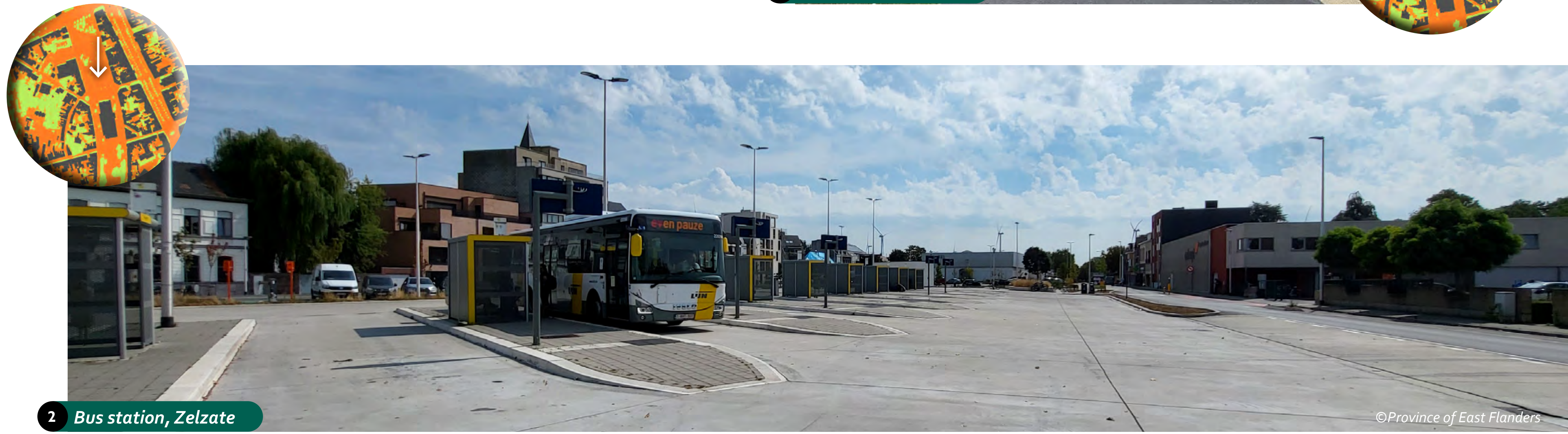
46-51	Extreme Heat Stress (LV2)	Building
41-46	Extreme Heat Stress (LV1)	Water
35-41	Strong Heat Stress	Rail
29-35	Moderate Heat Stress	City centre
23-29	Slight Heat Stress	Neighbourhood

0 250 500 m

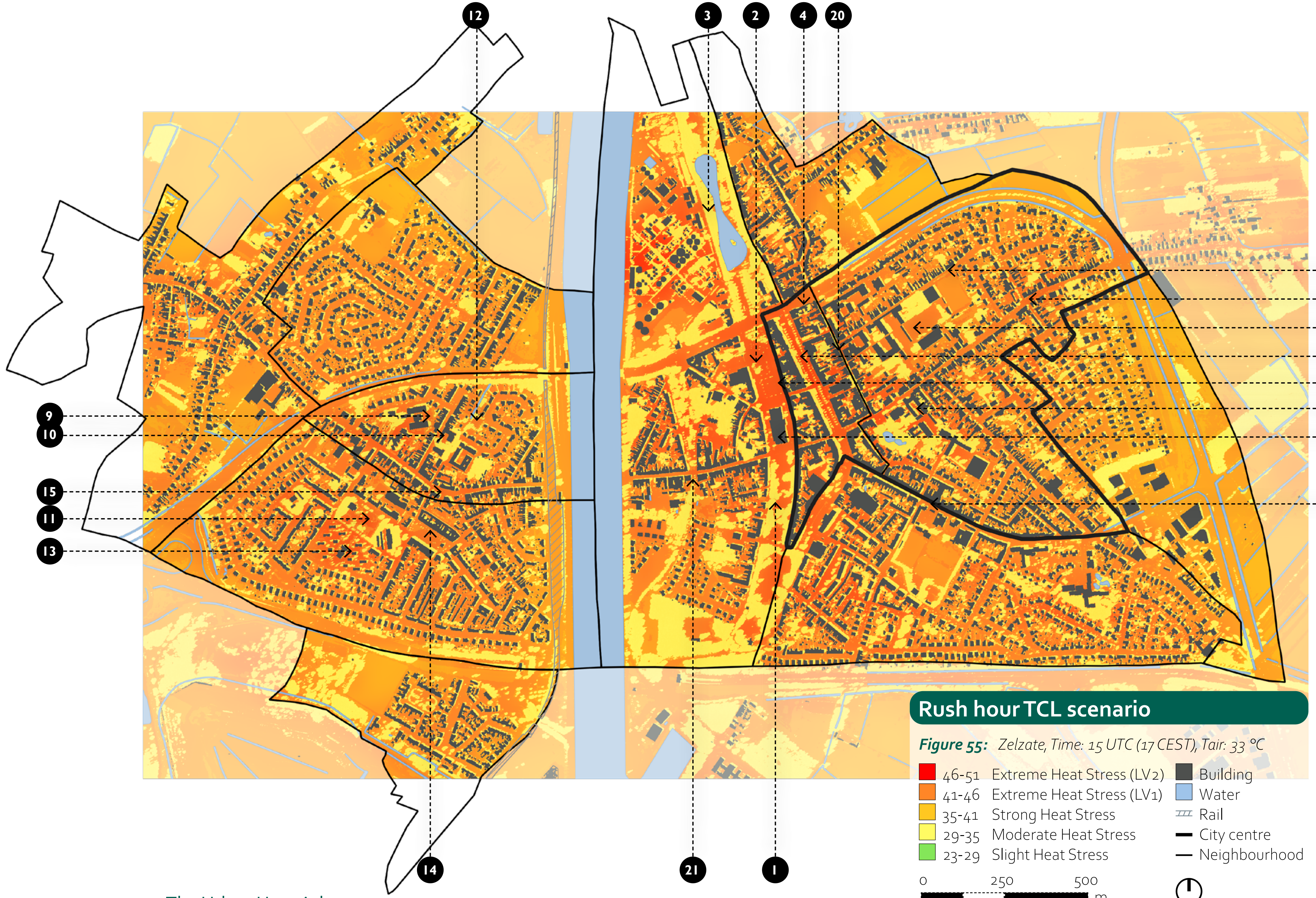
Zelzate lunchtime TCL scenario

The heat maps of Zelzate demonstrate the effectiveness of trees in reducing heat stress. During the lunchtime scenario (see fig.54), most of Zelzate suffers from Level 1 Extreme Heat Stress, the exception being areas under mature trees which only experience Slight Heat Stress. Zelzate Park (1) to the south of the central bus station (2) and the Visvijver fishing pond area (3) to the north of it, are parks where residents may escape the heat during their lunch break. These are currently not connected because the station area (2) and the RW4 road (4) form a hard boundary between them. At the end of 2020, Zelzate planted 73 trees, a mixture of Maple (Acer), Ornamental pear (Pyrus) and Mountain ash (Sorbus aucuparia), next to the bus station on Oostkade (5) (Radio ZRO, 2020). When these trees mature, they will form a cool green corridor and reconnect the two parks to the north and south of the station.

5 *Oostkade, Zelzate*



2 *Bus station, Zelzate*



Rush hour TCL scenario

Figure 55: *Zelzate, Time: 15 UTC (17 CEST), Tair: 33 °C*

Zelzate rush hour TCL scenario

In the rush hour scenario (see fig.55), both the bus station (2) and the Grote Markt (6) stand out as areas under Level 2 Extreme Heat Stress. Many places that serve children and other vulnerable groups also suffer from extreme heat. For example, at the 'De Reigers' elementary school (7), mature trees provide cooling capacity to a large part of the school playgrounds, but the courtyards with sports areas have impervious surfaces and lack heat relief. This is where the East Flanders Province constructed one of their Cool Towns pilots, a canopy structure with a green roof, lime (Tillia spp.) trees and a green wall to create a more comfortable play environment for pupils. The heat stress situation is similar in the outdoor space of the Sint-Laurens secondary school (8) where a wooded area on the north side of the sports fields reduces heat stress to a Moderate level, however the sports fields and play areas lack shelter from the sun and suffer from Strong Heat Stress.

7 'De Reigers' elementary school, Zelzate ©Province of East Flanders

7 Cool Towns intervention at 'De Reigers' elementary school, Zelzate ©Province of East Flanders

The playgrounds of the Sint-Laurens (9) and 'De Krekel' (10) elementary schools are partially shaded while their play areas, with hard impervious surfaces, heat up significantly as the heat map illustrates.

The Sint-Antonius and Debbautshoek neighbourhoods, in west Zelzate, also stand out as having extreme heat stress levels. These have many large grassy areas exposed to the sun. For example, the park and play area on Hoogbouwplein (11) is a large open field, well-shaded around its edges, but otherwise open. Similarly, the playground on Omer de Bruyckerstraat (12) is an open meadow experiencing Level 1 Extreme Heat Stress with the play facilities exposed to direct sunlight in the hottest hours of the day. With additional heat stress interventions, the park and playground could provide facilities for children attending nearby schools or summer camps, even on hot days. Another nearby location with open grassy fields is the De Kastanje service centre (13) next to Hoogbouwplein (11). Even though this is surrounded by greenery, it receives little cooling and heat stress reaches Level 2 extremes. De Kastanje offers social services, activities, and training for vulnerable and elderly residents and therefore deserves attention as an amenity that could offer a cool refuge for those most in need. The nearby Groenplein (14), the centre of the Debbautshoek neighbourhood, suffers from similar heat stress conditions and illustrates the importance of allowing trees time to grow. Although a row of trees were planted on the square more than 10 years ago, their canopies are still too small to create a cool corridor. The municipality aims to redevelop the neighbourhood centre in accordance with the 'Healthy Living in Debbautshoek' project

14 *Groenplein, Zelzate* ©Province of East Flanders

12 *Playground on Omer de Bruyckerstraat, Zelzate* Image: East Flanders Province

13 *De Kastanje service centre, Zelzate* ©Province of East Flanders

framework (Agenschap Zorg & Gezondheid, 2022), the square will also have a new water feature and cycle path. Assenedesteenweg (15), the primary route separating the Sint Antonious and Debbautshoek neighbourhoods, is another major heat stress location the municipality aims to redevelop.

Zelzate heat vulnerability maps

Zelzate's vegetated land cover map highlights five neighbourhoods with lower than 30% vegetation (see fig.56): Sint-Antonius, Debbautshoek, Tussen Oud en Nieuw Kanaal, Grote Markt and Bloemenbos. The lack of green in these neighbourhoods means that, with the high level of hard, impervious, surfaces these will heat up faster and store the heat longer than greener neighbourhoods, exacerbating heat stress including at night. The Tussen Oud en Nieuw Kanaal neighbourhood has lower population density (see fig.57) so fewer residents would benefit from interventions to increase heat resilience. Grote Markt and Bloemenbos are not only the most densely populated neighbourhoods in Zelzate, but almost 30% of residents are elderly who are especially vulnerable to heat stress.

On the socioeconomic status and heat stress levels map (see fig.58), the Grote Markt and Bloemenbos areas still stand out as having a socioeconomic status moderately and slightly below the city average respectively. This suggests that inhabitants there not only live in less green neighbourhoods, share this with more elderly residents (based on the maps previously discussed) but may also lack the economic means to adapt to the heat. For example, residents may need local public facilities, such as well-shaded parks or accessible water areas, to cool down. While the Klein Rusland and Hendeken neighbourhoods also have low socio-economis status, these suffer less from heat stress, have a lower population density, and more vegetation and cool areas per inhabitant (see fig.59). This indicates that residents are likely to have better access to cool spaces. Whether such assumptions correspond to reality needs to be evaluated on a street-level scale and qualitative basis. For example, the green areas near Klein Rusland appear inaccessible to the public. Despite the neighbourhood appearing green on the map, residents seem to have limited access to cool spaces. It

15 *Assenedesteenweg, Zelzate* ©Province of East Flanders

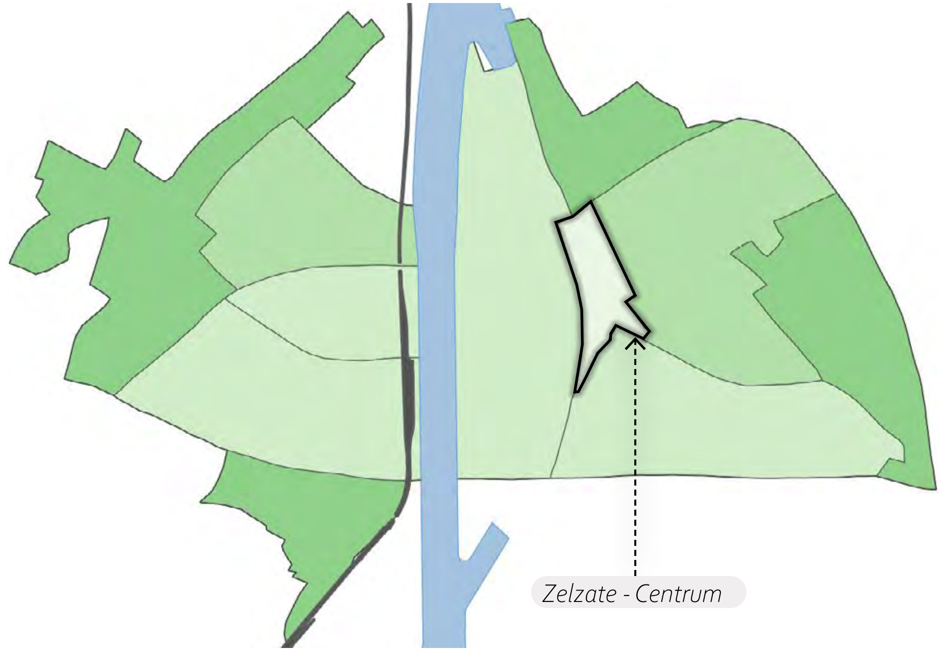
is important to remember that the cool area per inhabitant map included both public and private ground-level areas.

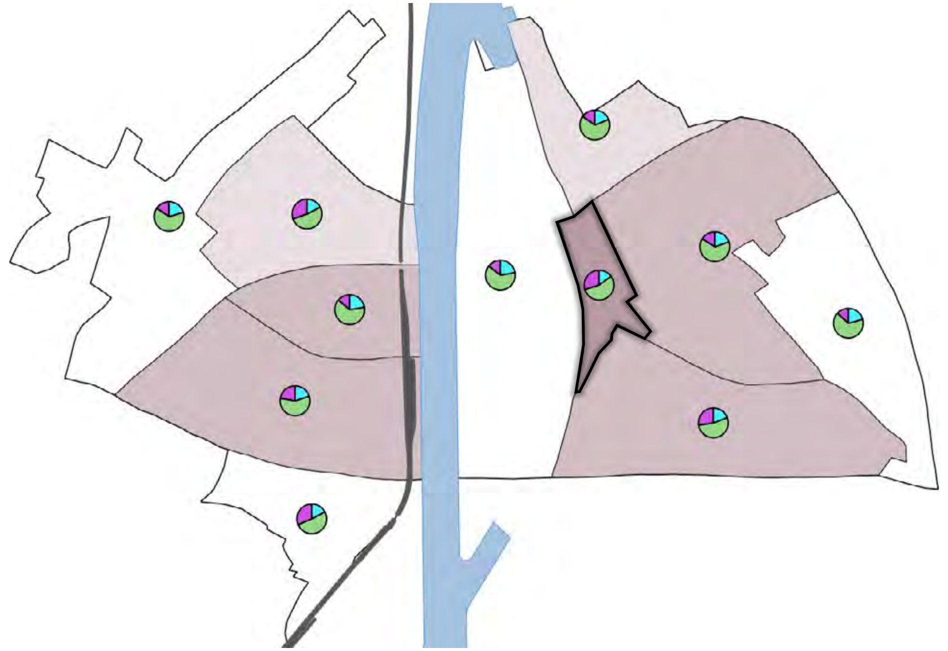
Zelzate advanced heat vulnerability map

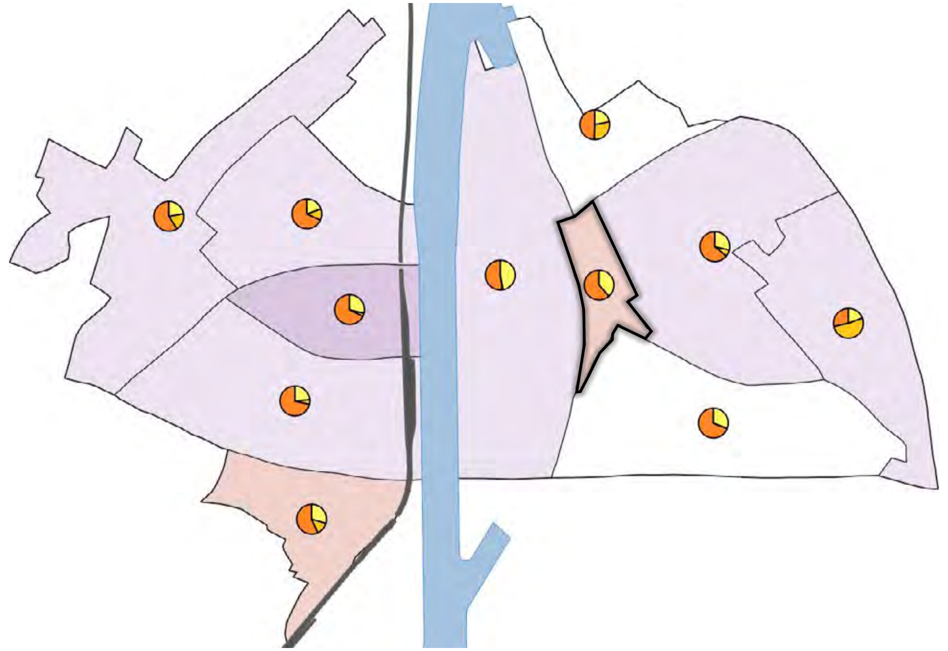
Based on Zelzate's PET and heat vulnerability maps, the Grote Markt neighbourhood in the centre emerges as one of the areas requiring attention. It has the lowest amount of vegetation, the highest population density, and least cool areas per inhabitant, combined with low socioeconomic status and a high percentage of elderly residents. In addition, it is also where the mobility hub and historic centre of the town are located. In other words, heat stress interventions here will benefit a wider audience than local residents. The municipality plans to redesign the area and prioritise cyclists and pedestrians (Zero Emission Solutions & Provincie Oost-Vlaanderen, 2018). The first greening intervention began in 2020 with tree planting on the Oostkade (5). The advanced heat vulnerability map (see fig.60) highlights not only the most urgent locations for heat stress mitigation in the neighbourhood, but also nearby parks and the primary pedestrian and cycling routes that connect this to the surrounding areas.

To form a cool corridor, the station also lacks inviting cool spaces where commuters can wait for their connection on a hot summer day. The site

Zelzate heat vulnerability maps







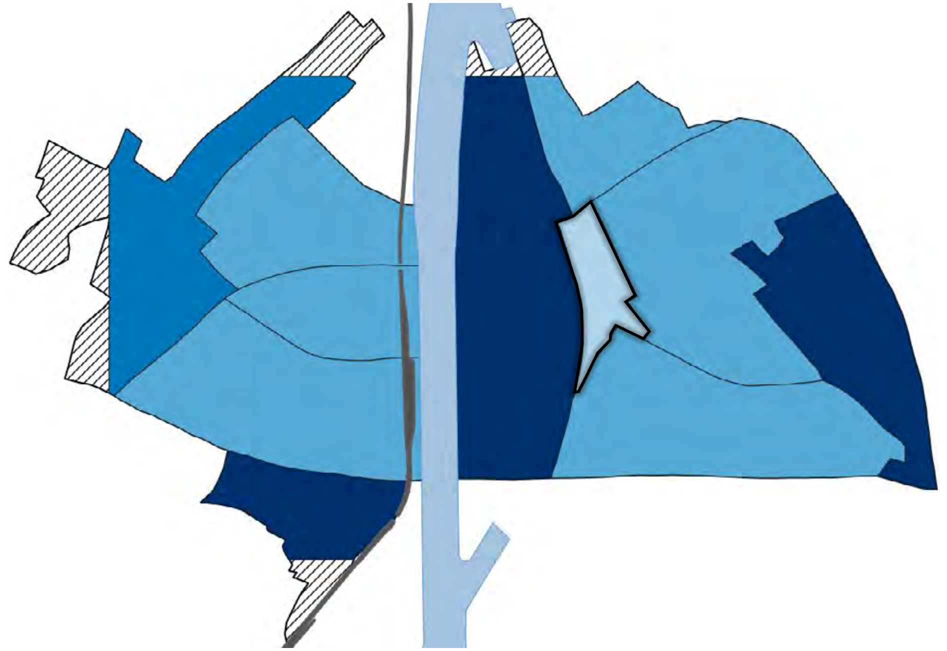


Figure 56: *Vegetated land cover*

0-10%	0-10%
0-20%	0-20%
20-30%	20-30%
30-40%	30-40%
40-50%	40-50%
	Train track

Figure 57: *Population density and age distribution*

Population density

- 0-50 m² per inhabitant
- 50-100 m² per inhabitant
- 100-150 m² per inhabitant
- 150-200 m² per inhabitant
- 200-350 m² per inhabitant
- 350-500 m² per inhabitant
- >500 m² per inhabitant

Age distribution

- > 65
- 18 - 64
- 0 - 17
- Water
- Train track

Figure 58: *Socioeconomic status (SES) and heat stress levels (PET)*

Socioeconomic status

- Extremely below city average
- Strongly below city average
- Moderately below city average
- Slightly below city average
- Slightly above city average
- Moderately above city average
- Strongly above city average

Heat stress levels

- 46-51 Extreme Heat Stress (LV2)
- 41-46 Extreme Heat Stress (LV1)
- 35-41 Strong Heat Stress
- 29-35 Moderate Heat Stress
- 23-29 Slight Heat Stress
- Water
- Train track

Figure 59: *Cool outdoor ground level area per inhabitant*

- 0-10 m² [PET < 35 °C] / inhabitant
- 10-20 m² [PET < 35 °C] / inhabitant
- 20-30 m² [PET < 35 °C] / inhabitant
- 30-40 m² [PET < 35 °C] / inhabitant
- 40-50 m² [PET < 35 °C] / inhabitant
- 50-75 m² [PET < 35 °C] / inhabitant
- 75-100 m² [PET < 35 °C] / inhabitant
- 100-125 m² [PET < 35 °C] / inhabitant
- 125-150 m² [PET < 35 °C] / inhabitant
- >500 m² [PET < 35 °C] / inhabitant

- Water
- Train track
- No data

Advanced heat vulnerability map

Figure 60: *The Centrum neighbourhood in Zelzate analysed during the rush hour TCL scenario to identify locations vulnerable to heat for visitors.*

Research areas: Zelzate - Centrum
User group: visitors

- Library
- Bus stop
- Healthcare related facilities
- Playground
- Supermarket
- Market
- Hotel
- Education
- Childcare
- Swimming pool
- Regional cycling and walking route
- Rail
- Road
- 300 meter walking distance
- Park or recreation area
- Potential cool place
- Water
- Building

PET values - Rush hour scenario
- 46 - 51 Extreme heat stress (LV2)
- 41 - 46 Extreme heat stress (LV1)
- 35 - 41 Strong heat stress
- 29 - 35 Moderate heat stress

0 350 700 m

has the potential to reconnect two existing parks (1 and 3) to the north and south of the station and also to the public swimming pool in the centre (16).

The Grote Markt (6) area also suffers from Level 2 Extreme Heat stress. It already features a double row of London plane trees (Platanus X hispanica) and when these are 10-15 metre tall they could have a PET reduction capacity of 15-17 °C PET (see Spanjar et al., 2022). However, the plane trees have been topped with severe consequences for the effectiveness to mitigate heat stress. Even though the PET-map does not take anthropogenic heat into account, for example from air conditioner outlets or the infrared radiation from cars, heat stress is likely further exacerbated by the parking function of the site. The municipality's Sustainable Energy and Climate Action Plan (Zero Emission Solutions & Provincie Oost-Vlaanderen, 2018)

21 *Pedestrian path near Warrande street, Zelzate* ©Province of East Flanders

6 *Grote Markt, Zelzate* ©Province of East Flanders

aims to make the area car free and dedicate it to pedestrians and cyclists. Hopefully pruning trees in this way will not happen in future to optimise thermal comfort of these users during hot periods.

The advanced heat vulnerability map demonstrates important pedestrian and cycling routes leading from the centre to east Zelzate that are vulnerable to heat. For example, Burg. J. Chalmetlaan (17), Patronagestraat (18) and Leegstraat (19) connect the central mobility hub to shopping areas, educational and healthcare facilities, and all suffer from extreme heat stress levels. There are also some routes that already receive cooling from parks or nearby buildings, for example the Kerkstraat (20) is shaded by the buildings on its western side. The municipality aims to allocate the pedestrian path parallel to Warande street (21) as a pedestrian and cycling route as this path runs through a park and a wooded area and has potential to become a cool route (Traject, 2010).

7. Saint-Omer, France

Saint-Omer satellite map

Figure 61: *Google, Imagery ©2022 CNES / Airbus, Landsat / Copernicus, Maxar Technologies, Map data ©2022*

Area	*16,4 km²*
Population	*14.903 (2019)*
Population density	*909 people / km² (2022)*

0 500 1000 m

Saint-Omer

The French municipality of Saint-Omer is part of the Agglomeration Community of the Pays de Saint-Omer and the home to the historic town of Saint-Omer and the associated wetlands and marshes (see fig.61). In its climate adaptation agenda, the municipality aims to build on this heritage and work with water to create a climate resilient urban habitat (Atelier Iris Chevret, 2021; AUD Saint-Omer, 2021). Saint-Omer's Nature and Biodiversity Plan (ibid.) envisages the transformation of the historic courtyards into islands of refreshing green space forming a cool network in the town. Softening and greening impervious surfaces forms the other pillar of the municipality's heat adaptation strategy (ibid.). The PET-maps developed in the Cool Towns project provide the opportunity to directly link these ambitions to current heat stress challenges and highlight future redevelopment projects and new sites for climate adaptation.

8 *Le Jardin Public, Saint-Omer* *Image: Saint-Omer City Archive*

City — *Neighbourhood* — *User Network*

4 *Rue Saint-Martin, Saint-Omer* *Image: Saint-Omer City Archive*

Saint-Omer lunchtime TCL scenario

Observing Saint-Omer's Thermal City Life lunchtime scenario (see fig. 62), major areas of green infrastructure, with bushy or wooded land cover come to the forefront. The Audomarois marshland (1) for example, north of the town is of high biodiversity value and recognised under the RAMSAR convention as a wetland of international importance. Much of this protected area is cooler than its surroundings with Slight Heat Stress, instead of Level 1 Extreme Heat Stress but to benefit from this would require residents and visitors to take a boat trip as there is no easy access by bike or on foot. In contrast, to the east of the town lies the Clairmarais forest (2) which provides a great escape from the heat with its densely enclosed foliage, and multiple cycling and walking paths. The cycling route leading from the station and city centre to the forest, Rue de Dunkerque (3) and Rue Saint-Martin (4), are exposed to high heat stress. This may form a barrier for citizens wishing to escape the heat. In contrast, a segment of the path is conveniently cool to walk and cycle under the large, full grown,sweet

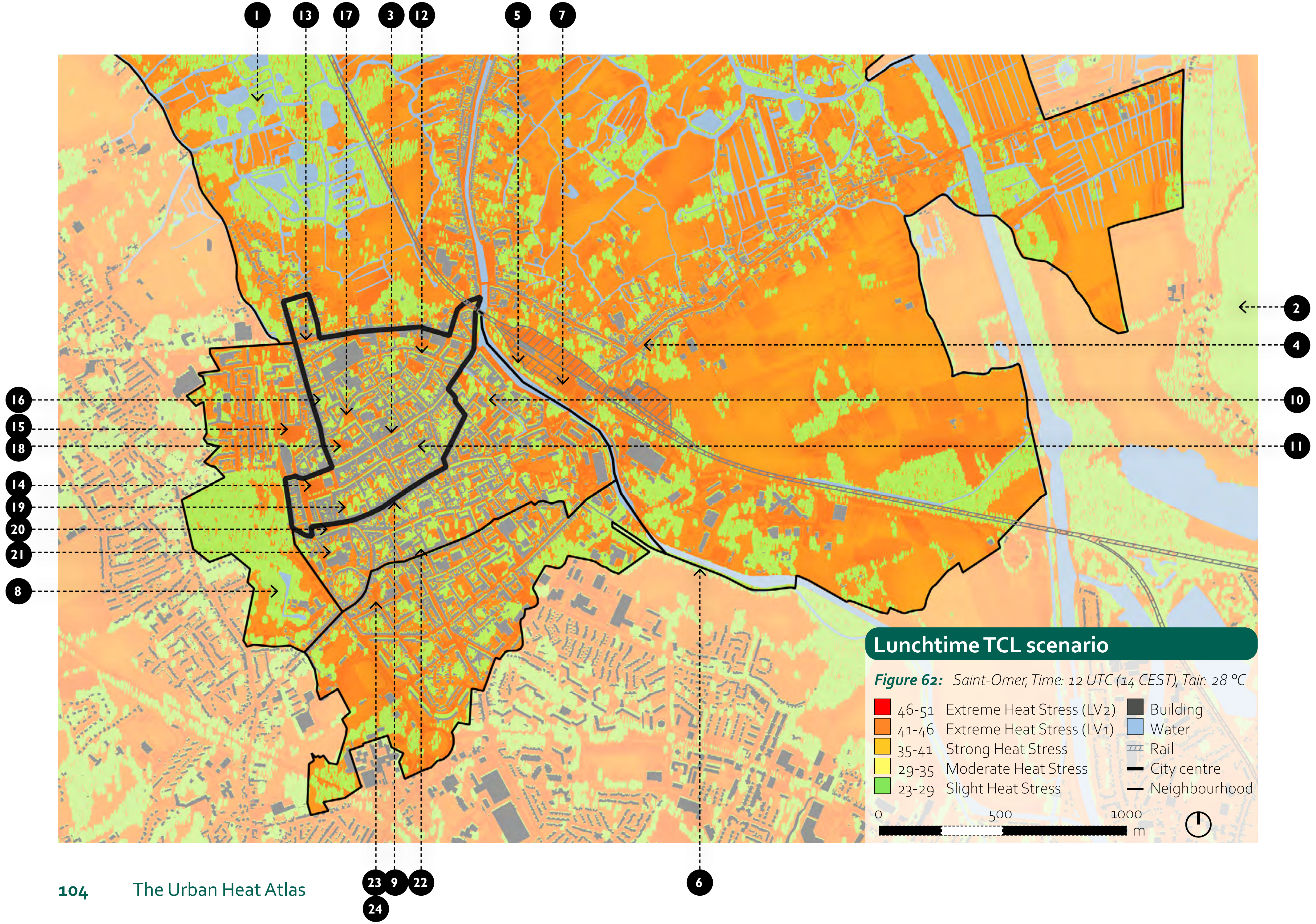


Figure 62: Saint-Omer, Time: 12 UTC (14 CEST), Tair: 28 °C

chestnut trees (Castanea sativa) at Allée des Marronniers (5). Saint-Omer measured the cooling benefit of this row of trees during the Cool Towns project, and demonstrated an 18 °C PET reduction on a warm August day around lunchtime (see Spanjar et. al., 2022 for the specific factsheet). The Nature and Biodiversity plan (AUD Saint-Omer, 2021) aims to green the Rue de Dunkerque (3) to benefit not only cyclists but also shoppers and tourists who visit this important historic street for its amenities. Creating cool routes can contribute to Saint-Omer's climate-friendly mobility ambitions (AUD Saint Omer, 2020) by encouraging cycling and walking all year-round.

The cooling of Alleé des Marronniers (5) will also benefit cyclists using the new section of the EuroVelo n°5 cycling route that connects many villages in the region famous for their viticulture (Eurovelo, 2022). This European route will pass through the Chemin de Halage (6) green park alongside the canal that in the lunchtime scenario has only Slight Heat Stress.

9 Rue Carnot, Saint-Omer

5 Allée de Marronniers, Saint-Omer

Next to the station the municipality is developing the Halle aux Choux (7) urban regeneration project, and when this is complete the new users will immediately benefit from the existing cooling capacity of this row of chestnut trees (5). Currently the site is exposed to extreme heat stress around lunchtime and will serve as a demonstration site for tackling heat stress. The most accessible park for residents and employees looking for thermal comfort outdoors during their lunch break is the Jardin Public de Saint-Omer (8) with a typical 19th century landscape lay-out. The garden is popular with citizens. The area offers a combination of French and English gardens with ponds and fountains providing additional cooling features; there are also remnants of historic fortifications. Rue Carnot (9) is the fastest route between the station and the park and, even though it lacks trees, the east-west orientation of the street creates a shaded route on the southern pavement.

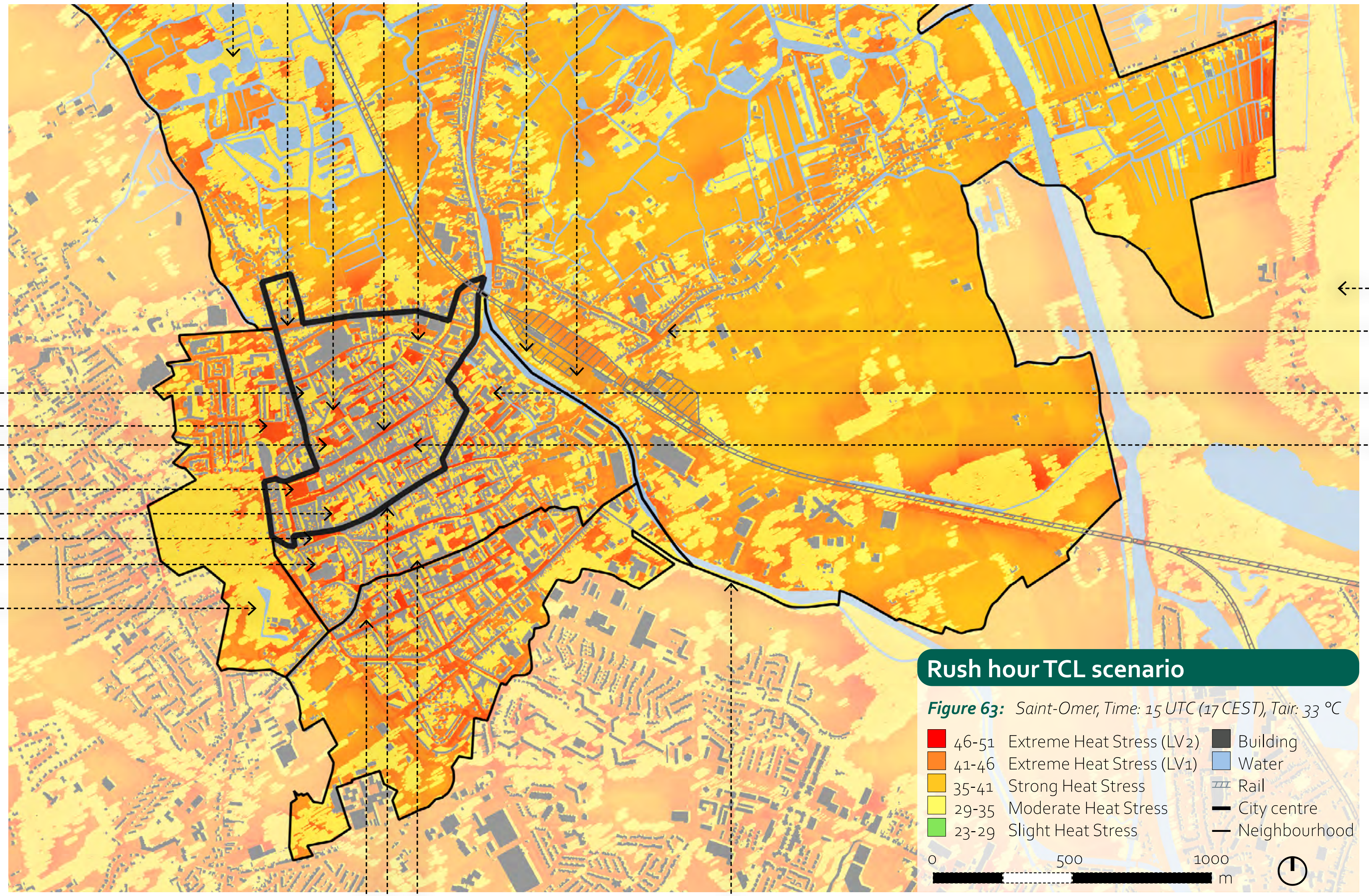


Figure 63: Saint-Omer, Time: 15 UTC (17 CEST), Tair: 33 °C

Saint-Omer rush hour TCL scenario

In the rush hour scenario (see fig.63) Saint-Omer demonstrates how heat stress develops through the course of the day, intensifying in the urban areas while the open green fields on the peri-urban fringe, with plenty of air circulation, begin to slowly cool down. Most of the town's public spaces, such as main streets, squares, school playground and parking plots suffer from Level 2 Extreme Heat Stress. Impermeable hard surfaces play a major role in this by absorbing heat and then releasing it during the afternoon (and night). The Montaigne school playground (10) is located in a Level 2 Extreme Heat spot and has been used as a Cool Towns pilot site. The new design softens the hard, impervious surfaces by changing the land cover, by planting trees and creating water infiltration ditches. Through this project the municipality aims to set a minimum standard for climate-proofing school playgrounds and intends to carry out a series of similar projects across the town.

10 Montaigne school (left & right) , Saint-Omer

City — Neighbourhood — User Network

Saint-Omer heat vulnerability maps

Climate proofing school yards is an important step towards a heat resilient Saint-Omer ensuring that outdoor play, important for child development, can continue even during the warmest periods of the year. The town centre has no less than sixteen primary and secondary schools, many exposed to extreme heat. Apart from children, understanding where other vulnerable groups, such as the elderly and ill, reside and how these groups use amenities, provides important data for prioritising heat stress interventions. The age distribution charts for Saint-Omer (see fig.65) show a balanced picture with the exception of the Saint Expúry - Saint Michel neighbourhood. This has a higher population of children, while the Vauban Canal neighbourhood has fewer elderly residents than other areas. The same map shows the city centre is the most densely populated area and implies that interventions there will be likely to benefit most inhabitants.

Saint-Omer's map of socioeconomic status (see fig.66) highlights the Saint Expúry - Saint Michel neighbourhood as having a lower score than the town average. The municipality has designated part of this neighbourhood, Saint Expúry and Léon Blum, as requiring intervention to address social challenges. The pie charts of the neighbourhood PET averages provide a more nuanced understanding of heat stress exposure showing the Saint Expúry - Saint Michel neighbourhood suffers less heat stress than the rest of the town. Nevertheless, heat stress interventions here are still important as residents with low socio-economic status are often limited in their ability to adapt to heat stress and might suffer increased indoor heat due to poorly insulated housing.

The vegetated land cover map (see fig.64) and cool outdoor ground level area per inhabitant map (see fig.67) bring the historic centre, the Centre Ville and Vauban Canal neighbourhoods, into focus. Based on the analysis of the two Thermal City Life scenarios it is not surprising that hard impermeable surfaces, combined with absence of greenery, in the town centre contributes to the highest average heat stress levels and lowest quantity of cool outdoor space per inhabitant.

Saint-Omer advanced heat vulnerability map

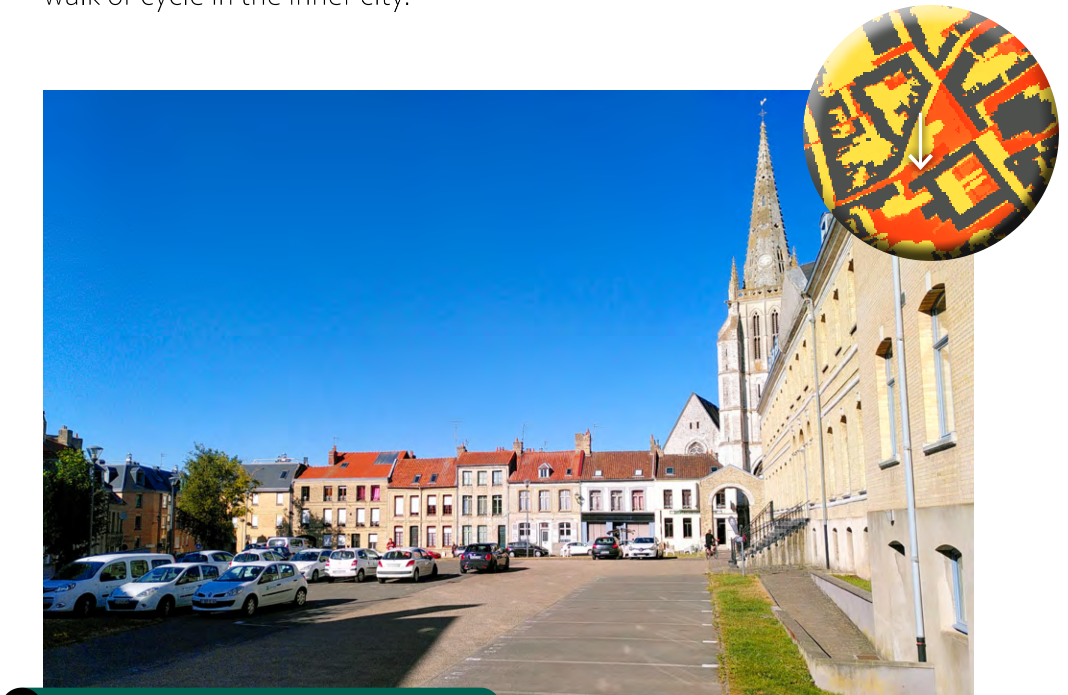
Saint-Omer's heat vulnerability maps highlight the town centre as having the highest heat stress vulnerability. Historic centres with narrow passages, high building density and an excess of impermeable surfaces often follow this trend and require innovative heat adaptation strategies due to the congestion of below ground services and monumental value. In Saint-

3 *Rue Dunkerque, Saint-Omer* ©AUD Saint-Omer

14 *Place du Maréchal Foch, Saint-Omer* ©AUD Saint-Omer

Omer, the area within the mediaeval city walls suffers Level 1 Extreme Heat Stress at lunchtime which intensifies to Level 2 around the rush hour. In a co-creation session, the municipality prioritised the centre to zoom in on for advanced heat vulnerability analysis. The area was recently designated for remarkable heritage (Site patrimoniale remarquable) providing Saint-Omer with the opportunity to go beyond preservation to enhancing it with climate-resilient interventions. As the area provides amenities for a range of user groups, such as children, the elderly, commuters, shoppers and recreational visitors, the advanced heat vulnerability map (see fig.68) can be used to analyse the challenges and opportunities for improvement based on how visitors might use the area during the rush hour.

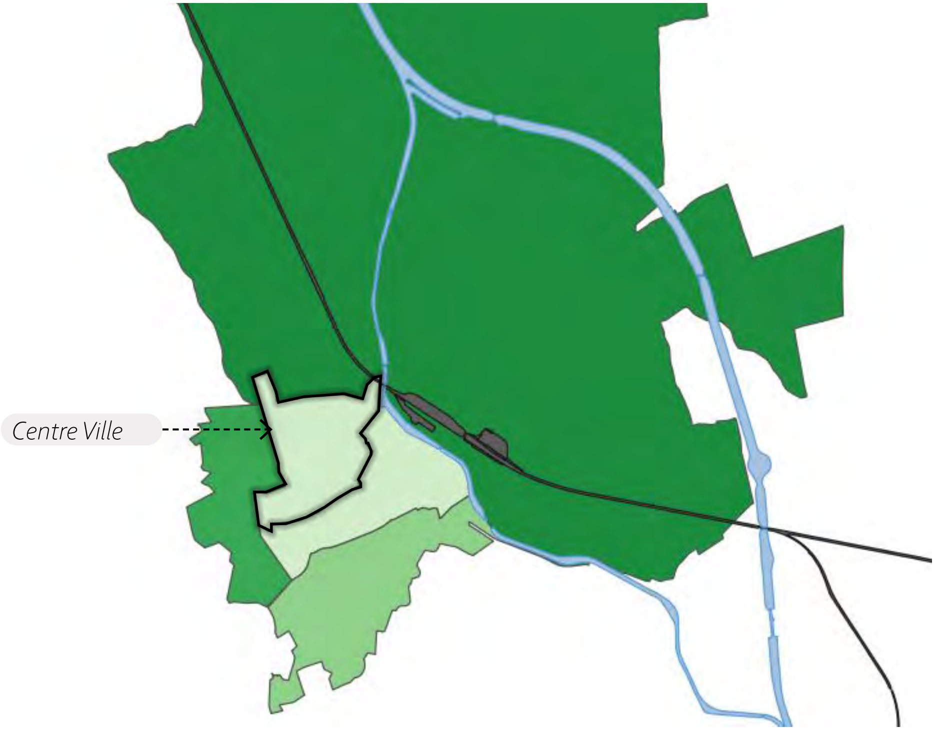
The northeast – southwest oriented primary streets leading from the station towards the old town centre are under Level 1 to Level 2 Extreme Heat Stress. Apart from the Rue de Dunkerque (3), Rue Carnot (9), Rue Allent (11), Rue Edouard Devaux (12) and the Boulevard de Strasbourg (13) all are uncomfortable routes on hot days. Conversely, streets running from north to south begin to receive shade in the afternoon from the buildings on their western side reducing heat stress to Moderate level. The area around Saint-Omer's theatre, with many cultural and shopping facilities, is also in need of cooling interventions. Around the Place du Maréchal Foch (14) square and parking area, a row of trimmed lime (Tilia spp.) trees provide shade but only cars seem to benefit. The municipality's Nature and Biodiversity Plan (AUD Saint-Omer, 2021) has identified this parking area, along with six others nearby (Parking de l'Esplanade (15), Parking Suger (16), parking on Rue Victor Luc (17), Parking des Carmes (18), parking on Place du Vieux Marché (19), and the parking on Place Victor Hugo (20)), as future areas for greening and/or improvement. The abundance of car parks also signifies Saint-Omer's car dependency. Cool cycle and pedestrian routes and attractive places may influence, as discussed in chapter one, the choice of transport. Improvements may encourage more residents to walk or cycle in the inner city.

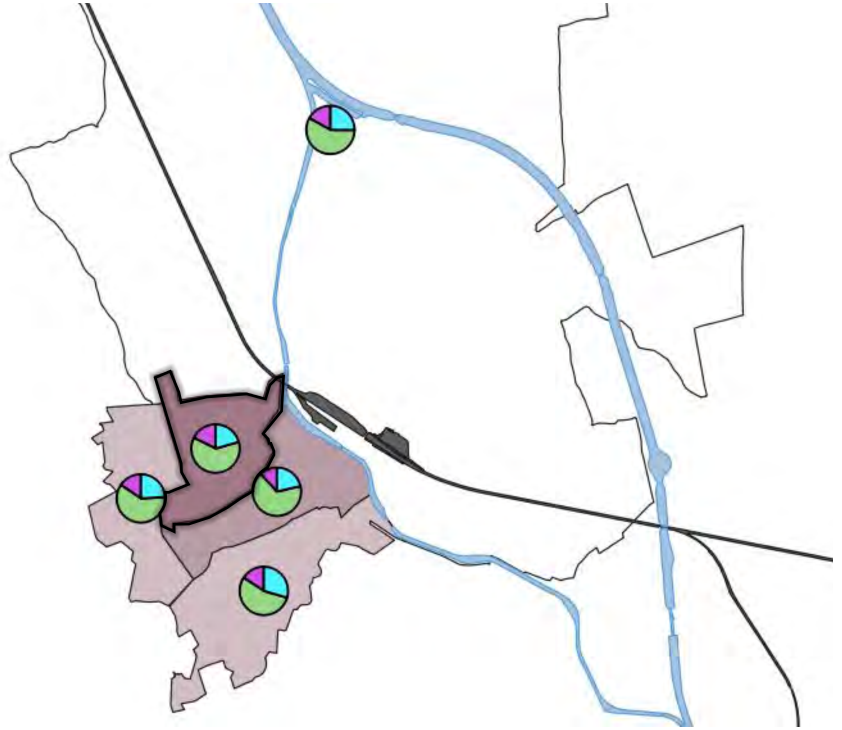


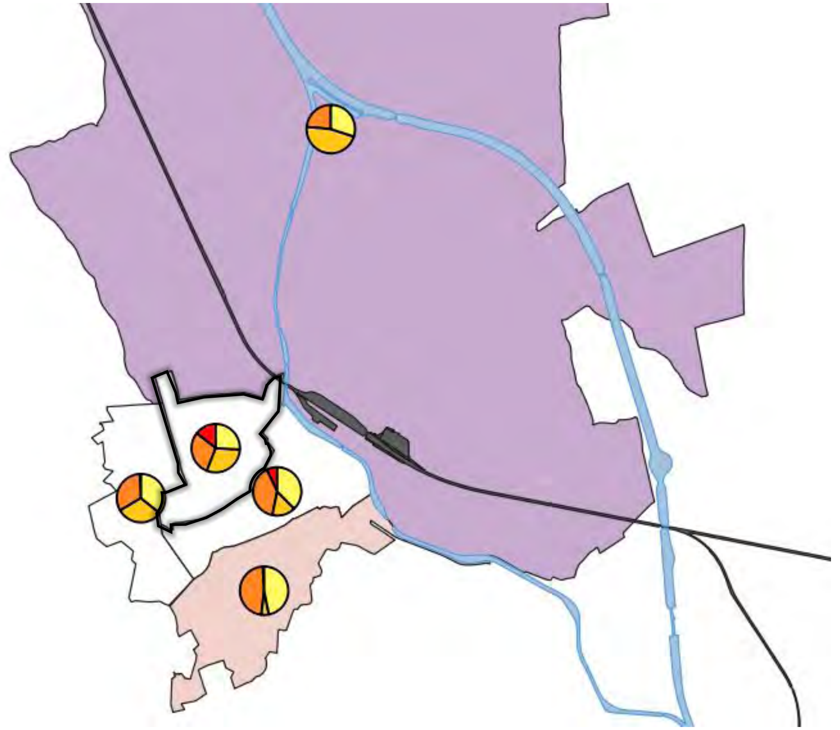
17 *Parking on Rue Victor Luc, Saint-Omer* ©AUD Saint-Omer

City — Neighbourhood — User Network

Saint-Omer heat vulnerability maps







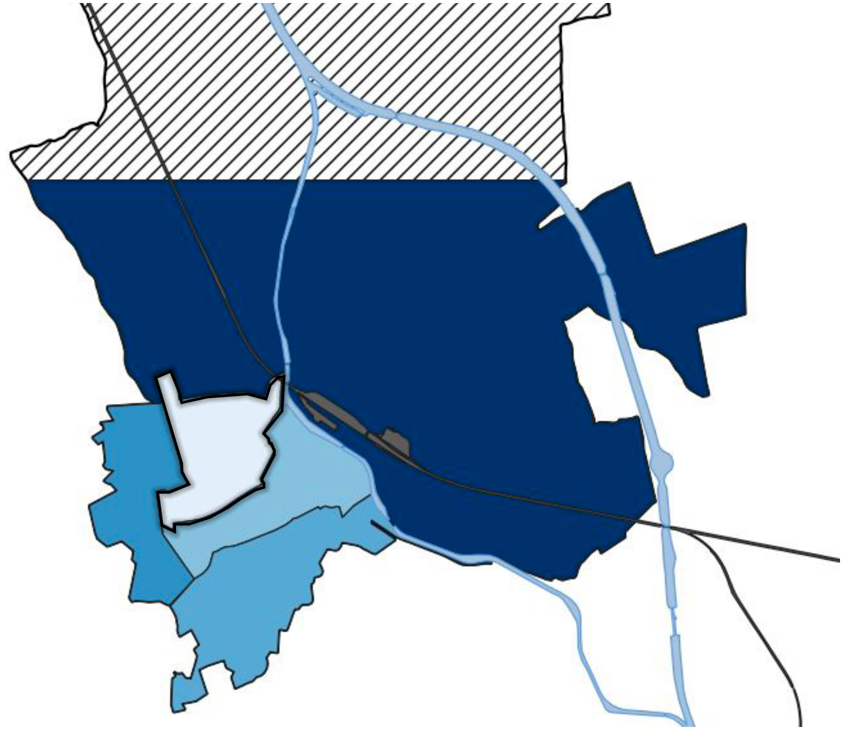


Figure 64: *Vegetated land cover*

- 0-10%
- 0-20%
- 20-30%
- 30-40%
- 40-50%

- 0-10%
- 0-20%
- 20-30%
- 30-40%
- 40-50%
- Water
- Train track

Figure 65: *Population density and age distribution*

Population density

- 0-50 m^2 per inhabitant
- 50-100 m^2 per inhabitant
- 100-150 m^2 per inhabitant
- 150-200 m^2 per inhabitant
- 200-350 m^2 per inhabitant
- 350-500 m^2 per inhabitant
- >500 m^2 per inhabitant

Age distribution

- > 65
- 18 - 64
- 0 - 17
- Water
- Train track

Figure 66: *Socioeconomic status (SES) and heat stress levels (PET)*

Socioeconomic status

- Extremely below city average
- Strongly below city average
- Moderately below city average
- Slightly below city average
- Slightly above city average
- Moderately above city average
- Strongly above city average

Heat stress levels

- 46-51 Extreme Heat Stress (LV2)
- 41-46 Extreme Heat Stress (LV1)
- 35-41 Strong Heat Stress
- 29-35 Moderate Heat Stress
- 23-29 Slight Heat Stress
- Water
- Train track

Figure 67: *Cool outdoor ground level area per inhabitant*

- 0-10 m^2 [PET < 35 °C] / inhabitant
- 10-20 m^2 [PET < 35 °C] / inhabitant
- 20-30 m^2 [PET < 35 °C] / inhabitant
- 30-40 m^2 [PET < 35 °C] / inhabitant
- 40-50 m^2 [PET < 35 °C] / inhabitant
- 50-75 m^2 [PET < 35 °C] / inhabitant
- 75-100 m^2 [PET < 35 °C] / inhabitant
- 100-125 m^2 [PET < 35 °C] / inhabitant
- 125-150 m^2 [PET < 35 °C] / inhabitant
- >500 m^2 [PET < 35 °C] / inhabitant

- Water
- Train track
- No data

Advanced heat vulnerability map

Figure 68: The Centre Ville neighbourhood in Saint-Omer analysed during the rush hour TCL scenario to identify locations vulnerable to heat for visitors.

Research Area: Saint-Omer - Centre Ville
User group: visitors

- Cultural facility
- Supermarket
- Bus stop
- Hotel
- Train station
- Education
- Childcare
- Playground
- Rail
- Road
- 300 meter walking distance
- Future park
- Potential cool place
- Park or recreation area
- Water
- Building

PET values - Rush hour scenario
- 46 - 51 Extreme heat stress (LV2)
- 41 - 46 Extreme heat stress (LV1)
- 35 - 41 Strong heat stress
- 29 - 35 Moderate heat stress

0 250 500 m

The advanced heat vulnerability map shows the Jardin Public de Saint-Omer (8) as the largest cool place where inner city visitors can escape hot weather. Even though heat is exacerbated in the park, rising from Slight Heat Stress levels at lunchtime to Moderate levels at rush hour, under the dense foliage temperatures are still below 35 °C PET. Tucked away in the courtyard of the nearby Tourist Information Centre (21) hides another cool oasis where visitors can rest and refresh. The courtyard of the Library de l'Agglomération de St-Omer (22) is a similar hidden gem. Saint-Omer has a rich heritage of historic courtyards that the municipal Heritage Strategy aims to transform into restful islands linked in a blue-green network (ibid.). The municipality is building on pilot interventions such as the Cool Towns project at the Montaigne school playground (10) to understand best practices for introducing permeable surfaces and planting trees with substantial cooling benefits. As many courtyards are semi-private, Saint-Omer is also looking at introducing opening times when, for example, a school playground could be open to visitors at weekends. The town will test this strategy by connecting an adjacent parking lot and school playground with water as a climatic and design element. They envision the courtyard as a green oasis and playground for children and visitors alike.

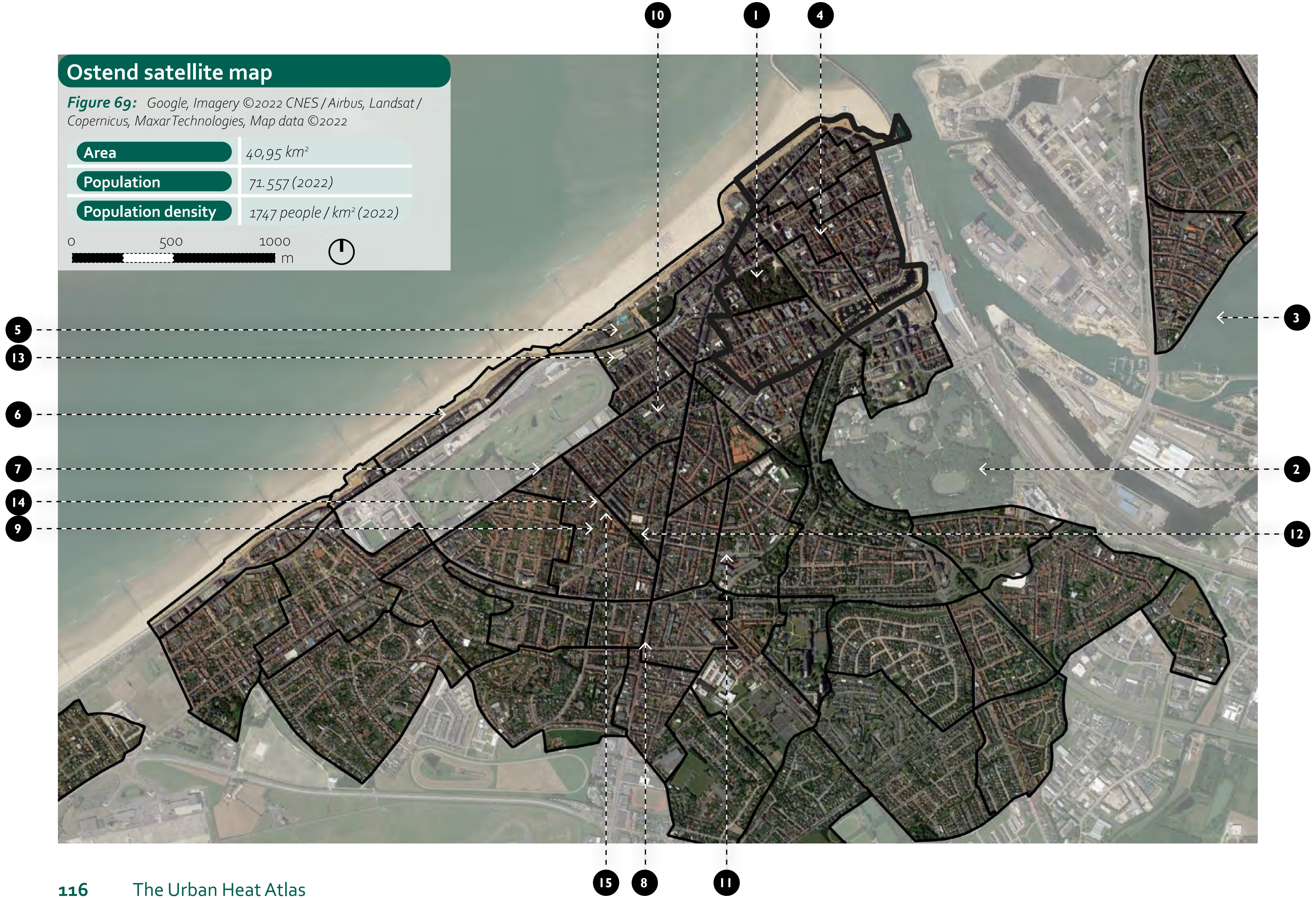
21 *Tourist Information Centre, Saint-Omer* © AUD Saint-Omer

8. Ostend, Belgium

Ostend satellite map

Figure 69: *Google, Imagery ©2022 CNES / Airbus, Landsat / Copernicus, Maxar Technologies, Map data ©2022*

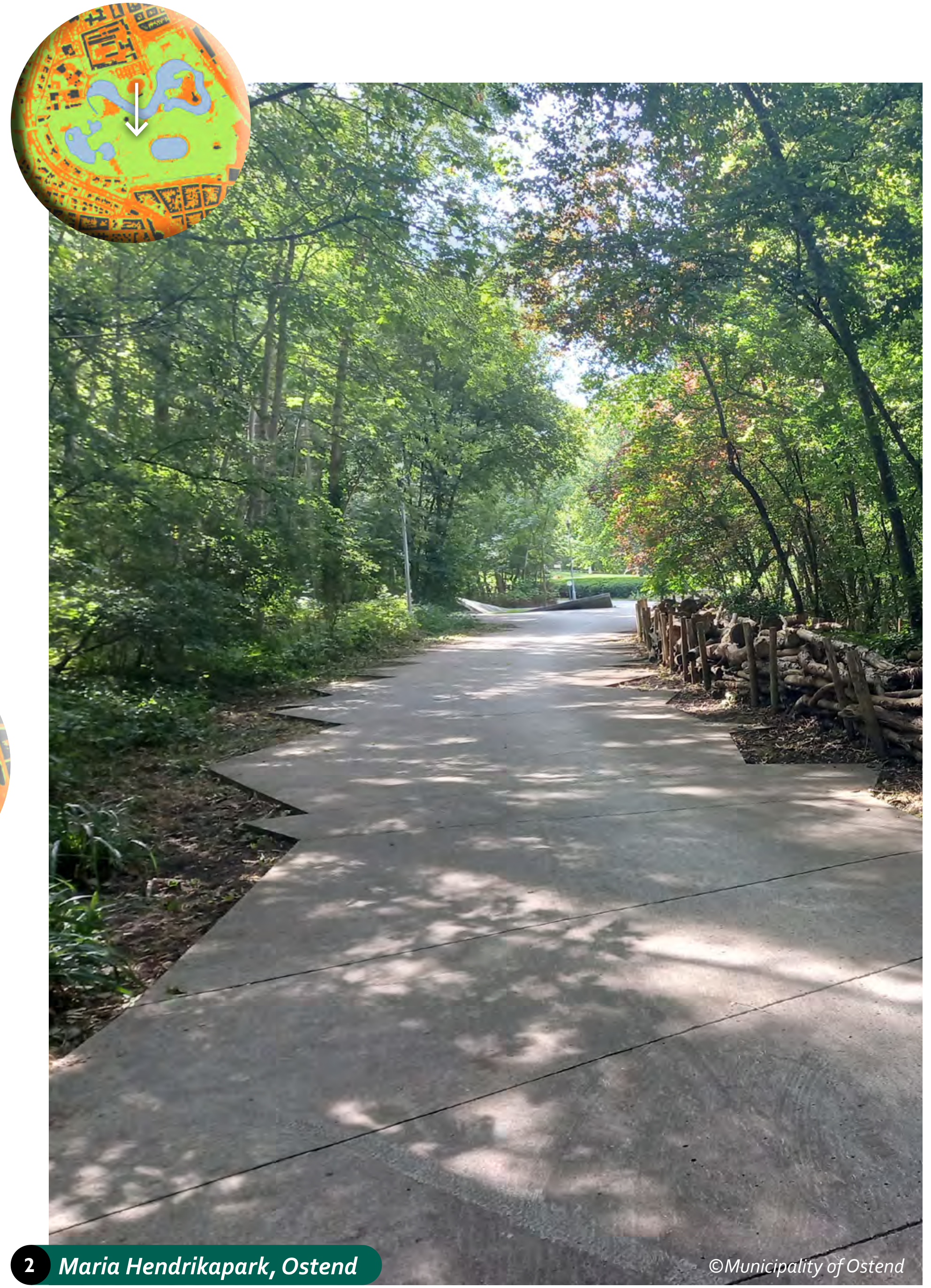
Area	40,95 km²
Population	71.557 (2022)
Population density	1747 people / km² (2022)



Ostend

Ostend is a medium-sized city on the Belgian coast, in the province of West Flanders (see fig.69), with an ambitious plan to achieve climate neutrality by 2050. In the summer of 2021, the city published a new climate agenda, 'Liveable Ostend' (Cyx & Berghe, 2021), in which climate related goals play an important role in adapting the urban fabric to the unavoidable consequences of climate change including extreme urban heat. Ostend recognises heat stress as an urgent local impact of climate change with severe consequences for the health and wellbeing of residents. In the 'Liveable Ostend' climate plan, the city proposes to map the impact of heatwaves and assess the associated risks and vulnerabilities as a first step to prioritising adaptation actions (ibid.).

1 *Leopoldpark, Ostend* ©Municipality of Ostend



2 *Maria Hendrikapark, Ostend* ©Municipality of Ostend

City → *Neighbourhood* → *User Network*

Lunchtime TCL scenario

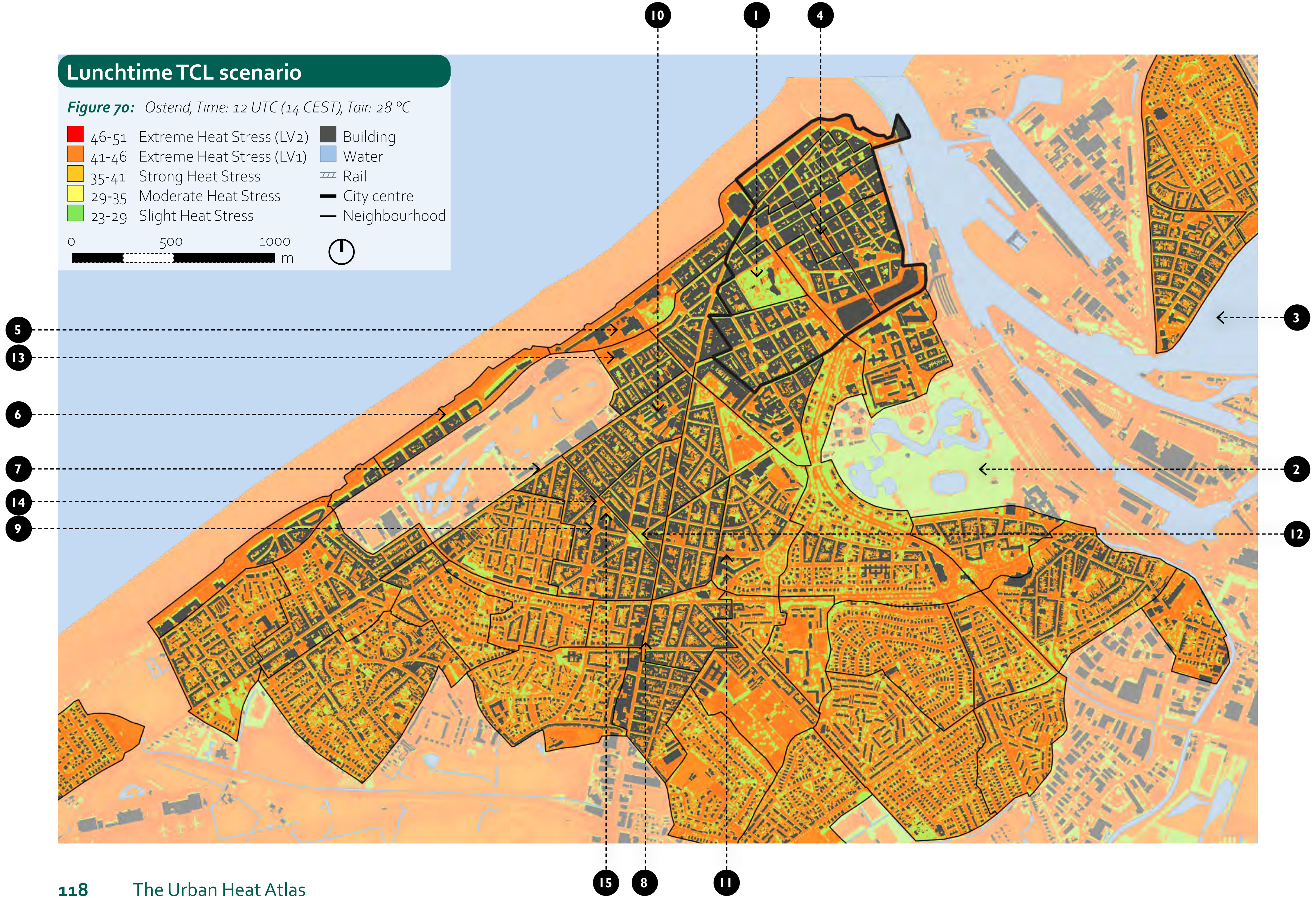


Figure 70: *Ostend, Time: 12 UTC (14 CEST), Tair: 28 °C*

3 ***Spuikom, Ostend***

©LimoWreck, cc by-sa 3.0, unedited

Ostend lunchtime TCL scenario

The Thermal City Life scenarios (TCL) aim to provide in-depth insights into local heat stress dynamics in Ostend. During the lunchtime scenario (see fig.70), the entire city is under Level 1 Extreme Heat Stress, except the green-coloured pockets (Slight Heat Stress), indicating locations shaded, often by buildings in the dense centre, and closer to the urban edge by lines of trees. Leopoldpark (1) and Maria Hendrikapark (2) built on the old city wall and in the military zone were transformed in the late 20th century into public parks where residents can enjoy green space and play sports (football, cycling and mini- golf) in thermally comfortable surroundings. Water recreation plays an important role with several large ponds and fountains in both these parks complementing the cooling effect of the greenery - an attractive way to mitigate heat stress. Larger water bodies, such as the North Sea and the Spuikom artificial lake (3), appear to have limited effect in reducing heat stress in the historic city centre. This would require strong winds to carry water vapour into the city through carefully oriented streets acting as wind channels. The lunch time scenario also shows that peri-urban areas with vast green fields also heat up significantly as there is no shade from direct solar radiation.

6 ***The North Sea at Zeedijk, Ostend***

©Municipality of Ostend

City – *Neighbourhood* – *User Network*

Rush hour TCL scenario

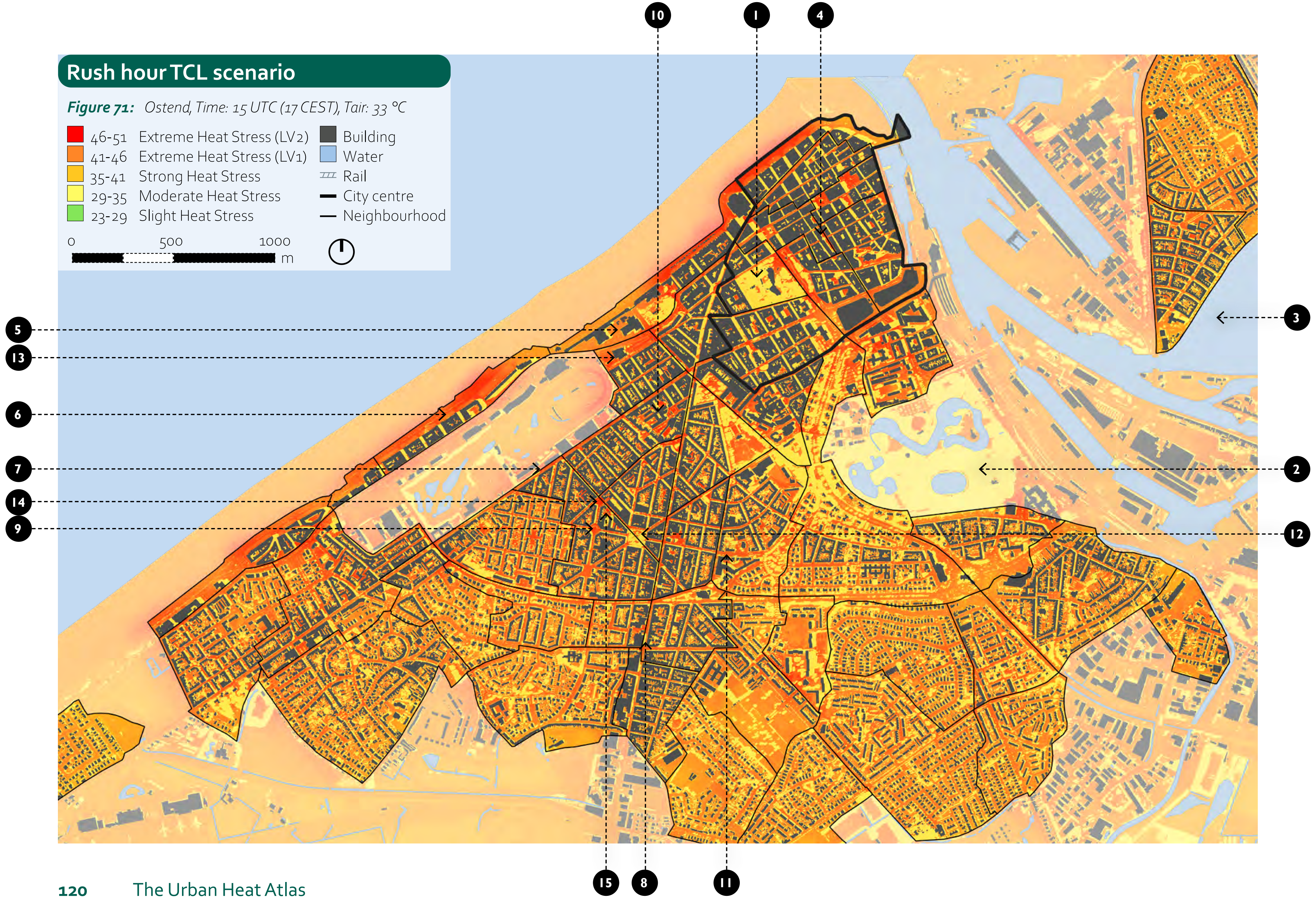
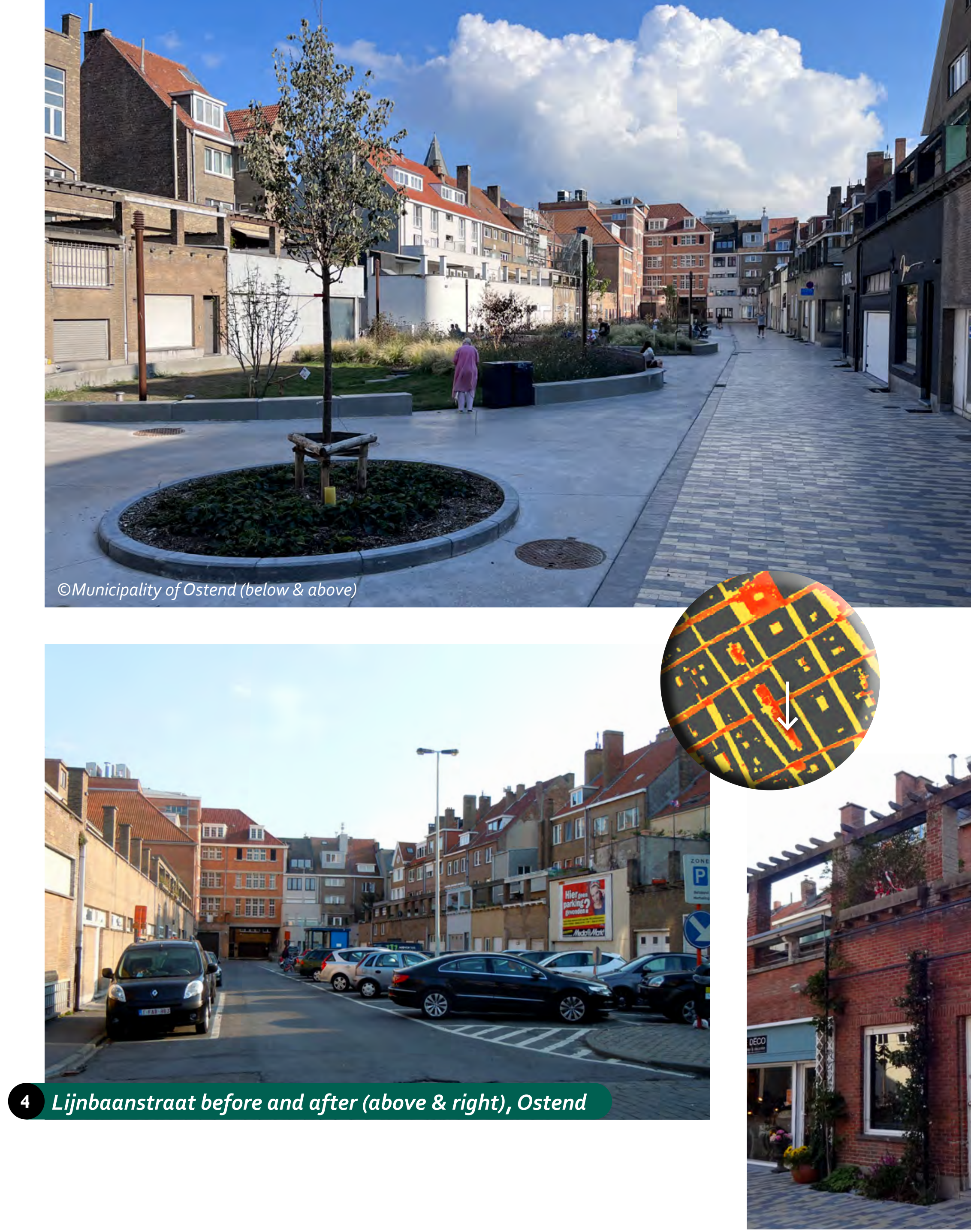


Figure 71: *Ostend, Time: 15 UTC (17 CEST), Tair: 33 °C*

Ostend rush hour TCL scenario

In the rush hour scenario (see fig.71), heat in the city increases especially in the historic, densely built up inner-city which is then experiencing Level 2 Extreme Heat Stress. These historic districts dating back to the Middle Ages and which have evolved organically with narrow passages and paved piazzas, are symptomatic of heat problems. Solutions are not easy to implement in these narrow shopping streets although there is potential to reach a large number of inhabitants as every inch has been used. Ostend has investigated how cooling capacity could be built-in to reduce the risk of heat related illnesses and improve the thermal comfort of visitors. A car park in the busiest historic area, called the Lijnbaanstraat (4), was chosen as a Cool Towns pilot site to be transformed to a cool green spot for people who would like to rest while doing their shopping. The design consists of pergolas with climber plants placed along the walls of the shops and several 'islands' of raised flower beds, with seating around the edges. The green facades, when fully established, will make it thermally attractive to walk next to these and the islands of green with trees are inviting resting places. Rain water is collected in underground water reservoirs to make sure the plants here - and in other parts of the centre - can be watered in times of drought.

Following this inspiring project, the city intends to further reduce parking in the centre, thereby creating more opportunities for greening. For example, with the projected demolition of the old municipal swimming pool (Stad Oostende, 2022) and the transformation of the nearby parking area at the Thermal Palace (5) the opportunity arises to recreate the former garden by the Royal Galleries as a cool oasis, at the intersection of two severe heat stress areas: the historic centre and the beach. A large cool walking area such as the Cliff Gardens (in Southend) can ensure that the city remains



4 *Lijnbaanstraat before and after (above & right), Ostend*

City *Neighbourhood* *User Network*

8 *Torhoutsesteenweg, Ostend*

©Municipality of Ostend

attractive during heat waves and extreme temperatures when the strategy of taking a refreshing jump into the sea is no longer sufficient to cool down. The Zeedijk (6), the coastal promenade which is the main route to the beach, exposes visitors to extreme heat even before they reach the beach. During the lunchtime scenario, seaside buildings still provide a narrow ribbon of shade. However, a few hours later, the Zeedijk stands in full sun, and is also exposed to high infrared radiation, reflected by the impervious surfaces, glassy facades and the sandy beach. When aiming to work towards heat resilience this could be one of the main priorities for spatial adaptation.

Other important routes in the city, such as the Nieuwpoortsesteenweg (7) or Torhoutsesteenweg (8), also experience high heat stress. On the latter, small scattered Dutch elm (Ulmus 'Columella') trees provide sporadic shade with their columnar crowns but these are too far apart to merge. Here in the dense inner-city area, many squares and car parks present an opportunity to become cool spots. The H. Conscienceplein (9) already functions as a small neighbourhood park, but the fastigiate trees provide limited cooling for users. The former site and parking area of the Sint-Jozef hospital (10), next to the Rose d'Ivry Park, are also vulnerable to heat stress. Ostend has anticipated the heat problems here and reacted by transforming this area with residential infill development featuring a series of public green courtyards.

Ostend heat vulnerability maps

The four heat vulnerability maps complement the two Thermal City Life scenarios in Ostend with an additional layer of information showing where heat stress becomes a pressing issue and for whom. Ostend's vegetated land cover map (see fig.72) shows most coastal, historic and inner-city neighbourhoods have low amounts. Residents in these areas might struggle with both daytime and night-time heat stress. When areas of high population density are added (see fig.73), the historic centre and the inner city stand out, corresponding to the Centre and Westerkwartier districts, respectively. These highly populated areas indicate where climate-adaptive interventions may benefit most inhabitants. Looking at the age distribution in Ostend's neighbourhoods, elderly residents are the majority in the historic centre deserving special attention, whilst children are a significant vulnerable group in the inner city.

The map showing socio-economic status and heat stress levels (see fig. 74), further emphasises residents' vulnerability to heat in these areas. The socioeconomic status is below city average in the Centre and Westerkwartier districts, implying that residents here might have limited capacity to adapt to heat. For example, they might be unable to travel far to recreational places on hot days so need to find cool public spaces nearby to find relief from their poorly insulated homes. In Ostend Centre, there are twice as many houses dating from before 1900 as the city average, and in Westerkwartier, the percentage of homes constructed between 1900-1945 is double, underlining residents' possible increased exposure to indoor thermally uncomfortable conditions (Kadaster en Rijksregister, 2021).

The final map, cool outdoor ground level area per inhabitant (see fig.75), summarises the need to tackle heat stress in the inner city and historic centre. The overwhelming majority of homes in these areas are closed building typologies, lacking shared or private gardens and pointing to a lack of cool outdoor space where residents can escape the heat. In comparison, Ostend's peri-urban areas, where houses with gardens are the dominant typology, show high vegetation levels, lower population density, high socio-economic status and ample outdoor private space where residents may refresh.

9 *H. Conscienceplein, Ostend*

©Andries van Rijsbergen, M021152,
Beeldbank Kusterfgoed, Stadsarchief Oostende

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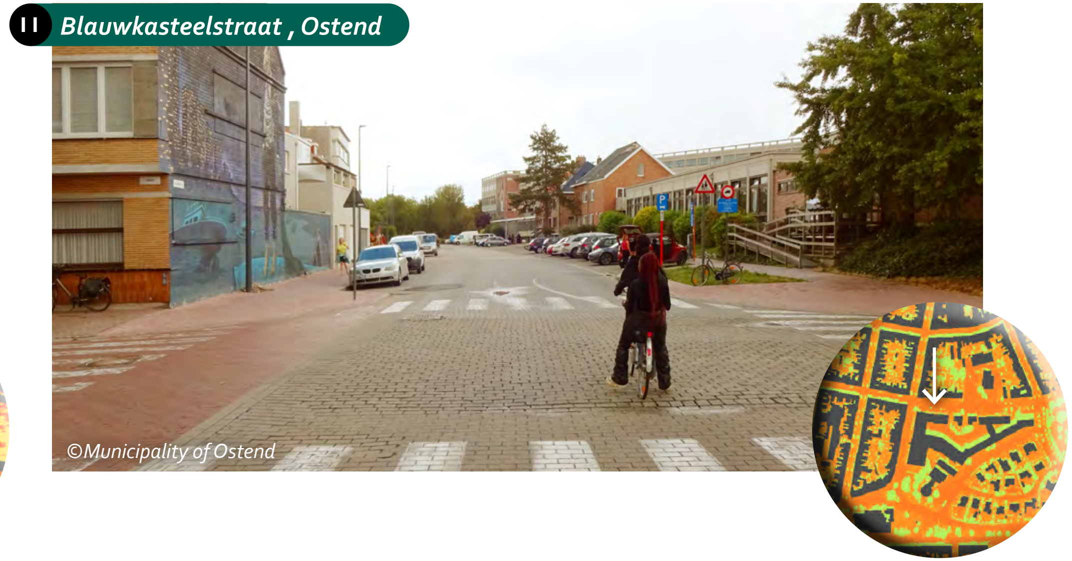
Ostend advanced heat vulnerability map

Through a collaborative analysis of the heat vulnerability maps and Thermal City Life scenarios for the City of Ostend, elderly residents living in the Centre emerge as a particularly vulnerable group. Ostend's heat adaptive Cool Towns pilot site on the Lijnbaanstraat (4) already brings an effective cool spot to this area so the advanced heat vulnerability map was used to investigate another highly vulnerable group, children, living in the inner city. The Westerkwartier has a high percentage of children and many schools, child care facilities, and playgrounds (see fig.76). The map shows how heat stress affects the walking routes and places children use during lunch hours.

In terms of cool routes, most east-west oriented roads enjoy shading on their southern pavements from the adjacent buildings, but when facades recede, the entire street is under Level 1 Extreme Heat Stress. The back of the Ensor Instituut High School on Blauwkasteelstraat (11) illustrates this well. The wide profile of the street offers room for breaking up the

11 *Blauwkasteelstraat , Ostend*



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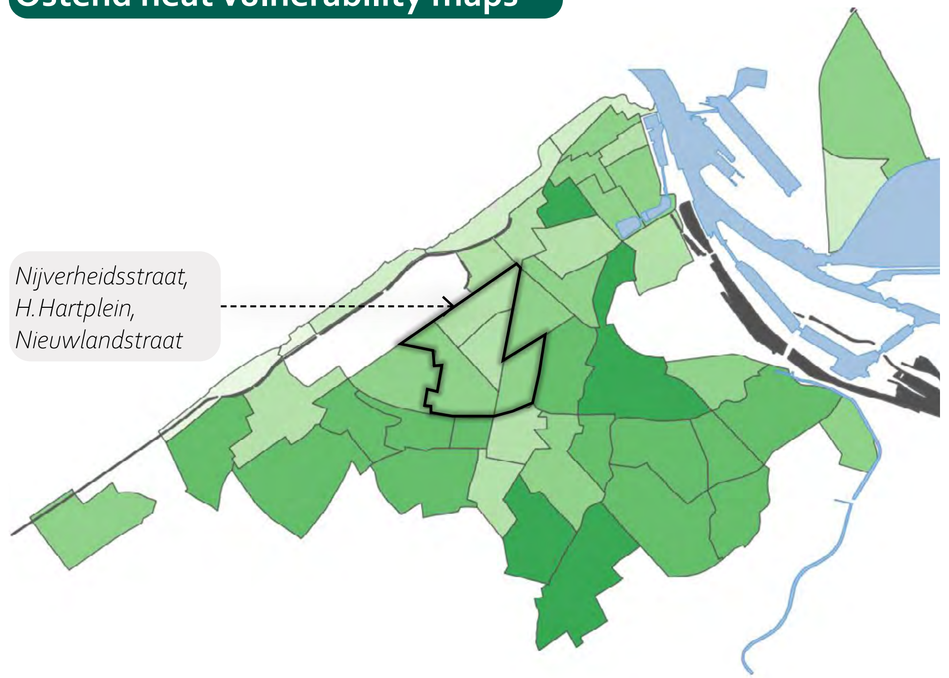
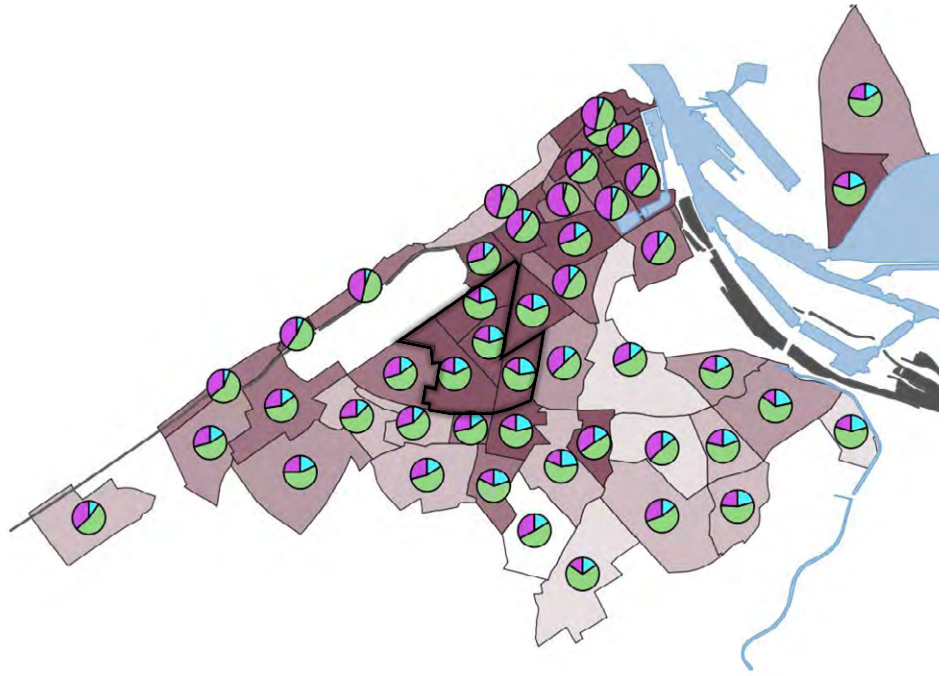
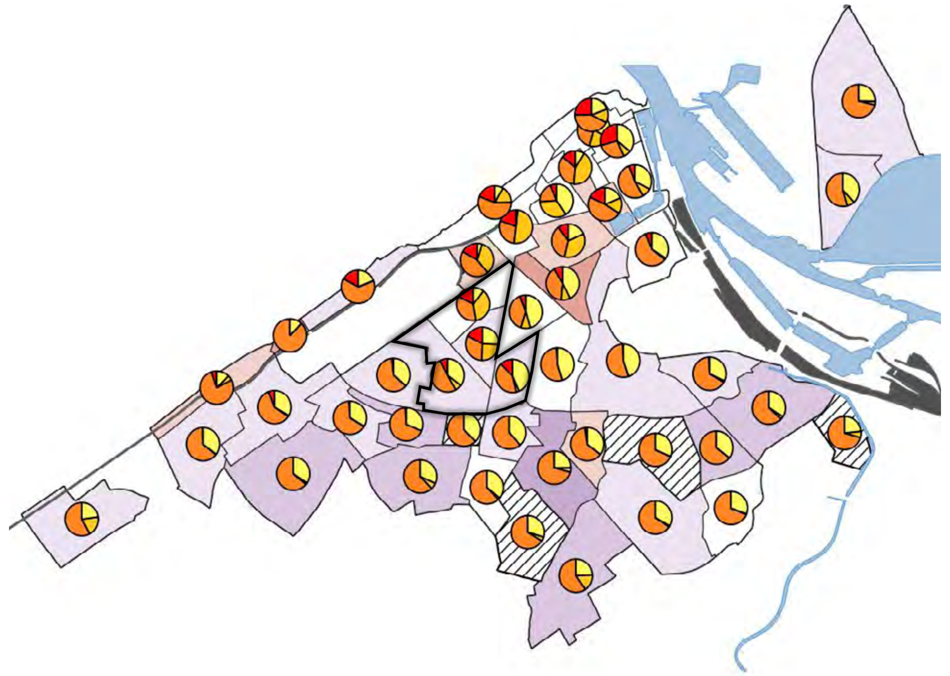
Ostend heat vulnerability maps







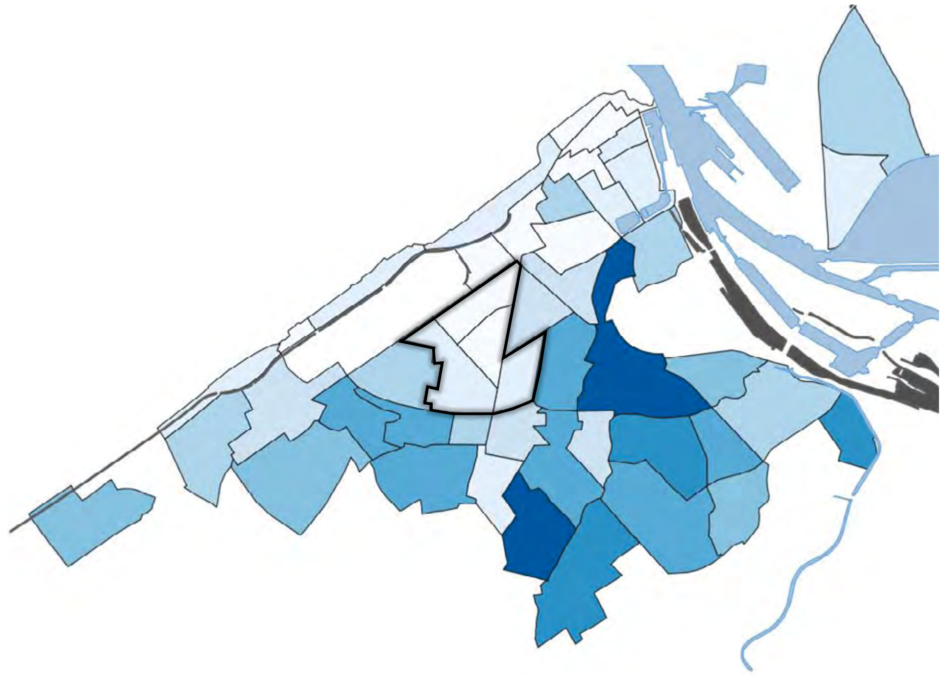


Figure 72: *Vegetated land cover*

- 0-10%
- 0-20%
- 20-30%
- 30-40%
- 40-50%
- 0-10%
- 0-20%
- 20-30%
- 30-40%
- 40-50%
- Water
- Train track

Figure 73: *Population density and age distribution*

Population density

- 0-50 m² per inhabitant
- 50-100 m² per inhabitant
- 100-150 m² per inhabitant
- 150-200 m² per inhabitant
- 200-350 m² per inhabitant
- 350-500 m² per inhabitant
- >500 m² per inhabitant

Age distribution

- > 65
- 18 - 64
- 0 - 17
- Water
- Train track

Figure 74: *Socioeconomic status (SES) and heat stress levels (PET)*

Socioeconomic status

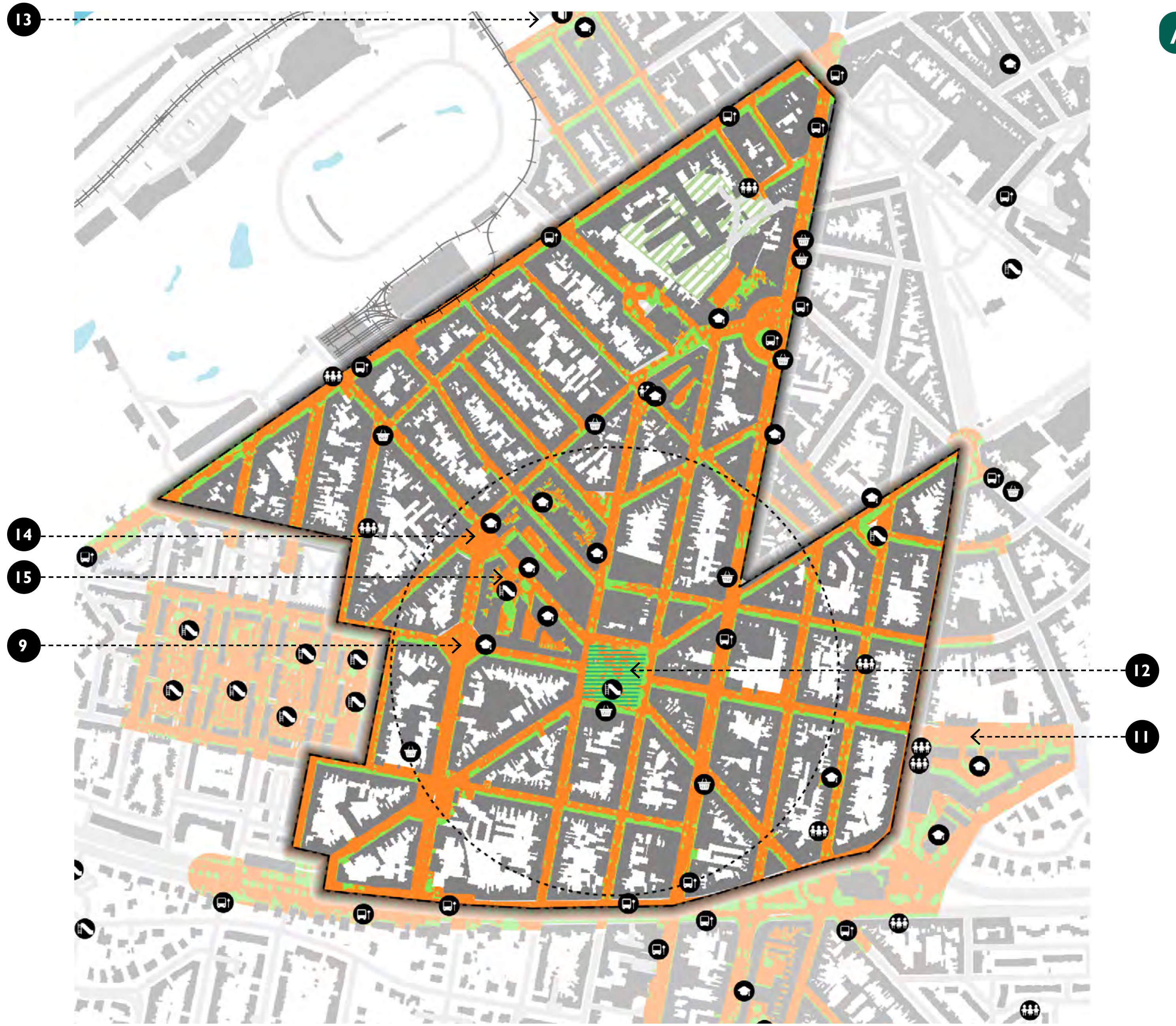
- Extremely below city average
- Strongly below city average
- Moderately below city average
- Slightly below city average
- Slightly above city average
- Moderately above city average
- Strongly above city average

Heat stress levels

- 46-51 Extreme Heat Stress (LV2)
- 41-46 Extreme Heat Stress (LV1)
- 35-41 Strong Heat Stress
- 29-35 Moderate Heat Stress
- 23-29 Slight Heat Stress
- Water
- Train track
- No data

Figure 75: *Cool outdoor ground level area per inhabitant*

- 0-10 m² [PET < 35 ° C] / inhabitant
- 10-20 m² [PET < 35 ° C] / inhabitant
- 20-30 m² [PET < 35 ° C] / inhabitant
- 30-40 m² [PET < 35 ° C] / inhabitant
- 40-50 m² [PET < 35 ° C] / inhabitant
- 50-75 m² [PET < 35 ° C] / inhabitant
- 75-100 m² [PET < 35 ° C] / inhabitant
- 100-125 m² [PET < 35 ° C] / inhabitant
- 125-150 m² [PET < 35 ° C] / inhabitant
- >500 m² [PET < 35 ° C] / inhabitant
- Water
- Train track



Advanced heat vulnerability map

Figure 76: The Nijverheidsstraat, H.Hartplein, and Nieuwlandstraat neighbourhoods in Ostend analysed during the lunchtime TCL scenario to identify locations vulnerable to heat for children.

Research areas: Ostend - Nijverheidsstraat, H.Hartplein, and Nieuwlandstraat
User group: children

- Childcare
- Library
- Playground
- Supermarket
- Cultural facility
- Bus stop
- Education
- Tram
- Road
- 300 meter walking distance
- Potential cool place
- Future park
- Park or recreation area
- Water
- Building

PET values - Lunchtime scenario

- 41 - 46 Extreme heat stress (LV1)
- 35 - 41 Strong heat stress
- 29 - 35 Moderate heat stress
- 22 - 29 Slight heat stress

0 250 500 m

surface and introducing shading. At the same time, the neighbourhood's dominant north-south grid subjects many primary streets to the sun at lunchtime. Recognising the crucial function of Sint-Catharinaplein (12), the municipality envisages a series of green interventions connecting it to the hippodrome and the Kris Lambert Library (13). This offers the opportunity to transform one of the neighbourhood's vital mobility axes into a cool route.

At present, the Sint-Catharinaplein (12) is the only public square and playground children can enjoy that is sufficiently protected from the heat. The map also reveals other potential squares, such as the Gerechtsplein (14) or the previously discussed H. Conscienceplein(9), where pocket parks and play areas with higher cooling potential could easily be developed. These small green oases would also provide rest areas along future cool routes crossing the neighbourhood. In addition to public squares, school playgrounds are specific spatial typologies children use extensively even during heatwaves, providing essential playing, learning, and sporting opportunities. The outdoor school areas of Westerkwartier appear as highly vulnerable locations with paved surfaces and no shading. Even the grassy playground of the H. Conscience Elementary School on Stuiverstraat (15) suffers from extreme heat stress. The advanced heat vulnerability map points to the urgent need for heat stress mitigation interventions in these places. In the coming years, the children and residents of the Westerkwartier will also benefit from new green structures. The municipality is investigating ways to make the hippodrome's greenfield visually more accessible by means of a bridge over the hippodrome to connect Westerkwartier with the beach. Residents will also be able to relax and cool down in the urban vegetable garden, pergola or orchard of Green C, the new residential development with a neighbourhood park on the site of the former Sint-Jozef hospital (10).

12 *Sint-Catharinaplein, Ostend*

©Municipality of Ostend

15 *H. Conscience Elementary School, Ostend*

©Municipality of Ostend

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9. Southend, Great Britain

Southend satellite map

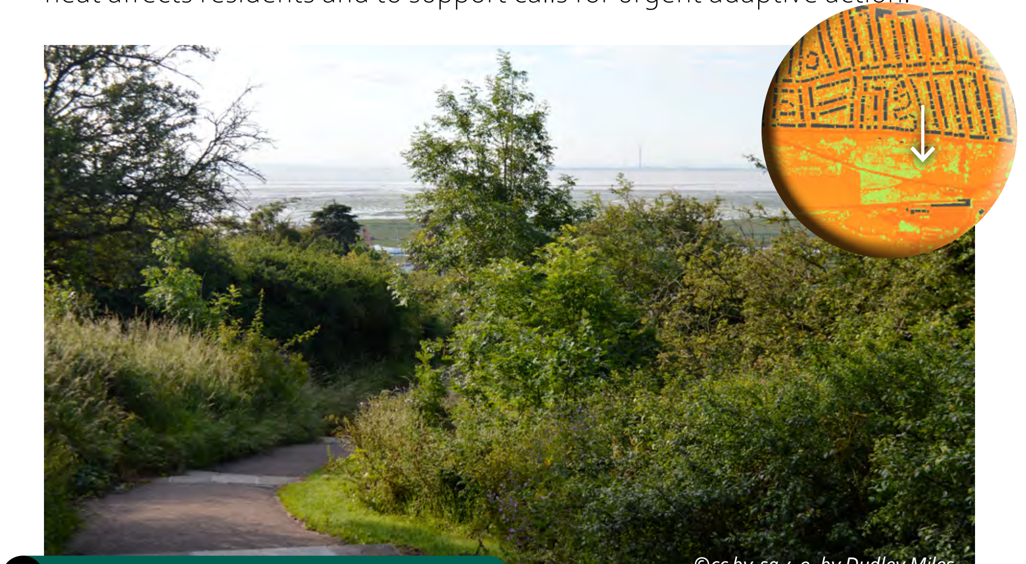
Figure 77: Google, Imagery ©2022 CNES / Airbus, Getmapping plc, Infoterra Ltd & Bluesky, Landsat / Copernicus, Maxar Technologies, The GeoInformation Group, Map data ©2022

Area	41,76 km²
Population	180.700 (2021)
Population density	4327 people / km² (2022)

0 500 1000 m

Southend

Southend-on-Sea, commonly referred to as Southend, is on the English coast, north of the River Thames Estuary, in the county of Essex (see fig.77). The Local Climate Impact Profile of the city (Southend on Sea, 2018-2019) forecasts hotter and drier summers and identifies spatial actions such as greening, expanding permeable surfaces and heat-proofing the housing stock as priorities. Southend's low Carbon Energy and Sustainability Strategy (Southend on Sea, 2015-2020) has the stated aspiration for Southend to become "the 'Greenest Borough' in the East of England". Climate resilience is a high priority (Southend on Sea, 2018-2019) and climate adaptation will be taken into account in all future policies and plans to address the risks associated with a changing climate. The Thermal City Life scenarios for Southend provide a foundation for understanding how heat affects residents and to support calls for urgent adaptive action.



3 *Belton Hills Nature Reserve, Southend*

4 *Chalkwell Park, Southend*

Southend lunchtime TCL Scenario

In the lunchtime scenario (see fig.78), the scarcity of light green on the map indicates that large urban woodlands are unusual in the city and surroundings, only Belfair's Park Wood is close to the westside of the city, although not included in the maps' focus area. Given the densely wooded character of this nature reserve, it would be likely to experience only Slight Heat Stress and be the closest cool escape for residents. Zooming in on the more urban fabric, the golfers suffer from extreme heat stress, with a PET between 41-46°C, on the Garon Park Golf Complex (1) and the former Prittle Brook Industrial Estate (2). Only the larger green structures lining some of the routes offer coolness. The same is the case with the bushes of the Belton Hills Nature Reserve (3) that catch the eye with their bright

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Lunchtime TCL scenario

Figure 78: *Southend, Time: 12 UTC (14 CEST), Tair: 28 °C*

46-51	Extreme Heat Stress (LV2)		Building
41-46	Extreme Heat Stress (LV1)		Water
35-41	Strong Heat Stress		Rail
29-35	Moderate Heat Stress		City centre
23-29	Slight Heat Stress		Neighbourhood

0 500 1000 m

green colour indicating Slight Heat Stress but they offer little shading for pedestrians.

The parks and school fields of Southend are recognizable in the lunchtime scenario as orange zones with scattered green dots, such as the Chalkwell Park (4) and the Southchurch Park (5). These are mostly used for sports which explains the absence of trees. However, these locations expose children and their parents to extreme heat stress levels on hot summer days. Priory Park (6) provides a good example of integrating sport fields with sufficient cooling capacity. Groups of trees surround the sport fields with open meadows creating a pleasant cool route that runs along the Prittle Brook. There are also several pergolas in Priory Park, around the Old Walled Garden (7). They create shaded seating while the one next to Prittle Brook (8) provides an enclosed canopy.

6 *Priory Park, Southend* ©Southend City Council

7 *Old Walled Garden in Priory Park, Southend* © Southend City Council, southendmuseums.co.uk

City — *Neighbourhood* — *User Network*

Rush hour TCL scenario

Figure 79: *Southend, Time: 15 UTC (17 CEST), Tair: 33 °C*

46-51	Extreme Heat Stress (LV2)		Building
41-46	Extreme Heat Stress (LV1)		Water
35-41	Strong Heat Stress		Rail
29-35	Moderate Heat Stress		City centre
23-29	Slight Heat Stress		Neighbourhood

0 500 1000 m

Southend rush hour TCL scenario

The open green fields of parks and school playgrounds begin to cool off during the afternoon and into Southend's rush hour scenario (see fig. 79) while more enclosed urban spaces experience elevated heat stress depending on the spatial context. For example, the multi-storey row of houses at Leigh-on-Sea (9) form an almost continuous façade that shields the street from the east wind and traps heat. In North Leigh (10), residents frequently live in one-storey detached houses (bungalows) with large gardens. These characteristics decrease reflected and infrared radiation which, in combination with the position of the houses, allows the public space to gradually cool down. Southend's city centre stands out as a red area with a PET between 46-51°C. Visitors and commuters arriving at Victoria Station (11) face an area dominated by asphalt and concrete which makes it difficult to escape the heat. The Better Queensway redevelopment project presents an opportunity to integrate heat adaptive measures at the station and adjacent to it for more heat resilience.

The High Street (12) is the main shopping street that leads straight from the station to the pier. It is partially shaded by buildings on its western side. Underground utilities make planting trees challenging. Shade sails are also difficult to install due to the necessity of not obstructing CCTV cameras and the need to anchor them onto privately owned facades. Given these challenges, Southend selected sites just off the High Street for their Cool Towns pilot sites. On London Road (13), as part of the Cool Towns project, a row of Maple (Acer), Birch (Betula), and Honey locust (Gleditsia triacanthos) trees were planted with their horizontally spreading foliage in combination with picnic tables and benches to provide a cool spot where people could rest, drink and eat their lunch when doing their shopping.

At York Road (14), there are two planters with integrated seating under the shade of sumac (Rhus typhina) trees. Southend measured the effectiveness of these interventions at this Cool Towns pilot site. On a hot summer day, when air temperature reached 27°C , sitting under the young sumac tree

12 *High Street, Southend*

©cc by-sa 3.0, by Beata May, brightened, www.wikimedia.org

13 *Cool Towns Pilot site on London Rd, Southend*

City *Neighbourhood* *User Network*

16 *Cliff Gardens, Southend* ©Southend City Council

14 *Cool Towns Pilot site on York Rd, Southend* ©Southend City Council

was 9.5 °C PET cooler than standing under the sun (see Spanjar et. al., 2022 for the specific factsheet). A similar PET reduction was found in the shade of a green screen with integrated seating next to the supermarket on London Road. This is another location where shoppers could find a cool spot to rest for a moment. As the area around High Street is built up with commercial buildings being converted to residences, Southend is seeking additional locations just off High Street to create cool spots and pocket parks. Creating cool seaside promenades, for example Westcliff parade (15), could encourage visits to Southend to stroll, shop or bathe here on hot summer days. The Southend Cliff Gardens (16) show how a large park-like setting near a hot place such as a beach can be effective as an escape from heat where it is most needed.

Southend heat vulnerability maps

Southend's map of population density (see fig.81) shows that many neighbourhoods around the High Street are densely populated with residents likely to rely on the cultural and shopping amenities, making it a busy area year-round. Southend's most densely populated neighbourhoods are all on the southern side, near the coast, such as Leigh-on-Sea, Westcliff, Milton, Porters, West and North Shoebury. The most deprived areas are concentrated around the city centre and to the northwest and northeast (see fig.82). The outdoor cool area per inhabitant map (see fig.83) complements this pattern and identifies disadvantaged neighbourhoods from a heat stress perspective. Residents living here may have insufficient refreshing green spaces in their direct surroundings and also lack the economic means or time to visit cooler locations, such as Belfair's Park Wood nature reserve (discussed earlier). The dashed line on the vegetated land cover map (see fig.80) shows that the data comes from two different suppliers. The northern part captures a relatively large area of agricultural land and, because the colour-infrared aerial photograph was taken in summer, when the crops have a yellow appearance, it was not perceived as green and consequently not identified as vegetation. Although this vegetation type provides no substantial thermal comfort during the day for citizens, the agricultural land is still important to combat the Urban Heat Island effect in particular for night temperatures.

Based on Southend's heat vulnerability maps, the city centre and Westcliff are two of the areas requiring immediate attention. The city centre primarily welcomes visitors, including shoppers, and tourists, and was the first area to have heat adaptive interventions, in the form of the Cool Towns pilot sites. The age distribution charts (see fig.81) show that the previously mentioned densely populated neighbourhoods with low socio-economic status are mostly inhabited by children and adults. Westcliff is no exception and with many schools in its surroundings it emerges as a priority area for intervention as pupils have a lunchtime break and exercise outside.

17 *Southend High School for Boys, Southend* ©Southend City Council

Southend advanced heat vulnerability map

Following analysis of Southend's heat vulnerability maps and consultation with the city authorities, the north part of Westcliff was chosen for detailed analysis to identify heat stress challenges and adaptation opportunities (see fig.84). The focus was on how children and students use the area around midday as the map showed a large number of primary and secondary schools, such as Southend High School for Boys (17). The large paved outdoor area and green sports field of this school and the pedestrian routes towards it are exposed to Level 1 Extreme Heat Stress at lunchtime, similar to the nearby Chase High School (18), St Thomas More High School (19), and Westcliff High School for Boys and Westcliff High School for Girls across the road. Historically and culturally these large open areas may have encouraged physical exercise in the city's mild coastal climate but as temperatures rise there may be health risks associated with outside exercise classes so planting more trees may be beneficial for the wellbeing of these young users.

The situation is similar in the outdoor areas of the neighbourhood's primary and middle schools: Chalkwell Hall Junior School (20), Our Lady of Lourdes Catholic Primary School (21), Westborough School (22) and Lancaster middle school (next to Chase High School). Providing shade in playgrounds and small courtyards is easier than shading sports fields. Planting trees or installing shade sails are effective interventions to combat direct solar radiation, and breaking up impermeable hard surfaces is important to reduce infrared radiation. Children might also find shaded play areas in the nearby Chalkwell (4) or Priory (6) parks, although the playgrounds, designed for young children, are fully exposed to the sun at lunchtime.

City — Neighbourhood — User Network

Southend heat vulnerability maps

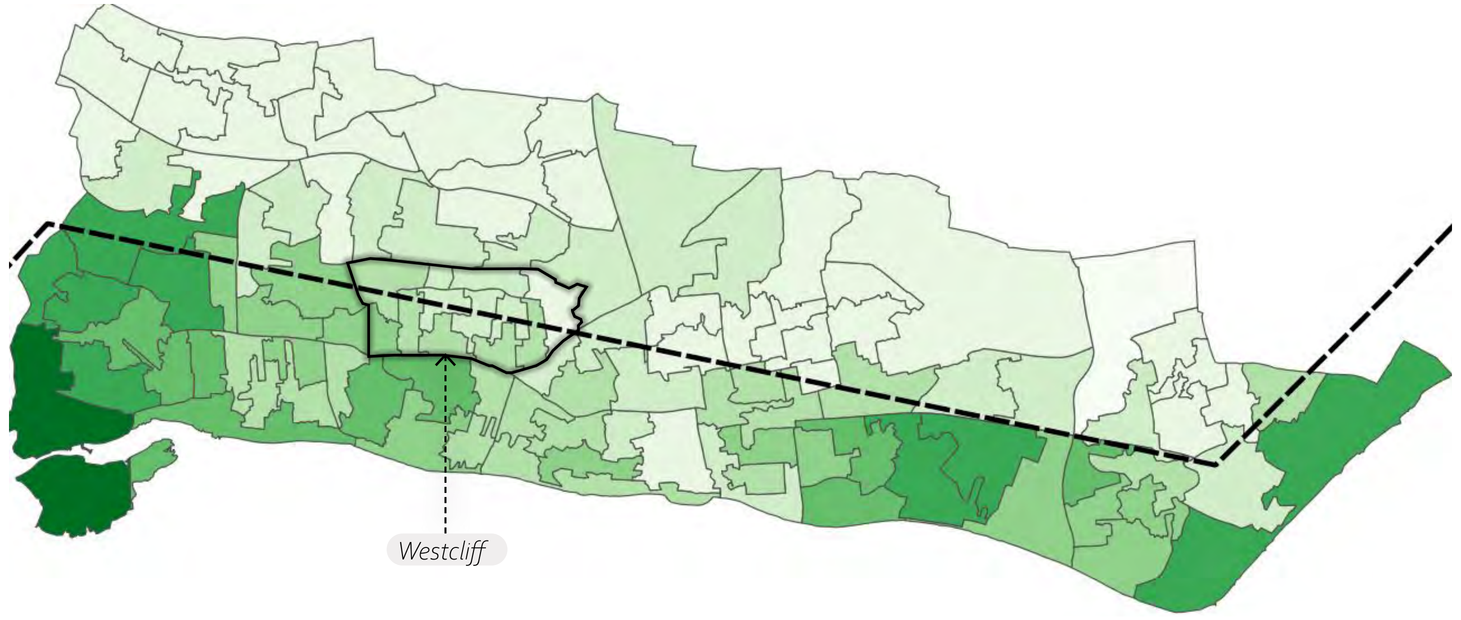


Figure 80: *Vegetated land cover*

- 0-10%
- 0-20%
- 20-30%
- 30-40%
- 40-50%
- 0-10%
- 0-20%
- 20-30%
- 30-40%
- 40-50%

For an explanation see section on Southend heat vulnerability maps.

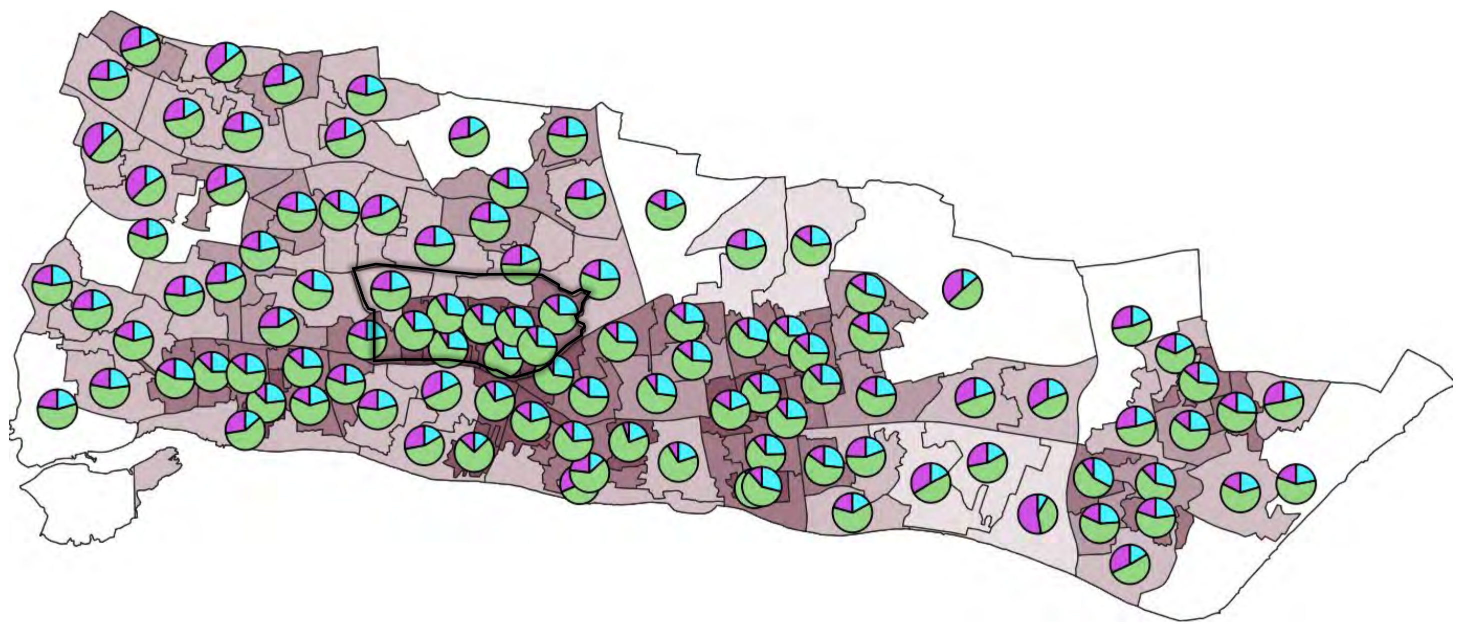


Figure 81: *Population density and age distribution*

Population density

- 0-50 m^2 per inhabitant
- 50-100 m^2 per inhabitant
- 100-150 m^2 per inhabitant
- 150-200 m^2 per inhabitant
- 200-350 m^2 per inhabitant
- 350-500 m^2 per inhabitant
- >500 m^2 per inhabitant

Age distribution

- > 65
- 18 - 64
- 0 - 17

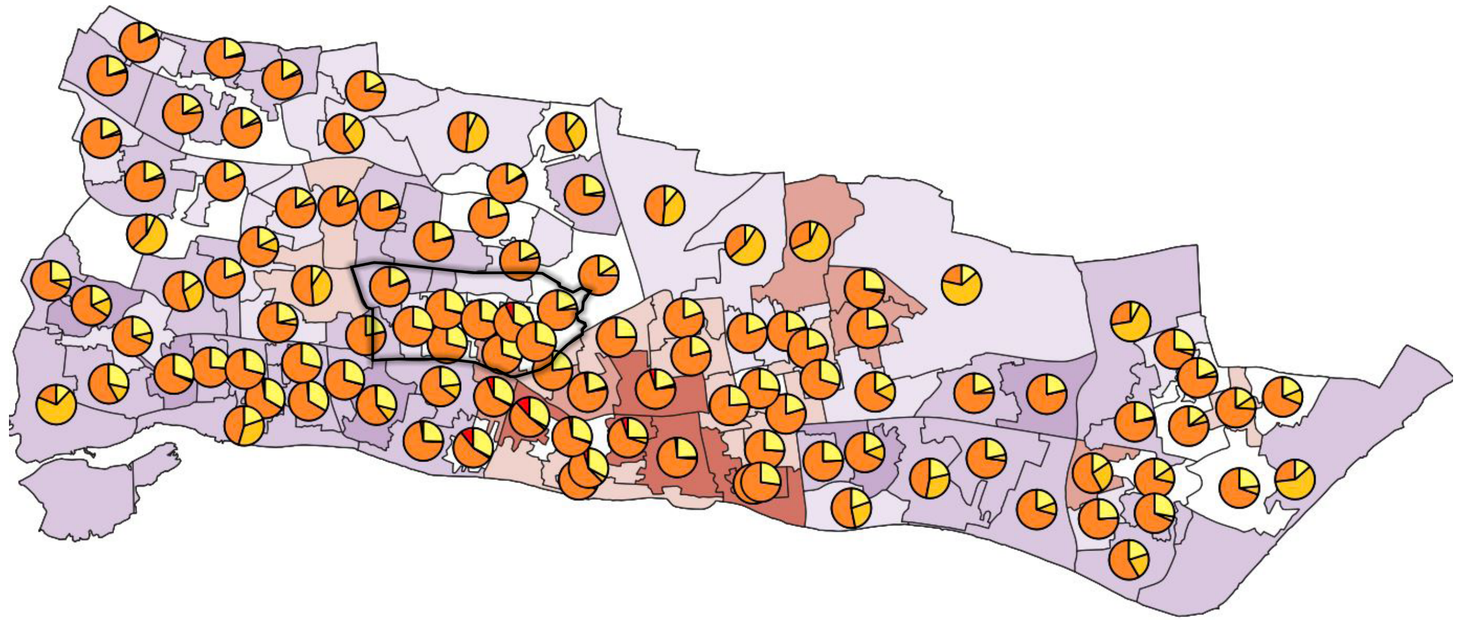


Figure 82: *Socio-economic status (SES) and heat stress levels (PET)*

Socioeconomic status

- Extremely below city average
- Strongly below city average
- Moderately below city average
- Slightly below city average
- Slightly above city average
- Moderately above city average
- Strongly above city average

Heat stress levels

- 46-51 Extreme Heat Stress (LV2)
- 41-46 Extreme Heat Stress (LV1)
- 35-41 Strong Heat Stress
- 29-35 Moderate Heat Stress
- 23-29 Slight Heat Stress

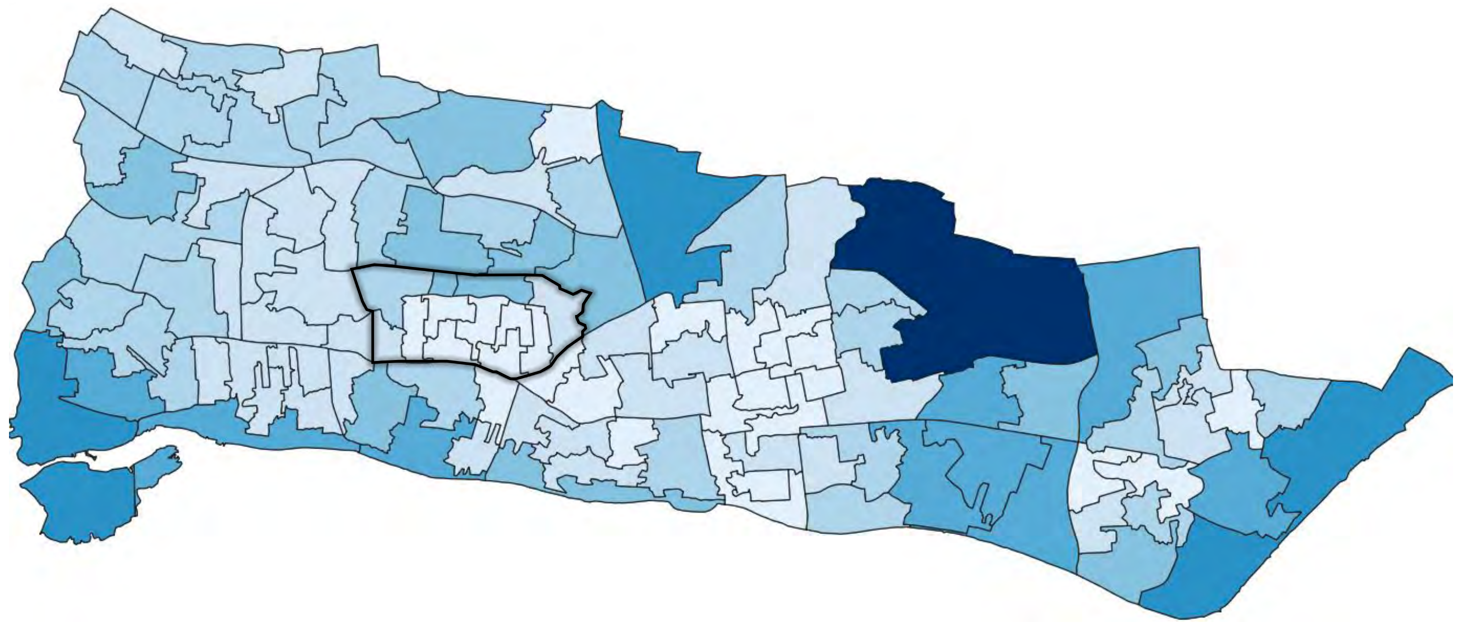


Figure 83: *Cool outdoor ground level area per inhabitant*

- 0-10 m^2 [PET < 35 °C] / inhabitant
- 10-20 m^2 [PET < 35 °C] / inhabitant
- 20-30 m^2 [PET < 35 °C] / inhabitant
- 30-40 m^2 [PET < 35 °C] / inhabitant
- 40-50 m^2 [PET < 35 °C] / inhabitant
- 50-75 m^2 [PET < 35 °C] / inhabitant
- 75-100 m^2 [PET < 35 °C] / inhabitant
- 100-125 m^2 [PET < 35 °C] / inhabitant
- 125-150 m^2 [PET < 35 °C] / inhabitant
- >500 m^2 [PET < 35 °C] / inhabitant

Advanced heat vulnerability map

Figure 84: The Westcliff neighbourhood in Southend analysed during the lunchtime TCL scenario to identify locations vulnerable to heat for children.

Research area: Southend - Westcliff
User group: children

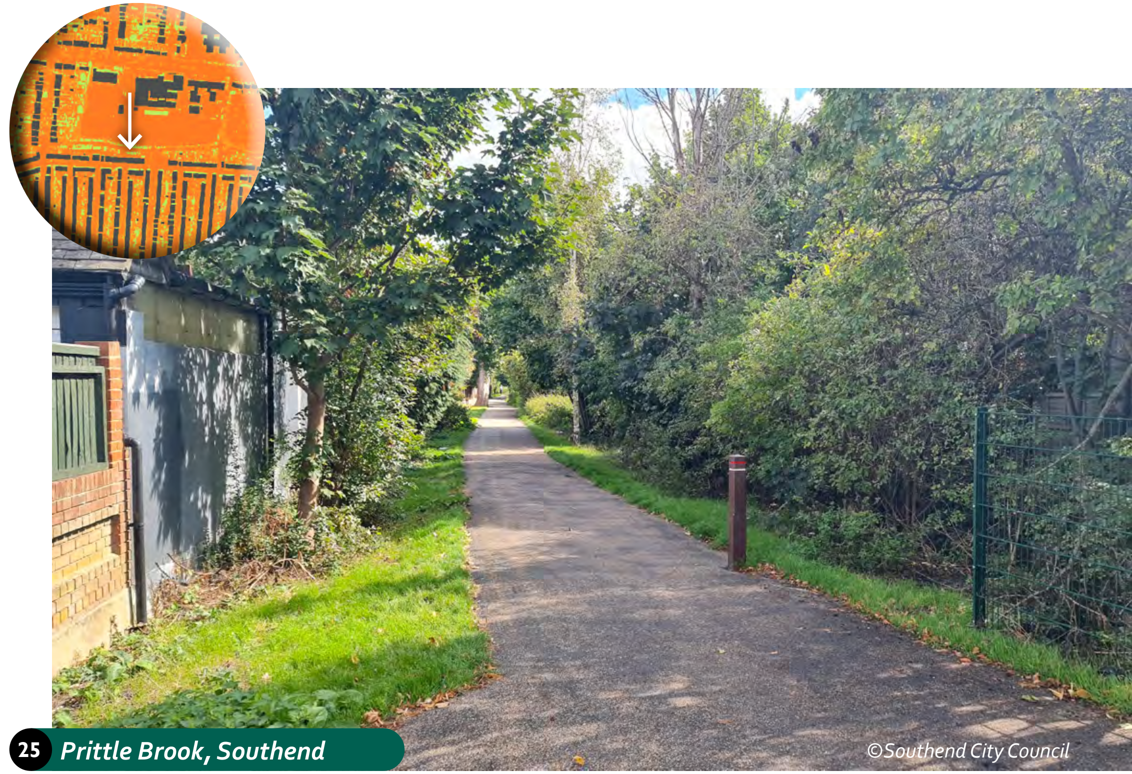
Childcare
Shopping centre or mall
Supermarket
Bus stop
Education
Playground
Rail
Road
300 meter walking distance
Building
Potential cool place
Park or recreation area
Water

PET values - Lunchtime scenario
41 - 46 Extreme heat stress (LV1)
35 - 41 Strong heat stress
29 - 35 Moderate heat stress
23 - 29 Slight heat stress

0 400 800 m

Westcliff's urban structure is composed of a few main roads that connect many smaller secondary streets in the neighbourhood. Before the motorway was built, London Road (13) was, as the name suggests, the access to the capital. Nowadays it is still the main road and shopping area of Westcliff, connecting it to Southend centre. On hot summer days, the few main roads are exposed to extreme heat stress yet all residents need to use these to get around. The secondary streets are narrow and on-street parking makes tree planting difficult. The wider profiles of main roads, such as Fairfax Drive (23), London Road (13) and Prittlewell Chase (24), provides the potential for transforming them into cool corridors. The latter already features a linear green structure in the middle, but it is inaccessible for pedestrians. In contrast, the hidden linear park along the Prittle Brook (25) provides intermittent shade and could become a blue-green corridor giving pedestrian access to some of the neighbourhood schools. Pleasant and refreshing pedestrian pathways and cycle routes may encourage residents to choose these modes of transport contributing to Southend's aspiration to promote sustainable transport (Southend on Sea, 2015-2020) as the local climate becomes warmer and drier.

24 *Prittlewell Chase, Southend* ©Southend City Council



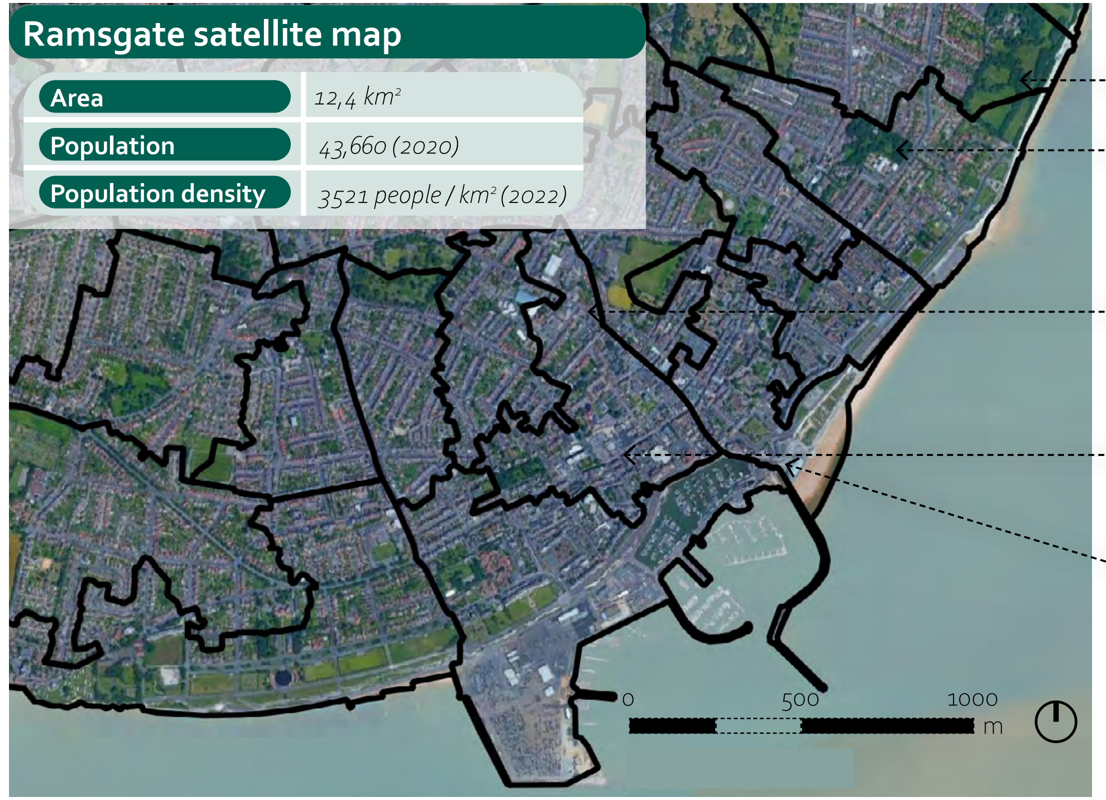
25 *Prittle Brook, Southend* ©Southend City Council

Another transport project that may integrate heat adaptation is Southend's aim to make bus travel the first choice for residents (Southend on Sea, 2022). The advanced heat vulnerability map highlights that most bus stops are located on three parallel roads, Fairfax Drive (23), London Road (13) and Prittlewell Chase (24). The latter is also an important access point to Southend University Hospital which may receive increased visitor numbers during heat waves. The glass bus stops along these routes can trap the heat like a greenhouse and expose travellers to even higher heat stress than on the street (Laan, 2022). Shading bus stops with trees, green roofs or creating seating next to green walls may encourage residents to choose public transport.

City — Neighbourhood — User Network

10. Margate & Ramsgate, Great Britain

Figure 85: (above, right & below), Google, Imagery ©2022 CNES / Airbus, Getmapping plc, Infoterra Ltd & Bluesky, Landsat / Copernicus, Maxar Technologies, Map data ©2022



Margate & Ramsgate

In this chapter the seaside towns of Margate and Ramsgate, located in the county of Kent on the southeastern extremity of England (see fig.85), are discussed together and demonstrate how regional and local authorities can collaborate effectively to reduce heat risks.

Kent is known for its long, strategically important, coastline. Ngai (2020b) her study was commissioned by Kent County Council and conducted in 2019, forecasts Kent as likely to be acutely affected by flooding and hot summers due to its coastal position and warmer base climate than the rest of the country. Kent is becoming more built up with the Kent and Medway Growth and Infrastructure Framework (ibid.) likely to exacerbate the Urban Heat Island effect (see chapter 1) and increase public demand for regional woodlands such as the Blean Woods. This in turn will increase congestion on roads and the demand for local cool routes and corridors towards nature areas. In addition, thermal discomfort in urban areas is likely to increase further with more house building. Kent's risk assessment (ibid.) identified risks to health, wellbeing, and productivity as essential areas affected by high temperatures while also highlighting how hot summers cause overheating in buildings, worsening air quality, traffic congestion and biodiversity loss.

The assessment recommends further research into the local effects of climate risks to enable adaptive action. This chapter presents how conducting a Thermal Comfort Assessment can contribute to this aspiration by making visible the potential heat stress locations in Margate and Ramsgate. The maps also enable integration of heat adaptation in public spaces such as residential streets. Two of these were chosen as

City Neighbourhood User Network

1 *Cool Towns Pilot site on Garrard Avenue, Margate* ©Kent County

Kent's Cool Towns pilot site to lower ambient temperatures and create attractive places. Garrard Avenue (1) and the parallel Maynard Avenue in Margate both suffer sustained Level 1 Extreme Heat Stress during both the lunchtime (see fig.86) and rush hour (see fig.87) Thermal City Life scenarios. A few existing mature trees create limited sporadic shading; these have been complemented with a mixture of thirty Maples (Acer) and Maidenhair (Ginkgo biloba) trees, planted as part of the pilot project. When mature, these will provide continuous shade enabling residents to access the local George Park by a cool route.

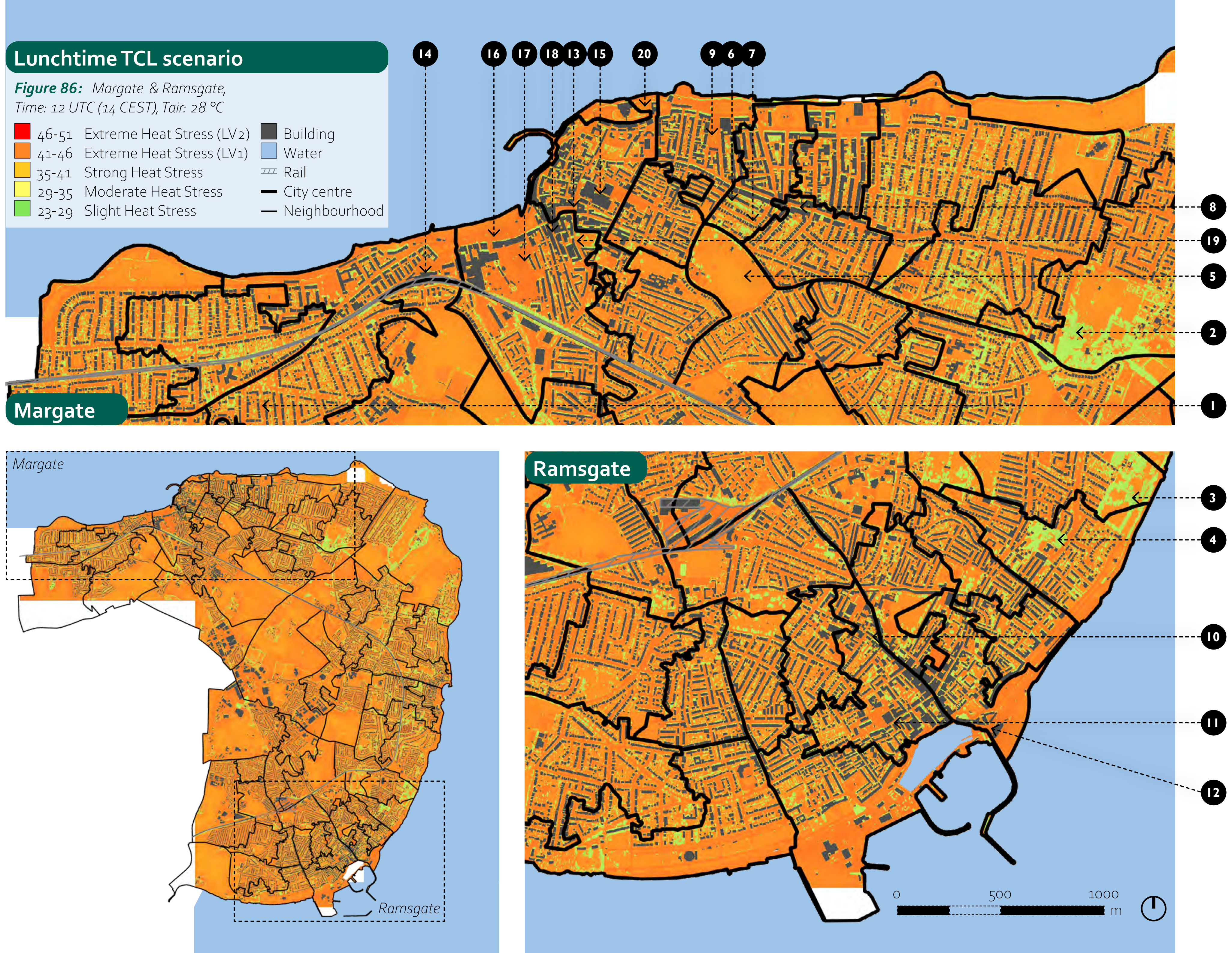


Figure 86: Margate & Ramsgate, Time: 12 UTC (14 CEST), Tair: 28 °C

Margate & Ramsgate lunchtime TCL scenario

Kent's lunchtime scenario shows that, like Garrard and Maynard Avenues, almost the entire mapped area suffers from extremely hot conditions with a PET between 41-46°C, including the agricultural fields between urbanised areas. Solar radiation is the highest at this time and only shade from trees, buildings or other devices can substantially reduce heat. In woodland areas such as the southern part of Northdown Park (2), in King George VI Memorial Park (3) or in the Montefiore Woodlands (4), the dense foliage creates relatively cool areas with only Slight Heat Stress, where residents can enjoy a refreshing lunch break or children play comfortably. In contrast

2 *Northdown park, Margate* ©cc-by-sa/2.0 - by Philip Halling - geograph-org.uk/p/519854

Dane park (5) does not offer any cool spots yet where workers, or adults living in the nearby care facilities of Cliftonville West, could find temporary shelter. Almost all the roads leading from this area to the park also suffer from extreme heat stress. Clarendon Road (6) is an inspiring exception where a line of trees with understory of adjacent gardens creates a cool pedestrian path. This is in stark contrast to the parallel Madeira Road (7) where pedestrians are exposed to challenging conditions.

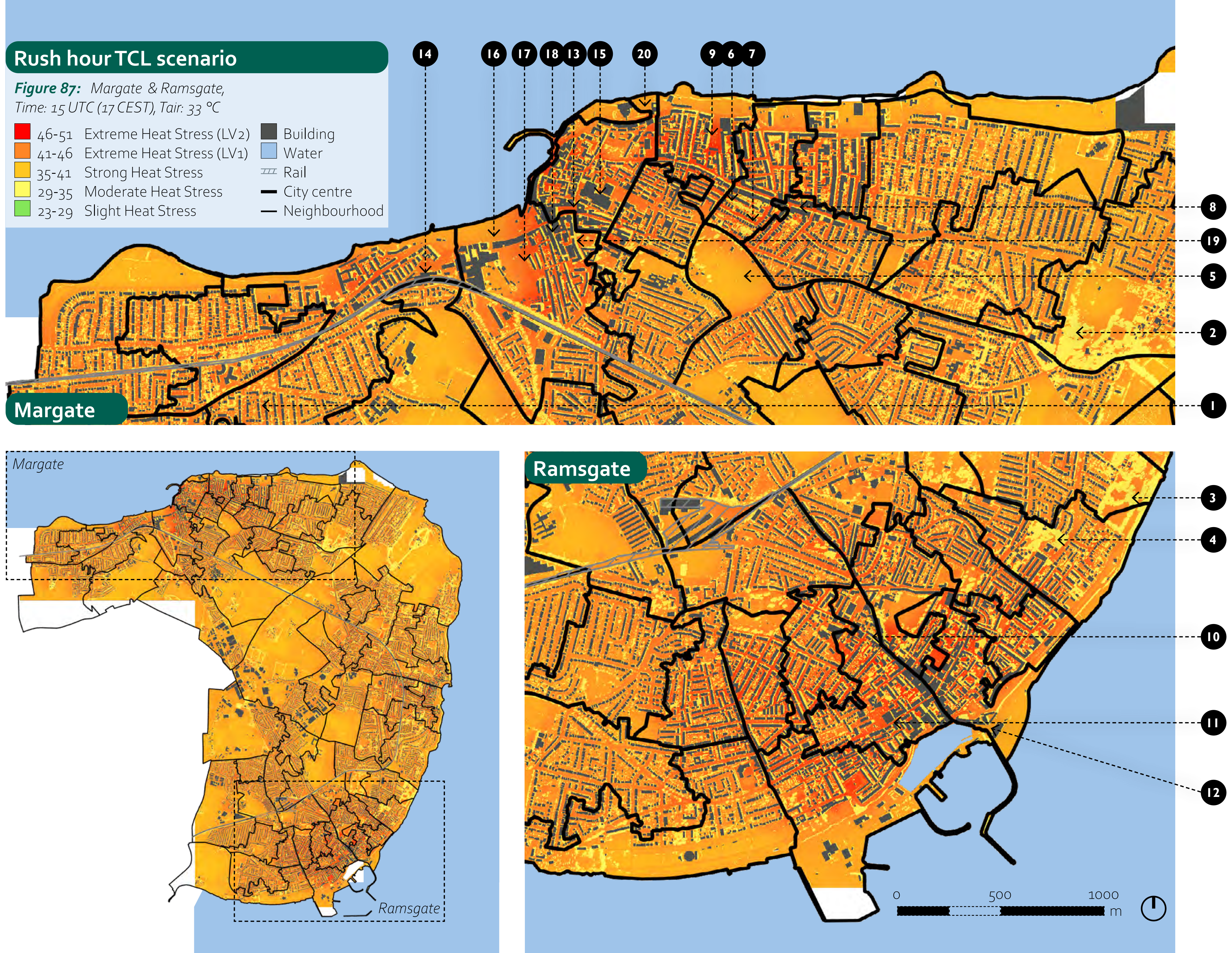
City — Neighbourhood — User Network

6 *Clarendon Road, Margate* ©Kent County

7 *Madeira Road, Margate* ©Kent County

Rush hour TCL scenario

Figure 87: Margate & Ramsgate,
Time: 15 UTC (17 CEST), Tair: 33 °C



Margate & Ramsgate rush hour TCL scenario

During the course of the afternoon, heat stress increases in the denser central areas which feature multi-storey apartment buildings and an excess of conventional hard surfaces, whereas neighbourhoods where houses have gardens and there are parks begin to cool off. Apart from Margate central, analysed in detail at the advanced heat vulnerability map section (fig.92), Cliftonville West comes to the fore as suffering from Level 2 Extreme Heat Stress. Northdown Road (8) is the neighbourhood's most important pedestrian and cycle route that is likely to be busy during rush hour although only part of the pavement is shaded by nearby buildings. This is not only the connection to the centre but also provides shopping facilities and amenities, such as the Dalby Square playground (9), the nearby supermarket, and restaurants where residents can relax at the end of a working day.

The centre of Ramsgate, similarly to Margate, also suffers from extreme heat stress. Shops, restaurants, and cultural facilities - such as Ramsgate Library - and schools are located in the dense inner city. Some sections of the pavement are shaded by nearby buildings, such as Harbour Street and its continuation as High Street (10), but most primary slow-traffic

City — Neighbourhood — User Network

10 *Harbour Street, Ramsgate*

routes such as Queens Street (11) suffer from Level 2 Extreme Heat Stress. This could make the public space around these central amenities quite unbearable in the rush hour. Some may point out that it is more comfortable to travel by air-conditioned cars instead of walking or cycling, or decide to not visit the area at all. This can affect visitor numbers and the local economy (see chapter 1). The rush hour scenario also shows that heat stress slowly decreases at the nearby Harbour Parade (12). This is a more open site with buildings only on one side which reduces reflected radiation and opens the promenade to the cooling breeze of the sea.

12 *Harbour Parade, Ramsgate* ©Kent County

Margate & Ramsgate heat vulnerability maps

The TCL-scenario maps for Kent's north-eastern tip highlight that this urban area is in urgent need of heat stress interventions. The heat vulnerability maps provide nuance helping decision makers prioritise locations by understanding where, and for whom, interventions can provide the most benefit. The population density map (see fig.89) confirms that Margate and Ramsgate are densely populated areas and where creating cool places and routes can positively influence the lives of many in hot summers. Based on the age distribution charts, the neighbourhoods with the largest proportion of elderly residents are less dense than those with younger residents. A good example is Cliftonville East, where the higher vegetated land cover (see fig.88) also points to homes having larger gardens compared to Cliftonville West. Ramsgate shows a similar dynamic with the younger population living in the centre, the more elderly living to the west of it.

The central areas of Margate and Ramsgate are not only hotter, denser, inhabited by a younger population with less vegetation and cool areas per inhabitant, but they also have a lower socioeconomic status (see fig. 90) than adjacent neighbourhoods. While Kent is an affluent county, it also has some of the most deprived areas in England and these include Margate and Ramsgate (Ngai, 2020b). Residents in these deprived areas can experience a combined effect of these spatial, social and economic conditions that aggravate heat waves. They might be limited in ability to drive far to find cool places and may live in poorly insulated houses or old buildings designed for the historically mild climate so are now more exposed to indoor heat stress than those in more affluent neighbourhoods.

Margate advanced heat vulnerability map

Apart from vulnerable groups in Margate and Ramsgate, others such as employees, recreational visitors, and shoppers deserve attention when prioritising heat adaptation. Margate's beach and central area welcomes many summer visitors and is already on the county's radar for making it comfortable on hot days. The advanced heat vulnerability map (see fig.92) for Margate centre is based on an user network analysis of how visitors may use this area and highlights where they may suffer from heat stress.

Arriving at Margate's beach on a hot summer day by public transport can be a heat-stressed experience. The bus station on Cecil Square (13) and the town's train station (14) both lack sufficient shelter from the sun and suffer from Level 1 to 2 Extreme Heat Stress. Transport hubs are a common spatial typology that need special attention when redesigning urban spaces for a hotter climate. They are often designed focusing on functionality and seamless flow resulting in hard impermeable surfaces, such as coach stands and adjacent car parks. Shaded seating areas with trees or shade sails and elements like green walls or water features can contribute to a more comfortable urban microclimate and a more pleasant arrival experience. While these towns recognise the urgency of addressing rising temperatures, they also see an opportunity to benefit from their coastal position and boost tourism (Ngai, 2020a). Balancing the availability of hot 'sandy' spaces where visitors may enjoy the heat and also experience cool areas can add to this goal.

16 *Coastal promenade, Margate* ©Kent County

14 *Train station, Margate* ©Kent County

Margate & Ramsgate heat vulnerability maps

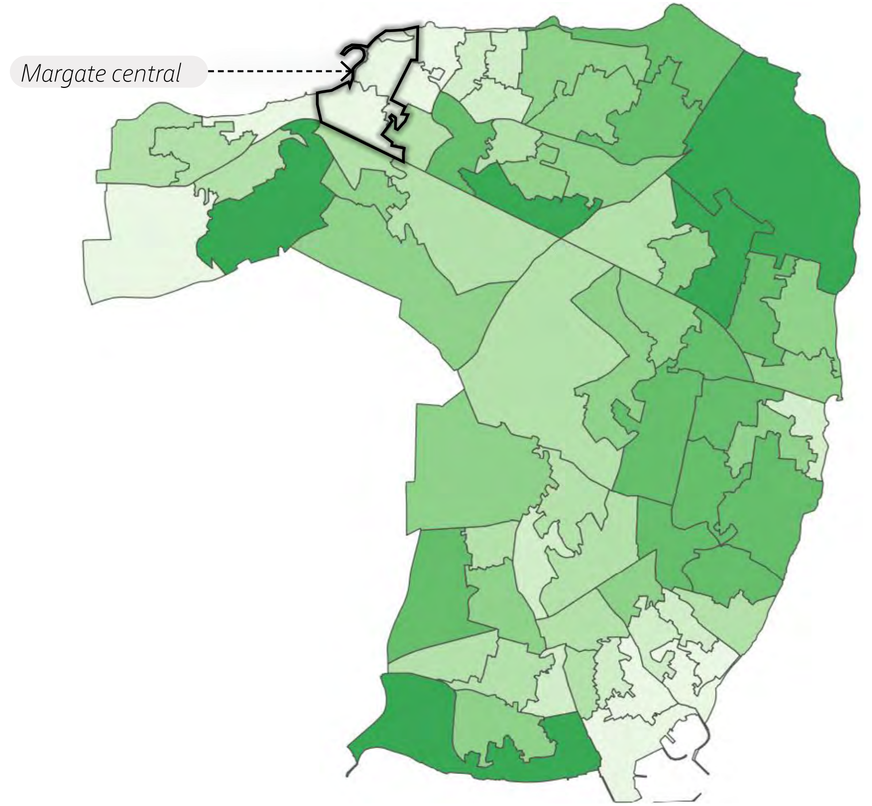


Figure 88: *Vegetated land cover*

- 0-10%
- 0-20%
- 20-30%
- 30-40%
- 40-50%
- 0-10%
- 0-20%
- 20-30%
- 30-40%
- 40-50%

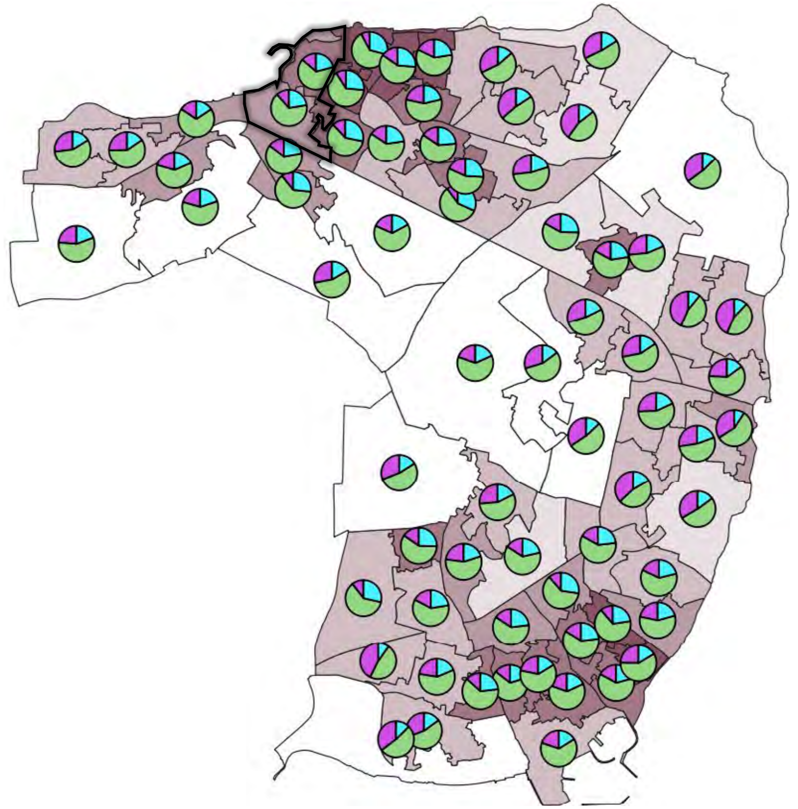


Figure 89: *Population density and age distribution*

Population density

- 0-50 m^2 per inhabitant
- 50-100 m^2 per inhabitant
- 100-150 m^2 per inhabitant
- 150-200 m^2 per inhabitant
- 200-350 m^2 per inhabitant
- 350-500 m^2 per inhabitant
- >500 m^2 per inhabitant

Age distribution

- > 65
- 18 - 64
- 0 - 17

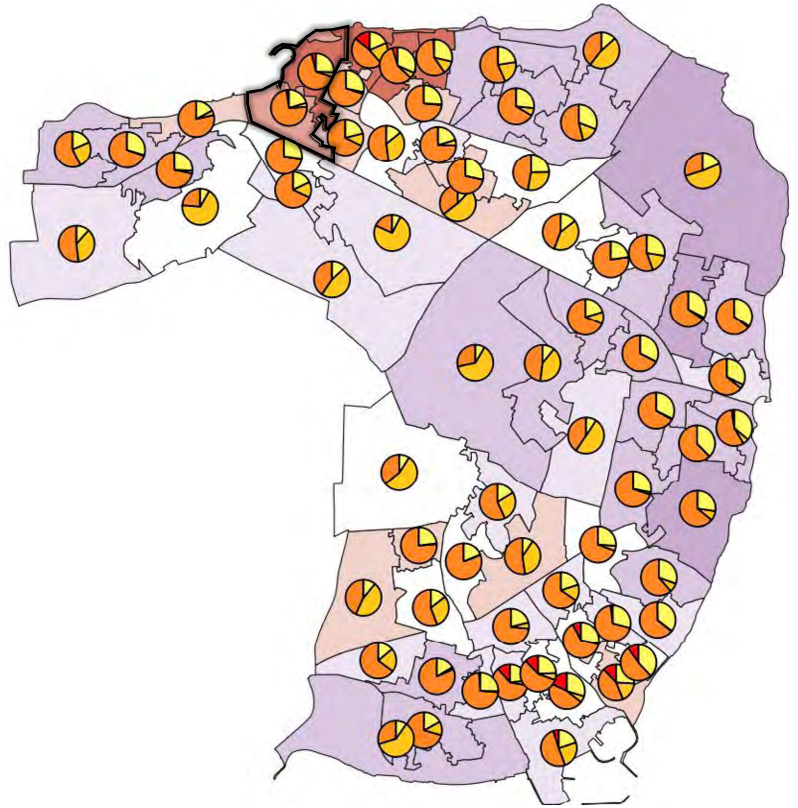


Figure 90: *Socioeconomic status (SES) and heat stress levels (PET)*

Socioeconomic status

- Extremely below city average
- Strongly below city average
- Moderately below city average
- Slightly below city average
- Slightly above city average
- Moderately above city average
- Strongly above city average

Heat stress levels

- 46-51 Extreme Heat Stress (LV2)
- 41-46 Extreme Heat Stress (LV1)
- 35-41 Strong Heat Stress
- 29-35 Moderate Heat Stress
- 23-29 Slight Heat Stress

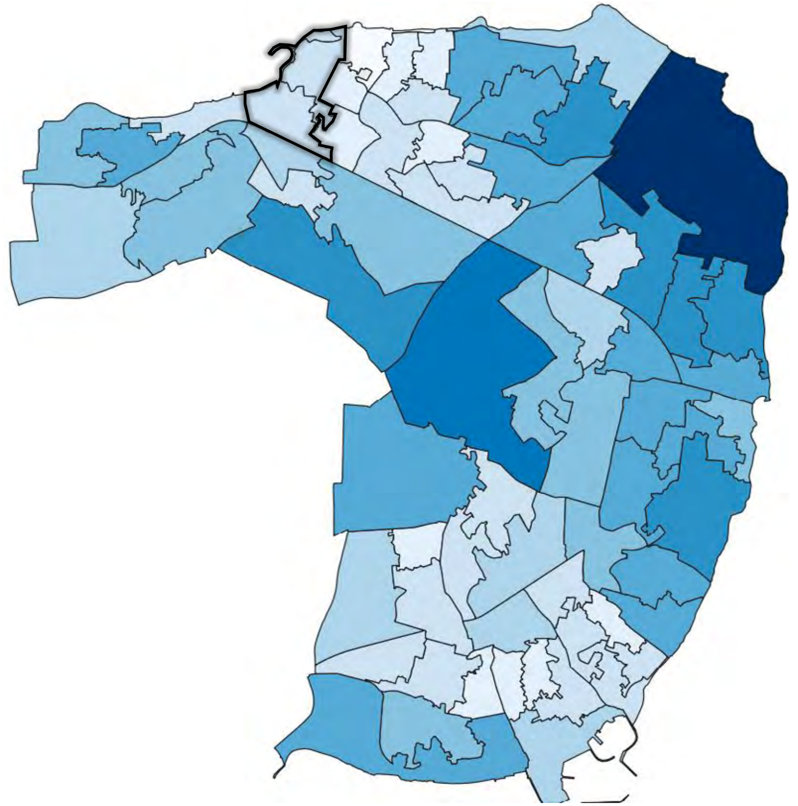
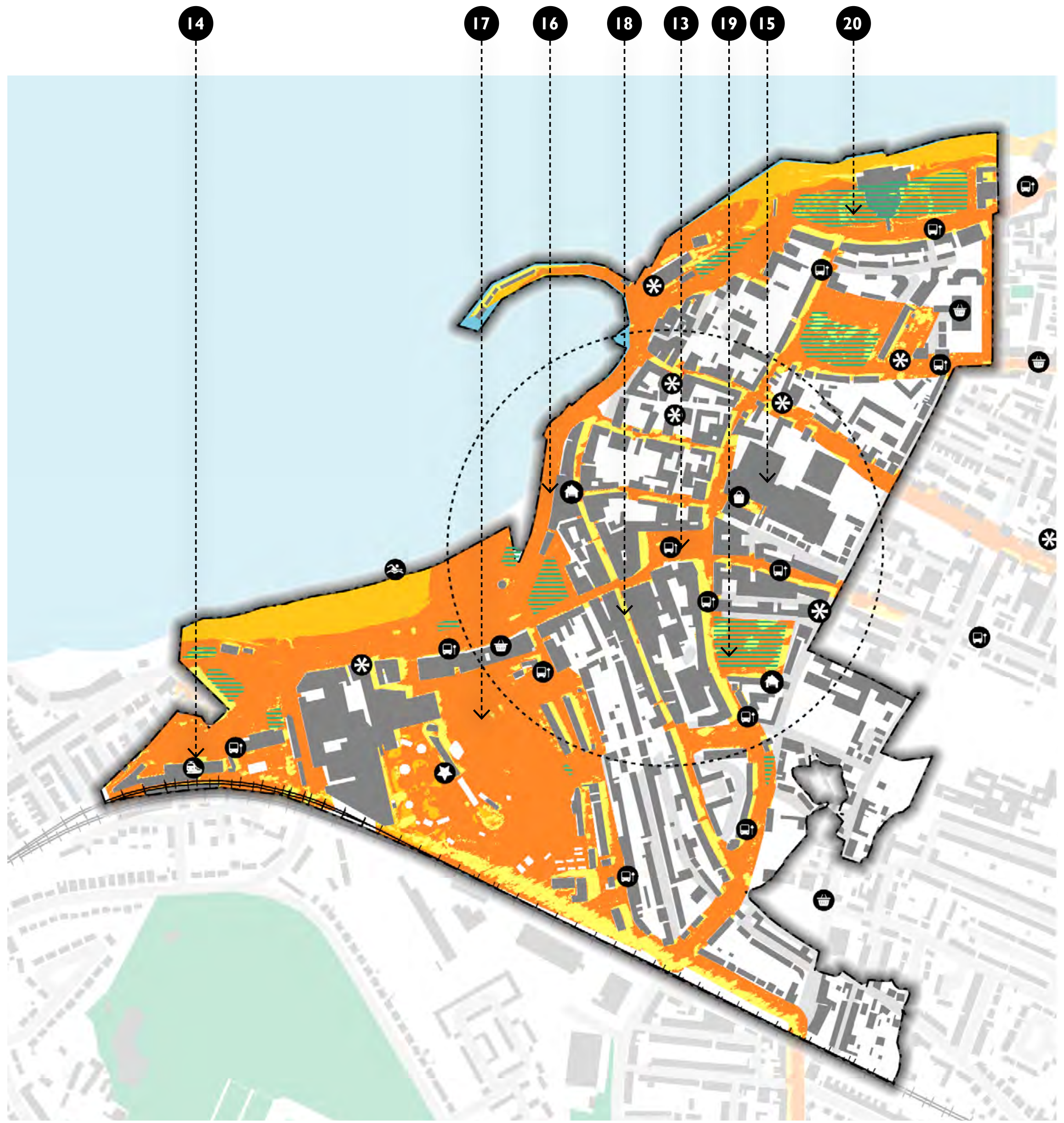


Figure 91: *Cool outdoor ground level area per inhabitant*

- 0-10 m^2 [PET < 35 °C] / inhabitant
- 10-20 m^2 [PET < 35 °C] / inhabitant
- 20-30 m^2 [PET < 35 °C] / inhabitant
- 30-40 m^2 [PET < 35 °C] / inhabitant
- 40-50 m^2 [PET < 35 °C] / inhabitant
- 50-75 m^2 [PET < 35 °C] / inhabitant
- 75-100 m^2 [PET < 35 °C] / inhabitant
- 100-125 m^2 [PET < 35 °C] / inhabitant
- 125-150 m^2 [PET < 35 °C] / inhabitant
- >500 m^2 [PET < 35 °C] / inhabitant



Advanced heat vulnerability map

Figure 92: The Margate central neighbourhood in Margate analysed during the rush hour TCL scenario to identify locations vulnerable to heat for visitors.

Research area: Kent - Margate central
User group: visitors

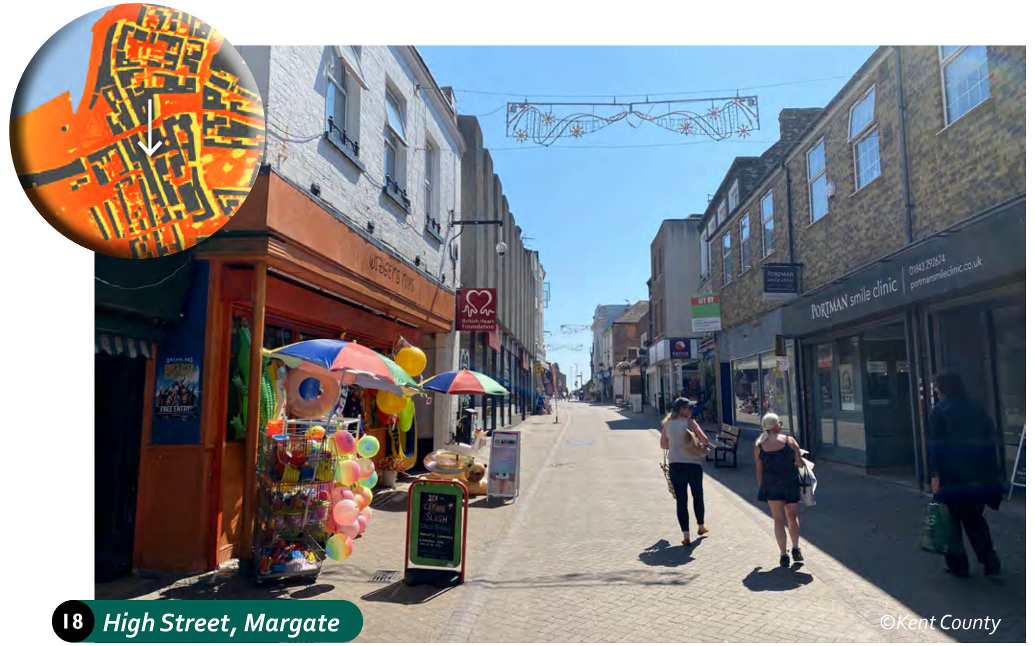
- Train station
- Attraction
- Swimming
- Cultural Facility
- Shopping centre or mall
- Supermarket
- Bus stop
- Hotel
- Rail
- Road
- 300 meter walking distance
- Building
- Water
- Park or recreation area
- Potential cool place

PET values - Rush hour scenario
- 46 - 51 Extreme heat stress (LV2)
- 41 - 46 Extreme heat stress (LV1)
- 35 - 41 Strong heat stress
- 29 - 35 Moderate heat stress

0 250 500 m

Looking at the advanced heat vulnerability map, main routes from the two transport hubs to the beach and College Square Shopping Centre (15) may expose pedestrians and cyclists to excessive heat. Station Approach, Northdown Road, Trinity Hill, Queen street and Marine Gardens all lead to the coastal promenade (16) which could be transformed into a tree-lined boulevard. Welcoming pedestrians to stroll on a well-shaded walkway by the sea or an extensive green area, such as the Cliff gardens in Southend (see chapter 9), may ensure a steady number of visitor numbers all year round. The same applies to the Dreamland Amusement Park (17) south of the beach. Attractions for children are especially important to heat-proof as this group are less aware of how heat affects them and their bodies are closer to the ground, exposing them to more intense infrared radiation than adults (see chapter 1).

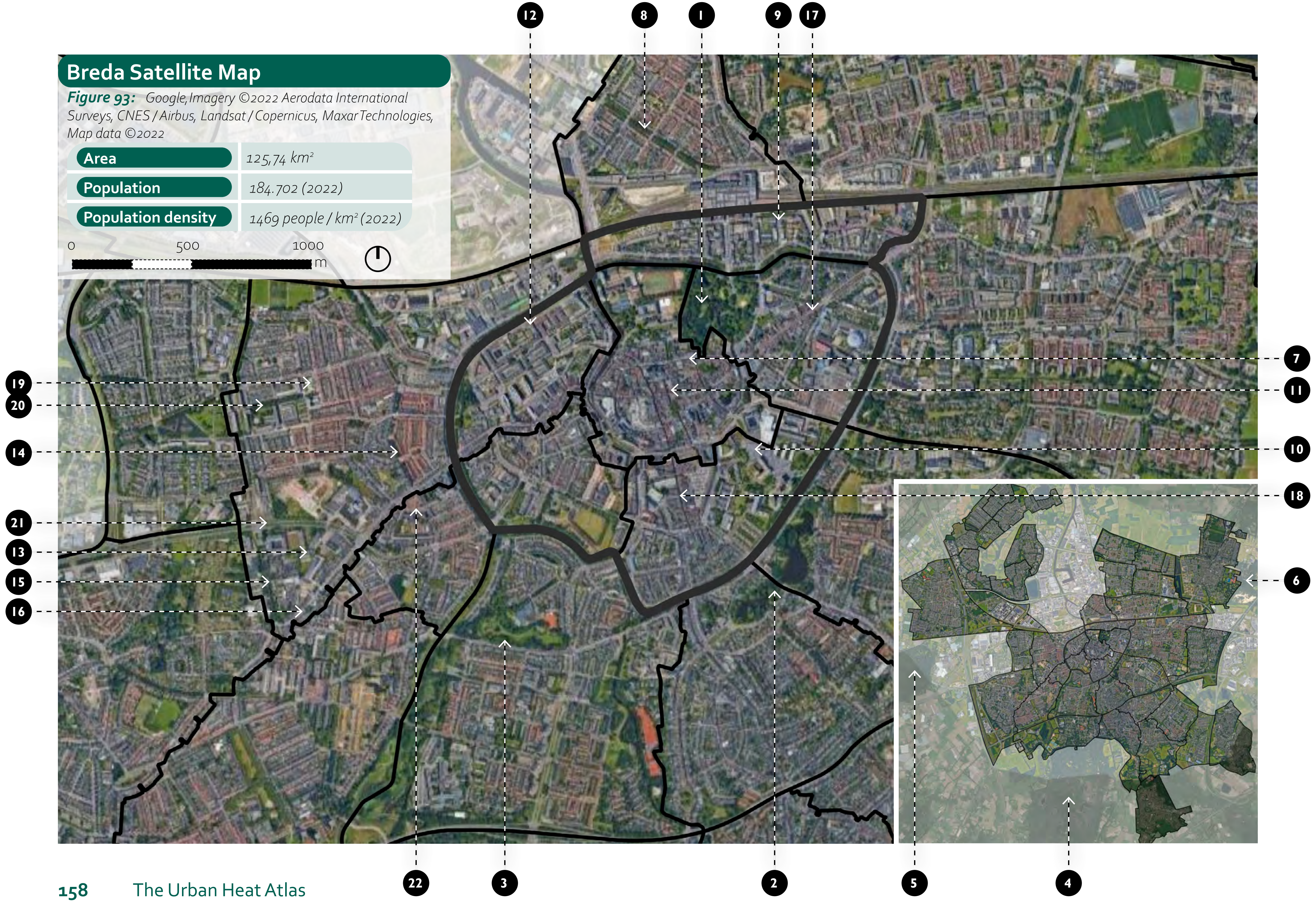
19 *Hawley Square, Margate* ©Kent County



18 *High Street, Margate* ©Kent County

Narrow streets east of the beach are better shaded with only Moderate Heat Stress levels. For example, the busy shopping area on High Street (18) is exposed to a PET between 46-51°C at lunchtime but during the rush hour buildings on the western side give protection from direct solar radiation. Visitors can also seek cool refuge under the foliage on the edges of Hawley Square (19). Other nearby parks, such as Margate Winter Gardens (20), would benefit visitors with more shade. Overall, the advanced heat vulnerability map for Margate's centre offers a wide range of opportunities to create cooling capacity to ensure visitors find it a thermally comfortable and pleasant area even on hot days.

11. Breda, The Netherlands



Breda Satellite Map

Figure 93: *Google, Imagery ©2022 Aerodata International Surveys, CNES / Airbus, Landsat / Copernicus, Maxar Technologies, Map data ©2022*

Area	*125,74 km²*
Population	*184.702 (2022)*
Population density	*1469 people / km² (2022)*

Breda

Breda is located in the south of the Netherlands, and it is one of the largest cities in the country (see fig.93). It aspires to become the first Dutch 'City in a Park' by strengthening its green and blue infrastructure within urban areas and outwards into the surrounding forests and countryside. The green-blue network will not only directly connect nature and people but also contribute to meeting many sustainability targets such as the interrelated climate resilience and liveability goals (Gemeente Breda, n.d.). Breda's Environmental Vision 2040 (ibid.) outlines the ambition to also become a climate resilient city by reducing the flood risk, adapting to periods of drought and mitigating heat stress.

2 ***Wilhelminapark, Breda***

©Marketing Department, Municipality of Breda

8 ***Speelhuislaan, Breda***

©Reginald Kluijtmans

In terms of heat stress, the adaptation strategy focuses on providing pedestrian and recreational areas with ample shade on hot summer days using the cooling effect of trees and shade from buildings. Reducing hard impervious surfaces and particularly those composed of dark heat retaining material, will increase the sponge capacity of natural soils, also mitigating urban heat. Breda strives to be a city where each inhabitant lives within 200 metres, a 'slipper distance', to a park, forest or the countryside (ibid.).

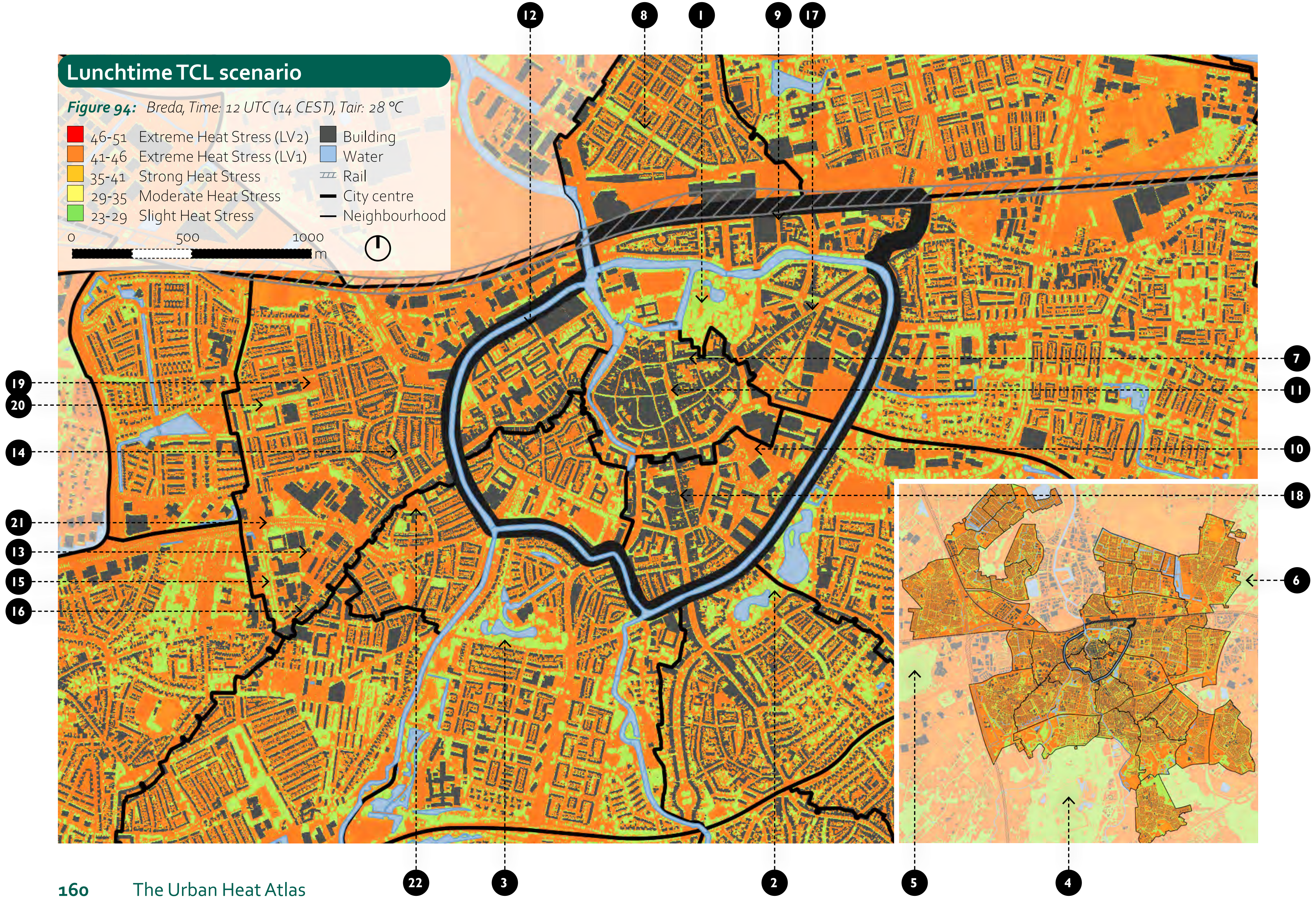


Figure 94: Breda, Time: 12 UTC (14 CEST), Tair: 28 °C

Breda lunchtime TCL Scenario

The PET-maps presented in the following pages help to identify areas vulnerable to heat stress and those with cooling capacity. The two TCL-scenarios also reveal how the city heats up through the course of the afternoon. During the lunchtime scenario (see fig.94), almost the entire city is under Level 1 Extreme Heat Stress, with the exception of areas under the shadow of trees or buildings. These cooler spots are indicated by green on the map (Slight Heat Stress). The green lungs of the city also stand out, such as in the historic city centre Valkenburg Park (1) and just outside the centre Wilhelmina park (2) and Van Sonsbeeck Park (3), where inhabitants can have a refreshing lunch break away from the heat. The large, forested national parks surrounding the city, such as Mastbos (4), Liesbos (5) or Boswachterij Dorst (6), demonstrate the difference in heat stress between patches of forest (transpiration and shading) and unshaded green fields.

A great number of important pedestrian and cycle routes are also under extreme heat stress during the lunchtime hours, but a few well-shaded streets stand out, showing how effective the positions of buildings and mature trees are to create cool routes. For example, the east-west orientation of Catharinastraat (7) in the historic centre means that the buildings to the south side provide ample shade. Speelhuislaan (8) is a good example of a parkway, where a double row of trees creates a cool route and a park-like setting. Currently only the southern half of Speelhuislaan is lined by trees but in the coming years these will be extended towards the Mark river as part of CrossMark, one of the city's development projects (CrossMark, 2022). Another green connection leading from the train station to the city centre is Menno van Coehoornstraat (9). Breda planted 18 Magnolia trees with a built-in water retention system from GreenBlue Urban on this Cool Towns pilot site.

9 *Menno van Coehoornstraat before and after (above) the Cool Towns intervention, Breda*

City – Neighbourhood – User Network

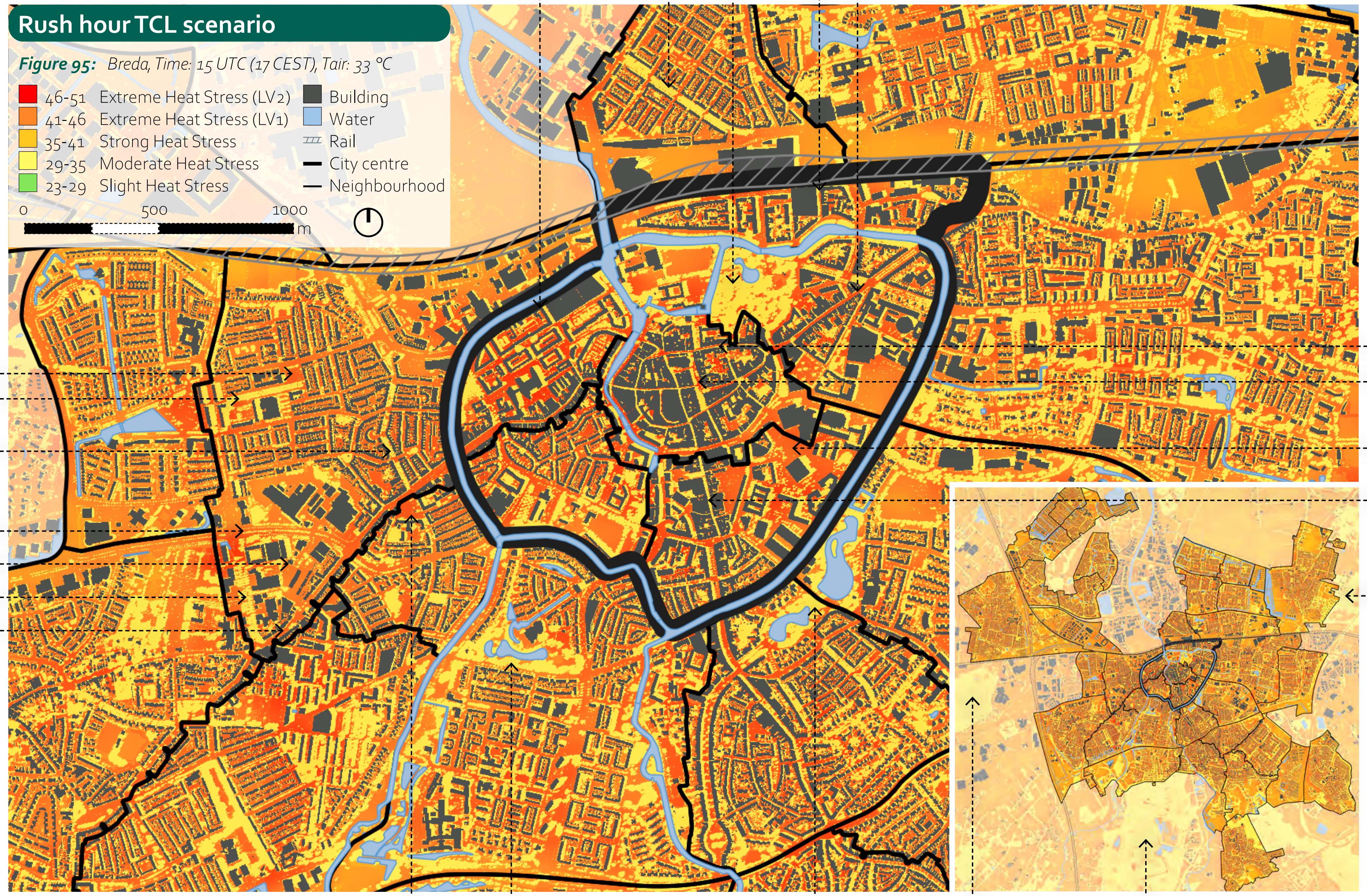


Figure 95: *Breda, Time: 15 UTC (17 CEST), Tair: 33 °C*

Breda rush hour TCL scenario

The rush hour scenario (see fig.95) reflects how the dense urban areas in Breda continue to heat up through the course of the afternoon, while peri-urban areas begin to cool off. Many public spaces in the inner city suffer from a PET between 46-51°C, for example the Chassé promenade (10) or the nearby parking site of the Chasséveld. The city's Environmental Vision aims to redevelop this car parking site into a vibrant cultural location. On the southern part of the main square, the Grote Markt (11) has Moderate Heat Stress, with mature plane trees (Plantanus x hispanica) creating a cool spot. On the northern part of the square another Cool Towns pilot site contributes to mitigating heat stress with a new water playground, in the shape of the city's coat of arms, which has been installed in front of the town hall. It invites visitors to the city centre to cool off and enjoy themselves when it is unusually warm. Following Breda's 'City in a Park' vision, five large city parks will be created by 2040. One of these, Seelig-zuid, is a park on a former military barrack site along the inner city canals. New landscape elements and bridges complement the canal forming a solid green-blue ring around the historic centre where residents can relax by the water and exercise to maintain their physical and mental wellbeing during hot periods. The third Cool Towns pilot site is contributing to this by restoring the double row of trees on the Nijverheidssingel (12).

12 Nijverheidssingel Cool Towns pilot site, Breda ©Municipality of Breda

10 Chassé promenade, Breda

11 Grote Markt, Breda ©Municipality of Breda

Breda heat vulnerability maps

The heat vulnerability maps of Breda help to identify neighbourhoods where socioeconomic and spatial challenges contribute to increased heat vulnerability. Pinpointing such areas helps decision makers to develop high-impact city-wide climate adaptation strategies. The vegetated land cover map (see fig.96) highlights almost the entire historic centre within the inner canal as an area without sufficient greenery. The Valkenberg neighbourhood is an exception because it is the only inner city park. Areas to the west and north of the centre also suffer from a lack of vegetation. Three new parks, outlined in the Environmental Vision (Gemeente Breda, n.d.), Seelig-zuid, CrossMark and Sterk West, are likely to bring cool spaces to these areas and serve the growing population.

The population density map (see fig.97) strongly correlates with the map of cool outdoor ground-level space per inhabitant (see fig.99). In neighbourhoods where more people live there is often additional need for greening. These areas also provide an opportunity for the municipality to increase their impact and positively influence the living conditions of many. Examples in Breda are Haagport and Heuvel, south of the centre, and Kroeten and Overkroeten on the north-west periphery. While no major city parks are planned in these areas, they will benefit from the new parks in their vicinity, and the neighbouring countryside. Looking at the age distribution across Breda's neighbourhoods (see fig.97), most children live outside the historic city centre. This pattern might reflect the common trend that families with children move to less central locations with more space such as private gardens. The majority of homes in the historic centre are multiple occupancy while outside the inner canal single-family dwellings prevail.

The map of socioeconomic status (see fig.98) highlights three large areas corresponding to areas Breda's Environmental Vision (Gemeente Breda, n.d.) has identified clusters of vulnerable neighbourhoods that need improvement. Breda intends to create an undivided city where individual possibilities are not affected by the neighbourhood one lives in. In terms of heat stress, low socioeconomic status indicates areas where residents might struggle to travel to cool places on hot days and need quality green space within their neighbourhood to escape extreme indoor heat. The municipality aims to create better neighbourhood connections in these vulnerable clusters to essential facilities, such as the centre or the station quarter. Cool bicycle and pedestrian routes, for example the northern ring road, that will be redeveloped as a parkway, may contribute to this goal. Projects outlined in the Environmental Vision, such as Sterk West and Spooras-oost, will serve as area-oriented reinforcements to raise the living quality in these neighbourhoods.

Breda advanced heat vulnerability map

In collaboration with officers from the municipality of Breda and based on discussions of the PET and heat vulnerability maps the Tuinzigt neighbourhood was identified as a priority and further analysis was requested. This neighbourhood lies west of the centre, just outside the inner canal (see fig.100). The neighbourhood has a socioeconomic status moderately below the city average with a low quantity of vegetation and insufficient cool outdoor space for residents on hot days. The advanced heat vulnerability map focused here on elderly residents and helped to identify vulnerable routes and places through user network analysis.

Breda's Environmental Vision (Gemeente Breda, n.d.) outlines a new development in Tuinzigt called Sterk West (Strong West) where a large city park (13) is proposed to benefit all surrounding neighbourhoods (marked as 'future park' on the advanced heat vulnerability map). It is an unique opportunity to connect this major development through cool corridors (bicycle and pedestrian routes) to Tuinzigt and beyond. Since most primary pedestrian and cycling routes have thermally uncomfortable conditions, with a PET between 41-46°C during the lunchtime hours, Dijklaan (14) and the southern section of Tuinzigtlaan (15) are exceptions where trees provide intermittent shading. Haagweg (16), and the continuation into the inner city, Nieuwe Haagdijk and Haagdijk, creates an important route for neighbourhood residents for shopping and reaching the train station. This is also a historic route lined by buildings dating back to the beginning of the 20th century. Looking back at the Thermal City Life (TCL) scenarios at city scale, a pattern emerges showing that the oldest historic routes often lack shade. Examples are Boschstraat (17) and its outward continuation or Ginnekenstraat (18) and its continuation as Nieuwe Ginnekenstraat, Ginnekenweg and Prins Hendrikstraat. These historic streets often have a

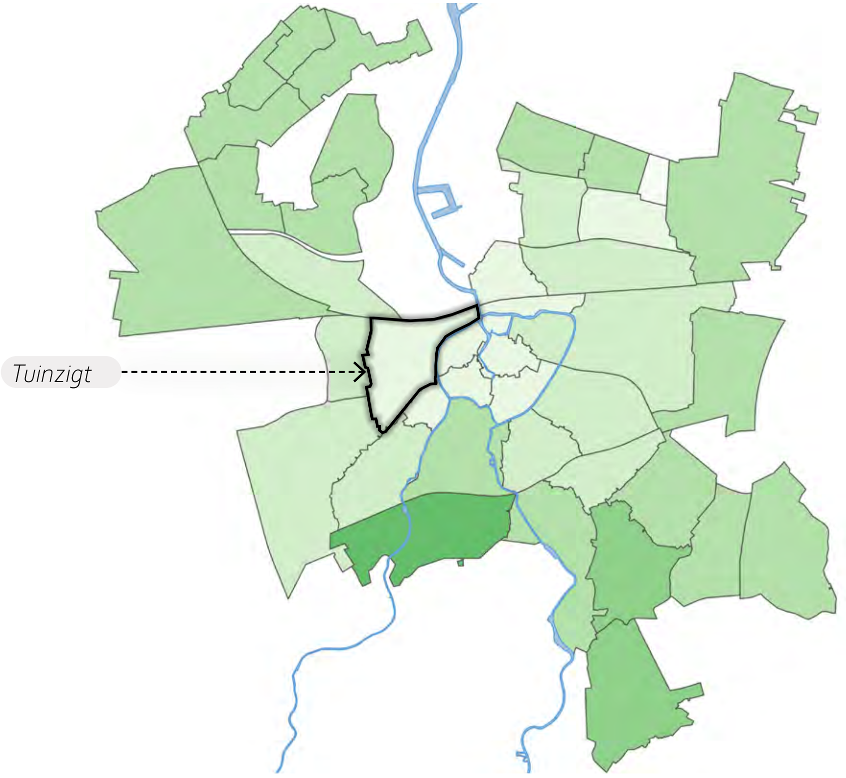

Haagdijk, Breda

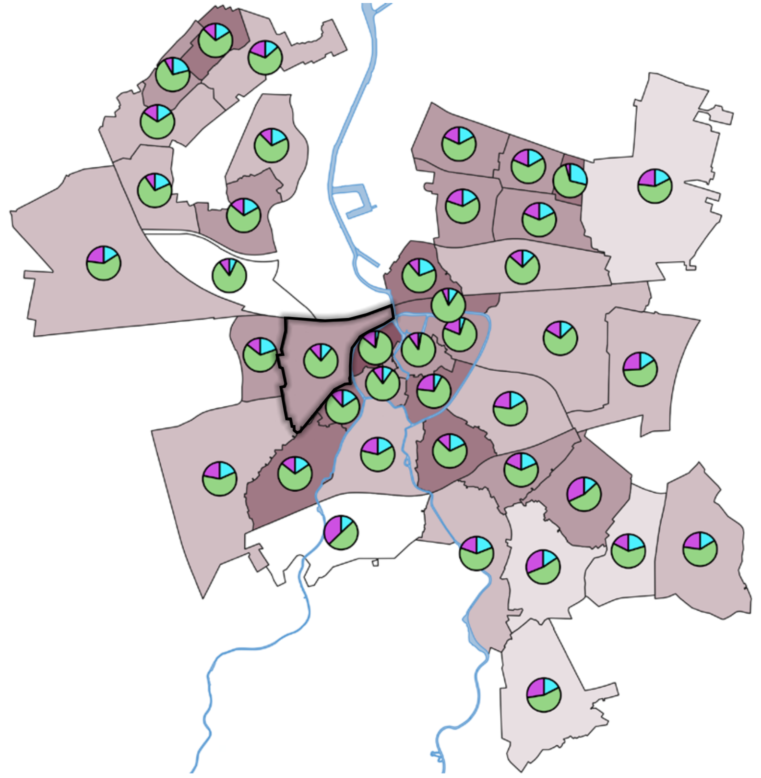

Nieuwe Haagdijk, Breda

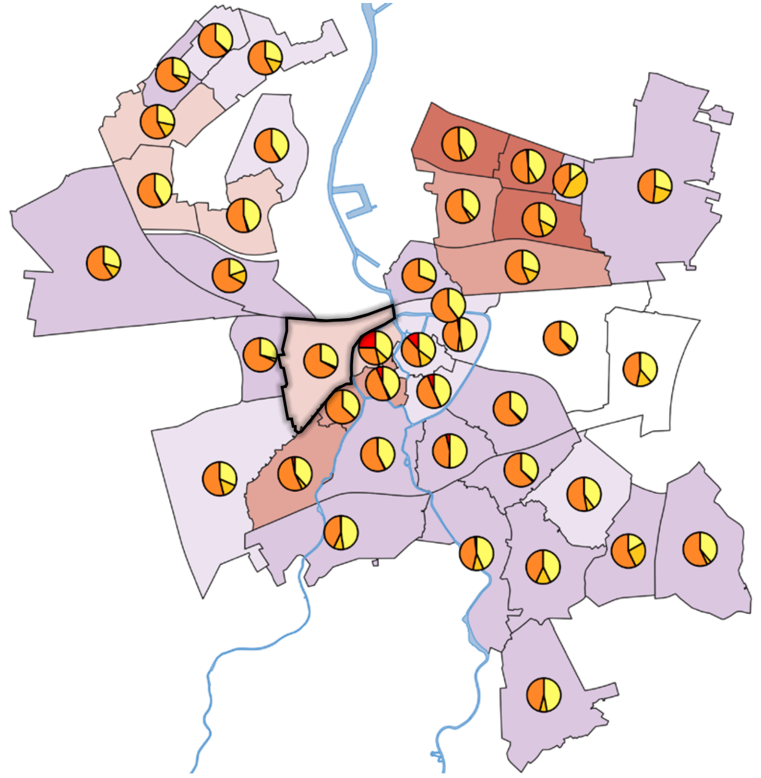

16 Haagweg, Breda

©Municipality of Breda (below & above)

Breda heat vulnerability maps







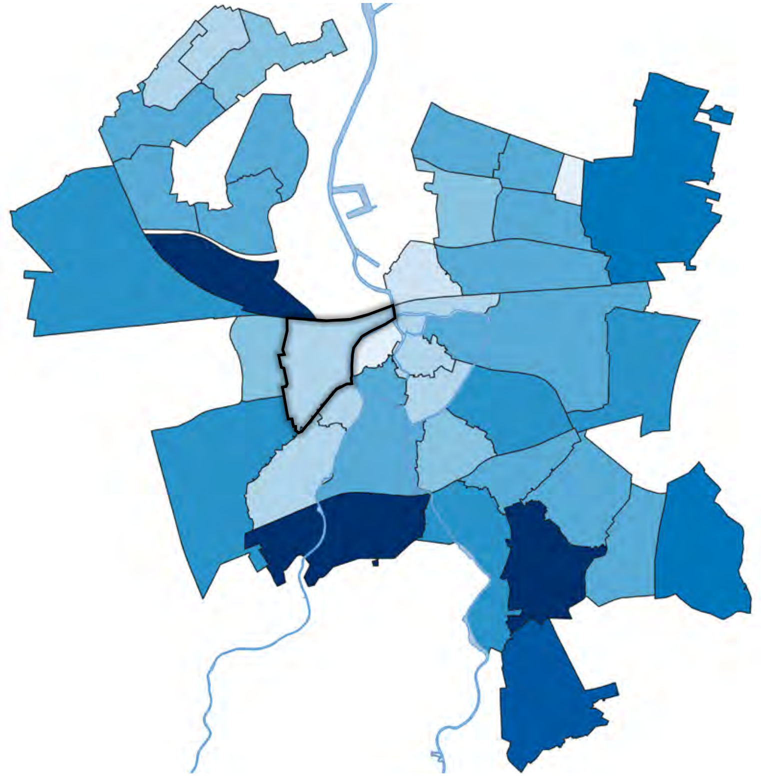


Figure 96: *Vegetated land cover*

- 0-10%
- 0-20%
- 20-30%
- 30-40%
- 40-50%
- 0-10%
- 0-20%
- 20-30%
- 30-40%
- 40-50%

Figure 97: *Population density and age distribution*

Population density

- 0-50 m^2 per inhabitant
- 50-100 m^2 per inhabitant
- 100-150 m^2 per inhabitant
- 150-200 m^2 per inhabitant
- 200-350 m^2 per inhabitant
- 350-500 m^2 per inhabitant
- >500 m^2 per inhabitant

Age distribution

- > 65
- 18 - 64
- 0 - 17

Figure 98: *Socioeconomic status (SES) and heat stress levels (PET)*

Socioeconomic status

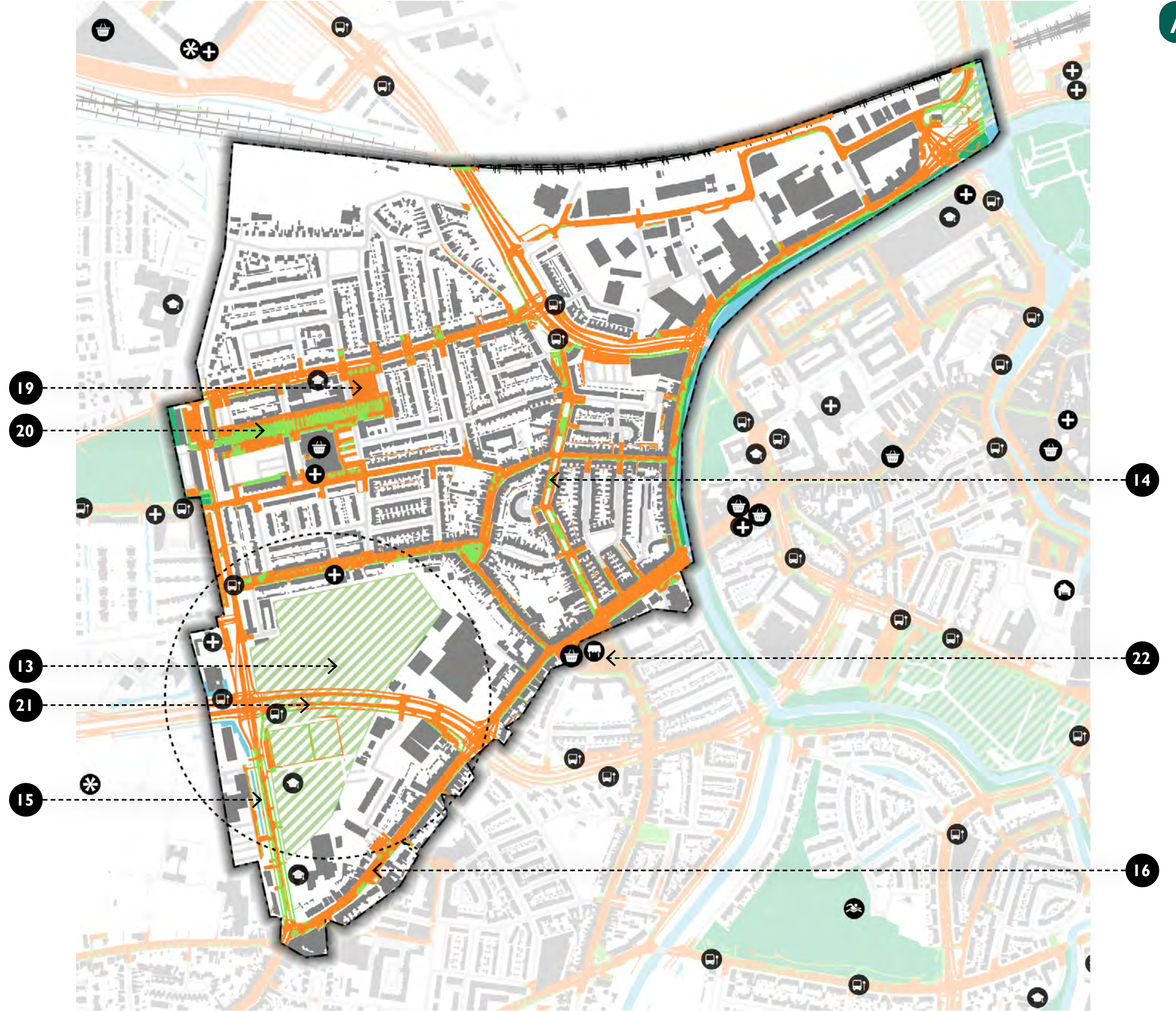
- Extremely below city average
- Strongly below city average
- Moderately below city average
- Slightly below city average
- Slightly above city average
- Moderately above city average
- Strongly above city average

Heat stress levels

- 46-51 Extreme Heat Stress (LV2)
- 41-46 Extreme Heat Stress (LV1)
- 35-41 Strong Heat Stress
- 29-35 Moderate Heat Stress
- 23-29 Slight Heat Stress

Figure 99: *Cool outdoor ground level area per inhabitant*

- 0-10 m^2 [PET < 35 °C] / inhabitant
- 10-20 m^2 [PET < 35 °C] / inhabitant
- 20-30 m^2 [PET < 35 °C] / inhabitant
- 30-40 m^2 [PET < 35 °C] / inhabitant
- 40-50 m^2 [PET < 35 °C] / inhabitant
- 50-75 m^2 [PET < 35 °C] / inhabitant
- 75-100 m^2 [PET < 35 °C] / inhabitant
- 100-125 m^2 [PET < 35 °C] / inhabitant
- 125-150 m^2 [PET < 35 °C] / inhabitant
- >500 m^2 [PET < 35 °C] / inhabitant



Advanced heat vulnerability map

Figure 100: The Tuinzigt neighbourhood in Breda analysed during the lunchtime TCL scenarioto identify locations vulnerable to heat for elderly.

Research area: Breda - Tuinzigt
User group: Elderly

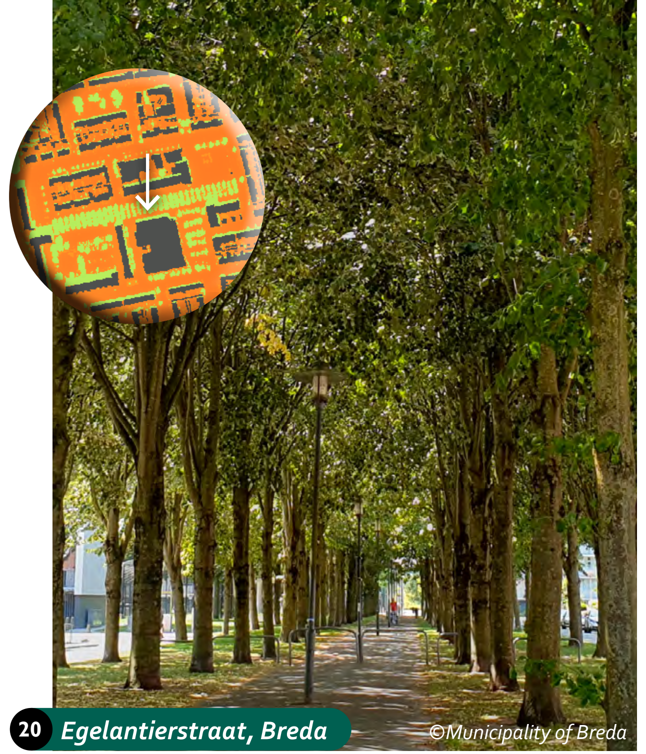
- Cultural facility
- Shopping center
- Hotel
- Market
- Supermarket
- Swimming
- Bus stop
- Healthcare related facility
- Education
- Train station
- Rail
- 300 meter walking distance
- Road
- Building
- Future park
- Park or recreation area
- Water

PET values - Lunchtime scenario
- 41 - 46 Extreme heat stress (LV1)
- 35 - 41 Strong heat stress
- 29 - 35 Moderate heat stress
- 23 - 29 Slight heat stress

0 300 600 m

continuous façade that reflects the heat and does not let in a cool breeze. Narrow street profiles can make planting trees challenging and are better suited to the installation of shade sails.

For elderly residents living in Tuinzigt, essential facilities are clustered in the local shopping centre. Close to this lies Nelson Mandelaplein (19) that was redesigned a few years ago. The new square features a fountain where children can play and feel refreshed on hot summer days. This new square is not shown on the advanced heat vulnerability map. The shopping centre and the square can be reached through a well shaded route, as the Egelantierstraat (20) has four rows of trees protecting pedestrians from the sun. The other routes leading to the area all require additional heat adaptive interventions. As part of the new living quarter, on the south of the neighbourhood, the municipality also aims to create a green structure between the Tuinzigtlaan (15) and the Haagweg (16). In addition, the Ettensebaan (21) will be redeveloped as a parkway. These interventions will create a variety of new routes through the neighbourhood that can be designed with rising temperatures in mind. They will also enable Tuinzigt residents to reach the Doctor Jan Ingen Houszplein (22), a square where Saturday markets are held.



20 *Egelantierstraat, Breda* ©Municipality of Breda

19 *Nelson Mandelaplein, Breda* ©Johan C. van Gurp, 20203140, collectie Stadsarchief Breda

12. European Urban Areas Compared

European urban heat patterns

The application of the developed Thermal Comfort Assessment (TCA) for identifying the impact of heat on urban areas in four European countries of the North Sea region shows that although municipalities may differ in size and location, the heat problems their citizens are confronted with in their daily lives are very similar. The two developed Thermal City Life scenarios, reflect the dynamic heat stress development in cities through two crucial time periods when thermal conditions and heat peaks coincide with peaks in daily urban rhythms. Together with the heat vulnerability maps, they reveal patterns in the heat-related challenges that now can be associated with spatial typologies, social activities and user groups and how existing (green) resources cities can capitalise to address these (see fig.101 for an overview of all maps).

Central hot spots

People who visit the historical city centres during hot periods are often exposed to heat. The large concentration of concrete and brick, in combination with narrow streets, can create substantial thermal discomfort for users. The high position of the sun, the orientation of the buildings and the height/width ratio of old streets can fuel solar and infrared radiation. When there is no wind, this can cause heat to be trapped in the centre, such as in Ostend and Saint-Omer. Users of market squares and other central locations are frequently exposed to direct solar radiation, but their cluster of functions and/or heritage status hinders heat mitigation. Transforming parking areas to green spaces often provides a good alternative for historical sites to create cool spots in the short term. While green space in city centres is often scarce, and underground utilities make greening interventions challenging, these areas are home to essential amenities and of local economic importance.

Wapenplein, Ostend

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Historical green capital for heat-resilience

Peri-urban and rural areas around cities may seem green on satellite maps but often entail open meadows and agricultural fields offering little to no shade and refuge in periods of extreme heat. Fortunately, the municipalities assessed valued their large historical parks with high cooling properties. Built in the 19th century, replacing city walls, fortifications and other historical military structures around the inner city, these still act as the first line of defence, but this time to combat the heat. European cities are investing in restoring and adding to these green-blue rings and other large green areas around their centres (e.g. Breda, Middelburg, Oostende and Saint Omer) to increase heat resilience. Improving the accessibility of these cool radial areas by adding greenery and pedestrianising the roads extending from the centre to these locations, like spokes of a wheel, is recommended as a follow-up strategy.

Valkenberg Park, Breda

©Breda Municipality, Marketing Department

Coping with heat at the beach

For the coastal cities, the outcome of the Thermal Comfort Assessment indicates that visitors are, on hot days, exposed to extreme conditions even before they have reached the beach (e.g. Ostend, Southend, Margate). Walking routes leading from parking areas and transport hubs to the sea suffer from extreme heat stress conditions. Cooling these by greening promenades and creating large parks nearby, such as Westcliff Parade in Southend, may offer cool alternatives on hot days when staying at the beach for long is unbearable. In the context of the predicted longer and more intense heat waves, introducing shade near the coast would also provide beach goers a choice of when to sunbathe and when to rest in the shade. This may ensure a steady number of visitors through summer which many coastal towns rely on for income.

Margate beach, Margate

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Climate proofing infrastructure

Mobility hubs are frequently identified as hot spots, as are cycle and pedestrian routes, with a hidden economic impact. More research is needed on how this could affect the productivity of workers but it is clear that hot conditions are a difficult start to the working day. Chapter one describes how cycling is sensitive to heat and the need to ensure that train stations, bus terminals, etc. remain accessible during warm days. To support sustainable mobility, the thermal comfort of cyclists and pedestrians needs to be improved on the main primary routes into mobility hubs and also shopping areas. Good examples are Middelburg (see chapter 3) and Zelzate (see chapter 6) where cooling capacity of the bus station and the road to the city centre has been improved. Ensuring enclosed canopy cover on the main cycle and pedestrian routes is important to retain access to these vital areas for securing the continuation of city life in the summer months. When creating these cool corridors, special attention needs to be given to the design of junctions where people frequently have to wait in the sun because of traffic lights or traffic. Waiting areas at mobility hubs such as bus stops, which can heat up like a greenhouse when made of glass, also call for cooling measures (Beckers, 2022).

Station, Middelburg

©Aart van Belzen

Extra vulnerable groups to heat

Prioritising the development of cool areas near the homes of people who have to rely on the cooling capacity of their neighbourhood is particularly important for those vulnerable to heat. In a large number of the urban areas analysed the amount of vegetation is unequally distributed revealing socioeconomically challenged neighbourhoods that are insufficiently equipped with cool outdoor space. The residents here are extra sensitive to heat exposure due to poor thermal comfort indoors and limited financial ability to travel far for cool outdoor spaces. Integrating parks in urban renewal projects could reduce health risks related to heat stress and promote overall well-being.

Essential facilities for elderly residents appear to be clustered in local shopping centres. The advanced heat vulnerability maps show that important walking routes to these vital locations, for example in Tuinzigt (Breda) or in Dauwendaele (Middelburg) are partly exposed to heat despite the elderly having mobility limitations and increased risk of heat-related morbidity and mortality (see section 1.4). Identifying heat vulnerabilities in the local network of walking routes, amenities and functions which are associated with certain user groups such as the elderly, for example pharmacies and community centres, can help to prioritise the most effective heat stress intervention and location to boost the user network and make systemic improvements.

An analysis of the local networks that children, another heat-vulnerable group, use, indicates that large paved school playgrounds and open sports fields are a risk for physical exercise classes outside on hot days. When children are playing or taking part in sports in these uncovered areas they adjust more slowly than adults to heat, have lower sweat rates and their learning capacity is reduced (see also section 1.4 and Southend chapter 9 for a children's network analysis). While many sport activities require large open areas, planting multiple rows of trees along the edges of playing fields may allow children (and spectators) to retreat from the heat when needed. Additionally, the walking and cycling routes to schools and other amenities they use are important and should provide cooling capacity. Merelbeke aimed to tackle these top-priorities by creating pocket parks where climate adaptation interventions such as water infiltration go hand in hand with small playgrounds where children can play comfortably during summer months (see chapter 5). Opening heatproof school playgrounds to the public on weekends and out-of-school-hours, a measure Saint-Omer is testing, is another way to amplify the impact of heat mitigation measures aimed at children.

Cyclists

© Floris Oosterveld i.o.v Marketing Department, Municipality of Breda

Children

©Bureau Duizenddingeni.o.v Marketing Department, Municipality of Breda

Elderly

©Province of East Flanders

Figure 101: *Overview of all the heat maps generated for the ten municipalities assessed in England, Belgium, The Netherlands and France.*

Heat stress levels (PET)

- 46-51 Extreme Heat Stress (LV2)
- 41-46 Extreme Heat Stress (LV1)
- 35-41 Strong Heat Stress
- 29-35 Moderate Heat Stress
- 23-29 Slight Heat Stress

Vegetated land cover

0-10%	0-10%
0-20%	0-20%
20-30%	20-30%
30-40%	30-40%
40-50%	40-50%

Population density

- 0-50 m² per inhabitant
- 50-100 m² per inhabitant
- 100-150 m² per inhabitant
- 150-200 m² per inhabitant
- 200-350 m² per inhabitant
- 350-500 m² per inhabitant
- >500 m² per inhabitant

Age distribution

- > 65
- 18 - 64
- 0 - 17

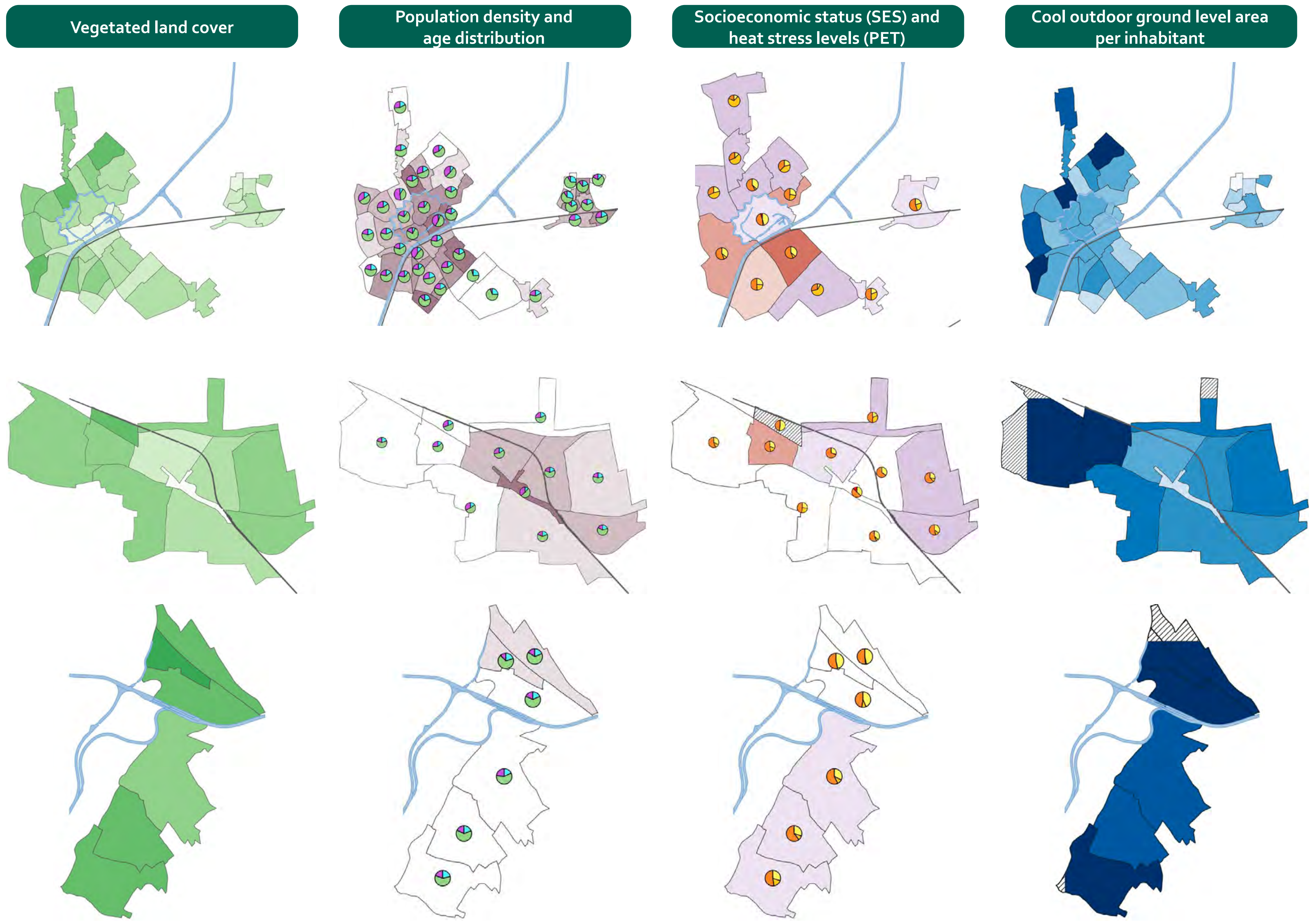
Socioeconomic status (SES)

- Extremely below city average
- Strongly below city average
- Moderately below city average
- Slightly below city average
- Slightly above city average
- Moderately above city average
- Strongly above city average

Cool outdoor ground level area

- 0-10 m² [PET < 35 °C] / inhabitant
- 10-20 m² [PET < 35 °C] / inhabitant
- 20-30 m² [PET < 35 °C] / inhabitant
- 30-40 m² [PET < 35 °C] / inhabitant
- 40-50 m² [PET < 35 °C] / inhabitant
- 50-75 m² [PET < 35 °C] / inhabitant
- 75-100 m² [PET < 35 °C] / inhabitant
- 100-125 m² [PET < 35 °C] / inhabitant
- 125-150 m² [PET < 35 °C] / inhabitant
- >500 m² [PET < 35 °C] / inhabitant

- Water
- Train track
- No data



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- >500 m² [PET < 35 ° C] / inhabitant

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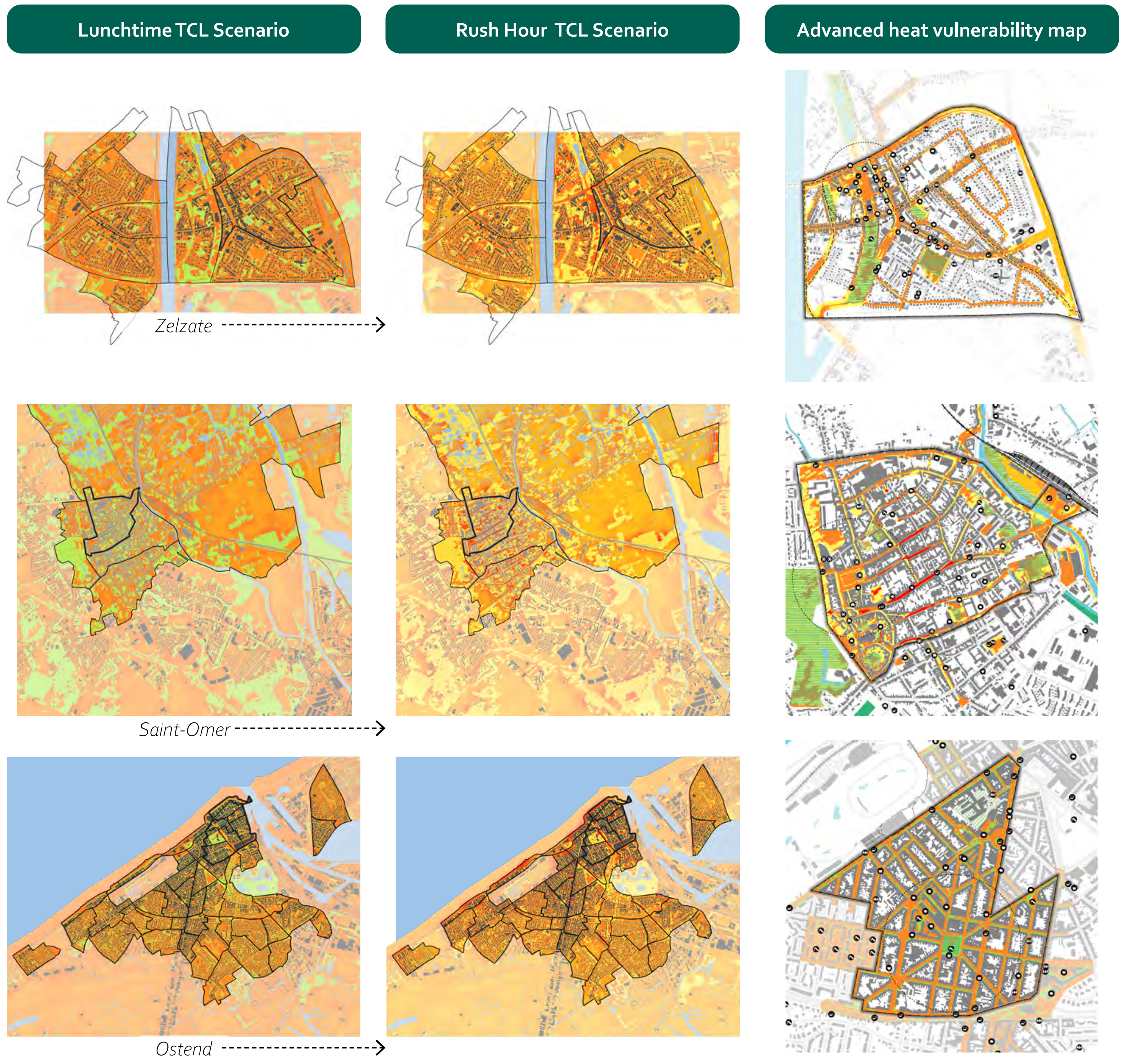
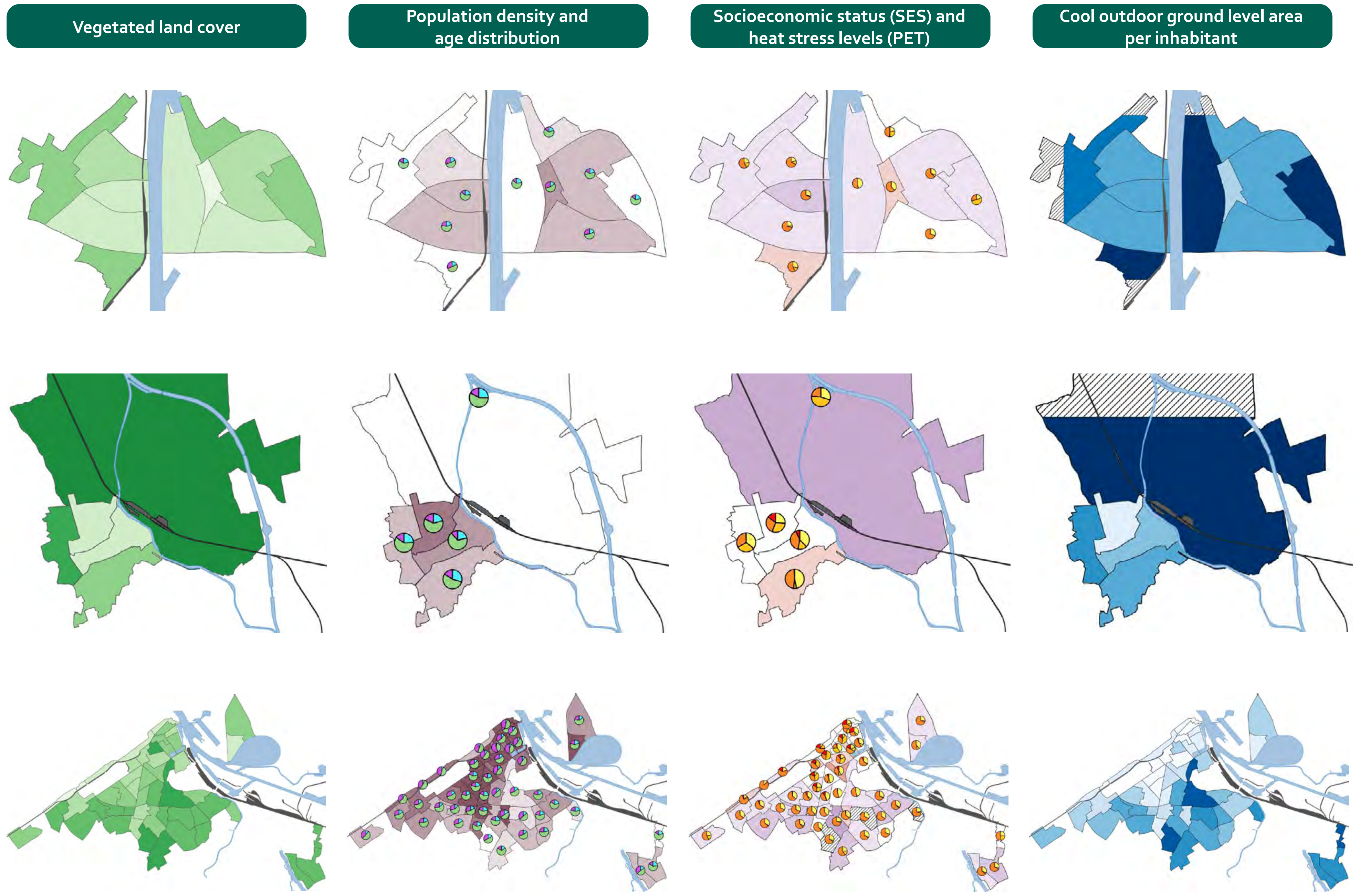
- Train track
- No data





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Heat stress levels (PET)

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- 35-41 Strong Heat Stress
- 29-35 Moderate Heat Stress
- 23-29 Slight Heat Stress

Vegetated land cover

- 0-10% / 0-10%
- 0-20% / 0-20%
- 20-30% / 20-30%
- 30-40% / 30-40%
- 40-50% / 40-50%

Population density

- 0-50 m^2 per inhabitant
- 50-100 m^2 per inhabitant
- 100-150 m^2 per inhabitant
- 150-200 m^2 per inhabitant
- 200-350 m^2 per inhabitant
- 350-500 m^2 per inhabitant
- >500 m^2 per inhabitant

Age distribution

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- 18 - 64
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Socioeconomic status (SES)

- Extremely below city average
- Strongly below city average
- Moderately below city average
- Slightly below city average
- Slightly above city average
- Moderately above city average
- Strongly above city average

Cool outdoor ground level area

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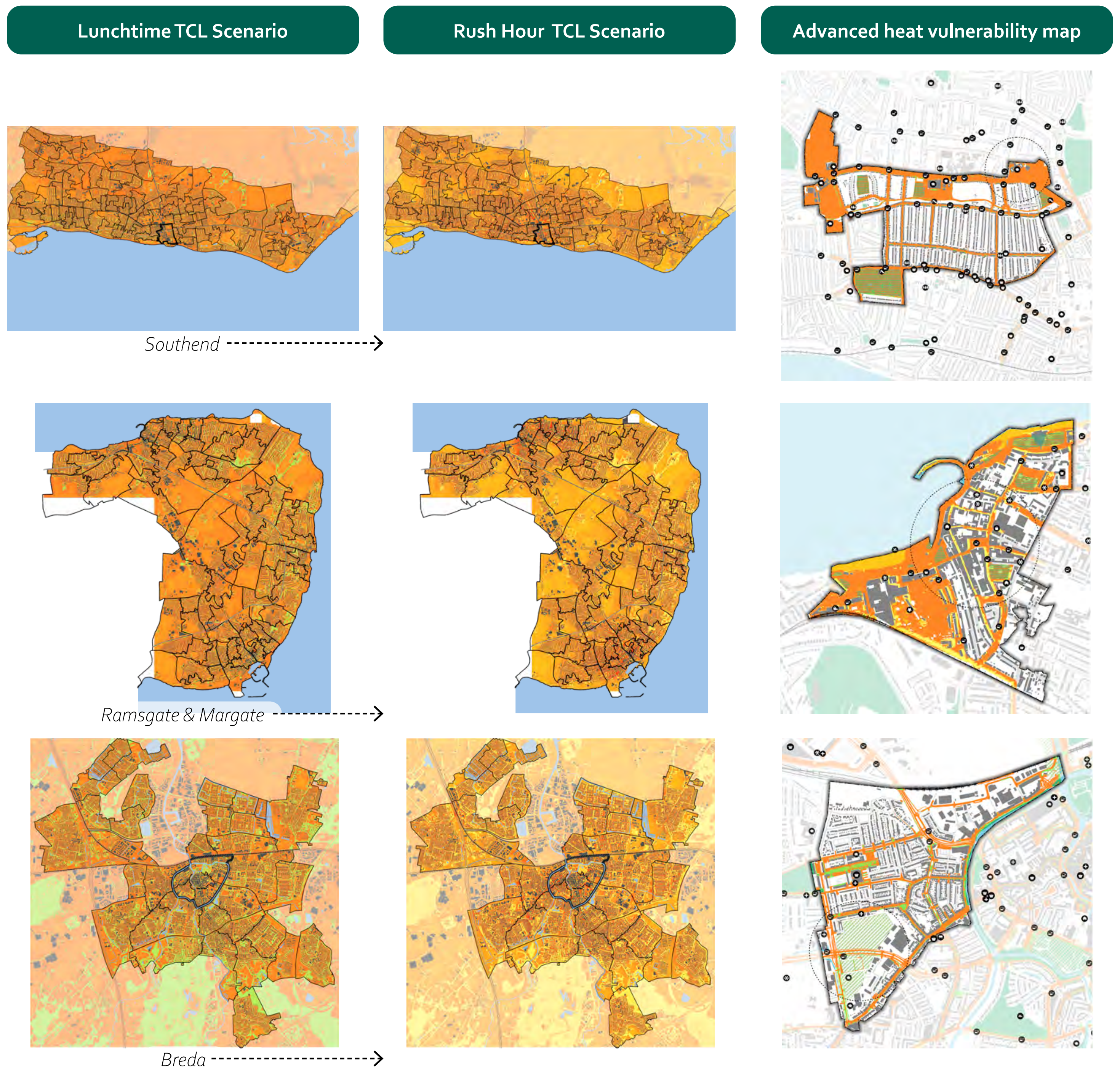
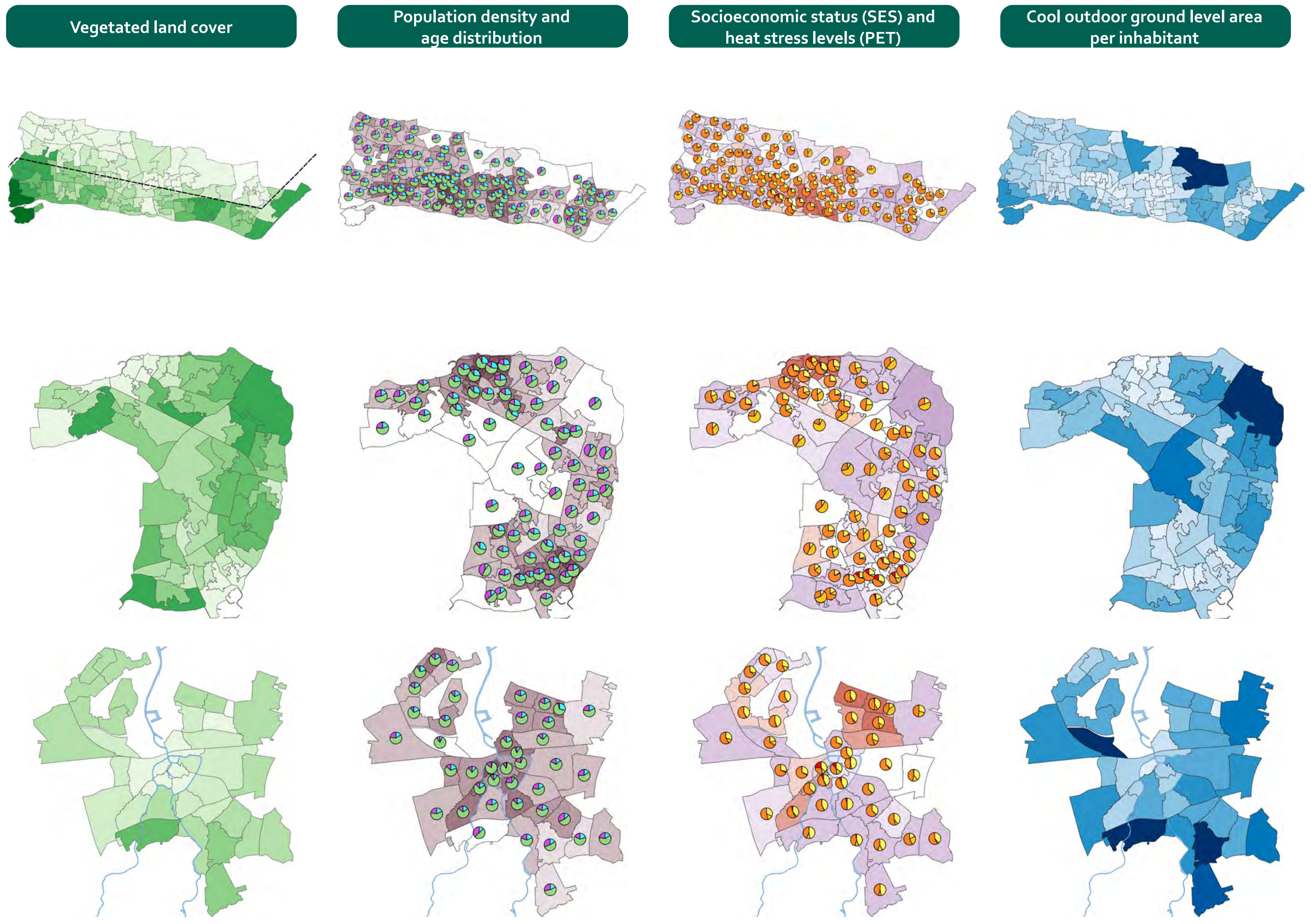
- 10-20 m^2 [PET < 35 °C] / inhabitant
- 20-30 m^2 [PET < 35 °C] / inhabitant
- 30-40 m^2 [PET < 35 °C] / inhabitant
- 40-50 m^2 [PET < 35 °C] / inhabitant
- 50-75 m^2 [PET < 35 °C] / inhabitant
- 75-100 m^2 [PET < 35 °C] / inhabitant
- 100-125 m^2 [PET < 35 °C] / inhabitant
- 125-150 m^2 [PET < 35 °C] / inhabitant
- >500 m^2 [PET < 35 °C] / inhabitant

- Water
- Train track
- No data





13. Conclusions

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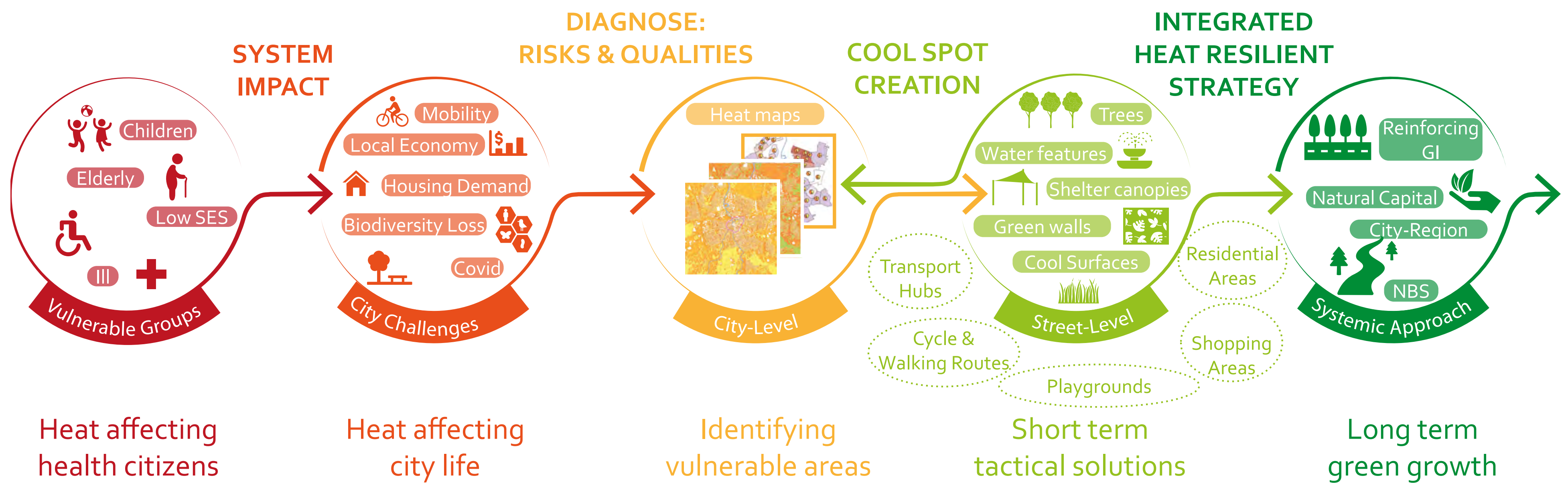

Figure 102: *Demonstrating how heat makes cities vulnerable and how the creation of cool spots can provide relief where it is most needed while stimulating green growth that can lead to systemic improvements and climate proofing cities.*

European towns and cities densify their cities to accommodate the growing population of citizens. However, the conventional way in which urban areas are redeveloped and buildings are constructed greatly increases the Urban Heat Island effect. The results of the Thermal Comfort Assessment shows that many important urban areas we use in our daily lives such as shopping areas, mobility hubs, parks, and the roads between these we use for cycling and walking, are frequently the locations experiencing severe heat stress (see fig.101 for an overview of maps). This brings thermal discomfort and health risks to citizens, in particular children and the elderly, and was confirmed by the functional network analyses. With the rising temperatures due to climate change, more discomfort for citizens in summer is foreseen. The historical blue-green infrastructure on its own is not sufficient to safeguard comfortable urban conditions for living in this changing climate. Escaping the heat by residing in the countryside during summertime was a solution for the happy few in ancient Rome but is currently not an affordable option for most citizens. How heat affects citizens and how comfortable living conditions can be maintained in warm periods, with spatial and behavioural adaptations, is the question we now need to raise.

Cool spot creation

The densely built urban fabric and narrow street profiles require innovative adaptation. Creating water features on squares in central areas like in Breda (see chapter 11) where green alternatives are not possible yet, is an effective solution for children and adults to cool off. A quick win is to improve the growing conditions of trees to increase cooling capacity. Pruning the top of trees and creating artificial shelter with sun shades for example, is an underuse of resources. Giving up parking places in shopping streets to install greenery has been done in Southend (see chapter 9) and is effective but not always possible.

Ostend has shown, by transforming the car park in the Lijnbaanstraat (see chapter 8) into a green oasis, that creating a large cool area nearby can be an effective strategy to increase the thermal comfort for shoppers and visitors and to contribute to other city challenges such as sustainable transport (see fig.102). Providing cool play areas in neighbourhoods for children by planting trees, (see e.g. Merelbeke chapter 5 and Saint-Omer chapter 7) and installing shade sails and green walls (see Zelzate chapter 6) are all tactical solutions to ensure that children will be able to spend time outdoors. See also the Cool Towns Interventions Catalogue for some evidence-based interventions to create cool capacity at playgrounds (Spanjar et al., 2022). Well shaded picnic zones near community centres or in green spaces (see Eeklo chapter 4) may promote gathering and counteract social isolation and loneliness in periods of extreme heat. Transforming main routes for cycling and walking into cool corridors by planting a row of trees can secure the accessibility of important areas in the city (see for example Middelburg chapter 3, and Margate chapter 10).

Towards green growth

The creation of cool spots are all important street-level interventions where short term heat relief is required (see a Spanjar et al., 2022 for a collection of evidence based examples). However, an integrated heat resilient strategy requires systemic change (see fig.102). 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. Also the distribution of cool spaces needs to happen in a more equitable way. Deprived neighbourhoods are frequently seen to be inadequate with respect to cool capacity near people's homes. In urban renewal projects, attention should be given to designating substantial green areas in these neighbourhoods and at least within walking distance - such as Breda (chapter 11).

When it is extremely hot those who can financially afford it escape by travelling to the larger green and blue areas in the region or even further. Cities that have dense forests with mature trees within the city and nearby - for example Southend (chapter 9) and Merelbeke (chapter 5), have an advantage in warm periods. In the long term, increasing heat resilience in cities means investing in green growth (see fig.102). Extending and improving natural capital in the neighbouring countryside and connecting it to cities' green-blue infrastructure benefits citizens during heat waves, which are predicted to become more frequent and intense. Improving the accessibility of these large green cool areas, as in Merelbeke (chapter 5), aims to benefit the wider population of inhabitants and may be an advisable first step in unlocking the potential of natural capital in the region. Shorter travel distances and stimulating climate-friendly modes of transport in hot periods with a network of cool corridors also reduces CO_2 emissions for climate change mitigation and the promotion of human health and well-being.

Fortunately, European municipalities have launched the first generation of climate change adaptation strategies to address climate change challenges, including heat stress (as previously discussed). The Thermal Comfort Assessment developed, and the collection of heat-related maps produced, is the result of four years of close collaboration between universities and municipalities in the Cool Towns project. We hope it will provide decision-makers, urban planners, landscape architects and other related professionals with useful guidance to translate city heat stress challenges into priorities, and effective green interventions to increase heat resilience.

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CREDITS

Authors
Dr. Gideon Spanjar
Cool Towns Project leader - senior researcher
Amsterdam University of Applied Sciences

Dr. Debbie Bartlett
Professor Environmental Conservation
University of Greenwich

Sába Schramkó
Junior Researcher Architecture and Urban Design
Amsterdam University of Applied Sciences

Dr. Jeroen Kluck
Professor Climate Resilient City
Amsterdam University of Applied Sciences

With the cooperation of
Luc van Zandbrink, PET model and maps development
Junior researcher, Amsterdam University of Applied Sciences

Stephanie Erwin, Advanced heat vulnerability maps development
Medior researcher, Amsterdam University of Applied Sciences

Leen Meheus, Advisory role
Scientific staff member, Province of East-Flanders

Dante Föllmi, Vera Wetzels, Kylian Postema, Data visualization
Junior researchers, Amsterdam University of Applied Sciences

Figures
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More information
Cooltowns.eu and HvA.nl

Contact
Gideon Spanjar, G.Spanjar@hva.nl

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Benoit Dauchy ... *Municipality of Saint Omer*
Boris Fillon ... *AUD-Saint-Omer*
Carolyn Jonkers ... *Municipality of Middelburg*
David Bennett ... *Kent County*
Eli Devriendt ... *Municipality of Ostend*
Els de Vilder ... *Municipality of Zelzate*
Freya Kingsland ... *Kent County*
Irène Rauch ... *Province of East Flanders*
Ivo Adam ... *Municipality of Merelbeke*
Jeroen van der Kuur ... *AUAS*
Kristof Verhoest ... *Municipality of Ostend*
Kurt Bullynck ... *Municipality of Ostend*
Louise Page ... *GreenBlue Urban*
Mechtild Zoeter Vanpoucke ... *Province of East Flanders*
Niek Meijer. ... *Municipality of Middelburg*
Peter Jeucken ... *Municipality of Breda*
Pieter Lommerse ... *AUAS*
Sabine Courouble ... *CAPSO*
Sarah Singer ... *AUD-Saint-Omer*
Saskia Libbrecht ... *Province of East Flanders*
Severine Verschaete ... *Province of East Flanders*
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Wim de Jaeger ... *AUD-Saint-Omer*

Interreg 2 Seas Mers Zeeën

Provincie Noord-Holland

Provincie Zeeland

With increase in awareness of the risks posed by climate change and increasingly severe weather events, attention has turned to the need for urgent action. While strategies to respond to flooding and drought are well-established, the effects - and effective response - to heat waves is much less understood. As heat waves become more frequent, longer-lasting and more intense, the Cool Towns project provides cities and municipalities with the knowledge and tools to become heat resilient. The first step to developing effective heat adaptation strategies is identifying which areas in the city experience the most heat stress and who are the residents most affected. This enables decision-makers to prioritise heat adaptation measures and develop a city-wide strategy.

The Urban Heat Atlas is the result of four years of research. It contains a collection of heat related maps covering more than 40,000 hectares of urban areas in ten municipalities in England, Belgium, The Netherlands, and France. The maps demonstrate 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. The comparative analyses of the collated maps also provide a first overview of the current heat resilience state of cities in North-Western Europe.

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