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Towards fast energy performance evaluation: A pilot study for office buildings

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ABSTRACT

Given the growing concern about building energy efficiency and the difficulty in applying complex simulation tools during retrofit practices, the need for easily and quickly estimating the building energy performance becomes pressing. As a pilot test, this study proposes a systematic method to develop a model, which can immediately assess the annual electricity consumption for office buildings with fan coil system in Shanghai. First, a base-case building model is established by EnergyPlus to create a pool of candidate inputs using orthogonal experiment design. Then, analysis of variance is used to identify a total of 10 key building design parameters, which are selected as the input variables in the support vector regression (SVR) model based on a well-structured database. The performance of SVR is optimized using genetic algorithm (GA) based on radial basis function kernel. Finally, two real office buildings in Shanghai with reliable measured data serve to evaluate the developed hybrid model. The resulting differences between the predicted and measured values are generally within 10%. It is expected that the developed database and model can be used to assess the likely energy savings/penalty related with certain parameter changes to some extent during the retrofit process for office buildings.

1. Introduction

For building professions throughout the world, energy is one of the key issues in the overall efforts to realize sustainable development [1]. According to International Energy Agency (IEA), buildings represent about 32% of total final energy use [2]. In terms of primary energy consumption, buildings account for around 40% in most IEA countries [2]. These figures could be higher in major cities (e.g. Shanghai), due partly to the significant economic growth and the shift of local economy from manufacturing-oriented to service-based. In the meantime, office building is one of the fastest growing parts in the building sector, particularly in some major cities of China [3]. Energy efficiency is thus of great importance to sustainable building design, especially for office buildings.

During the past decades, researchers have made great efforts in the improvement of building energy efficiency. In particular, building energy prediction has drawn increasing attention [4,5], since it is valuable to develop various retrofit concepts and strategies for enhancing building energy performance. Examples of the computer simulation introduced into architectural and engineering retrofit practices are DOE-2 [6], EnergyPlus [7], TRNSYS [8], etc. However, discussions with architects and engineers have revealed that full hourly physics-based building energy simulations are usually complicated, costly and time-consuming. Instead, most building owners and stakeholders, who lack unique expertise and resources, tend to depend on rule-of-thumb assessments. These approaches, though initially inexpensive, may result in design strategies for isolated measures without considering interactive effects between the measures. Such case will remain a challenge for maximizing the energy savings or economic benefits. Thus, there is a need for simple estimation models, especially during the decision making process when various energy retrofit concepts and schemes need to be quickly considered and compared.

Many previous studies have developed some simple energy prediction models for commercial and office buildings by using regression analysis [9–15]. But few models have been updated on recent performances of parameters in the building system, as well as have been validated or evaluated through real cases. In addition, many existing studies mainly adopted simple methods to select input variables and develop linear models, indicating the possibility that some useful information may be underestimated in a non-linear building system. Therefore, more advanced techniques and more sound energy audits of real buildings are needed to develop and evaluate related models for improving the accu-

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Nomenclature

c	Regularization constant
Err_i	Relative error between predicted and measured values for building i (%)
F	F-test value
f	Degree of freedom of the error
f	Degree of freedom of factor j
g	Inverse width of Gaussian radial basis function
n	Number of measurements
R^2	Coefficient of determination
SS_A	Sum of squared deviations
V_A	Variance
$\bar{Y}$	Mean of measured and predicted values
Y	Measured value for building i
$\hat{Y}_i$	Predicted value for building i

Abbreviation

AEC	Annual electricity consumption (kWh/m^2 a)
ANN	Artificial neural network
ANOVA	Analysis of variance
COP	Coefficient of performance
CSWD	Chinese standard weather data
COMBAT	Commercial building analysis tool
DEEP	Database for energy efficiency performance
DOE	Department of energy
EQ	Equipment load density (W/m^2)
FCU	Fan coil unit
FE	Fan efficiency
FEMP	Federal energy management program
GA	Genetic algorithm
HPC	High performance computing
HVAC	Heating, ventilation, and air-conditioning
IEA	International energy agency
LBNL	Lawrence Berkeley national laboratory
LL	Lighting load density (W/m^2)
MSE	Mean square error
OED	Orthogonal experiment design
OP	Occupant density (m^2/person)
PAT	Parametric analysis tool
PE	Pump efficiency
RBF	Radial basis function
SC	Shading coefficient of window
Sig	Significance
SST	Summer set point temperature (°C)
SVR	Support vector regression
WU	Window U-value (W/m^2 K)
WWR	Window-to-wall ratio

racy and stability of building energy predictions. These practical reasons motivate the authors to make an exploration of the non-linear performance for estimating building energy consumption by using hybrid statistical techniques.

To provide an easy and reliable solution for fast energy retrofit estimation, a large set of simulations performed by experts seems to be necessary. Although the pre-simulated method has some limitations, such as the geometrical mismatch between the prototype and actual buildings, it still can give us an immediate and authentic energy estimation. Some massive pre-simulated databases developed in the past five years include the LBNL's COMBAT (Commercial Building Analysis Tool) [16] and DEEP (Database for Energy Efficiency Performance) [17], Energy Impact Illinois' EnCompass [18], and US DOE's 179D easy calculator [19]. With recent advancement in computing environment, executions of large scale simulations

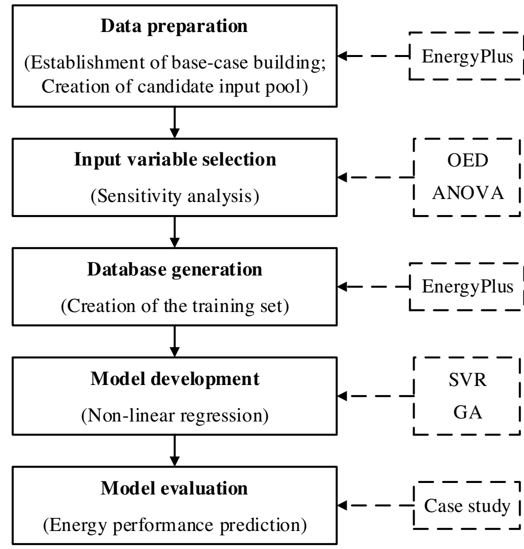

Fig. 1. Schematic outline of the research.

for building energy database development can offer users more new resources to conduct reliable energy estimations quickly. However, the work is usually challenging and expensive, which makes the building energy modeling sometimes unfeasible to small projects. In order to promote the use of these resources, there is an increasing need for a systematic establishment of the energy performance database.

As a pilot test, this study intends to develop an energy prediction model, which can easily estimate the annual electricity use of office buildings with FCU system in Shanghai. Fig. 1 shows the schematic outline of the present research, which includes five main aspects:

(i) Establishment of a base-case model for the office building to generate simulation data for the study.
(ii) Identification of key design variables for the office building using sensitivity analysis technique.
(iii) Generation of an energy use database via a series of simulations using orthogonal experiment design.
(iv) Development of a prediction model based on the pre-simulated database using support vector regression.
(v) Evaluation of the developed model against the measured data from two office buildings in Shanghai.

The resulting database and model are expected to provide a simple direct decision making process for helping estimate the energy-saving potential of some energy conservation measures to retrofit existing office buildings quickly.

2. Base-case building design

EnergyPlus [7] is employed as the simulation tool in the present study because it can provide the capability to simulate a wide range of building design features and energy conservation measures. Although EnergyPlus can perform energy modeling with a good accuracy, it is quite complex and error-prone to conduct such a large number of simulations due to the huge amount of data to be analyzed. To ensure model robustness and consistency, great care should be taken to first establish the model building in a simplified form, and then to refine the building system with more details.

A base-case office building is created to serve as a baseline reference, which is of great importance since all the subsequent calculations and analyses are performed based on it. The established base-case model is a 12-storey office building (40 m × 40 m)