Future Cities
urban networks to face climate change

Urban Climatic Map of Arnhem City

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1 INTRODUCTION

In the framework of urban planning strategies as well as the global climate change, urban climate maps are an important tool for master or zoning plans. Moreover in a changing climate the analysis is used to mitigate heat stress and heat risk. Beside the thermal comfort conditions a clean air strategy can be based on that. In this report an urban climate map for the City of Arnhem (Nl) is presented.

The concept of **Urban Climate Map (UCMap)** has been generated by German researcher since the 1970s. It has been used as an appropriate tool for presenting climatic phenomena and problems into 2 D spatial maps. The map analysis the urban climate and gives recommendations toward defined climatopes.

The Urban Climate Map synergistically combines various climatic parameters like wind directions and speeds, solar radiation, air temperature with information about the city topography, landscape, building bulks, street grids and so on. The UC-AnMap can tell how the streets are ventilated, where the more comfortable spots are , where the problematic areas are, and how the buildings affect the city wind environment (Ng, E., Katzschner L. and Wang U. 2007). With information like these, planners and designers could have a better climatic basis of decision making. Apart from the physical factors, the development of the UC-AnMap is also based on qualitative and subjective criteria (Scherer, Fehrenbach, Beha, & Parlow, 1999). Evaluation is carried out through a GIS based model, which could calculate weighting factors for each mesh with a result of thermal load aspect and dynamic potential aspect. Then the general urban climatic understanding from UC-AnMap is transferred by expert and planners into the UC-ReMap with planning advices from the climatic point of view.

For **Arnhem** the UC-AnMap and the UC-ReMap are combined following the latest developments of the "Klimaplanatlas" Frankfurt 2009, Kassel 2010 and Berlin 2008. Based on the 4th Assessment Report of Intergovernmental Panel on Climate Change (IPCC)[1], climate change and higher summer temperature is an inevitable future. For The Netherlands the warming up will continue with a temperature rise of 2 to 4ºC in the next century that Dutch people will especially suffer in summer. After the recent heat waves in 2003 and 2006, the effects of climate change on public health start to be recognized in The Netherlands. The Netherlands is a densely populated country, which occupies 41.546km² with a total population of 16.339 million.[3] Careful spatial planning for mitigating climate change and creating a comfortable living environment is therefore needed. However, until recently, urban climatology has not been a popular issue in The Netherlands and it has low impact on the spatial planning in Dutch planning practice. The main reasons include the communication problem between climatologists and planners[4], and a lack of tool for presenting urban climatic conditions with spatial information in planning language, which could help planners to understand climatic phenomena and make urban design appropriately. Thus, there is a need for conducting Urban Climatic Map (UC-AnMap) study in The Netherlands. It may assist designers and planners better strategically plan the city so as to result in a quality environment for the benefits and enjoyments of the local inhabitants and visitors.

Arnhem is located in the temperate climatic zone with cool summers and mild winters. Optimizing urban human thermal comfort is important. The drafting of urban climatic map taking into account the synoptic climate information, planning and land use information can be a useful information tool.

2 SCALES

Table1. *Planning and urban climate scales*

Administration level	Planning level	Urban climate issue	Climatic scale
city 1:25.000	urban development; master plan	heat island effects; ventilation and air paths	meso scale
neighbourhood 1: 5.000	urban structures	thermal comfort, air pollution	meso scale
block 1: 2.000	open space design	thermal comfort	micro scale
single building 1:500	building design	radiation and ventilation effects	micro scale

UC-AnMap is useful assisting planning decision-making ranging from the regional scale of 1:100,000 to the urban scale of 1:5000. UC-AnMap provides a holistic and strategic understanding upon which detail and further micro-scale studies could be identified and conducted.

For the urban planning results urban climatic maps are an important tool. It is not only the analysis but also the recommendations from it. Any planning aspect needs spatial climatic information with a high resolution in a classification system following thermal and ventilation criteria to find urban climatic characteristics.

All decisions based on the microscale level need further investigations and cannot be answered by the urban climatic map.

For the regional level an investigation was done concerning the wind distribution and characteristic of climates. With that the relation between regional circulations and local circulations can be derived and used for the urban climatic map.

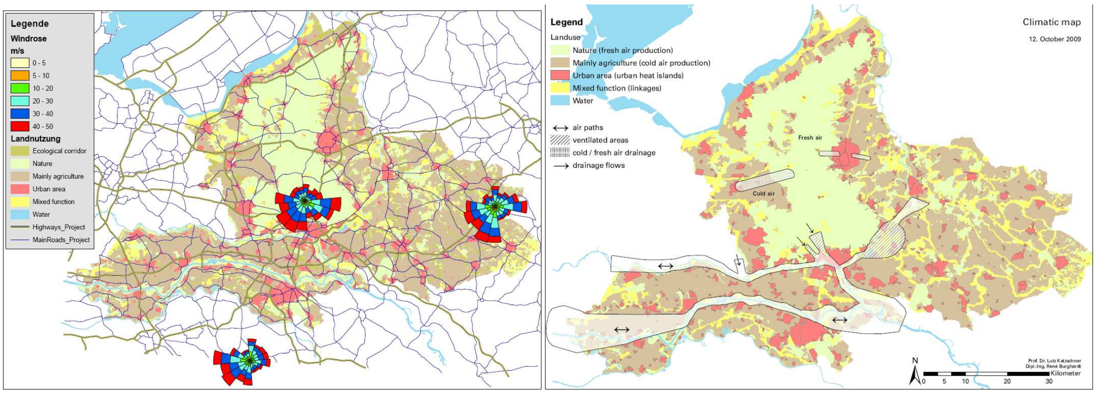

Figure 1. *Regional climate map (province Gelderland) with wind distribution as background information for the urban climatic studies in Arnhem and Nijmegen; urban heat islands, cool areas and main wind circulation from a regional point of view*

The wind distribution from three stations shows southwesterly winds with higher wind speeds on the one hand and some easterly winds, which occur mainly in winter and during high pressure situations with low wind speeds, on the other hand. In the evaluation of the urban climatic map these wind characteristics was taken up and incorporated in the urban climatic map.

3 Methodology

3.1 Climatopes

The system of climatopes describes areas with the same urban climatological climatological characteristics. They are gained and influenced by morphological and city fabric factors. They include thermal load, ventilation and can also evaluate the air pollution aspect (VDI 1997)

3.2 Wind

For the urban climatic map the two wind systems of background wind and thermal induced winds have to be delt separately. Wind roses give information about the annual wind direction distributions. Combined with low surfaces and channeling effect ventilation n areas and air paths were derived.
Beside this phenomena the thermal induced circulations mainly influenced by slopes and large differences in surface heat budget. Both wind systems appear in different dominant or predominant ways (VDI 1997).

3.3 Urban climate maps

The UC-ReMap is planning oriented. Based on the analysis obtained from the urban climatic analysis (UC-AnMap), climatic zones and air paths could be developed and recommendations derived. The colors and symbols showing “Place which requires an improvement” and “Place which should be conserved” from the view of urban climate. Then, with the aim of mitigating the negative situation and protecting the positive situation, the planning advices and guidelines for each zone are offered by expert and planner.

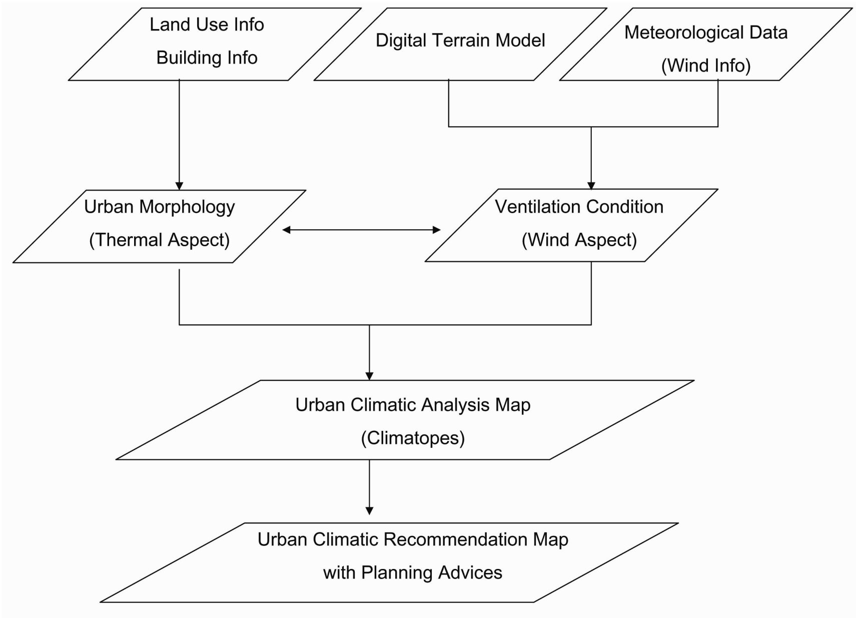

Figure 2. *Methodology of urban climate analysis for Arnhem*

The underlying methodology for the map is to combine layers, which were conducted from land use maps or others, translated to thermal and dynamic aspect with weighting factors. These weighting factors come from building volume to heat storage, greeneries to heat budget, openness to ventilation, roughness to wind speed and topographical information to downhill movements.

3.4 Description of Layers

For urban climate heat storage, heat balance of surfaces and surface roughness are the important influencing factors. These have to be quantified. Therefore layers are developed, which take the urban climate modification in above mentioned sense into account. Principle factors:

- heat balance of surfaces express the cooling rates as well as the heat storage rates, combined with slope analysis downhill movements can be derived. Input data are land use and the surface conditions (C and E),
- buildings effect heat storage and therefore the urban heat island. Volume, density and height are input factors calculated by the building volume parameter (A and B),
- dynamical factors are influenced by roughness length (derived from the vertical wind profile) supported by topographical structures, background wind as well as thermal induced wind are factored in, input parameters to deriver roughness are land use and openness overlaid by slope winds and small scale thermal winds (D).

The last column in table 2 shows the weighting factors for each GIS layer. The number means the importance of the specific layer. So building volume for the heat balance as well as the openness for ventilation has the highest values. This corresponds to the thermal comfort conditions of man where wind and radiation are the most dominant parameters (Katzschner 2006). Here the thermal index of the physiological equivalent temperature is used (Höppe 1999).

Table 2. *Layers used for the urban climatic map*

	layers	**urban climate aspect**	**data used**	**classification with weighting factors**	**no. of factors**
A	building volume	heat storage	building information and land use	in m^3 building volume	6
B	built up areas and openness	heat storage and ventilation	building information and land use	% relation of built to non built areas	6
C	cold and fresh air production, green areas	heat balance of surfaces production of fresh and cool air, influencing neighbourhoods	land use classification, surface conditions	in m^3 /m^2*h as cooling rate	3
D	roughness, air paths and ventilation	land use, openness, use of background wind and local circulations	land use and openness surface data	z_o derived from the wind profile	2
E	slope analysis, downhill movements	relief energy for thermal induced circulations	digital elevation model	in percent slope inclination	3

4 **RESULTS** URBAN CLIMATIC MAP OF ARNHEM

The map synergizes all collected information and analysis to present the climatic understand and evolution. The above mentioned layerstranslated to meteorological characteristics like heat storage (thermal load), cooling effects, surface conditions and surface roughness and dynamic parameters (wind pattern). Different categories were derived and can be described for planning aspects. The evaluation follows the thermal load index Physiological Equivalent Temperature (PET) The physiological equivalent temperature (PET) is used because it describes the thermal load based on the heat balance of man. PET is calculated from the influencing meteorological parameters of wind speed, radiation, air temperature and humidity. The index tells how different people from around the world are able to cope with different temperatures. For people in the Netherlands a temperature of 22°C is most suitable. Below and above that threshold people could have an uncomfortable feeling.

The legend of the map has two categories. One comes from the calculation, and the other is wind information with land use information in addition to that. Green colours mean cold air production with downstream drainage or fresh air with or without relief energy, the light green and orange areas are mixed zones which can be warm during day but are able to cool down at night, while the red colours indicates areas with more risk of heat accumulation. So altogether there are six classifications from strong heat load, mixed climates, cold production areas, including the sublayers to explain land use differences. Here one can even differentiate with one classification following the city structure and building density. The wind information as well as the sublayers are added in the map as an information layer, but they are already factored in into the six classification results. They show the direction as well as whether they are part of an air path or a slope circulation system. All layers are explained in detail in chapter 5.

The urban climate map of Arnhem shows three different sections of a heat island. City centre, residential areas and parts of the built up outer surroundings. The sublayers express some variability inside one classification due to city structures. Further on in the table as well as in the map, the sublayers are an additional information added on to the calculation. With this one can explain the inhomogenousity of one classification but not in a detailed spatial accuracy.

Industrial areas have head load but somewhat buffered through a sufficient ventilation, especially those affected by the main air path with background wind.

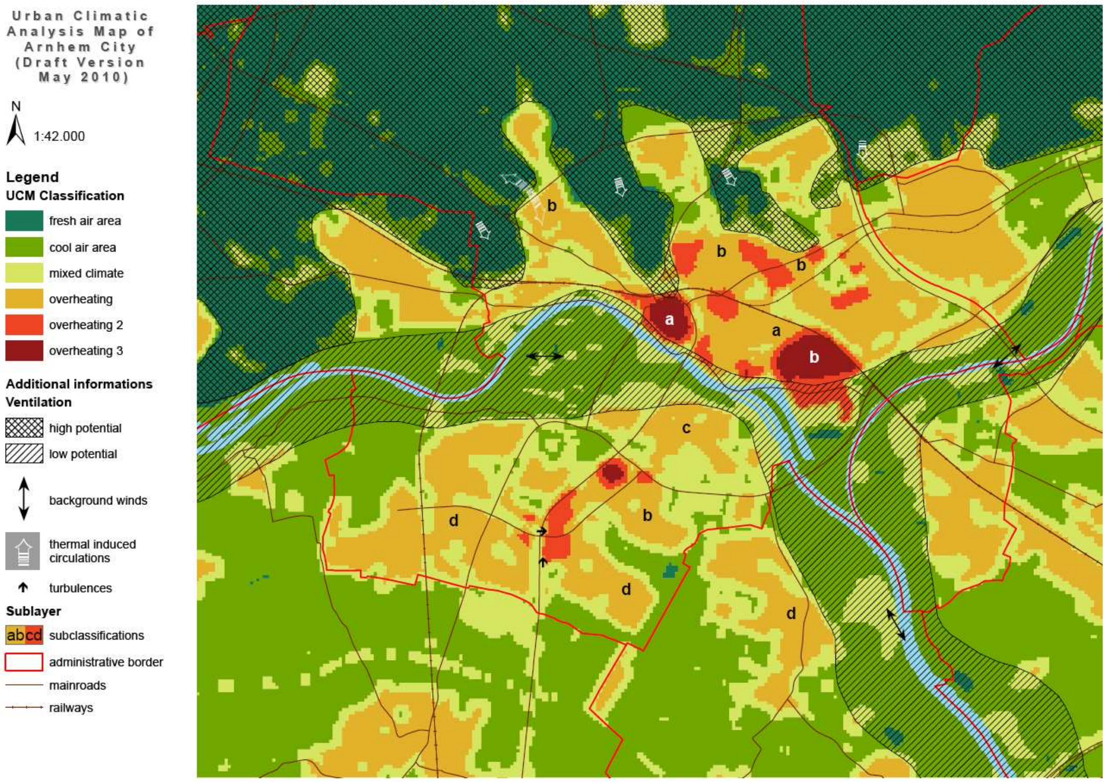

Figure 6. *Urban climatic map of the City of Arnhem*

The effect of air paths as well as thermal induced circulation in the northern part of the city (on the slopes of the 'Veluwe') is remarkable The difference of 70 m height is enough to create downhill movements. In connection to the valley wind (upstream and downstream) and to background winds are important factors. For the map the ventilation classification is separated in: low potential, which needs background winds and high potential, which is driven by relief and heat balance differences of surfaces.

5 Conclusions from the Urban Climate Map of Arnhem

To understand and to use the map for urban planning some evaluations must be done. Here the conclusions are written in a table following the legend from the map (figure 6). This is a general recommendation on the level of the urban climate map zones. Cool and fresh air areas have to be preserved or even enhanced, while the urban heat island, especially zones 5 and 6 should be improved. The first two react sensible to land use change, while in the last two land use change should lead to an improvement of heat stress.

Concerning the sublayers in the table as well as in the map, these are additional information added on to the calculation. With this one can explain the inhomogenousity of one classification but not in a detailed spatial accuracy.

Detailed local recommendations will follow, but cannot dealt with here on the urban scale.

classification	climatic description	Morphology	Evaluation
1 Cool air and fresh air production zones	Open areas with significant climatic activity, cool and fresh air production; climatically active open sites in direct relation to the housing area; in combination to slopes very effective in cooling the city	All areas with vegetation including parks and forests	Areas to carefully preserve: High sensitivity with respect to intervention which changes in land use. Do not allow to increase the surface roughness (e.g. no further constructions or buildings). Keep open of cold/ fresh air stream; Minimize the existing barrier on the air streams. The air movement connections must be fully analyzed and understood including the source of the air stream channels, which may be far away from the concerning area.

2 Cool air production zones	Open areas with less significant climatic activity; but fresh air is production effects neighborhoods	All areas with vegetation here mainly agriculture, parks and gardens, no pollutions sources	Areas to preserve: The increasing surface roughness (e.g. further constructions or buildings) can only be allowed if they respect slope winds and thermal induced circulation pattern; furthermore, redevelopments should only be allowed in exception case, which is supported by detailed investigation and analysis on climatic function aspect.
3 Mixed areas including a) train track b) residential areas, urban edge situation, transition zones c) park areas	strong daily variation through income radiation, but good cooling effect	Train areas as well as small housing areas and smaller parks, the built up areas with linkages to surroundings	Areas with possible development: Important linkage areas, foresee the orientation and density of buildings, surface roughness should not be increased due to reduction in ventilation with effect on neighbourhoods
4 moderate urban heat a) dense row houses 4 -5 storey b) Less dense row houses three to four storey c) Row houses as before up to 10 storey d) Low raised buildings max. 3 storey	Some heat storage but mainly buffered through greeneries and wind	small housing areas all with low heat storage but with some heat load	Development allowed: No appreciable sensitivity in terms of climate with respect to intensification of use and building agglomeration. Generally redevelopment is possible if they take care about ventilation and if the ratio between built up area versus green area is maintained/respected.

5 remarkable urban heat island including a) city b) offices, low industrial but ventilated	heat storage remarkable but still some wind effects and cooling potentials	more dense and higher buildings, but still some cooling effect either through greeneries or wind	Areas for improvement and plan actions are necessary: Risk of future heat stress with some ventilation. So generally the areas should be maintained or improved, and not worsen. Development can only be allowed with compensation for climate effects. The existing air circulation should be analyzed before any proposed change so that the urban climate is respected
6 urban heat island maximum including a) inner city b) industry high also shopping mall in southern part of the city	heat storage high and low cooling potentials and low ventilation	densely build up areas with high percentage of concrete, ventilation rather low	Areas for improvement and plan actions are necessary: In need of renewal from the point of view of urban climate. Greenery for facades and surfaces are needed. Increasing of existing heat stress, due to the accumulated problems on thermal load in the high dense built-up area, the climatic condition of this zone should be improved. Development in this zone is allowed only if enough compensation is done. Improving air exchange is one major recommendation together with shadow providing design.

7 air paths for background wind and thermal induced ventilation pattern	background and regional winds	Open areas with low roughness, used for background winds	
8 areas for thermal induced circulations	thermal winds and slope circulations	Open areas with some buildings but affected by thermal induced circulation such as cool and fresh air movements	
Wind information from urban climate map a) regional wind using air paths b) thermal induced circulation c) downhill winds d) turbulences			

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