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Predicting energy performance of a net-zero energy building: A statistical approach

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HIGHLIGHTS

- A regression model is applied to actual energy data from a net-zero energy building.
- The model is validated through a rigorous statistical analysis.
- Comparisons are made between model predictions and those of a physics-based model.
- The model is a viable baseline for evaluating future models from the energy data.

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ABSTRACT

Performance-based building requirements have become more prevalent because it gives freedom in building design while still maintaining or exceeding the energy performance required by prescriptive-based requirements. In order to determine if building designs reach target energy efficiency improvements, it is necessary to estimate the energy performance of a building using predictive models and different weather conditions. Physics-based whole building energy simulation modeling is the most common approach. However, these physics-based models include underlying assumptions and require significant amounts of information in order to specify the input parameter values. An alternative approach to test the performance of a building is to develop a statistically derived predictive regression model using post-occupancy data that can accurately predict energy consumption and production based on a few common weather-based factors, thus requiring less information than simulation models. A regression model based on measured data should be able to predict energy performance of a building for a given day as long as the weather conditions are similar to those during the data collection time frame. This article uses data from the National Institute of Standards and Technology (NIST) Net-Zero Energy Residential Test Facility (NZERTF) to develop and validate a regression model to predict the energy performance of the NZERTF using two weather variables aggregated to the daily level, applies the model to estimate the energy performance of hypothetical NZERTFs located in different cities in the Mixed-Humid Climate Zone, and compares these estimates to the results from already existing EnergyPlus whole building energy simulations. This regression model exhibits agreement with EnergyPlus predictive trends in energy production and net consumption, but differs greatly in energy consumption. The model can be used as a framework for alternative and more complex models based on the experimental data collected from the NZERTF.

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1. Introduction

In 2014, roughly 41% of total U.S. energy consumption came from commercial and residential buildings [1]. The growing concerns about energy consumption in buildings – in particular, residential buildings – have driven an interest in low- and net-zero energy buildings and legislation to increase building energy efficiency. States' building energy codes continue to increase the energy efficiency requirements across the US, with greater emphasis on performance-based over prescriptive-based requirements. Performance-based building requirements give more freedom to builders while still maintaining energy performance that meets or exceeds the resulting energy performance from prescriptive-based requirements.

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Nomenclature

List of abbreviations

AMY	Actual Meteorological Year
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
AR	autoregressive
ARIMA	Autoregressive Integrated Moving Average
CONS	electricity consumption
DOE-2	department of energy building energy analysis program
DoW	Day of Week
E+	EnergyPlus
EPT	electricity export
HVAC	heating, ventilation, and air conditioning
IMP	electricity import
INS	plane of array solar insolation
KGAI	call letters of weather station nearest to the net-zero energy residential test facility
NC	net consumption
NIST	National Institute of Standards and Technology
NZ	net-zero
NZERTF	Net-Zero Energy Residential Test Facility
ODB	Outdoor Dry Bulb Temperature
POA	Plane of Array
PROD	electricity production
PV	photovoltaic
R^2	correlation coefficient
RH	relative humidity
RMSE	Root Mean-Squared Error
s-significant	statistically significant
TMY3	Typical Meteorological Year 3

In order to determine if building designs reach the target level of energy-efficiency, it is necessary to estimate the energy performance of a building using predictive models and regional weather conditions. Physics-based whole building energy simulation models (e.g., DOE-2, EnergyPlus, or TRNSYS) using one or more years' worth of weather data are the most common approach to estimate this energy performance.[1] However, these models include underlying assumptions and require significant amounts of information in order to specify the input parameter values, including equipment performance specifications across a variety of conditions. The performance specifications supplied by manufacturers are based on standard test procedures (specific temperatures, loads, etc.) that rarely represent the conditions under which the equipment operates once installed. The combination of varying weather conditions and integrated design considerations may be difficult to model using simulation models. Even when detailed information is available to a simulation modeler to define these inputs using post-occupancy equipment performance and occupant activity, the modeling software may not be able to accurately predict energy performance as a result of capabilities, or lack thereof, built into the software. Issues due to capability limits in these simulation models are more prominent when modeling low- and net-zero energy building designs, which often incorporate emerging technologies, new processes and techniques, and renewable-based energy production systems.

An alternative approach to test the performance of a building is to develop a predictive regression model using post-occupancy data that can accurately predict energy consumption and production based on a few common weather-based factors. A specific building design should perform similarly for two days that have the same weather conditions and similar occupant activity. Assuming that occupant activity is relatively stable, a regression model based on measured data should be able to predict energy performance of this building design for a given day as long as the weather conditions are similar to those during the data collection timeframe (i.e., locations within the same climate zone). The statistics-based model estimates can be compared to validated energy models of the same building to determine similarities in the results. If the regression estimates match the simulation model results, then the regression model could be used in lieu of the simulation software to estimate performance for different weather conditions, either due to seasonal variations at the building's location or for different locations across the same climate zone while potentially requiring less information.

Completing such a model and comparing its performance to that of a simulation both require detailed specifications for a building's design combined with post-occupancy energy performance data and simulation models developed to predict that building's design. The National Institute of Standards and Technology (NIST) constructed a Net-Zero Energy Residential Test Facility (NZERTF) in order to demonstrate that a net-zero (NZ) energy residential design can "look and feel" like a typical home in the Gaithersburg area while creating a test facility for building technology research. This facility includes extensive collection of data on the building's energy use and on-site renewable energy production. The NZERTF design includes a 10.2 kW solar photovoltaic array mounted on the roof, a solar water heating system, energy efficient wall and roof designs, energy efficient appliances, as well as a heat recovery ventilation system [2]. Data collection and simulation of occupants is automated and includes a weekly schedule of routines based on a family of four [3]. Table 1 provides the full specifications for the NZERTF design.

The initial year of demonstration for the NZERTF (referred to moving forward as "Round 1") has been completed and successfully met its net-zero goal of producing as much or more energy as it consumed over the entire year (July 1, 2013 through June 30, 2014). The data collected during Round 1 was used to adjust and validate both an *EnergyPlus* (E+) and *TRNSYS* whole building energy simulation developed for the NZERTF [4,5]. The plethora of information on the NZERTF makes it an ideal case for generating a predictive regression model that can then be compared to an existing simulation model. A brief overview of E+ can be found in Crawley et al. [6].

This article uses the NZERTF database for Round 1 to develop and validate a parsimonious regression model that can accurately predict the energy performance of the NZERTF using only the most important daily weather conditions, applies the model to estimate the energy performance of the NZERTF as though it were located in different locations throughout the Mixed-Humid Climate Zone,[2] and compares these estimates to the results from comparable E+ whole building energy simulations. The regression model will serve as a framework for alternative and more complex models based on

[1] Certain trade names and company products are mentioned in the text in order to adequately specify the technical procedures and equipment used. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products are necessarily the best available for the purpose.

[2] The Mixed-Humid zone is defined according to the U.S. Department of Energy's Building America Program Classification. These climate zones are meant to guide builders in identifying best practices for construction to improve energy performance, and various other aspects of residential buildings [7].

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