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Cover Image: Wind travels across Lake Washington, buffeting the 520 floating bridge as the storm grows in strength. (Steve Ringman / The Seattle Times).

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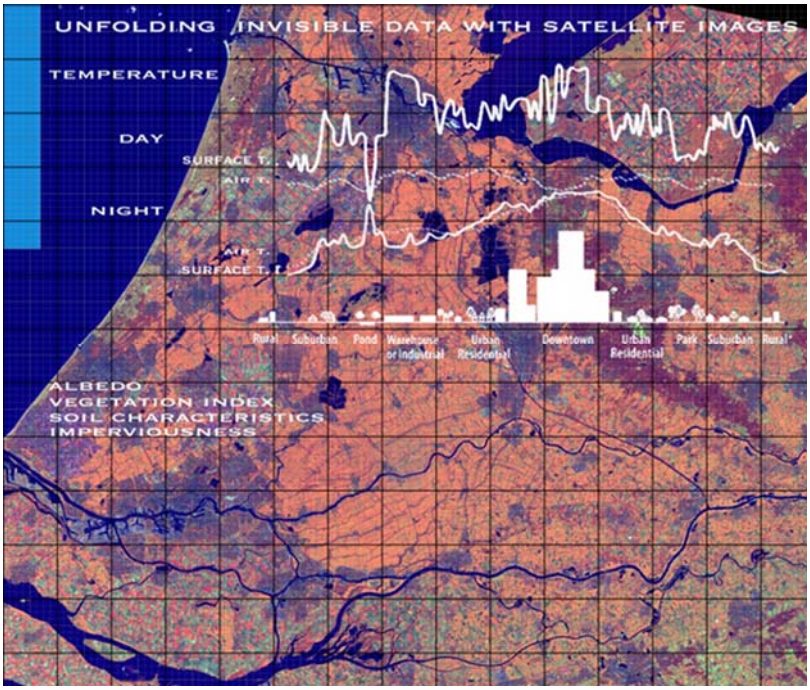

SURFACE THERMAL ANALYSIS OF NORTH BRABANT CITIES AND NEIGHBOURHOODS DURING HEAT WAVES

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ABSTRACT

The urban heat island effect is often associated with large metropolises. However, in the Netherlands even small cities will be affected by the phenomenon in the future (Hove et al., 2011), due to the dispersed or mosaic urbanisation patterns in particularly the southern part of the country: the province of North Brabant. This study analyses the average night time land surface temperature (LST) of 21 North-Brabant urban areas through 22 satellite images retrieved by Modis 11A1 during the 2006 heat wave and uses Landsat 5 Thematic Mapper to map albedo and normalized difference temperature index (NDVI) values. Albedo, NDVI and imperviousness are found to play the most relevant role in the increase of night-time LST. The surface cover cluster analysis of these three parameters reveals that the 12 "urban living environment" categories used in the region of North Brabant can actually be reduced to 7 categories, which simplifies the design guidelines to improve the surface thermal behaviour of the different neighbourhoods thus reducing the Urban Heat Island (UHI) effect in existing medium size cities and future developments adjacent to those cities.

KEYWORDS:
Urban Heat Island; Climate Change; Sustainable Urban Planning; Remote Sensing.

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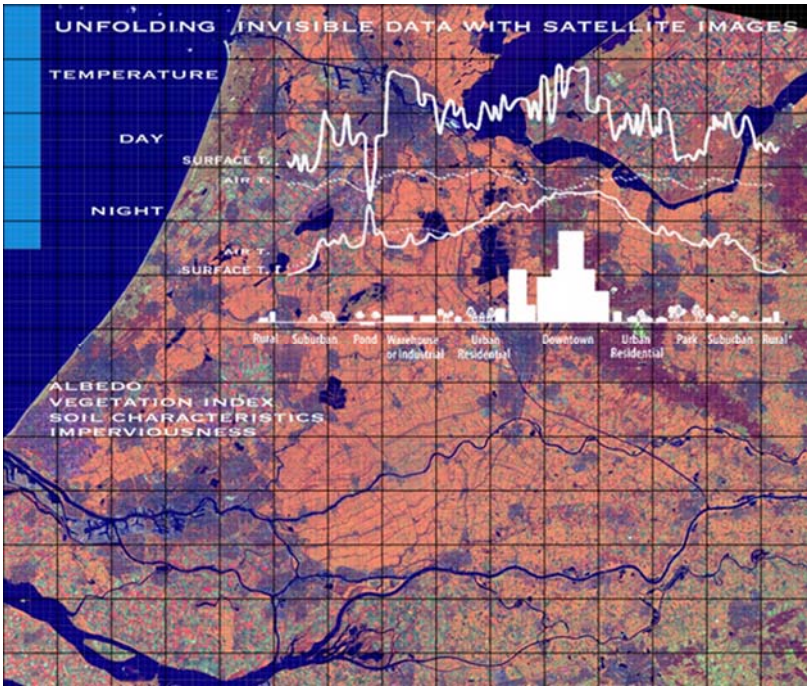

对遭遇热浪袭击的布拉班特省北部城市及其周边地区进行的地表热力分析

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摘要

城市热岛效应经常与大城市密切相关。然而，荷兰的城市大多是像南部的布拉班特省一样分散式或马赛克式的，这导致一些小城市都将在未来受到这种热岛效应的影响（Hove et al., 2011）。本研究通过 MODIS 11A1（搭载在terra和aqua卫星上的一个重要的传感器）传回的22幅关于2006年热浪的卫星图像和陆地卫星5号（Landsat 5）专题测图仪（Thematic Mapper）绘制的反射率和归一化温度指数（NDVI）值，研究分析了布拉班特省北部21个地区的夜间平均地表温度（LST）。研究发现，反射率、归一化温度指数（NDVI）值和不渗透性是导致夜间平均地表温度上升最有关联性的因素。通过上三个参数对地表覆盖聚丛的分析，体现出曾用于布拉班特省北部地区的12个“城市居住环境”类型可以减少到7类。这有利于简化设计指导方，提高周边地区的地表热力体现，减少中等城市的城市热岛效应，并促进毗邻城市未来的发展。

关键词:
城市热岛效应；气候变化；可持续的城市规划；遥感

1 INTRODUCTION

1.2 HEAT ISLANDS AND MEDIUM SIZE CITIES

The urban heat island (UHI) refers to the temperature difference between urban areas and their rural and/or natural surroundings. This temperature difference may affect the air temperature, the land surface temperature (LST) or both. Although the two are related, the difference is that while land surface temperature´s peak takes place during the day, the air temperatures differences are largest after sunset. The air temperature difference peak that is typically reached after sunset can reach up to 12ºC for a city of 1 million inhabitants (United Stated Environmental Agency). These relative high temperatures are especially problematic during heat waves and can easily result in heat stress among vulnerable segments of the urban population, leading to widespread mortality. Several climate studies show that even though The Netherlands may seem relatively safe from heat events due to its moderate maritime climate and its polycentric urban structure, it is actually also affected by heat events like those that took place in France in 2003 or in Russia in 2010 (Hove et al. 2011, Van der Hoeven F. and Wandl A. 2014, Albers et al., 2015). Many studies highlight the importance of developing and implementing urban planning measures to adapt our cities to climate change (Galderisi A. and Ferrara F.F., 2012; Papa R., Galderisi A., Vigo Majello M.C., Saretta E., 2015; Deppisch S., Dittmer D., 2015; Balaban O., Balaban M.S., 2015). The impact that heat islands can have on society has been studied in the last decade by several research groups (Stone B., 2012). A link was found between the night-time urban heat island as observed by satellites and the excess mortality in Paris during the heat wave of 2003 (Dousset et al., 2011). Other investigations showed that the urban heat island did have a measurable effect on aggravating the impact of the same heat wave event in Paris (Vandentorren et al., 2006). Similar conclusions were drawn in the case of London (Mavrogianni et al., 2011). In all of these cases the object of research is the large metropolis. Similar investigations into dispersed regional urbanization patterns are lacking.

North Brabant is a province located in the South and Center of the Netherlands. It is one of the biggest and most populated Dutch provinces. Due to its polycentric urban structure the Netherlands still has a relative high population density. The population that inhabits the Dutch towns and cities is ageing and becomes more vulnerable to heat. The four climate scenarios that are drawn up by the Royal Netherlands Meteorological Institute (KNMI) predict an increase of the global temperatures of at least 1 ºC (Van den Hurk B. et al., 2006) and predictions foresee an increased probability of summer heat waves (Sterl et al, 2008). The definition of a heat wave differs from country to country. In the Netherlands each period of at least five consecutive days with a maximum temperature above 25˚C, of which at least three days peak above 30˚C is registered as an official heat wave.

1.3 NORTH BRABANT: PARTICULAR MOSAIC URBAN STRUCTURE

In the context of urban heat the province of North Brabant is particularly interesting. The urban structure of NorthBrabant (2.5 million inhabitants, 500,000 ha) consists of a network of almost 300 small-size cities (urban cores in rural areas with surfaces below 900 ha) and some 60 midsize cities (urban concentration areas with surfaces below 8,000 ha) interleaved with rural and natural park areas. The overall percentage of urbanized land represents 15.4%. The future spatial vision of North Brabant region (Provincie Noord-Brabant, 2010) organizes the midsize cities in three clusters: the first one comprises the two most important agglomerations Tilburg (12,000 ha and 550,000 inhabitants) and Eindhoven (750,000 inhabitants), the second one which comprises a group of cities to the west: Bergen op Zoom, Roosendaal, Etten-Leur, Breda, Oosterhout, Waalwijk, ´s-Hertogenbosch and Oss (with sizes ranging from 12,900 ha in Breda to 5,590 ha in Etten-Leur) and the third category which consists of Uden (6,700 ha) and Veghel (7,900 ha), two former

villages that have strongly grown in the last decade and that have a marked suburban and industrial character. The urban structure is considered as a network up to the point that the five most important cities of the region - Tilburg, Breda, ´s-Hertogenbosch, Eindhoven and Helmond - receive the name of Brabantstad, which means in Dutch as much as: Brabant City.

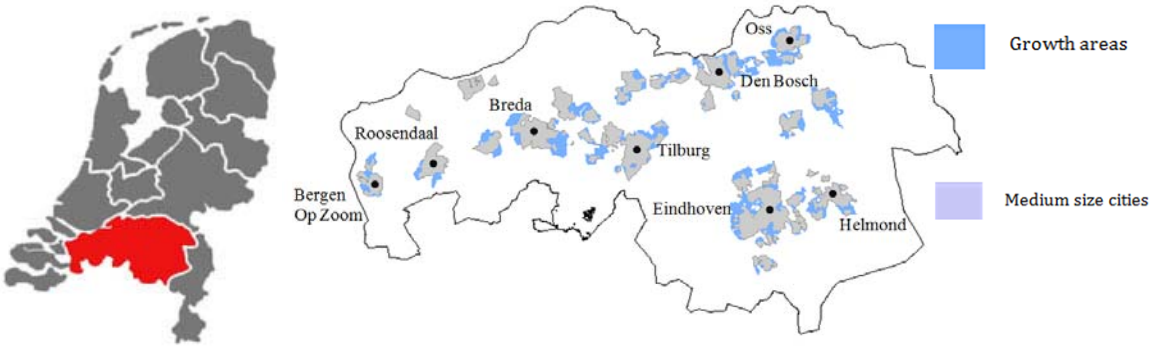


Fig. 1 Growth areas adjacent to medium-size cities

1.4 FUTURE EXPANSION PLANS OF THE REGION

The future spatial vision of North-Brabant (Provincie Noord-Brabant, 2010) foresees to enhance the spatial structure of the urban network through two different development prospects for small cities and for medium-size cities. The intention is to have midsize cities host regional urban infrastructures, as opposed to the small cities, which will inevitably play a role at a more local scale. In order to materialise the reinforcement of the urban network, the region of North Brabant has identified growth areas (in Dutch "zoekgebieden voor verstedelijking") connected both to small and midsize cities (Provincie Noord-Brabant, 2014). These are rural areas, which will be converted into urban plots, connected to existing cities (figure 1). The Province plans to urbanise over 25,000 hectares of which roughly 17,000 ha are adjacent to midsize cities. Overall the future percentage of urbanised land will increase from 15.4% to 20.4%. The province of North Brabant is aware of the implications of increasing the urbanised areas, and has used the "ladder for sustainable urbanisation" developed by the Dutch Ministry of Infrastructure and Environment to compare the urban development needs with the options to restructure nearby derelict areas prior to delimiting the "growth areas". However, the potential urban heat island aggravation produced by the growth of urban areas has not been taken into consideration.

1.5 RESEARCH QUESTIONS:

How can we ensure that future development plans do not aggravate the urban heat island effect in the province of North Brabant?

In order to answer this question we have formulated four sub questions:

- What is the extend of the current heat island problem in North Brabant?
- How does albedo, normalized difference vegetation index (NDVI), imperviousness, city size and proximity to other urban areas influence the phenomenon?
- Which of these play the most relevant UHI role?
- Can we establish a surface thermal urban classification to provide design guidelines to ensure that future developments do not aggravate the UHI phenomenon?

2 METHODOLOGY

2.1 DETERMINING THE ROLE OF DIFFERENT PARAMETERS IN THE FORMATION OF THE UHI IN THE REGION OF NORTH BRABANT

In the first section of the study we have mapped and calculated the average night-time land surface (LST) temperature (which has been calculated for 21 medium-size cities in the region of North Brabant with MODIS 11A1 images retrieved during the heat wave of 2006 in The Netherlands), albedo (calculated with Landsat 5TM imagery retrieved during the 2006 heat wave), NDVI (calculated with Landsat 5TM imagery retrieved during the 2006 heat wave), imperviousness coefficient (calculated using official Netherlands ArcGis files) and surface, and we have completed a multiple regression analysis to understand how each of these parameters affected the average night-time LST, and which of them played the most important role in the region of North Brabant. We have also used Excel´s dynamic charts to establish thresholds and reference figures for each of the analysed parameters.

2.1.1 NIGHT-TIME LAND SURFACE TEMPERATURE FROM JULY 2006 AS A KEY UHI INDICATOR

The spatial pattern of the daytime (LST) urban heat island differs often significantly from the spatial pattern of the night time (air temperature) urban heat island. However, the night-time air temperature and LST heat islands have strong correlations (Nichol J. 2005). The main exceptions are water surfaces. Because the cities in the province North-Brabant have relatively little open water, we can use night-time satellite imagery as a source of data for determining for the overall UHI effect. In this context we analysed the average night-time surface temperature of 21 midsize cities (with surfaces ranging from 117 ha to 7,700 ha) using 22 satellite images retrieved by Modis 11A1 during July 2006. July 2006 was the warmest month on record since systematic measurements started some 300 years ago in the Netherlands. The mean daily temperature in July 2006 was 22.3ºC, almost 5ºC higher than the average over the period of 1971-2000: 17.4ºC according to the Royal Netherlands Meteorological Institute (KNMI, 2006). Temperatures reached on July 19th 2006 a maximum of 35.7 ºC (KNMI, 2013). Statistics Netherlands published an article in its web magazine that states that 1,000 inhabitants died in July 2006 above the average mortality in a July month.Predeominatly in the western part of the country, by the way. Topography plays a significant role in many regions in the world when it comes to climate. Not so in the case of North-Brabant. North-Brabant is like much of the rest of the Netherlands: flat. The lowest parts in the western part of the province measure 1-2 metres above sea level. The highest parts in the east at a distance of 100 kilometres are 45 metres above sea level.

There is a lack of prevailing winds during heat waves. Heat waves emerge in the Netherlands predominantly under the condition of low or even lacking wind speeds. Problems with urban heat occur especially when there is no or little wind. For example, during the temperature peak on July 19th the KNMI measured wind speeds between 2.0-3.0 m/s^2, while in urban areas these wind speeds would be significantly lower due to the many buildings, trees and other obstacles. Temperature is the dominant factor here.

The data we used, MOD11A1, is a satellite imagery product issued by the Moderate Resolution Imaging Spectro-radiometer (MODIS), which has a resolution of 1,000 m and a daily temporal frequency. The images have been downloaded from the United States Geological Survey webpage. First, the average night time surface temperature for each of the medium size cities was calculated for each of the satellite images and afterwards the average value of all the heat wave satellite images retrieved during the heat wave. These two operations were performed using ArcGis.

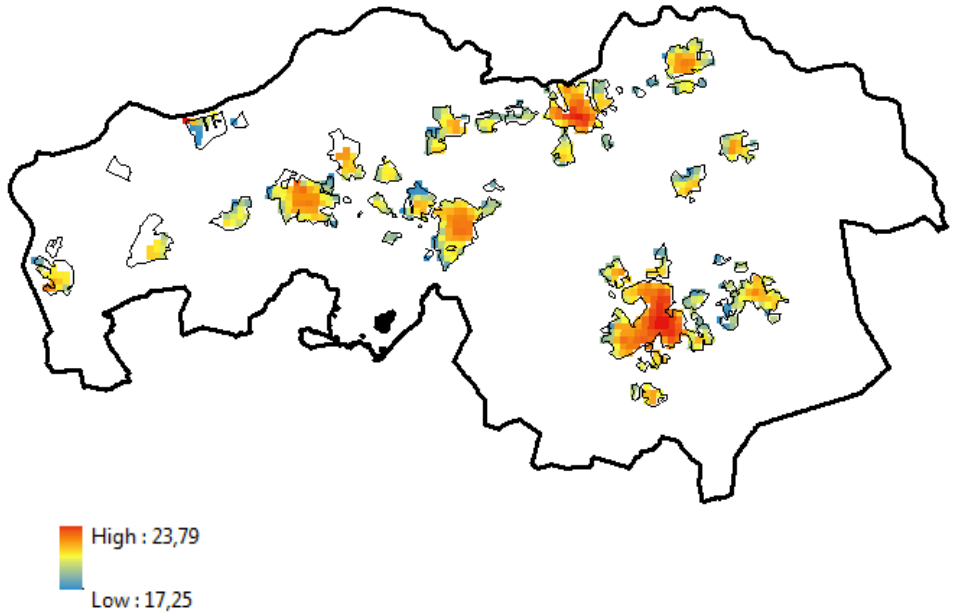


Fig. 2 Average night time LST urban areas of the province of North Brabant. LST values retrieved from Modis 11A1 imagery of the 23rd of July 2006

2.1.2 UHI-RELATED PARAMETERS ANALYSED

PARAMETERS RELATED THE URBAN DESIGN

Albedo, imperviousness and vegetation seem to be relevant parameters influencing the UHI. Several works have investigated the role of surface albedo in the UHI formation (Gao et al. 2014; Prado & Ferreira, 2005; Akbari et al. 2001; Taha 1997; Sailor 1995; Taha et al. 1992; Taha et al. 1988). Other studies have found a strong linear relationship between the land surface temperature (LST) and the imperviousness percentage and an inverse linear relationship between LST and the NDVI during the summer seasons (Nie & Xy 2014, Yu & Lu 2014; Heldens et al. 2013; Xu et al. 2012; Zhang et al. 2009; Weng & Lu 2008; Xiao et al. 2007; Yuan & Bauer 2007).

In this study we have used Landsat 5 TM satellite imagery from the 25th of July 2006 to calculate albedo and NDVI. We have downloaded the raw satellite images from the US Geological Survey (USGS) webpage, Earth Resources Observation and Science Center (EROS). For the albedo calculation, we have used software for satellite imagery atmospheric topographic correction called ATCOR 2/3 which allows not only to correct atmospherically the images but also to generate the corresponding albedo distribution image (Richter & Schlapfer, 2013) (figure 3). For the NDVI calculation we have first corrected Landsat 5 TM spectral bands 3 (visible) and 4 (near-infrared) – both with a 30 m resolution - in ATCOR 2/3 and we have further used a geospatial imagery treatment software called ENVI 4.7 to map the actual index, which is defined as (NIR-VIS)/(NIR+VIS), where VIS (visible radiation) is the surface reflectance in the red region (650 nm) and NIR (near-infrared radiation) is the surface reflectance in the near-infrared region (850 nm) (figure 4). The final average calculation of the average albedo and NDVI values for each of the 21 analysed cities has been done in ArcGis.

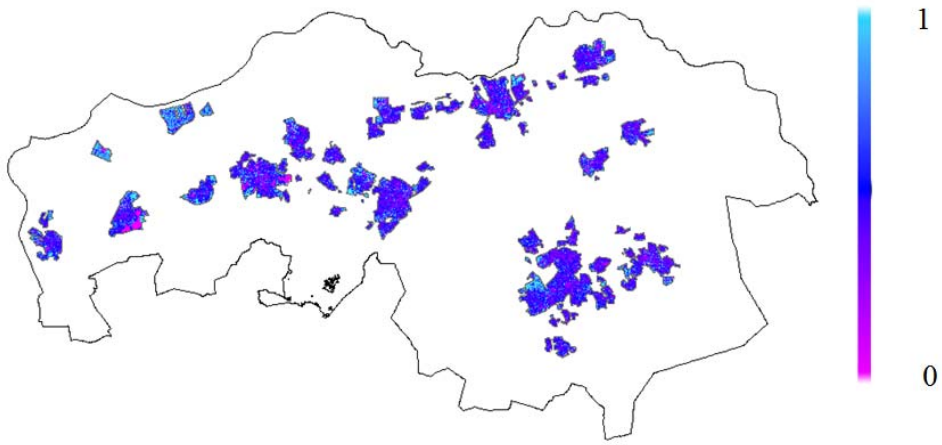


Fig. 3 Average albedo in urban areas of the province of North Brabant

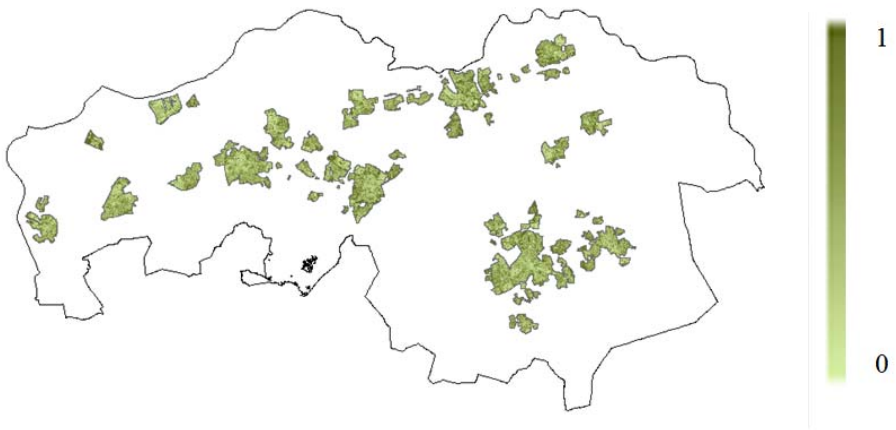


Fig. 4 Average NDVI in urban areas of the province of North Brabant.

The mapping and calculation of the average imperviousness was done calculating for each of the 21 midsize cities, the surface occupied by buildings and roads. We have processed in ArcGis the TOP10NL file to obtain the percentage of imperviousness for each city.

PARAMETERS RELATED TO CITY SIZE

The accumulation of urban heat is correlated with the size of cities. Several studies have made an effort to quantify the relationship between city size and the UHI effect. Oke (1973) found a linear relationship between the maximum urban heat island intensity (max UHI) and the logarithm of the population of cities in North America and in Europe: equations 1 and 2 that were obtained using data from the 1970s and 1980s.

North America

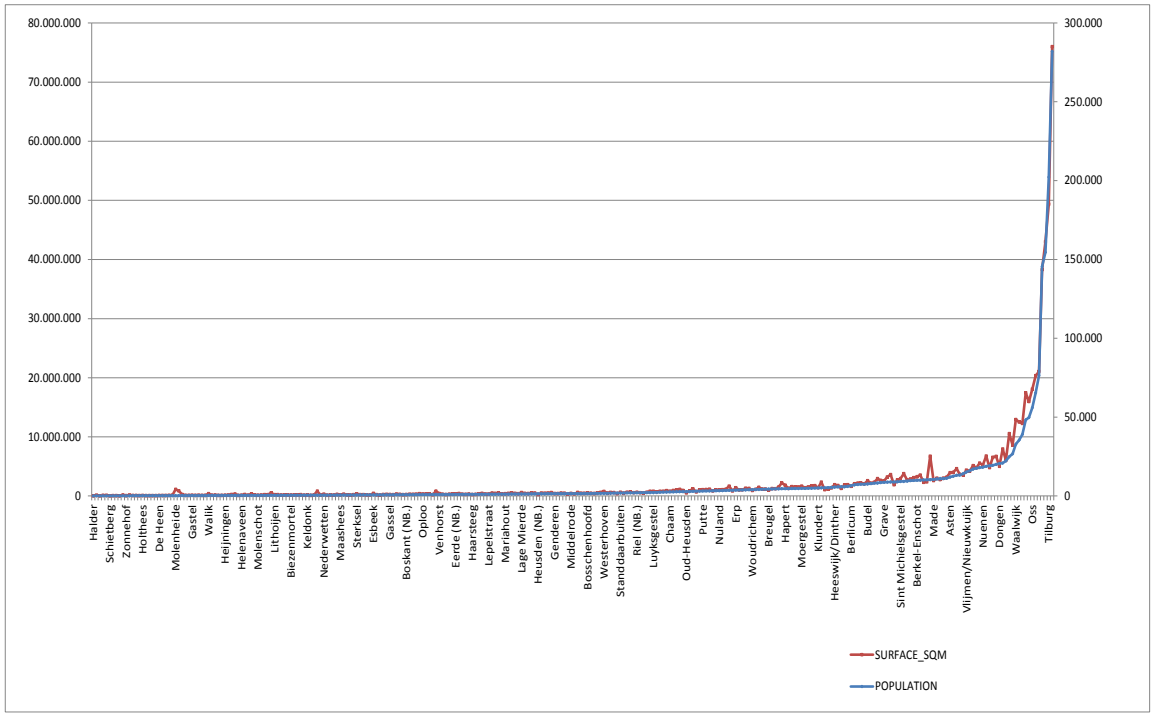
[max UHI = 2.96 log (P) - 6.41] (1)

Europe

[max UHI=2.01 log (P) - 4.06] (2)

Park and Kufuoka have attempted to find the relationships for South Korea and Japan (Park, 1986; Fujuoka, 1983). Hove(2011) highlights that the studies carried out with results from 1987 to 2008 reveal that there is a steeper relationship between the maximal UHI intensity and the population, and that the maximal UHI for Dutch cities with a population between 100,000 and 800,000 inhabitants would range from 4 to 8ºC. In

North-Brabant the vast majority of the midsize cities have less than 100,000 inhabitants (except for Tilburg, Breda,'s-Hertogenbosch and Eindhoven). This study aims at analysing how the size of smaller Dutch cities affects the UHI effect. For the analysis of the size of the cities we have chosen to analyse the city surface instead of the city population, since we have found a very high correlation (r2= 0.99) between the number of inhabitants (2006, PBL Netherlands Environmental Assessment Agency) and the surface of the cities (Graph 1).



Graph 1 Analysis of surface and population of North Brabant medium-size cities

2.2 THERMAL URBAN CLASSIFICATION OF MEDIUM-SIZE CITIES IN THE REGION OF NORTH BRABANT

In the second part of our study we have created a surface thermal classification map of the different neighbourhood typologies present in the analysed medium-size cities of the region of North Brabant. Urban climate classification maps provide practical information on the behaviour of different urban structures and climate, thus connecting climatological studies to urban planner´s reality. There is a first group of investigations that have been completed based on site measurements and available urban morphology documentation. It is the case of several studies carried out before. Chandler (1965) used climate, physiography and built form to classify Greater London in four zones. Auer (1978) analysed vegetation and building characteristics to create 12 "meteorologically significant" land uses in the city of St. Louis. Ellefsen (1990) analysed geometry, street configuration and construction material for the creation of "urban terrain zones". Wilmers (1991) worked on urban and rural structures, use and vegetation to identify the main "climatotopes" in Metropolitan Hannover. Scherer (1999) analysed land use and topography for the generation of a refined "climatope" classification of the region of Basel. Oke (2004) studied urban structure, cover, fabric, metabolism and potential to generate "urban climate zones". Stewart & Oke (2012), finally, researched "local climate zones" for urban heat island observation. There is a second group of papers that have produced urban climate classifications based on remote sensing analysis, which systematizes and makes it more cost effective. It is the case of the semi-automatic classification carried out for the city of Toulouse (Houet & Pigeon, 2011) to classify sample areas in "urban climate zones", the surface material

assessment of urban zones for the generation of "urban structure types" in the city of Munich (Heiden et al., 2012), the socio-economic and environmental impacts of the different urban structures in the same city (Pauleit & Duhme,2000), the object-based image classifiation used to map urban structure typologies also in Munich (Wurm et al. 2010) and the land-use classification produced for metropolitan Atlanta (Tang, 2007).

In the Netherlands there are two main "urban living environment" classification systems. One is the one developed by ABF (ABF research, 2005) and the other one is RIGO-typology for neighbourhoods built before and after the war (RIGO 1995; RIGO 1997). Both analyse physical characteristics of housing and urban equipment but Rigo classification also takes into consideration socio-economic factors (Planbureau voor de leefomgeving, 2006). Even though these "urban living environment" typologies are consistent throughout the country, since 2004 the role of these classification systems has considerably been reduced since the approval of the Spatial Strategy of 2004 - Nota Ruimte 2004 (VROM, 2004) - which conferred most of the spatial policy competences to provinces and municipalities. Most provinces and municipalities have used these as a basis to develop their own classification systems to analyse the existing built environment and to create design guidelines for future developments from different angles. In the case of the province of North Brabant, an "urban living environment" classification was carried out based on physical characteristics of the neighbourhoods (location, density, housing typology and mix of uses) (figure 5) in the context of a housing survey carried out in 1998 (WBO, 1998) and further been used in other housing surveys of the region (Poulus & Heida, 2002). This classification establishes twelve main categories: high-density city centre, city centre, pre-war neighbourhood, post-war compact neighbourhood, post-war soil bound neighbourhood, urban green, small urban centre, small urban, small urban green, village centre, village, rural accessible.

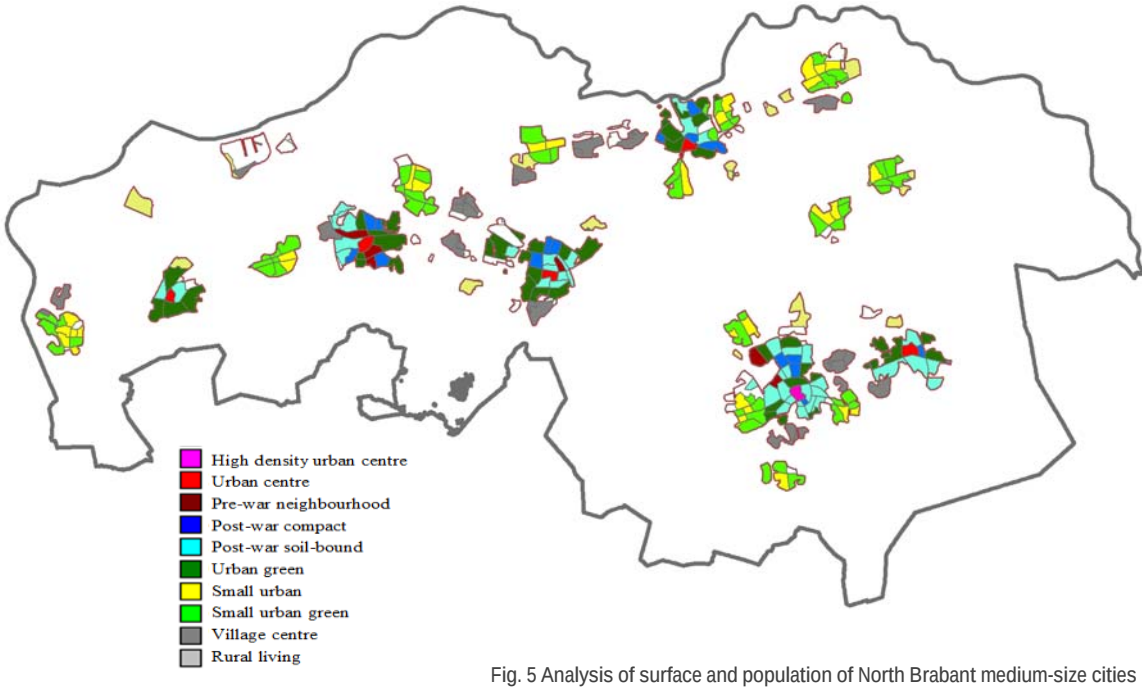


Fig. 5 Analysis of surface and population of North Brabant medium-size cities

In this study we have created a 6-cluster surface cover thermal classification of the urban cores of the region of North Brabant using the three most relevant parameters (identified in the first part of the study) influencing night time urban LST to complete an unsupervised cluster classification in GIS. Further we have overlapped the obtained surface cluster classification with the "urban living environment" classification of the region of North Brabant, in order to review this official "urban living environment" classification with surface cover thermal criteria.

3. RESULTS AND DISCUSSION

3.1 THE ROLE OF DIFFERENT PARAMETERS IN THE FORMATION OF THE UHI IN THE REGION OF NORTH BRABANT

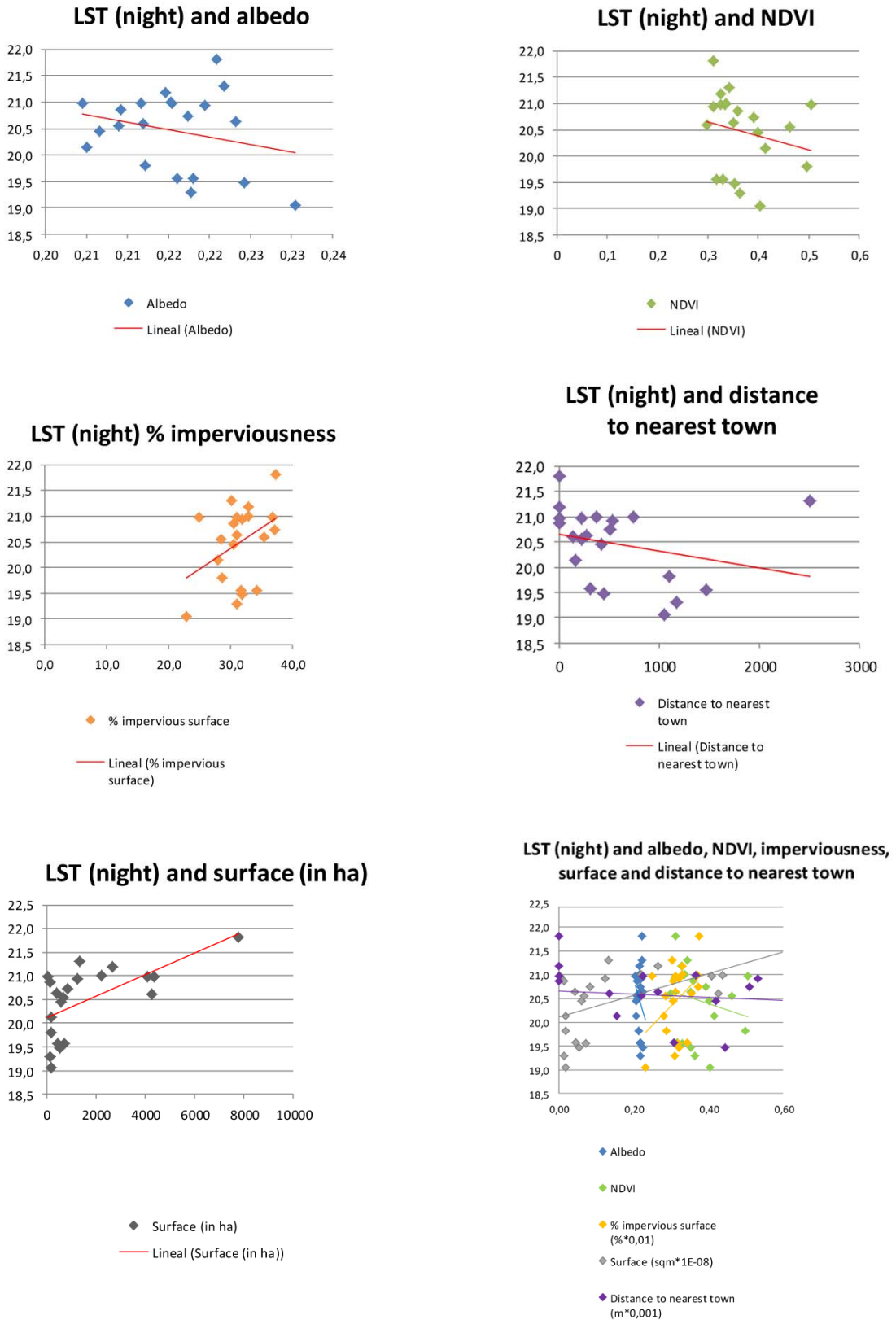
The multiple regression analysis of the average values obtained for Albedo, NDVI, imperviousness, distance to the nearest urban area and town size, shows that there is a multiple correlation coefficient of R=0.7 and R2=0.5 that relates these parameters with the average night time surface temperature (chart 1). We have obtained the following parameter coefficients:

LST (average night) = 27.7 – 34,8*A + 2.3E-08*S - 0,1*NDVI
Where A = Albedo, S = surface and NDVI = Normalized Difference Vegetation Index

It seems that the most relevant indicators in this case are albedo and NDVI (Graph 2). Imperviousness, the distance to nearest town and the surface of the analysed cities do not seem to play a significant role in the LST night values for the medium-size cities analysed in the region of North Brabant, which do not exceed 7,700 ha in any case. The maximum calculated average city night time LST difference is 2.9ºC. The average city albedo values are pretty similar for all cities and range from 0.20 to 0.23. NDVI variations vary from 0.31 till 0.50 and imperviousness coefficient ranges from 23% to 37.4%. The future growth of most medium-size cities of the regions will not per se aggravate the UHI phenomenon, in turn it will be the design of the new neighbourhoods, which will impact or not the formation of urban heat in the province.

Average Modis night time lst. July 2006.	Albedo	NDVI	% impervious surface	distance to nearest town (in m)	Surface (in sqm)
19,1	0,23	0,40	23,0	1051	1.731.927
19,3	0,22	0,36	31,0	1175	1.185.046
19,5	0,22	0,35	32,0	445	5.344.222
19,6	0,22	0,33	31,7	1472	7.077.232
19,6	0,22	0,32	34,2	306	4.523.848
19,8	0,21	0,50	28,8	1101	1.699.638
20,1	0,21	0,41	28,0	154	1.815.197
20,4	0,21	0,40	30,5	419	5.880.326
20,5	0,21	0,46	28,4	220	6.569.954
20,6	0,21	0,30	35,4	135	42.534.733
20,6	0,22	0,35	31,0	264	4.112.599
20,7	0,22	0,39	37,2	509	8.318.652
20,9	0,21	0,36	30,5	0	1.328.614
20,9	0,22	0,31	31,9	532	12.355.689
21,0	0,20	0,50	24,9	225	229.409
21,0	0,21	0,33	31,1	0	40.850.073
21,0	0,22	0,33	36,9	365	43.619.598
21,0	0,22	0,34	33,0	733	21.948.146
21,2	0,21	0,33	32,9	0	26.512.601
21,3	0,22	0,34	30,2	2500	13.259.052

Tab.1 Data list of the analysed medium size cities of the region of North Brabant. Parameters analysed: night time LST, albedo, NDVI, imperviousness, distance to nearest town and surface.



Graph 2 Analysis of the relationship between the different parameters and night time average LST, for each of the analysed medium size cities in the region of North Brabant

3.2 REDEFINING THE "URBAN LIVING ENVIRONMENT" CLASSIFICATION BASED ON THERMAL SURFACE COVER CRITERIA

3.2.1 UNSUPERVISED SURFACE THERMAL CLUSTERING

Even though the average LST presents maximum variations of 3ºC (section 3.1), we have completed an unsupervised cluster classification of the three most relevant surface cover parameters (albedo, NDVI and imperviousness), in order to understand the different surface behaviours within each town. We have obtained 6 different clusters.

Even though the average night time LST of these clusters are pretty similar, each of these clusters has a singular albedo, NDVI and imperviousness combination (graph 3).

The thermal surface cover assessment is more accurate when performed through the unsupervised classification of albedo, NDVI and imperviousness than through the calculation of the night time LST, due to the tools used in this study for these calculations.

Albedo and NDVI are calculated based on Landsat satellite imagery which has a resolution of 30 m and imperviousness is calculated based on a GIS model whereas night LST is calculated based on Modis 11A1 satellite imagery which has a 1km resolution.

Modis 11A1 has a resolution appropriate for average city LST calculations, but not for surface cover discrimination.

The combined analysis of these three parameters allows classifying different surface typologies. The scatterplots analysis (graph 4, 5 and 6) highlights the importance of the combined analysis.

There are many areas from different clusters sharing identical values for each parameter separately; however they present different albedo, NDVI and imperviousness combinations.

Even though the average city values for albedo, NDVI and imperviousness did not differ considerably from one city to the next (graph 2), the surface cover cluster analysis presents average albedo ranging from 0.11 till 0.30, NDVI varying from 0.18 till 0.55 and imperviousness coefficients going from 0.21% till 0.41%.

The spatial distribution of each of these clusters reveals that three of these clusters (clusters 1 to 3) correspond to clusters of built area surface cover, and three of these clusters (clusters 4 to 6) correspond to non-built areas surface cover clusters (figure 6).

Cluster 1 corresponds to specific urban areas with the poorest surface thermal behaviour, mainly present in small specific areas of the city centres or of industrial areas.

They have very low albedo (0,11), high imperviousness (39%), and low NDVI (0,17)).

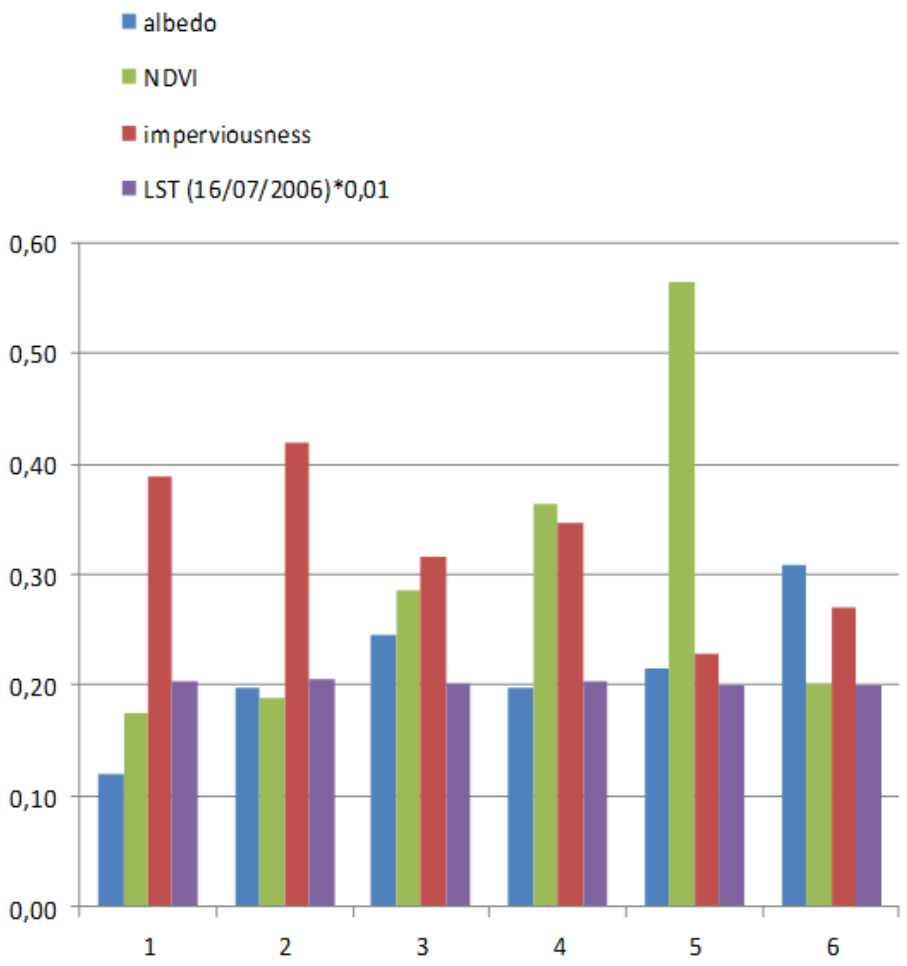
Cluster 2 presents a similar average NDVI value (0,19), slightly higher imperviousness (0,42) and considerably higher albedo (0,2) than cluster 1. The main difference between cluster 1 and cluster 2 is the albedo.

The majority of the city centre surfaces belong to cluster 2.

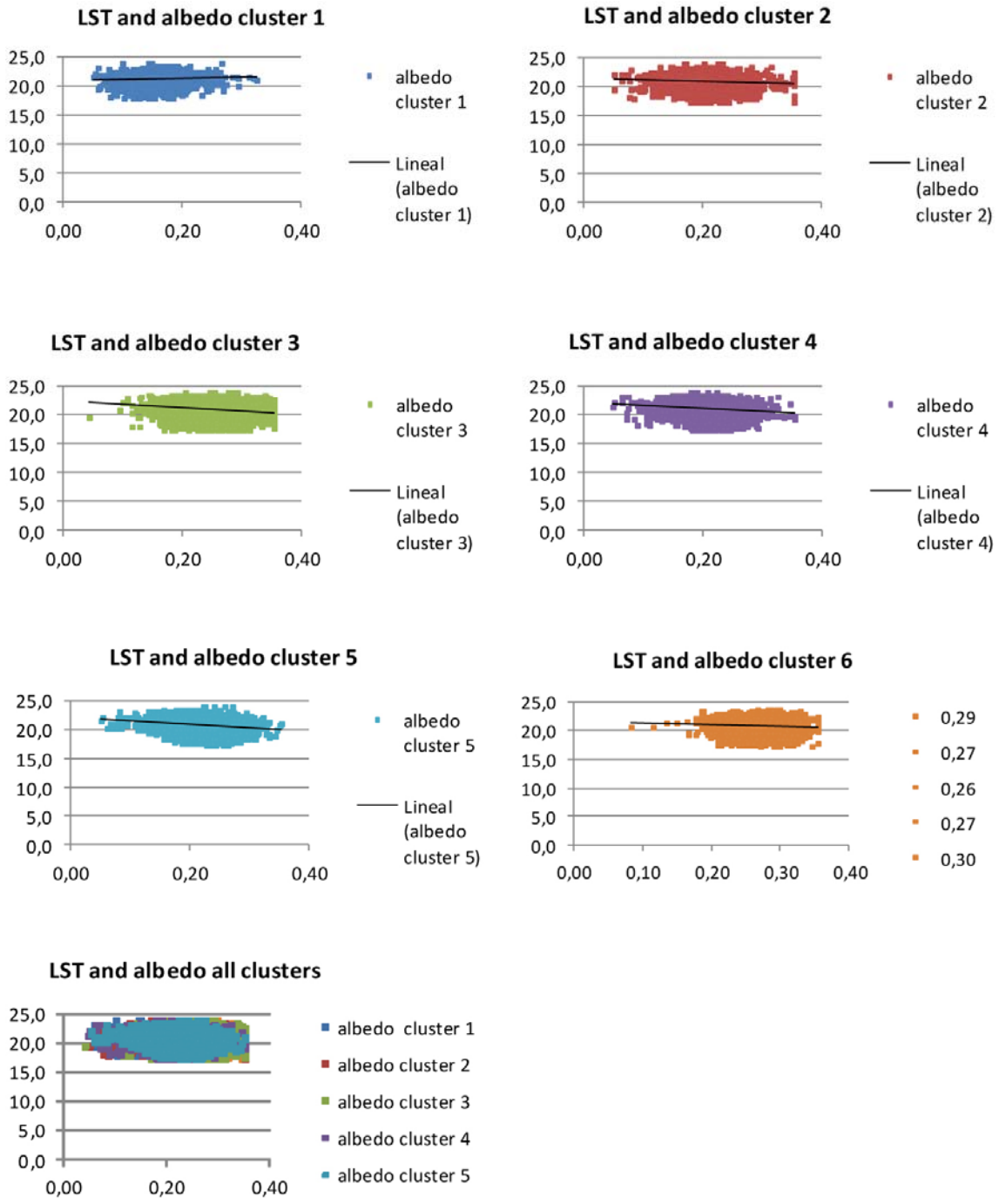
Cluster 3 seems to correspond to urban residential areas (row houses) with interspersed green areas, presenting a slightly higher albedo (0,24), higher NDVI (0,28) and lower imperviousness (0,31).

Cluster 4 can be identified with low density residential areas (detached houses) areas of urban parks with trees with higher NDVI, lower albedo (due to the presence of greenery) and slightly higher imperviousness.

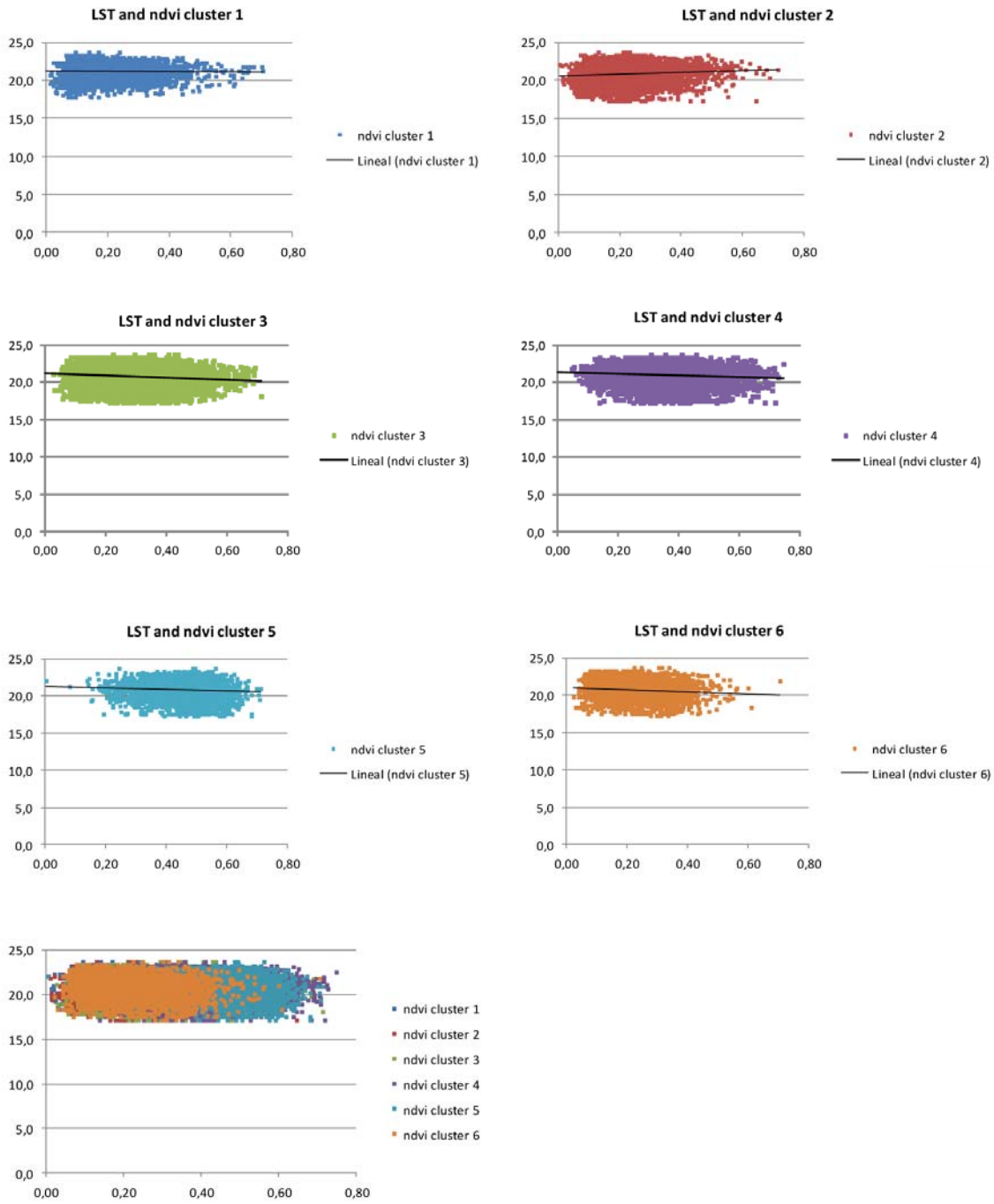
Cluster 5 corresponds to urban trees and water areas with the highest NDVI (0,55), the lowest imperviousness 22% and a relatively low albedo (0,21 due to the presence of vegetation) and cluster 6 corresponds to bare soil areas with the highest albedo (0,31), considerably low NDVI (0,20) and small imperviousness 26% (Graph 3).



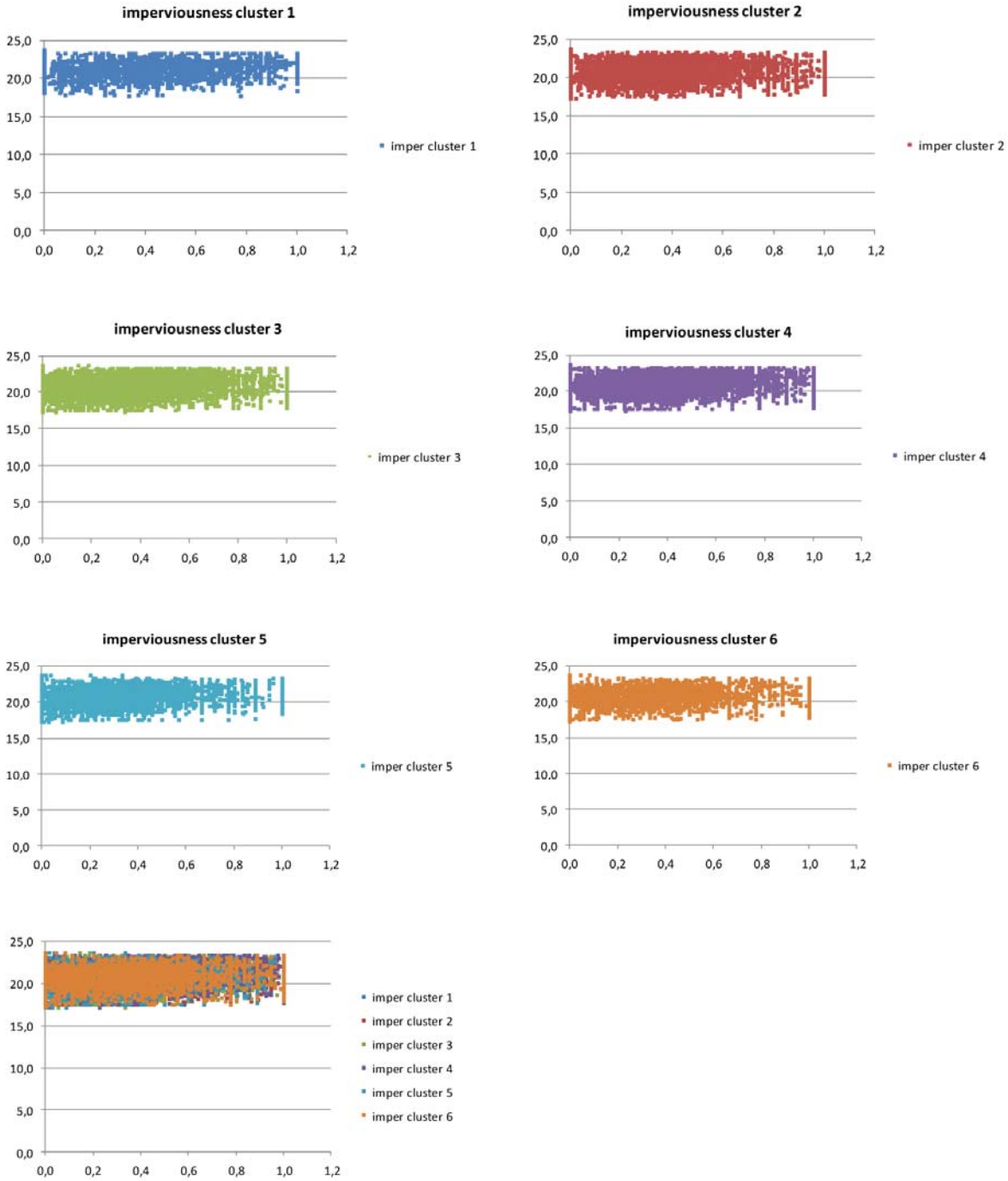
Graph 3 Average albedo, NDVI, imperviousness and night LST values for each of the 6 clusters resulting from the unsupervised classification of the albedo, NDVI and imperviousness maps of the analysed medium-size cities of North Brabant.



Graph 4 Scatterplots of night LST and albedo, for each of the different surface cover clusters



Graph 5 Scatterplots of night LST and NDVI, for each of the different surface cover clusters



Graph 6 Scatterplots of night LST and imperviousness, for each of the different surface cover clusters

If we analyse the case Eindhoven metropolitan area we can see that the city centre is mostly covered with cluster 2 surfaces, and that in turn, cluster 4 has more presence in areas outside the city centre. Cluster 1 is only present in very specific, heat absorbing surface areas, whereas cluster 6 is hardly present in the city area (this is why it was not included in the analysed figure) (figure 6 and 7).

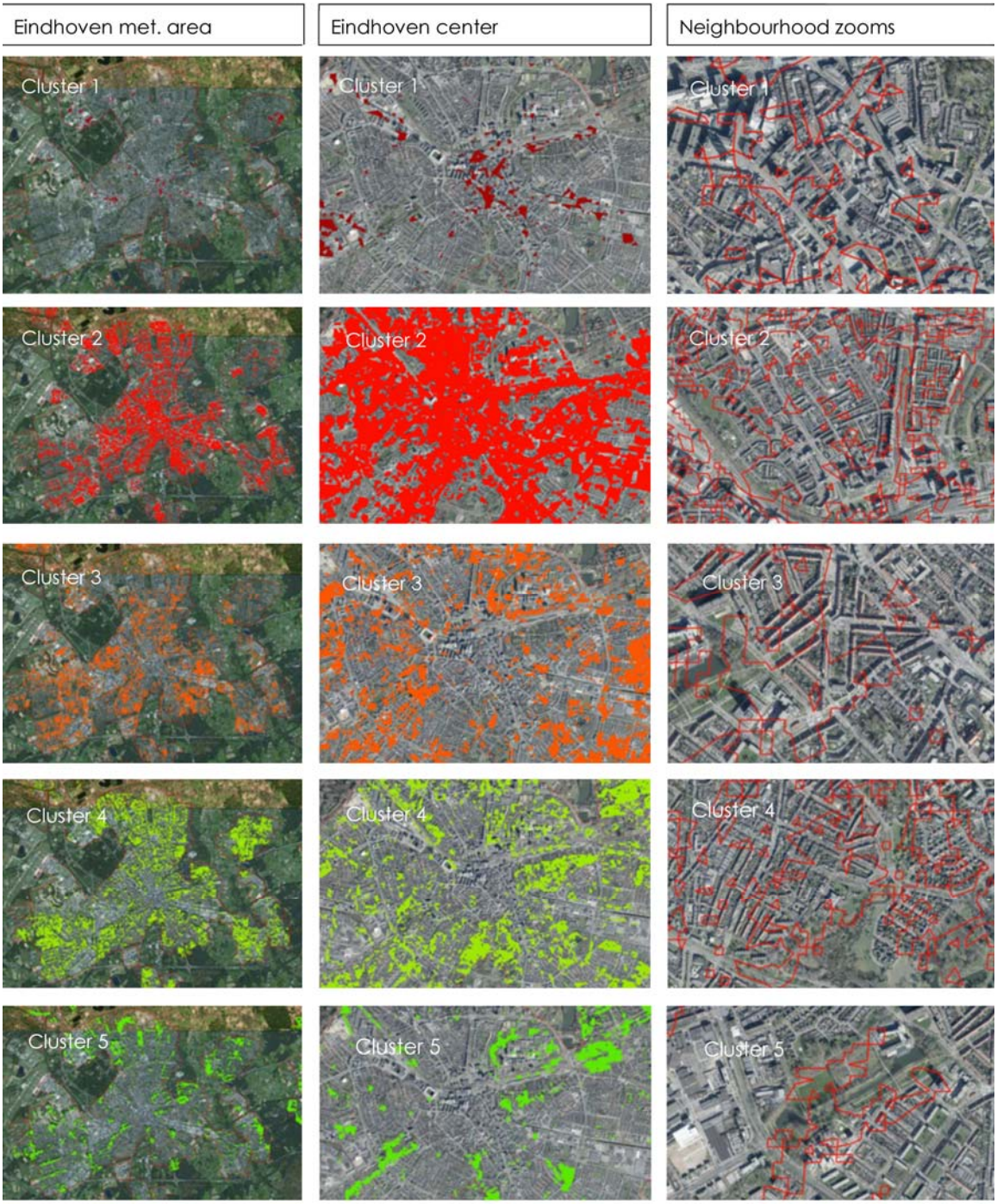


Fig. 6 Spatial distribution of surface cover clusters in Eindhoven metropolitan area

3.2.2 ANALYSIS OF THE PRESENCE OF SURFACE THERMAL CLUSTERS IN "URBAN LIVING ENVIRONMENT" CATEGORIES

The maps of Eindhoven metropolitan area illustrate the different spatial distribution of the clusters and the "urban living environment" maps. Each "urban living environment" map comprises a specific surface cluster mix (figure 7). In order to analyse how the surface thermal clusters match with the "urban living environment" categories of the region of North Brabant, we have calculated the proportion of clusters found in each of the " urban living environment" categories (graph 7). This analysis reveals that "urban living environment" classes 3, and 5 (pre-war neighbourhood and post-war ground based) present similar surface covers where clusters 2 cover more than 35% of the surface and where the proportion of urban clusters (1, 2 and 3) is in all cases above 60%.

The cluster mix analysis, also reveals that "urban living environments" 4, 6, 7, 8 and 9 (post-war compact, green, small urban centre, small urban and small urban green) present similar surface cover mixes, with similar cluster 2 and 4 presence, and where the proportion of urban surface cover clusters (1,2 and 3) is around 50%. We can establish that the 12 category "urban living environment" classification applied in North Brabant, could be reduced to a 7 surface cover classification.

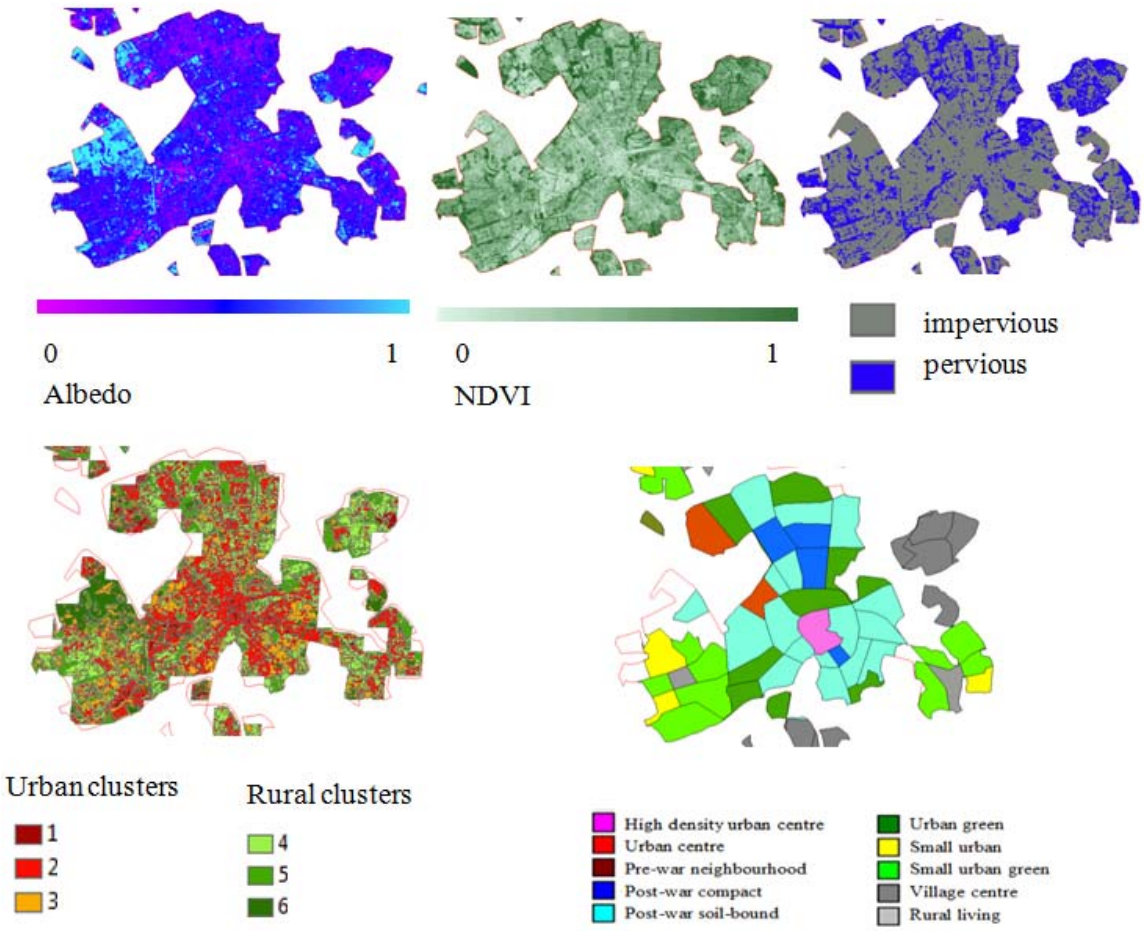
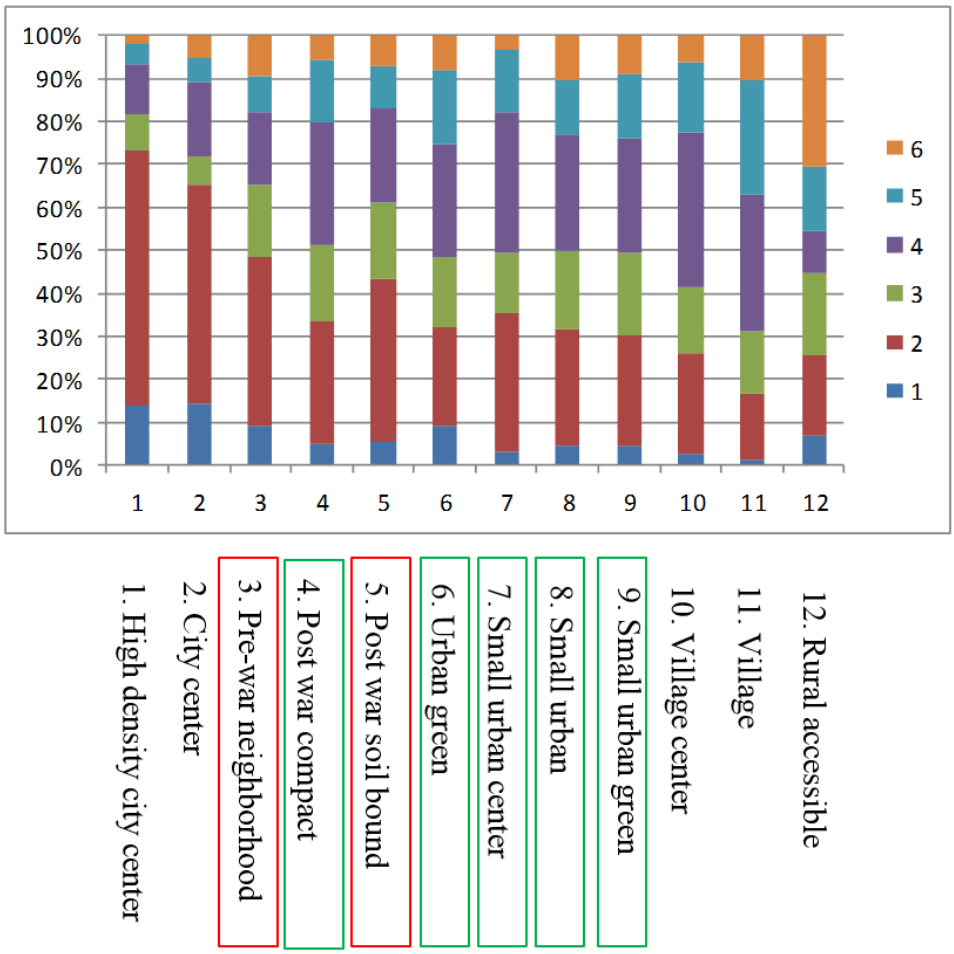


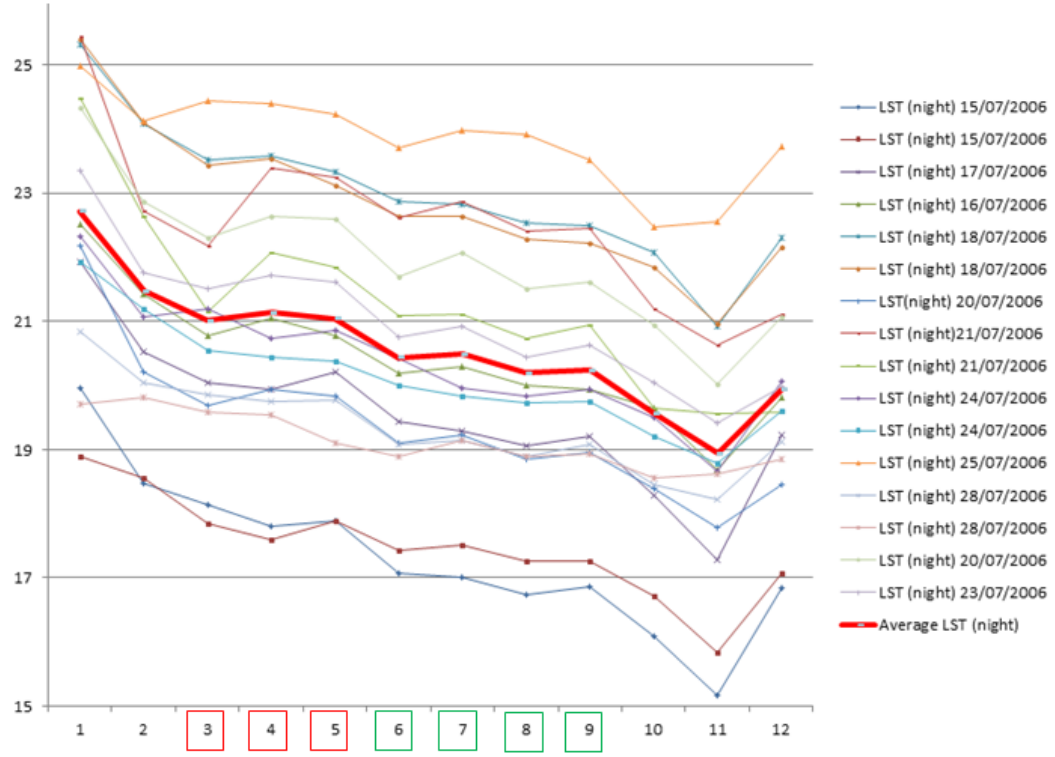
Fig. 7 Compilation of LST-related maps for Eindhoven metropolitan area: Albedo, NDVI, imperviousness, surface cover clustering and "urban living environment" categories



Graph 7 Surface cover cluster proportions for each of the "urban living environment" categories in the analysed medium-size cities of the North Brabant region. Neighbourhoods 3 and 5 present similar cluster proportions, and thus could be grouped. Neighbourhoods 4, 6, 7, 8 and 9 present similar cluster proportions, and thus could be grouped.

3.2.3 ANALYSIS OF AVERAGE NIGHT LST OF THE DIFFERENT "URBAN LIVING ENVIRONMENT" CATEGORIES

The analysis of the average night time LST retrieved by Modis 11A1 in 16 satellite images during the heat wave experienced in the month of July 2006 (Graph 8) reveals that 12 "urban living environment" categories could actually be grouped in 7, since categories 3, 4 and 5 (pre-war neighbourhood, post-war compact and post-war ground based) could be grouped into one single category since they present similar average LST (around 21ºC) and categories 6,7, 8 and 9 could be grouped into another category because they present similar average LST (around 20.3ºC).



Graph 8. Average night LST for each of the "urban living categories". Neighbourhoods 3, 4 and 5 present similar night LST, and thus could be grouped. Neighbourhoods 6, 7, 8 and 9 present similar night LST , and thus could be grouped.

3.2.4 PROPOSED "URBAN LIVING THERMAL CATEGORIES" FOR THE REGION OF NORTH BRABANT

The surface cluster analysis of the different "urban living environment categories" suggests that these can be grouped into 7 categories. 1/ High density city centre 2/ City centre 3/ pre-war neighbourhood & post-war soil bound 4/ post-war compact & urban green & small urban centre & small urban & small urban green 5/Village centre 6/Village 7/Rural accessible. The average night time land surface temperature analysis of the "urban living environment categories" suggests the same groups except for the post-war compact neighbourhood's category which has a night LST similar to pre-war and post war soil bound. The main reason is that post-war compact neighbourhoods is a category that consists of scattered high rise dwelling blocks, interleaved with green areas and large infrastructural roads. The proportion of green areas that can be found in these neighbourhoods is similar that the ones of small urban areas, however the overall night LST is higher in these post-war areas.

4 CONCLUSIONS

This paper addressed the main question how to ensure that the future development plans do not aggravate the urban heat island (UHI) effect in the North-Brabant urban areas, by focusing on three sub-questions: How bad is the urban heat island problem currently? How does albedo, normalized difference vegetation index (NDVI), imperviousness, city size and proximity to other urban areas influence the phenomenon? Which of these play the most relevant UHI role? Can we establish a surface thermal urban classification to provide design guidelines to ensure that future developments do not aggravate the UHI phenomenon?

The answer to the main question is found in adjusting the design of the growth areas that are designated by the province North-Brabant. The growth areas are based on the "ladder for sustainable urbanisation" developed by the Dutch Ministry of Infrastructure and Environment. The aspect of urban heat islands is not included in this methodology. We propose to include considerations about albedo, greenness (NDVI) and imperviousness, in the design of these future developments. Our study has revealed that albedo and NDVI are the most relevant parameters influencing the average night time LST for the analysed North Brabant medium-size cities. Correlation coefficients extracted from the multiple regression analysis are:

LST (average night) = 27.7 – 34,8*A + 2.3E-08*S - 0,1*NDVI
Where A = Albedo, S = surface and NDVI = Normalized Difference Vegetation Index

The surface cover cluster analysis of these three parameters reveals that the 12 "urban living environment" categories used in the region of North Brabant (high-density city centre, city centre, pre-war neighbourhood, post-war compact neighbourhood, post-war soil-bound neighbourhood, urban green, small urban centre, small urban, small urban green, village centre, village, rural accessible) can actually be reduced to 7 categories, since classes 3, 4 and 5 (pre-war neighbourhood, post-war compact and post-war ground based) present similar surface covers (and could thus be grouped) and the "urban living environments" 6, 7, 8 and 9 (green, small urban centre, small urban and small urban green) also present similar surface cover mixes (and could thus be grouped). This surface cover classification provides guidelines to improve the surface behaviour of the most common urban typologies that can be found in the province of North Brabant and to guide the urban design of the planned future urban developments. All of these conclusions could be integrated in a climate-robust growth areas policy.

5 DISCUSSION

The purpose of using the surface cover cluster analysis for the thermal assessment of the different "urban living environment" assessment (instead of calculating directly the average night time LST of each of these neighbourhood typologies) is to actually map and quantify parameters that can be addressed and improved. Measures to improve albedo, NDVI and imperviousness can be simulated and quantified. Mapping surface cover categories allows designing specific mitigation solutions, instead of only assessing on the intensity of the problem (night LST temperature).
The intention of the study is to analyse the thermal surface cover behaviour of the different "urban living environment" categories in order to design UHI adaptation measures in the existing neighbourhoods and to produce some surface adaptation guidelines for the future developments that will grow adjacent to the existing medium-size cities. The same urban structures can considerably improve their thermal behaviour though the implementation of measures that only affect their surface covers. We understand that parameters related to the neighbourhood structure (sky view factor, wind, shadow, ...) as well as factors such as anthropogenic heat emissions should be the object of another study to determine to what extent they influence the formation of the UHI in the province of North Brabant, and to explore and design the development of design guidelines concerning the urban structure for the design of future urban developments.

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IMAGE SOURCES

Cover image: Courtesy of the U.S.Geological Survey.USGS/NASA Landsat.Further processed

Fig. 1: Province North Brabant. Spatial vision, 2010

Fig. 2: Courtesy of the U.S. Geological Survey. USGS/NASA Modis

Fig. 3: Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3.

Fig. 4: Landsat image (Courtesy of the U.S. Geological Survey. USGS/NASA Landsat) further processed with ENVI 4.7 and Atcor 2.3.

Fig. 5: ABF research, 2005

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