Hotterdam

How space is making Rotterdam warmer, how this affects the health of its inhabitants, and what can be done about it.

TU Delft, Architecture and the Built Environment
Frank van der Hoeven
Alexander Wandl

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Content

Summary

Background

Heat waves will occur in Rotterdam with greater frequency in the future. Those affected most will be the elderly – a group that is growing in size. In the light of the Paris heat wave of August 2003 and the one in Rotterdam in July 2006, mortality rates among the elderly in particular are likely to rise in the summer.

Method

The aim of the Hotterdam research project was to gain a better understanding of urban heat. Heat was measured and the surface energy balance modelled from that perspective. Social and physical features of the city were identified in detail with the help of satellite images, GIS and 3D models. The links between urban heat/surface energy balance and the social/physical features of Rotterdam were determined on the basis of multivariable regression analysis. The decisive features of the heat problem were then clustered and illustrated on a social and a physical heat map.

Results

The research project produced two heat maps, an atlas of underlying data and a set of adaptation measures which, when combined, will make the city of Rotterdam and its inhabitants more aware and less vulnerable to heat wave-related health effects.

Conclusion

In different ways, the pre-war districts of the city (North, South, and West) are warmer and more vulnerable to urban heat than are other areas of Rotterdam. The temperature readings that were carried out confirm these findings as far as outdoor temperatures are concerned. Indoor temperatures vary widely. Homes seem to have their own dynamics, in which the house's age plays a role.

The above-average mortality of those aged 75 and over during the July 2006 heat wave in Rotterdam can be explained on the basis of a) the concentration of people in this age group, b) the age of the homes they live in, and c) the sum of sensible heat and ground heat flux.

A varying mix of impervious surfaces, surface water, foliage, building envelopes and shade make one area or district warmer than another.

Adaptation measures are in the hands of residents, home owners and the local council alike, and relate to changing behaviour, physical measures for homes, and urban design respectively.

Why heat?

When it comes to climate change, the focus in the Netherlands is often directed at water-related problems. Examples that come to mind are heavy showers, high river levels and rising sea-levels. Water is something of a traditional enemy. Flooded streets, rivers that burst their banks and coastal erosion are perceptible and mediagenic. These climate effects appeal easily to the imagination and are simple for a wide audience to appreciate. With heat, things are more difficult.

The effects of heat, and especially heat in urban areas, are more or less unknown. Whenever any (media) attention is given to heat, it focuses on the warming of the earth as a whole, and the question of whether that process will amount to more or less than two degrees Celsius. But few of us know that the temperature inside urban areas is sometimes ten degrees Celsius higher than outside their limits, or that for long periods of the day, the temperature inside homes is warmer than out on the street. Heat is invisible and its direct effects are easy not to see. The fact that more elderly people die during heat waves than usual is not widely known and some do not even believe it.

It does not help that meteorological institutes, such as the Royal Netherlands Meteorological Institute (KNMI), prefer to measure weather outside cities, at a safe distance from built-up areas. Buildings may influence the readings, but because they are taken where nobody lives, we know little about the exposure of city dwellers to a changing urban climate, or about the local and other effects of heat.

In this context, Hotterdam illustrates the heat related problems in a specific city in order to outline the links between the climate and the built environment. We do so on the basis of the realisation that the climate within a city behaves differently to outside, while that same urban climate continue to play a key part in the well-being of the city's residents: Rotterdam in this case.

Heat in the city of tomorrow

The Royal Netherlands Meteorological Institute (KNMI) has drawn up studies for the future climate in the Netherlands. But there are other changes too.
The population forecast for the Netherlands is for a considerable rise in the number of old people. And it is precisely this group that is vulnerable to (urban) heat. In 20 years, more than a quarter of the population will be over 65. We show what the actual significance of this combination of extreme weather and greater numbers of elderly people is by using the heat wave that affected Paris in the summer of 2003. At the same time, this gives us a clear picture of what we can expect: more heat, more vulnerable residents, and (if we fail to act), more heat-related deaths.

Climate scenarios KNMI'14

In 2014, the KNMI published new scenarios for how the climate in the Netherlands will develop in future. The scenarios contain predictions for the years 2050 and 2085. Using these four scenarios, the KNMI predicts that the number of hot summer days will increase, as will the likelihood of heat waves. Air quality deteriorates during hot summers and long periods of drought. The rise in temperature leads to more deaths in the summer. Hot summers like the one in 2006 will become more the rule than the exception.

Climate scenarios	**Climate now**	**Scenario G_L**	**Scenario G_H**	**Scenario W_L**	**Scenario W_H**
	1981-2010	**2071-2100**	**2071-2100**	**2071-2100**	**2071-2100**
Warmest summer day per year	24,7 °C	+2,0 °C	+2,6 °C	+3,6 °C	+4,9 °C
Number of summer days (max temp ≥ 25 °C)	21 days	+30%	+50%	+90%	+130%
Number of tropical nights (min temp ≥ 20 °C)	0,1 days	+0,9%	+1,2%	+4,5%	+7,5%

KNMI'14 climate scenario core figures for temperature.

The four KNMI scenarios differ with regard to worldwide rises in temperature and possible changes in air flow patterns. G stands for a moderate worldwide rise in temperature and W for a strong one.

There are two variants for both scenarios. GL and GH , and WL and WH. L stands for a low value in terms of changes in air flow patterns. H stands for a high value.

Statistics Netherlands population forecast

Statistics Netherlands has issued a forecast on how the population will develop between 2012 and 2060. Up to 2040, the number of those aged 65 and above will quickly rise from 2.8 million to 4.7 million, before stabilising at just over quarter of the population.

Population forecast	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**	**2060**
Total (millions)	16,9	17,1	17,4	17,6	17,7	17,8	17,8	17,9	17,9	17,9
65 years and older (millions)	3,0	3,4	3,8	4,2	4,5	4,7	4,7	4,7	4,7	4,7
65 years and older (percentage)	17,8	19,8	21,8	23,9	25,6	26,5	26,4	26,2	26,1	26,3

Statistics Netherlands population forecast for the Netherlands and number aged 65 and over.

Heat in Paris, August 200

The heat wave that affected Europe in August 2003 made it painfully clear that as a society, we are vulnerable to warm weather. If there was one situation that summer that made an impression on experts, politicians and the public alike, it was the humanitarian disaster in Paris, France. It occurred in early August 2003, and mainly affected the elderly.

Mass mortality among the elderly and an inefficient government

Usually, around 30 to 50 people die every day in Paris. During the heat wave in early August 2003, that number rose sharply, peaking at more than 400. It was later established that 14,800 people died in France during this period as a result of the heat. The inability of the French authorities to act effectively led to a parliamentary enquiry. The enquiry determined that the effects of the heat on public health had not been anticipated, that notification of deaths was below standard, and that the actions of the emergency services were of little help due to a lack of experts, poorly-functioning healthcare services, and inadequate exchange of information between government bodies.

Greater or less risk of dying during the heatwave

A fair amount of research was subsequently carried out into the link between the heat wave, the Paris heat island, and the deaths of the elderly in particular. One such research project (Dousset & Gourmelon, 2011) suggested that there was an important link between the deaths of older people and the nightly heat island. Another project (Vandentorren, Bretin, Zeghnoun, Mandereau-Bruno, Croisier, Cochet, … Ledrans, 2006) showed that certain elderly people were at greater risk than others. During the 2003 heat wave in Paris, the elderly who died tended to be those who were bedridden, had cardiovascular disease or neurological conditions, but also those who lived in old buildings with poor insulation, in areas with a strong heat island effect, or who slept in a bedroom immediately under the roof. By contrast, older people had a lower chance of dying if they wore lighter clothing, if they used cooling equipment (ventilators or air-conditioning), and if they acted carefully (e.g. by opening windows when it was cooler outside, or by drinking enough water).

05 AUG

PARIS: View over the roofs of Paris under a thick layer of smog. After breaking countless **heat records**, Paris and Île de France are struggling with the consequences of **severe air pollution**. Just visible on the left: Montparnasse Tower, and on the right, the Eiffel Tower. Heat and (summer) smog go together and both have an adverse effect on public health. [Photo: AFP]

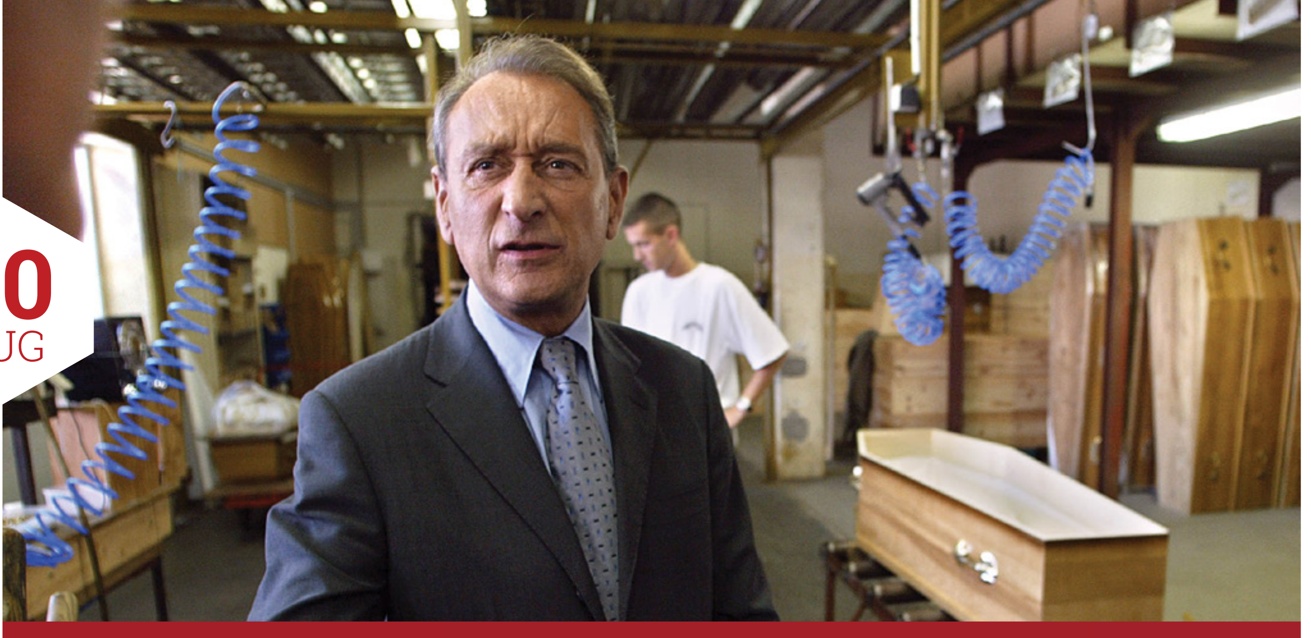
13 AUG

PARIS: Members of the fire brigade bring an old man suffering from heat exhaustion to a military hospital in Saint-Mandé, Paris. A leading Paris doctor says that **more than 100 people have died as a result of the heat wave** that has had France in its grip for a week. Hospitals throughout France are being inundated with **elderly patients suffering heat-related problems** and have insufficient resources to cope with the flood of patients. [Photo: AFP]

15 AUG

PARIS: Parisian undertakers deliver a corpse to an **improvised morgue** that was set up the night before, with capacity for **70 bodies**. [Photo: AFP]

20 AUG



PARIS: The mayor of Paris, Bertrand Delanoë, speaks to an employee of the Parisian funeral director. French undertakers today report that there have been **over 10,400 more deaths than usual** in August. Exactly one week earlier, doctors were warning that just 100 extra deaths could be expected. Once the heat wave was finally over, the definitive total was established: 14,800 victims throughout France. [Photo: AFP]

24
AUG

FRANCE, Ivry-sur-Seine: Inside and outside a warehouse in the Parisian suburb of Ivry-sur-Seine, stand **refrigerated trucks, loaded with victims of the heat wave**. The mortuaries in Paris and Île de France can no longer cope. While 130 bodies lie stored in refrigerated trucks, **the legal deadline for burying bodies has been extended** from six to ten days as a result of the backlog that has occurred in dealing with the deaths. [Photo: AFP]

03
SEPT

FRANCE, Thiais: French president Jacques Chirac arrives at the cemetery in Thiais, on the outskirts of Paris. 57 residents of Paris were buried that day in an official ceremony that was attended by Chirac and the mayor of Paris, Bertrand Delanoë. **The Parisians in question died last month during the catastrophic heat wave. However, their bodies had not been claimed by their next-of-kin**. Isolated residents and the homeless make up a special category within the group that is vulnerable to heat. [Photo: AFP]

Research framework

This chapter gives a concise overview of the aspects that make up the framework of the Hotterdam research project:

– the impact of the summer 2006 heat wave;
– the urban heat island;
– the research questions;
– the demarcation of the research area in the municipality of Rotterdam;
– the methods used (such as crowd sensing, remote sensing, multivariable regression analysis and cluster analysis).

Impact of the July 2006 heat wave

The heat wave that affected France so terribly in 2003 had very little effect on mortality rates of the elderly in Rotterdam. Three years later, things were different. In July 2006, there were two heat waves in quick succession. That month went down in Dutch history as the hottest in 300 years. The heat can be detected in Rotterdam's mortality figures. In July 2006, there were 75 more deaths among older residents than in an average July (measured from 2000 to 2013).

1,000 deaths throughout the Netherlands

Statistics Netherlands determined that 1,000 more people died in the Netherlands in July 2006 than in an average July. Most deaths occurred in the west of the country. In this context, Statistics Netherlands also demonstrated the link between the peaks in temperature and deaths has a time lag of two days. With these 1,000 deaths as a result of the two heat waves, the Netherlands found itself in fourth place in the world natural disaster rankings in 2006, measured by number of fatal victims. This list is maintained by the Centre for Research on the Epidemiology of Disasters (CRED).

In Rotterdam: twice the national average

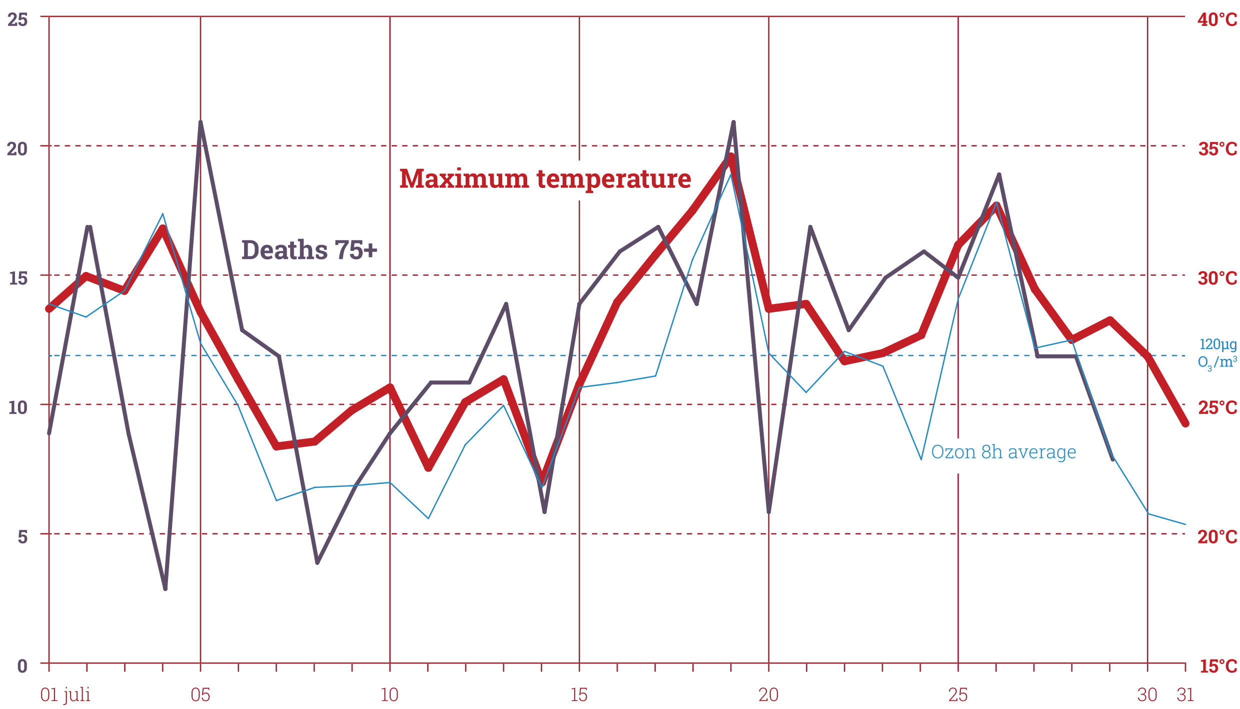
In order to describe the effect of heat on the elderly in Rotterdam, we drew up an overview of the average maximum temperatures in the summer months of June, July, and August between 2000 and 2013 and the number of deaths among those aged 75 and over. July 2006 stands out above the other months in two respects. There was no other summer month with such a high average temperature in Rotterdam (27.8 °C) and there was no other month with such a high mortality rate among those aged 75 and over in the city (385).

The high number of deaths in July did not lead to a dip in the number of fatalities in August that year, which were in fact slightly higher than average. The temperatures were taken at Rotterdam The Hague Airport – that is, just outside the city. The actual temperatures in the city, where the 75-plus age group lived, was higher as a result of the urban heat island, especially at night. With a national population of 16.3 million (2006) and 1,000 additional deaths, we should expect an additional 36 deaths for Rotterdam, of its 589,000 inhabitants (2006). Based on information provided by the Rotterdam city council, we established that there were 75 extra deaths among those aged 75 and over in July 2006. This was twice the national average. It should also be remembered that this applies only to those aged 75 and over, not people in other groups. An examination of the figures for each day in the month of July shows that the peak in death rates among the 75-plus age group did indeed occur two to three days after the peak in temperature. The link with ozone concentrations is also striking.

Average maximum temperature versus the number of deaths among those aged 75 and over

Year	Avg. max. temp.	Deaths of people aged 75+	Avg. max. temp.	Deaths of people aged 75+	Avg. max. temp.	Deaths of people aged 75+
	June		July		August	
2006	21,3 °C	308	27,8 °C	385	20,5 °C	293
Avg. 2000-2013	20,7 °C	298	22,4 °C	310	22,3 °C	292

Summer 2006 and average summer (2000–2013) in Rotterdam, avg. maximum temperature and number of deaths among those aged 75 and over.



Heat wave 2006 in Rotterdam, deaths of those aged 75 and over (two-day time lag), maximum daytime temperature and ozone.

The red line shows the maximum daytime temperature. The scale on the right is shown in degrees Celsius. The concentrations of ozone are shown by the blue line. On the right, the European target value of 120 micrograms (µg) per cubic metre of air is shown. The mortality rate among those aged 75 and over is shown by the purple line. The figures have been brought forward by two days, in view of the time lag. This brings the peaks in temperature, heat, and ozone together.

Urban heat island

A heat island is an area where the temperature is higher than in the surrounding area. When heat islands are generated by cities, we term this an urban heat island. Rotterdam clearly has an urban heat island effect.

Surface temperature and air temperature

In the case of urban heat islands, the temperature in the city is higher than in a rural or natural environment. Here, there is sometimes confusion regarding the terms used. Is it the air temperature that is being referred to, or the surface temperature?
Large differences in temperature on the earth's surface occur mostly in the daytime, when the sun is shining. Differences in air temperature between cities and the surrounding area arise in the evening, after sunset. The heat island in the daytime (surface temperature) is what causes the heat island at night (air temperature). In the daytime, the ground and the built-up areas heat up. The heat is then released at night. As a result, it stays warm for longer in the city in the evening and at night.

Shadow and sky view

In cities, buildings and trees are comparatively close to each other. This produces shade and reduces the heating up process. However, this compactness means that cities also take longer to cool down. The technical term for this is the 'sky view factor' – the degree to which a building is exposed to the sky. If this factor is high and the building is exposed to the sky on all sides, it will cool off quickly. This explains why the countryside around cities cools off quickly while the cities themselves do not.

Relationship with indoor temperature

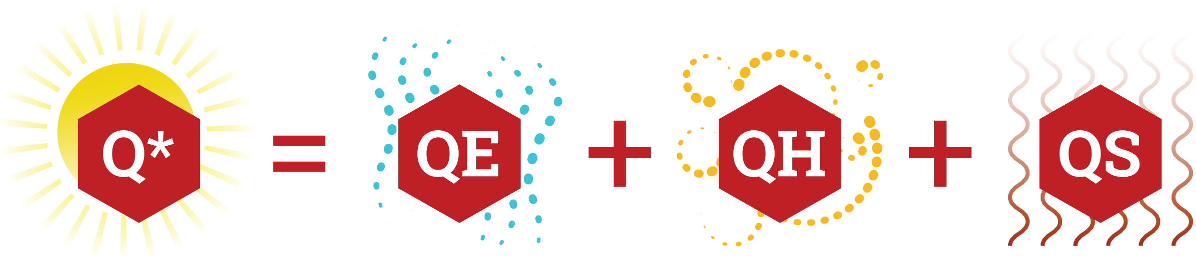
In research into the link between health and heat, it is usual to use outdoor temperature readings from a meteorological institute, such as the KNMI in the Netherlands. These temperatures are taken outside cities in the outdoor air. However, most people spend the most of the day in homes or in other buildings in the city. Therefore, in this research project, we examined the indoor temperatures of homes in Rotterdam. Are heat levels in homes a good indicator for the health of residents or should it be the outdoor temperature in the city?

Surface energy balance

The heat we experience in a city is the product of what is known as the surface energy balance.

The surface energy balance is based on the principle that energy is not lost. This means that the net energy that the surface of a city receives from the sun is equal to the energy that passes through the heat processes that take place in the city, such as the heating of the air through convection (sensible heat), the evaporation of water and transpiration through trees and plants (latent heat), and the absorption of heat in the ground, buildings, and surface water (ground heat flux).

As a formula, the surface energy balance is expressed as follows:



Q*	Net solar radiation received by the earth's surface
QE	Energy consumed through evaporation (by water and greenery)
QH	Sensible heat (conversion of heat from surface to air)
QS	Energy absorbed by the ground, buildings and surface water

Net solar radiation

Net solar radiation (Q*) is the energy the earth's surface receives from the sun. However, the earth's surface has characteristics that can reflect or radiate the radiation: albedo and emissivity.
Albedo expresses the degree to which the earth's surface reflects radiation. Emissivity expresses the degree to which the surface re-radiates the radiation it has received. Radiation that is reflected does not contribute to the heating of the city or its region, unless the radiation is then reflected back by clouds or air pollution.

Latent heat

Latent heat (QE) is the energy needed to cause water to evaporate. Vegetation is an important 'consumer' of latent heat. However, trees do not only capture heat. An additional benefit they bring is that they offer shade.
Surface water has a cooling effect as long as the heat it receives is converted into evaporation. However, some of the heat is stored in the water itself and this contributes to the heat island at night. Large surface areas of shallow water are therefore recommended. Fountains, for example, are excellent.

Sensible heat

Sensible heat (QH) is the energy needed to heat the air. This heating process takes place primarily above surfaces with a high temperature (such as asphalt roofs). In the conversion of surface temperatures to air temperatures, (small) pockets of air turbulence – known as eddies – play an important role.

Ground heat flux

A significant part of the sun's radiation does not go towards heating the air or evaporation through vegetation. Radiation is also stored as heat in the ground, in buildings and in surface water (QS). This stored heat is almost entirely responsible for nightly heat islands.
If the surfaces of a city and its buildings are well exposed to the sky, then the city will cool off relatively quickly. But if that exposure is blocked by buildings or trees, then the heat remains in the city for longer, resulting in relatively high night-time temperatures.
The degree of exposure to the sky is expressed in a special indicator, the sky view factor.

Research questions

The Hotterdam research project examined the heat problems in the city of Rotterdam from the perspective of climate adaptation: altering the behaviour of residents, improving homes, and intervening in the built environment.

Hotterdam is the follow-up to a previous study – 'Amsterwarm' – in which we researched the heat island of the city of Amsterdam.

01 **We started the Hotterdam research project by establishing the (spatial) extent of the heat problems in Rotterdam:**

Which areas of Rotterdam experience the urban heat island effect most strongly, and what is the relationship between the outdoor temperature and homes heating up?

02 **The next question was whether the inhabitants of the city really do suffer harmful consequences from the heat indoors and outdoors:**

Is there a link between the heat problems in the city of Rotterdam and public health, in relation to the increased levels of mortality among those aged 75 and over?

03 **Assuming that there are differences regarding heat and health between the various districts in Rotterdam:**

Can the differences in heat between the districts of Rotterdam be explained on the basis of physical features of the city?

04 **Simply noting that things are not going well is not enough if we do not also offer solutions:**

Which parties can take what action in resolving the heat problems in Rotterdam?

Research area

Rotterdam was of course the main focus of the Hotterdam research project. The choice of Rotterdam as the research area was prompted by the 'hotspot' of Rotterdam's participation in the 'Climate Proof Cities' project.

The city of Rotterdam, excluding the port

At the end of 2014, the city of Rotterdam had more than 620,000 inhabitants. Much of its territory is taken up by the port. This section of the city was not included in the research. The research area concerned the eastern part of the city, with the Oude Maas river forming the boundary, and containing Rotterdam, Hoogvliet, Pernis, Heyplaat and Kralingse Veer, excluding Rozenburg and Hoek van Holland.

Research area in the city of Rotterdam

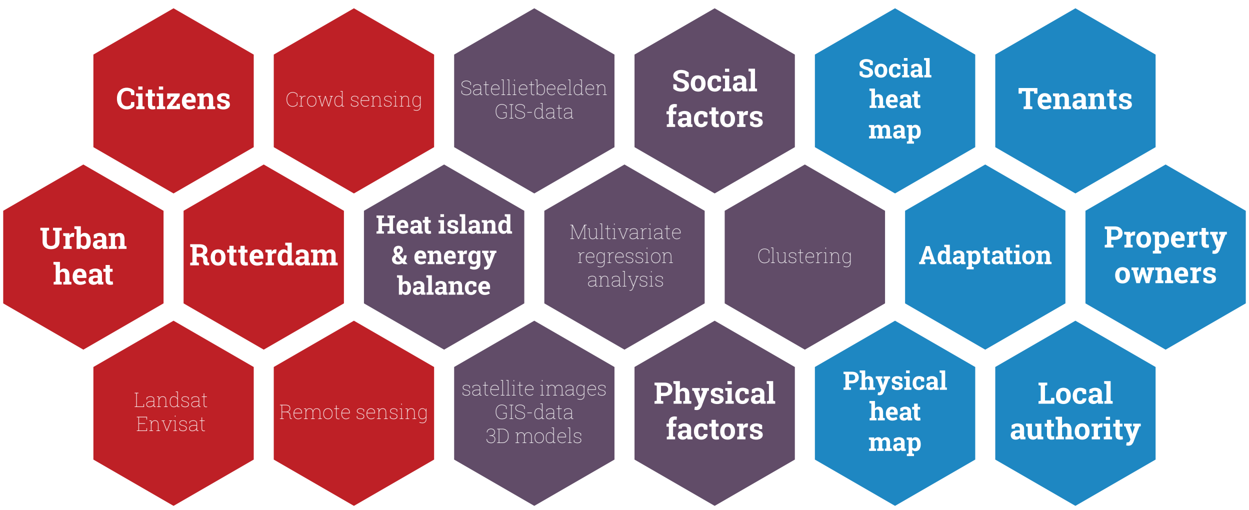
Objective and methods

The objective of the Hotterdam research project is to gain a better understanding of urban heat in Rotterdam, and to use this as a basis for explaining the links between the health of the city's population and the features of its physical spaces that make it more or rather less warm. This information will hopefully make the city of Rotterdam and its inhabitants more aware of and less susceptible to the health effects of heat waves.

Measuring, analysing and mapping

The Hotterdam research project therefore encompassed three key points: urban heat, social factors and physical factors. Urban heat and the surface energy balance were determined using crowd sensing and remote sensing. Social and physical factors were identified with the help of satellite images, GIS and 3D models.

The links between urban heat/surface energy balance and social/physical factors were determined with the aid of multivariable regression analysis. The social and physical features that matter were then clustered and incorporated in the social and physical heat maps. The heat maps and underlying data offer an understanding of the mechanisms that make the residents of Rotterdam vulnerable to heat waves. Based on these insights, we have briefly described the most important measures that tenants, home owners (individuals, residents' associations, corporations) and the city council can take to change their behaviour, to improve the quality of their homes and to adapt the built environment to hot weather.



Hotterdam methodology

Sensing Hotterdam

As part of the Hotterdam research project, the temperature was recorded in 1,000 Rotterdam homes and at 300 public spaces in the summer of 2013.

Crowd sensing

In the summer of 2014, we measured the temperature in Rotterdam ourselves. This was made possible by a financial contribution from the 3TU.Bouw Center of Excellence for the Built Environment for the 'Sensing Hotterdam' project.

Temperature sensors

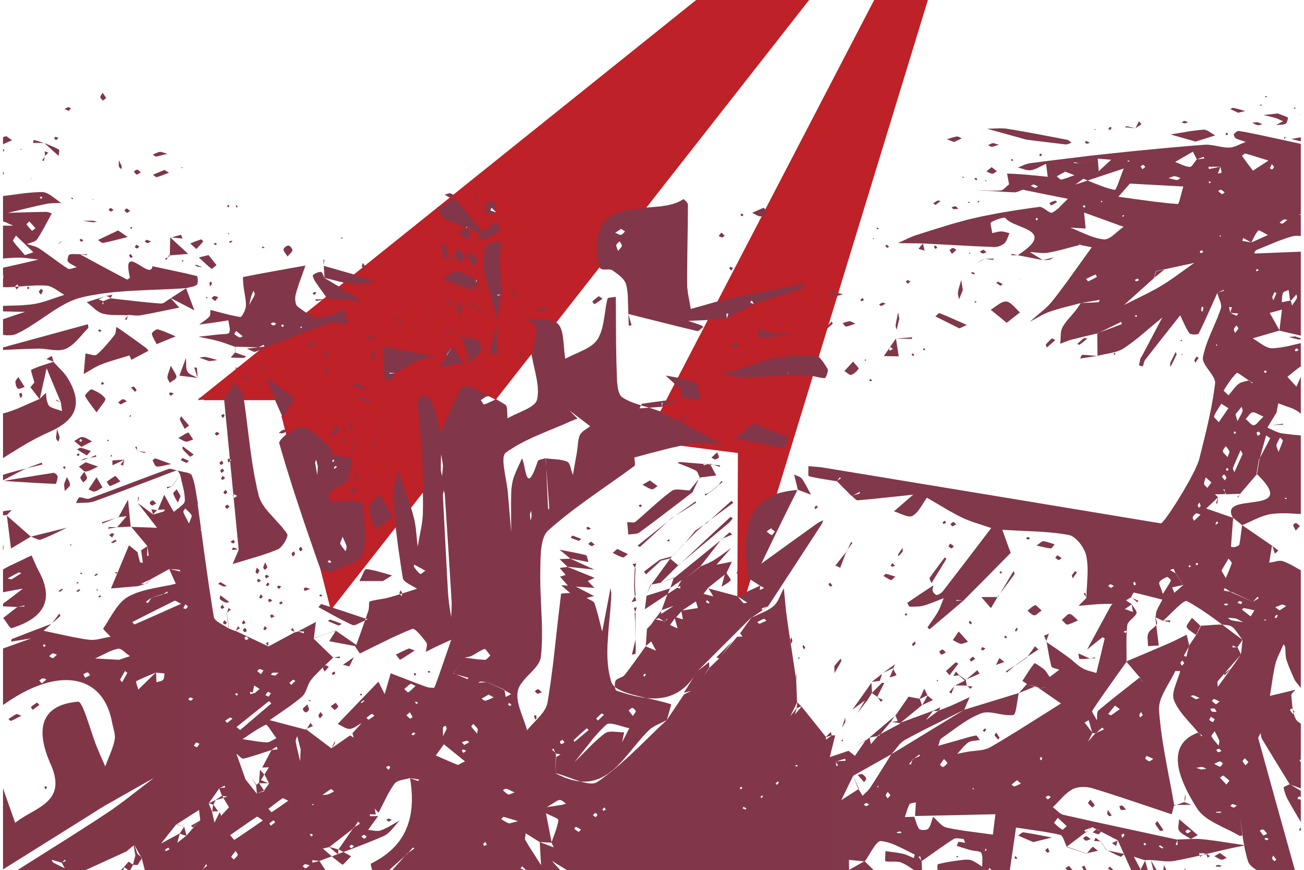
For Sensing Hotterdam, we enlisted the help of a large number of citizens to carry out the readings. This is also known as ‘crowd sensing’. We divided the city into 20 areas. Five streets were selected in each area, so as to properly represent the diversity of the relevant area. Students were then asked to find ten households in every street to take part in the research project. The students asked the residents to place a temperature sensor (Paksense brand) in their living room for two months. Three hundred of the same type of sensor were also placed in the selected streets in order to take the outdoor temperature. After two months, we received 800 of the 1,000 sensors back from the residents. We also retrieved 200 of the sensors that had been placed on the streets.

Indoor and outdoor temperatures measured

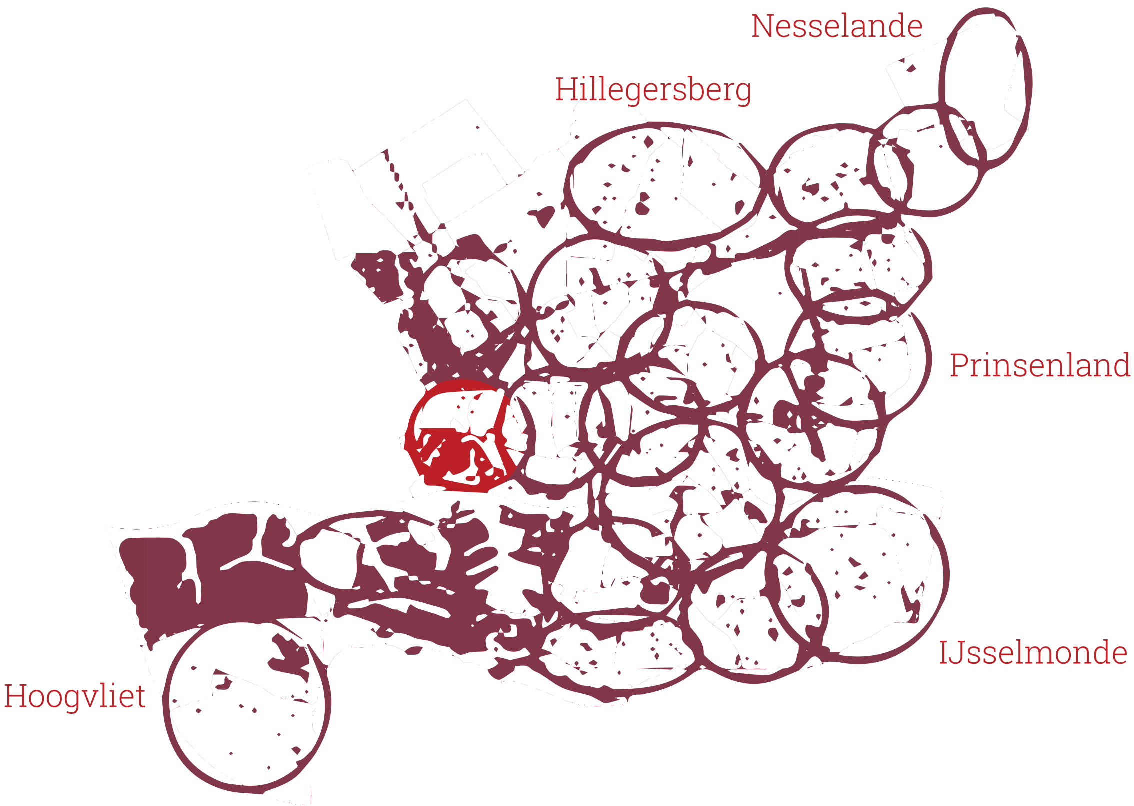
The indoor temperatures were taken using temperature sensors (Paksense brand), which were issued to the residents. They were asked to place them in their living rooms, out of the sun. The readings were taken from the end of July until mid-September 2014.

The outdoor temperature was also measured using sensors (Paksense brand). They were placed two metres above ground level in public spaces. The readings were taken over the same period as the indoor temperature readings in the same streets where residents had been approached to take the indoor temperature readings.

The readings from the sensors that were placed outdoors were used as an indicator of the temperature after sunset. The results are of less value for determining the temperature in the daytime. In the daytime, the sensors could have been exposed to direct radiation from the sun at set times. Test readings in the daytime sometimes showed outliers that were not representative of the air temperature.

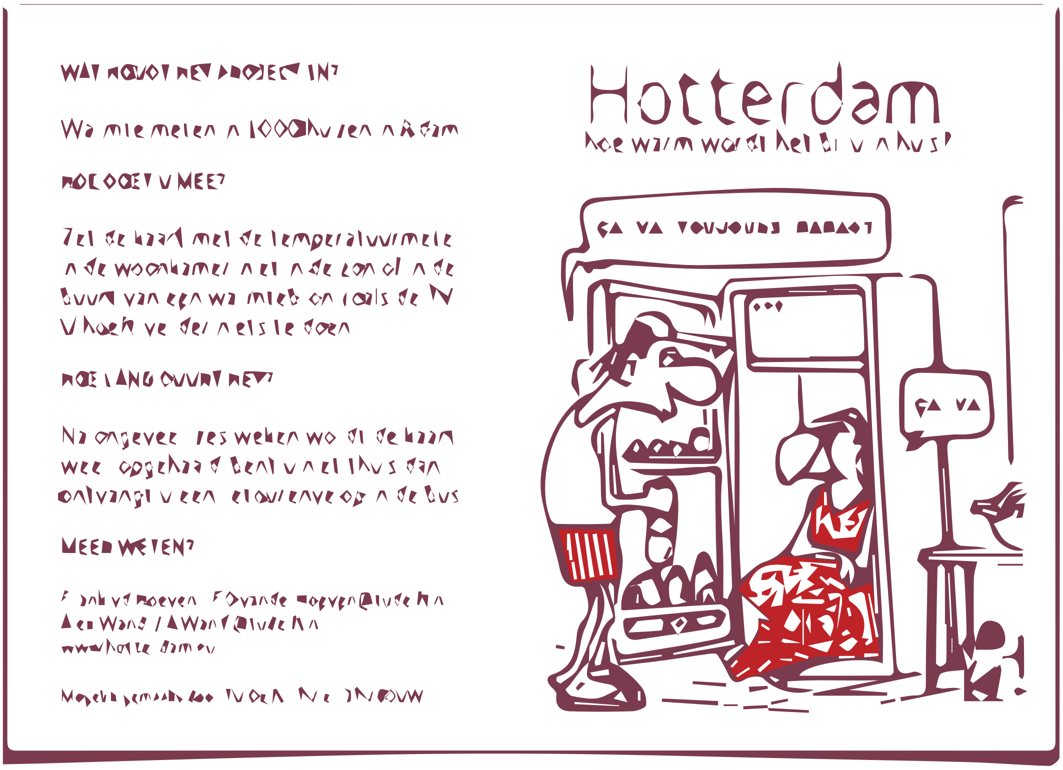


01 **Sensing Hotterdam (the research project into heat in the city), divided Rotterdam into 20 areas.**

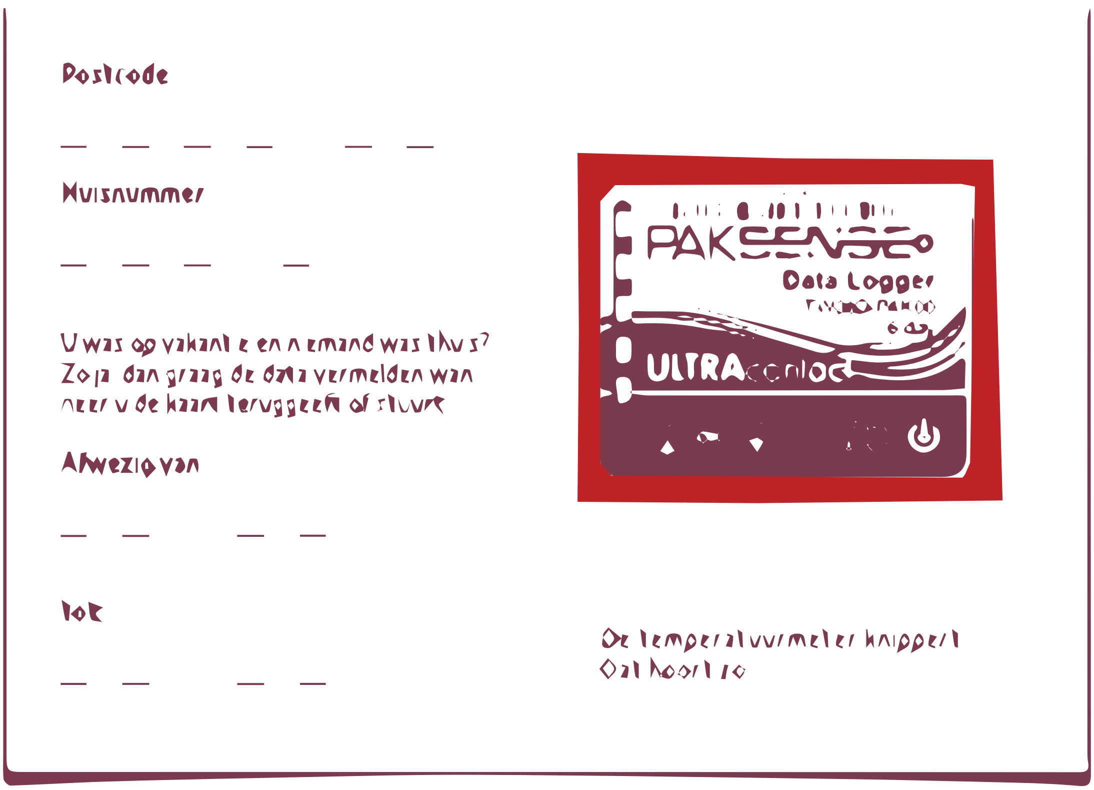


02 Five representative streets were selected in each area, with the aim of finding ten households in each street.

03 **Twelve students were offered holiday jobs, with the task of finding these ten households in each street.**



04 They also had to leave a chart with the occupants with a brief explanation, and a temperature sensor on the rear.



05

Therefore 1,000 sensors were used to measure the indoor temperature, and 300 the night-time outdoor temperature.

06 **The results are set out on two heat maps (social and physical) that can help prevent unnecessary deaths among the elderly during heat waves.**

Atlas

The atlas contains the research data that form the basis for the heat maps. The maps were generated in a Geographic Information System (GIS): ArcGIS. All the information was gathered on the basis of a $100m^2$ grid.

Numerical values were calculated for each of the individual cells (or pixels) in relation to the social and physical features of the city of Rotterdam. Three main sources – satellite images, GIS data and 3D models – were used. The atlas was divided into three sections: heat, social and physical.

Heat

Identifying the spatial dimension of heat in the city of Rotterdam.

Background

The KNMI carries out temperature readings at just one location in Rotterdam: onsite at the airport, which is outside the city. These readings cannot be used to determine differences between the various districts. There is also no information on temperatures inside people's homes. In order to better understand the relationship between heat, health and space, we required a more detailed picture of heat in the city and of the processes that determine that heat: the urban heat island and the surface energy balance. This part of the atlas offers new insights in this area.

Method

For this study, three temperatures were determined: the surface temperature, the outdoor air temperature, and the indoor air temperature. Remote sensing was used for the surface temperature. The night-time outdoor air temperature and the indoor air temperature were used with the help of crowd sensing. The surface energy balance was modelled with remote sensing software (ATCOR2).

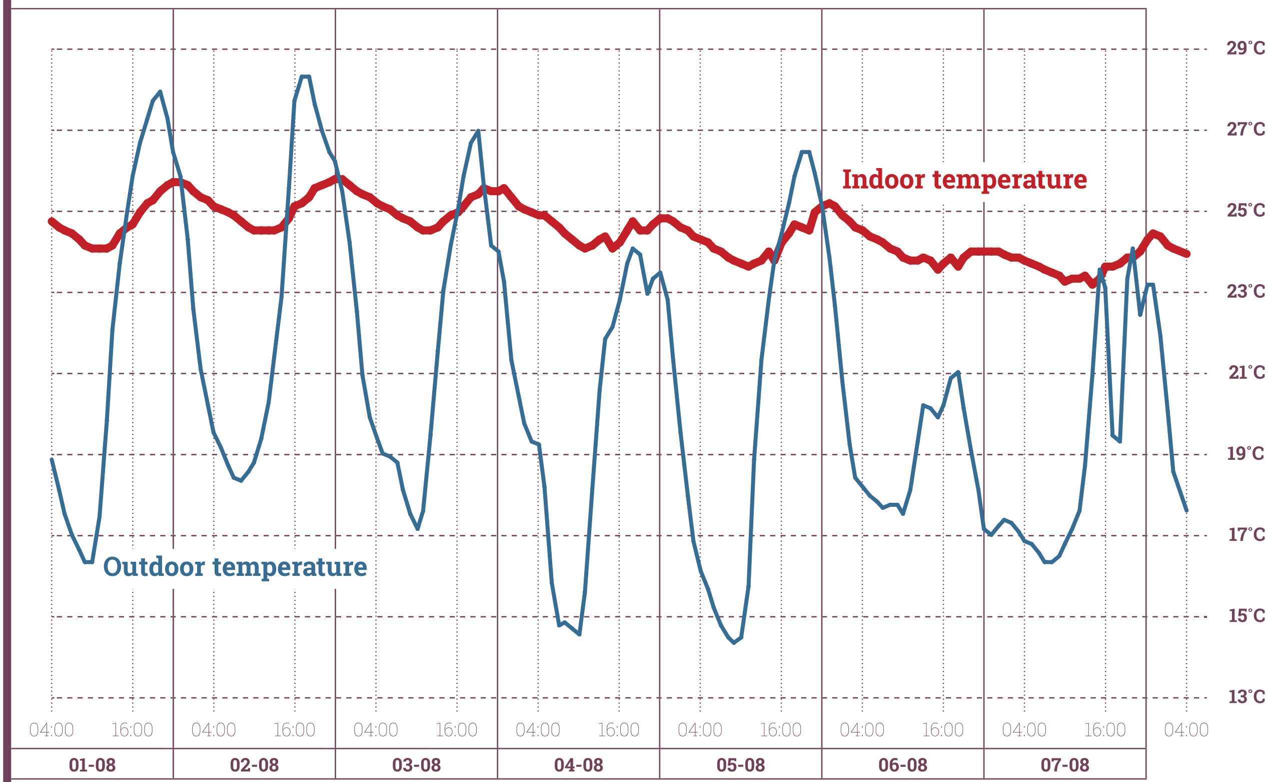
Results

The results of measuring the heat are the maps relating to outdoor air temperatures, indoor air temperatures, surface temperatures, net radiation, sensible heat, latent heat, and ground heat flux.

Conclusion

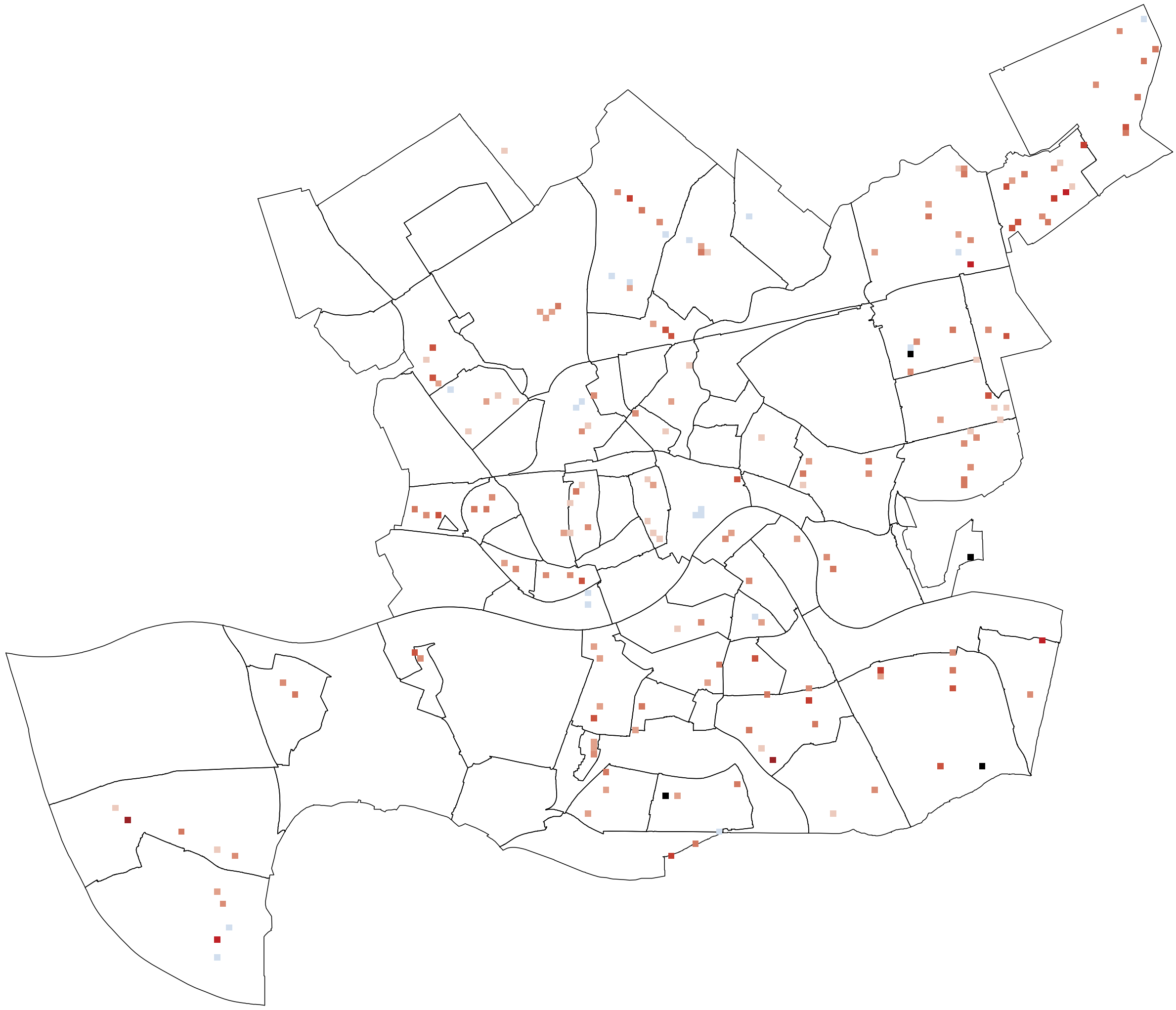
The air temperature, surface temperature, and energy balance readings point to a clear heat island effect in Rotterdam. The heat island is strongest at the sites used by the port, industry and businesses. The centre and the pre-war districts in North, South, and West Rotterdam also experience a clear urban heat island effect. Temperatures in homes are generally higher than those in the surrounding area, and also show a large degree of variation. Indoor temperatures are less affected by local outdoor temperatures than we had expected.

Air temperature indoors/outdoors



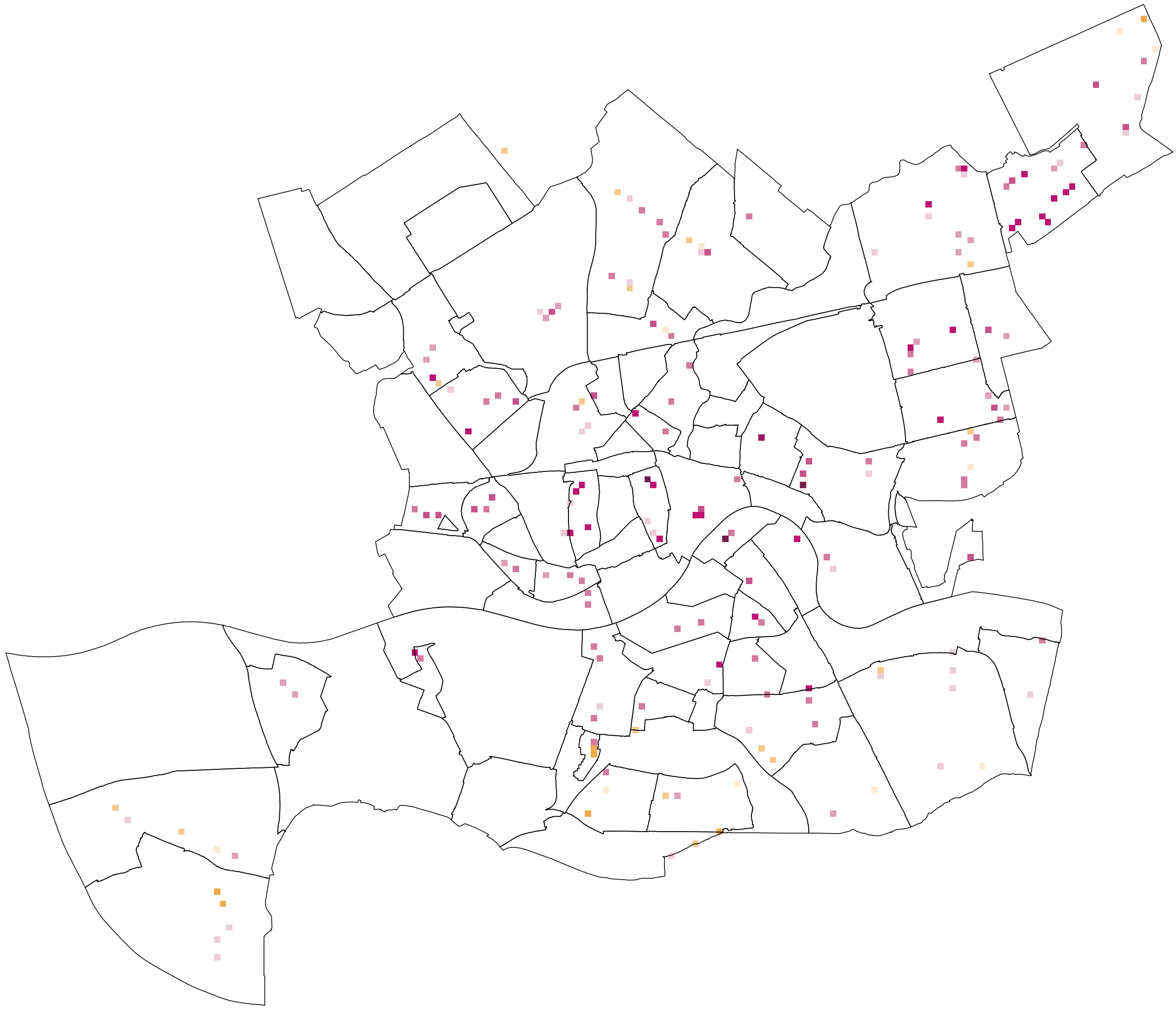
Contents	Air temperature measured in the evenings/at night in selected homes and streets in Rotterdam. The diagrams above show the averages of all the indoor and outdoor temperature readings in the first week of August 2014. Indoor temperatures fluctuate much less and are mostly higher than the outdoor temperatures, except during the afternoon. It is therefore very possible to cool homes naturally, especially at night.
Values	Degrees Celsius
Method	Readings with Paksense temperature sensors
Software	ArcGIS
Data	Crowdsensing, first week of August 2014

Outdoor air temperature, 18.00



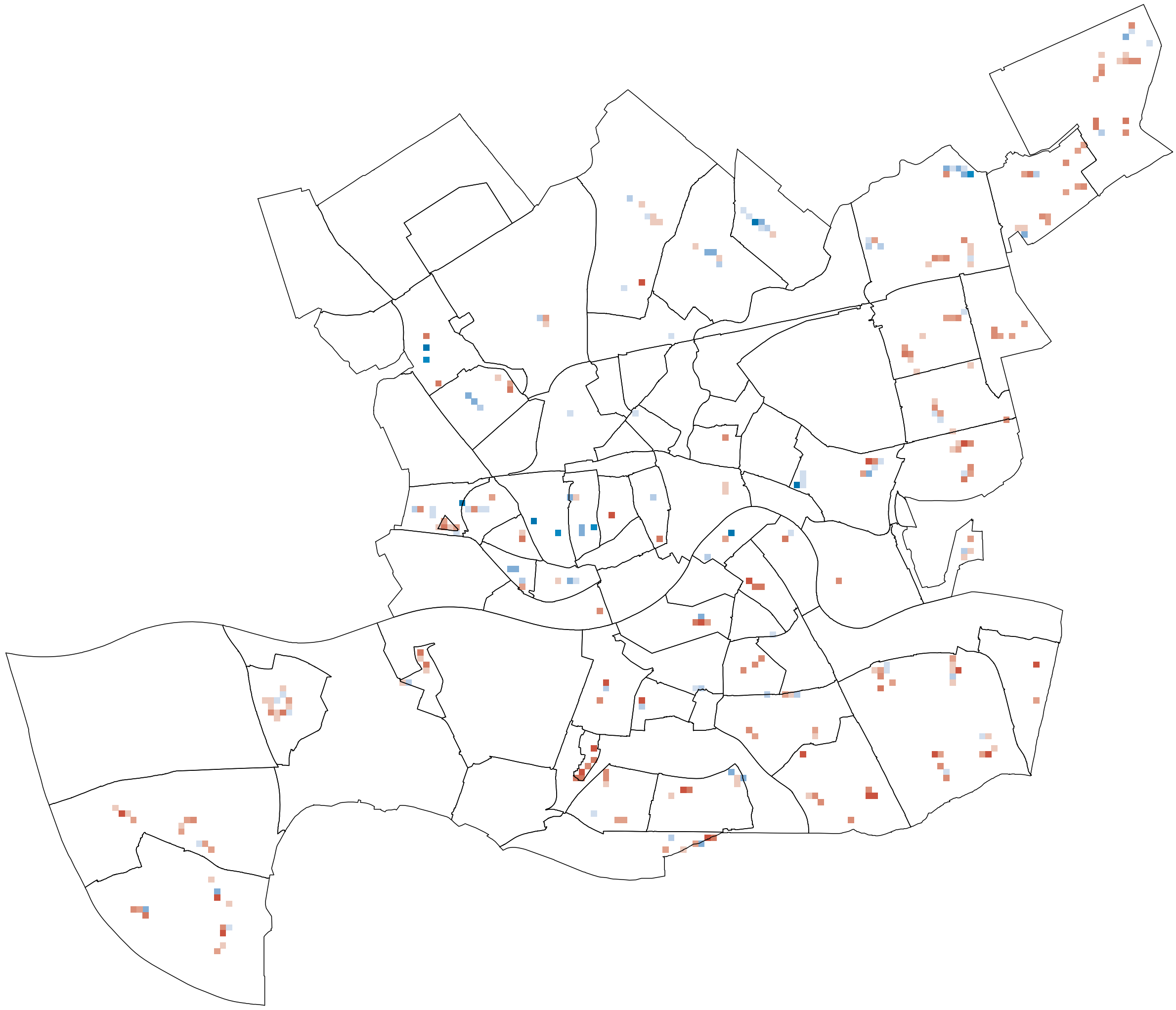
Key	≤25,0 · >25,0 ≤25,5 · >25,5 ≤26,0 · >26,0 ≤26,5 · >26,5 ≤27,0 · >27,0 ≤27,5 · >27,5 ≤28,0 · >28,0 ≤28,5 · >28,5 ≤29,0 · >29,0
Contents	Air temperature measured in the evening in selected streets in Rotterdam at 18.00, on 2 August 2014. The temperature in the centre and the surroundings districts is relatively cool.
Values	Degrees Celsius
Method	Readings with Paksense temperature sensors
Software	ArcGIS
Data	Crowdsensing, 2–3 August 2014

Outdoor air temperature, 03.00



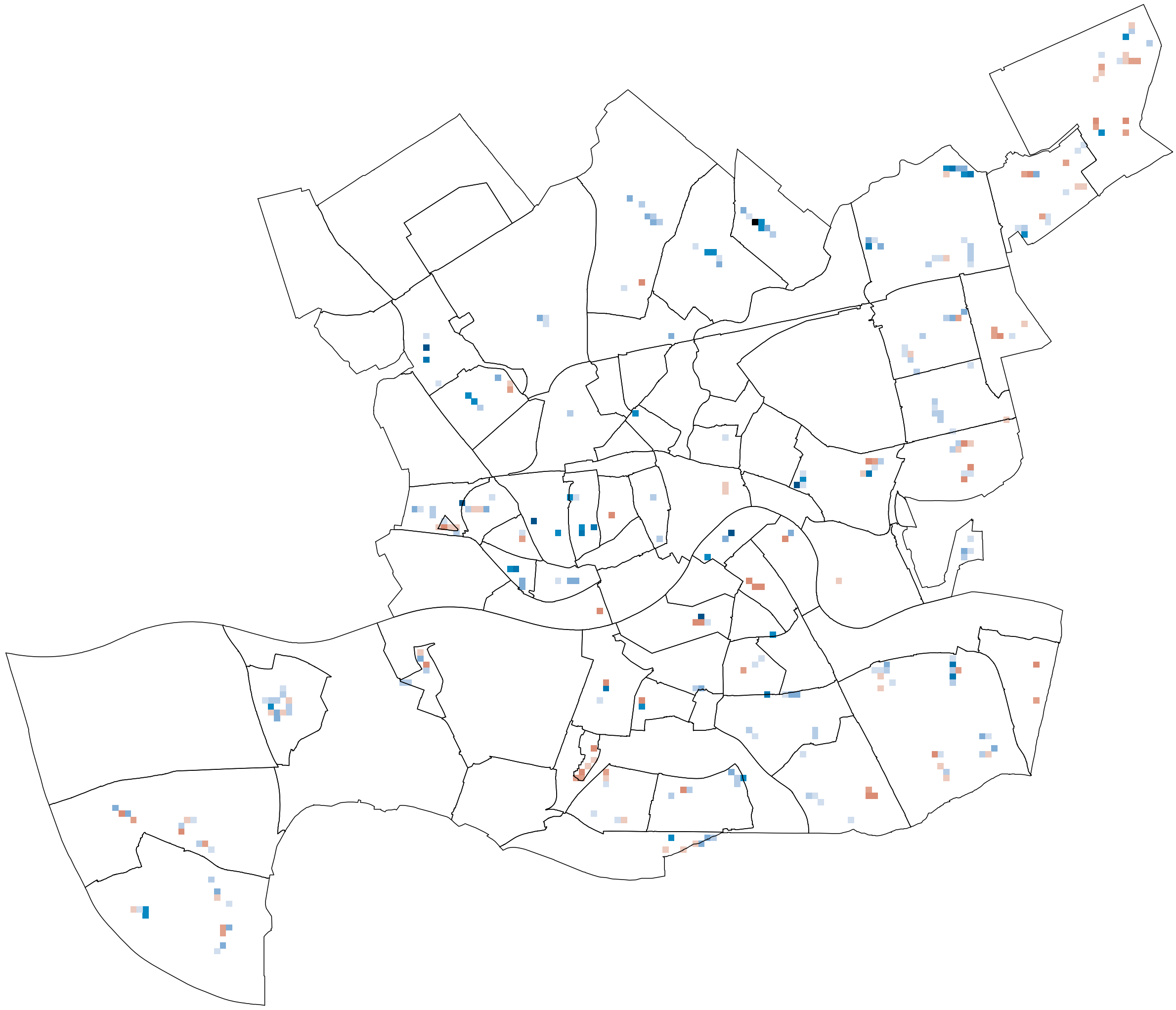
Key	≤17,75	>17,75 ≤18,0	>18,0 ≤18,25	>18,25 ≤18,50	>18,5 ≤18,75	>18,75 ≤19,00	>19,00 ≤19,25	>19,25 ≤19,50	>19,50 ≤19,75	>19,75
Contents	Air temperature measured at night in selected streets in Rotterdam at 03.00, on 3 August 2014. The centre and surrounding districts only lose their heat to a limited degree, and have become actually relatively warm.									
Values	Degrees Celsius									
Method	Readings with Paksense temperature sensors									
Software	ArcGIS									
Data	Crowdsensing, 2–3 August 2014									

Indoor air temperature, 18:00



Key	≤23,0 · >23,0 ≤23,5 · >23,5 ≤24,0 · >24,0 ≤24,5 · >24,5 ≤25,0 · >25,0 ≤25,5 · >25,5 ≤26,0 · >26,0 ≤26,5 · >26,5 ≤27,0 · >27,0
Contents	Air temperature measured in the evening in selected homes in Rotterdam at 18.00, on 2 August 2014.
Values	Degrees Celsius
Method	Readings with Paksense temperature sensors
Software	ArcGIS
Data	Crowdsensing, 2–3 August 2014

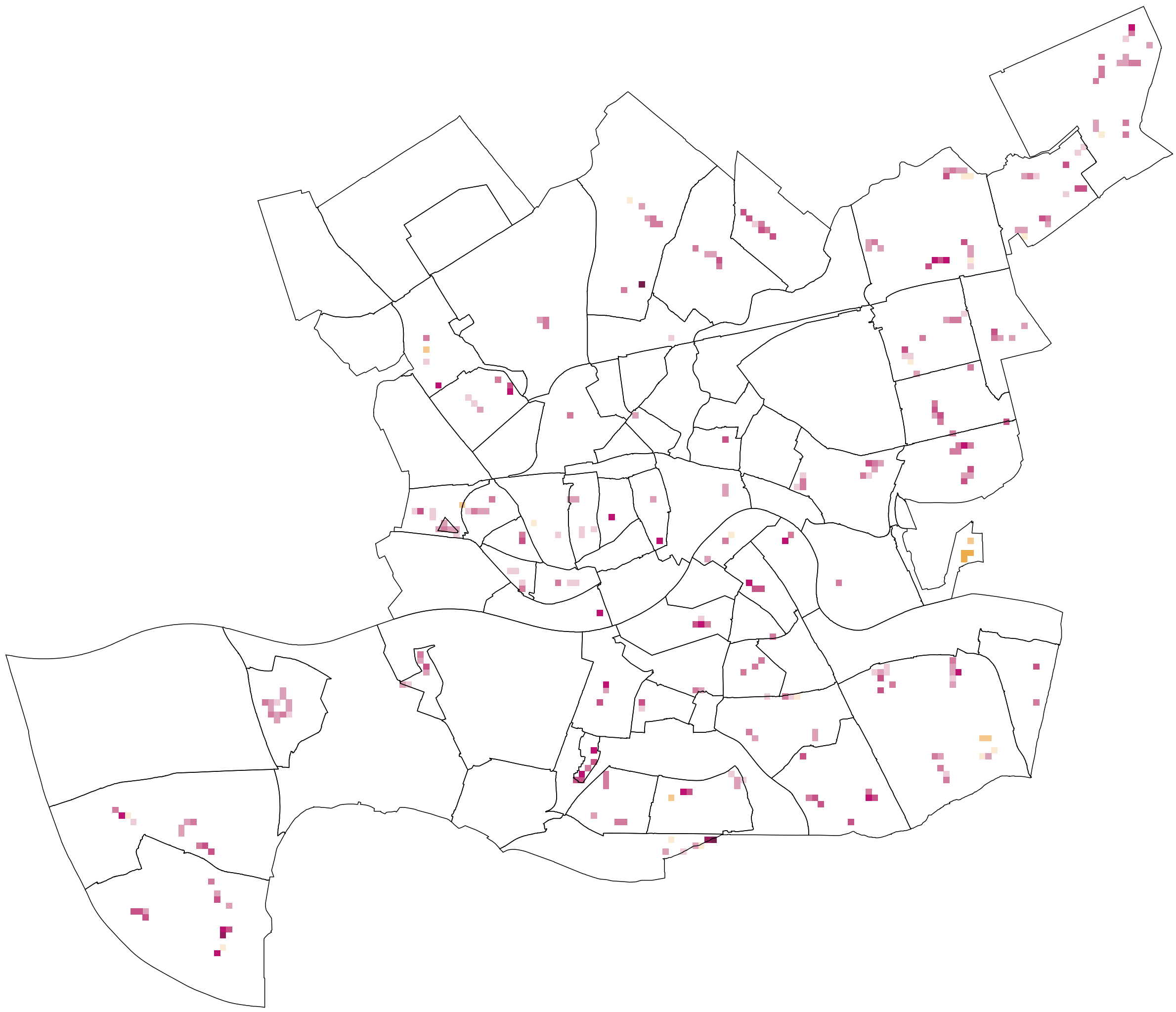
Indoor air temperature, 03:00



Key	≤22,0	>22,0 ≤22,5	>22,5 ≤23,0	>23,0 ≤23,5	>23,5 ≤24,0	>24,0 ≤24,5	>24,5 ≤25,0	>25,0 ≤25,5	>25,5 ≤26,0	>26,0

Contents	Air temperature measured at night in selected homes in Rotterdam at 03.00, on 3 August 2014.
Values	Degrees Celsius
Method	Readings with Paksense temperature sensors
Software	ArcGIS
Data	Crowdsensing, 2–3 August 2014

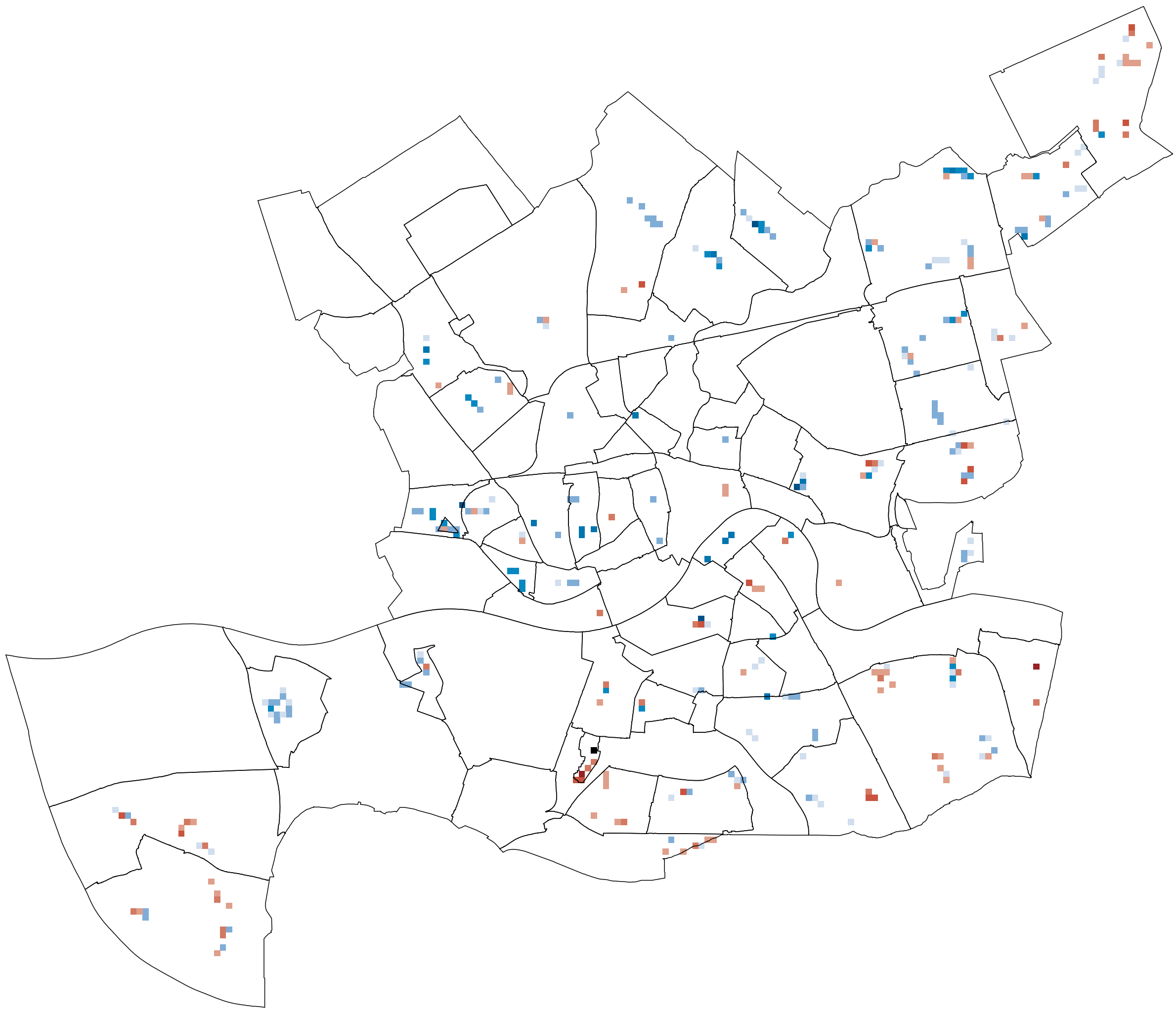
Temperature differences indoors and outdoors, 18:00



Key	≤-5,0	>-5,0 ≤-4,0	>-4,0 ≤-3,0	>-3,0 ≤-2,0	>-2,0 ≤-1,0	>-1,0 ≤0,0	>0,0 ≤1,0	>1,0 ≤2,0	>2,0 ≤3,0	>3,0

Contents	Difference between indoor and outdoor temperature at 18:00, 2 August 2014. In most parts of the city it is cooler indoors than outdoors (negative values).
Values	Degrees Celsius
Method	Outdoor temperature (measured near selected homes) subtracted from the indoor temrature (measured in selected homes)
Software	ArcGIS
Data	Crowsensing, 2/3 augustus 2014

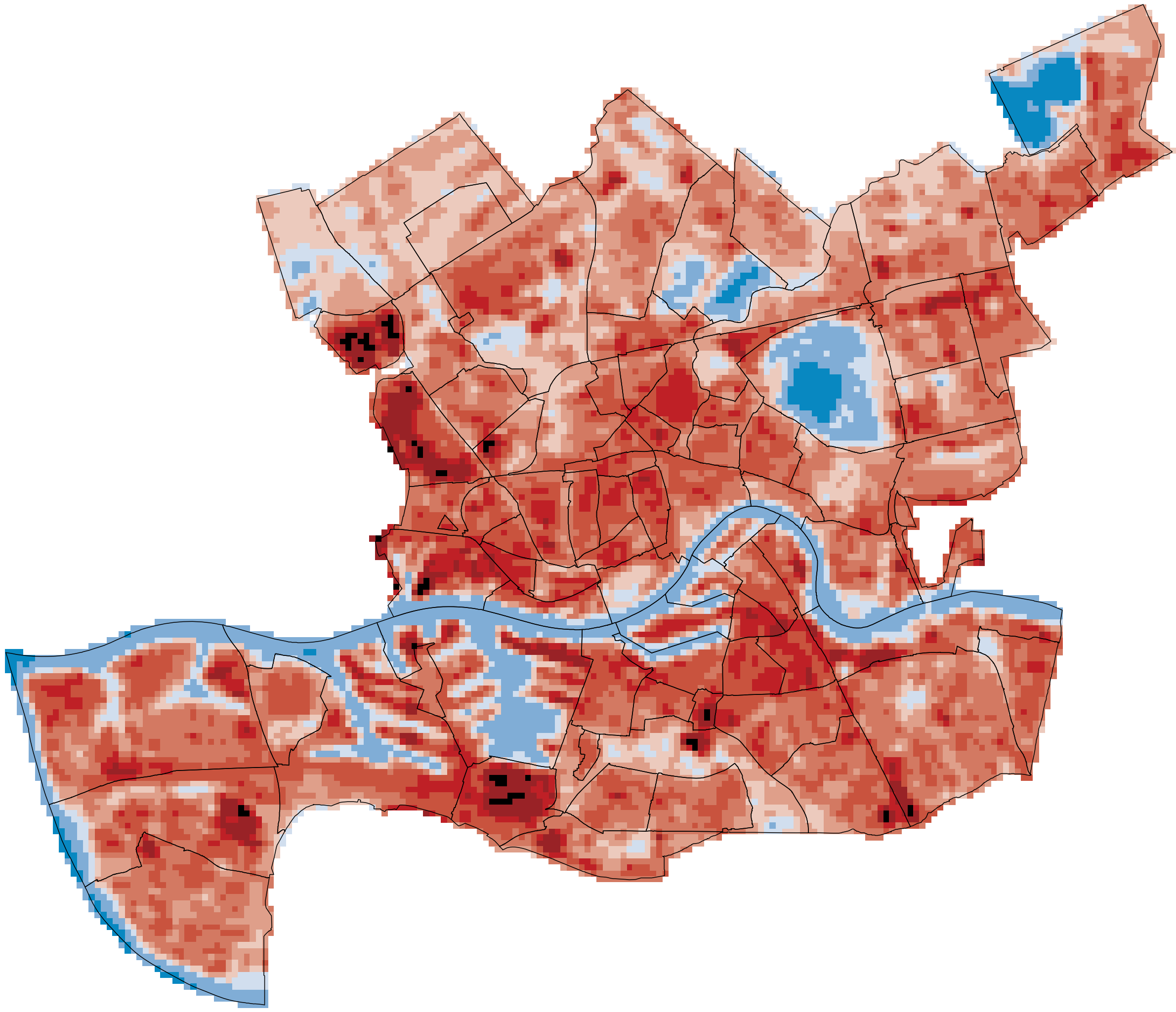
Temperature differences indoors and outdoors, 03:00



Key	≤3,3	>3,3 ≤4,0	>4,0 ≤4,8	>4,8 ≤5,5	>5,5 ≤6,3	>6,3 ≤7,0	>7,0 ≤7,8	>7,8 ≤8,5	>8,5 ≤9,3	>9,3

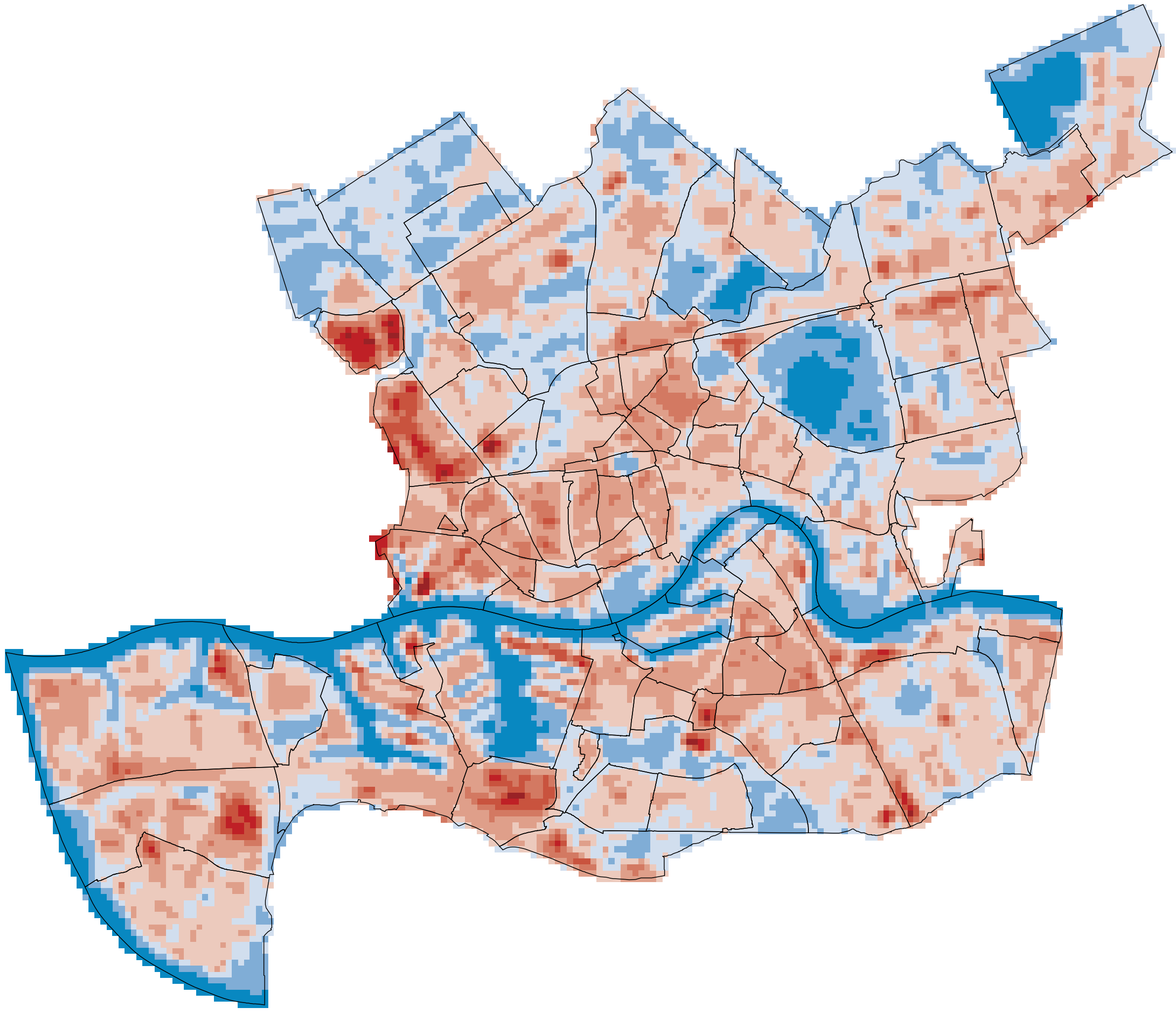
Contents	Difference between indoor and outdoor temperature at 03:00, 3 August 2014. Everywhere in the city it is warmer indoors than outdoors (positive values).
Values	Degrees Celsius
Method	Outdoor temperature (measured near selected homes) subtracted from the indoor temrature (measured in selected homes)
Software	ArcGIS
Data	Crowsensing, 2/3 augustus 2014

Surface temperature, 16 July 2006



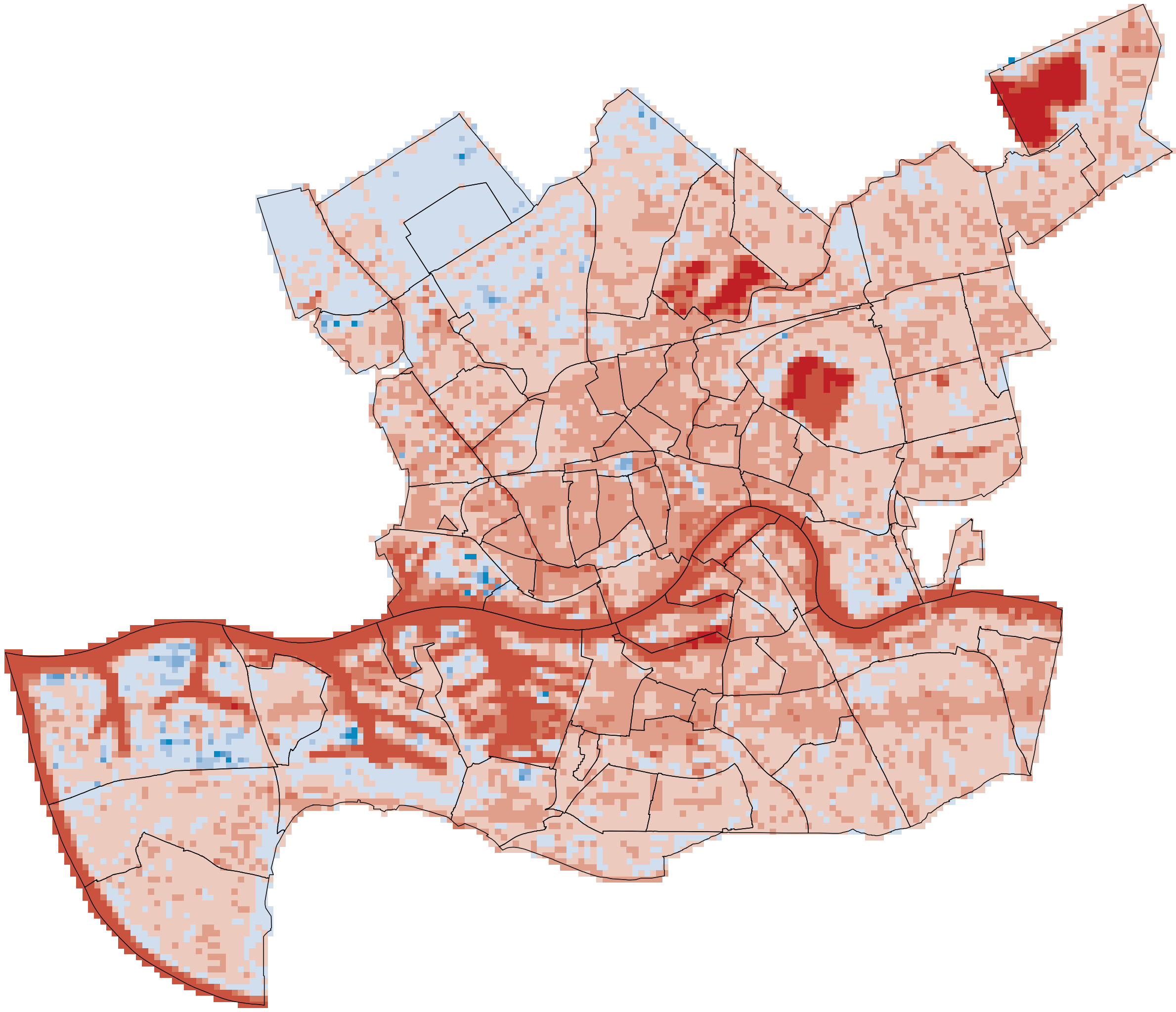
Key	≤-4,0 · >-4,0 ≤0,0 · >0,0 ≤2,5 · >2,5 ≤5,0 · >5,0 ≤7,5 · >7,5 ≤10,0 · >10,0 ≤12,5 · >12,5 ≤15,0 · >15,0 ≤20,0 · >20,0
Contents	Differences in land surface temperature in the city of Rotterdam
Values	Degrees Celsius (29° Celsius = 0)
Method	Surface temperature is determined with Band 6 in Landsat 5 image
Software	BEAM-VISAT, ATCOR2, ArcGIS
Data	NASA, Landsat 5, 16 July 2006, 12.32

Surface temperature, 22 July 2014



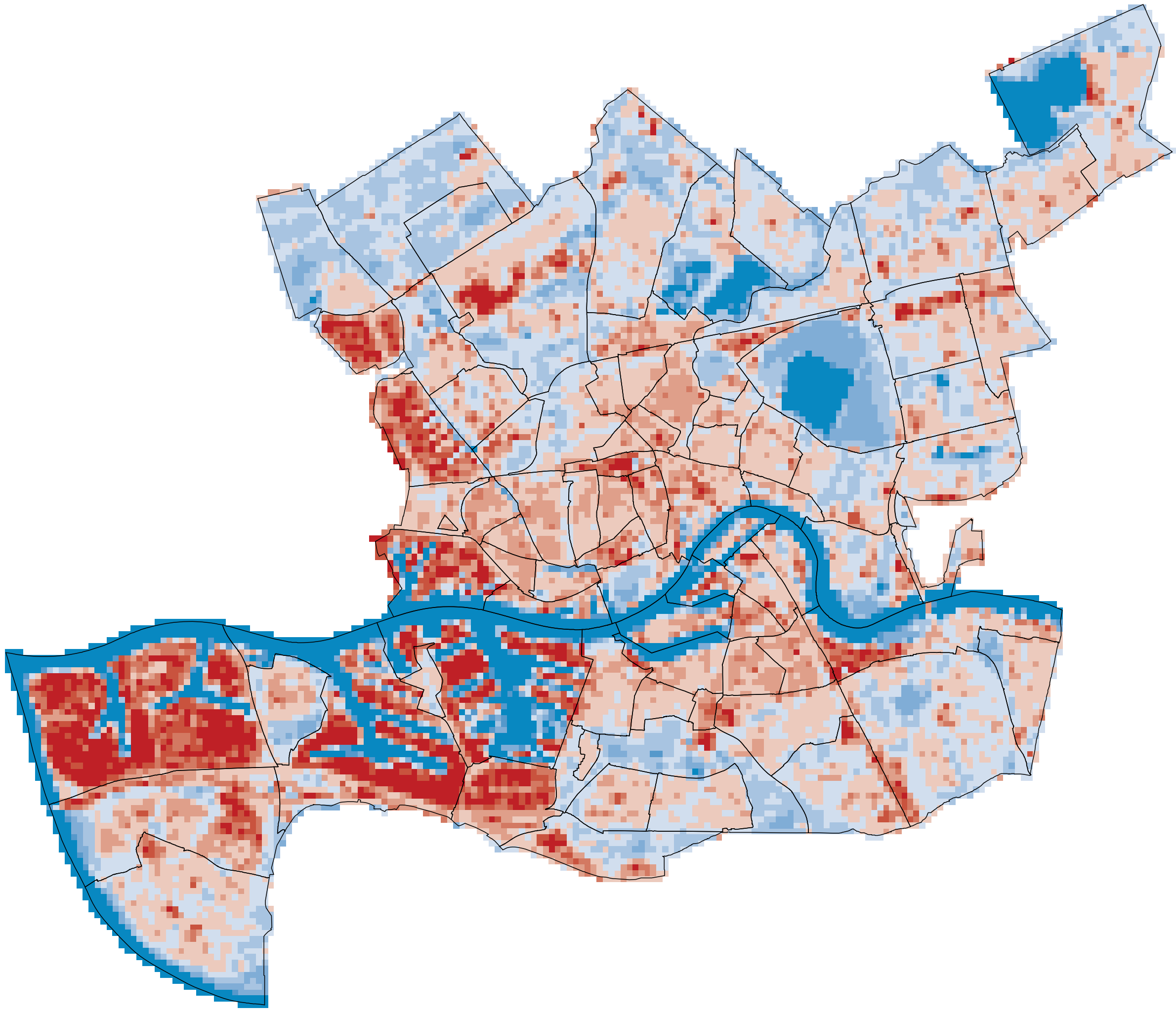
Key	≤-4,0 · >-4,0 ≤0,0 · >0,0 ≤2,5 · >2,5 ≤5,0 · >5,0 ≤7,5 · >7,5 ≤10,0 · >10,0 ≤12,5 · >12,5 ≤15,0 · >15,0 ≤20,0 · >20,0
Contents	Differences in surface temperature in the city of Rotterdam
Values	Degrees Celsius (29° Celsius = 0)
Method	Surface temperature is determined using TIRS Band 10 in Landsat 8 image
Software	BEAM-VISAT, ATCOR2, ArcGIS
Data	NASA, Landsat 8, 22 July 2014, 12.40

Net radiation



Key	≤500 · >500 ≤525 · >525 ≤550 · >555 ≤575 · >575 ≤625 · >625 ≤650 · >650 ≤675 · >675 ≤700 · >700 ≤725 · >725
Contents	The net radiation received by the earth's surface from the sun. The radiation reflected by the earth's surface and the heat radiated by the earth's surface form no part of this.
Values	W/m2
Method	Surface energy balance
Software	BEAM-VISAT, ATCOR2, ArcGIS
Data	NASA, Landsat 8, 22 July 2014, 12:40

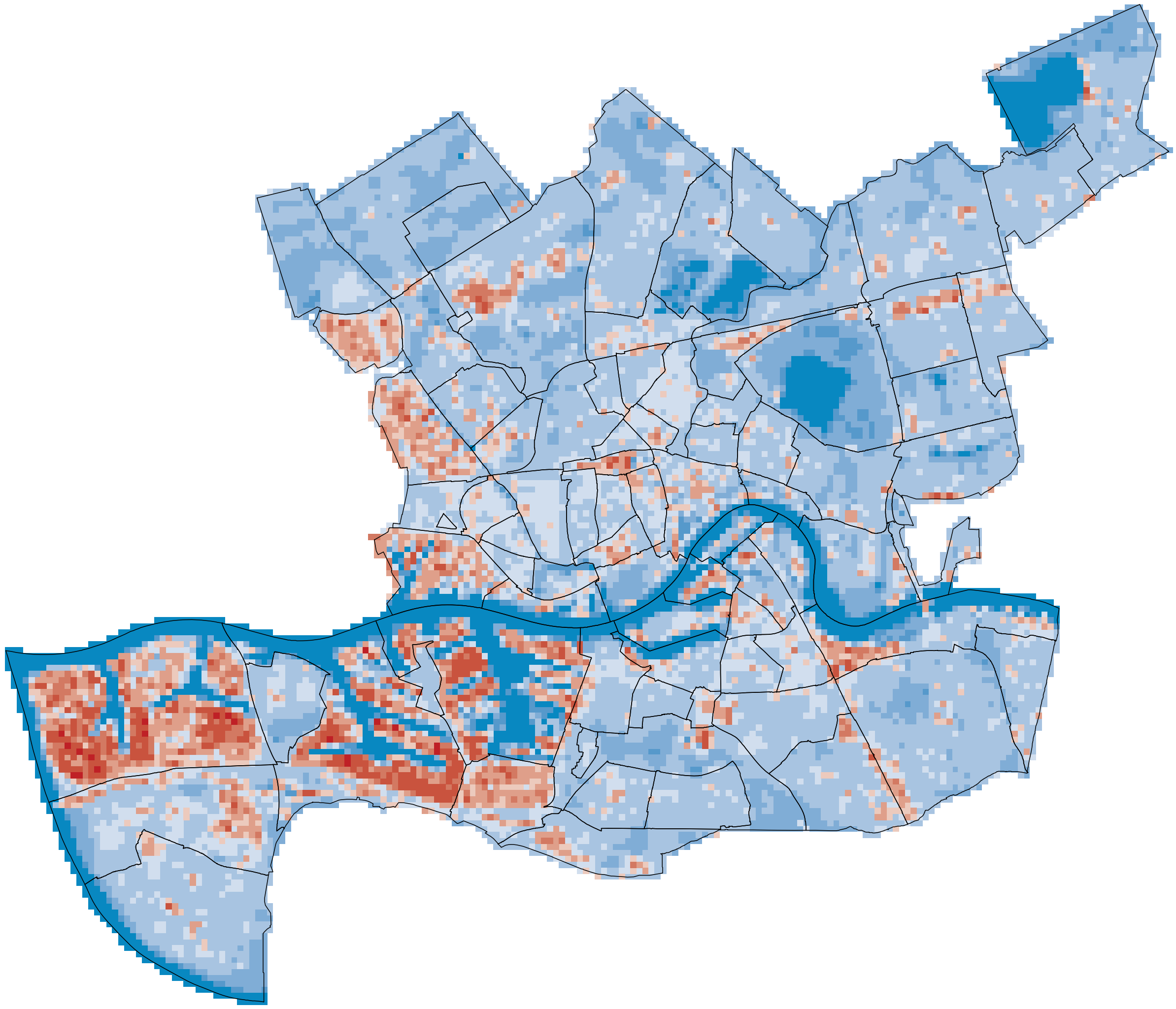
Latent heat



Key	≤100	>100 ≤150	>150 ≤200	>200 ≤250	>250 ≤300	>300 ≤350	>350 ≤400	>400 ≤450	>450 ≤500	>500

Contents	Latent heat is the energy required to evaporate water. Vegetation and surface water are important 'consumers' of latent heat. Latent heat indicates that the surroundings are cooling.
Values	W/m2
Method	Surface energy balance
Software	BEAM-VISAT, ATCOR2, ArcGIS
Data	NASA, Landsat 8, 22 July 2014, 12:40

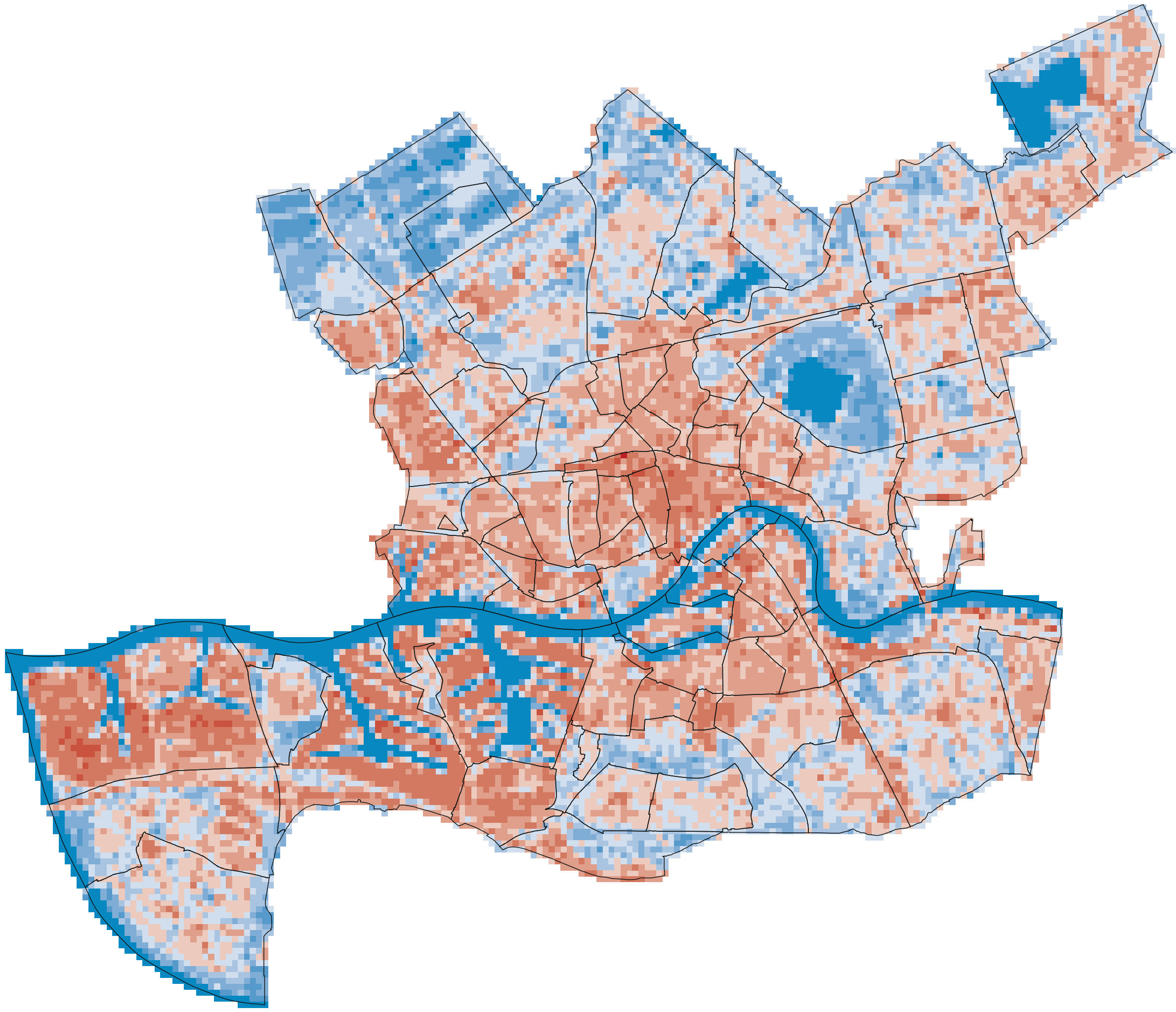
Sensible heat



Key	≤25	>25 ≤50	>50 ≤75	>75 ≤100	>100 ≤125	>125 ≤150	>150 ≤200	>200 ≤225	>225 ≤250	>250

Contents	Sensible heat is the convection heat that heats the air. This heating process takes place primarily above surfaces with a high temperature. In the conversion of surface temperatures to air temperatures, (small) pockets of turbulence – known as eddies – play an important role.
Values	W/m2
Method	Surface energy balance
Software	BEAM-VISAT, ATCOR2, ArcGIS
Data	NASA, Landsat 8, 22 July 2014, 12:40

Ground heat flux



Key	≤ 25	>25 ≤50	>50 ≤75	>75 ≤100	>100 ≤125	>125 ≤150	>150 ≤175	>175 ≤200	>200 ≤215	>215

Contents	Ground heat flux is the heat absorbed by the ground, buildings, and surface water. The stored heat is released at night and affects the nightly heat island.
Values	W/m2
Method	Surface energy balance
Software	BEAM-VISAT, ATCOR2, ArcGIS
Data	NASA, Landsat 8, 22 July 2014, 12:40

Social

Identifying the socio-spatial factors in the city of Rotterdam that affect the vulnerability of residents to heat.

Background

The elderly, especially those aged 75 and above, are vulnerable during heat waves and run an increased risk of dying prematurely. The conditions that play a part in this and the spatial distribution of the elderly differ from one area to the next. Literature suggests that the degree of home insulation, the age of homes, and the intensity of the heat island determine the likelihood of elderly residents dying.

Method

Based on the available data, the features suggested by literature were examined: the number of people aged 75 and over, the rate of mortality among this group in July 2006, the difference between the mortality rate in July 2006 and the July average for 2000–2013, and the age of the buildings per hectare.

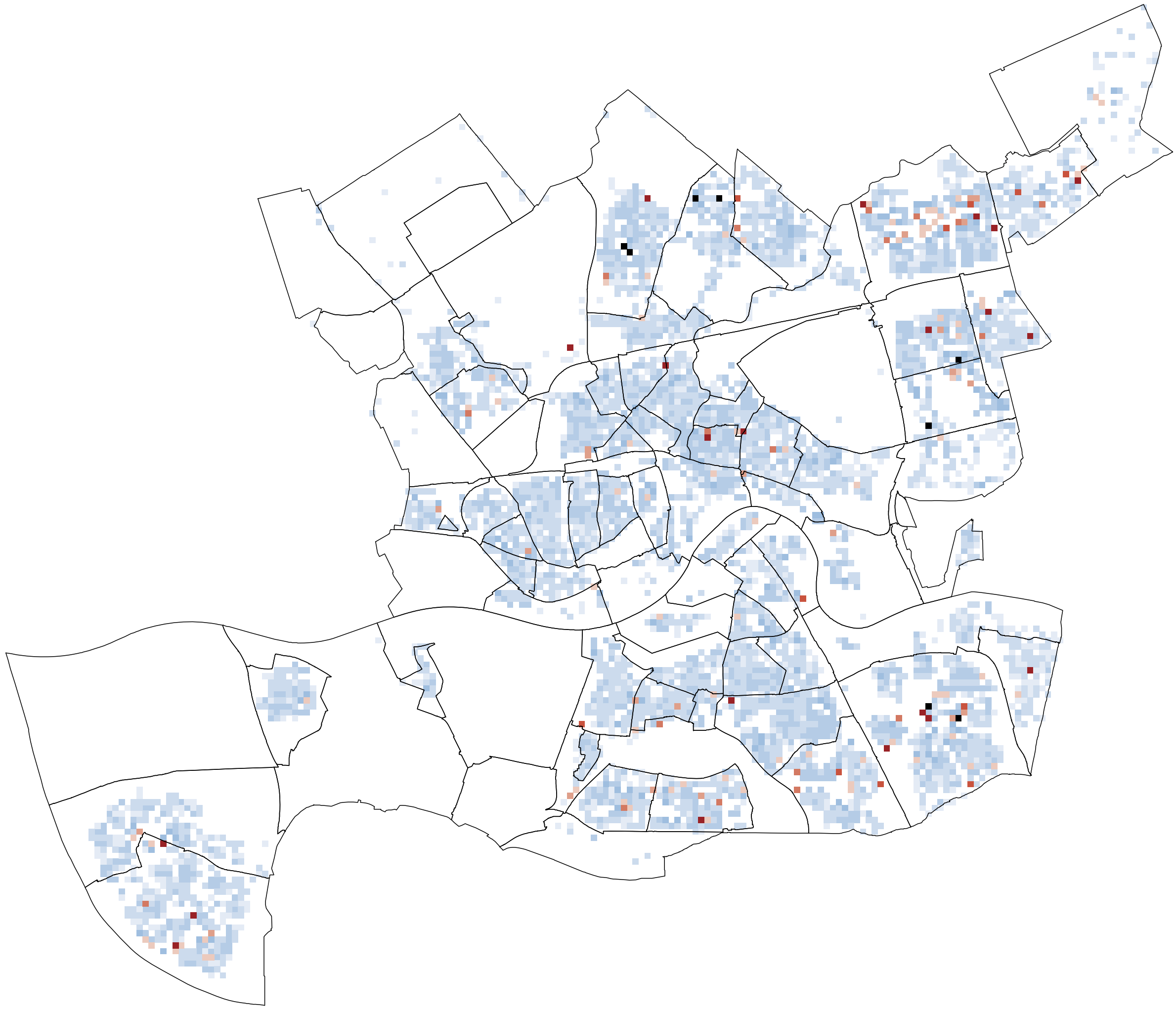
Results

Measuring the social features resulted in the maps relating to the spatial distribution of those aged 75 and over, the mortality rate of this age group during July 2006, their above-average mortality rate in July 2006 (compared to the period 2000-2013), and the age of the buildings.

Conclusion

The vulnerable group of those aged 75 and over are strongly concentrated (in old people's homes and care homes) in the post-war districts such as Schiebroek, Ommoord, IJsselmonde, Zuidwijk, Pendrecht and Hoogvliet. The above-average mortality rate during the July 2006 heat wave shows a pattern that is more spread out. It is clear that there is more to it than simply the concentration of those aged 75 and over.

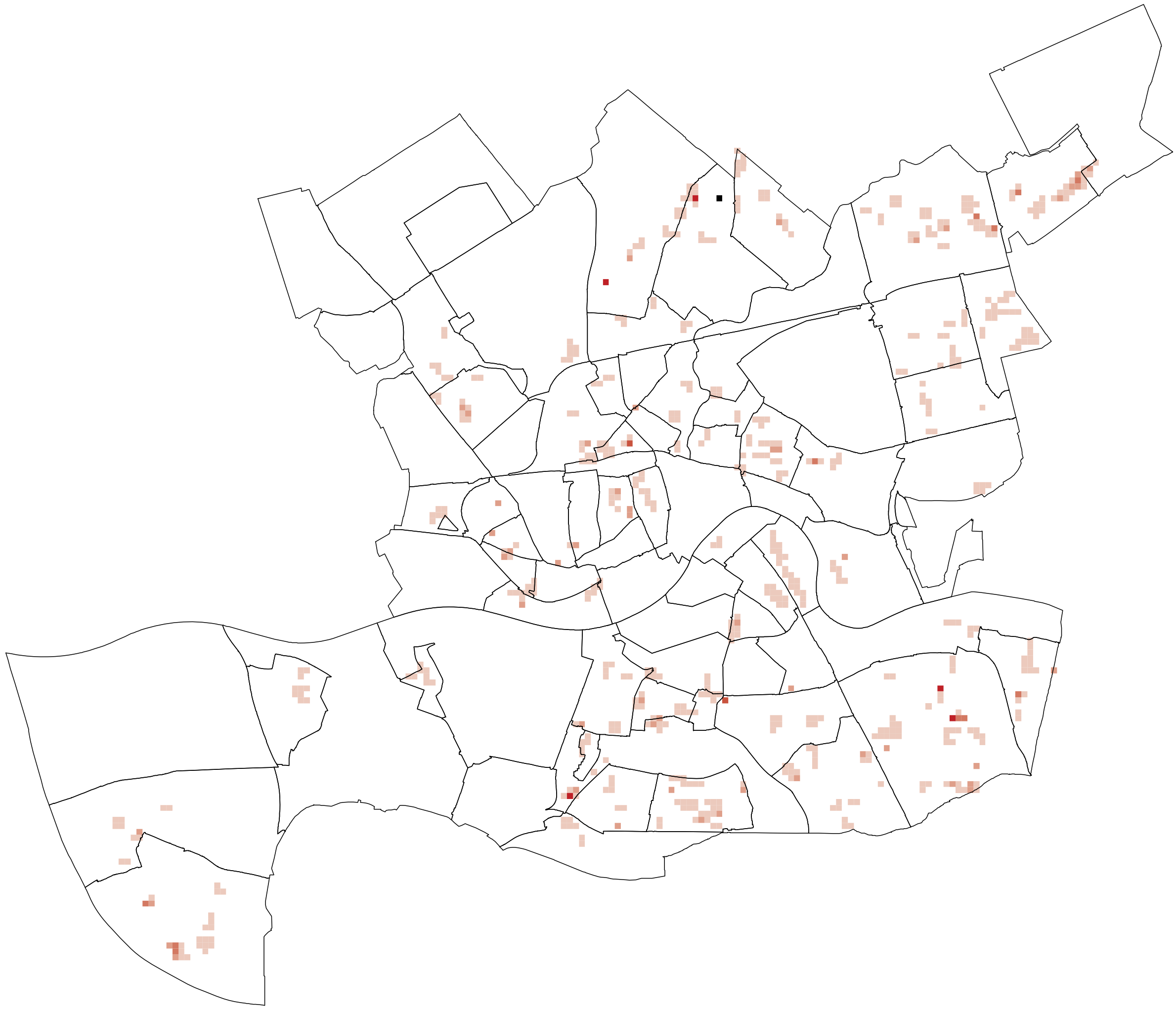
Spatial distribution of those aged 75 and over



Key	1	2-5	6-25	26-50	51-75	76-100	101-125	126-150	151-200	201-255

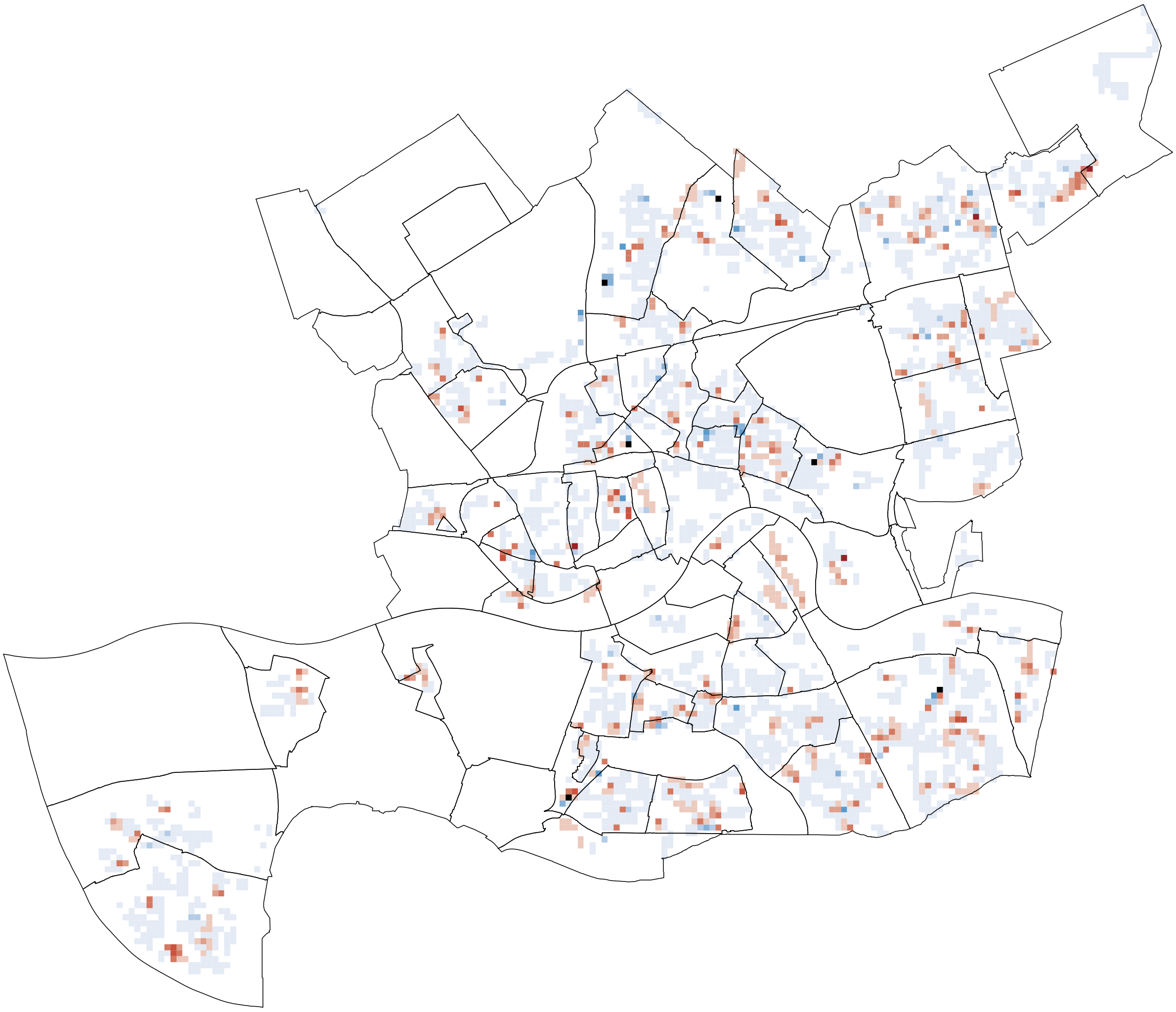
Contents	Inhabitants aged 75 and over per hectare
Values	Absolute numbers per hectare
Method	–
Software	ArcGIS
Data	Municipal personal data records

Mortality age 75 and over, July 2006



Key	0	1	2	3	4	5	6	–	8	–
Contents	Number of deaths among inhabitants aged 75 and over per hectare in July 2006									
Values	Absolute numbers per hectare									
Method	–									
Software	ArcGIS									
Data	Municipal personal data records									

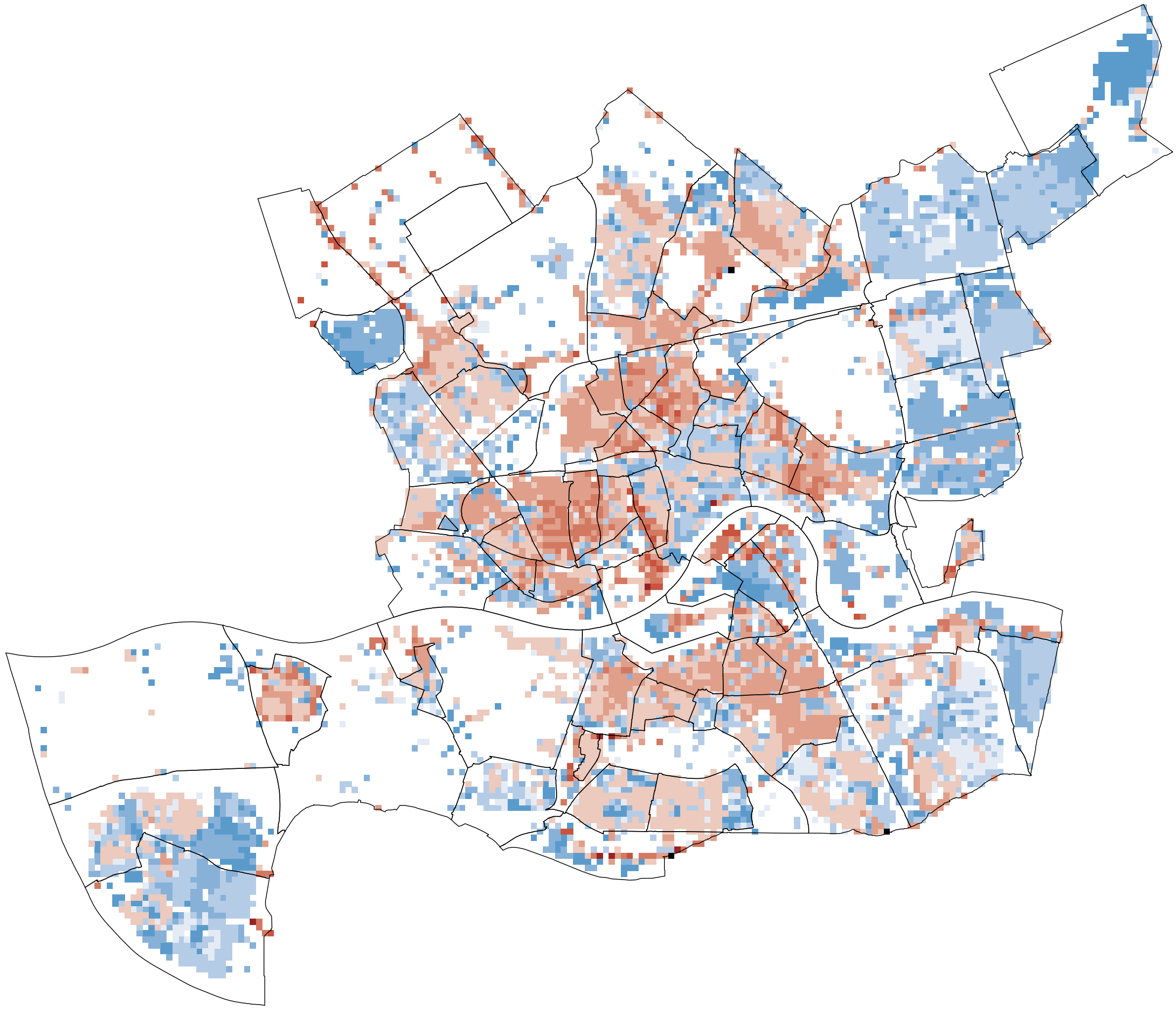
Above average mortality age 75 and over, July 2006



Key	≤-1,0	>-1,0 ≤-0,5	>-0,5 ≤-0,3	>-0,3 ≤0,0	>0,0 ≤0,3	>0,3 ≤0,5	>0,5 ≤1,0	>1,0 ≤1,5	>1,5 ≤2,0	≥2,0

Contents	Above average number of deaths among inhabitants aged 75 and over per hectare in July 2006
Values	Absolute numbers per hectare
Method	Mortality rates among those aged 75 and over in July 2006 minus the average number of deaths for 2000–2013 per hectare
Software	ArcGIS
Data	Municipal personal data records

Building age



Key	≤15	>15 ≤30	>30 ≤45	>45 ≤50	>50 ≤75	>75 ≤100	>100 ≤125	>125 ≤150	>150 ≤200	>200

Contents	Average age of buildings
Values	Averages per hectare, expressed in years
Method	–
Software	ArcGIS
Data	Basic Registration of Addresses and Buildings (BAG)

Physical

Identifying the physical spatial features that contribute to the urban heat island in the city of Rotterdam.

Background

The physical space of Rotterdam has features that affect heat levels in the city. By accurately identifying these features, we can determine the influence of each hectare on urban heat in Rotterdam. This information can be used to manage urban heat by making modifications to the spatial design of the city.

Method

In the analysis, three types of data were used: satellite images, data obtained from the city council's GIS system, and data derived from a 3D model of the city of Rotterdam. The satellite image is a Landsat 8 image (OLI), taken on 22 July 2014 during the most recent summer. Using the city council's GIS system, the percentage of space used in each hectare was calculated. A calculation was also made of the sky view factor, shade, the building envelope index and building volume, based on the Dutch Elevation Dataset 2 (AHN-2).

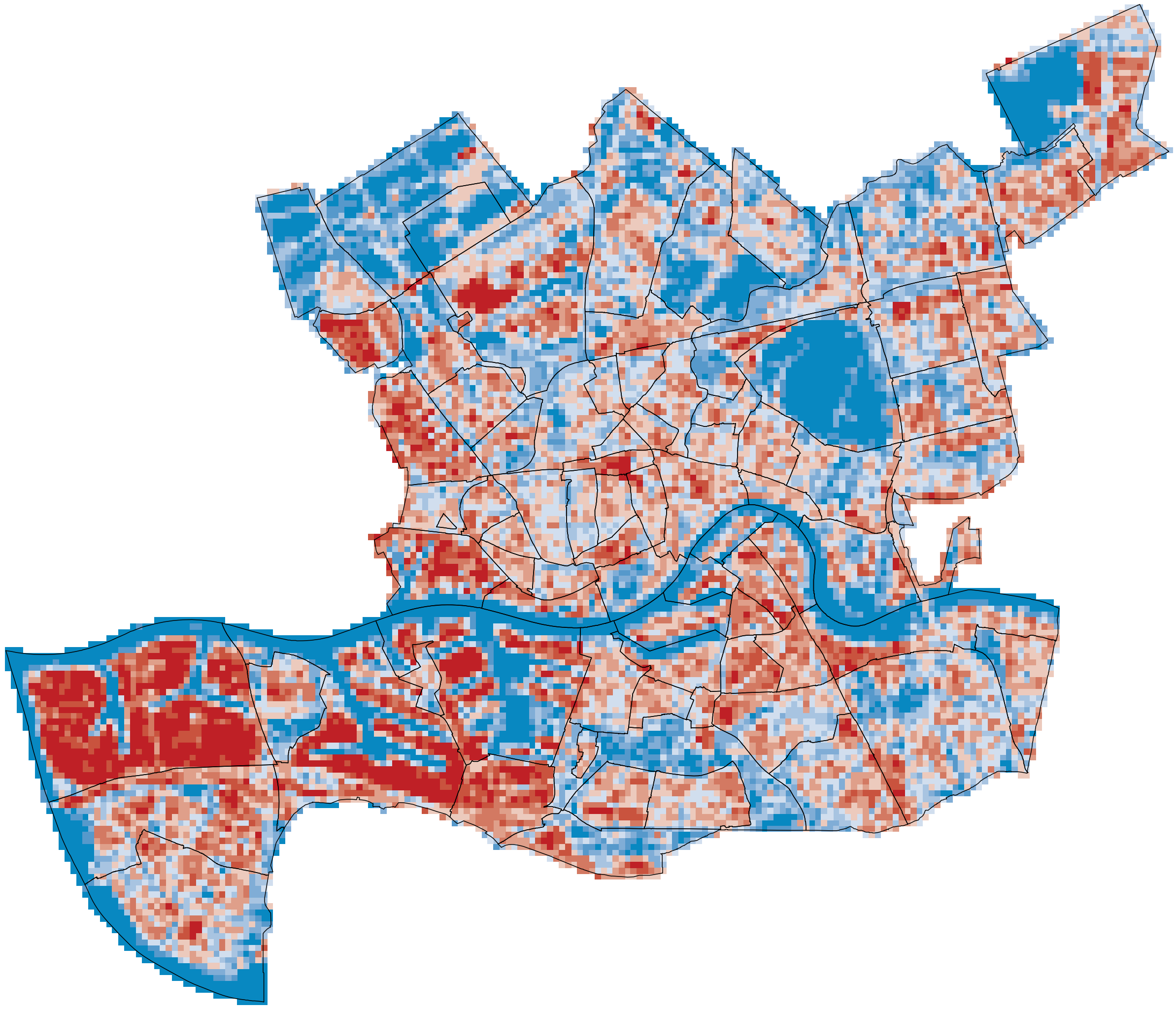
Results

Identifying the physical spatial features resulted in the maps in relation to imperviousness, surface water, albedo, vegetation, shade, the sky view factor, building volume and building envelopes.

Conclusion

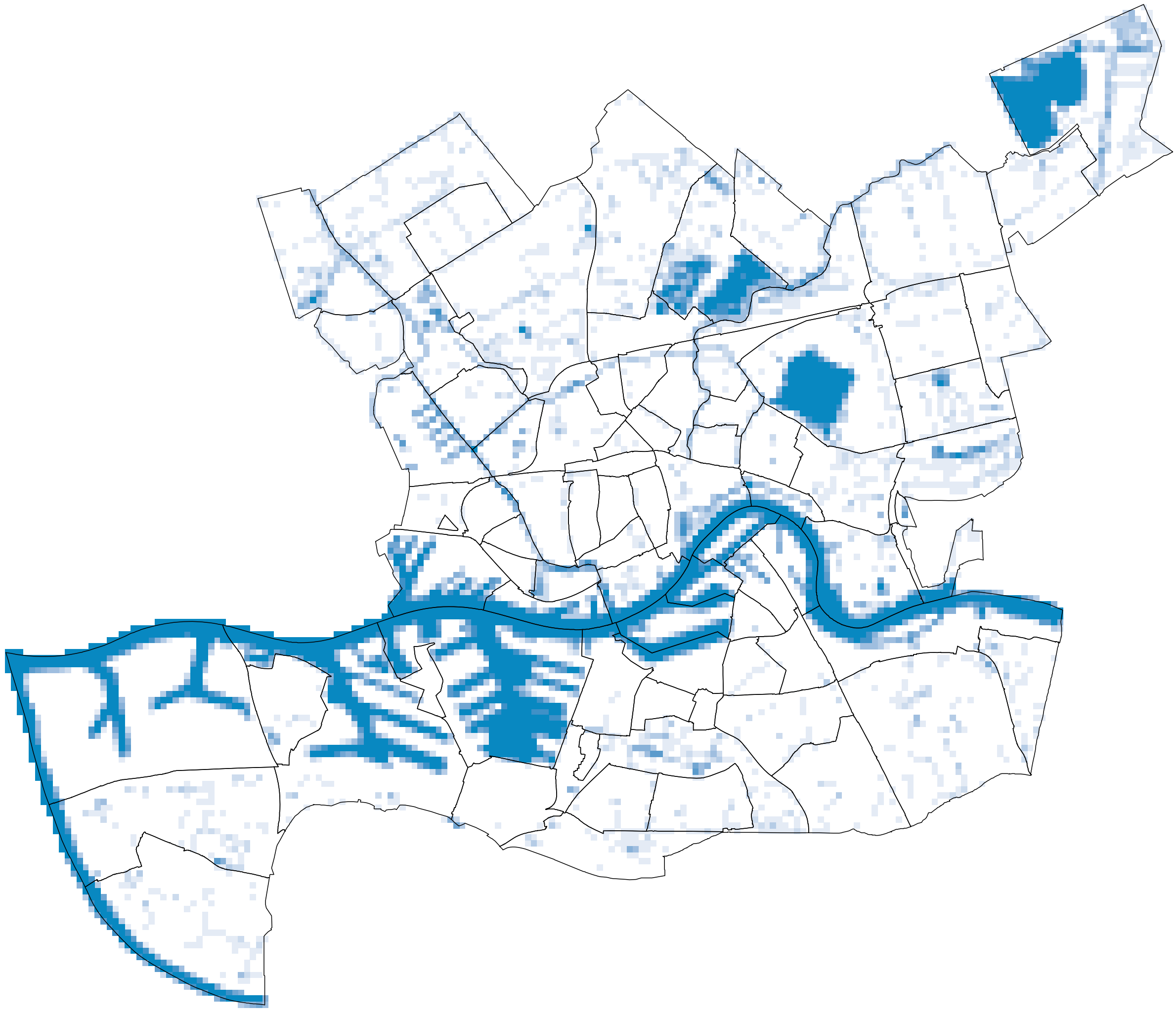
The physical features that play a part in the heat island demonstrate stark differences between 1) port/industry/business areas; 2) the pre-war part of the city including the centre; 3) the post-war part of the city; and 4) areas of vegetation. These four features determine largely the heat map.

Imperviousness



Key	≤0,10 · >0,10 ≤0,20 · >0,20 ≤0,30 · >0,30 ≤0,40 · >0,40 ≤0,50 · >0,50 ≤0,60 · >0,60 ≤0,70 · >0,70 ≤0,80 · >0,80 ≤0,90 · >0,90
Contents	Imperviousness makes a strong contribution to urban heat. It seals the surface, prevents water from evaporating, and hinders the growth of vegetation. It also prevents solar radiation from being converted into latent energy. In addition, it has the capacity to store heat during the daytime. This stored heat is then released at night.
Values	No dimensions. 1–100. 0 = least imperviousness, 100 = most imperviousness.
Method	Landsat 8 image has been atmospherically corrected. Spectral unmixing was then applied in order to determine the extent of imperviousness.
Software	BEAM-VISAT, ATCOR, ArcGIS
Data	NASA, Landsat 8, 22 July 2014, 12:40

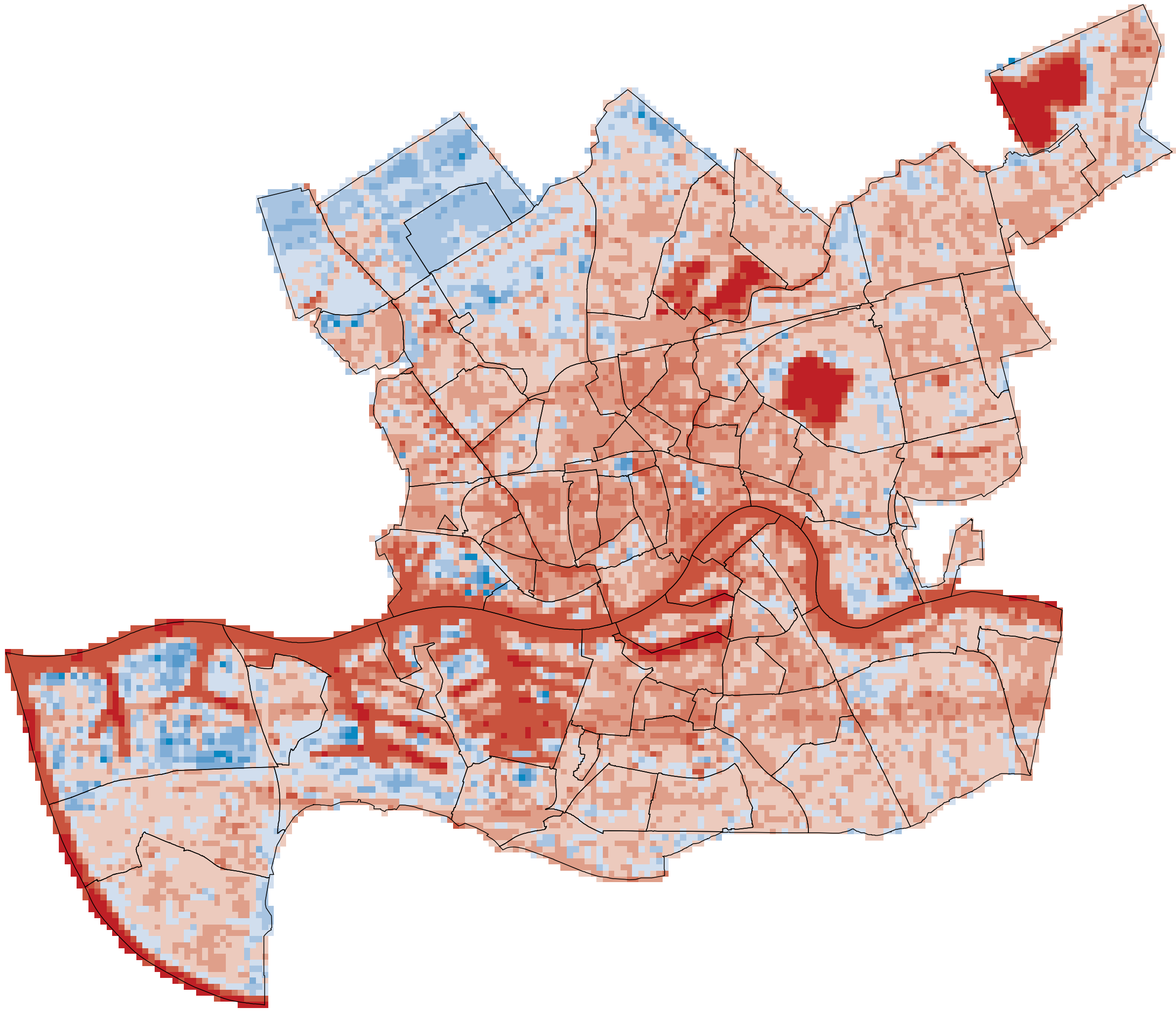
Surface water



Key	≤10	>10 ≤20	>20 ≤30	>30 ≤40	>40 ≤50	>50 ≤60	>60 ≤70	>70 ≤80	>80 ≤90	>90

Contents	Latent energy used by the evaporation of surface water has a cooling effect. However, surface water may also absorb solar radiation. In the daytime, surface water in the summer is one of the cool parts of the city's surface, but at night it actually contributes to the urban heat island effect.
Values	0-100%.
Method	The percentage of space used in each hectare is determined in ArcGIS on the basis of the TOP 10 map.
Software	ArcGIS
Data	TOP 10, Rotterdam

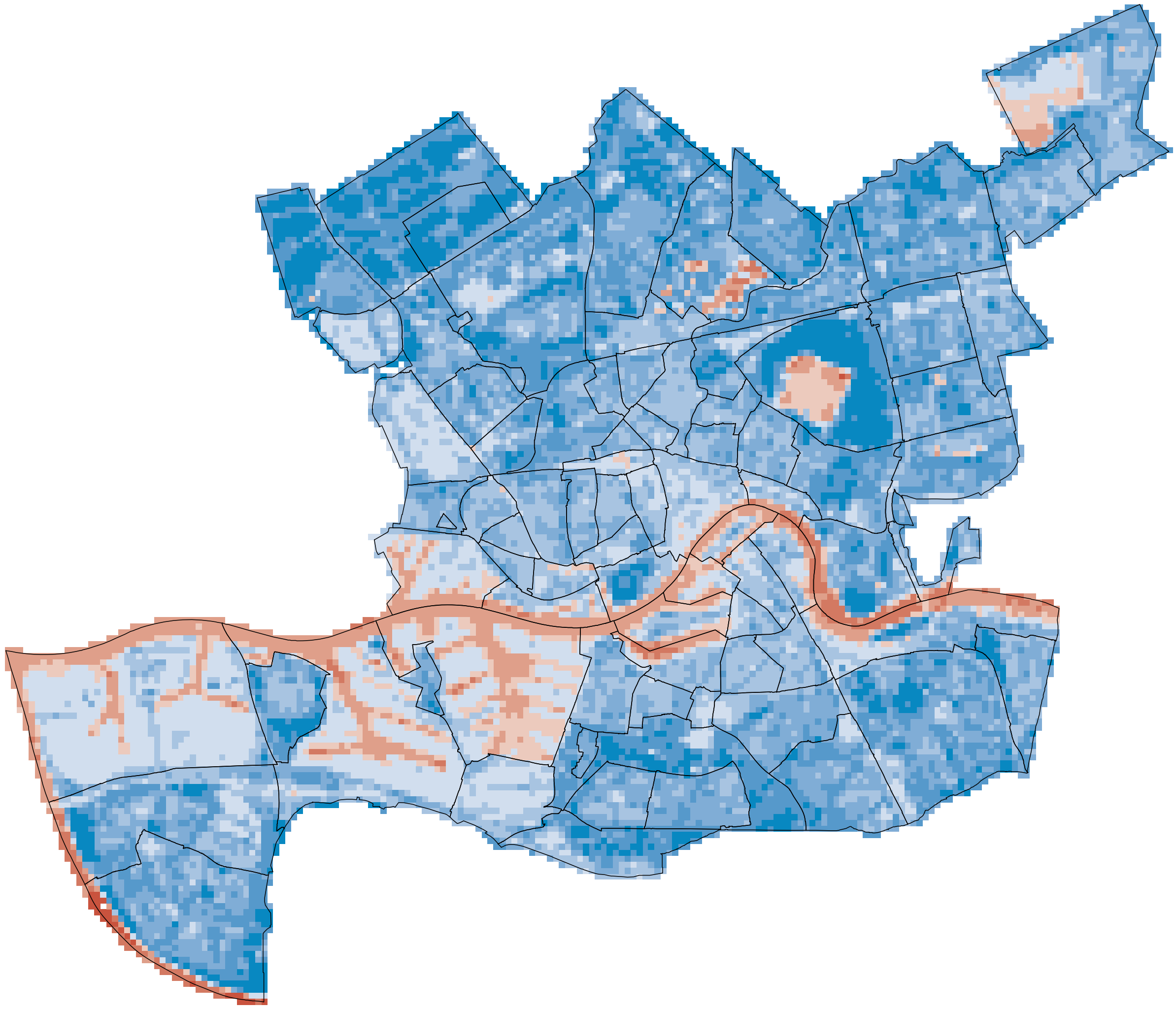
Surface albedo



Key	≤25	>25 ≤75	>75 ≤100	>100 ≤125	>125 ≤150	>150 ≤175	>175 ≤200	>200 ≤250	>250 ≤300	>300

Contents	Albedo is an indicator that expresses the degree to which buildings, streets and the ground reflect solar radiation. In general, a high albedo value means that buildings and cities heat up less quickly.
Values	0–1, 0 = no reflection, 1 = maximum reflection
Method	Landsat 8 image has been atmospherically corrected. The albedo overview was produced as an added value by-product in this process.
Software	BEAM-VISAT, ATCOR2, Envi, ArcGIS
Data	NASA, Landsat 5, 16 July 2006, 12:32

Vegetation index (NDVI)



Key	≤-0,90	>-0,90 ≤-0,75	>-0,75 ≤-0,50	>-0,50 ≤-0,25	>-0,25 ≤0,00	>0,00 ≤0,20	>0,20 ≤0,40	>0,40 ≤0,60	>0,60 ≤0,80	>0,80

Contents Normalized Difference Vegetation Index (NDVI), a standard indicator for green.

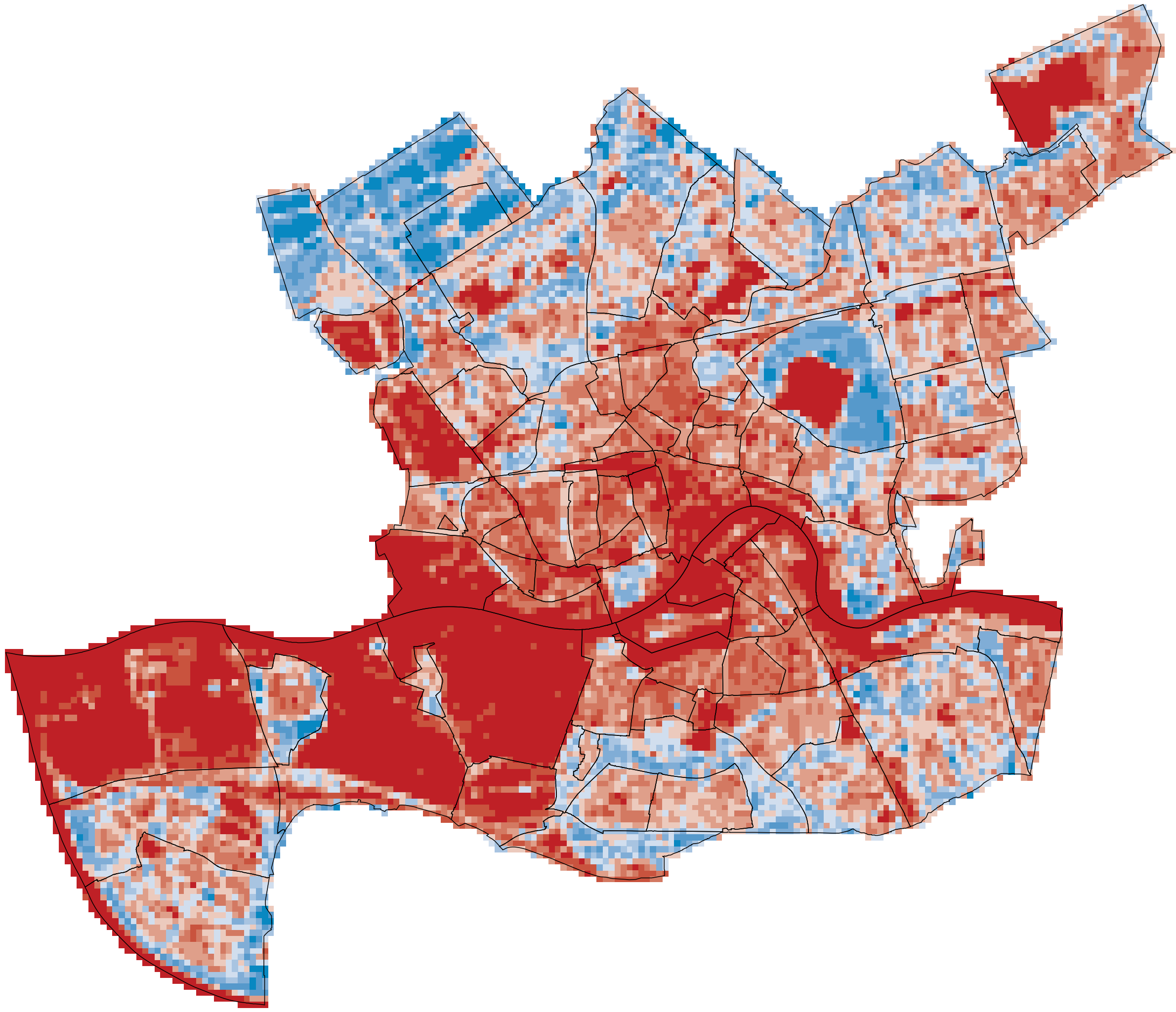
Values No dimensions

Method Landsat 8 image is atmospherically corrected. The NDVI is calculated with the formula (NIR - RED) / (NIR + RED).

Software BEAM-VISAT, ATCOR2, Envi, ArcGIS

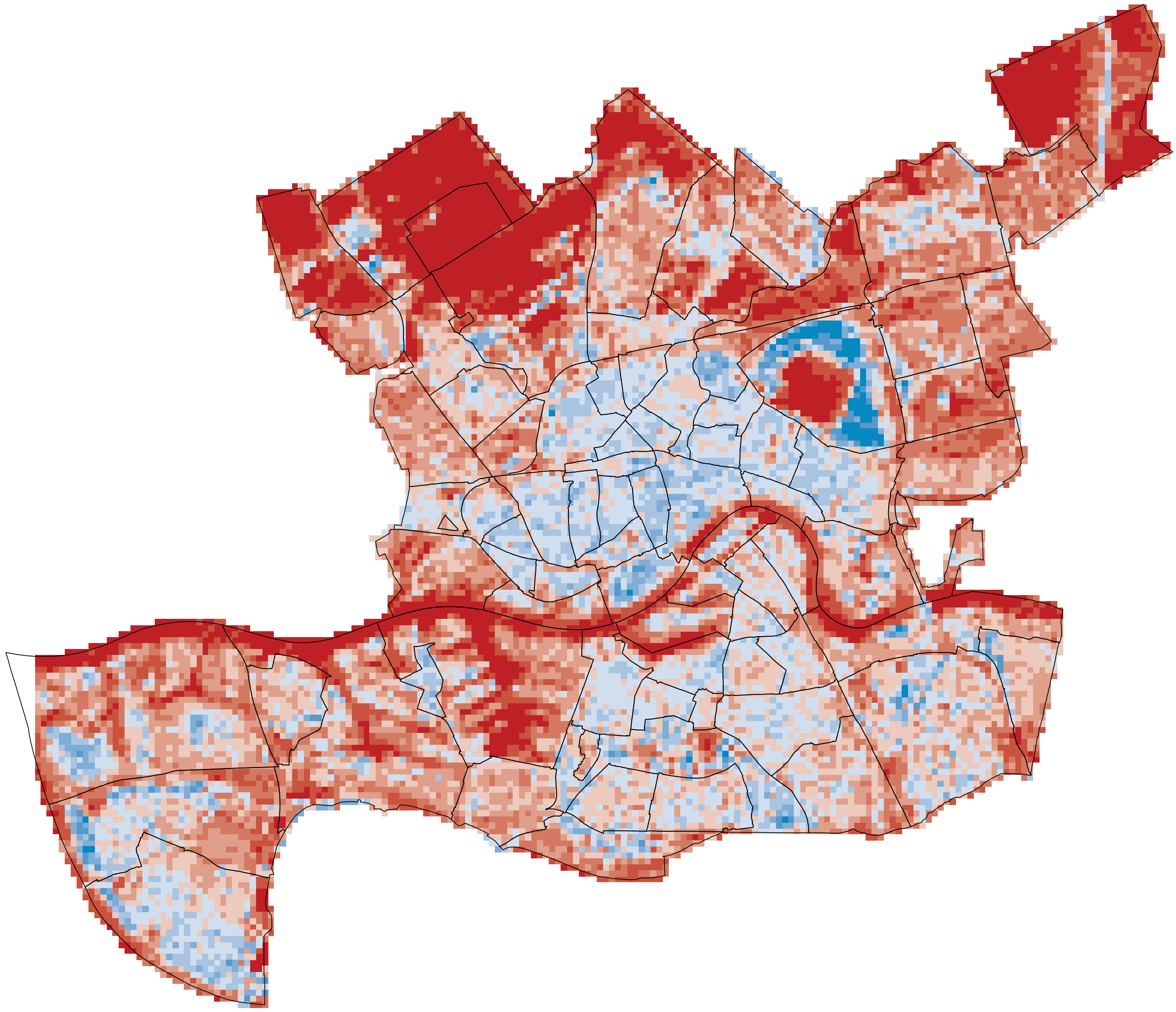
Data NASA, Landsat 8, 22 July 2014, 12:40

Leaf Area Index (LAI)



Key	≤0,15 · >0,15 ≤0,30 · >0,30 ≤0,50 · >0,50 ≤0,75 · >0,75 ≤1,00 · >1,00 ≤1,25 · >1,25 ≤1,50 · >1,50 ≤2,00 · >2,00 ≤2,50 · >2,50
Contents	The Leaf Area Index indicates the extend an area is covered by foliage.
Values	No dimensions
Method	The LAI overview was produced as an added value by-product in the process of atmospheric correction in ATCOR.
Software	BEAM-VISAT, ATCOR2
Data	NASA, Landsat 8, 22 July 2014, 12:40

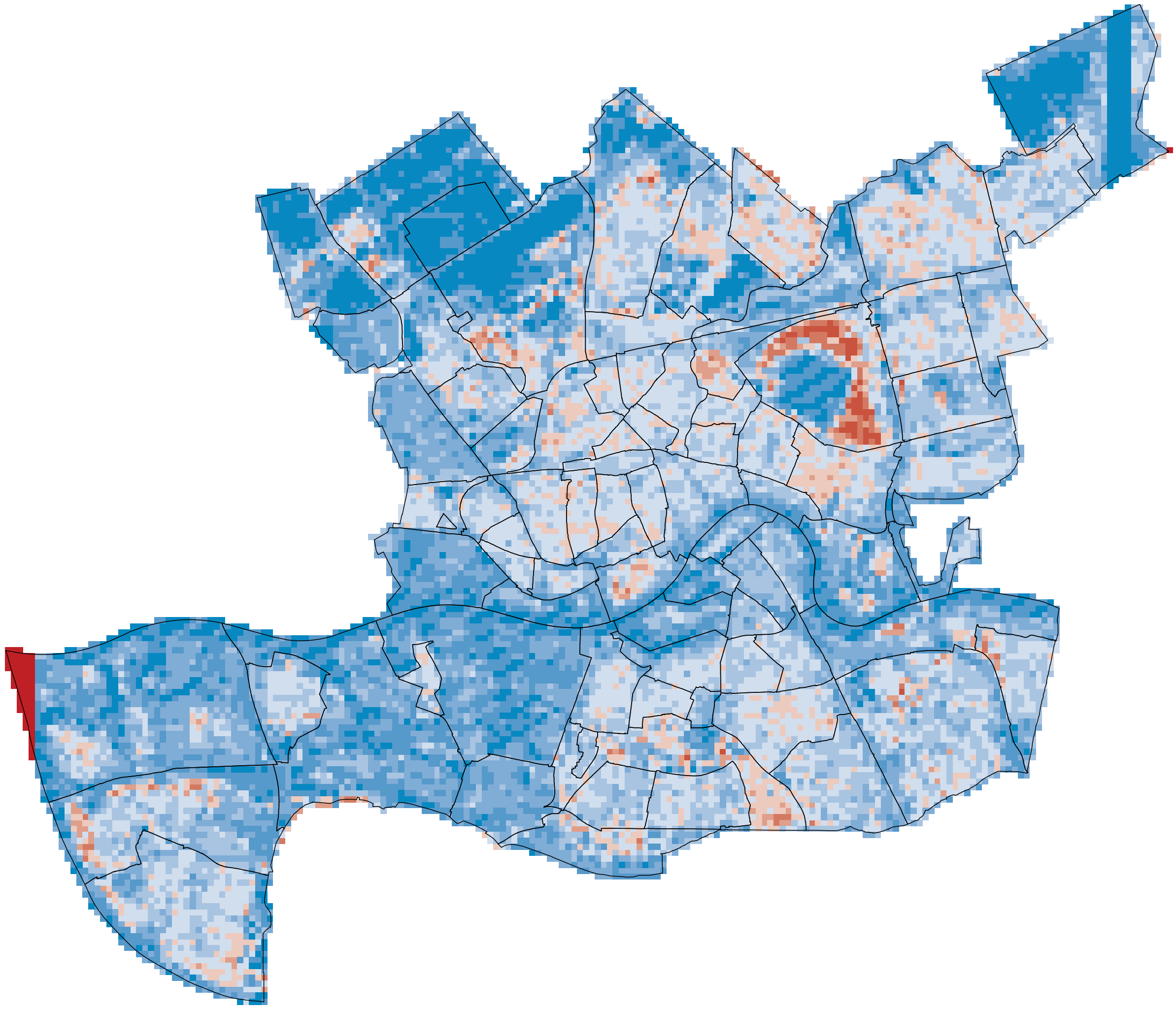
Shadow



Key ≤0,84 | >0,84 ≤1,67 | >1,67 ≤2,51 | >2,51 ≤3,34 | >3,34 ≤4,18 | >4,18 ≤5,01 | >5,01 ≤5,85 | >5,85 ≤6,69 | >6,69 ≤7,52 | >7,52

Contents	Shadow prevents the land surface from being exposed to solar radiation (Q*), the most important source of urban heat. The average shadow for each hectare was calculated for mid July and represented in the map above. Shadow caused by vegetation was included in the calculations.
Values	Number of shadow hours, calculated from sun rise until noon.
Method	Shadow was calculated up to 12:40 uur, the moment that the Landsat satellite captures images above Rotterdam.
Software	ArcGIS, hill shade
Data	Current Dutch Elevation (AHN 2), Rijkswaterstaat (RWS)

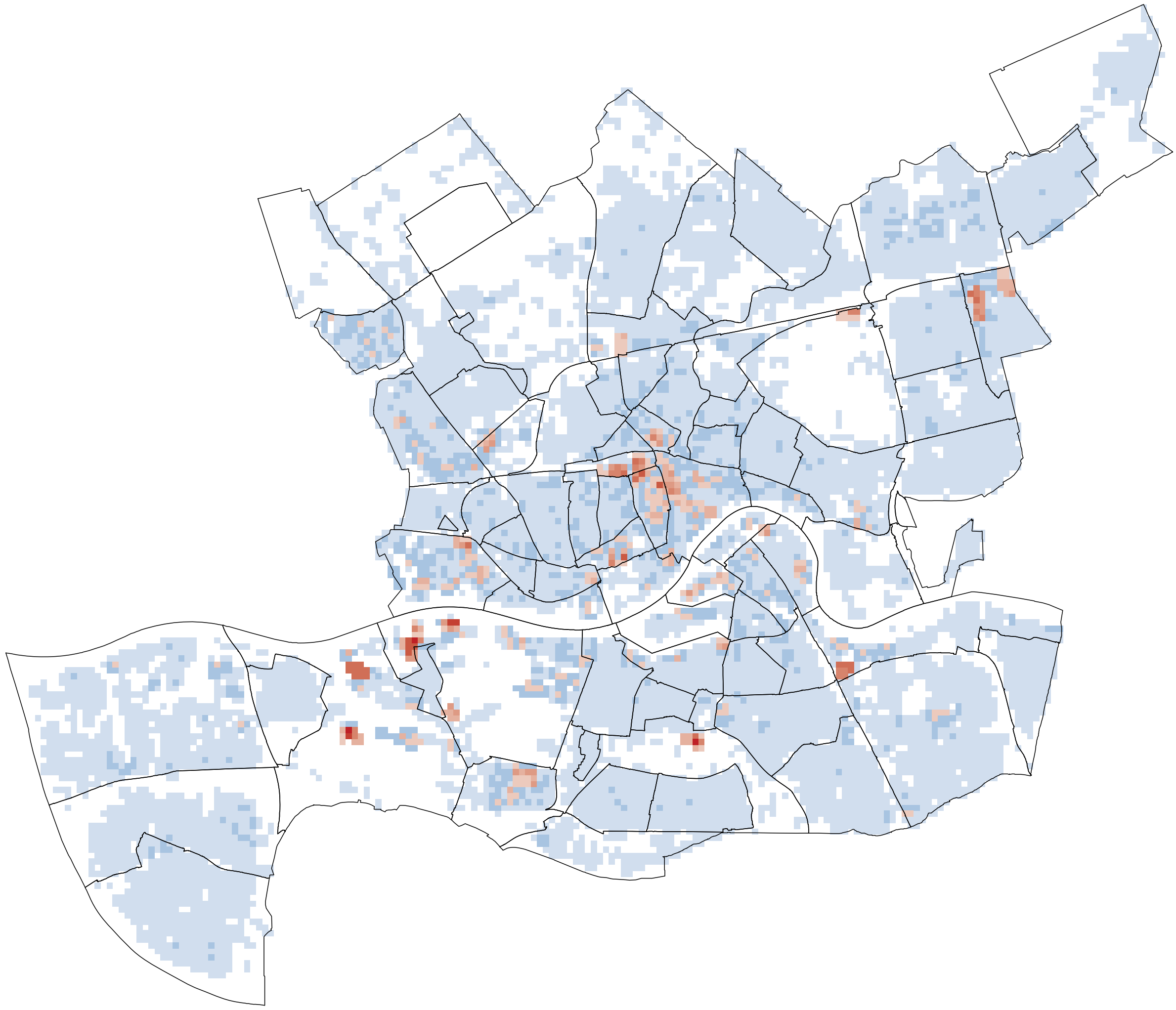
Sky view factor



Key	≤0,10	>0,10 ≤0,20	>0,20 ≤0,30	>0,30 ≤0,40	>0,40 ≤0,50	>0,50 ≤0,60	>0,60 ≤0,70	>0,70 ≤0,80	>0,80 ≤0,90	>0,90

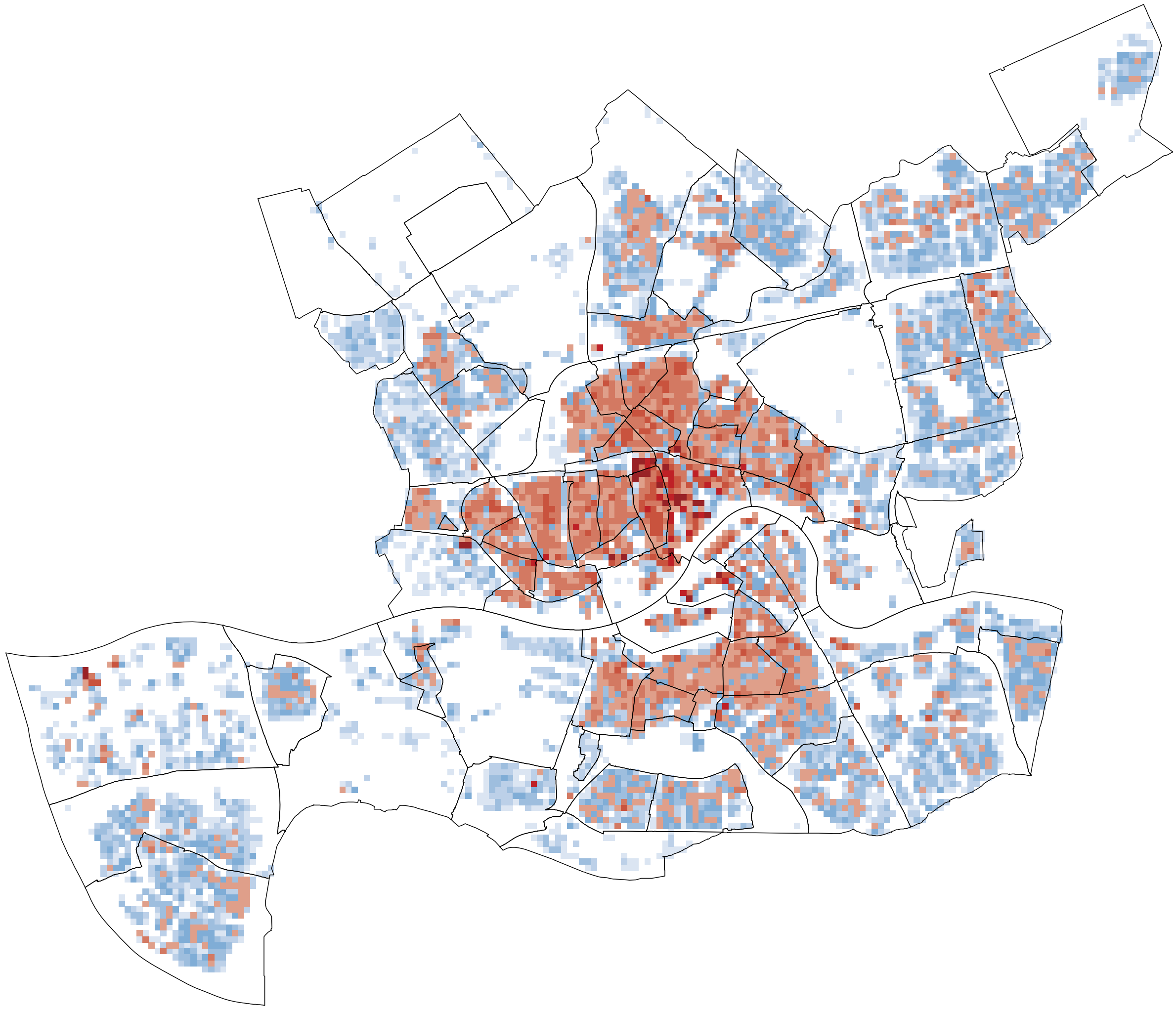
Contents	The 'sky view factor' is the degree to which a building is exposed to the sky. If this factor is high and the building is exposed to the sky on all sides, it will cool off quickly. This explains why the countryside around cities cools off quickly while the cities themselves do not.
Values	0-1.0 = no exposure to the sky, 1 = full exposure to the sky.
Method	De sky view factor is calculated for each gridcel measuring 0.5 x 0.5 meter. In this case 32 search directions were used and a search radius of 100 pixels. The result is aggregated in averages for each hectare.
Software	SVF Computation code (SAV), version 1.11, for ENVI, by Research Centre of the Slovenian Academy of Sciences and Arts
Data	Current Dutch Elevation (AHN 2), Rijkswaterstaat (RWS)

Building volume



Key	≤70 · >70 ≤140 · >140 ≤210 · >210 ≤280 · >280 ≤350 · >350 ≤420 · >420 ≤480 · >480 ≤560 · >560 ≤630 · >630
Contents	Building volume is an indicator of building mass, and therefore possibly of the thermal mass – the capacity of the built environment to store heat.
Values	x 1,000 m^3 per hectare
Method	The volume of built-up areas for each hectare was calculated using a 3D model of the city of Rotterdam.
Software	ArcGIS
Data	Current Dutch Elevation (AHN 2), Rijkswaterstaat (RWS)

Building envelope



Key	≤0,1	>0,10 ≤0,20	>0,20 ≤0,30	>0,30 ≤0,40	>0,40 ≤0,50	>0,50 ≤0,75	>0,75 ≤1,00	>1,00 ≤1,25	>1,25 ≤1,50	>1,50

Contents The building envelope determines the degree to which a building is exposed to the sun and the sky. In the daytime, the building envelope determines how much solar radiation is received. At night, it determines how much heat is given off.

Values x 10,000 m² of building envelope per hectare

Method The surface area of the exteriors of built-up areas for each hectare was calculated using a 3D model of the city of Rotterdam.

Software ArcGIS

Data Basic Registration of Addresses and Buildings (BAG); Kadaster; the Netherlands; Municipal Records; Current Dutch Elevation (AHN 2), Rijkswaterstaat (RWS)

Heat maps

The Hotterdam project produced two heat maps:

The **social heat map** expresses the vulnerability of the elderly in particular to the urban heat island effect in the city of Rotterdam.

The **physical heat map** expresses the relationship between heat and the land use in Rotterdam. What combinations of land use make the city of Rotterdam more or less warm?

Social heat map

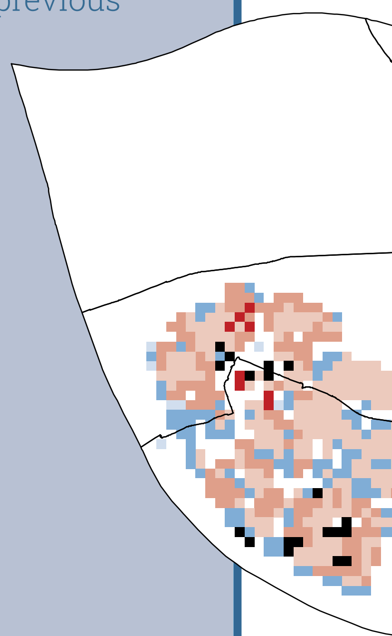
The spatial pattern of the vulnerability of the elderly in particular to the urban heat island effect in the city of Rotterdam.

Background

The idea behind the social heat map is to find out where in the city vulnerability to hot weather leads to problems for the elderly in particular. Any local authority seeking to manage its policies in a targeted way, rather than for the entire city, would be best advised to start taking measures, and informing residents and home owners in priority areas.

Method

The atlas identifies the social features that have been designated in previous research projects as possible causes of heat-related problems. Hierarchical multiple regression analyses were used to establish which of these are statistically significant in the case of Rotterdam: the number of those aged 75 and over per hectare, the average age of the buildings, the sum of sensible heat and ground heat flux. A cluster analysis was used to identify the links between these features.

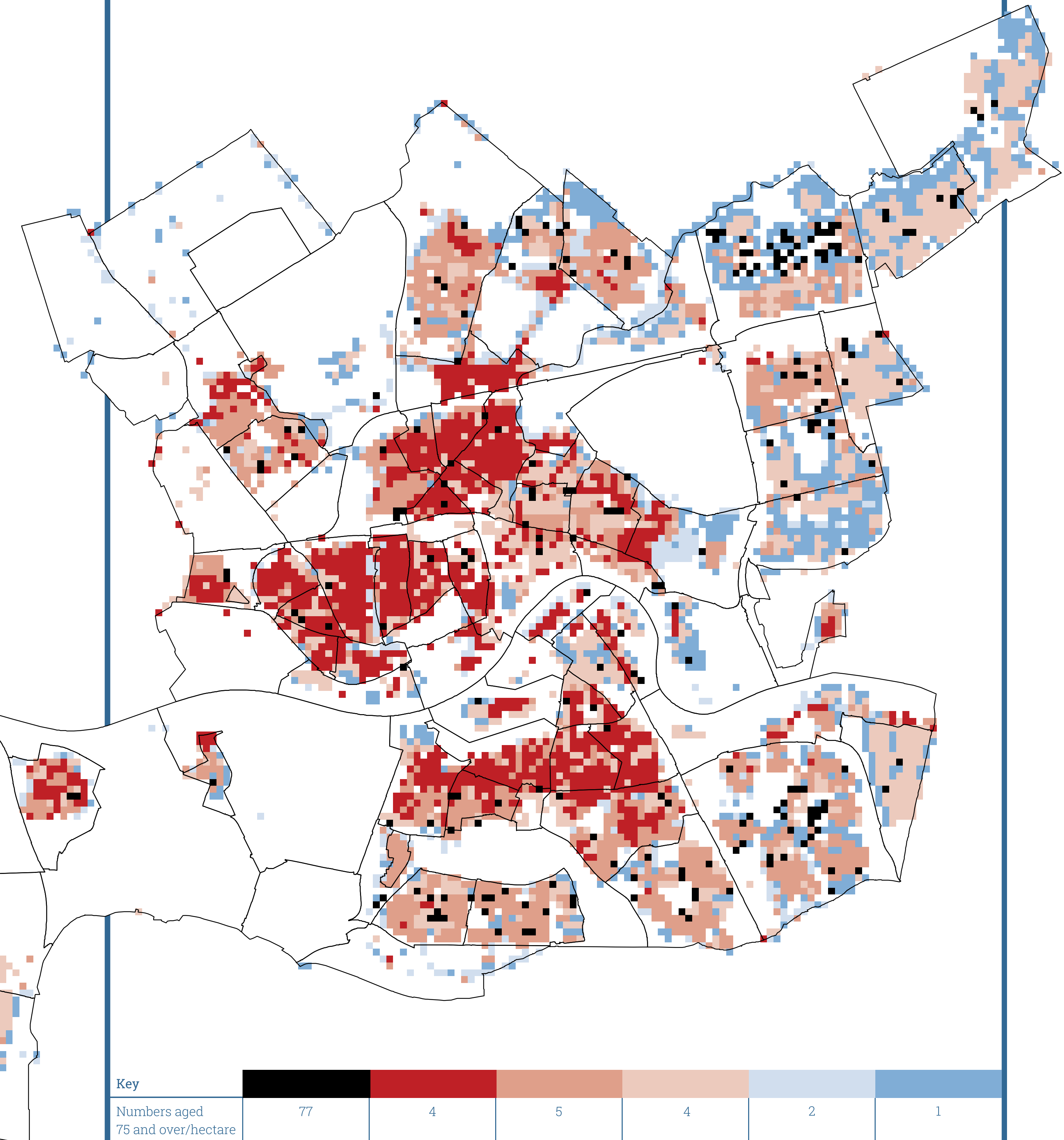


Results

This results in six clusters (or typologies) that are shown here on the map with different colours, together with a table explaining the underlying values.

Conclusion

The distribution of elderly people in the Netherlands is still strongly concentrated in a limited number of care institutions (black). These residential environments require particular attention. The districts around the centre (North, South, and West) have fewer elderly residents per hectare. They capture the most radiation, the homes here are the oldest on average, and the areas themselves are large (red). These areas require attention as well.



Key						
Numbers aged 75 and over/hectare	77	4	5	4	2	1
Age of buildings	36 years	85 years	59 years	27 years	23 years	88 years
QH + QS	363 W/m²	411 W/m²	353 W/m²	396 W/m²	314 W/m²	294 W/m²

Results from the cluster analysis of the social heat map.

Physical heat map

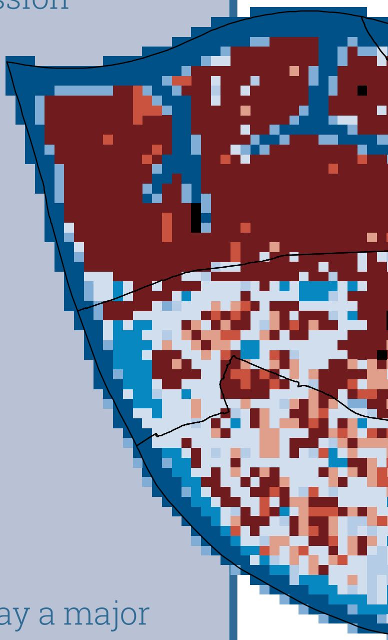
The pattern of spatial use that contributes to a greater or lesser degree to the urban heat island in the city of Rotterdam.

Background

The idea behind the physical heat map was to find out where in the city the features that strengthen the urban heat island occur. This information shows which combinations of spatial usage are better avoided and which should actually be applied more frequently, with a view to making the city cooler.

Method

The atlas identifies the social features that have been identified in previous research projects as possible causes of heat-related problems. Regression analysis was used to establish which of these are statistically significant: imperviousness, surface water, foliage (leaf area index), building envelopes and shade. A cluster analysis of these features was carried out. This analysis was used to identify and group the links between features.

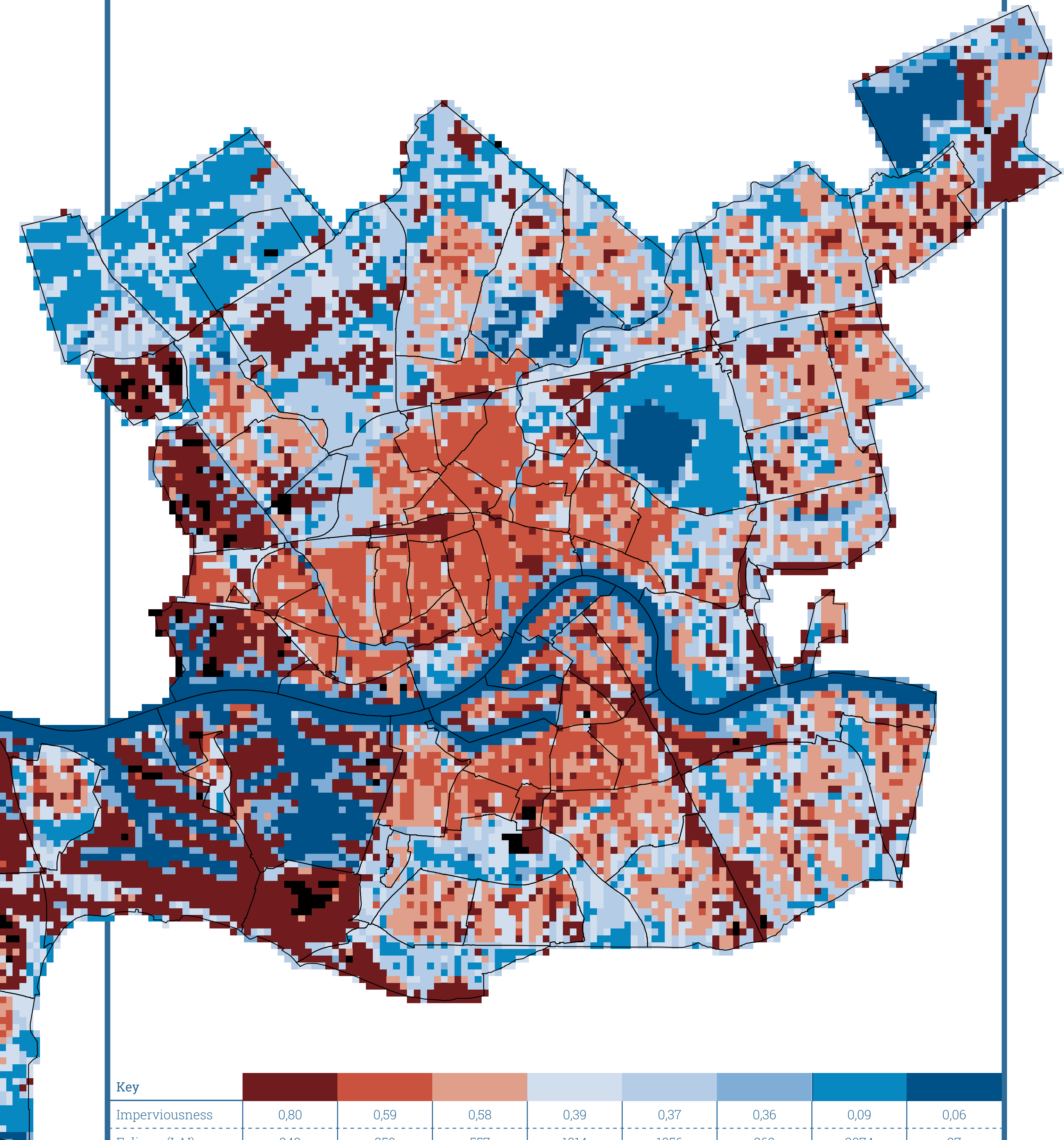


Results

The result is eight clusters (or typologies) that are shown here on the map in different colours, together with a table explaining the underlying values.

Conclusion

The extensive areas taken up by the port, industry and businesses play a major part in the formation the Rotterdam heat island: Vondelingenplaat, Eemhaven, Waalhaven, Vierhavens, Spaanse Polder and Noordwest business park. These areas do not appear on the social heat map as nobody lives there. The centre of the city and the surrounding districts (to repeat: North, South and West) are more strongly characterised by the physical features that determine the urban heat island than other districts.



Key								
Imperviousness	0,80	0,59	0,58	0,39	0,37	0,36	0,09	0,06
Foliage (LAI)	249	350	557	1014	1056	262	2074	27
Building envelope	1261 m²/ha	8136 m²/ha	4269 m²/ha	1139 m²/ha	663 m²/ha	732 m²/ha	136 m²/ha	23 m²/ha
Surface water	3%	2%	4%	7%	8%	54%	8%	96%
Shadow	2,4	2,8	3,9	1,4	4,5	2,9	2,8	2,5
QH + QS	456 W/m²	406 W/m²	375 W/m²	324 W/m²	316 W/m²	311 W/m²	242 W/m²	119 W/m²

Results from the cluster analysis of the physical heat map.

Adaptation

Rotterdam will face hot summers and heat waves more often in the future. This is not good news for the older inhabitants of the city in particular. However, it is not as if there is nothing we can do about it... There are specific actions that residents, home owners and the Rotterdam city council can take in order to adapt to urban heat.

Adapt at three levels

Urban heat is a complicated challenge that can evolve rapidly and unexpectedly into serious emergencies that could claim hundreds, if not thousands, of lives.
Urban heat requires a mix of solutions that call upon residents, property owners and the city council to take steps to adapt to a future built environment that will be hotter more often and for longer periods.

Residents

The Dutch are not used to heat. The houses here have disproportionately large windows and most have no sun blinds. When the weather is hot, we simply open doors and windows. Resting at the hottest time of a day and retreating to where it is cool for a siesta are an unknown behaviours here. After all, isn't that something only the Spanish do? This is in spite of the fact that the problems that occur during heat waves can be prevented by changing our behaviour. Seeking out cooler spots, drinking enough liquid, preventing your home from heating up, and making sure your home can cool off when possible: these are all measures that are inexpensive and measurably effective.

Home owners, residents' associations and corporations

We should also seriously consider adapting homes and their gardens. Too many gardens have been concreted or tiled over. These gardens could easily be made greener and wetter. Although homes can be cooled mechanically by air-conditioning, this strengthens the heat island effect. During the next few years, many homes will be modified to make them more energy-efficient. Staying cool in the summer must become part of this operation. Roofs in particular should be kept cool.

Local authority

Finally, it makes a difference if the built environment in which you live helps you and your home to stay cool. Streets with large trees offer shade and cooling through evaporation. This cooling process can be further enhanced by replacing unnecessary impervious surfaces with natural materials and more (shallow) surface water. Finally, certain features can be added to public spaces to provide shade. It is perhaps best to do this in the more prominent public spaces.
One consequence could be attractive architecture and urban space. All in all, climate adaptation is perfectly feasible.

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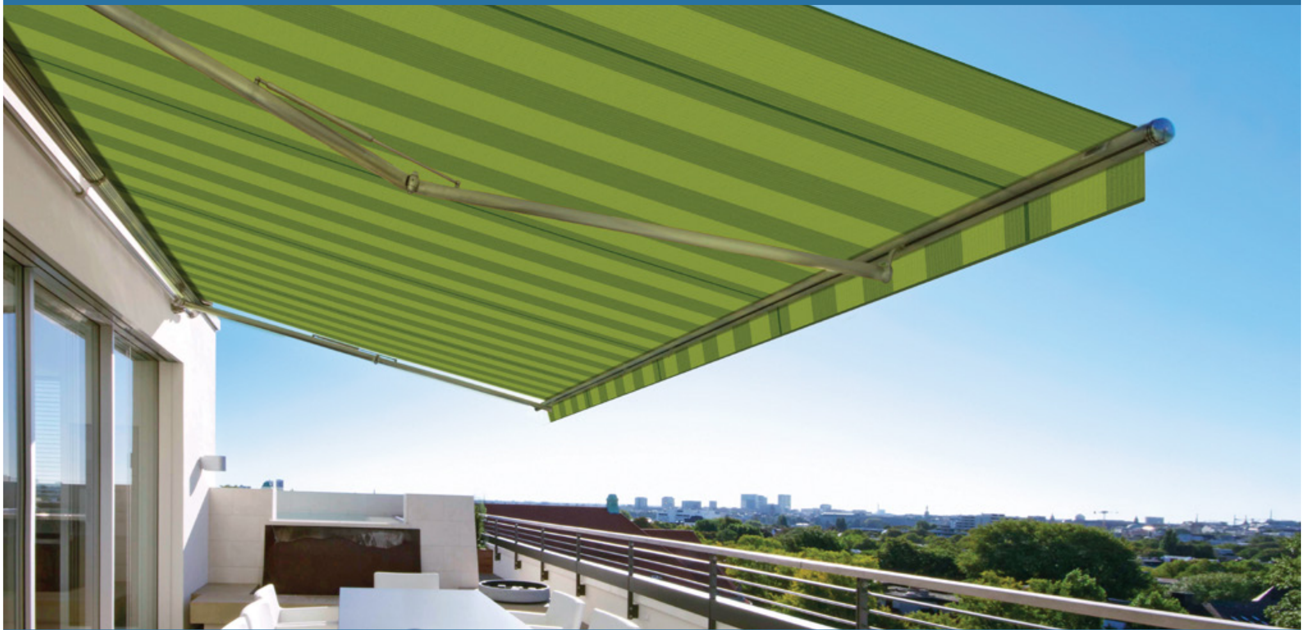
Change your behavior

Seek out cool areas

Do not expose your body to heat during hot weather. Wear light clothing and do not exert yourself. Find a comfortable place that is cool and out of the sun.

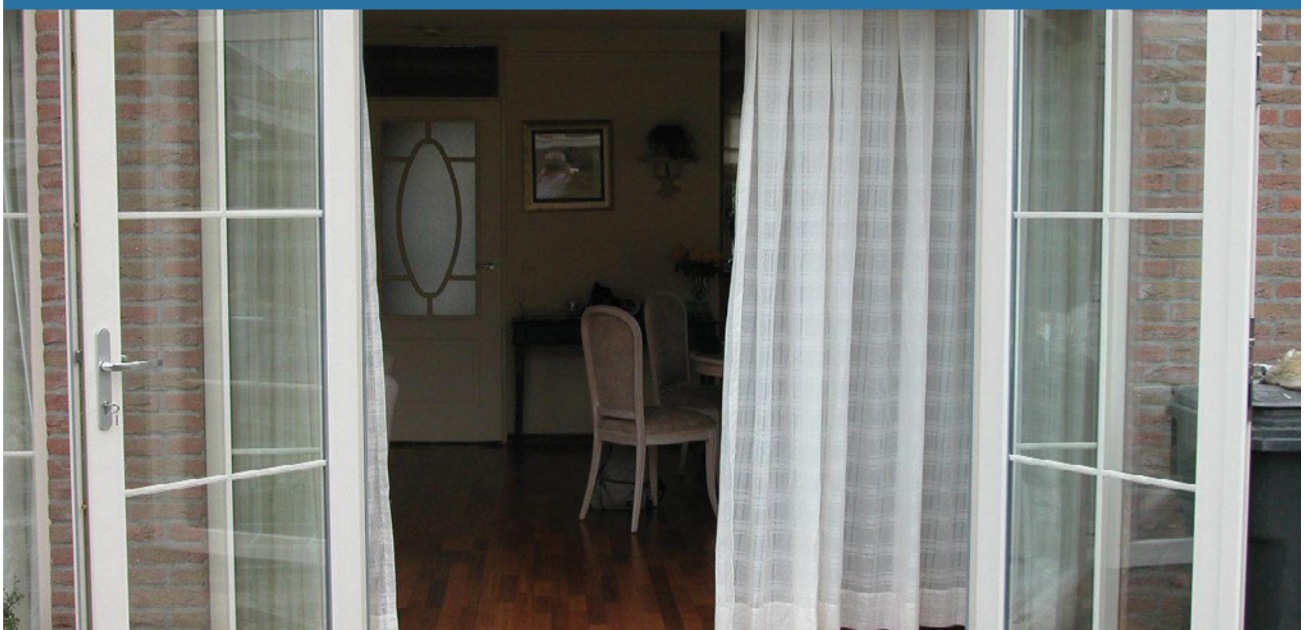
Drink enough water

During hot weather, it is important that your body is properly hydrated. This is because you run the risk of becoming dehydrated. Drinking water is therefore a must.



Repel the sun

Your home heats up through heat radiation that comes in through your windows. You can keep this radiation out by using sun screens, louvre screens, shutters or foils.



Cool naturally

Whenever it is warmer outside than in, close the windows and doors to keep out the warm air outside. Conversely, as soon as it is cooler outside, open the windows and doors in order to allow the interior to cool down.

Adapt your home

Make gardens greener

Many people concrete over or tile their gardens. With regard to heat, it is better to add water, greenery and trees for shade to your (communal) garden, as shown here in the 'Tuin van Jan' in Amsterdam.

Be careful with mechanical cooling

You can of course cool your home with air-conditioning. For vulnerable groups (the elderly) this can be a quick solution. However, using air-conditioning does strengthen the heat island. So this option is best disregarded, unless it really is unavoidable.

Increase energy efficiency

From 2020, Europe has stated that buildings must be 'nearly zero energy buildings'. This concerns not just energy consumption in the winter but also future energy consumption for keeping homes cooler in the summer.

Keep roofs cool

The solar radiation that falls on your roof can be reflected using special albedo coatings or converted into electricity. Green roofs also help, but you have to keep them very moist during hot weather.

Cool your city

Make streets greener

Trees evaporate water and provide shade. Trees in streets are the most effective for reducing urban heat. Here, they can provide direct shade for homes, such as in Graaf Florisstraat in Rotterdam West.

Cool street surfaces

Asphalting streets and roads significantly worsens the problems caused by urban heat. Every year, a small proportion of the asphalt is being replaced. This offers the possibility of using greener materials that absorb less heat or have a higher albedo value.

Play with water

Shallow reservoirs, ponds and fountains evaporate a significant amount in relative terms and therefore have a cooling effect; moreover, they are unable to store much heat. Water storage is also needed to capture excessive rainfall.

Add shade to public places

Shade is an effective way of combating heat. With a little thought, amenities can be designed and developed that give public spaces their own identity and enrich the city. 'Forest of Hope' by El Equipo De Mazzanti is a good example of this.

Annex

The Hotterdam research project would not have been possible without the Climate Proof Cities and 3TU.Bouw Lighthouse Projects programmes, without excellent literature, or without various helpful bodies that made their data available. We are very grateful for this.

Projects

This Hotterdam publication is the result of two projects: Climate Proof Cities and Sensing Hotterdam. Climate Proof Cities forms part of the 'Knowledge for Climate' programme. Sensing Hotterdam is a 3TU. Built Environment activity.

Climate Proof Cities

The Hotterdam research project has been carried out in the context of the Climate Proof Cities (CPC) programme. CPC is one of the consortia in the national Knowledge for Climate research programme. Its aim is to strengthen the urban system`s capacity to adapt and to reduce its vulnerability to climate change. In cooperation with stakeholders, strategies and policy instruments have been developed for adapting cities and buildings.

Sensing Hotterdam

The Hotterdam research project expresses its gratitude for being able to use the results of one of the 3TU.Bouw Lighthouse Projects, which was made possible by the 3TU.Federation: Sensing Hotterdam. Sensing Hotterdam is a joint TU Delft and Eindhoven University of Technology project in which Frank van der Hoeven, Alex Wandl and Bert Blocken took part.

Sources

In the Hotterdam research project, we used the following literature, websites and data sources.

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Data sources

GIS data in relation to use of space was obtained from the Rotterdam city council, including data derived from the TOP 10 Rotterdam and the Current Dutch El-evation 2 (AHN-2).

The satellite images used in this study come from NASA. The Landsat 5 and 8 images were downloaded from USGS's Earth Explorer website: http://earthexplorer.usgs.gov/

Hotterdam illustrates the heat related problems in a specific city in order to outline the links between the climate and the built environment. We do so on the basis of the realisation that the climate within a city behaves differently to outside, while the urban climate plays a key part in the well-being of the city's residents – Rotterdam in this case.

The objective of the Hotterdam research project is to gain a better understanding of urban heat in Rotterdam, and to use this as a basis for explaining the links between the health of the city's population and the features of its physical spaces that make it more or rather less warm.

This information will hopefully make the city of Rotterdam and its inhabitants more aware of and less susceptible to the health effects of heat waves.
The insights into the urban heat island that were gained in this project are relevant for other cities in Holland (Amsterdam, The Hague) and abroad.