
François Leconte

Estimation of spatial air temperature distribution at sub-mesoclimatic scale using the LCZ scheme and mobile measurements

François Leconte[1,2,3], Julien Bouyer[1], Rémy Claverie[1], Mathieu Pétrissans[3]

[1] *Territorial Division for the Eastern Regions, Cerema, 71 rue de la Grande Haie 54510 Tomblaine, France, francois.leconte@cerema.fr, julien.bouyer@cerema.fr, remy.claverie@cerema.fr*

[2] *French Environment and Energy Management Agency, 20 Avenue du Grésillé, BP 90406, 49004 Angers Cedex 01, France*

[3] *LERMAB, Lorraine University, Boulevard des Aiguillettes, BP 70239, 54506 Vandoeuvre les Nancy Cedex, France, mathieu.petrissans@univ-lorraine.fr*

dated : 15 June 2015

1. Introduction

Urban planners are strongly encouraged to include climatic information in the urban planning process. Therefore, decision-makers are looking forward to accessible approaches that can evaluate quantitatively the climatic impact of different urban planning proposals (Grimmond et al., 2010).

Climate classifications show interesting potential regarding this issue. For instance, the Local Climate Zone (LCZ) scheme (Stewart, 2011) has been first proposed in the context of urban climate studies. One of the goals of this classification was to redefine the Urban Heat Island (UHI) phenomenon by expressing it as the air temperature between two climatic zones. This classification has been also used to estimate the spatial air temperature distribution at the conurbation scale (Sundborg, 1951) (Stewart, 2011) (Emmanuel and Krüger, 2012) (Alexander and Mills, 2014) (Fenner et al., 2014). However, even if the Local Climate Zone scheme has been mostly use for urban climate studies so far, it could also offer numerous perspectives regarding the production of quantitative climatic data that can be managed by institutional stakeholders.

This paper presents the climate analysis of a middle size European city (Nancy, France). In this study, the Local Climate Zone scheme has been applied to the area of interest. LCZ have been used to organize the field campaigns and to build areas that are homogeneous in terms of thermal behavior and urban features. Then, mobile measurements have been carried out using an instrumented vehicle. This has led to determine the mean air temperature between different LCZ and to estimate the amplitude of the urban heat island.

By definition, LCZ are supposed to demonstrate a specific thermal behavior. However, since the urban heat island phenomenon is generally intense at the center of cities, and then decreases when it reaches non urbanized areas (Oke, 1982), this paper aims to question how the relative position of LCZ within the conurbation influences their thermal features.

Therefore, the impact of the distance to the center of the conurbation is first discussed for a selection of LCZ. Afterwards, observations about this selection are compared with other LCZ located at various distance to the center.

2. Material and methods

2.1 Local Climate Zone in the area of interest

Local Climate Zone have been built in Nancy, which is a middle sized French conurbation of approximately 286,000 inhabitants. The building process of LCZ has been specified in details in (Leconte et al., 2015).

First, contours of LCZ have been estimated using information regarding building height and land use. A LCZ type has been assigned to all the LCZ. This step has led to an almost complete estimation of the LCZ over the studied conurbation.

Second, thirteen LCZ has been selected, in order to deepen the study over particular LCZ types. Within these thirteen LCZ, seven urban indicators have been calculated, namely sky view factor, aspect ratio, mean building height, terrain roughness class, building surface fraction, impervious surface fraction and pervious surface fraction. These indicators calculations have been used to adjust the contour or the assigned LCZ type when it was necessary.

In the case of residential area, it has been difficult to choose the most suitable LCZ type between the two types Open Lowrise and Sparsely Built, even after the calculation of urban indicators (Leconte et al., 2015). Therefore, residential areas have been considered as a dual type called Open Lowrise / Sparsely Built.

Over the seventeen existing LCZ types, only ten have been identified in Nancy (Figure 1). In the Great Nancy Area, the urbanized LCZ types seem to be arranged following a concentric patterns, with LCZ types Compact Midrise and Open Midrise at the center and LCZ types Large Lowrise and Open Lowrise / Sparsely Built at the periphery.

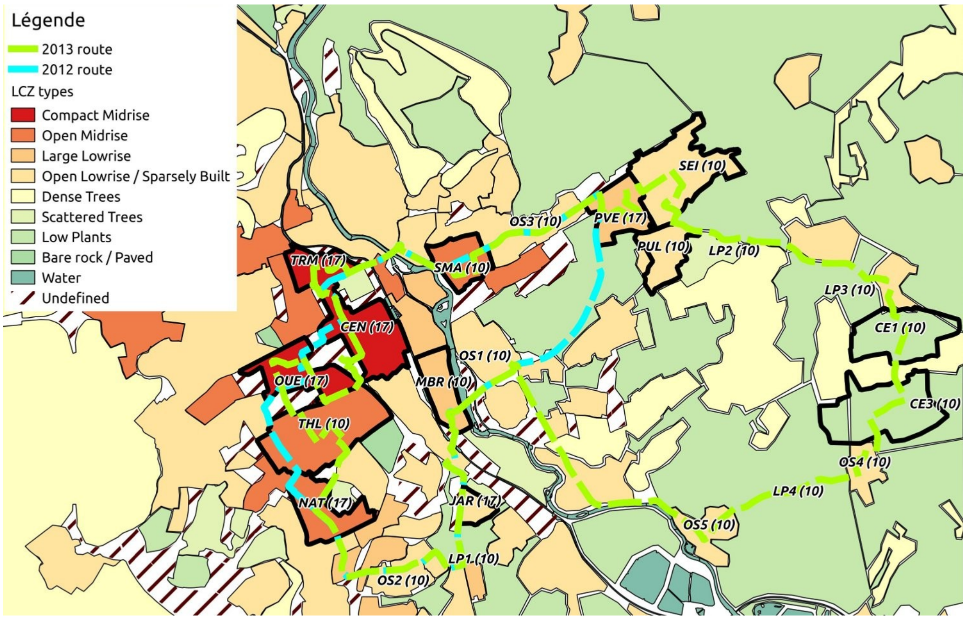

Fig. 1 LCZ map of the Great Nancy Area. The routes performed in 2012 and 2013 are displayed in blue and green respectively. The thirteen selected LCZ for the field experiment are circled in black. Nine other LCZ are presented, they are designated by their type: OS: Open Lowrise / Sparsely Built, LP: Low Plants. The number of nocturnal traverses per LCZ are in parenthesis. Adapted from (Leconte et al., 2015).

2.2 Air temperature measurements within Local Climate Zone

At the end of this building step, the thermal behaviors of the Local Climate Zone have been investigated. Mobile measurements have been performed between July and September 2012 and 2013 under specific meteorological conditions, namely low wind speed, clear sky, anticyclonic conditions, dry road and absence of precipitation during the previous twenty-four hours. Wind direction has impacted only marginally the temperature dataset, since measurements have been realized only during low wind speed days (below 9 m.s^{-1}, wind speed measured at ten meters high). This paper focuses on nocturnal measures that have been performed between 12:30 PM and 3:00 AM.

Measurements have been carried out with an instrumented vehicle equipped with a PT100 probe, which has an accuracy of 0.2°C. This sensor is mounted inside a ventilated cylinder located on the roof, at approximately two meters high. Air temperature has been recorded with a distance step of three meters. Measures corresponding to car speeds below 15 km.h^{-1} and above 60 km.h^{-1} have been removed from the dataset. Topography is supposed to do not impact the temperature measurements within the thirteen LCZ, since these LCZ have been chosen with similar elevation.

One measurement session takes approximately 2:30 hours to examine the thirteen selected LCZ. Since regional temperature evolves between the beginning and the end of the session, a linear time-correction scheme has been applied. For each measurement point, the air temperature has been corrected taking into account the elapsed time between the beginning of the session and the moment of measure.

3. Results

3.1 Distance to center of the conurbation and thermal behavior for thirteen LCZ

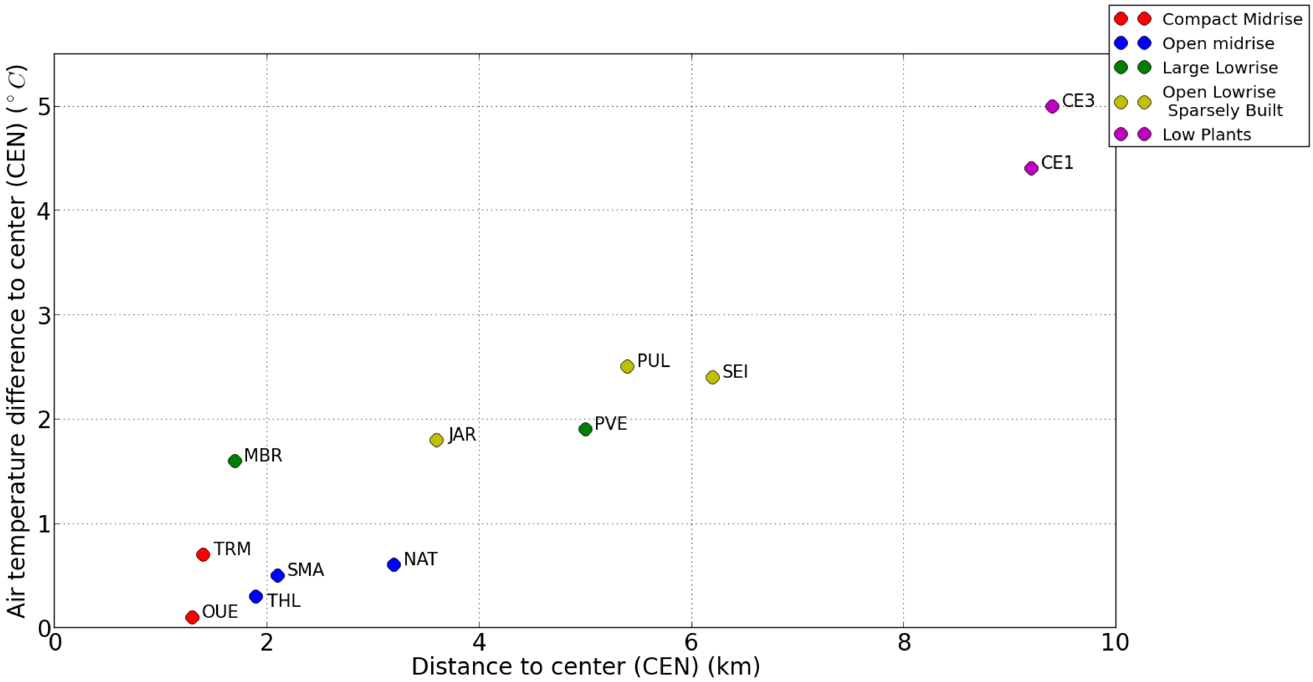

Fig. 2 Mean air temperature differences as a function of the distance to the LCZ CEN, located approximately at the center of the conurbation. Air temperature differences and distances are expressed relatively to the LCZ CEN. Measurement time is 12:30 PM.

Figure 2 focuses on the influence of the relative position of the LCZ within the conurbation, showing the mean nocturnal air temperature differences as a function of the distance to the center of the conurbation. Here the latter correspond to the LCZ CEN. The approximated center of each LCZ is used to calculate the distance to CEN.

LCZ types Compact Midrise and Open Midrise are mainly located at the center of the conurbation, up to 3.2 km far from CEN. In general, these two LCZ types are the warmest LCZ, and show a very similar thermal behavior. The mean air temperature difference between them is about 0.8°C or less.

LCZ types Large Lowrise and Open Lowrise / Sparsely Built are spread within the conurbation, distance to CEN varies from 1.7 km to 6.2 km. However, their temperature differences are close to each other, namely between 2.5°C and 3.4°C. There are differences in terms of urban indicators between Large Lowrise and Open Lowrise / Sparsely Built, however it seems that they are quite similar regarding their thermal behavior.

Results show that the LCZ type of a neighborhood is the parameter that drives the thermal behavior at local scale. For instance, NAT and JAR are respectively 3.2 km and 3.6 km far from CEN, but NAT (Open Midrise) is much warmer than JAR (Open lowrise / Sparsely built) (temperature difference of 0,6°C for NAT and 1,8°C for JAR). Similarly, MBR and THL are located at 1.7 km and 1.9 km far from CEN, but nocturnal air temperature is lower for MBR (temperature difference of 1,6°C) than for THL (temperature difference of 0,3°C).

However, the parameter distance to CEN has an influence over the thermal behavior of LCZ of same type. For the LCZ type Open Lowrise / Sparsely Built, the warmer LCZ is the one that is the closest to CEN. For JAR, distance to CEN is 3.6 km and temperature difference is 1.8°C, while PUL's distance to CEN is 5.4 km and temperature difference is 2.5°C, and SEI's distance to CEN is 6.2 km and temperature difference is 2.4°C.

The air temperature difference between LCZ of same type could be explained by air circulation. The warmest LCZ are located at the center of the conurbation, and warm air can be advected from these warm LCZ toward the contiguous LCZ. In this way, these latter LCZ may show air temperature higher than the other LCZ of same type that are located at the outskirts of the conurbation.

3.2 Distance to center of the conurbation and thermal behavior for the entire 2013 route

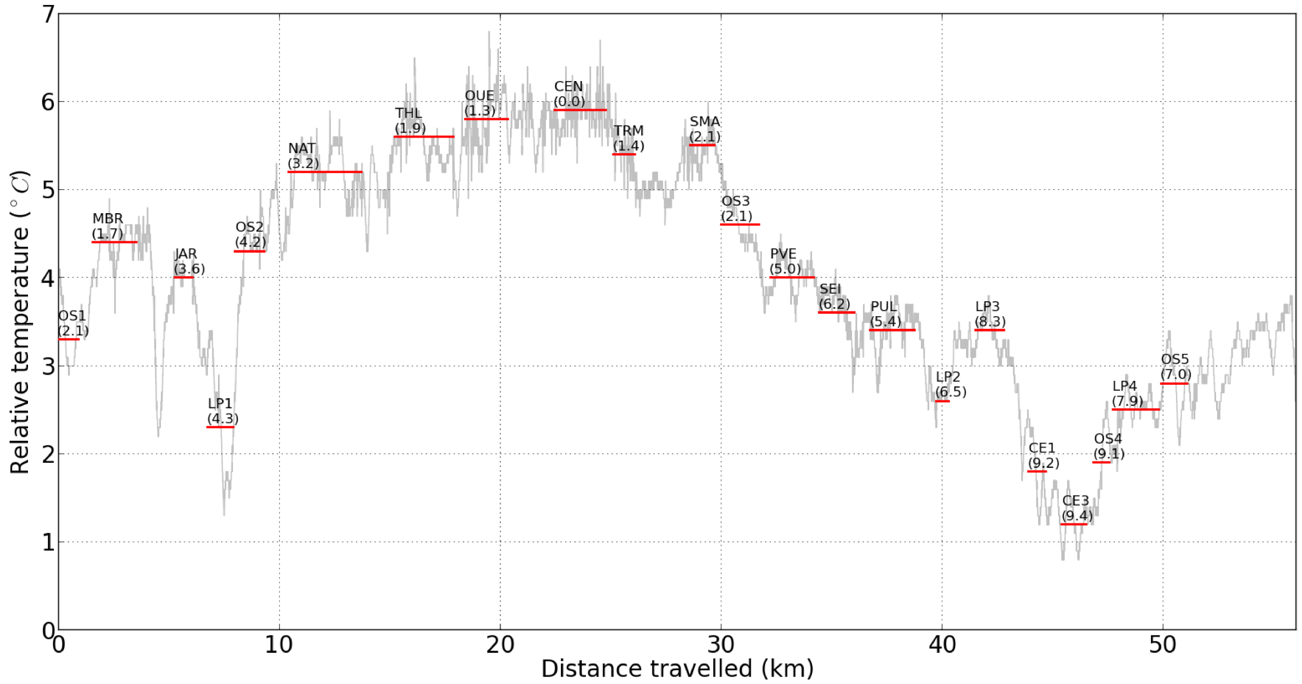

Fig. 3 Relative temperature over ten measurement sessions as a function of the distance travelled. The relative temperature is expressed relatively to the minimum temperature for each session. Horizontal red lines represent the spatial mean relative temperature for a given LCZ. Distance to the center of the conurbation is in parenthesis. Measurement time is 12:30 PM.

The previous analysis - that deals only with thirteen LCZ - can be extended to the entire 2013 route. In Figure 3, the air temperature is expressed as a difference from the minimum temperature of the route. For each one of the ten measurement sessions, a relative temperature has been calculated. This calculation follows three steps. First, for a given route, the coldest area of the route has been determined. This correspond to the 150 meters where the air temperature recorded is the lowest. Second, the relative temperature has been calculated for each measurement point, as the difference between the air temperature measured and the air temperature of the coldest area. Third, the relative temperature of ten sessions have been averaged.

Figure 3 presents the relative temperature as a function of the distance travelled. LCZ types Compact Midrise and Open Midrise are the warmest areas, with a relative temperature always above 5°C. LCZ from the type Large Lowrise demonstrate similar relative temperature (4.5°C for MBR, 4.0°C par PVE).

The thermal behavior of type Open Lowrise / Sparsely Built is more heterogeneous. The range of relative temperature is between 4.6°C and 1.9°C. However the results concerning this LCZ type can be arranged into two cases.

The first case refers to the LCZ Open Lowrise / Sparsely Built that are both part of the conurbation – in a sense that they are contiguous to other urbanized LCZ – and so that demonstrate a reduced distance to the center – in this case, up to 6.2 km. The LCZ OS1, JAR, OS2, OS3, SEI and PUL correspond to this definition. Their relative temperature is between 3.4°C and 4.6°C, which is mostly above the relative temperature observed for LCZ types Low Plants (between 1.2°C and 3.4°C).

The second case concerns the LCZ Open Lowrise / Sparsely Built that are both not part of the conurbation – in a sense that they are surrounded by non urbanized LCZ – and that demonstrate a significant distance to the center - in this case, 7 km and further. The LCZ OS4 and OS5 meet this definition. Their relative temperature is 1.9°C and 2.8°C respectively, which is in the range of the relative temperature of the LCZ Low Plants.

It seems that in the first case, when the LCZ Open Lowrise / Sparsely Built are part of the conurbation, they benefit from the heat of the global urban heat island and they show a thermal behavior similar to LCZ Large Lowrise.

In the second case, when LCZ types Open Lowrise / Sparsely Built are not contiguous to the conurbation, they show a thermal behavior similar to LCZ Low Plants. In this situation, they do not benefit from the urban heat island of the conurbation. It seems that these LCZ, located at a significant distance to the center (in this case above 7km), are out of the thermal influence of the conurbation nearby. Giving this information, it is possible to postulate that a non urbanized area located further this distance to the center could be relevant to estimate the “background climate” of the conurbation.

LCZ types Low Plants show homogeneous behavior. These LCZ correspond to a low relative temperature, even when they are located at a reduced distance to the center, e.g. LP1 (distance to center 4.3 km). Moreover, small vegetalized areas and urban parks – that a too small to be considered as a LCZ – lead to a relative temperature drop (e.g. between MBR and JAR, and between TRM and SMA), even when the vehicle is only going along.

4. Conclusion

This paper discusses the estimation of spatial air temperature at sub-meso-climatic scale, with a focus on the influence of the distance to the center of the conurbation. Eighty-two urbanized LCZ have been built for the conurbation of Nancy, and urban indicators have been calculated within a selection of thirteen LCZ. Thereafter, mobile measurements have been performed in order to record the air temperature within the LCZ and to investigate their thermal behavior during the nocturnal period. The following observations are valid only for the selected meteorological conditions which include low wind speed.

For the thirteen selected LCZ, it appears that LCZ of types Compact Midrise and Open Midrise form a group of similar thermal behavior located in the center of the city. These LCZ are warmer than the LCZ Large Lowrise and Open Lowrise / Sparsely Built from about 1.5°C. These latter LCZ types also demonstrate close thermal behavior, and are located both close to the center and at the periphery of the conurbation. Results show that within the conurbation, the LCZ type is a parameter more influent that the distance to the center. However, in the case of Open Lowrise / Sparsely Built, the closer the LCZ is from the center, the higher is the air temperature inside the LCZ.

The study of the entire itinerary highlights that the distance to the center plays an important role when LCZ are not contiguous to the conurbation. In the case of the LCZ type Open Lowrise / Sparsely Built, these LCZ demonstrate different thermal behavior depending of their distance to the center and their contiguity to the conurbation. When they are away from the conurbation further than 7km in the present case, it seems that they do not undergo the thermal influence of the conurbation, and they show a relative temperature similar to the non urbanized LCZ nearby.

This paper shows that LCZ's thermal behaviors are influenced by the relative position of the zones in the conurbation. Therefore, it is not possible to extrapolate the air temperature differences observed within the conurbation to LCZ located outside the conurbation. Above a given distance to the center, small urbanized LCZ can be similar to non urbanized LCZ. This observation needs to be taken into account, for instance in a perspective of the building of a LCZ's thermal behavior model at meso-climatic scale.

Acknowledgment

This work has been supported by the French Environment and Energy Management Agency (ADEME).

References

Alexander, P.J., Mills, G., 2014: Local Climate Classification and Dublin's Urban Heat Island, *Atmosphere*, **5**, 755 – 774.

Emmanuel, R., Krüger, E., 2012: Urban heat island and its impact on climate change resilience in a shrinking city: The case of Glasgow, UK, *Building and Environment*, **53**, 137 – 149.

Fenner, D., Meier, F., Scherer, D., Polse, A., 2014: Spatial and temporal air temperature variability in Berlin, Germany, during the years 2001 – 2010, *Urban Climate*, **10**, 308 – 331.

Grimmond, C.S.B., Roth, M., Oke, T.R., Au, Y.C., Best, M., Betts, R., Carmichael, G., Cleugh, H., Dabberdt, W., Emmanuel, R., Freitas, E., Fortuniak, K., Hanna, S., Klein, P., Kalkstein, L.S., Liu, C.H., Nickson, A., Pearlmutter, D., Sailor, D. and Voogt, J., 2010: Climate and more sustainable cities : climate information for improved planning and management of cities (producers/capabilities perspective). *Procedia Environmental Sciences*, **1,** 247 - 274.

Leconte, F, Bouyer, J., Claverie, R. and Pétrissans, M., 2015: Using Local Climate Zone scheme for UHI assessment: evaluation of the method using mobile measurements. *Building and Environment*, **83**, 39 – 49.

Oke, T., 1982: The energetic basis of the urban heat island, *Quarterly Journal of the Royal Meteorological Society*, **108**, 1 – 24.

Stewart, I., 2011: Redefining the Urban Heat Island. *Ph.D Thesis*, The University of British Columbia, Vancouver.

Sundborg, A., 1951: Climatological studies in Uppsala with special regard to the temperature conditions in the urban area. *Geographica,* **22**, Geographical Institute of Uppsala.