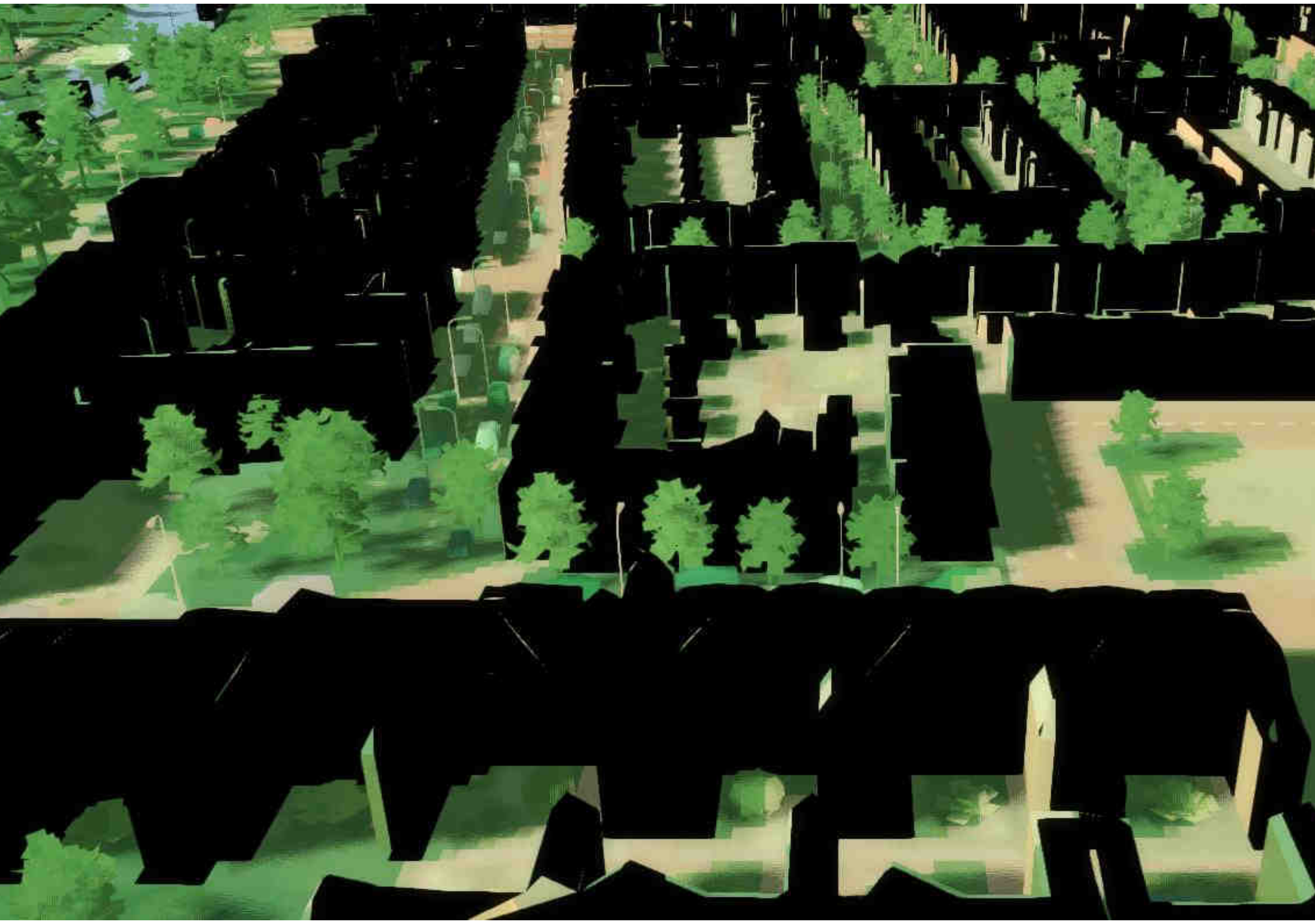
The Most Effective Way of Planting Trees to Reduce Heat Stress

A case study for the *Rivierenwijk* in *Utrecht* at August 8, 2020 using the *Tygron Geodesign Platform*



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Introduction

Since 1901, 2020 has been the hottest year in the Netherlands (Copernicus, 2020; KNMI, 2021) (figure 1). Part of this year, was a heat wave of 13 days (from August 5 to August 17). The heat wave had 9 tropical days (temperature 25,0 °C or higher). The highest temperature was measured at August 8 2020, with a maximum temperature of 34.6 °C (KNMI, 2020).

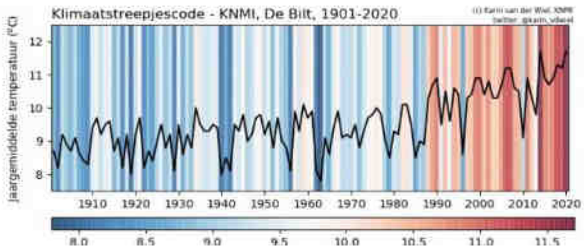


Figure 1 Average temperature per year, measured for De Bilt (KNMI, 2021).

Heat waves such as in 2020 will occur more frequently in the future, as result of climate change. Heat stress, resulting from these heat waves can cause a wide range of problems, such as an increase in energy consumption and a decrease of water quality. But also health related illnesses and an increase in mortality can be the result of heat stress (EPA, 2019). In cities the heat stress problems will be aggravated because of the Urban Heat Island effect (UHI). The UHI is the phenomena that the urban environment is much hotter compared to its rural surrounding (figure 2). The main causes for this phenomena are; the absorption of solar radiation by the urban infrastructure, and the relatively low wind speed in urban areas (EPA, 2019; RIVM, 2019).

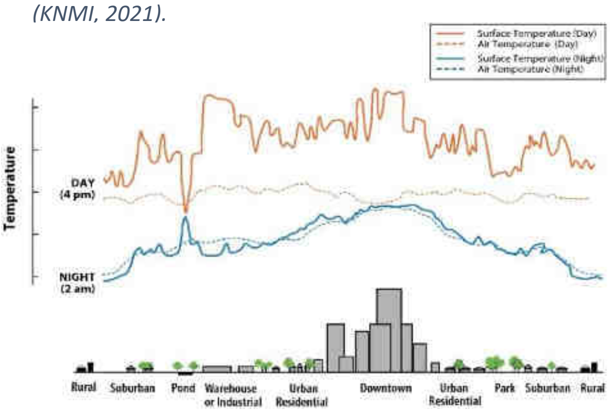


Figure 2 Urban Heat Island effect (EPA, 2019).

An example of a city in the Netherlands which has to deal with an increase in heat stress is Utrecht. Within Utrecht one of the areas confronted with heat stress is the Rivierenwijk (Hupscher, 2019). This area includes a high density of middle class homes, with limited green spaces in between (*Tygron Geodesign Platform*, 2020) (figure 3). This area will serve as study area for this research. More information about this location will follow in the methodology

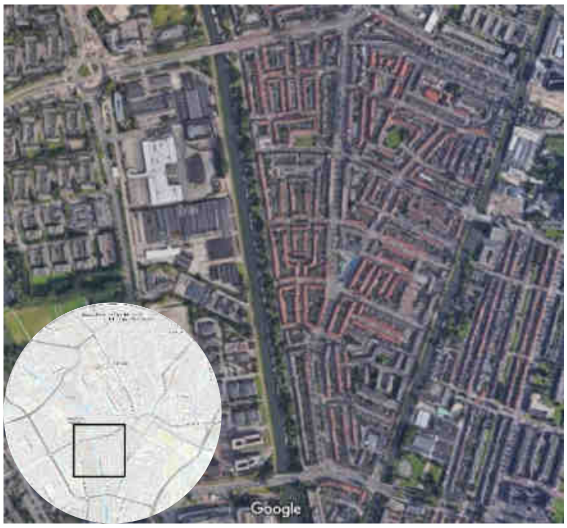


Figure 3 The Rivierenwijk in Utrecht (Google maps 2021, ArcGIS Pro, 2021)

For measurements on the heat stress in cities the physiologically equivalent temperature (PET or 'gevoelstemperatuur') is often used. This is done because the air temperature alone does not describe the thermal comfort people experience in certain places. In addition to the air temperature, the PET is influenced by the humidity, the wind and radiation (RIVM, 2019) (figure 4).

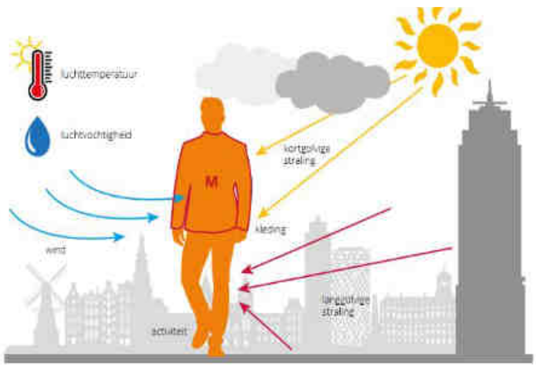


Figure 4 A schematic representation of the factors influencing the PET (HvA, 2020).

In a recent report (May 2020); '*De Hittebestendige Stad*', three clear guidelines are provided for identifying the most important locations where intervention is needed to reduce heat stress (HvA, 2020). Two of the guidelines focus on the PET. These two guidelines will also be used for this research. These guidelines are:

1. Every household should be close to a 'cool place' (within 300 meters, equivalent to 5 min walking with 4 km/h)

2. The main walking routes should have enough shadow (>40%) for the hottest times of the day.

Other requirements for these guidelines, for example, the definition of a 'cool place', will be discussed in the methodology.

Using trees and vegetation are the most frequently used measures to decrease heat stress in cities. Not only do trees provide shadow, they also cool the environment by evaporation (Venter et al., 2020; EPA, 2019). However, as will become clear from this research, trees can also have an adverse effect on the PET, by blocking the wind (HvA, 2020). There are different ways trees are being placed in urban areas. Considering the often limited amount of space, trees are often either placed along roads, or placed in groups, such as in parks (Tan et al., 2017; Brown et al, 2015). However, the effects of these different implementation types on the heat stress is still largely unknown. Therefore, the research questions for this research are as follows.

Research questions

What is the most effective way to place trees in Utrecht to reduce the PET during a heat wave?

- What is the effect of trees placed in lanes along roads, on the reduction of the PET during a heat wave, in Utrecht?
- What is the effect of trees placed in groups, on the reduction of the PET during a heat wave, in Utrecht?

In answering these questions, no strict numbers will be used. Instead, several different maps will be developed to analyse the impact of the two different measures on the guidelines described in the report: '*De Hittebestendige Stad'* (HvA, 2020). The maps will be made with the *DPRA* (Delta Plan for Spatial Adaptation) *Heat Stress Module* of the *Tygron Geodesign Platform*. For answering the research questions, two time series (14:00 and 17:00) will be used. Both for the hottest day of 2020; August 8. Further details on the set-up of the research project will follow in the methodology. Figure 5 shows a schematic overview of the research project.

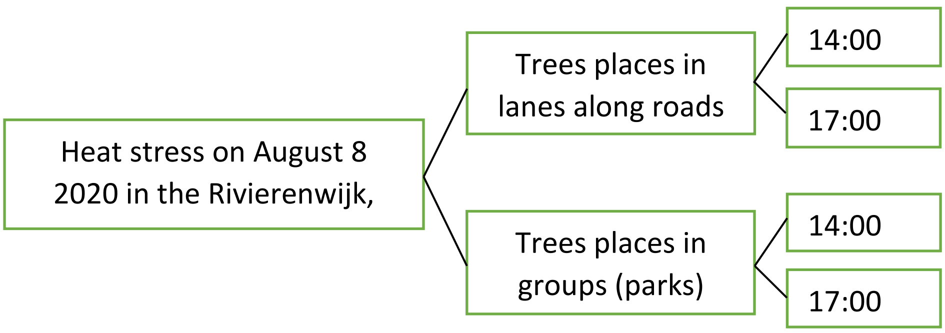


Figure 5 Overview of the research project.

Methodology

The Tygron Geodesign Platform

As described in the introduction, for this research project the *Tygron Geodesign Platform* will be used. This platform is developed by the Dutch software company Tygron. The *Tygron Geodesign Platform* automatically connects to open datasets (figure 6). Geo Data (vector and raster data) from these open datasets is used for creating high detailed geographical 3D maps (Tygron Support, 2019). In these maps future designs can be made. This includes the construction of trees, buildings and more. Combined with data from, for example the KNMI, overlays (e.g. the *Water Overlay* and the *Heat Stress Overlay*) can be constructed to directly see the effects of these designs (Tygron, n.d.).

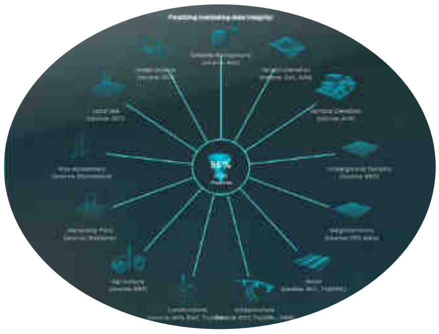


Figure 6 Loading display of the Tygron Geodesign Platform, including the used open data sources (Tygron Geodesign Platform, 2020).

Within the *Heat Stress Overlay*, two modules are available. The first 'old' module is called *UNESCO*. This module is rather simplistic. Recently, Tygron has developed a new module, called *DPRA Heat Module*, which is much more accurate and detailed, and will therefore be used for this research. (Tygron, 2020a) (Tygron Support, 2020b).

The DPRA Heat Module

The *DPRA Heat Stress Module* is developed to be in accordance with the *2019 DPRA Heat Stress Report (Ontwikkeling Standaard Stresstest Hitte)* (RIVM, 2019). This report, which was made in collaboration with *Wageningen University and Research*, is developed to provide a standard in measuring the heat stress for municipalities (Tygron, 2020a). An important part includes the PET measurements. The required input data and calculations for this PET measurement standard are shown below, in a flowchart.

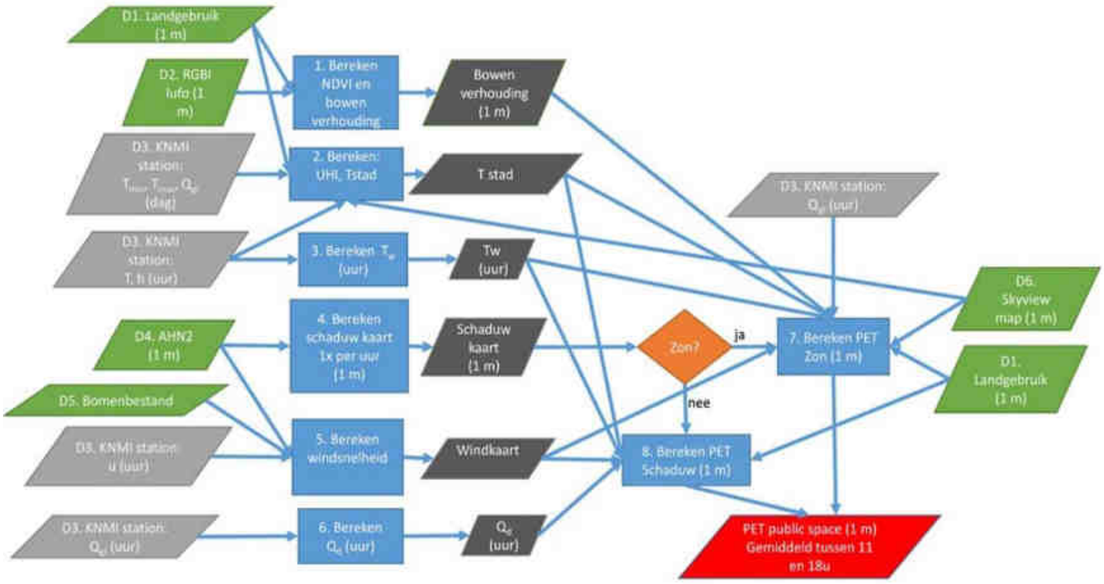


Figure 7 Flowchart of the data sources (D) and the calculations (blue) to measure the PET (RIVM, 2019).

Since the *DPRA Heat Stress Module* of the *Tygron Geodesign Platform* is developed in accordance with the report, the module looks very similar to the flowchart in figure 7. A schematic drawing of the *DPRA Heat Stress Module* within the Tygron Platform has been shown in figure 8 (Tygron Support, 2020b).

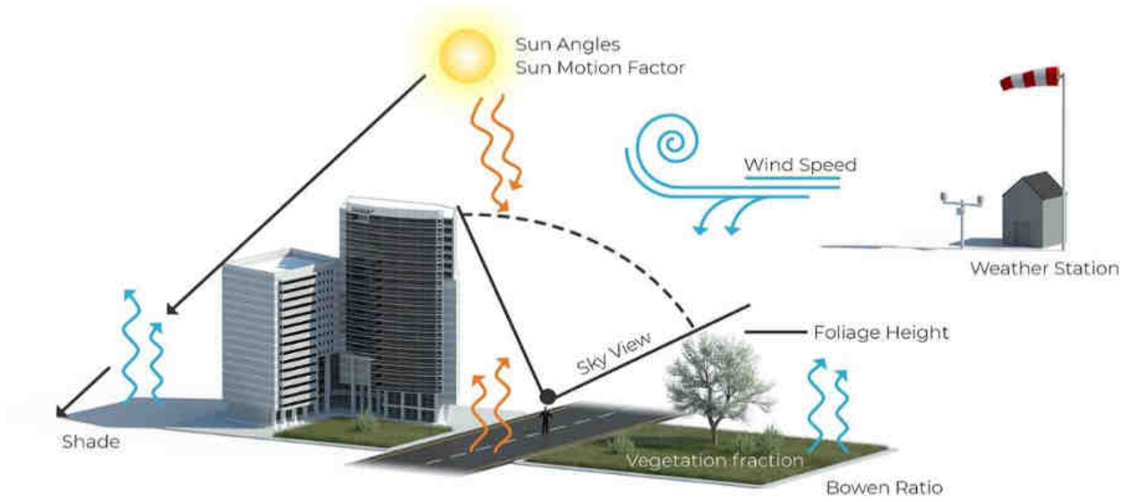


Figure 8 Inputs used for the DPRA Heat Stress Module of the Tygron Platform (Tygron, 2019a).

The PET within the DPRA Heat Module

The following factors influence the Physiological Equivalent Temperature (PET) for locations directly in the sun, as described by the Tygron Support page:

- *The atmospheric temperature, calculated by the atmospheric temperature formula;*
- *The hourly global radiation from the sun, supplied as weather station data;*
- *The wind speed at 1.2 meter above ground, calculate by the wind speed calculation model;*
- *The Wet-Bulb temperature, calculated by the Wet Bulb temperature formula;*
- *The sun altitude, calculated automatically based on the project area, date and time of day;*
- *The Bowen ratio, an attribute obtained from Buildings or Terrain on that specific location;*
- *The sky view factor, calculated by the sky view factor calculation model.*

(Tygron Support, 2019, p1)

For places without direct solar radiation (e.g. places in the shadow and at night), the sun altitude and Bowen ratio are not used. In addition to the PET sun, the diffuse radiation, calculated by the diffuse radiation formula is used. This formula is based on the sun radiation at day time and the atmospheric transmittance factor (Tygron Support, 2019)

Configuration and data collection DPRA Heat Module

Within the *Tygron Geodesign Platform*, settings and (weather) input data, for the *DPRA Heat Module*, can be changed with the *Heat Overlay Configuration Wizard*. Most of the standard settings in the wizard are not sufficient for this research and should therefore be changed:

- First of all, the grid cell size should be set to 0.5 meters to get the most detailed result.
- Secondly, the date of August 8, 2020 should be inserted.
  The time frame 08:00 to 20:00 will be used, as it gives a good indication for the PET during day time. This whole time frame will be used for animations in an additional Storymap. More information about this Storymap is available at the end of this paper.
  In this report the hottest hour, 14:00 and a later hour, 17:00 (when the neighbourhood was cooled down), will be used.

- Finally, within the Tygron program, the perspective of the municipality is used. The ownership of the municipality is set to the whole area. This makes it possible to make changes (e.g. adding trees) in the whole area.

There are many meteorological and spatial factors which are taken into account, by the *DPRA Heat Module*. In the following part all of these factors are summed up, with information about the data sources used for August 8, 2020 (Tygron, 2020a; Tygron, 2020c).

Meteorological factors:

- **Sun angles, altitude and azimuth**
  These factors are all calculated by the *Tygron Geodesign Platform* itself, based on the date, the time of the day and the project location. The date chosen for this research is August 8, 2020. The location is the main part of *Rivierenwijk*, a part of *Transwijk* and a small part of *Dichterswijk*, in Utrecht. Sun daily motion is automatically calculated, based on the sunrise/sunset table, described in the DPRA Heat Stress Report (Tygron, 2019).

- **Air temperatures (hourly, daily minimum and maximum)**
  Air temperatures are all measured at a nearby weather station at 1,5 m height. In this case the closest KNMI weather station is in *De Bilt* (KNMI, n.d.). The hourly, daily minimum and maximum temperature all can be directly used from this weather station (Tygron, 2020c).

- **Global radiation (hourly and average)**
  The hourly and daily average radiation have to be calculated, from the KNMI weather data, using Excel. The formula used is:

$$radiation_{hourly} = \frac{Q_t + Q_{t+1}}{2} \cdot \frac{10000}{3600}$$

(Tygron Support, 2019b)

The result of these calculations have been shown in table 1. The daily average radiation, which describes the average of the amount of sun radiation per hour, per square meter for this day, is calculated using this formula:

$$radiation_{daily} = \frac{\sum_{t=n}^{m} Q_t}{m-n+1} \cdot 10000/3600,$$

(Tygron Support, 2020d)

In this formula n is the first full hour with sun radiation (07:00 for August 8) and m is the last full hour with sun radiation (21:00 for August 8).

The result of the daily average radiation is: 402.2 W/m^2.

Table 1 Result of hourly radiation calculations.

Time (Netherlands)	Radiation (hourly; W/m^2)
08:00	176.39
09:00	329.17
10:00	481.94
11:00	605.56
12:00	700.00
13:00	759.72
14:00	759.72
15:00	712.50
16:00	588.89
17:00	380.56
18:00	241.67
19:00	152.78
20:00	59.72

- **Humidity (hourly)**
  Similar to the air temperatures, the hourly humidity (in percentages) is measured at a KNMI weather station at 1.5 meter from the ground. Hourly humidity can directly be used from the KNMI weather station data as well (Tygron Support, 2020c).

- **Wind speeds (hourly and daily average)**
  The hourly and daily average wind speeds are both measured at a weather station, 10 meters above the ground. For this, KNMI weather station data can directly be used as well. For both the hourly as the daily average wind speed, the values of the KNMI weather station should be calculated to m/s (divide wind speed data from weather station with 10) (Tygron Support, 2020c).

- **Wind direction (hourly)**
  The hourly wind direction is defined as the mean wind direction from the last 10 minutes of the last hour. These values (in degrees) can be used directly from KNMI weather station data (Tygron Support, 2020c).

The daily result of the calculations in the *Heat Overlay Configuration Wizard* are shown in figure 9.

Date	Daily Min. Temperature (°C)	Daily Max. Temperature (°C)	Daily Avg. Radiation (W / m2)	Daily Avg. Wind Speed (m)
08 Aug 2020	20,6	33,9	402,2	2,2

Figure 9 The daily values for the Heat Overlay Configuration Wizard, for August 8, 2020

The result of the hourly values in the *Heat Overlay Configuration Wizard* are shown in figure 10.

Hour of day	Sun Daily Motion	Humidity (%)	Sun Radiation (W / m2)	Temperature (°C)	Wind Speed (m/s)	Wind Direction (°)
8	0,057	75	176,4	20,6	0	0
9	0	55	329,2	25,7	1	130
10	-0,02	45	481,9	28,9	1	150
11	-0,005	31	605,6	31,4	1	160
12	0,013	33	700	32,7	1	360
13	0,037	26	759,7	33,4	2	70
14	0,063	29	759,7	33,9	2	310
15	0,09	30	712,5	33,7	3	310
16	0,15	26	588,9	33,7	4	50
17	0,222	31	380,6	32,6	4	30
18	0,318	32	241,7	31,9	4	20
19	0,45	32	152,8	31,3	4	30
20	0,6	37	59,7	30	3	20

Figure 10 The hourly values for the Heat Overlay Configuration Wizard, for August 8, 2020.

Spatial factors

- **Land use, vegetation fraction and rate of evaporation (Bowen ratio).**
  To determine the land use, including for example the places with buildings, trees, and parks, the *Tygron Geodesign Platform* uses geo-data (vector and raster data) from open datasets (e.g. BAG, BGT) (Tygron Support, 2019; Tygron Support, 2020e). These datasets include the location of vegetation. The *DPRA Heat Module* calculates with this information the vegetation fraction and the evaporation rate. The Bowen ratio describes the rate of heat transfer for a surface that has moisture as a factor. The wetter the surface, the lower the Bowen ratio. Since the Bowen ratio is a property of a surface, the value can be based on the land use (Tygron, 2020c). Using land use data within open data sources, the *DPRA Heat Module* calculates the Bowen ratio (Tygron Support 2020e).

- **Terrain, foliage and building heights**
  The terrain and building height both influence the heat stress. Within the *Tygron Geodesign Platform* the terrain is loaded in from the BGT. The Building heights are loaded in from the BAG (Tygron Support, 2020e). The foliage crown factor, within the *DPRA Heat Module* is described as: ''The ratio between the height of tree trunks and the radius of the foliage of the tree'' (Tygron Support, 2020f, p1). The values for the foliage crown factor are used from open data as well (Tygron Support, 2020f).

Project location

The study area includes the main part of the *Rivierenwijk*, a part of *Transwijk* and a small part of *Dichterswijk*, in Utrecht. This area has been chosen, because of the variety of land use. This variety includes a mix of middle class homes, industrial area, a park, part of a construction site and a small river (Tygron Geodesign Platform, 2020). This mix will gives an indication for the city Utrecht as a whole, and can give some insights useful for cities in general. The study area is exactly 1000m^2 (maximum based on the Tygron education licence).

Tree Placements

Trees already present in the area.

The open data set BGT, includes the exact locations of trees, already present in the area. The AHN3 is used to determine the height of these trees. Normally, the crown factor, which determines the width of the trees is calculated with this data, and data about the tree types (Tygron, 2020a). However, since there is no information about the exact tree types, all trees in the area have been classified as standard broad-leaved tree by the Tygron Platform. The crown factor of this standard type is 0.75. This tree type will also be used when adding new trees within the new designs.

New trees

Lanes along roads

Along several roads in the study area already trees are present. For this situation, only trees are added along roads which had no trees previously. Road crossings are excluded.
The total area where trees have been planted is 13282m^2 (calculated by the Tygron Platform itself). This is equal to approximately 240 trees.

Grouped blocks

For the second situation trees where 'planted' in several blocks, similar to parks. The blocks where all placed in 'empty' spaces, such as open squares or fallow land. To be able to accurately compare the two situations, a similar size of 13000 m^2 has been used. Considering the available space this resulted in 7 area's of 1000m^2 and 2 of 3000m^2 (figure 11).

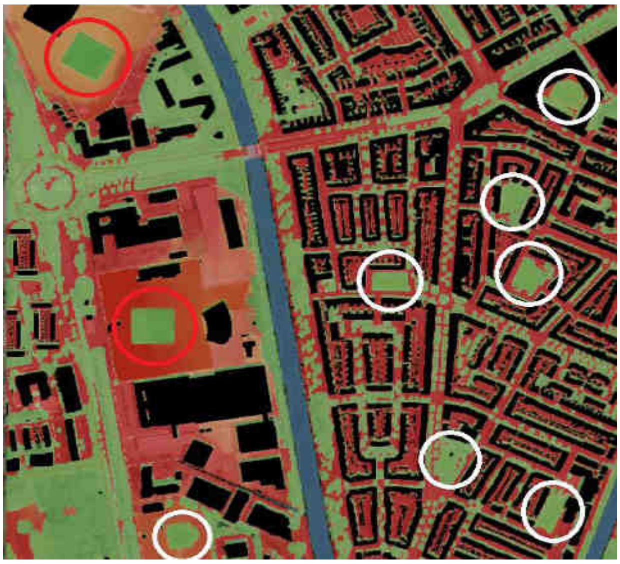


Figure 11 Locations of the different blocks placed for the second design. The white circles show the location of the smaller parks (1000 m^2). The red circles show the location of the bigger parks (3000 m^2)

Analysis PET (Spatial data handling and visualization approach)

As described in the introduction, the report; *'De Hittebestendige Stad'*, provides two guidelines important for the PET. These are defined as; *percentage of shadow for walking areas,* and *distance to a cool place.*

Percentage of shadow for walking areas

The report describes in this guideline that a minimum of 40% shadow at important walking routes in cities is required to reduce heat stress. 30% or more shadow is required for neighbourhoods (HvA, 2020). For this research the exact percentages of shadow will not be calculated. Instead maps will be made, with the Tygron Platform, to give insight in the overall effect of the trees for this guideline. These maps will then be compared to the original situation. ArcGIS Pro will be used for the final layout.

Distance to cool place

The second guideline is that a cool place should be within 300 meters for every household. The guidelines for what a 'cool place' is, are defined as follows in the report (HvA, 2020):

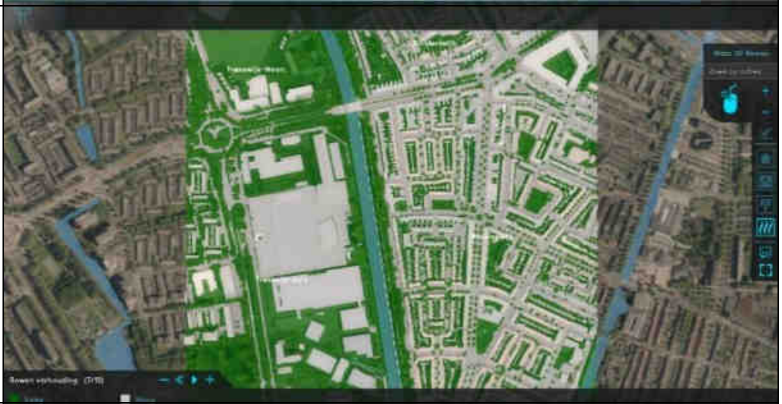
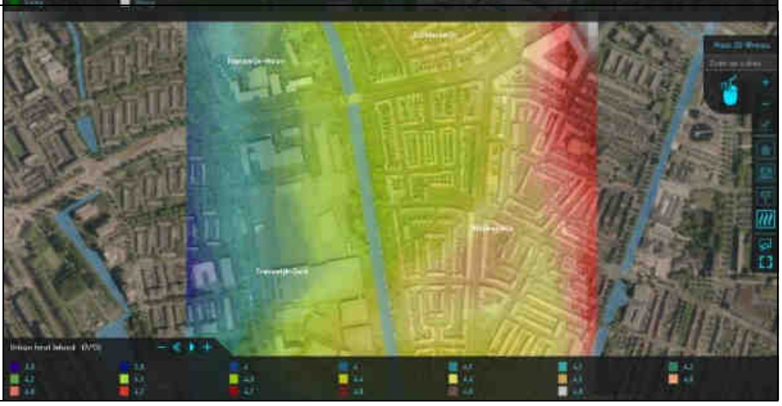
1. A 'cool place' should be an attractive place with seating opportunities in the shadow and attractive greenery with a feeling of peace, cosiness and safety
2. Any surface that remains below the perceived temperature of 35 °C PET during an average warm summer day may be part of a cool place. A size of 200 m^2 is large enough for cooling, but a larger area is usually required for a pleasant place to stay.
3. Swimming areas and fountains (which can be entered) in a cool place provide extra cooling and are much appreciated.

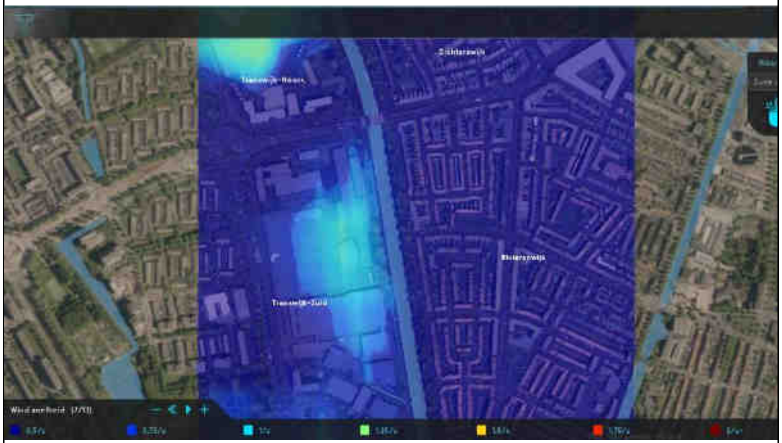
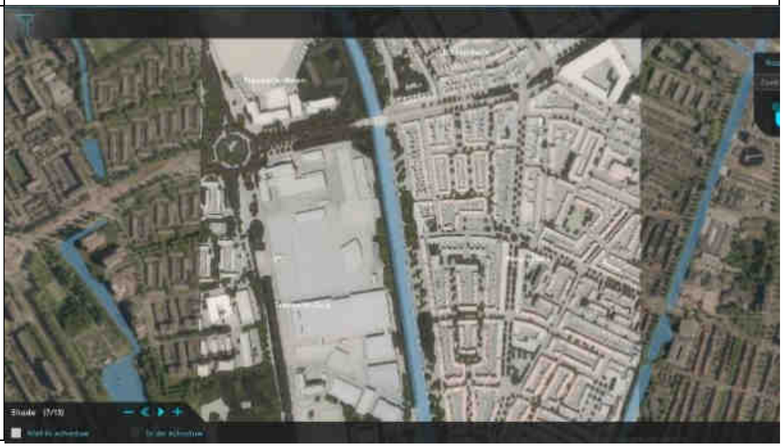
To determine the 'cool places' in the area, mainly the second guideline, describing the minimum size of 200 m^2 will be used.

Results

Submaps

The *DPRA Heat Module* within the Tygron Platform has the option to show the different submaps (e.g. wind speed and UHI) leading to the main PET map. The submaps are useful for giving an indication why a certain part of the area is hotter or cooler than its surrounding (Tygron, 2020a). To get a better insight and explain small differences of the final PET, the most important submaps for the original situation have been shown below. The time 14:00 (frame 7) has been used for the different maps, since this time had the hottest temperature, measured in the Bilt (KNMI, 2020). Additional information, about other time frames, is provided at the left.

The sky view factor (From 0 to 100 % visibility) Note: the sky view factor does not change over the day.	
The Bowen ratio (Green areas have a low Bowen ratio, 0.4 / White areas have a high Bowen ratio, 3.0) Note: the Bowen ratio does not change over the day.	
The Urban Heat Island effect (UHI) (in °C, 'additional' temperature) Note: the variation of the UHI over the day is very minor.	

The wind speed (in m/s) Note: there is a significant variation of wind speed over the day. From 08:00 in the morning onwards, the wind speed becomes higher and higher. However, this only happens for the (open) areas, coloured light blue in the image at the right. The highest wind speed is at frame 13 (19:00, up to 2.1 m/s). The wind speed at 20:00 is somewhat lower.	
Shadow map (Black areas are in the shadow, white areas are not) Note: there is a significant variation of shadow over the day, as the sun turns.	

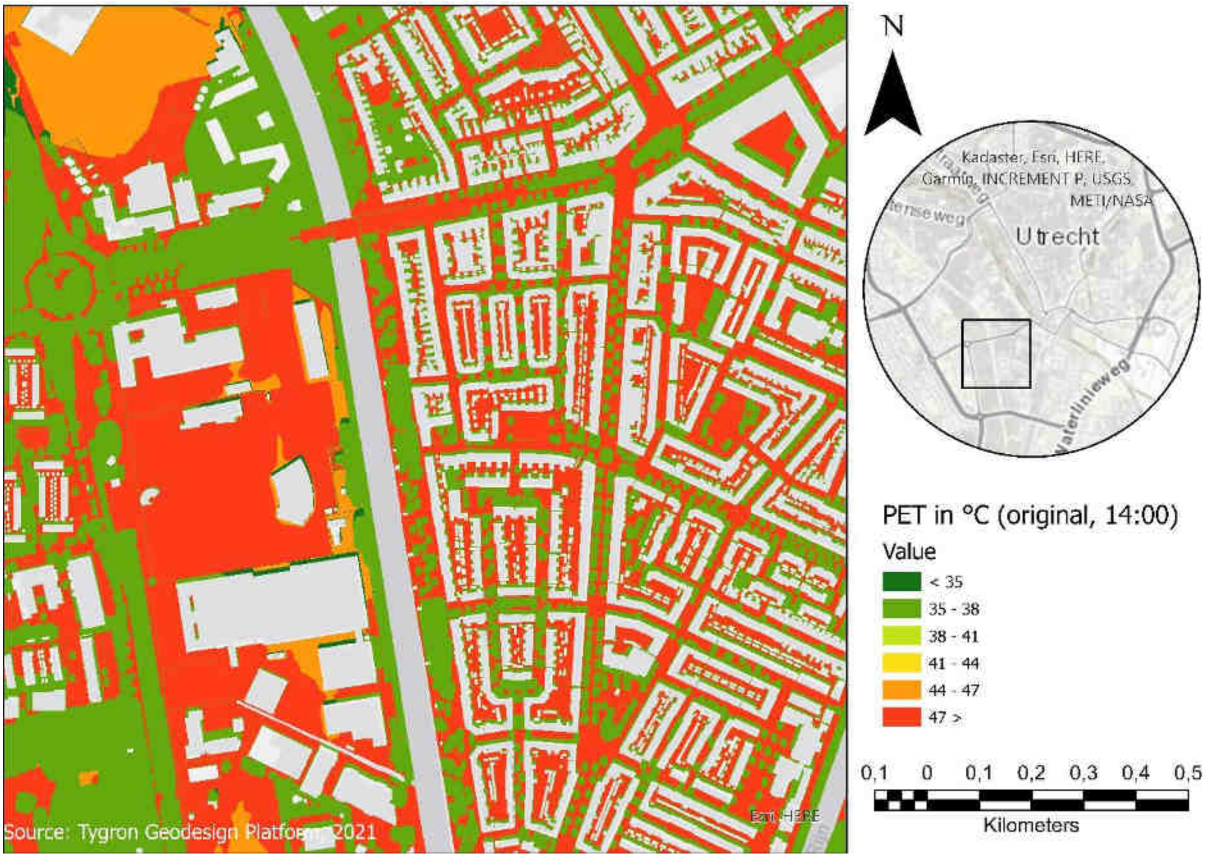
Results heat stress analysis

For both the time 14:00 as the time 17:00, the following sequence for presenting the results will be used:

1. The first PET heat stress map will show the original, current situation.
2. The second map shows the PET heat stress map for the situation with trees along the road, as described for research (sub)question one.
3. The third map shows the PET heat stress map for the situation with trees places in groups, as described for research (sub)question two.
4. The last two maps will show the difference between the original situation and the situation after applying the two measures. These maps will be used for comparison. By showing the improvement or worsening of the PET, these maps can help answering the main research question.

In addition, for the first three maps, a close-up (3D) image from the Tygron Platform is included, to provide some more detailed information on the heat stress.

The PET for the current situation in the Rivierenwijk, at 14:00



The actual overall heat stress of August 8 at 14:00 in the Rivierenwijk is very high. The PET goes in some places up to 50 °C. As figure 12 shows, the places where trees are present, are the most cool. However, the PET below these trees is often still between 35 °C and 38°C .

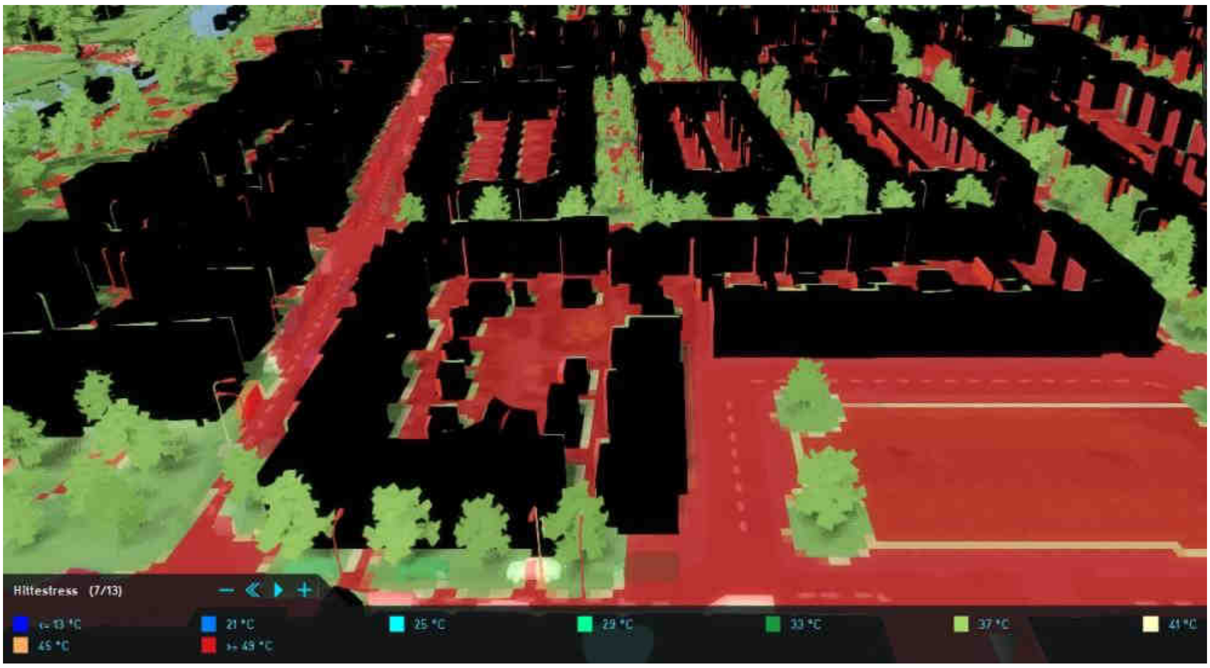
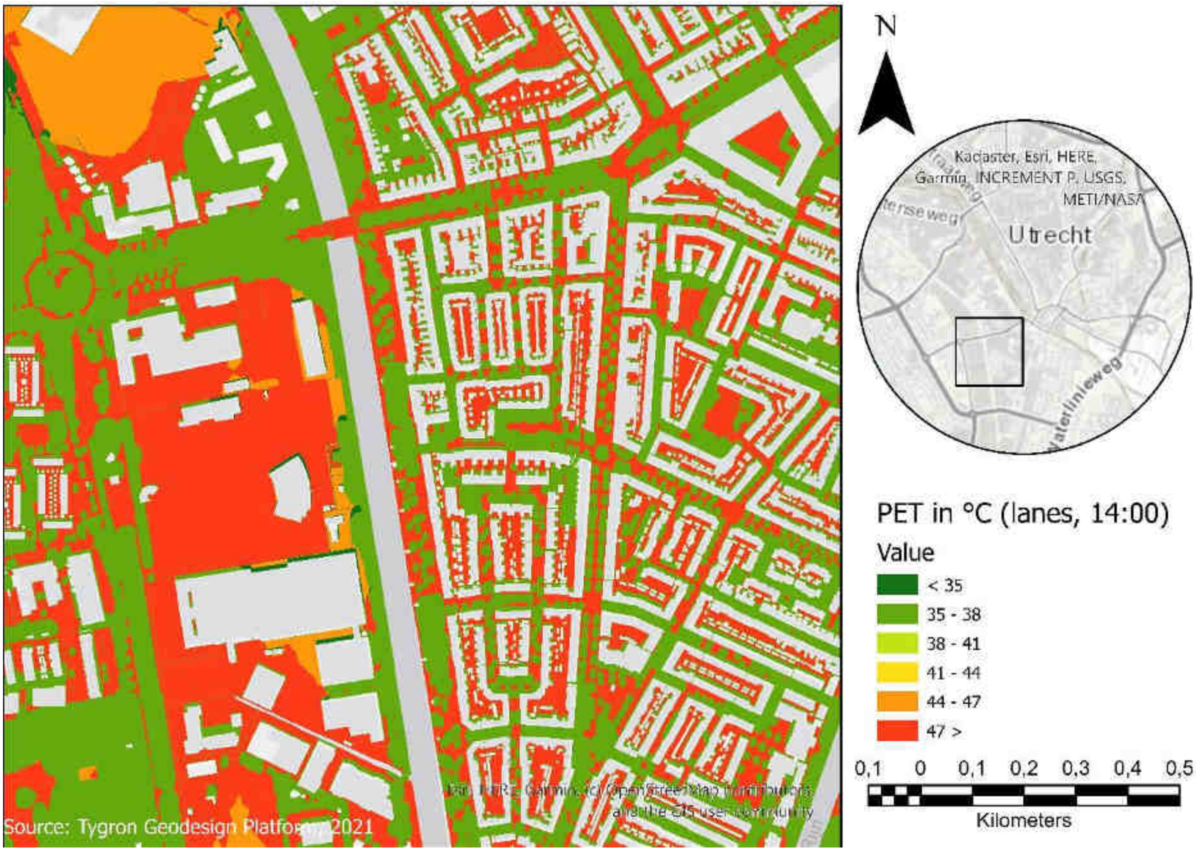


Figure 12 A close-up image at 14:00, with the DPRA Heat Module, for the current situation in the Rivierenwijk (Tygron Geodesign Platform, 2020).

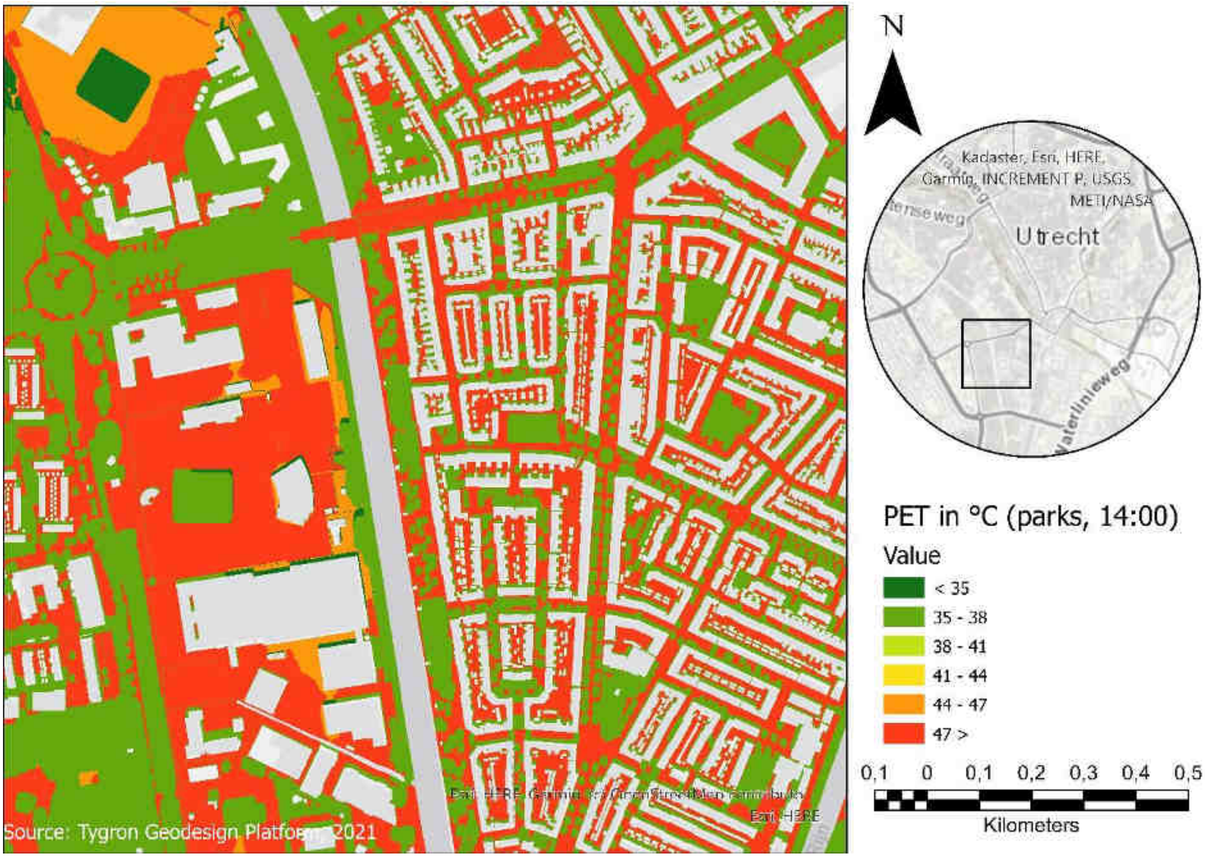
The PET for the lane situation in the Rivierenwijk, at 14:00



The effect of planting trees around roads, on the heat stress of 8 August at 14:00 is limited to the place where these trees have been planted. Many roads with trees added, in the Rivierenwijk neighbourhood are now cooler compared to the original situation. However, places somewhat further away from these trees, for example, the backyards and the industrial area have no cooling effect from these trees (figure 13).

Figure 13 A close-up image at 14:00, with the DPRA Heat Module, for the situation with trees in lanes along the road, in the Rivierenwijk. The red circle shows a street with trees, which had no trees previously (Tygron Geodesign Platform, 2020).

The PET for the grouped trees measure in the Rivierenwijk, at 14:00



Similar to the roadside tree situation, the effect of planting trees in several blocks, on the heat stress of August 8 at 14:00 is limited to the place where these trees are 'planted'. The places where these groups of trees are added show a decrease in heat stress. However, the surroundings of these groups show no change (figure 14).

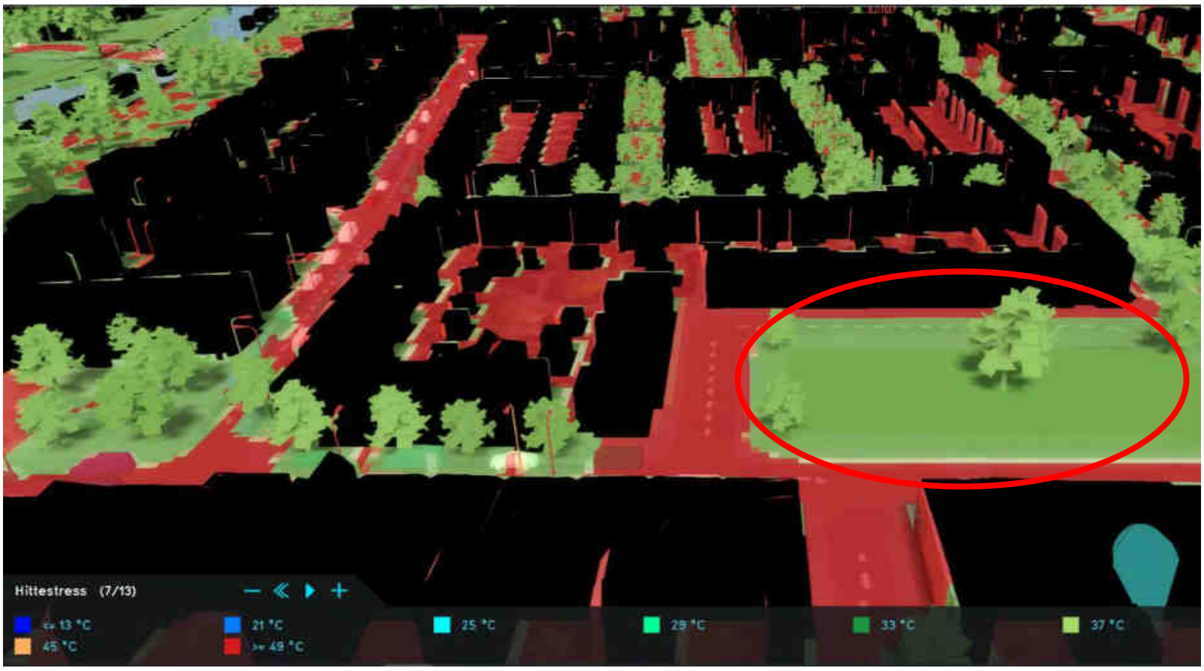


Figure 14 A close-up image at 14:00, with the DPRA Heat Module, for the situation with trees placed in groups, in the Rivierenwijk. The red circle shows the area where trees are placed in a group (Tygron Geodesign Platform, 2020).

Comparison for 14:00

To answer the main research question, the two different types will be compared with each other. The maps which are used, show the improvement (green) and worsening (red) of the heat stress (PET). The two guidelines from report '*De Hittebestendige Stad'*, will be used for comparison (HvA, 2020).

The effect of placing trees in lanes along roads on the heat stress

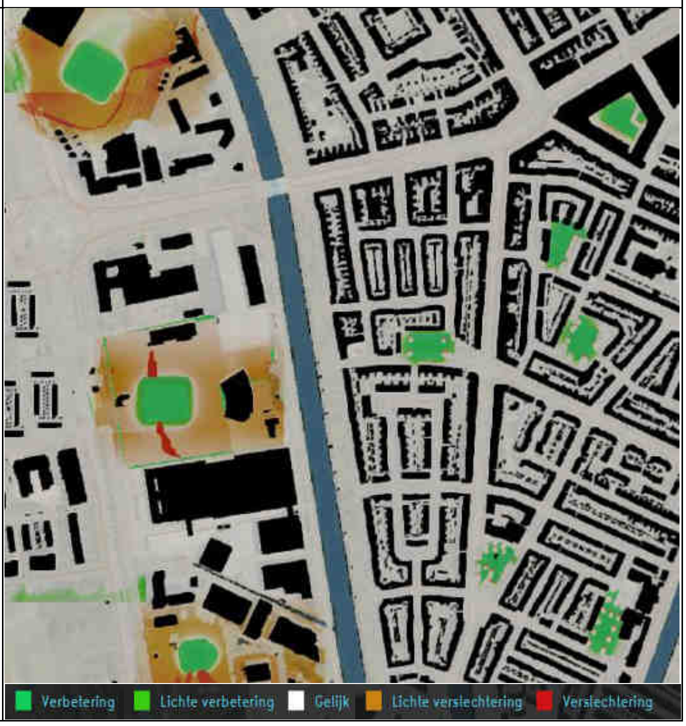
For 14:00, the difference map shows a very high decrease of the heat stress for many areas. For some places, especially the open area in the West of the study area, there is a slight increase of the PET. This is result of the wind being blocked by the trees along the road in the West.

There is an improvement regarding the first guideline of the report. Walking routes, mainly within the neighbourhood of the *Rivierenwijk* have more shadow. Since trees are placed in lanes, no new places which fulfil the requirements of a 'cool place' are created. Therefore, there is no effect of this measure regarding the second guideline.

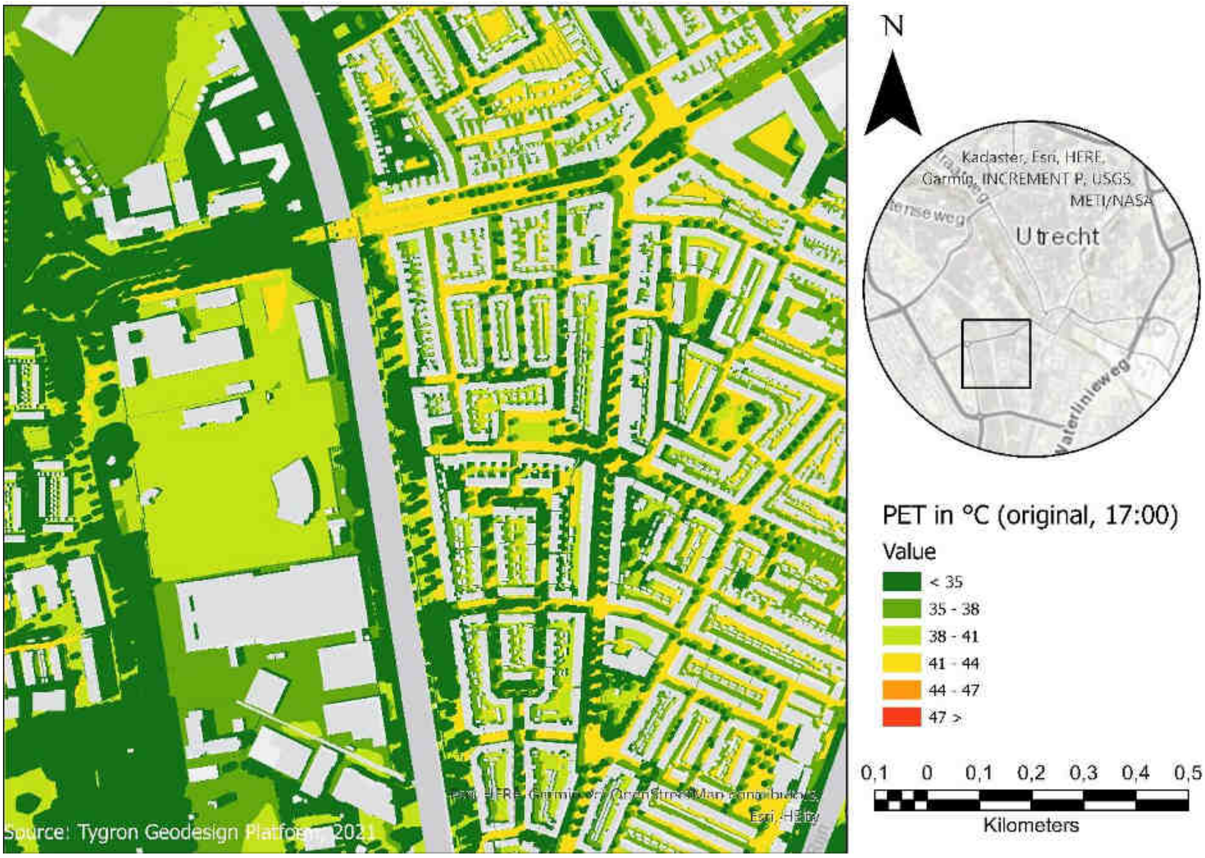
The effect of placing trees in groups on the heat stress

The decrease of the heat stress is very local for the situation of trees placed in groups, at 14:00. The areas West of the small river, around the tree parks, show some increase in the PET, as result of the blocked wind.

The effect of this measure regarding the first guideline is very limited. Walking routes in the *Rivierenwijk* have almost no extra shadow.
However, the effect of this measure for the second guideline is significantly higher. New places are created, which fulfil the requirements to be called a 'cool place' (with the size being bigger than 200m^2 as most important requirement).



The PET for the current situation in the Rivierenwijk, at 17:00



At August 8, 17:00, the actual heat stress has overall decreased in the study area, compared to the hottest time of the day, 14:00. However, the PET is in many places in the Rivierenwijk neighbourhood still between 41 - 44°C, which is rather hot for this time of the day. This is also visible in figure 15. As result of a lower sun, the shadow areas of the trees and buildings are significantly bigger.

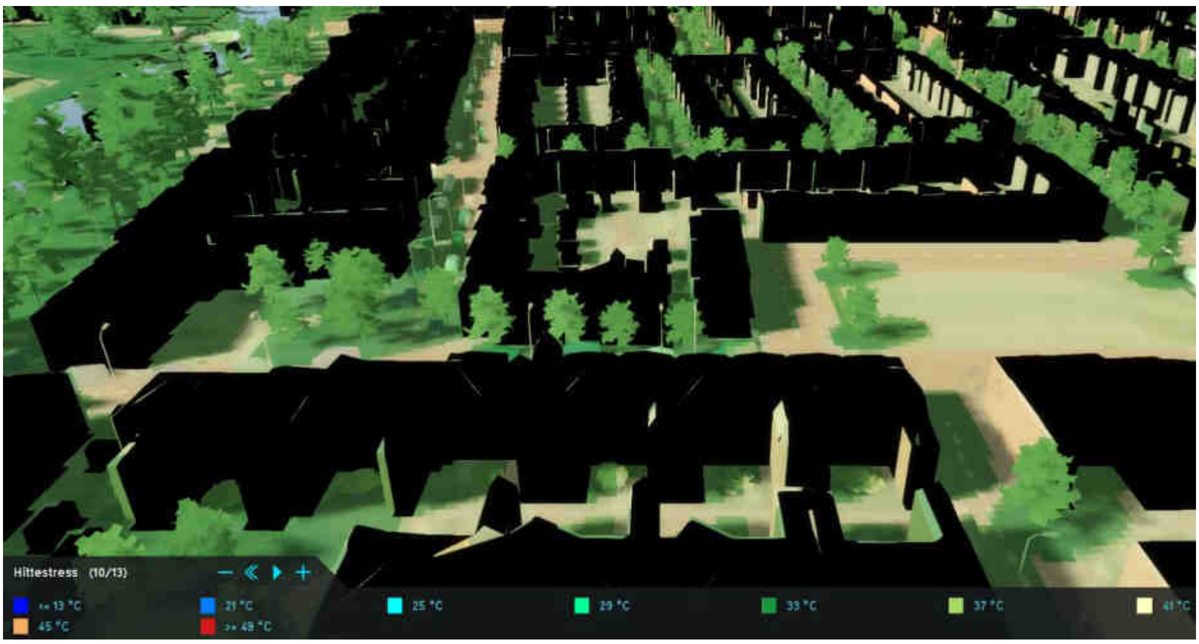
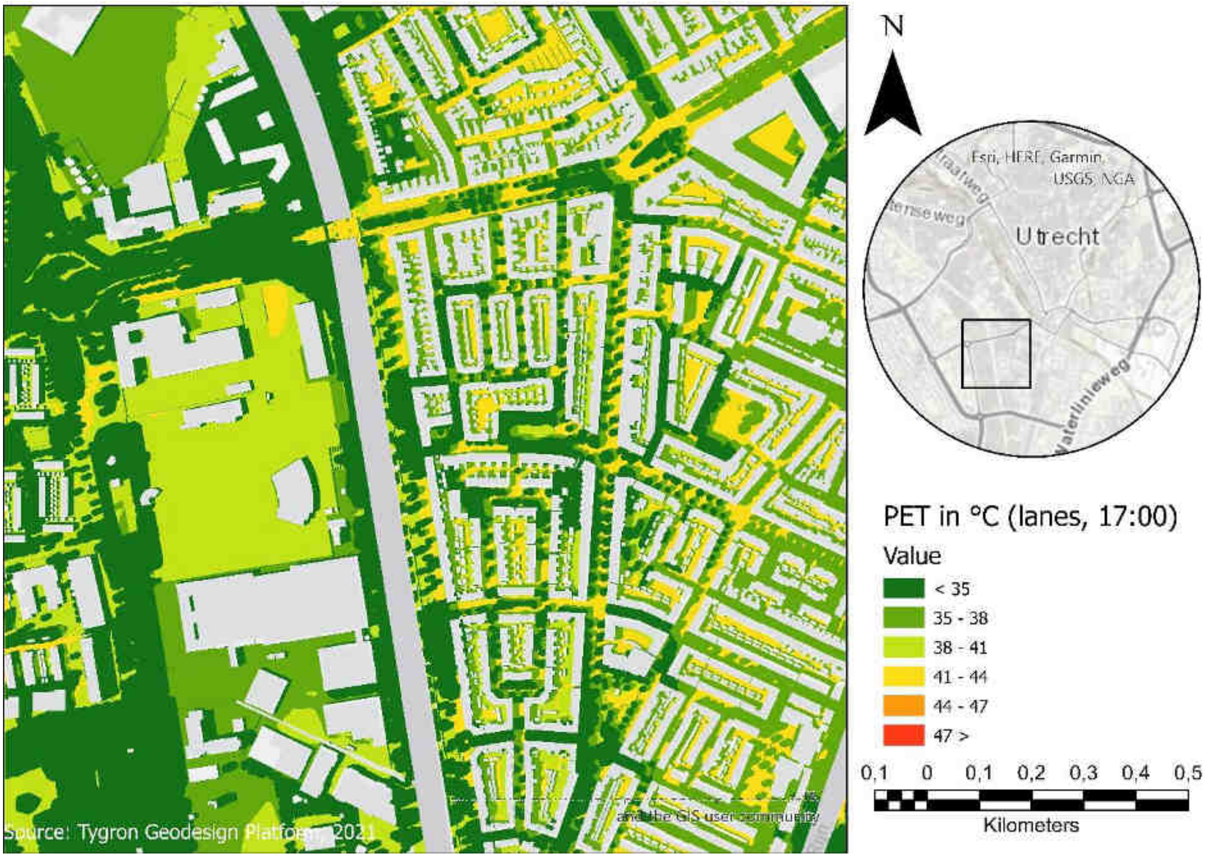


Figure 15 A close-up image at 17:00, with the DPRA Heat Module, for the current situation in the Rivierenwijk (Tygron Geodesign Platform, 2020).

The PET for lane situation in the Rivierenwijk, at 17:00



Similar to the time 14:00, the effect of planting trees in lanes around roads, on the PET at 17:00, is mostly limited to the place where these trees have been added. Since the sun is relatively lower, the shadow space has somewhat increased (figure 16). However, places further away from these trees, for example, the backyards and the industrial area have not much cooling effect from these trees.

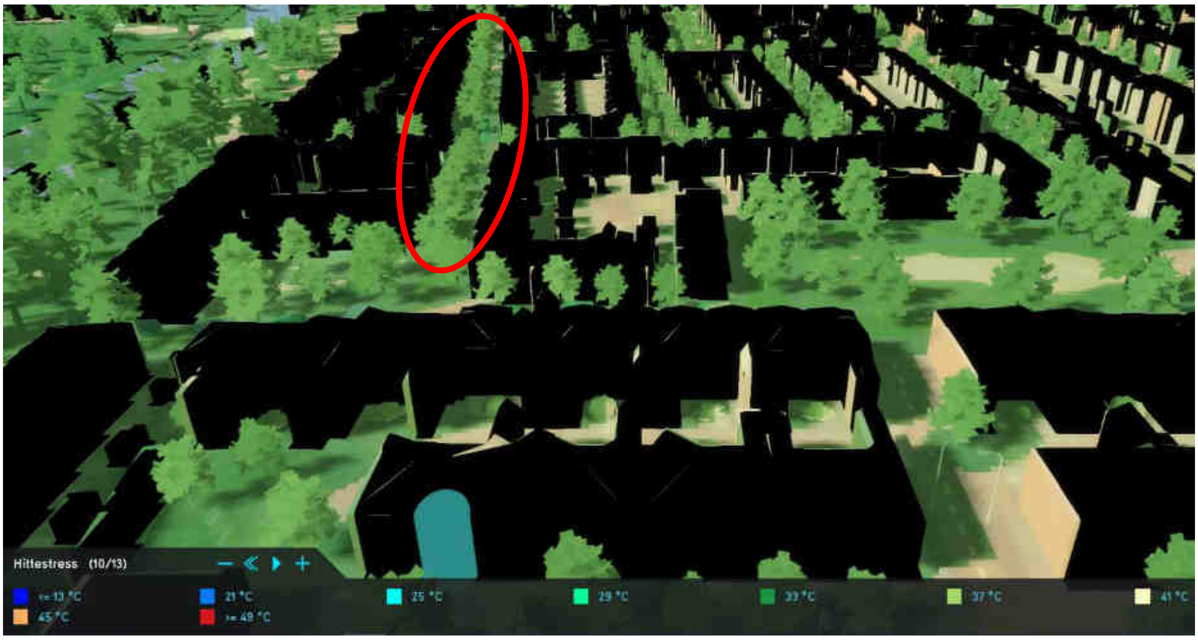
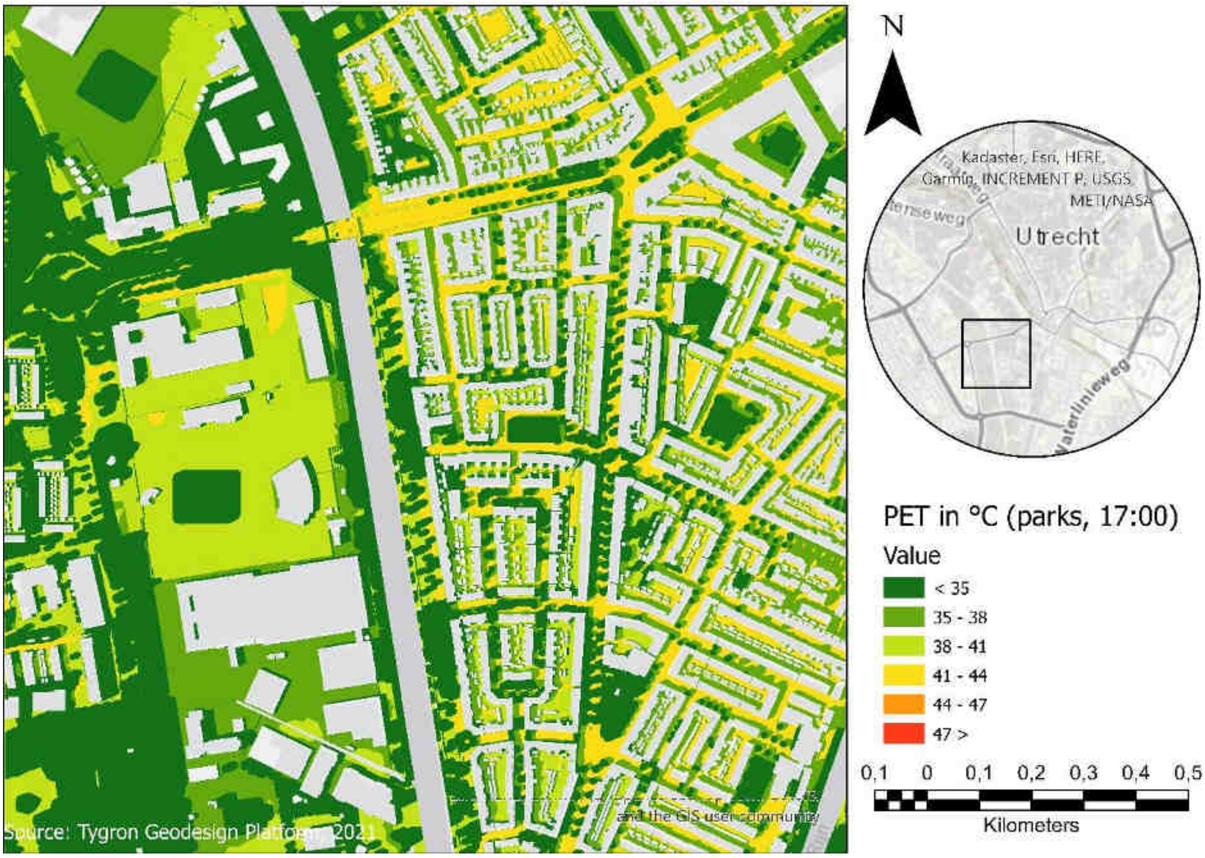


Figure 16 A close-up image at 14:00, with the DPRA Heat Module, for the situation with trees in lanes along the roads, in the Rivierenwijk. The red circle shows a street with trees, which had no trees previously (Tygron Geodesign Platform, 2020).

The PET for the grouped trees measure in the Rivierenwijk, at 17:00



For 17:00, the effect of planting trees in several blocks on the heat stress of August 8 is (similar to 14:00), limited to the place where these trees are planted. The places where the groups of trees are planted show a decrease in the PET. However, the areas around these blocks do not show this decrease (figure 17).

Figure 17 A close-up image at 14:00, with the Heat Overlay, for the situation with trees placed in groups, in the Rivierenwijk. The red circle shows the place where trees are added in a group (Tygron Geodesign Platform, 2020).

Comparison for 17:00

Similar to 14:00, the two different planting methods will be compared with each other for 17:00 as well. The maps which are used show the improvement (green) or worsening (red) of the heat stress (PET). In addition, the two guidelines from report '*De Hittebestendige Stad*', are used (HvA, 2020).

The effect of placing trees in lanes along roads on the heat stress

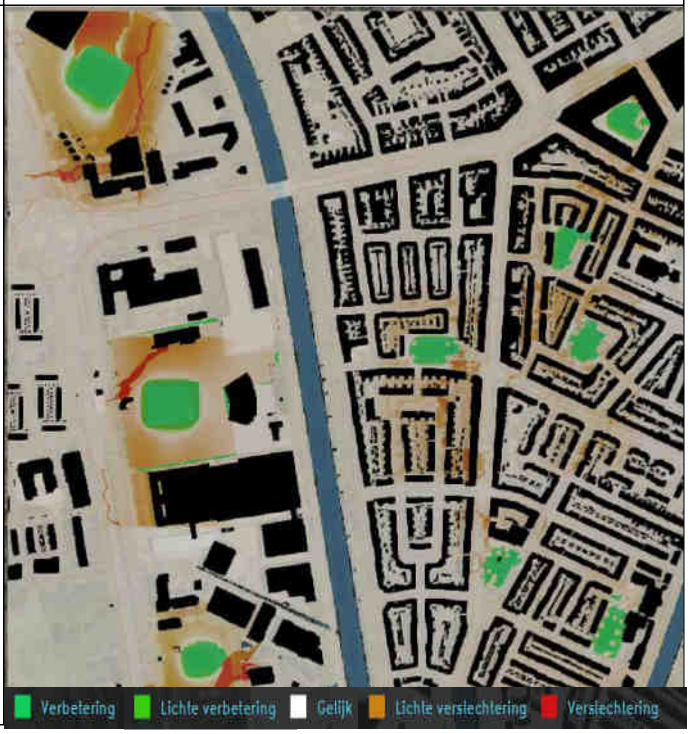
For 17:00, the difference map does only show a high decrease in PET for specific places where new trees were added. Nevertheless, this measure results mainly in an overall increase of the PET for 17:00. Especially in the neighbourhood of the *Rivierenwijk*. Compared to 14:00, the PET resulting from this measure did increase significantly for 17:00.

Since the places with shadow did increase with this measure for 17:00, this could be seen as an improvement for the first guideline of the report.
Since trees are placed in lanes, no new places, which fulfil the requirements of a 'cool place' are created. Therefore there is no effect of this measure regarding the second guideline of the report.

The effect of placing trees in groups on the heat stress

The decrease of the heat stress is very local for the situation of trees placed in groups, for 14:00. Places around the trees placed in groups have a slightly increase in heat stress, compared to the original situation. This effect at 17:00 is very similar to the situation at 14:00.

The effect of this measure regarding the first guideline is very limited. Walking routes in the *Rivierenwijk* have almost no extra shadow.
However, the effect of this measure on the second guideline is significantly higher. New 'cool places' are created (with the size being bigger than 200m^2 as most important requirement).



Discussion

The DPRA Heat Module

As explained earlier, the *DPRA Heat Module* from the *Tygron Geodesign Platform*, is based on the *DPRA Heat Stress Report* (RIVM, 2020). All factors, leading to the PET, are described in this report. These factors are individually calculated, and combined by the *Tygron Geodesign Platform* to create an overall PET map, with a very high spatial detail (0.5m). The *DPRA Heat Module* has been validated and benchmarked for local PET measurements in Wageningen. The performed benchmark had an average difference below 0.68% for selected measurement points. Therefore, this model can be considered as highly accurate (Tygron, 2020a).

However, as with all models, this model is a simplification of reality. Consequently, some discussion points should be considered regarding the *Tygron Geodesign Platform*. First of all, the open data the Tygron Platform uses (the BGT), does only include public placed trees, registered by municipalities (Tygron, 2020a). Private placed trees and other vegetation, for example in backyards, are therefore not included (Tygron, 2020a). However, these trees and vegetation can still have a significant impact on the heat stress. For further development it is advised to use data including these trees. This data can made with, for example deep learning software, which can identify both public as well as private placed trees, from aerial photographs. Finally, the heat stress of buildings and water itself are not included with the *DPRA Heat Module*. To calculate the heat stress of buildings itself, different models are needed, which are not included in the *DPRA Heat Stress Report* or the Tygron *DPRA Heat Module* (RIVM, 2020).

User input

Most of the input used for the Tygron *DPRA Heat Module*, is loaded in from open data. However, part of the input data should be inserted by the user itself. Consequently, the choices made about the input and settings determine the accuracy of the final result as well. Several discussion points regarding these choices and settings should be noted.

First of all, although there is the possibility to use different tree types for certain areas within the program, a standard tree type, with a standard size has been used for this research. Since different tree types can have different effects on the final (PET) heat stress, it would have been more accurate to include these different types within the research project.

Secondly, Although the chosen location includes a variation of land uses, it was still quite a specific location. As a result, the research will not directly be applicable for the whole of Utrecht, or other cities. With 1000m^2, the size of the chosen area was rather limited. This was the result of the license type.

Thirdly, it important to note that the placement of trees has not always been realistic. The suitability of placing trees in certain areas has not been taken into account. Furthermore, some roads had to be removed within the program to make it possible to plant trees. However, removing roads itself can already have an effect on the heat stress.

Finally, it should be noted that for this research project only two ways of placing trees have been considered. However, there are many more other methods for placing trees. The effect of these other methods could be explored in further research.

Conclusion

Conclusion tree placement

Before answering the main research question, first the sub-questions will be answered.

	*What is the effect of trees **places in lanes along roads**, on the reduction of the PET during a heat wave, in Utrecht?*	*What is the effect of trees **placed in groups**, on the reduction of the PET during a heat wave, in Utrecht?*
14:00	• Walking routes, mainly within the neighbourhood of the Rivierenwijk have more shadow. • Trees placed in lanes, do not create new 'cool places'. Therefore, the amount of cool places stays the same with this measure. • At 14:00, the shadow effect of the trees placed in lanes results in a decrease of the PET.	• The walking routes, within the Rivierenwijk area do not have more shadow. • New 'cool places' are created with this measure. • For 14:00, the PET has mainly decreased. The overall increase of the PET is very minor.
17:00	• Walking routes, mainly within the neighbourhood of the Rivierenwijk have even more shadow as the sun has turned at 17:00. • No new 'cool places'. • For 17:00 there is an overall *increase* of the PET, as the wind is reduced and the heat stays within the area.	• Not more shadow. • Same amount of new cool places as for 14:00. The shadow given by these 'cool places' is somewhat larger. • At 17:00, the PET has decreased for the places where new trees where added. Around these places there is a minor increase of the PET.

General conclusion:

- *What is the most effective way to place trees in Utrecht to reduce the PET during a heat wave?*

The most effective way for placing trees in Utrecht to reduce the PET during a heat wave will include a mix of both trees placed in lanes and trees placed in groups. Trees placed in lanes will provide shadow for the most important walking routes in the area. For urban planners it will be important to consider the possible increase in heat stress surrounding the placed trees, especially later during the day. This increase, mainly caused by trees blocking the wind, is most severe between small streets. Design choices, such as placing trees on one side of the road to give the wind space at the other side of the road, can help limit this negative effect. Trees placed in groups will provide new cool places in the area.

Further research

The *Tygron Geodesign Platform* is nowadays mainly used by municipalities, water boards and provinces for discussions about certain land use decisions. However, as this project has shown, the options for using the validated overlays, such as the Heat Overlay, make the platform also suitable for research projects.

The options for making heat stress maps for night situations, within the *Tygron Geodesign Platform* are rather limited. Night maps require different calculations and modelling techniques, compared to daytime maps. In my internship starting this February, I will research these different factors to help improve these heat stress, night maps.

Additional Information (Storymap)

Considering the limited amount of space within this project report, it was not possible to show all the 14 frames made with *DPRA Heat Module*. However, the frames of the difference map do show an interesting overall effect of the two different measures, when placed in a sequence. Therefore, a Storymap has been made with ArcGIS StoryMaps, which includes the difference maps for the entire time frame. Click here for the link to the Storymap.

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