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Quantifying the domestic electricity consumption for air-conditioning due to urban heat islands in hot arid regions

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HIGHLIGHTS

- Effects of urban heat islands on domestic electricity consumption for air-conditioning.
- Variation in electricity consumption is a direct result of modifications on urban microclimate.
- The domestic cooling load is up to 17–19% higher than the rural load over the year.
- Domestic electricity consumption in urban centres is higher than the rural consumption by 10%.
- Estimates of urban consumption based on data of airports cause an error that can reach 6%.

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ABSTRACT

Authoritative reports show that building electricity consumption can increase steadily once temperature values within urban regions exceed their rural values. This study first assesses the role of higher temperatures in the variation of Bahrain's domestic electricity consumption for air-conditioning, using the cooling degree days (CDD) as a quantitative index. It then examines how this consumption is affected by urban features. The assessment is performed using established scenarios of the urban heat island (UHI), advanced statistics of building stock and data for electricity consumption. Simple regression equations are developed to predict the effects of temperature alterations on the electricity consumption. This work shows that the variation in CDD is a direct result of modifications to the urban microclimate. The annual total urban CDD value is up to 17% higher than the rural CDD value. A sharp increase of up to 10% in electricity consumption for air-conditioning occurs in urban regions from April to October. Estimates of the electricity demand for dense urban centres that are based on air temperature values measured in open areas, such as airports, can cause an error of almost 6%. The developed statistical equations can be a valuable and convenient method of quantifying the domestic electricity consumption for air-conditioning in Bahrain and other Gulf countries.

1. Introduction

Centres of newly developed built up areas normally experience higher temperatures when compared to their rural surroundings. This difference is what constitutes the urban heat island (UHI) phenomenon. Various factors contribute to the development of this phenomenon. Some are related the nature of the site, such as geographical location and weather. Other factors are related to human activities, such as urban geometry, choice of building materials, anthropogenic heat emissions and the reduction of vegetation areas and bodies of water [1]. In a previous study [2], the authors examined the effects of these factors in a two step analysis. In the first step, the role of urban expansion in the development of UHI was assessed. In the second step, the impact of urban elements on the UHI was evaluated. Master plans, satellite images and geographical information systems (GIS) were first employed to track the process of urbanisation. Measured hourly temperature data were then used to assess the effect of urbanisation on the UHI development. The measured data, in addition to computational fluid dynamics (CFD) applications, were also used to evaluate the effect of urban elements on the UHI. This study showed that metropolitan areas of Bahrain, particularly their centres, experienced higher temperatures compared to rural areas. The UHI was found to be partly influenced by natural factors such as location and sea breezes. However, the appearance of the UHI was mainly reinforced by urban activities such as on-going construction processes, industrialisation, sea reclamation and the shrinkage of green areas.

Authoritative reports have stated that the UHI can affect the quality of human life, particularly in hot arid regions. Examples

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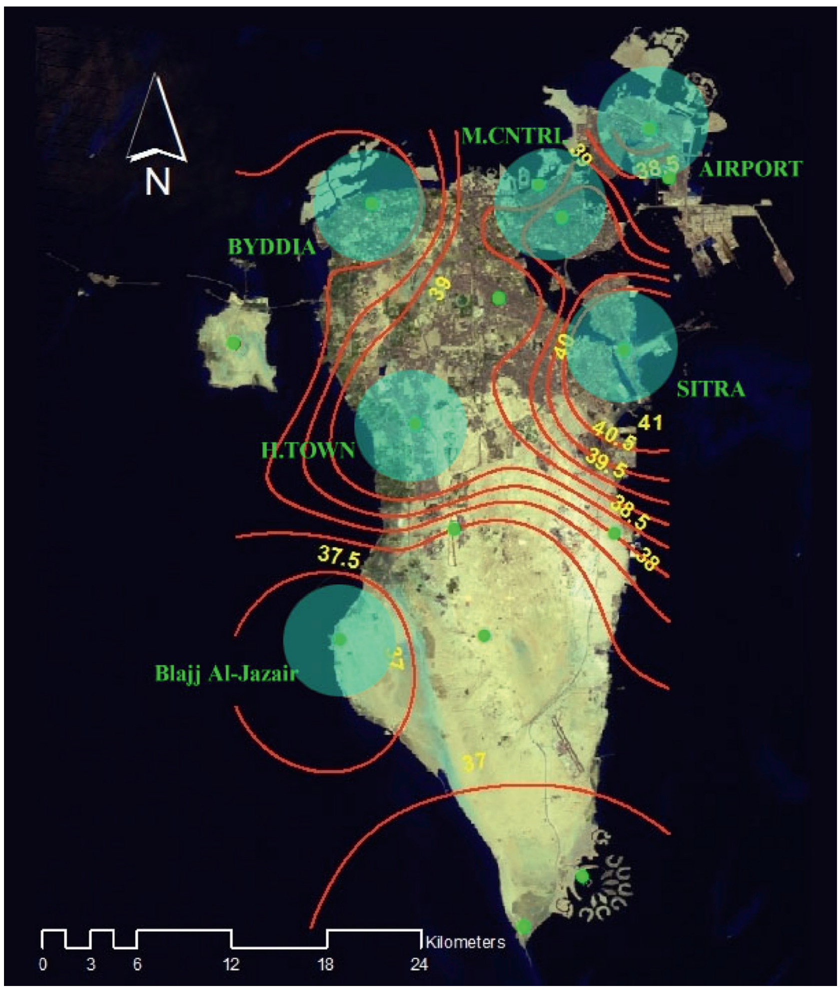
are seen in the compromised thermal comfort conditions and increased energy demand to cool buildings [3]. The variations in thermal conditions and energy demands have recently become a target for scientific research that aims to improve urban environments and the energy efficiency of metropolitan centres. For example, Bouyer et al. [4] used computational fluid dynamics coupled with simulation tools to examine the variation in urban cooling energy and found that the contributions of different physical phenomena were dependent largely upon urban design, surface materials and landscape elements. Flor and Dominguez [5] showed that building energy consumption was related to microclimate aspects of solar loads, wind flow patterns and external air temperatures. These findings indicate that improvements in urban microclimates can have both direct and indirect consequences for energy savings. Hassid et al. [6] examined the effect of UHI on the cooling energy and peak power demand in the Greater Athens area and concluded that calculations made based on the typical meteorological year could misestimate the real energy consumption. In Tokyo metropolis, Huang et al. [7] investigated the actual status of an urban thermal environment in a complex urban area covering a large district heating and cooling system. Kikegawa et al. [8] quantified the possible effects of UHI countermeasures



Scenario	Study site	Temperature
Rural land	Blajj Al-Jazair	Tem (-2)
SCE-1	BYDDIA	Tem (-1)
SCE-2 (BASE)	AIRPORT (Al-Diar Village*)	Tem (+0)
SCE-3	M. CNTRL	Tem (+2)
SCE-4	SITRA	Tem (+3)
SCE-5	H. TOWN	Tem (+1)

*Al-Diar Village is located within 100 m distance from the airport

Fig. 1. Characteristics of adopted UHI scenarios [2].