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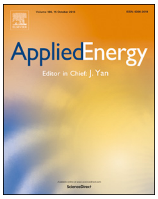

Impacts of urban morphology on reducing cooling load and increasing ventilation potential in hot-arid climate

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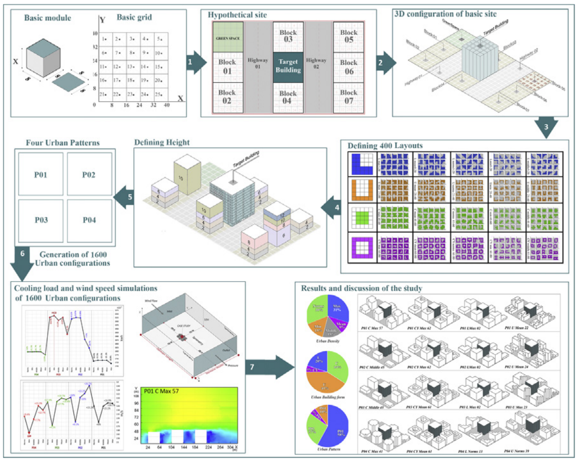
HIGHLIGHTS

- A novel approach introduced to model and assess an urban morphology.
- 1600 urban models are generated and evaluated considering urban micro-climate.
- An optimal technique is introduced for ventilation regarding the air pollution.
- 10.2% cooling demand reduction and 15.2% ventilation potential increase is observed.
- Design-based suggestions are presented as a guide for newly-built urban areas.

GRAPHICAL ABSTRACT



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ABSTRACT

Cooling buildings in urban areas with hot-arid climate put huge loads on the energy system. There is an increasing trend in urban energy studies to recognize the urban design variables and parameters associated with the energy performance of buildings. In this work, a novel approach is introduced to investigate the impacts of urban morphology on cooling load reduction and enhancing ventilation potential by studying a high-rise building (target building), surrounded by different urban configurations, during six warm months of the year in Tehran at four major sections including: (1) generating 1600 urban case studies considering three parameters (Urban Density, Urban Building Form, and Urban Pattern) and modelling the urban morphology of Tehran based on a technique namely "Building Modular Cells", (2) validation study of CFD simulation of the wind flow around buildings, (3) calculating the average cooling load and wind flow at the rooftop of the target building, and (4) investigating sixteen best urban configurations with the lowest cooling load and highest ventilation potential. Results indicate that urban morphology has a notable impact on the energy consumption of buildings, decreasing cooling load and increasing ventilation potential more than 10% and 15% respectively, compared to the typical

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cases. This work also proposes design solutions for architects and urban designers, based on Top 100 configurations (out of 1600), for improved energy performance and better ventilation of buildings in urban areas.

1. Introduction

The world population in urban areas has increased rapidly during the last century [1,2]; from 30% in 1950 to 54% in 2014 and it is expected to increase to 66% in 2050 [3,4]. This rapid urbanization and the consequent changes in urban density have increased the air pollution and energy consumption in cities, especially due to the demands from building sector [5]. Heating, cooling and lighting are accounted for more than 70% of energy consumption in the commercial and residential buildings in cities [6]. In countries with hot-arid and tropical climate a huge amount of energy, particularly electricity, is consumed for cooling buildings [7,8]. Conditions may worsen by climate change which induces warmer weather on average as well as stronger and more frequent extreme conditions [9,10] increasing the average and peak cooling load as well as thermal discomfort in urban areas with hot summers [11,12]. The energy performance of buildings in urban areas is highly affected by urban microclimate and urban heat island (*UHI*). A large amount of solar radiation is reflected from and stored in surfaces of buildings and urban components, increasing the surface and air temperature. *Kalnay and Cai* [13] have shown that rapid urbanization and high urban density have caused 0.27 °C mean air temperature increase during the last decade in the *United States*. This results in higher demands for air-conditioning and cooling in longer time periods, compared to rural areas [14,15].

The urban population in Iran has grown from 50.6% of the whole country population in 1987 to 74% in 2016, which is significantly higher than the global average growth rate [16]. Energy consumption per capita in *Iran* – with 1.06% of the world population – is five times higher than the world average [17]. The average electricity consumption growth in *Iran* (7.9%) is more than twice of the global average (3.3%) [18] and more than 33% of the annual electricity production is consumed for air-conditioning systems in cities [19]. The situation is more critical for megacities of *Iran* with high urban population growth and long hot-arid summers such as *Tehran*, *Isfahan*, *Tabriz,* and *Mashhad*; cooling demand during hot seasons (*April* to *September*) introduces very large base and peak loads on the electricity (and water) network. The current situation in induced by several factors such as climatic conditions, poor design and inefficient construction of buildings and *HVAC* systems (e.g. using typical “Evaporative Air-Cooler” in more than 70% of buildings in cities with very poor efficiency) as well as the lack of practical building codes and regulations for having low-energy and sustainable buildings. Moreover, air pollution is a big problem in the mega-cities (and the southern part of the country), especially in *Tehran* – the capital city of Iran – as one of the most polluted cities in the world [20,21]. This results in the need for air purification and makes it difficult to use typical passive methods such as natural ventilation or regular air conditioning systems as a part of a comprehensive plan to reduce cooling energy consumption and preserve thermal comfort simultaneously.

Improving the living conditions and energy performance of urban areas depends on several technical, environmental and economic factors. Although several studies have addressed the role of urban morphology on energy demand [22,23] and wind potential for ventilation [24,25], the impacts of urban morphology needs to be further explored considering larger variations and deeper analysis [26,27]. It is shown that wind flow plays an important role in passive or active ventilation systems, helping to reduce the cooling load of buildings [28,29] and urban heat island [30,31] and to enhance the thermal comfort [32] and thermal circulation around buildings [33]. Furthermore, research works have pointed to an indirect relation between higher wind flow rate in urban canopies and average surface temperature in urban areas [34,35], which can directly or indirectly affect the heat gain through external walls [36] and consequently the cooling load of buildings [37,38]. Thus, both thermal and wind flow characteristics should be taken into account to evaluate cooling load and ventilation potential in an urban area.

Selecting the influencing physical parameters to model an urban morphology is an inevitable challenge considering numerous variables and inputs such as urban form, type of buildings, microclimate, urban density, streets and canopies [39,40]. This becomes more complicated for simulating the cooling demand and ventilation potential in urban areas due to their dependence on numerous unsteady climatic inputs and complex boundary conditions, which are influenced by the heat transfer mechanisms, rates and coefficients. Assessing such a complex system requires solving the equations for conservation of energy, mass and momentum [41]. Thus, an integrated method is needed to combine these influencing parameters and indicators to model an urban area in order to simulate energy demand and ventilation potential. Although there have been some attempts to develop integrated methods (e.g. [42,43]), it has not been investigated in the modern architecture of Iran, despite of serious issues with the energy supply and consumptions in urban areas. Interestingly, the traditional Iranian architecture has implemented several effective and sustainable solutions to provide the highest possible thermal comfort in buildings and cities in the microclimate scale with the minimum energy consumption, such as wind catchers [44,45], domed and vaulted roof shape [46,47], courtyard houses [48,49] and using efficient materials [50,51]. Some attempts have been recently made in *Iran* to establish a national low-energy construction regulation (the most recent one is National construction regulation No.19) [52] based on modern concepts similar to *LEED* in the US, *CGBL* in China, *DGNB* in Germany, *HQE* in France and *BREEAM* in UK [7,53]. However, results are not stratifying in practice and unfortunately not enough attention has been paid to include the traditional methods during the urbanization boom. In fact, the national low-energy and green construction regulations have been developed more based on engineering calculations and mathematical language, while urban designers and architects – as one of the most influencing groups in designing buildings and cities – are neglected. Regulations and building codes should be more practical with design-based low-energy recommendations, easy to be applied by architects and urban designers at the early design stage in both building and urban scale. To improve the energy performance of buildings in urban areas and to take into account the important urban physical characteristics in urban planning, it is required to develop general and easy-to-use regulations and/or recommendations – based on integrated methods that model and evaluate numerous urban morphologies in cities – for architects and urban designers.

The literature in modeling urban morphology can be divided into three main approaches, based on studying hypothetical configurations (e.g. [54,55]), real-site configurations (e.g. [56,57]) or both configurations [58]. Through applying any of these approaches, several studies have investigated the relation between urban morphology and the energy demand and supply of buildings in urban areas, each considering some influencing parameters of urban morphology in terms of energy consumption [3,59] and wind assessment for ventilation [60,61]. Four mostly applied methods for simulating thermal behavior and ventilation potential of buildings in urban areas can be recognized including: observations in real-sites (e.g. [62]), real-site measurement (e.g. [63]), experiments in the laboratory scale (e.g. [64]) and numerical methods (e.g. [5]). Each method has its practical limitations;