Microclimatic Analysis of Arnhem

-Rijnbooggebied-

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1) Introduction

During the refurbishment of the inner city part called Rijnbooggebied the Department of Environmental Meteorology, University of Kassel, was mandated to give assessments of existing and future climate conditions in the study area.

For this case, existing and future development were simulated and analyzed with the microclimatic analysis model "ENVI-met" (Bruse & Fleer, 1998). Using the model, microclimatic maps can be created, which show different information like wind speed, median radiation temperature or thermal indices area-wide for the research area.

The "ENVI-met" model was validated by measurements in a research project of the Universities of Freiburg, Kassel and Mainz (KLIMES). Using simultaneously parallel questionnaires the thermal index could also be assigned to the subjective grading of human.

2) Urban Climate Description

The inner city parts of Arnhem are characterized by a high sealing rate and dense population. The existing wind system in the catchment area of the research area is mainly influenced by the thermal circulation from the river towards the city.

In the current development a large open space on the west side of the church, Eusebuiskerk, is the remarkable place of the research area. Different from unfavorable weather patterns this area is marked by partly strong wind channeling effects coming from southwest.

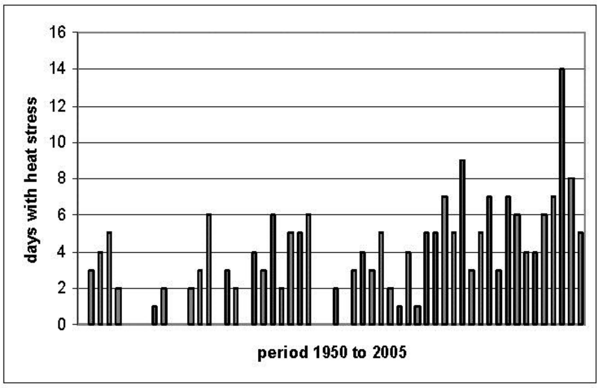
Because of the complexity and the chronologically dependence of the input variables, it isn't possible to perform a full automatic running system although the input dataset is high detailed. Weighting factors are an important auxiliary variable (Lohmeyer 2008). The experience and expertise of the editors is therefore of great importance.

Urban design and microclimatic conditions:

As seen below evaluation of the climate conditions are directed to the heat load of man, which is calculated on base of the heat energy balance of man (PET Index). For urban design it is important to know which factors influence man most, so that mitigation directly can be implemented in the design. Mean radiation temperature (radiation fluxes) and wind are the main meteorological parameters, which can be influenced in the Arnhem case.

2.1 Global Climate Change

As studies of urban heat islands (UHI) show, differences in temperature can vary by more than 5 °C during night hours. This situation is aggravated by global warming (Katzschner, 2009). An increase in incoming radiation can lead to greater heat storage, contributing to intensify UHI. To demonstrate this in terms of thermal comfort, the index PET (Höppe, 1999) gives a thermal evaluation. Moreover PET gives a better understanding on the influence of radiation and wind speed on thermal comfort and heat stress, which enables planners to respect these factors in their urban design.



Increase of hot days in urban areas:	
Calculation by the DWD (German Weatherservice) on base of urban climate map in the city of Frankfurt/ Germany T_{air} > 25 °C	
Annual heat stress today in Frankfurt	46 days
Scenario 2050	
increase at airport	3 days
increase city parks	4 days
Increase residential areas	6 days
Increase in dense structures	11 days

Figure 1 Increasing number of hot days (ta > 25 °C) in the city of Frankfurt (1950 – 2005) and increase taken a scenario depending on city structures

Regarding the increase of hot days and their spatial distribution during the period of 1950 to 2005 in the city of Frankfurt (figure 1). In Germany, cities like Frankfurt show an increase in the number of hot days – though this trend is not distributed equally throughout the city. Variations in density across the city affect heat load and therefore cities have different air temperature increases. In Frankfurt, people have been observed to complain after experiencing 46 days of temperatures above 25 °C. While in Hong Kong, for instance, this is accepted as normal occurrence. In Hong Kong namely air temperatures higher than 25 °C occur on average 255 days of the year. This indicates thermal comfort should be considered according to regional climates.

Arnhem:
In the existing situation the urban heat load of Arnhem exists in a moderate way. The densification of the city center will increase the summer problem similar like the Frankfurt example. Urban heat load increases through storage masses, but thermal load is decreased by shadow and therefore less short wave radiation results. This fact compensates climate change trends in the inner city.

2.2. Urban Heat Island Arnhem

In figure 2 the urban heat island Arnhem is mapped. As mentioned, the aim is to mitigate the urban heat stress effect. Looking to the mesoscale conditions, increased heat storage through denser building will also reduce nocturnal cooling and increase heat stress. But in the same time it is possible to provide shadow on a microscale with comfortable conditions. So in terms of a denser city the following assumptions have to be done:

Global climate change will increase heat stress days of at least 11 days more assuming a global climate change scenario of two degrees.

To mitigate this problem the shadow influence of buildings can decrease heat stress by 6 to 10 degrees on the microscale, not on the urban mesoscale level.

2.3. Thermal Comfort

Demonstration of thermal comfort conditions:

The heat island effect of the city of Arnhem will increase in difference of city surroundings (mesoscale). Therefore thermal comfort will be more comfortable in spring and autumn, which is mainly caused by a reduction of wind. Heat stress will occur in summer mainly.

The part of densification of the Rijnboog area is part of the increase, but small compared to global effects. Changing of heat storage mass and changing surfaces, long wave radiation will increase at some parts and increase urban heat island effect. Locally the thermal comfort can be seen as a positive development because:

- spring and autumn: wind speed reduction improvement of thermal comfort

- summer: reduction of short wave radiation mitigating heat stress (PET see below)

3) Method

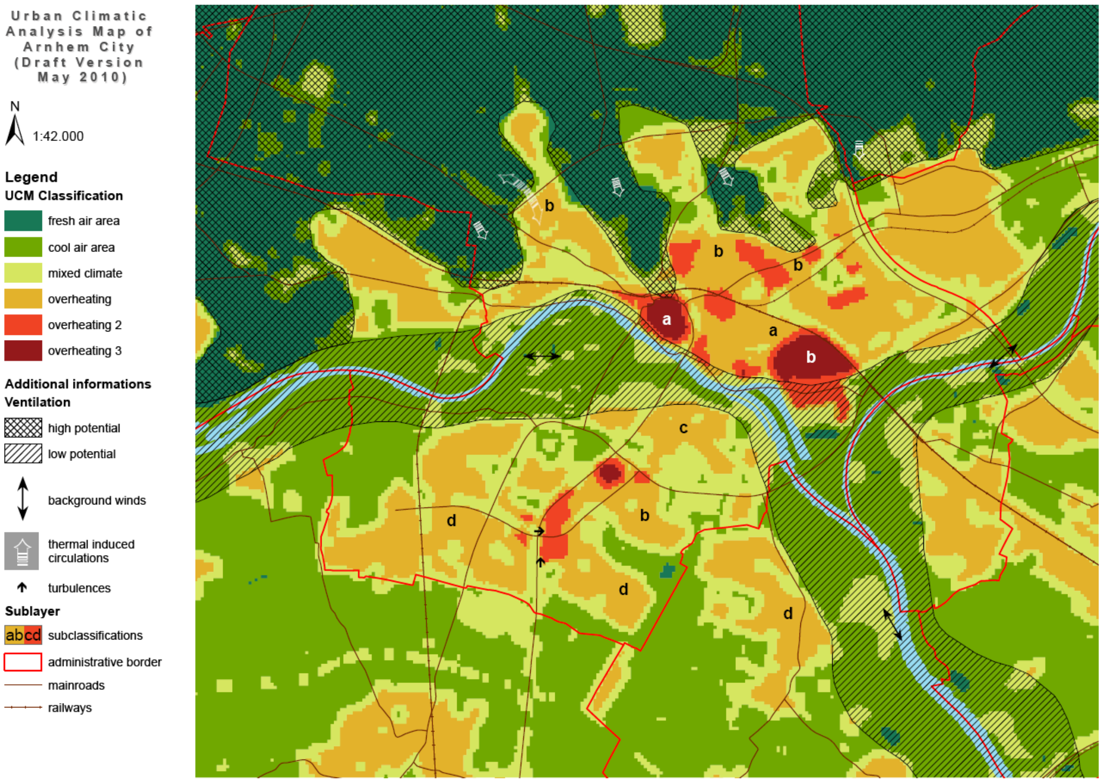


Figure 2 Urban Climate Map of Arnhem (Clipout)

To determine the climatic boundary conditions and the mesoclimatic initial situation, the Urban Climate Map of Arnhem was used and analyzed. Resultant the research area is mainly classified by overheating potential climatopes, called “overheating” (0-3) in the UCM. This has direct influence to the microclimatic situation.

ENVI-met

The modeling with ENVI-met calculates the thermal level, based on the variables of the heat balance of man (figure 3) by using a spatial resolution of 2 m for radiation balance, air temperature, air humidity and wind conditions. ENVI-met is a microscale 3-dimensional model, which can be modified through surface information, soil moisture or building information subject to the surface materials. Radiation balance and dynamic are calculated unique for every urban area.

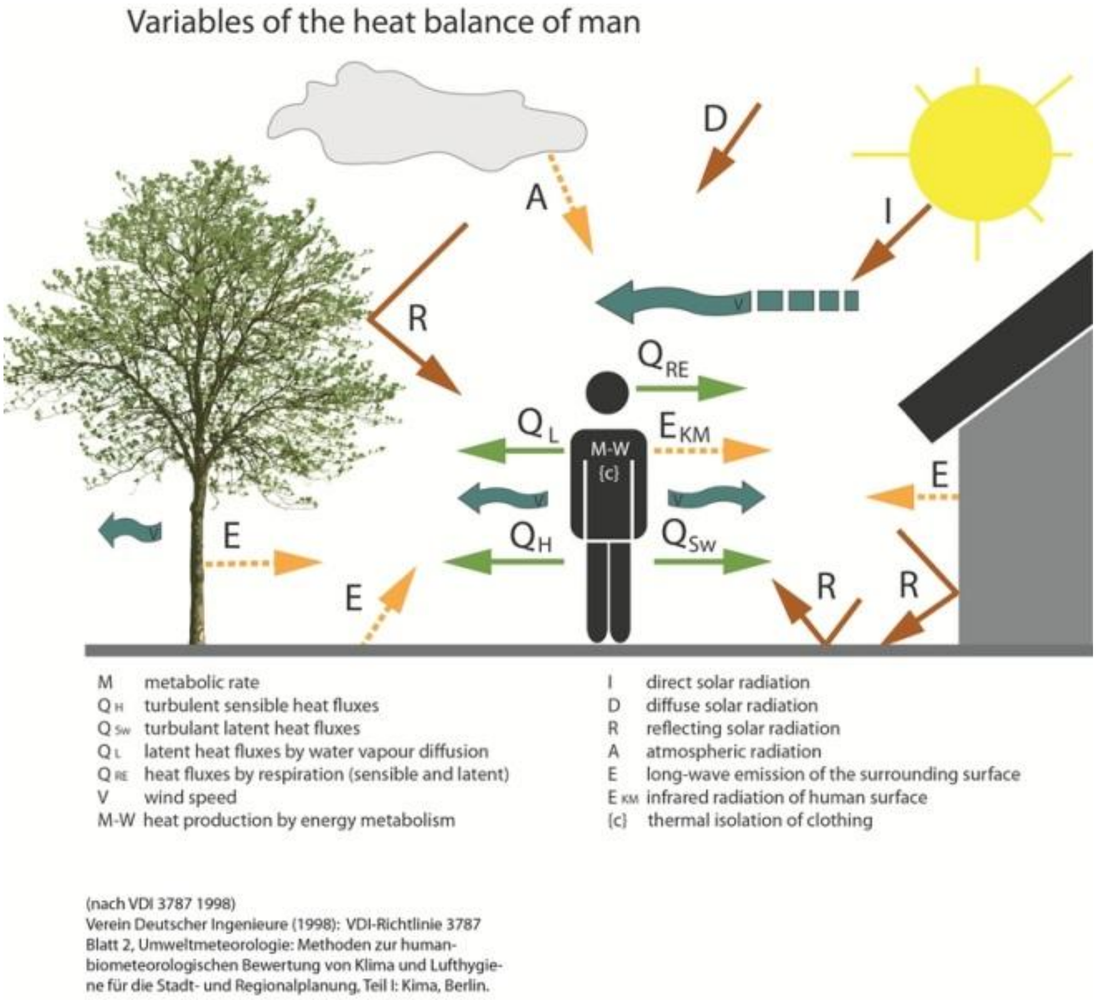


Figure 3 Variables of the heat balance of man

For all calculation runs, an average mid-european summer day was used. The boundary information is defined as an urban area. The input data for the PET calculation of air temperature, wind direction and speed were collected from the Urban Climate Map of Arnhem. To simulate the maximum solar radiation the model used the 21^{st} (cloudless) of June as calculation day. This is important in view of the increasing of very hot days (temps in excess of 30 °C), because all optimizing actions and recommendations are focused on this day.

As spring winter or autumn also influence the open space usage the following assumptions can be made for a seasonal aspect on thermal comfort:

- The spatial distribution is constant

Thermal stress and thermal perception is derived from the table below (figure 4):

- Areas with strong heat and moderate heat (classification five and six) have acceptable conditions in autumn and spring
- Winter - windy conditions in classification one and two have uncomfortable cold stress and need wind protection

PET (°C)	subjective feeling	stress level
< 13	cold	cold stress
13 – 17	slightly cold	weak cold stress
18 – 24	neutral	no thermal stress
25 – 28	warm	weak heat stress
29 – 34	very warm	moderate heat stress
35 – 41	hot	strong heat stress
> 42	very hot	extreme heat stress

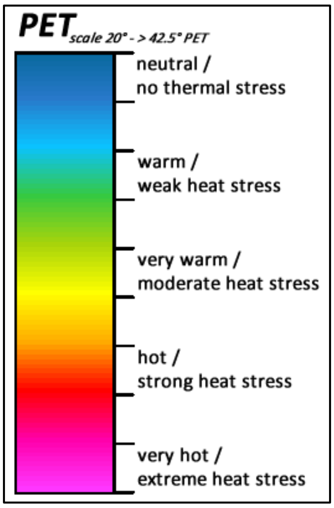


Figure 4 PET classification table and simplified ENVI-met PET legend

For the thermal analysis the PET (physiological equivalent temperature) index was used. PET combines all relevant meteorological data and correlates them to human beings. For the wind analysis, only one specific situation was simulated.

Structure of Analysis

Besides the current situation, the in development “Rijnbooggebied” was modeled and simulated. As result different PET and wind analyses were made. PET was calculated for the whole day (7:00 am to 7:00 pm) and also written to map for 8:00 am, 2:00 pm and 6:00 pm. Comparing to PET, the wind situation was also calculated for 8:00 am 2:00 pm and 6:00 pm. Finely the mean radiant temperature (MRT) for 2:00pm was created to see among others the direct differences between PET and MRT.

4) Recommendations

General:

From a climatological point of view the proposed buildings are positive to the city center. The urban heat island is increased but buffered to a comfortable shadow conditions during hot day and therefore positive for the long range development.

At hot spots greenery is proposed mainly at the facades of buildings in order to increase evatranspiration.

In the cooler areas some permeable wind protection is needed to improve spring and autumn comfort.

<u>For further discussions in a yearly distribution the summer calculations are taken as basics for the physical parameters and the conclusion derived from these for other seasons. It has to be said that the following statements are directly for the Rijnboog area:</u>

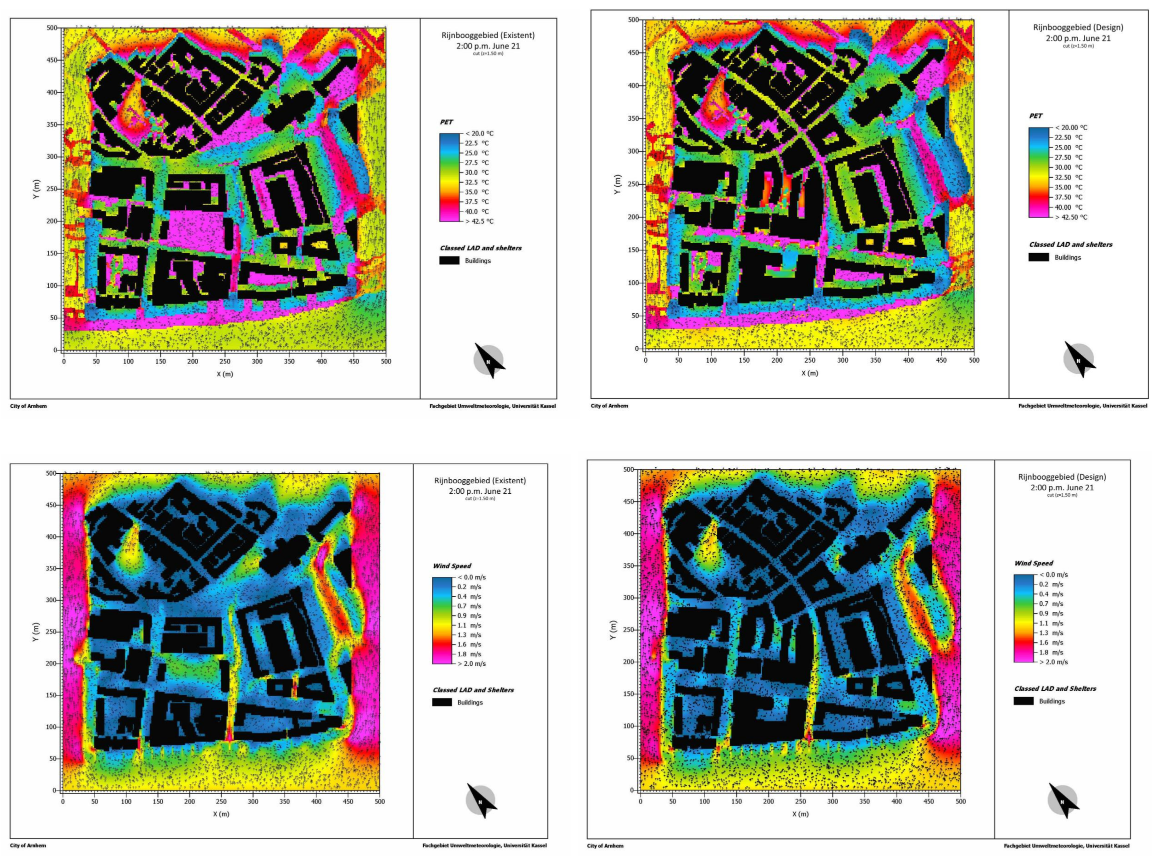


Figure 5 Thermal comfort (PET) and wind speed in the existing and proposed situation during a hot summer day

Two effects can be seen. Wind reduction and thermal load reductions, which means the negative effects by density of wind speed are compensated by shadow. Also very important for any thermal comfort discussions is the wind situation and the wind speed. From figure 6 the differences in wind speed can be seen during a moderate wind situation. Wind channeling effects are shown as red colors with increasing wind speed against blue colors with wind reduction areas.

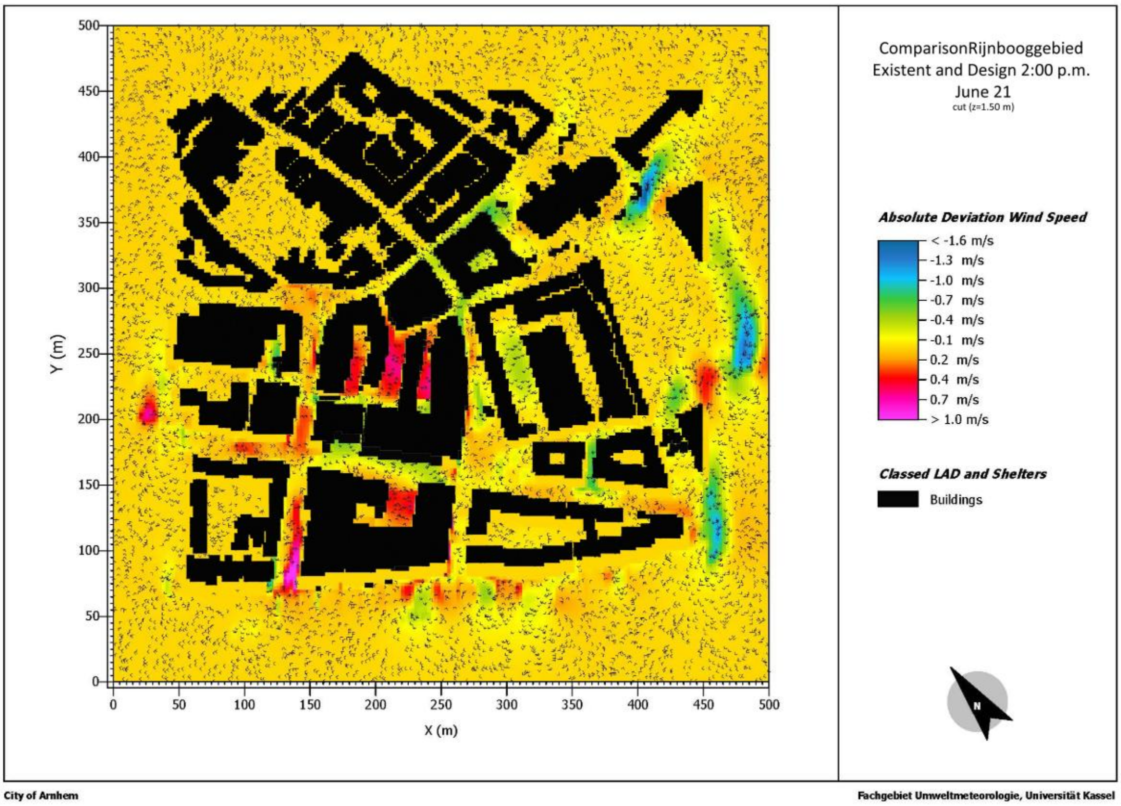


Figure 6 Wind speed differences

Summer conditions:

For summer the thermal load is positively affected. On the square near the church, the middy situation as well as the average is reduced compared to the original structure. Problem areas can be solved by additional greenery. Courtyards have problems, if there is direct sun, whether there is no wind.

Spring and autumn conditions:

By derivation summer situation towards in-between seasons more positive than negative developments are seen. If there is sunshine with moderate temperatures in spring and autumn neutral thermal conditions between 20 and 24 degrees of PET will be obtained.

Winter conditions:

For winter, the uncomfortable weather conditions either with the main wind direction of southerly winds or easterly weak but cold winds will persist. The easterly wind situation will be mainly at the corners of the church squares and at the easterly orientated streets. As this is not so much important for summer conditions, some wind barriers protecting easterly flows are recommended.

5) Results and maps

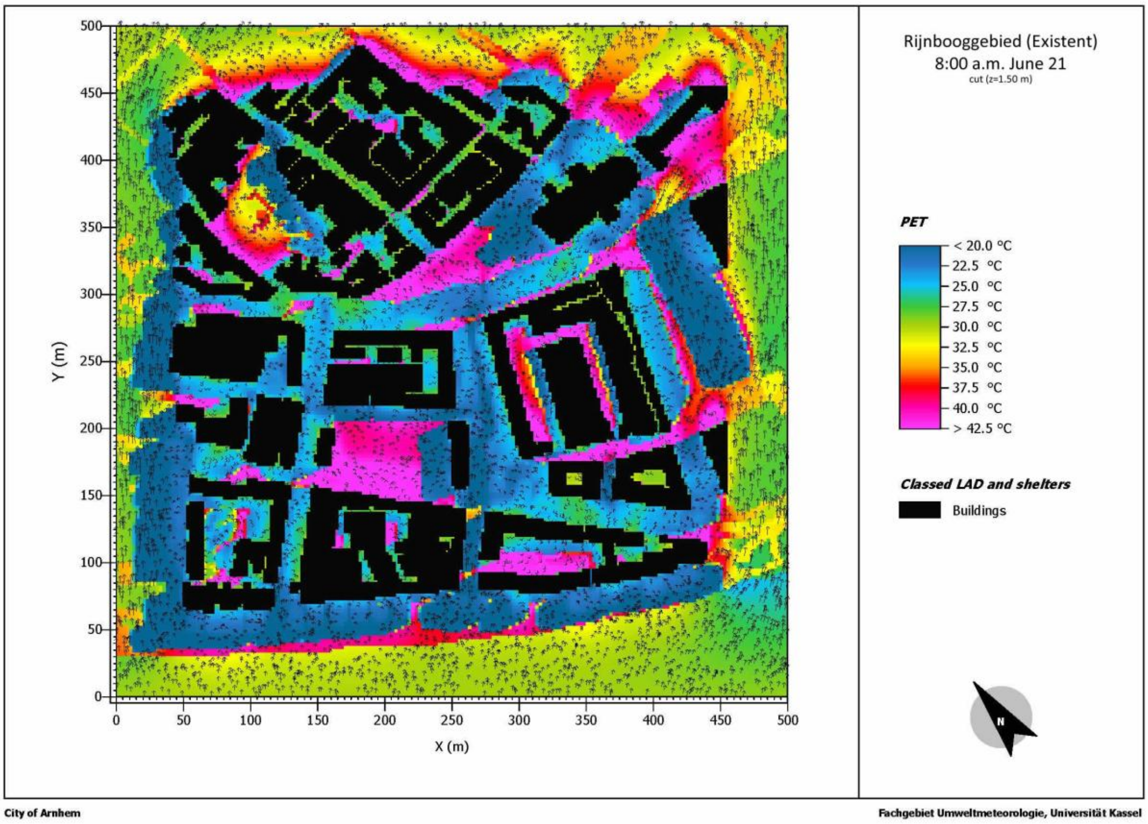
In the following appendix calculations with ENVI-met are shown with the parameters of

- PET (thermal index)
- Wind speed
- Tmrt (mean radiation temperature)

- For different times of the day
- For the existing situation and the planned proposal.

The parameters show important influences on thermal comfort, which can be influenced by planning in terms of roughness (barriers against wind), radiation (facades and surfaces) and long wave radiation from facades all combined in tmrt and finally the thermal comfort conditions as PET (physiological equivalent temperature, based on the human body comfort equation).

PET



Rijnbooggebied (Existent)
8:00 a.m. June 21
cut (z=1.50 m)
PET
< 20.0 °C
22.5 °C
25.0 °C
27.5 °C
30.0 °C
32.5 °C
35.0 °C
37.5 °C
40.0 °C
> 42.5 °C
Classed LAD and shelters
Buildings
Y (m)
X (m)
N
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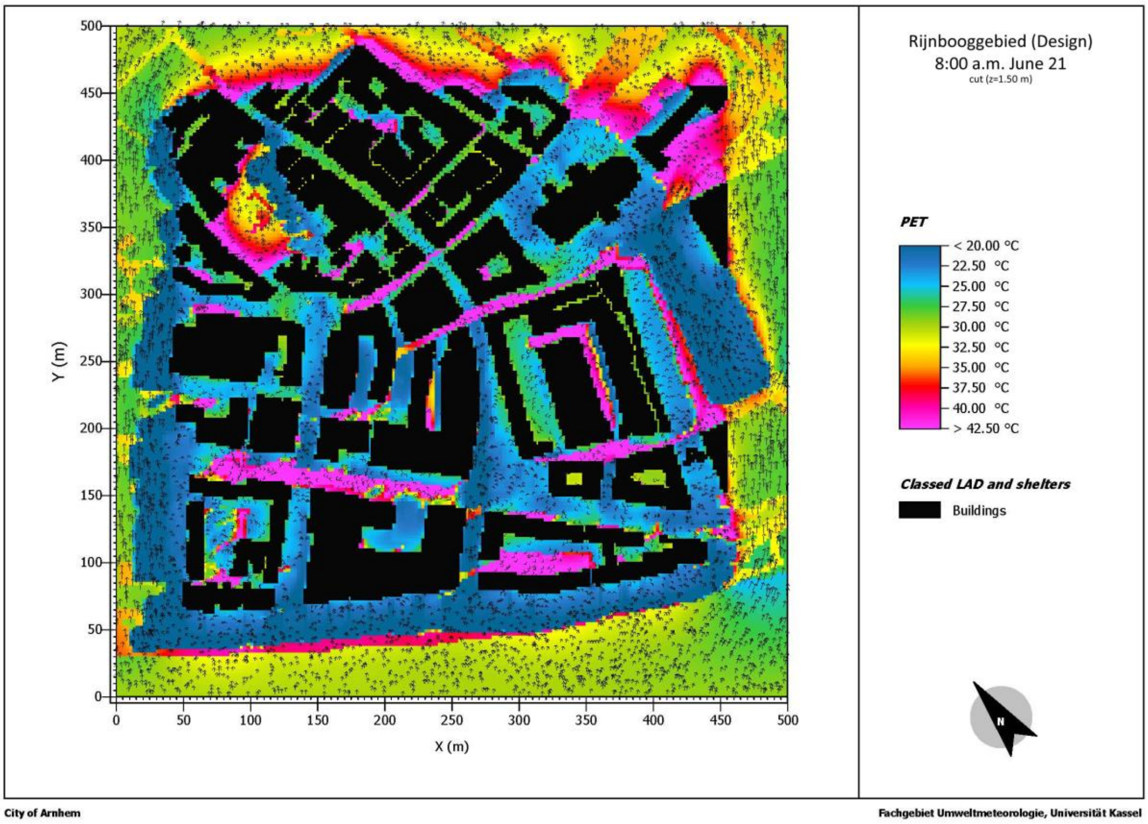

Rijnbooggebied (Design)
8:00 a.m. June 21
cut (z=1.50 m)
PET
< 20.00 °C
22.50 °C
25.00 °C
27.50 °C
30.00 °C
32.50 °C
35.00 °C
37.50 °C
40.00 °C
> 42.50 °C
Classed LAD and shelters
Buildings
Y (m)
X (m)
N
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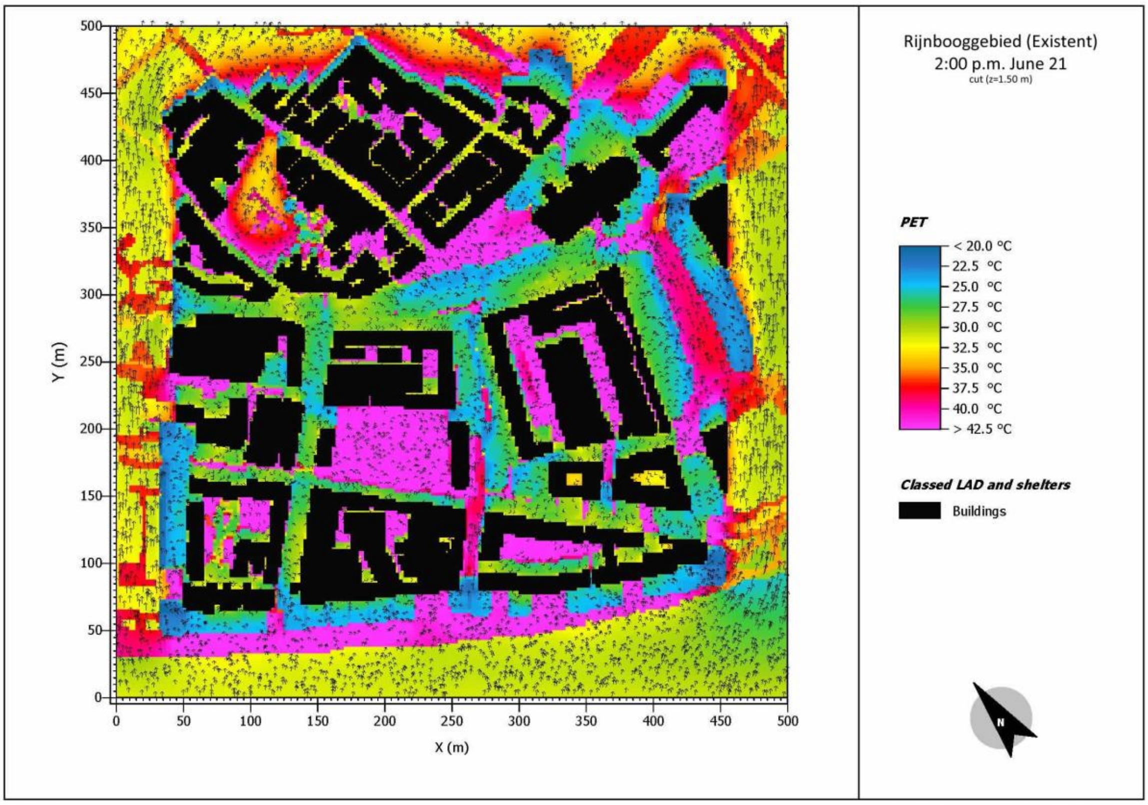

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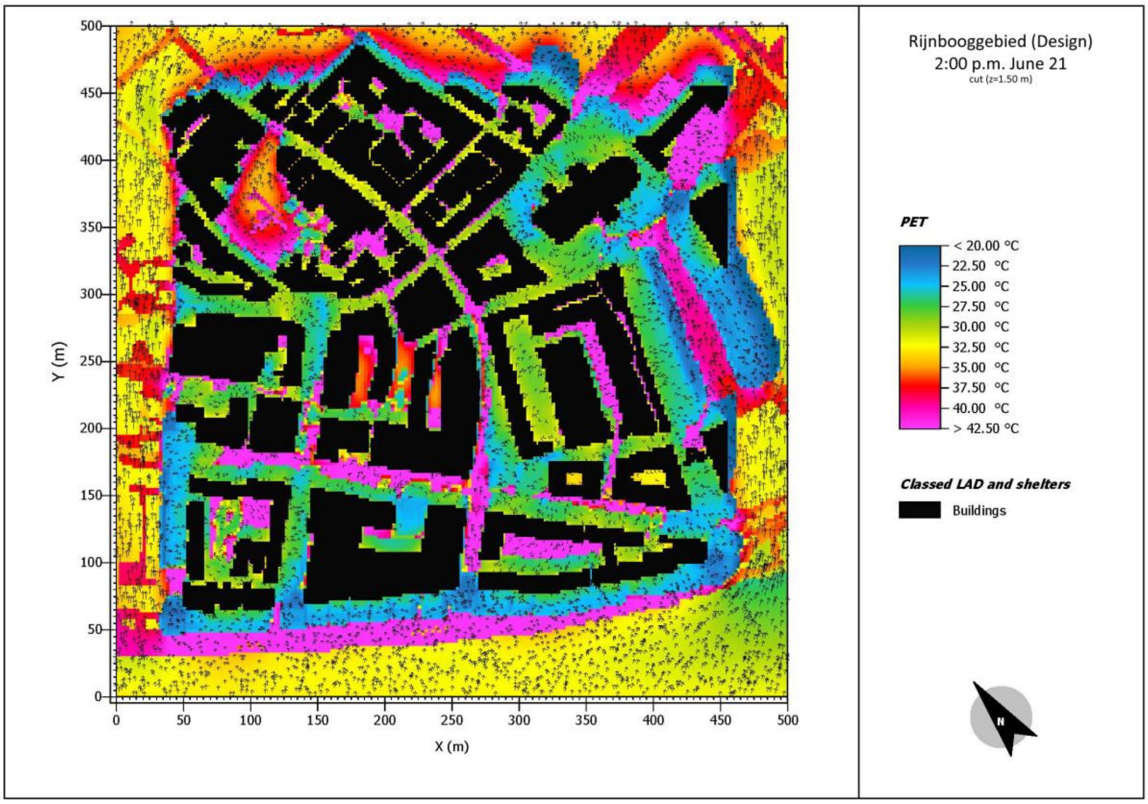

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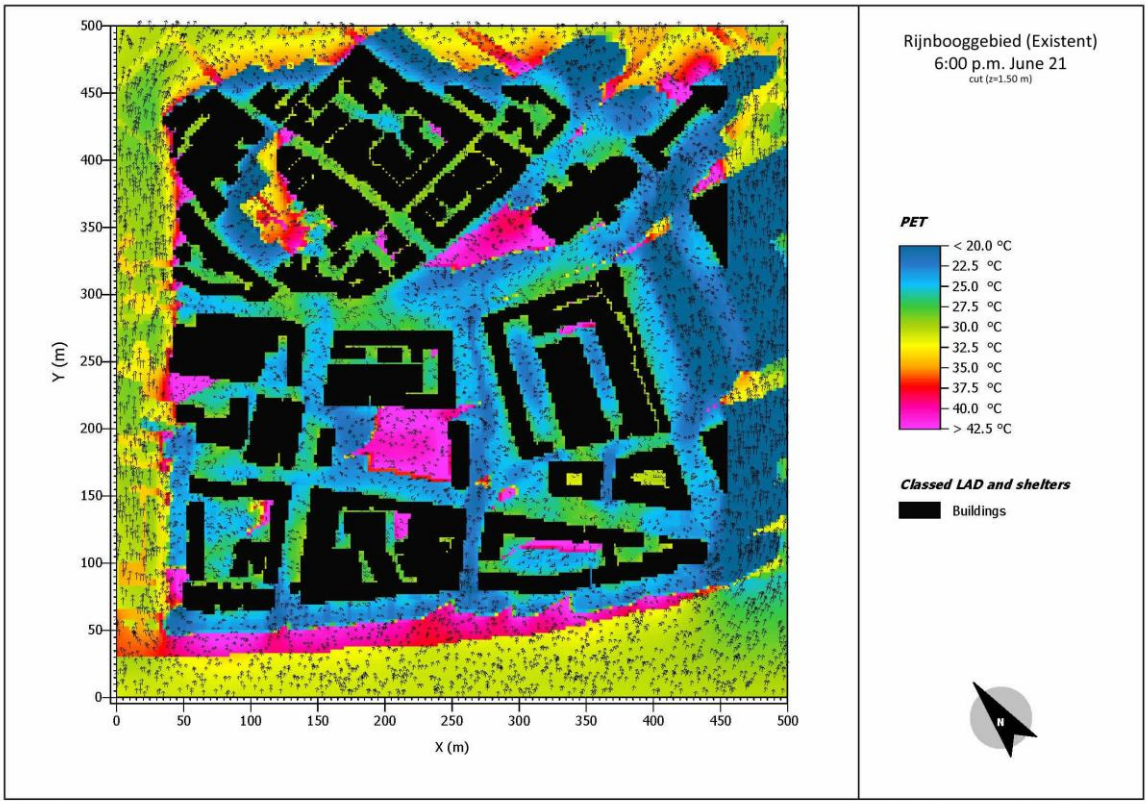

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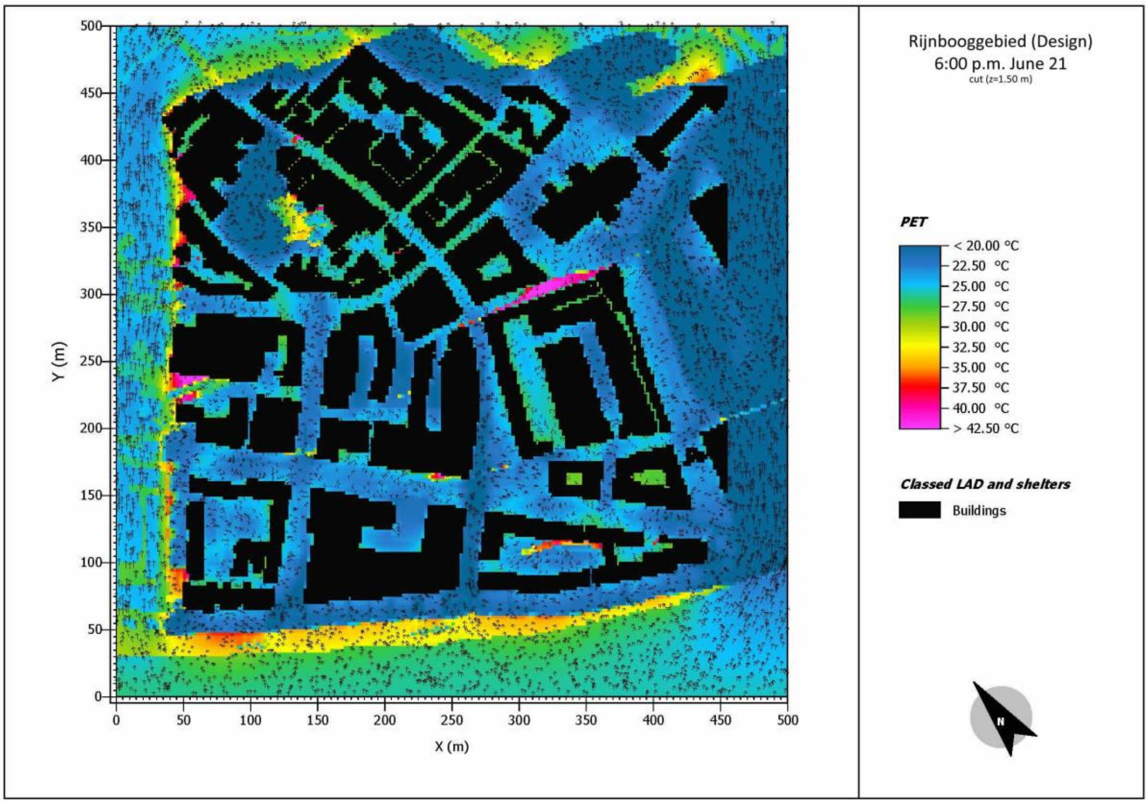

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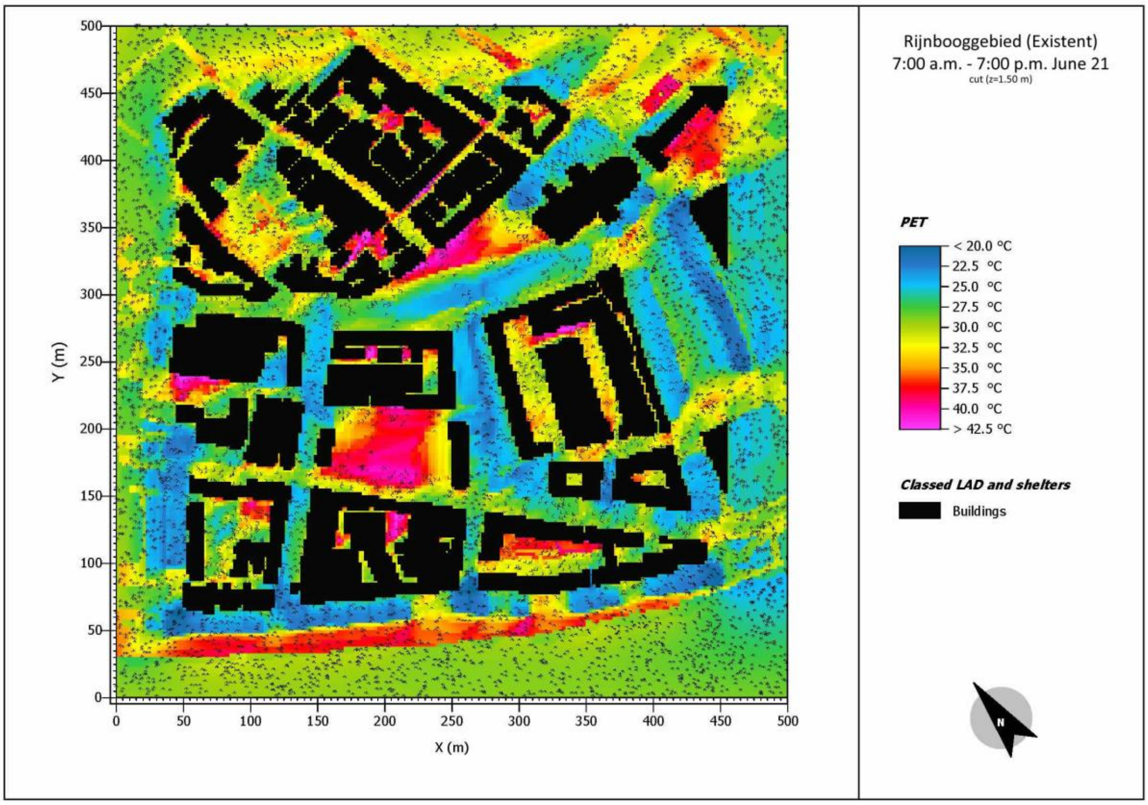

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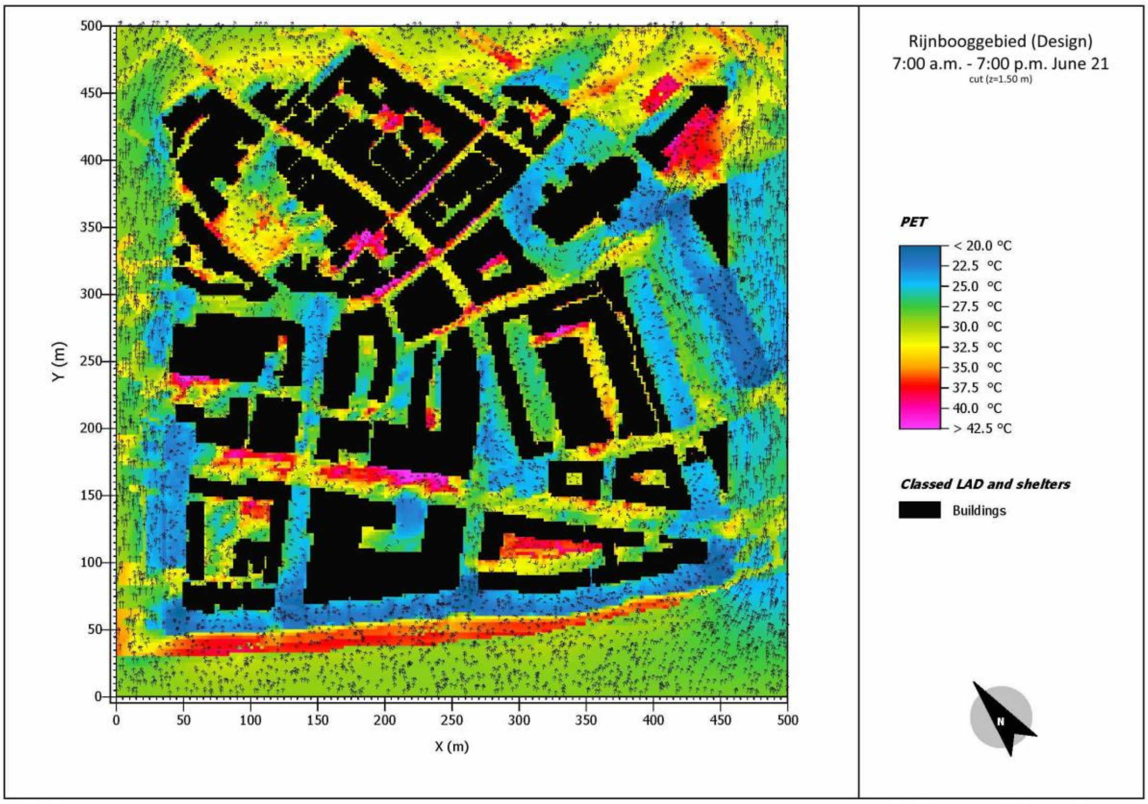

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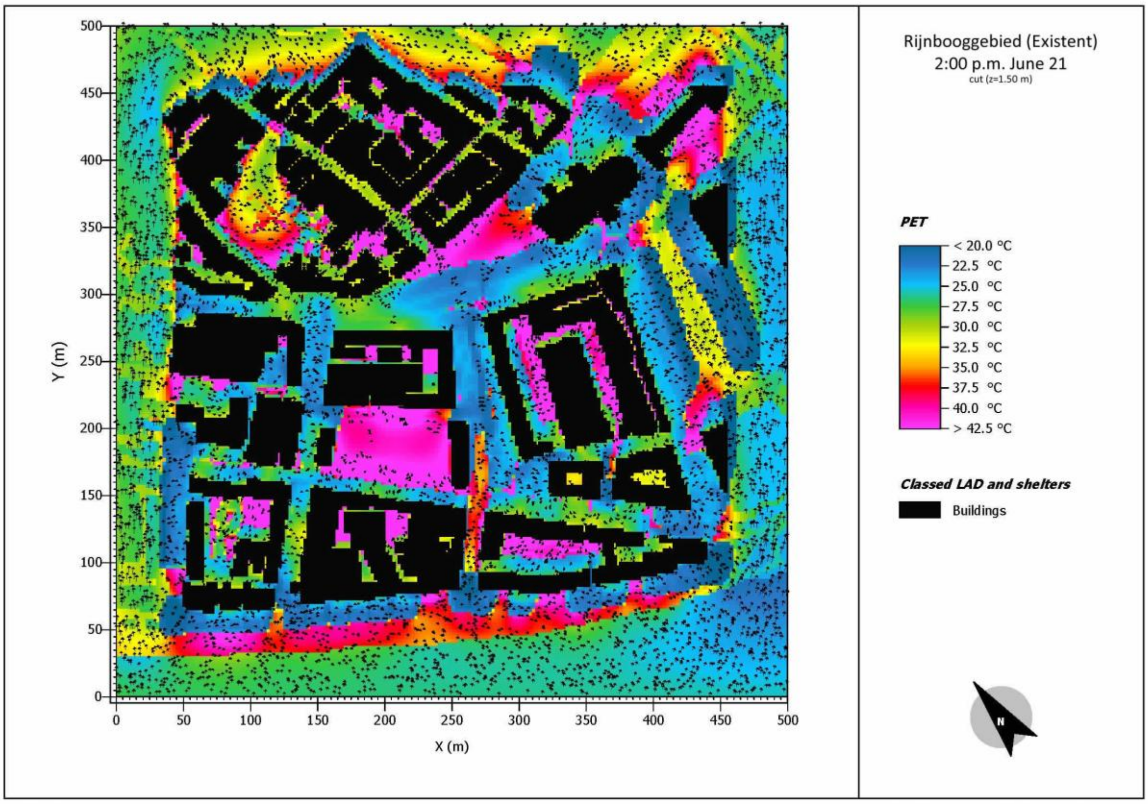
PET (strong wind situation 4m/s)



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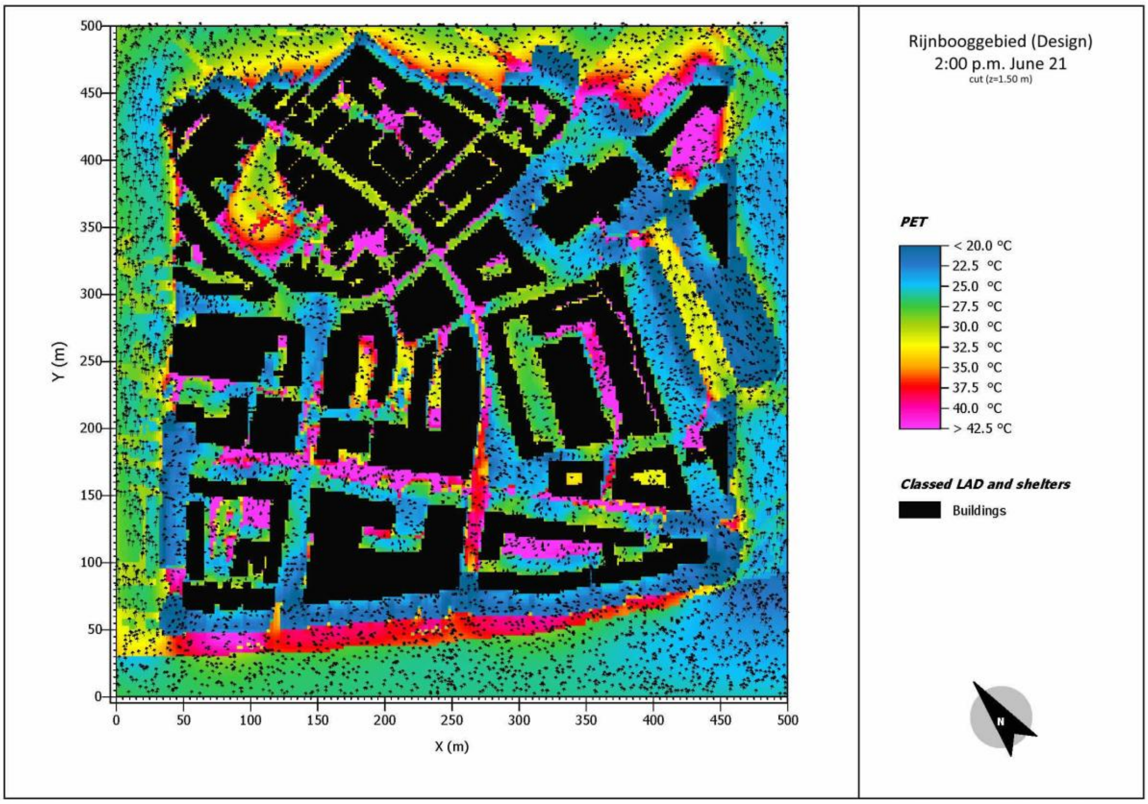

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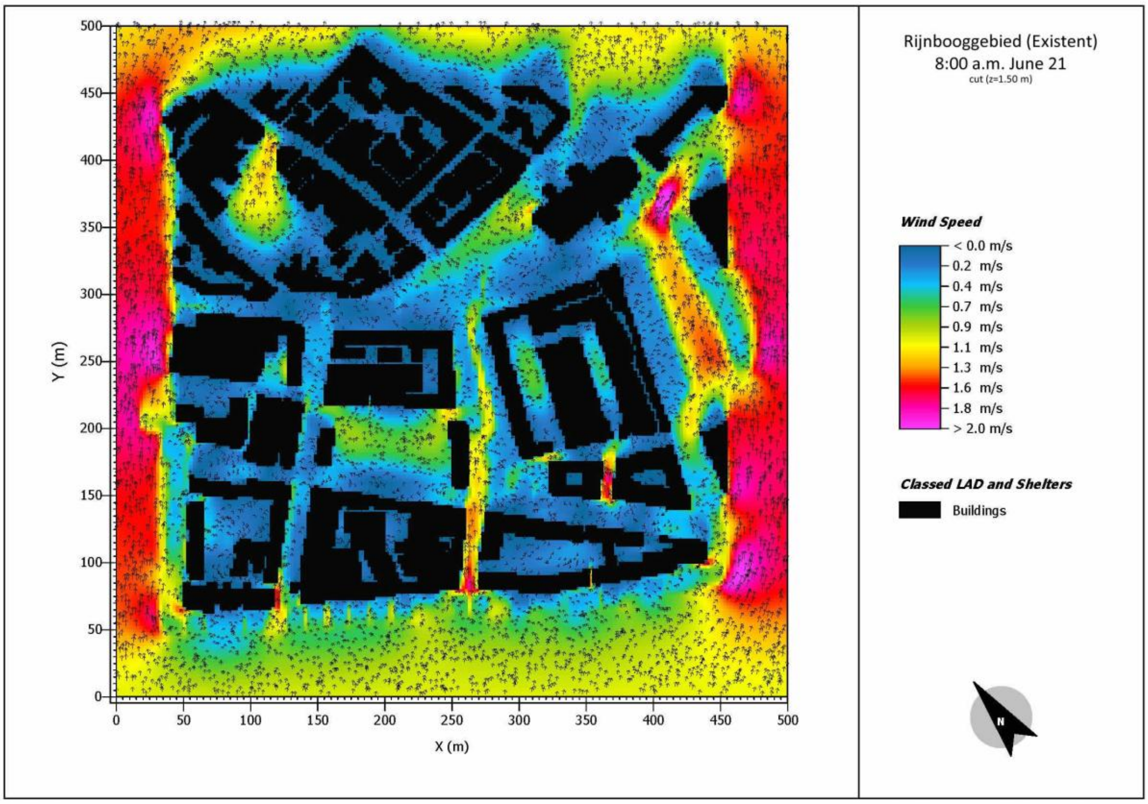
Wind (2m/s)



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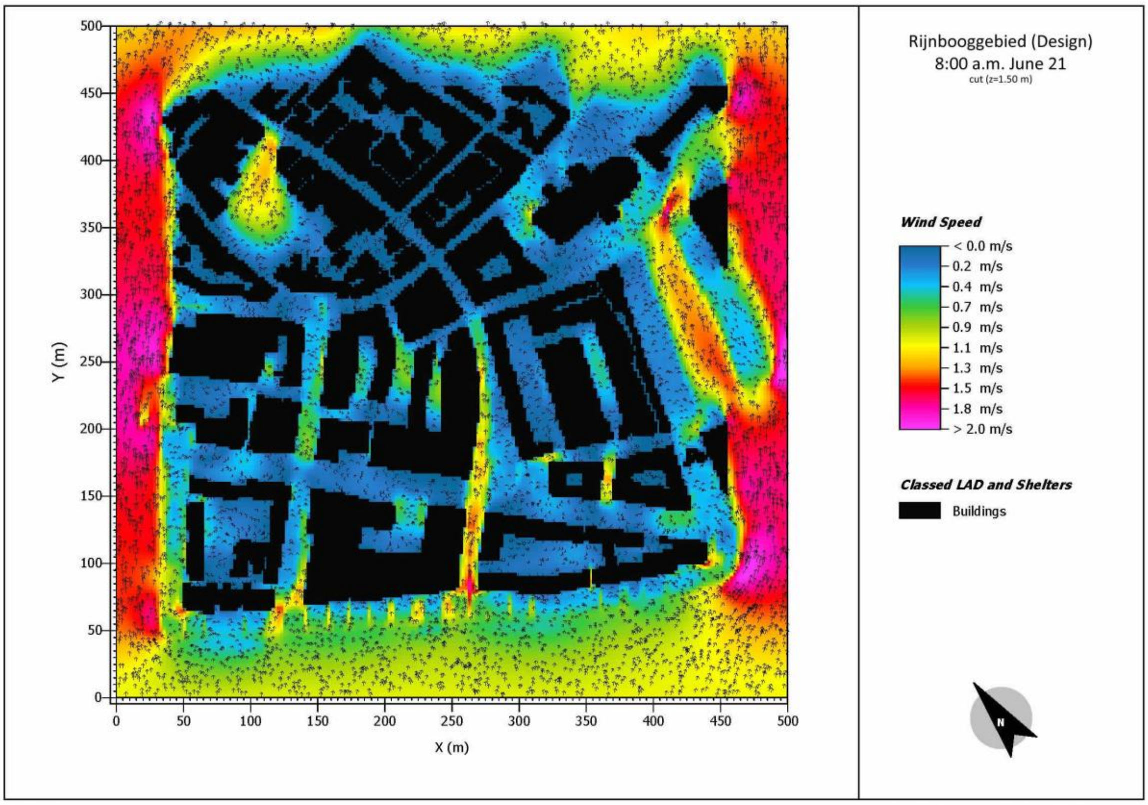

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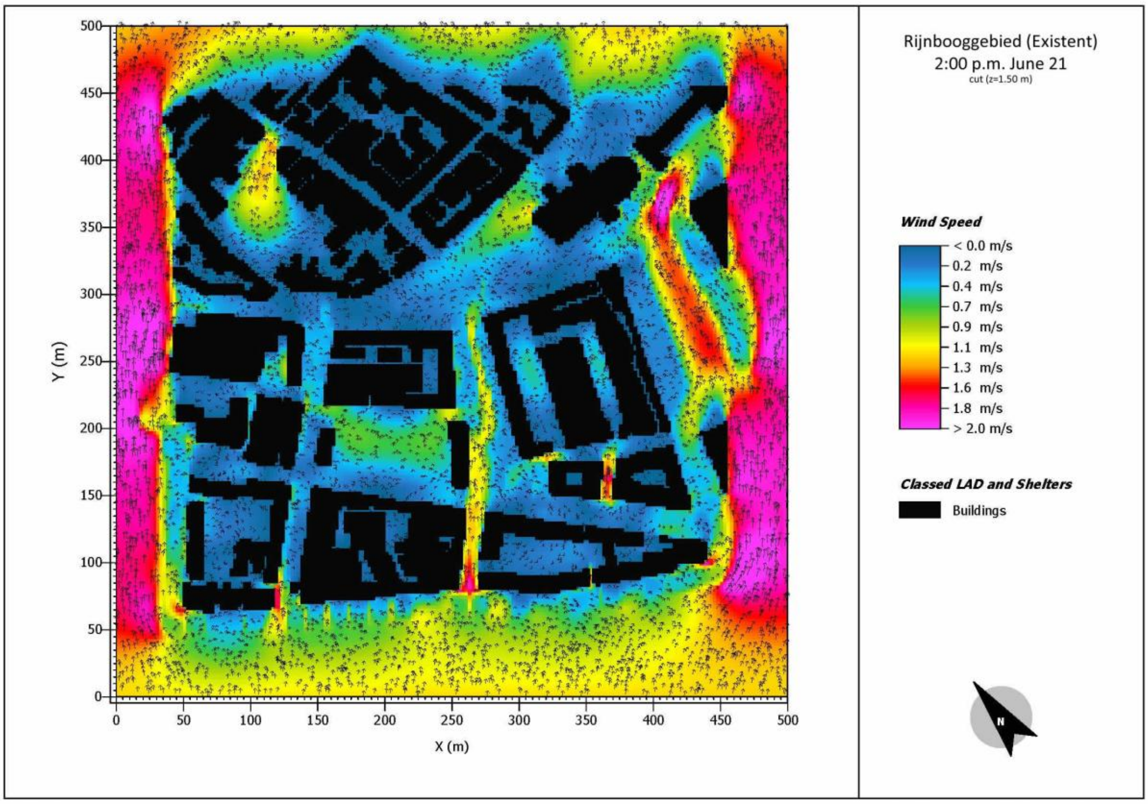

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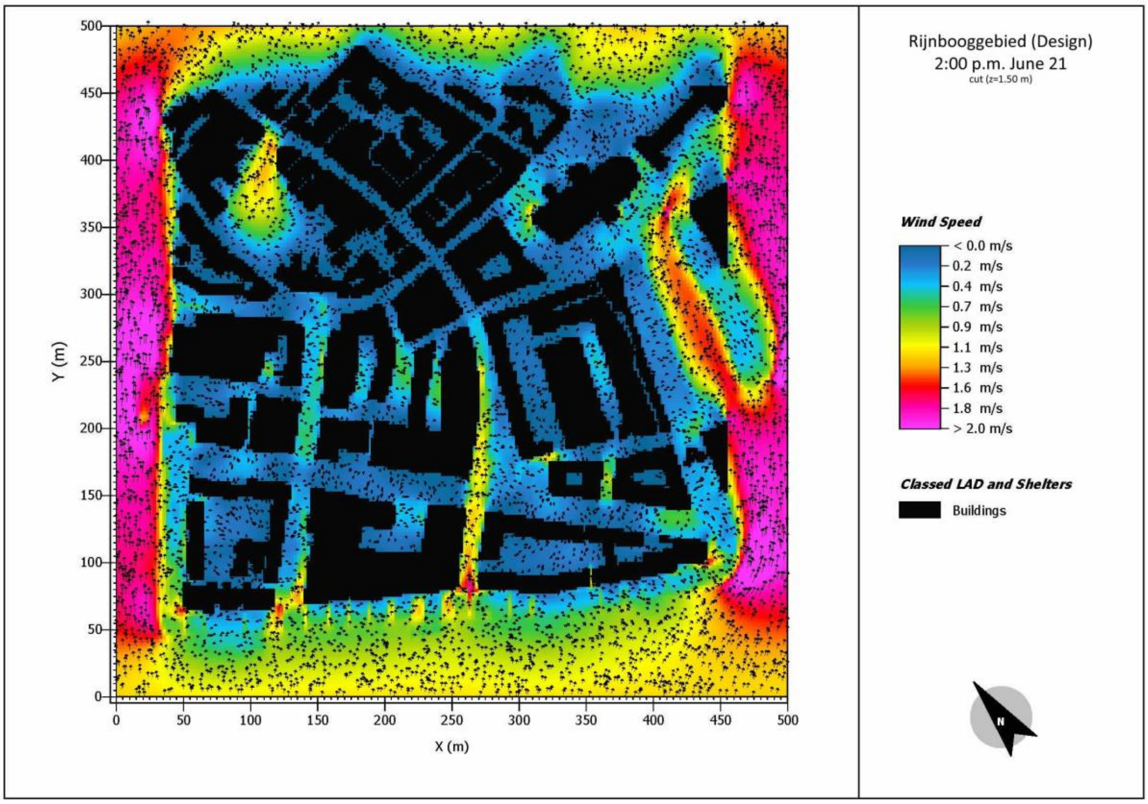

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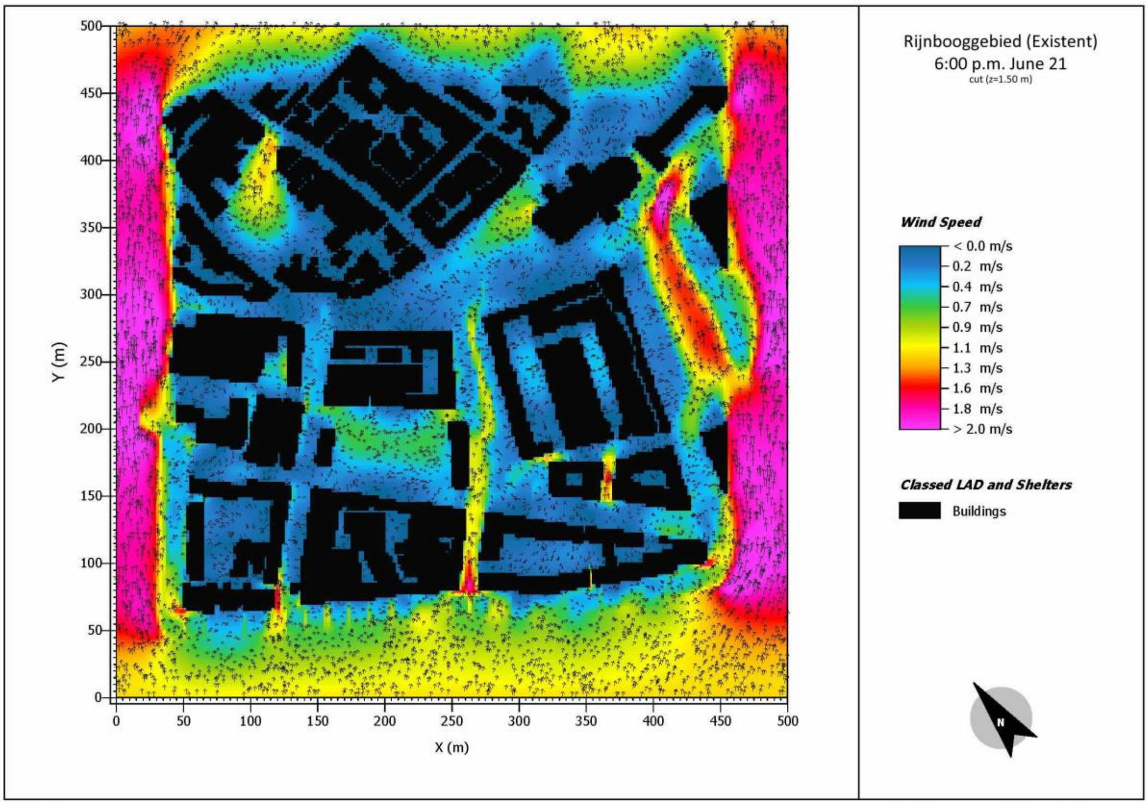

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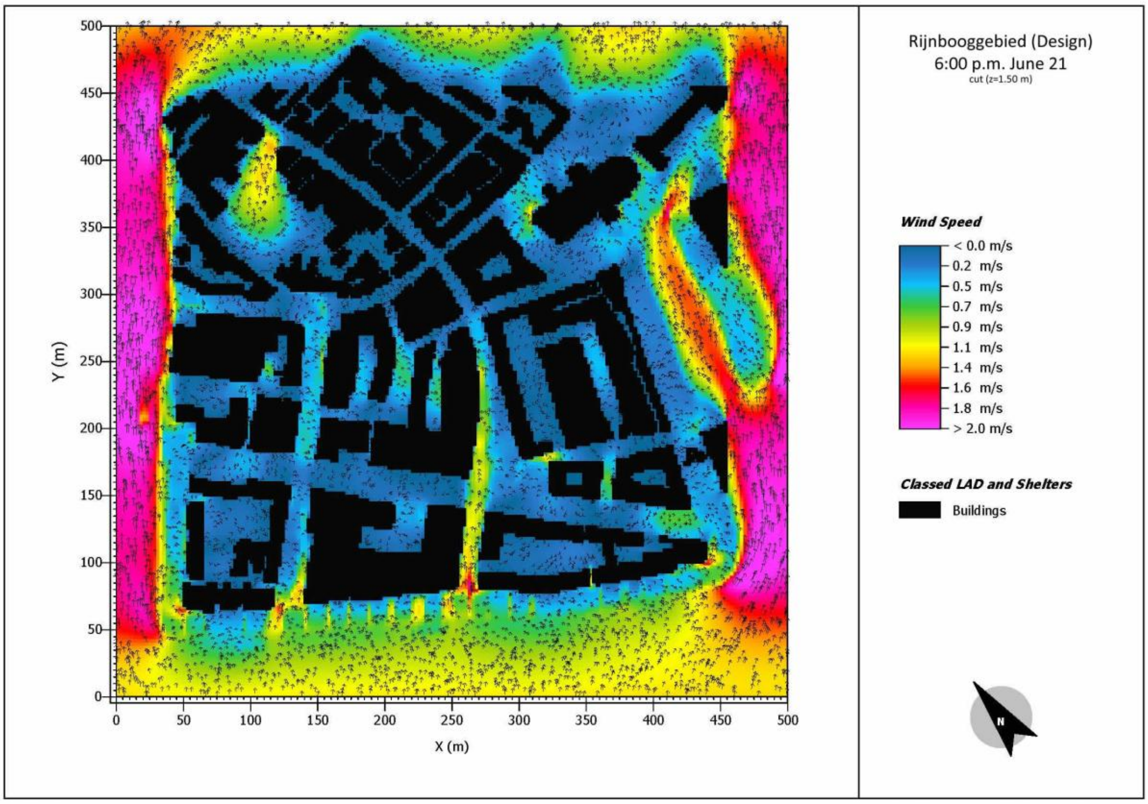

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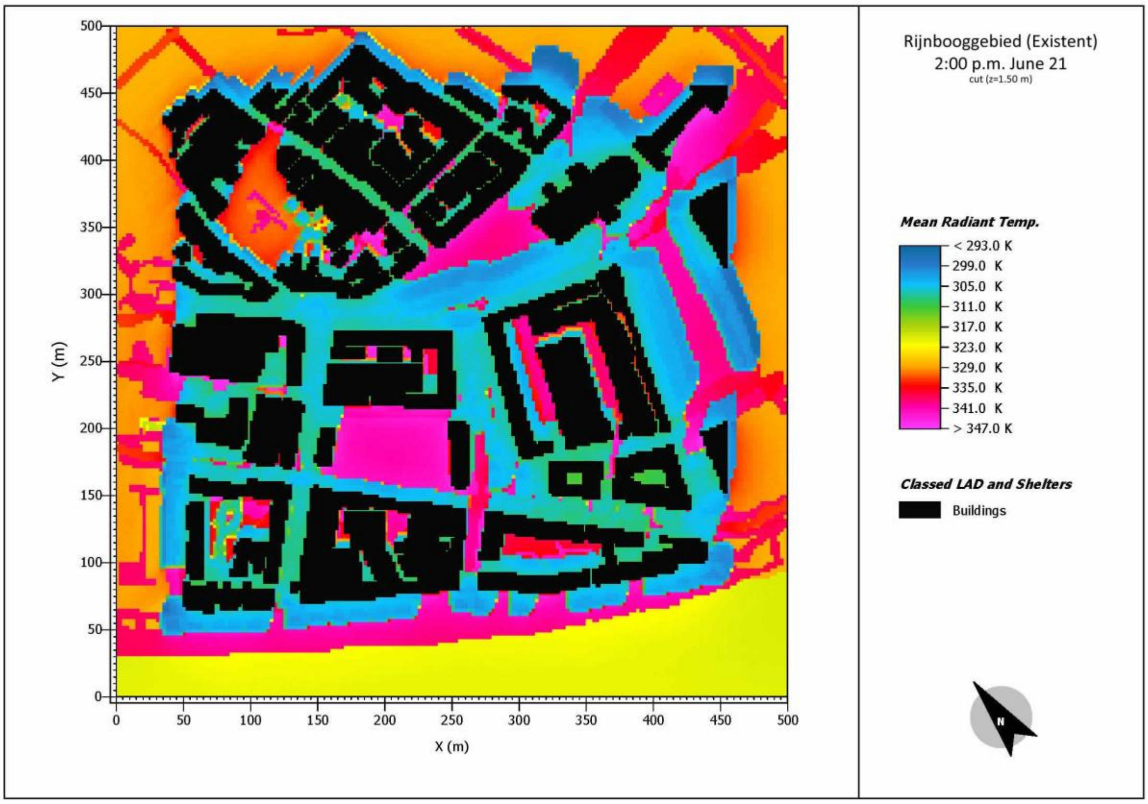
4.3 MRT



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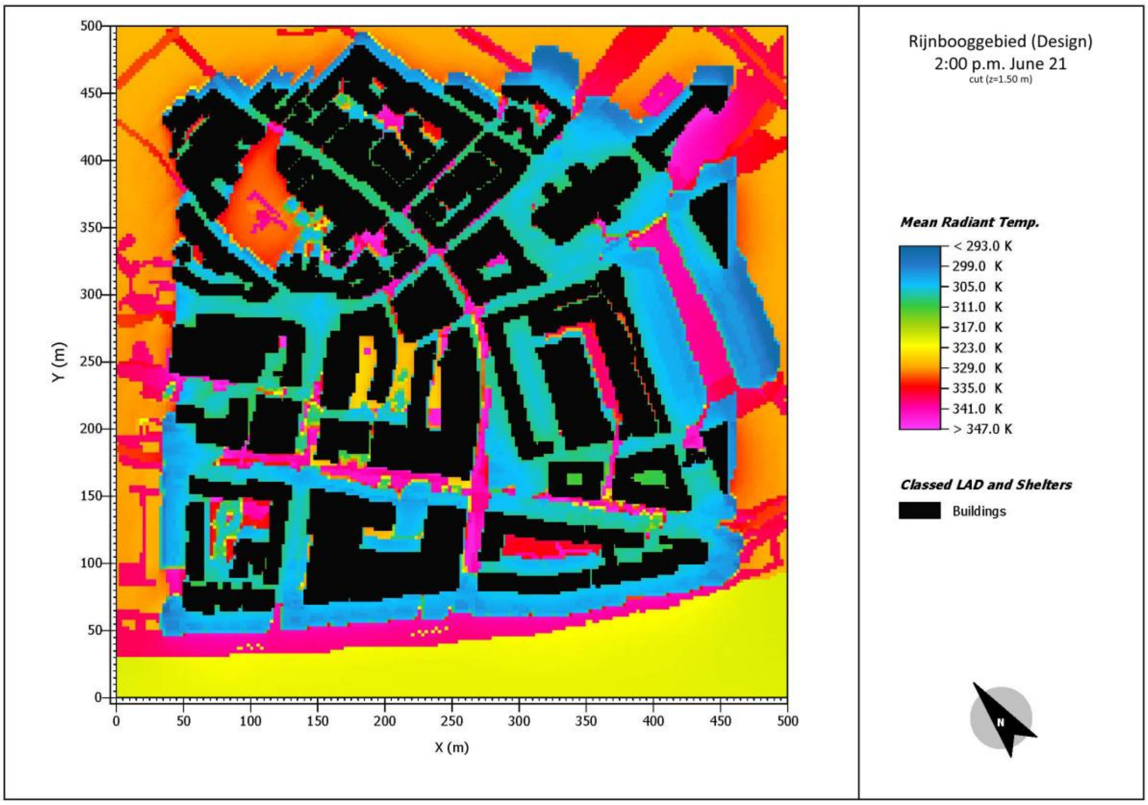

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