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# Impacts of several urban-sprawl countermeasures on building (space heating) energy demands and urban heat island intensities. A case study

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ABSTRACT

Controlling the urban development and protecting the natural habitats are major challenges for urban planners. With respect to these challenges, we assess the influence of different spatial planning policies on the urban heat island (UHI) intensity and the energy demand for building space heating in Strasbourg–Kehl urban region (France–Germany). For this purpose, the SLEUTH* urban growth model is coupled off-line with the WRF/urban climate modeling system in order to simulate the impacts of three types of urban development (compact, moderately compact, and sprawling development) combined with ecological preservation rules. Two additional software applications, Graphab and MorphoLim, are used to define the ecological and urban spatial structures, and drive the SLEUTH* simulations. The simulations for the year 2010 are consistent with the existing climate data (mean bias on temperatures less than or equal to 1 °C) and annual energy consumptions for building space heating estimated via a building typology energy assessment approach (discrepancies of 20%). Simulated urban development scenarios for the year 2030 show slight effects on UHI intensities and heating energy demands in buildings. Those results suggest that urban sprawl countermeasures have no significant effect on the UHI intensity and building energy requirements when considering a moderate urban growth and realistic planning scenarios.



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## 1. Introduction

One of the major challenges facing urban and regional planners is to limit the negative effects of urban sprawl, especially the increasing number of journeys by car and the fragmentation of natural and agricultural land. Another major challenge is to reduce the energy consumption in buildings for space heating and cooling as well as the urban heat island (UHI) effect (i.e. the characteristic warmth of the atmosphere in urban areas as compared to their surroundings). These two planning challenges relate largely, although not exclusively, to the question of where to locate new urban developments. The long-standing debate about the most efficient (or virtuous) urban form often opposes compact cities to sprawling cities. Yet no consensus has been reached about the urban form that will best allow planners to achieve the objectives set out above. Moreover, it is difficult to transcribe planning objectives into quantitative indexes or land use land cover maps, which is a source of endless debate (Mallampalli et al., 2016).

Many studies have already reported that urban forms, in particular built density, residential parcel design, and the type and arrangement of vegetation all impact microclimates (Givoni, 1989; Bonan, 2000; Emmanuel and Fernando, 2007; Guhathakurta and Gober, 2010; Hart and Sailor, 2009; Stone and Norman, 2006; Middel et al., 2014). Scholars generally observe stronger UHI effects in compact urban patterns than in dispersed urban patterns where the sources of heat are less concentrated and built areas intermeshed much more with vegetation (Brazel et al., 2007, Ewing and Rong, 2008; Kikegawa et al., 2003; De Munck et al., 2013). For instance, Aguejdad et al. (2012) found that disconnected built patterns reduce the impact area of the UHI by a factor of five to six compared to interconnected built patterns. Yet Lemonsu et al. (2015) found few differences between the UHI of a compact Paris city and a sprawling Paris city by 2100 (difference <0.2 °C): city fractions affected by different UHI thresholds are more numerous in the dense compact city than the greener sprawling city at night (built density enhances the UHI at night by reducing the amount of radiant energy lost by the surface). Conversely the UHI effect is lower in the compact Paris city during daylight (built density reduces the daytime UHI through shadow). Finally, Masson et al. (2013) reported a slight increase in summertime UHI and a 0.5–1 °C decline in winter UHI for moderate compact and green urban growth scenarios for the urban area of Toulouse (south-west France) in 2100 as compared to present-day conditions. These scenarios include the protection of existing green and agricultural areas, urban containment strategies such as green belt strategies, construction of moderately dense neighborhoods composed of strips of detached and semi-detached houses, or apartment buildings, and for some scenarios increased vegetation cover in open spaces, on sidewalks, and in parking lots. However, the highest increase in the summer UHI intensity (+1 °C) in the Toulouse suburbs and greatest decrease in its inner core (−2 °C) are reported for a scenario that combines a locally very dense urban development (construction of high-rise multifamily housing) and the absence of urban development in a large and unbroken ecological conservation area.

Changes in the urban built pattern also result in modified patterns of building energy demand (Santamouris, 2001). It seems that compact cities increase cooling energy requirements by increasing the number of cooling degree-days more than they reduce the number of heating degree-days (Ewing and Rong, 2008; Kolotroni et al., 2012). Yet, this rule depends on the study cases. For instance, UHIs were shown to contribute more to the annual energy savings by reducing the heating energy demands (−20%) instead of increasing the cooling energy demands (+8%) in Magli et al. (2015) for Modena (Italy). Masson et al. (2013), also, found a reduction in the space heating energy demands by a factor of three for their green and moderate compact city scenarios for Toulouse by 2100. However, alongside spatial planning options, these scenarios integrate virtuous individual energy consumption behaviors, suggesting that the behavior of individuals and the thermal properties of buildings drive the heating or cooling energy demands much more than UHI intensities. This is in agreement with the research results of Ewing and Rong (2008), who found that the housing effect (i.e. preferential construction of tall multi-storey and multifamily attached housing on smaller plots in compact cities as compared to sprawling residential developments) influences building energy consumption much more than UHI effects for several US cities.

Urban growth scenarios proposed by Masson et al. (2014) for Toulouse by 2100 that exhibit the lowest UHI effects and the highest heating energy savings contradict some of the recommendations made for limiting the negative effects of urban sprawl, especially the fragmentation of natural and agricultural lands. On the one hand, green belt planning strategies create leapfrog urban developments (Vyn, 2012; Peeters et al., 2015). On the other hand, patterns of small but connected patches of wildlife habitats seems to be a good way to preserve ecological biodiversity (Forman, 1995; Kindelmann et al., 2005).

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