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5A.7 INFLUENCE OF URBAN FEATURES ON INTRA-URBAN NOCTURNAL COOLING: AN EMPIRICAL APPROACH USING CLIMATIC MAPPING

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1. INTRODUCTION

Climate projections for Western Europe indicate that heat waves are likely to be more intense and more frequent in the coming decades. These climatic evolutions will impact notably urban planning. Planners and institutional stakeholders are urged to take into account present and future urban climate for the design of urban operations.

Urban heat island (i.e. air temperature gap between urban and rural areas) is a well known climatic phenomenon that strengthens negative effects of summertime heat waves. During the last decades, various modeling approaches of the urban heat island phenomenon have been proposed, including statistical models. Many of these models are linear regression of temperature differences between city center and surrounding rural area as a function of meteorological, topographical or urban parameters (Grimmond, 2010). In order to spatially organize the study of the air temperature distribution, statistical models can be totally or partially based on climatic mapping. This work combines a local scale climatic mapping scheme, and statistical methods to analyze the intra-urban nocturnal cooling. It investigates the relationship between the urban characteristics of a neighborhood, described by the urban indicators proposed in the Local Climate Zone classification (Stewart, 2011), and its climatic features.

2. MATERIALS AND METHODS

2.1. CLIMATIC MAPPING FOR THE AREA OF INTEREST

The Local Climate Zone scheme has been chosen to produce a climatic mapping of the

conurbation of Nancy (France). This middle-size city (approximately 286,000 inhabitants) is located north-east of France (Lat/Long: 48 41'N - 6 11'E) in the Lorraine plateau.

A Local Climate Zone is an area that demonstrates:

- A minimum diameter of 400 meters
- Uniform patterns in terms of urban morphology, land use, urban material and urban metabolism;
- Specific screen-height air temperature regime under calm and clear sky.

The climatic mapping method associated to this classification consists in find the best match between a given area and one of the seventeen existing LCZ types (ten built areas and seven non-built areas). At the beginning, airborne images and building height data are used to estimate the limits of homogeneous districts. Seven urban indicators are then calculated for a selection on thirteen districts. Finally, the most relevant LCZ type has been proposed for each of these areas.

Eleven LCZ types have been identified in Nancy. The denser types are located in the city center, while the less built and more vegetated areas are located in the periphery (Leconte, 2015).

2.2. MOBILE MEASUREMENTS FOR THE AREA OF INTEREST

The thirteen selected districts have been investigated using mobile measurements. A PT100 probe has been placed inside a ventilated cylinder mounted on the top of an instrumented vehicle (Figure 1). Air temperature measurements have been performed at a three meters distance step. A first set of data has been gathered including measures realized in the afternoon (from 2 pm and 5 pm) and in the middle of the night (from 12 am to 3 am). A second set concerns measurements performed every hour during 24 hours. Specific meteorological weather conditions have been chosen for the measurements, i.e. anticyclonic conditions, low cloud cover and low wind speed.

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Figure 1: Instrumented vehicle used for mobile measurements within Local Climate Zones

2.3. CLIMATIC INDICATORS

Using the hourly measurements, temperature evolution during calm and clear sky is presented for four different Local Climate Zone (Figure 2). Air temperature is similar for all zones during the morning and beginning of afternoon. Then, air temperature gaps appear between districts. According to Holmer (2007), the air temperature decrease is dissimilar between areas from one to two hour before sunset to three to five hours after sunset (Phase 1), and similar afterwards (Phase 2) until sunrise.

Three climatic indicators are used in this work to quantify the difference in terms of nocturnal cooling during phase 1, namely "Temperature gap between LCZ" (i.e. the air temperature gap between a given LCZ and the coolest LCZ, Figure 3), "Cooling rate" (i.e. the ratio between the daytime/nighttime air temperature drop and the time lapse between daytime and nighttime measures, Figure 4), and "Normalized cooling rate" (i.e. the ratio between the cooling rate and the daytime/nighttime air temperature drop of the coolest LCZ, Figure 5).

2.4. STATISTICAL APPROACH

Linear relationship are investigated between three climatic indicators (Temperature gap between LCZ, Cooling rate, Normalized cooling rate) and nine urban indicators, namely sky view factor, aspect ratio, mean building height, terrain roughness class, built surface fraction, impervious surface fraction, pervious surface fraction, distance to the center of the conurbation and elevation regarding sea level.

The thirteen LCZ selected in Nancy are taken into account. The coefficient of determination and the Akaike Information Criteria (AIC) are chosen to evaluate and compare regression equations. The statistical significance of all regression coefficients are tested with the Student's test.

3. RESULTS

The linear correlations have been investigated between each climatic indicators (CI) and urban indicators (UI), leading to 27 equations. Regression equations are written as follow:

$$CI = \beta_0 + \beta_1 UI_1 \quad (1)$$

Results for equation (1) show that all β_0 and β_1 coefficients pass the Student's test with a significance threshold of 0.05. For the three climatic indicators, the lowest AIC (i.e. the best regression from a statistical point of view) are found for the sky view factor, the terrain roughness class and the distance to the center of the conurbation. It appears that urban indicators related to the urban morphology tends to exhibit lower AIC values than land use indicators.

Regressions have been performed with multiple explanatory variables, i.e. multiple urban indicators. The main expected improvement of multiple linear regression against simple linear regression is the possibility to incorporate more explanatory variables, which can improve the quality of the statistical model. Regression theory states that collinearity between explanatory variables negatively impact the model, therefore correlations between urban indicators have been investigated. A correlation matrix has been calculated over the values of the nine urban indicators. Results show that morphological and land use urban indicators are significantly correlated between them. Morphological and land use indicators are correlated with the distance to the center of the conurbation partly because LCZ types are organized in Nancy following a concentric spatial pattern. Any urban indicator seems to be correlated with elevation, however there is no significant elevation differences between the selected districts. In this study, three linear regressions have been performed between each of the climatic indicator and the nine urban indicators, written as:

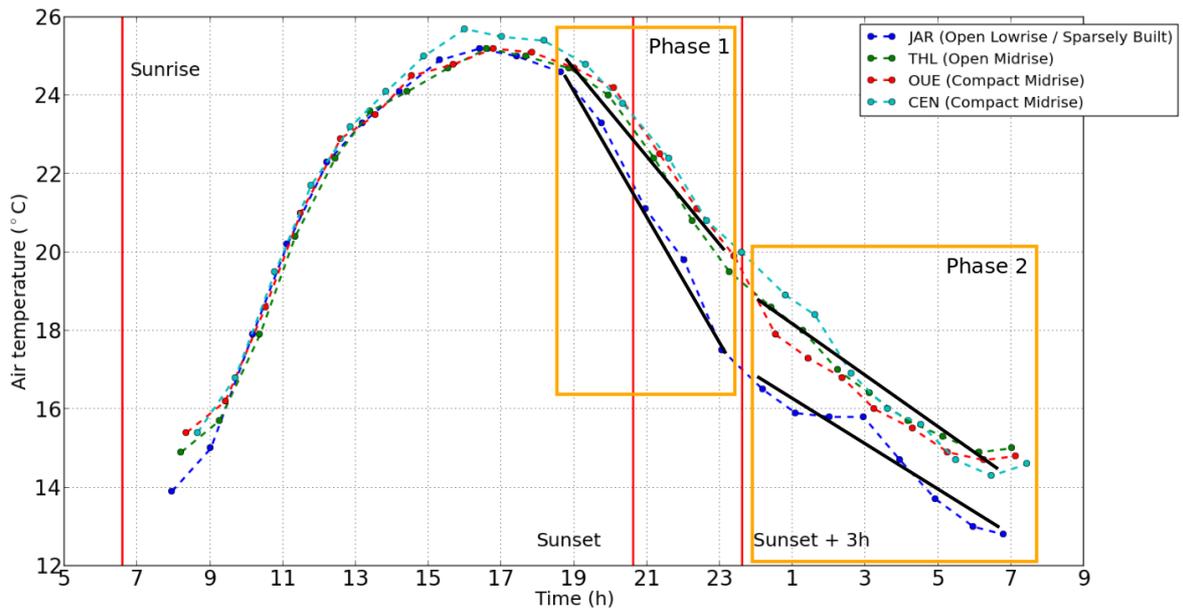


Figure 2: Air temperature measurements in four Local Climate Zones of Nancy. According to Holmer (2007), two phases of nocturnal cooling are highlighted.

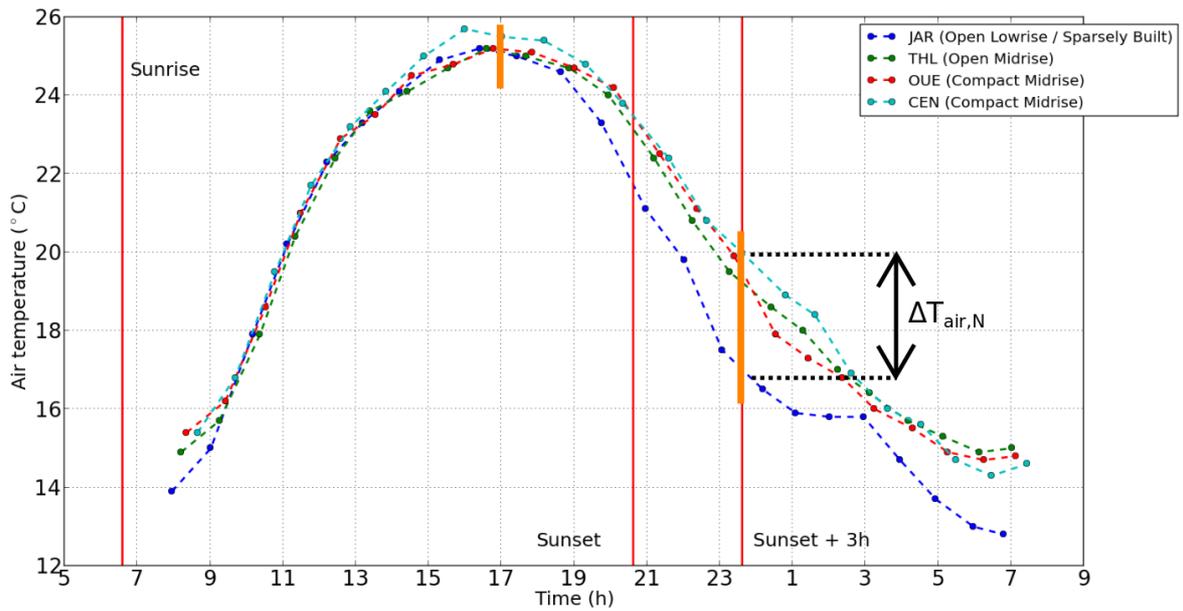


Figure 3: Air temperature measurements in four Local Climate Zones of Nancy. The temperature gap between LCZ is presented (i.e. the air temperature gap between a given LCZ and the coolest LCZ).

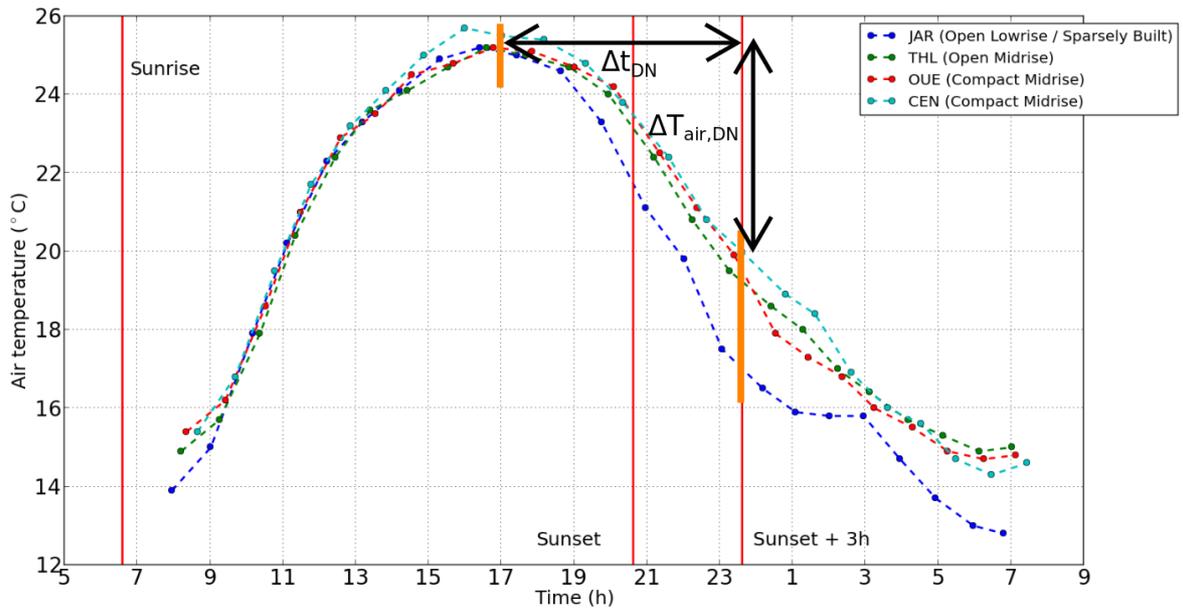


Figure 4: Air temperature measurements in four Local Climate Zones of Nancy. The cooling rate is presented (i.e. the ratio between the daytime/nighttime air temperature drop and the time lapse between daytime and nighttime measures).

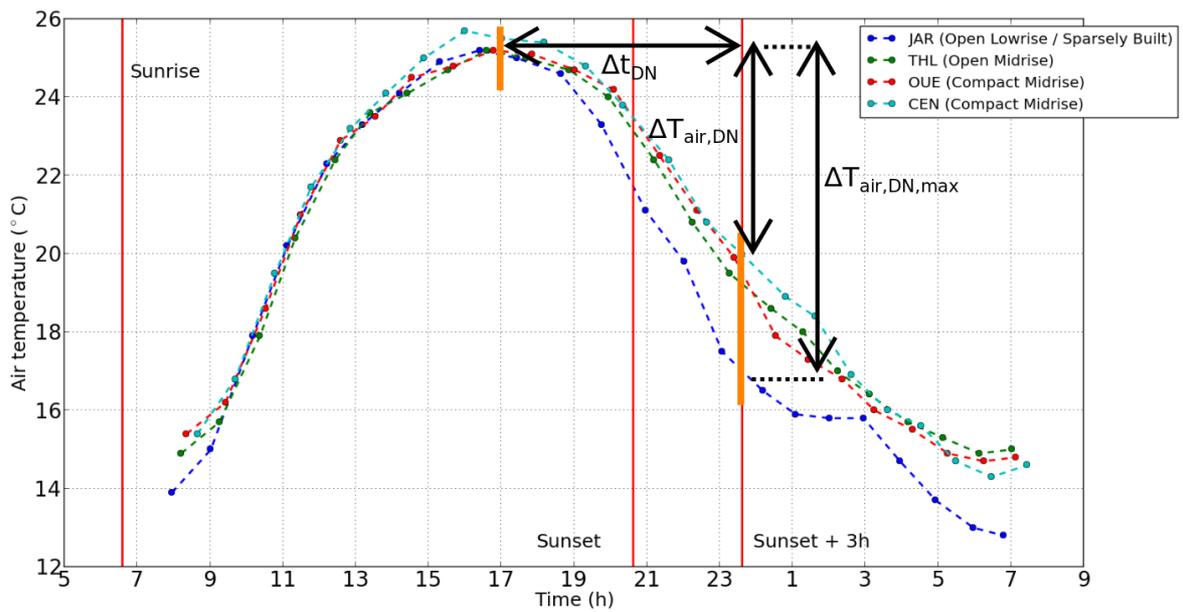


Figure 5: Air temperature measurements in four Local Climate Zones of Nancy. The normalized cooling rate is presented (i.e. the ratio between the cooling rate and the daytime/nighttime air temperature drop of the coolest LCZ).

	Temperature Gap $R^2=0.71$		Cooling rate $R^2=0.59$		Normalized cooling rate $R^2=0.53$	
	Value	Pr > t	Value	Pr > t	Value	Pr > t
β_0	9.5603	<0.0001	0.4809	<0.0001	0.0423	<0.0001
β_1	-6.5764	<0.0001	0.9343	<0.0001	0.0797	<0.0001
β_2	-0.0252	<0.0001	0.0019	0.0349	0.0002	0.0675

Table 1: β coefficients and Student's test results related to equation (3) for the three studied climatic indicators

$$CI = \beta_0 + \sum_{i=1}^9 \beta_i UI_i \quad (2)$$

Results exhibit that as expected, none of the β coefficients pass the Student's test if the significance threshold is 0.05. In that case, these coefficients are not statistically significant to explain the evolution of the studied climatic indicator.

An alternative approach consists in choosing a reduced number of explanatory variables. For this study, three regressions have been performed using the sky view factor and the pervious surface fraction as explanatory variables. These urban indicators have been selected because they demonstrate low AIC values in the single linear regression case, and because they provide an information on urban morphology and land use.

$$CI = \beta_0 + \beta_1 SVF + \beta_2 Pervious \quad (3)$$

Coefficient values for equation (3) are presented in Table 1. Almost all the β coefficients pass the Student's test if the significance threshold is 0.05. The R^2 values range from 0.53 to 0.71.

5. CONCLUSION

Mobile measurements and climatic classification have been used in order to gather high density air temperature datasets in the conurbation of Nancy. Statistical relationships have been investigated involving thirteen LCZ, nine urban indicators and three climatic indicators. For regressions with one explanatory variable, morphological urban indicator and pervious surface fraction perform better than other land

use indicators. In the case of linear regression with multiple explanatory variables, there are significant correlations between urban indicators. In order to counteract the drawbacks of collinearity, regression can be performed with a reduced number of explanatory variables.

6. ACKNOWLEDGMENTS

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