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A fresh look at weather impact on peak electricity demand and energy use of buildings using 30-year actual weather data

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HIGHLIGHTS

- Weather has a significant impact on both the peak electricity demand and energy use.
- Weather impact varies with building type, building efficiency level, and location.
- Simulated results using TMY3 weather data can under or over estimate those of AMY.
- It is crucial to assess performance of buildings using long-term actual weather data.
- Findings enable building stakeholders to make better decisions on weather impact.

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ABSTRACT

Buildings consume more than one third of the world's total primary energy. Weather plays a unique and significant role as it directly affects the thermal loads and thus energy performance of buildings. The traditional simulated energy performance using Typical Meteorological Year (TMY) weather data represents the building performance for a typical year, but not necessarily the average or typical long-term performance as buildings with different energy systems and designs respond differently to weather changes. Furthermore, the single-year TMY simulations do not provide a range of results that capture yearly variations due to changing weather, which is important for building energy management, and for performing risk assessments of energy efficiency investments. This paper employs large-scale building simulation (a total of 3162 runs) to study the weather impact on peak electricity demand and energy use with the 30-year (1980–2009) Actual Meteorological Year (AMY) weather data for three types of office buildings at two design efficiency levels, across all 17 ASHRAE climate zones. The simulated results using the AMY data are compared to those from the TMY3 data to determine and analyze the differences. Besides further demonstration, as done by other studies, that actual weather has a significant impact on both the peak electricity demand and energy use of buildings, the main findings from the current study include: (1) annual weather variation has a greater impact on the peak electricity demand than it does on energy use in buildings; (2) the simulated energy use using the TMY3 weather data is not necessarily representative of the average energy use over a long period, and the TMY3 results can be significantly higher or lower than those from the AMY data; (3) the weather impact is greater for buildings in colder climates than warmer climates; (4) the weather impact on the medium-sized office building was the greatest, followed by the large office and then the small office; and (5) simulated energy savings and peak demand reduction by energy conservation measures using the TMY3 weather data can be significantly underestimated or overestimated. It is crucial to run multi-decade simulations with AMY weather data to fully assess the impact of weather on the long-term performance of buildings, and to evaluate the energy savings potential of energy conservation measures for new and existing buildings from a life cycle perspective.

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1. Introduction

Buildings consume more than one third of the world's total primary energy. The IEA Annex 53 [1] identified and studied six influencing factors on building energy performance, including climate, building envelope, building equipment, operation and maintenance, occupant behavior, and indoor environmental conditions. Among these influencing factors, climate plays a unique and significant role. Weather contributes directly and significantly to the variations of thermal loads and energy use of HVAC (heating, ventilation, and air conditioning) systems, lighting (for buildings with

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daylighting controls), and energy production from solar-based renewable systems. In residential and commercial buildings in the US, heating and cooling accounts for more than 40% of end-use energy demand. It is important to understand and estimate the impact of weather on the long-term performance of buildings in order to support policy making, and to allow building operators and owners to respond better to climate changes in terms of building energy supply and demand. Additionally, considering the impact of yearly variations in weather can improve the evaluation of investment risks of energy conservation measures (ECMs) for new and existing buildings by taking into account their life-cycle energy and cost savings.

The accuracy of building energy simulations and economic assessments of renewable energy systems depend on the availability of reliable weather data. There are two primary sources of weather data that are used to generate weather data files used in building simulation: measured weather data using physical sensors and observations, and simulated data using mathematical weather models. Various methods to generate annual hourly weather data have been developed in the past. Such weather data include the Typical Meteorological Year (TMY), the test reference year (TRY), the weather year for energy calculation (WYEC), the design reference year (DRY), as well as the synthetically modeled meteorological year (SMY). However, the lack of long-term weather records usually limits the generation of typical annual weather data files in any format [2].

A TMY weather file contains hourly values of solar radiation and meteorological elements for a 1-year period. The 12 typical meteorological months (TMMs) are selected from various calendar months in a multi-year weather database. The criteria for TMM selection is based on the statistical analysis and evaluation of four weather parameters: the ambient dry-bulb temperature, the dew-point temperature, the wind speed and the global solar radiation. Algorithms are used to smooth discontinuities from the data to avoid drastic changes between two adjacent months selected from different years. The first generation of TMY weather data for the US is derived from the 1952–1975 SOLMET/ERSATZ database, while the second generation of data (TMY2) is derived from the 1961–1990 National Solar Radiation Database (NSRDB) covering 239 US locations. The latest, third generation data (TMY3) is derived from the 1976–1990 and 1991–2005 National Solar Radiation Data Base (NSRDB). TMY3 covers 1020 US locations. TMY, TMY2 and TMY3 data sets cannot be used interchangeably because of differences in the data structure such as time (solar vs. local), formats, elements, and units. The intended use of TMY weather data is for computer-based building performance simulations of solar energy conversion systems and building systems to facilitate performance comparisons of different system types, configurations, and locations in the US and its territories. Because they represent typical rather than extreme conditions, they are not suited for designing systems to meet the worst-case conditions occurring at a location [3]. For the calculations of peak cooling and heating loads of buildings, and sizing HVAC equipment, design day weather data are used. Design-day weather data tend to represent more extreme weather conditions in order to guarantee that HVAC systems can meet peak loads for most of the time during their life cycle. Various methods are used to create design-day weather data [4].

As TMY data may not be available for some cities or sites, SMY weather data provide a practical and useful alternative. SMY weather data can be generated from monthly average or total values of weather parameters using stochastic models and autoregressive moving average processes to represent the seasonal and daily weather variations [5]. Such stochastic weather models can be used to generate AMY weather data for use in deterministic building simulations, or together with a stochastic internal loads model, can be integrated with a building thermal model to obtain directly the probability distribution of building performance to investigate the uncertainty caused by the random meteorological processes and internal heat gains [6].

A new online weather data service with immediate access to precision, localized weather history, current conditions and forecasts are presented by Keller and Khuen [7]. Localized weather data is created by integrating all available ground station observations with high-resolution datasets from NOAA (National Oceanic and Atmospheric Administration). Both historical and forecast time series data are available for direct user access and application/system access through Web Data Services and API interfaces.

Selecting appropriate weather data to be used in building performance simulation is important. The use of inappropriate weather data can result in large discrepancies between the predicted and measured performance of buildings. In the late 1970s, Freeman [8] evaluated how well TMY represents actual long-term weather data based on simulations of an active residential space solar heating and cooling system for six US climates, Albuquerque, Fort Worth, Madison, Miami, New York, and Washington DC. High variability of the weather and solar heating system performance year to year was noted. Crawley [9] compared the influence of the various weather data sets on simulated annual energy use and cost. Using different weather data sets can cause significant variations in annual energy consumption and cost from simulation results. The results show that the TMY and the WYEC data sets represent the closest typical weather patterns. Simulated results using the TMY weather data provides the average/typical energy use for buildings, but the peak electricity demand predictions and uncertainty analyses based on TMY are often not reliable because a single year cannot capture the full variability of the long-term climate change [10]. In view of the long-term climate change, the time period assigned for TMY selection should include the most recent meteorological data and should be reasonably long to reflect well the weather variations [11]. Most of the available TMY weather data are from weather stations located at airports. It is possible to create a new TMY file localized to a building location by integrating the weather station observations with gridded reanalysis data. However, there are limited complete weather data collected by weather stations over 15–30 years, so TMY data is only available for only 1020 locations. Furthermore, some of the TMY weather data files were created up to 20 years ago. They are less representative of the typical present day climate and do not describe extreme weather conditions. Compared with the TMY weather data, the AMY is created from actual hourly data for a particular calendar year. AMY weather data is particularly useful for modeling years with extremes in weather and verifying the energy performance of buildings. However, as with the TMY weather data, the AMY weather data needs to be chosen as close to the building location as possible.

The potential impacts of various types of weather forecast models, weather data, and building prototypes have been studied from a number of perspectives. A prototypical small office building was modeled operating at three energy efficiency levels, using typical and extreme meteorological weather data for 25 locations, to study various predicted climate change and heat island scenarios [12]. The largest change to the annual energy use due to climate change was seen in the temperate, mid-latitude climates, where there was a swapping of energy use from heating to cooling. The heating energy was reduced by more than 25% and cooling energy was increased by up to 15%. The TMY weather data provides more localized and comprehensive climate indicators to further support the HVAC system design in buildings [3,13]. The space cooling plays a major role in determining the magnitude and timing of peak electricity demand. The archived General Circulation Model

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