5A.6 PRINCIPLE OF A SEMI-EMPIRICAL URBAN HEAT ISLAND MODELING USING CLIMATE CLASSIFICATION AND MOBILE MEASUREMENTS

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1. INTRODUCTION

Recent climate studies state that heat waves are likely to be more intense and more frequent in a few decades across Europe (Christensen, 2007). The magnitude and duration of heat waves within cities can potentially be increased by the urban heat island phenomenon (Tan, 2010). Consequently, the incorporation of urban climate and urban heat island in urban design process becomes a tremendous necessity. However, urban planners may not use urban climate models on a regular basis. Indeed, numerous numerical urban climate models are exhaustive and highly complex (Bouyer, 2011). Moreover, the models outputs may not fit with the operational information that urban planners are looking for (Grimmond, 2010). It must be considered to adapt the modeling approaches to the urban planners needs, in order to provide them relevant information at various horizontal scales: street scale, neigborhood scale, conurbation scale.

The overall objective of this study is to develop a decision-support tool that deals with different horizontal scales under calm and clear sky. Two major hypotheses have been adopted: first, a specific climate classification (the Local Climate Zone classification (Stewart, 2011)) has been applied; second, the decision-support method is build based on in situ measurements carried out within Local Climate Zones. These measurements have been performed using an instrumented vehicle. This paper aims to present the principle of the model and to discuss its conceptual framework regarding the air temperature records obtained via mobile measurements

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2. LOCAL CLIMATE ZONES IN THE NANCY AREA

A LCZ is an area which has a minimum diameter of 400 m. According to the definition provided by Stewart (2011), this area demonstrates:

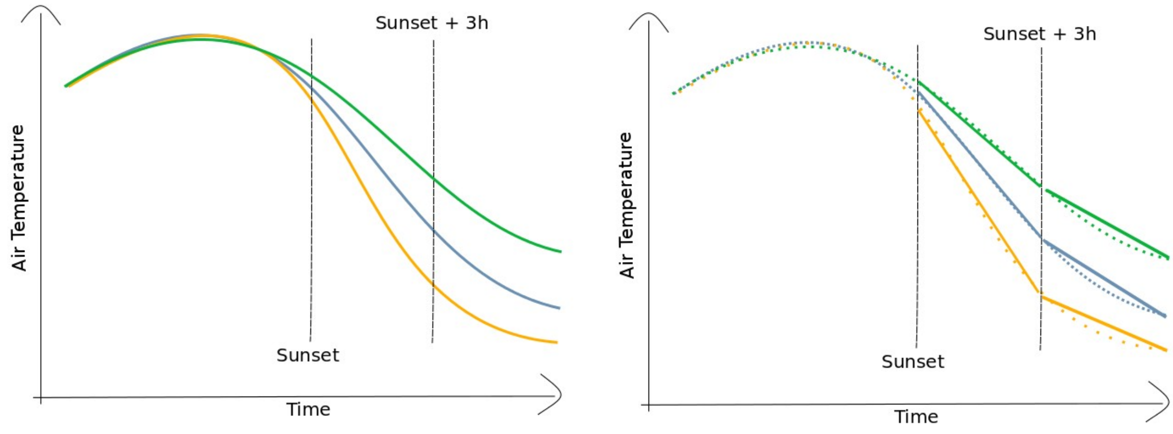
- Uniform characteristics in terms of urban morphology, land use, urban material and urban metabolism;
- Specific screen-height air temperature regime under calm and clear sky.

The LCZ scheme consists in 17 different types of LCZ. The methodology associated with this classification is find the best match between an existing area and one of these 17 LCZ types. Each type of LCZ is characterized by a definition, metadata and a specific combination of 10 indicators. The calculation of these indicators within the LCZ helps to identify the most accurate LCZ type.

The LCZ mapping has been carried out on the conurbation of Nancy (France), which numbers approximately 286.000 inhabitants. This city is located north-east of France (Lat/Long: 48 41’N - 6 11’E) and has a temperate climate.

Firstly, the contours of all the LCZ of the conurbation have been evaluated using a recent airborne image and buildings height database. Then, indicators have been calculated within LCZ, and contours have been corrected if necessary. At the end of this process, existing zones have been matched with most relevant LCZ types.

Over the 17 existing LCZ types, only 11 have been identified in Nancy. The city center corresponds to the LCZ type “Compact midrise”, which is densely built and shows a low pervious surface fraction. In the periphery, the LCZ types are less densely built, with lower mean building height and higher pervious surface fraction. More details about LCZ mapping methodology and global LCZ layout within the conurbation are described in a complementary study (Leconte, 2014).



(a) (b)

Figure 1: Theoretical air temperature evolution of urban and rural areas, before and after sunset, under calm and clear sky (adapted from Oke (1987)).

3. PRINCIPLE OF LOCAL CLIMATE ZONES THERMAL MODELING APPROACH

The model focuses on standard thermal behavior of Local Climate Zones. Figure 1(a) introduces the theoretical dynamic evolution of air temperature at different locations (urban, rural) under calm and clear sky (Oke, 1987). In this figure, air temperature is similar over all the areas during the afternoon. Then, temperature starts to diverge and air temperature differences appear between areas, leading to an urban heat island episode at nighttime.
The chosen modeling approach is inspired by a work of Holmer (2007), which suggests that the nocturnal urban cooling is divided into two distinct phases (Figure 1(b)). In the afternoon, air temperature is quasi similar over the conurbation. Then, the air temperature diverges during the first hours after sunset. From three hours after sunset to sunrise, the air temperature gap between areas remain approximately stable. This evolution can be expressed in terms of cooling rates, i.e. the air temperature decrease per unit of time. Cooling rates differ amongst urban areas during the first hours after sunset, and then turn to be similar for all areas around three hours after sunset.
The major hypothesis suggests that each LCZ is characterized by a specific cooling rate during the first hours after sunset. Thus, the model focuses on the cooling behavior of LCZ under calm and clear sky. In this context, mean air temperature pattern of different LCZ corresponding to different LCZ types have been analyzed via mobile measurements.

4. MOBILE MEASUREMENTS WITHIN LOCAL CLIMATE ZONES

Figure 2: Instrumented vehicle used for mobile measurements within Local Climate Zones

The dynamic evolution of air temperature has been recorded within LCZ during 24 hours. An itinerary involving four different LCZ has been designed, including LCZ types “Compact midrise”, “Open midrise” and “Open lowrise” / “Sparsely built”. One measurement per hour has been completed for each LCZ.
A PT100 probe has been placed inside a ventilated cylinder mounted on the top of an instrumented vehicle (Figure 2). Air temperature measurements have been performed at a three meters distance step. Measurements have been implemented under specific meteorological weather conditions, i.e. anticyclonic conditions, low nebulosity and low wind speed.

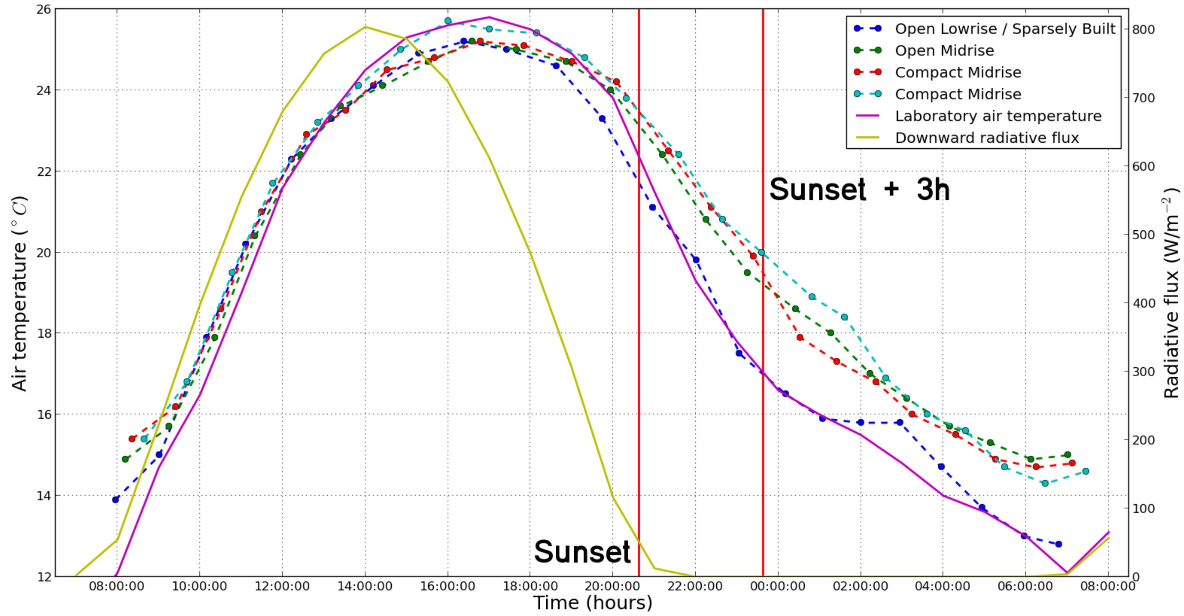


Figure 3: Downward radiative flux, air temperature at a fixed reference weather station and mean air temperature within selected LCZ between 21st August 2013 8am and 22nd August 2013 8am. Vertical red lines represent sunset time, and three hours after sunset time.

Figure 3 presents the downward radiative flux, the air temperature recorded at a fixed reference weather station and the mean air temperature within the four selected LCZ. During the morning and the afternoon, all air temperature records are similar within the four studied LCZ. From 7pm to midnight, which corresponds to three hours after sunset, LCZ shows different cooling rates. The LCZ "Open lowrise / Sparsely built" tends to have a higher cooling rate than the LCZ "Compact midrise" and "Open midrise", which leads to temperature divergence between LCZ. Three hours after sunset, the maximum air temperature difference is reached – approximately 3°C – between a LCZ "Compact midrise" on the one hand, and the LCZ "Open lowrise / Sparsely built" on the other hand. Cooling rates values are analogous between midnight and 8am, except for the LCZ "Open lowrise / Sparsely built" between 3am and 5am.

Nocturnal cooling of a greater number of LCZ has also been investigated. Similarly to the above-mentionned procedure, mobile measurements have been performed in the conurbation of Nancy within 13 LCZ of different types at two different hours:

- Between 2pm to 5pm, i.e. around the theoretical daily maximum air temperature;
- Between 12am and 3am, i.e. approximately three hours after sunset.

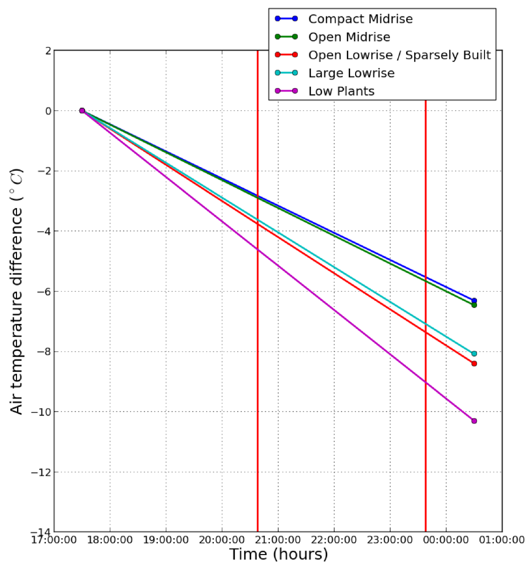


Figure 4: Mean air temperature difference between LCZ around three hours after sunset and mean cooling rate between approximately 5pm and around three hours after sunset, calculated over 8 days of measurements during summer 2013.

Figure 4 exhibits that the mean air temperature gap between LCZ types “Compact midrise” and “Open midrise” on the one hand, and “Large lowrise” and “Open lowrise / Sparsely built” on the other hand is about 2°C. The average maximum air temperature difference three hours after sunset is 4.4°C between LCZ types “Compact midrise” and “Low plants”.
Results illustrate that each LCZ types has a specific cooling rate under the chosen meteorological conditions. However, it appears that different LCZ types tends to have similar cooling rate. The cooling rates of LCZ types “Compact midrise” and “Open midrise” are analogous, since the two lines match well. The observation is similar for LCZ types “Large lowrise” and “Open lowrise / Sparsely built”.

5. CONCLUSION

As a prerequisite of the model construction, a LCZ mapping in Nancy has been performed. Then, the principle of the model has been introduced, including its major hypothesis about the two different cooling rate regimes:

- Heterogeneous cooling rates amongst LCZ during the first hours after sunset;
- Homogeneous cooling rates amongst LCZ from about three hours after sunset.

Mobile measurements within four LCZ have confirmed that the typical daily temperature evolution depicted by Oke (1987). Moreover, the two regimes of cooling rates suggested by Holmer (2007) have been observed. Additional measurements within 13 LCZ highlight that:

- Recurrent air temperature are observed between LCZ types;
- Thermal behaviors of LCZ demonstrate specific cooling rates, even if different LCZ types shows similar cooling rates.

Mobile surveys in Nancy tend to corroborate the conceptual framework and the hypotheses of the model. Thus, the concept of the model focuses on the cooling regimes of Local Climate Zones under calm and clear sky. The output of the model will be the average air temperature difference between LCZ, and also the mean cooling rate of each LCZ type. These outputs are considered as relevant information in an urban planning perspective at conurbation scale.

The next step for the modeling approach improvement is the analysis of the relationship between the thermal behavior of LCZ, the urban morphology and the land use. It will specifically tackle the relationship between temperature differences between LCZ, cooling rates and LCZ indicators that have been calculated.

6. ACKNOWLEDGMENTS

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