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Comparison of typical year and multiyear building simulations using a 55-year actual weather data set from China

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HIGHLIGHTS

- The typical year and multiyear building simulation are compared.
- Total 559 simulation runs of a prototype office building for 10 large cities are performed.
- The weather data varied significantly year-over-year.
- The representative of typical year simulation on building energy use and peak load is studied.
- It is recommended to using multiyear weather data for building design and performance simulation.

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ABSTRACT

Weather has significant impacts on the thermal environment and energy use in buildings. Thus, accurate weather data are crucial for building performance evaluations. Traditionally, typical year data inputs are used to represent long-term weather data. However, there is no guarantee that a single year represents the changing climate well. In this study, the long-term representation of a typical year was assessed by comparing it to a 55-year actual weather data set. To investigate the weather impact on building energy use, 559 simulation runs of a prototype office building were performed for 10 large cities covering all climate zones in China. The analysis results demonstrated that the weather data varied significantly from year to year. Hence, a typical year cannot reflect the variation range of weather fluctuations. Typical year simulations overestimated or underestimated the energy use and peak load in many cases. With the increase in computational power of personal computers, it is feasible and essential to adopt multiyear simulations for full assessments of long-term building performance, as this will improve decision-making by allowing for the full consideration of variations in building energy use.

1. Introduction

The global building sector consumes nearly one-third of the world's total energy [1]. The outdoor climatic conditions together with the building envelope, equipment used, and occupants in the building determine the total building energy consumption and the indoor thermal environment. Weather is an important factor when sizing and selecting HVAC (heating, ventilation, and air-conditioning) systems and lighting systems with daylight controls. Additionally, the energy production of weather-based renewable energy systems, such as solar energy systems and wind power systems, are influenced directly by the variability in climate. Because buildings are rather complicated, nonlinear, and dynamic systems, computer modeling and simulations are widely recognized as an efficient means of predicting the future performance of a building [2,3]. All the simulation tools used worldwide require reliable weather data inputs to drive the simulations accurately. However, different weather data sets in simulation tools can result in large discrepancies among the results [4]. In short, accurate and compatible weather data are fundamental and indispensable to the building professions.

Generally, a one-year weather sequence, known as a typical meteorological year, is used as the weather input to building simulation tools. The weather file usually contains 8760 hourly records of meteorological elements and is derived from a multiyear database to represent the long-term climatic conditions. In the last

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few decades, several data sets have been developed by different research institutions, which use various data structures and selection methods. A typical year could be an actual calendar year, such the Test Reference Year (TRY) [5], or a synthetic year consisting of 12 typical meteorological months (TMM) selected from historic weather data, such as the Typical Meteorological Year (TMY) [6] and the weather year for energy calculation (WYEC) [7], as well as the updated versions of them including TMY2 [8], TMY3 [9], and WYEC2 [10]. Given the fact that hourly weather data are not always available for some cities or sites, a synthetically generated meteorological year (SMY) can be a practical option [11]. For this purpose, hourly weather data are produced in accordance with the statistical summary data available, such as monthly or daily data; hence, SMY data can follow the sequence of real monthly or daily weather fluctuations well [12]. In addition, the synthesized data can represent the variations and uncertainties of climate to some extent [13].

Many efforts have been made to generate typical meteorological years in multitudinous locations globally, including Nigeria [14,15], Greece [16], Cyprus [17], Syria [18,19], Malaysia [20], Spain [21], Thailand [22,23], Saudi Arabia [24], South Korea [25], and Turkey [26]. In China, several typical year data sets have been published in recent years. These data sets are diverse in terms of the data sources, recording periods, and site quantities as well as the selection methods used. A typical meteorological database for 57 Chinese locations, generally called the (Chinese Typical Year Weather) CTYW database, was developed by Zhang et al. [27,28] in 2004. Because of a lack of observed solar radiation data, solar radiation was estimated by using other meteorological elements. In 2005, the Climatic Data Center of the China Meteorological Administration along with Tsinghua University developed a meteorological data set for 270 Chinese cities [29]. This data set, known as the Chinese Standard Weather Database (CSWD), has been used extensively in China and adopted into many simulation tools such as DeST [30] and EnergyPlus [31]. Yang et al. [32] investigated typical years for 60 cities in the five major climatic zones of China. In the paper by Chan et al. [33], weather data for a 25-year period (1979–2003) in Hong Kong were used to derive TMY data. Many other researchers have developed typical meteorological years for a variety of sites in China [34–36].

As can be seen in the state-of-the-art research, plenty of typical year data files have been developed worldwide, but appropriate weather data inputs must be used for building energy simulations. Crawley [37] indicated that single year, TRY-type weather data cannot represent typical long-term weather; instead, a synthetic year such as TMY2 or WYEC2 was recommended. Among the methods for deriving TMY files, there is no agreement either on the number of weather parameters to use or on the weighting of the weather parameters [38]. Some authors even claim that the generation of typical year weather data is not very sensitive to the weighting of different weather variables [39]. Studies have shown that climate change has significant impacts on building energy use [40,41], and thus, it needs to be incorporated in urban infrastructure planning [42]; because of the climate change taking place globally and its vital role in energy use, the record period for TMY selection should accordingly contain recent meteorological data and be reasonably long enough to reflect the climatic trend well [43]. Two sets of weather data files were formed based on different periods to assess their impact on the accuracy of building energy analyses [44]. This study found that the weather file developed with far older data underestimated the electricity consumption by up to 14.5%.

Although there is no doubt that typical year files can simplify the prediction process and reduce the computational work, some shortcomings are rooted in the selection method used for obtaining weather data. First, whichever method is used, the typical year is derived in compliance with the same criteria for the weather variables involved and the weightings. However, the criteria used for a typical year depend largely on the particular types or systems of buildings. For example, work on a solar-based building should place a high weight on solar radiation during the development of a typical year, whereas wind data should be the dominant parameter in the typical year selection process for a building that mainly uses natural ventilation. In other words, the typical meteorological year somehow assumes “an average building [2]” without taking into account the various sensitive variables of different building types and systems. To compare the performance of each TRY, 17 TRYs were applied to several typical energy systems [16]. The simulation results showed that the most optimal type of TRY differs from system to system. Second, a typical year does not necessarily represent the average value of the historic long-term climate and cannot reflect the variation and uncertainty inherent in the actual weather data. Some studies have shown that the building energy use predicted by a typical year followed the long-term mean quite well [34,45,46], whereas the conclusion from other research was that the representativeness of a typical year’s results could vary significantly in the considered locations [38]. Moreover, climate is such a complex and changeable phenomenon in which much variety can be found from year to year. As a result, the variation in annual building energy use calculated by using actual weather data can be significant. The energy use of office buildings in eight United States (U.S.) locations was simulated by using a 30-year actual weather data set [37]. It was concluded that annual energy consumption varied by as much as −11.0% to 7.0%. Predictions of peak cooling loads of fully air-conditioned office buildings in Hong Kong were found to differ by up to 14% [47]. Wang et al. [48] indicated that the impact of year-to-year weather fluctuations on energy use ranged from −4% to 6% in four cities in the U.S. The energy use during a typical year is just a single value, and thus, it inevitably fails to represent the variation range caused by actual weather fluctuations. Lastly, because they represent typical rather than extreme conditions, typical years are not suitable for designing systems that can accommodate worst-case conditions [8]. Given the limitations of a typical year, some authors have created an Extreme Meteorological Year (XMY) [49] or Untypical Meteorological Year (UMY) [50] to capture building performance under extreme conditions.

Considering the above factors, it is time to rethink the utilization of a typical meteorological year in building energy predictions and comparative energy efficiency studies. Because it is possible to run hundreds of simulations in mere minutes nowadays thanks to the rapid development in computational power, direct simulations with multiyear actual weather databases should be considered when assessing building performance. There are many benefits to using multiyear simulations instead of a single typical year. As buildings can have a long life cycle (greater than 50 years), the assessment and prediction of long-term building performance is very important. Simulations with multiyear actual weather data allow for comprehensive understanding of building performance in a long-term weather series from a life-cycle perspective. Such assessments provide the variation range in building energy use due to the changeable climate rather than single value data. Furthermore, building designers and operators or policymakers can evaluate the likelihood of any weather conditions and adopt appropriate response strategies based on the simulation results. Any year required for a specific design aim, such as an extremely hot year or a specific calendar year, can be chosen from a multiyear database easily. A few studies have investigated the advantages of multiyear building simulations over typical year simulations. Hui et al. [51] presented a pilot study in Hong Kong regarding long-term building energy performance using multiyear weather data. Large-scale simulations were conducted by Hong et al. [52]