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A New Performance Indicator to Assess Building and District Cooling Strategies

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Abstract

The goal of this study is to bring out the efficiency of district landscaping on local urban heat island mitigation. Two cooling strategies at the district scale are evaluated through the coupled effect computation of microclimate and building energy demand: vegetation (trees, green walls and roofs) and high albedo values (cool roofs and façades). The study focus on an existing district, Part-Dieu, in Lyon (France). This district has a high urban density and is composed of buildings for which rehabilitation is expected to be difficult. The city is particularly sensitive to summer heatwaves that are supposed to be more regular with global warming. Two specific urban blocks, of about 10 building blocks each, are modeled: a 60,000 m² site where the urban fabric is a mix of historical buildings and 60s' buildings, and a 70,000 m² new residential site under construction, more homogeneous compared to the first one. The simulation results are processed for a summer period (hourly time step) and cooling strategies are analyzed individually and combined. Two indexes, Energy Performance Index (*EPI*) and Ambient Temperature Mitigation Index (*ATMI*), are defined to evaluate strategy efficiencies. In our case studies, cooling energy demand is mitigated by around 3% with tree growth strategy, 35% with green roofs, and 76% with increased albedo of urban surfaces. Whereas detailed results of coupled simulation are useful here for engineers, global performance indicators defined in this study give useful hints for stakeholders and urban cooling strategy design.

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Keywords: urban climate ; building energy simulation ; urban heat island mitigation index ;

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1. Introduction

For buildings in dense urban areas, the use of air conditioning systems increases urban anthropogenic heat during the most critical periods [1,2]. Urban Heat Island (UHI) effect can mitigate the heating energy demand in winter, while the cooling energy demand during summer is increased [3]. This negative feedback increases UHI and building energy demand and leads to undersized air-conditioning systems. In order to improve thermal comfort and to reduce cooling energy demand, the urban environment can be designed to mitigate UHI and its consequences. A modification of urban landscaping, such as surface albedo [4, 5, 6] or green areas can mitigate the UHI, which consequently reduces energy demand. Thus, microclimatic considerations should be taken into account in urban planning. A simulation of the different physical processes that exist in urban areas would help urban planners determining the best urban landscapes in order to increase building energy efficiency [7] and to improve outdoor thermal comfort [8]. Various microclimatic models have been developed to compute the physical processes in the urban areas [9, 10, 11]. A first category allows to compute radiative exchange in urban area and their impact on building energy demand [12,13,14]. A second category of district simulation tools computes coupled heat and mass transfer [15,16,17,18,19]. These latter are detailed coupled simulations which are often limited to a limited period, e.g. several days. However, in this study, UHI mitigation impacts are assessed for a complete summer period, from May 1 to September 30, using EnviBatE coupled models [17]. UHI intensity was studied and quantified through various indicators [20]. However, in order to compare several urban planning strategies, detailed indexes were developed considering outdoor thermal comfort such as Universal Thermal Climate Index (UTCI) [21] or Physiological Equivalent Temperature (PET) [22]. These indexes are used to quantify impacts of urban planning with detailed for each time step of the studied period. Considering energy performance of each building, many indicators have been also developed and are sometime used in building regulations [23,24]. However, considering a complete summer period and the combination of local UHI and energy demand, urban planners would need a simpler estimator that can gives a quantified overview to help decision process. We propose in this study two indicators to evaluate and compare urban planning strategies, considering both building energy demand and local microclimate. The potential use of these indexes is studied considering impacts of vegetation and albedo increase in a dense urban district, Part-Dieu (Lyon, France) particularly sensitive to summer heatwaves. Moreover, heatwave frequency and intensity should increase with global warming and most of the considered buildings are expected to be difficult to refurbish. The district is modeled with EnviBatE [17] Green and increased albedo strategies are assessed for two specific urban sub-blocks, Moncey Street and Buire Street. This case study is developed to highlight the proposed methodology use and results.

2. Modeling Tools and Methodology

2.1. Models for building and ambient heat transfers

EnviBatE, a set of coupled simulation models is used to analyze efficiency of different urban landscaping. Different meshes of the same district are needed in order to adapt to different heat and mass models at the district scale [17] The main surface mesh is discretized consistently with the zones for the building energy simulation. Each wall with a specific orientation and physical properties is defined by its own nodes. Solar radiation simulation is computed in a first stage, using SOLENE [25], for direct and diffuse solar irradiance considering each building wall and ground. SOLENE software has been validated in several studies such as the district surface temperature measures in Toulouse (France) [26]. Direct solar irradiance and sky luminance are calculated considering a triangulated submesh of the main surface mesh. Solar reflections and longwave interchanges in the urban environment are then modelled in the coupled simulation using radiosity method in EnviBatE [17]. A zonal model, based on Rockle's model [27] and using QUIC software [28], computes spatially-resolved wind fields in the urban domain. This computation method was developed to respect mass conservation [29]. QUIC software capability to model urban canopy airflow was demonstrated through several experiments such as reduced district scale models [30,31] and a real district scale in Oklahoma City [32,33]. A more detailed hexahedral mesh (regular) is used here to give accurate velocity fields throughout the studied urban canopy. These velocities are then used to compute the airflows through the rougher mesh of the coupled thermal model. These airflows are used to compute the temperature field with a zonal method including indoor and outdoor heat balances [34]. Building energy demand is computed considering building operation and indoor heat transfers