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Simulated building energy demand biases resulting from the use of representative weather stations

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HIGHLIGHTS

- Building energy model biases in the WECC depend on the location/number of representative cities.
- Using 1 station per IECC climate zone results in a mean absolute summer temperature bias of 4.0 °C.
- Using 1 station per IECC zone can lead to a 20–40% overestimate of peak loads during summer/winter.
- Using all available stations reduces the mean absolute load bias by a factor of 2.5.
- Using 4 stations per IECC zone reduces both temperature/load biases and computational burden.

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ABSTRACT

Numerical building models are typically forced with weather data from a limited number of "representative cities" or weather stations representing different climate regions. The use of representative weather stations reduces computational costs, but often fails to capture spatial heterogeneity in weather that may be important for simulations aimed at understanding how building stocks respond to a changing climate. We quantify the potential reduction in temperature and load biases from using an increasing number of weather stations over the western U.S. Our novel approach is based on deriving temperature and load time series using incrementally more weather stations, ranging from 8 to roughly 150, to evaluate the ability to capture weather patterns across different seasons. Using 8 stations across the western U.S., one from each IECC climate zone, results in an average absolute summertime temperature bias of ~4.0 °C with respect to a high-resolution gridded dataset. The mean absolute bias drops to ~1.5 °C using all available weather stations. Temperature biases of this magnitude could translate to absolute summertime mean simulated load biases as high as 13.5%. Increasing the size of the domain over which biases are calculated reduces their magnitude as positive and negative biases may cancel out. Using 8 representative weather stations can lead to a 20–40% bias of peak building loads during both summer and winter, a significant error for capacity expansion planners who may use these types of simulations. Using weather stations close to population centers reduces both mean and peak load biases. This approach could be used by others designing aggregate building simulations to understand the sensitivity to their choice of weather stations used to drive the models.

1. Introduction

A large direct societal cost of climate change could come from the need to build an energy system capable of meeting spikes in energy demand under heat wave conditions that are changing in frequency in response to warmer temperatures [1–7]. It is important to energy system planners and other stakeholders that we understand the detailed regional, seasonal, and diurnal characteristics of building energy demand under current and future climate conditions. There are efforts underway across multiple research disciplines to understand and quantify this potential impact. Much of the literature on this topic is based on empirical studies which often utilize static representations of building stock and therefore do not capture dynamic responses to extreme events or evolving building technologies [8–15]. Climate and weather impacts on individual buildings have also been explored using numerical building models such as eQUEST [http://www.doe2.com/equest/], TRACE 700 [http://www.trane.com/commercial/north-america/us/en/products-systems/design-and-analysis-tools/analysis-tools/trace-700.html], and the Department of Energy's (DOE) EnergyPlus [16]. A typical approach with these models is to use weather

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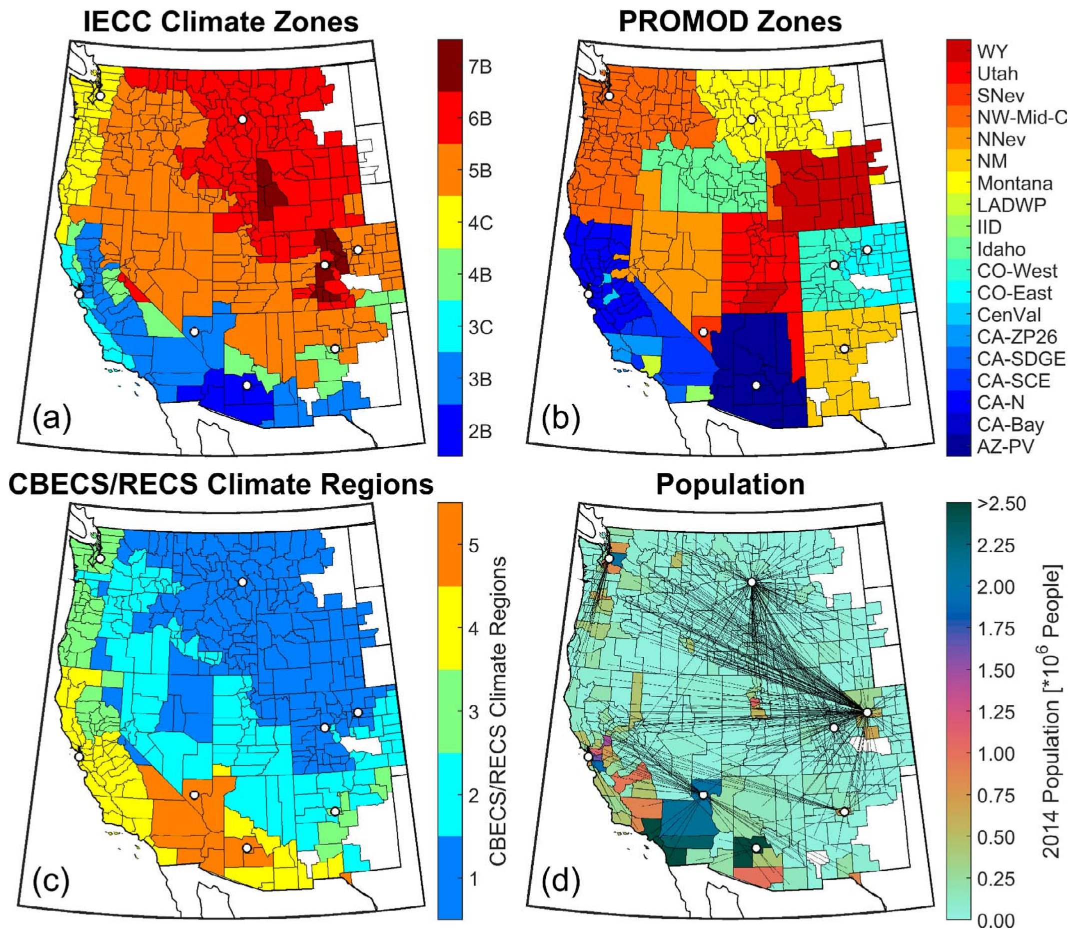

Fig. 1. (a) The 8 IECC climate zones that are present in the Western Electricity Coordinating Council (WECC); (b) the 19 PROMOD zones used in the calibration of our BEND simulation; (c) the 5 climate regions in the CBECS/RECS building databases; and (d) the population within each county in 2014. In all panels the white dots indicate the original 8 Class A representative weather stations, one for each climate zone, that are used to force BEND. Panel (d) includes a mapping from each county to its associated Class A representative weather station. The two blank counties in Colorado and New Mexico are not part of the WECC.

data at a single location as input to the model and then analyze the building energy demand response to changing weather conditions at that location [5,17–19].

One advancement facilitating new insights in this space is that composite models of building energy demand using tens of thousands of individual building simulations, based on different combinations of building technologies and characteristics or climate scenarios, are now possible due to increased access to high-performance computing. In these composite models, individual building simulations under current or future climate scenarios are aggregated on city [20,21], state [7,11], or national scales [5,22]. The composite model approach delivers the detailed, physically-based aspects derived from modeling individual buildings as well as information on the aggregate effect on larger spatial or longer temporal scales. Two key uses of these aggregate building energy models are to quantitatively evaluate the impact of proposed energy efficiency measures for energy efficient building designs or to assess the impact of climate or economic changes on aggregate building energy demand.

The DOE's Pacific Northwest National Laboratory (PNNL) has developed the aggregate Building ENergy Demand (BEND) model to explore the interaction between weather conditions and building energy demand (alternatively referred to as building loads in this paper). The BEND model was first described and utilized in Dirks et al. [7], which explored climate change impacts on peak and annual building energy demand in the Eastern Interconnection (EIC). At its root, the BEND model is a mechanism to aggregate EnergyPlus simulations for a representative sample of building types in a given geographical area. BEND uses the Commercial Buildings Energy Consumption Survey [CBECS; https://www.eia.gov/consumption/commercial/about.php] and Residential Energy Consumption Survey [RECS; https://www.eia.gov/consumption/residential/] datasets to generate a population of buildings that span the range of residential and commercial building sizes and vintages in a climate similar area of a census region. Energy usage in each building in the sample population is then simulated using forcing from Energy Plus Weather files that contain an hourly time series of observed or predicted meteorological variables (e.g., temperature, humidity, solar radiation). These forcing files are the primary mechanism by which the model responds to changes in weather and they represent the physical linkage between climate and building energy demand. The selection of which weather datasets or locations are used to force the model is a key component of the simulation design.

In an ideal scenario, simulations using BEND or other building energy models would be run using weather information that exactly corresponds to the physical location of each simulated building. However, computational and data constraints make this impractical and unwarranted: The CBECS and RECS databases only provide a statistical representation of the nation's building stock, rather than a complete geospatially explicit inventory, and there are only ~1000 surface weather stations in the U.S. with sufficient data density and quality to drive the underlying EnergyPlus models [23]. The key questions to address when developing an aggregated building energy demand model are thus (1) how many representative buildings are needed to adequately represent the diversity of building types and corresponding energy demand profiles, and (2) how many weather