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Developing a modified typical meteorological year weather file for Hong Kong taking into account the urban heat island effect

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A R T I C L E I N F O

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A B S T R A C T

Building energy computer simulation software is a useful tool for achieving sophisticated design and evaluation of the thermal performance of buildings. For successful thermal and energy simulation of buildings, it requires hourly weather data such as dry bulb air temperature, relative humidity, solar radiation, wind speed, etc. Nowadays, an urban city faces a problem of an urban heat island which causes the urban area to have a higher air temperature than the rural region. Since the currently available weather dataset used in building simulation software mainly comes from weather stations located in remote and rural areas, the impact of the urban heat island on thermal and energy performance of buildings may not be effectively reflected. This paper reports an approach to construct a modified typical meteorological weather file, taking into account the urban heat island effect in the summer season. Field measurements have been carried out in the summer months and the corresponding urban heat island intensities were then determined. With a morphing algorithm, an existing typical meteorological year weather file was modified. An office building and a typical residential flat were modeled with a renowned building energy simulation program EnergyPlus. Computer simulations were conducted using the existing and modified typical meteorological year weather files. It was found that there was around a 10% increase in air-conditioning demand caused by the urban heat island effect in both cases. The implications of this and further work will also be discussed in this paper.

1. Introduction

With its rapid economic development, Hong Kong has become one of the well-developed cities of the world. In this high-density city, a number of modern buildings have been designed and constructed in the past few decades. In order to achieve sophisticated building design and performance evaluation, computer simulation using thermal simulation software is a commonly adopted and effective approach. Computer simulation software requires hourly weather data such as dry bulb temperature, dew point temperature, solar radiation, wind speed and direction, etc. For successful building thermal and energy simulation, a set of representative weather data is one of the key factors. Since weather conditions can vary significantly from year to year, there is a need to derive a set of typical weather year data to represent the long-term typical weather conditions over a year. It is internationally recognized that a typical meteorological year (TMY) weather dataset can represent the long-term typical weather conditions and is more reliable in replicating average historical conditions. Therefore, TMY weather data files are commonly used by researchers around the world for studying building thermal and energy performance. In the past, there has been no local TMY weather dataset available in Hong Kong. Since 2006, a Hong Kong TMY weather data file has been developed by the author based on a 25-year hourly measured data record (1979–2003) [1].

In recent years, Hong Kong has encountered the problem of the urban heat island (UHI). The UHI effect means that an urban area is significantly warmer than its rural surroundings. The major causes of this effect include over-crowding of high-rise buildings with bulky thermal mass properties, tall buildings blocking the sea breeze and releasing thermal radiation, and lack of vegetation in urban areas. Since the meteorological data used for developing the TMY weather file come from data measured by the Hong Kong Observatory (HKO) stations which are mainly located in rural or sub-urban areas, the impact of the UHI effect cannot be reflected by these meteorological data and the subsequent TMY file developed. As a result, using the existing TMY weather file for evaluating the thermal and energy performance of buildings located in city centers with a UHI effect may not be accurate, or the average energy consumption of these buildings may be underestimated.

Therefore there is a potential need to derive a modified TMY weather dataset for Hong Kong and evaluate the difference of

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thermal and energy performance of buildings located in rural areas and city centers. The objective of this project is to develop a modified TMY weather file for the city center in Hong Kong, taking the UHI effect into account. With the modified TMY weather file, the thermal and energy performance of air-conditioned office buildings and residential apartments located in rural areas and urban cities will be investigated and compared.

There are a number of previous studies on the UHI effect around the world. Giridharan et al. investigated the impact of design-related variables on outdoor micro level daytime and nocturnal heat island effects in urban residential developments in Hong Kong [2–5]. Through mobile measurements and sensors in fixed stations in three large residential housing estates, it was discovered that surface albedo, sky view factor, vegetation above 1 m in height and average height to total floor area ratio have a very significant influence on the daytime and nocturnal UHI effect. The UHI intensity in London during the summer and winter seasons was studied by Kolokogtroni and Giridharan [6,7]. Six on-site variables including aspect ratio, surface albedo, plan density ratio, green density ratio, fabric density ratio and thermal mass were used in the study. The results revealed that the most critical variable that determined the daytime and nocturnal changes in outdoor temperature during summer season is the surface albedo. In the winter season, the average nocturnal UHI was of similar magnitude to the summer period but the peak winter UHI trends were not as regular as in the summer. Unlike the summer, most of the changes in outdoor temperature during the winter period were caused by climate factors (sky conditions and regional wind velocity) and not the on-site variables. In Greece, research on the UHI effect was carried out by Kolokotsa et al. [8]. Data from meteorological stations and field measurements were used for the analysis. The results indicated that during the summer period where the temperature is high, the UHI took its maximum intensity, of about 8 °C. Moreover, the form of UHI was strongly influenced by the wind speed and direction. The northern winds expanded the UHI front while the western winds contributed to a reduction in UHI. Bourbia and Boucheriba studied the impact of geometry on the street climate and UHI effect [9]. The investigation found an air temperature difference of 3–6 °C existing between the urban street and its surrounding rural environment. It was suggested that the UHI effect could be reduced by controlling the sky view factor and inclusion of vegetation. Shade from trees could reduce heat gain by directly shading buildings and also by evapotranspiration. The significance of on-site design variables in relation to UHI intensity has also been investigated by Yang et al. [10]. An empirical study on the summer time UHI patterns in three high-rise residential quarters of the inner-city in Shanghai, China was carried out. It was found that site characteristics in plot layout, density and greenery had different impacts on UHI-day and UHI-night patterns. Daytime UHI was closely related to site shading factor. Total site factor as an integrated measure of solar admittance showed a higher explanatory power in UHI-day than sky view factors under a partially cloudy sky condition. On the other hand, nocturnal UHI could not be well explained statistically by the on-site variables, indicating influences from anthropogenic heat and other sources. Evaporative cooling by vegetation played a more important role at night than it did during the day.

The effect of UHI on the air-conditioning load of buildings has been investigated by various researchers. Hassid et al. used building energy simulation software DOE2.1E and weather data of the years 1997 and 1998 at selected sites to study the UHI effect in Athens on the air-conditioning load [11]. The calculation of cooling energy and peak power in the western Greater Athens area based on a typical meteorological year of Athens without taking the UHI effect into account was shown to underestimate both the energy consumption and peak power of the building air-conditioning systems. A similar study was conducted by Radhi in Bahrain [12]. The study was related to climate variability and evaluated its impact on the performance of weather data used in building simulation. The results revealed that the weather file developed based on far past data (before 1991) tends to underestimate the electricity consumption by 14.5% and misrepresented the cooling load by 5.9–8.9%. For prediction of the present and future performance of buildings, it was suggested to use recently updated data (after 1991). In London, Kolokotroni et al. investigated the effect of the UHI on the summer cooling demand and night ventilation strategies for office buildings [13]. Results of air temperature measurements carried out in London in 1999/2000 were used to quantify the London UHI intensity. The measured maximum and minimum air temperatures were used as the air temperature input in the simulation tool. Hourly temperatures were calculated by sinusoidal curve fitting. Parametric analysis was carried out by using a thermal and air flow simulation tool specifically designed for offices in southeastern England. The results found that a rural reference office has an 84% energy demand for cooling compared to an urban office. Moreover, a rural office would not need any artificial cooling at nighttime and would be able to maintain a temperature below 24 °C. An urban office would not be able to achieve this. The results also indicated that increased urban temperatures should be taken into account in simulations for assessing the thermal and energy performance of buildings as they resulted in significant deviations from using standard meteorological weather data.

Under subtropical weather conditions, like the Hong Kong situation, so far little work has been done to investigate the thermal and energy performance of buildings with a modified TMY weather file taking into account the UHI effect. In the present study, mobile measurements were performed. The measured data were incorporated into an existing TMY weather data file by using a “Morphing” method. With the modified weather dataset, the impact of the UHI on the cooling demands of commercial and residential buildings in Hong Kong was evaluated. The results and analysis are reported in this paper.

2. Development of a modified typical meteorological year weather file

2.1. Geographical location and climate of Hong Kong

Hong Kong is located on the southern coast of Mainland China (latitude at 22°19′ N and longitude at 114°10′ E). The territory comprises four major parts namely Kowloon Peninsula, New Territories, Hong Kong Island and Lantau Island. A map of Hong Kong is shown in Fig. 1. Kowloon Peninsula, with an area of 46.94 km^2, forms the southern part of the main territory of Hong Kong. At the north of the Kowloon Peninsula, there is another major area called New Territories (976.85 km^2). These two areas are separated by a street named Boundary Street. The southern part of Kowloon Peninsula faces the Hong Kong Island which is separated from the mainland (Kowloon Peninsula and New Territories) by Victoria Harbor. The area of Hong Kong Island is about 78.51 km^2. Lantau Island is located at the west of Hong Kong Island with an area of 147.16 km^2. It is originally a fishing village. Major infrastructure projects including the Hong Kong International Airport and Hong Kong Disneyland were established on this island.

The climate in Hong Kong is subtropical, tending toward hot and humid summers. The winter season is relatively short and mild. In this city, January and February are often cloudy with dry northerly winds. The monthly mean air temperature is around 16 °C and the monthly mean daily total solar radiation ranges from 9.1 to