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A review of methods to match building energy simulation models to measured data

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ABSTRACT

Whole building energy simulation (BES) models play a significant role in the design and optimisation of buildings. Simulation models may be used to compare the cost-effectiveness of energy-conservation measures (ECMs) in the design stage as well as assessing various performance optimisation measures during the operational stage. However, due to the complexity of the built environment and prevalence of large numbers of independent interacting variables, it is difficult to achieve an accurate representation of real-world building operation. Therefore, by reconciling model outputs with measured data, we can achieve more accurate and reliable results. This reconciliation of model outputs with measured data is known as calibration.

This paper presents a detailed review of current approaches to model development and calibration, highlighting the importance of uncertainty in the calibration process. This is accompanied by a detailed assessment of the various analytical and mathematical/statistical tools employed by practitioners to date, as well as a discussion on both the problems and the merits of the presented approaches.

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1. Introduction

In order to understand building energy simulation, it is necessary to understand scientific models in general. According to Saltelli et al. [1], models can be

- *Diagnostic* or *Prognostic*: Diagnostic models are used to identify the nature or cause of some phenomenon. In other words, it may be used to better understand the laws which govern a given system. Prognostic models, on the other hand, are used to predict the behaviour of a system, given a set of well-defined laws governing that system.
- *Law-Driven or Data-Driven:* Law-Driven (or forward) models apply a given set of laws (e.g., gravity, heat/mass transfer etc.) which govern a system, in order to predict its behaviour given system properties and conditions. Data-Driven (or inverse) models work on the opposite approach, using system behaviour as a predictor for system properties. Therefore, data-driven models can be used to describe a system with a minimal set of adjustable inputs [2]. In contrast, law driven models are often over-parameterised, in that they require more inputs than available data can support. However, the advantage of law-driven models is that they offer the ability to model system behaviour given a set of previously unobserved conditions, while data-driven models would require prior data in order to model behaviour. A simplified comparison of law-driven and data driven models is presented in Fig. 1 [3].

Building energy simulation (BES) models, as used in building design, can generally be classified as prognostic law-driven models in that they are used to predict the behaviour of a complex system given a set of well-defined laws (e.g., energy balance, mass balance, conductivity, heat transfer, etc.).

Conversely, data-driven (inverse) approaches, in the context of building energy modelling, refer to methods which use monitored data from the building to produce models which are capable of accurately predicting system behaviour. Inverse methods for energy use estimation in buildings can be broadly classified into three main approaches [4] (Table 1),

(i) Black-box approach: This refers to the use of simple mathematical or statistical models (e.g., regression, neural-networks etc.) which relate a set of influential input parameters (e.g., occupancy and weather) to measured outputs. Model input coefficients are determined such that they produce an algorithm with the ability to predict system behaviour. It is important to note that these input coefficients have no direct link to a definitive parameter in the physical environment.

(ii) Grey-box/parameter estimation: Grey box approaches differ from black-box approaches in that they use certain key (or aggregated) system parameters identified from a physical system model.

(iii) Detailed model calibration: The final approach uses a fully-descriptive law-driven model of a building system and tunes the various inputs to match the measured data.This approach provides the most detailed prediction of building performance, given the availability of high-quality input data. Since it is explicitly linked to physical building, system and environmental paramters, it provides a platform for assessing the impact of changes to these parameters (e.g., retrofit analysis).

1.1. Building energy performance simulation (BEPS) tools

Whole building energy simulation tools allow the detailed calculation of the energy required to maintain specified building performance criteria (e.g., space temperature and humidity), under the influence of external inputs such as weather, occupancy and infiltration. Detailed heat-balance calculations are carried out at discrete time-steps based on the physical properties of the building and mechanical systems as well as these dynamic external inputs (weather, occupancy, lighting, equipment loads etc.). These calculations are generally performed over the course of a full year. These tools fall into the category of prognostic law-driven simulation tools. Some of the main tools which will be discussed during the course of this review are

- DOE-2 [5] is a freeware building energy simulation tool which predicts the hourly energy use and energy cost of a building given hourly weather information, a building geometric and HVAC description, and utility rate structure. Its development was funded by the U.S. Department of Energy (DOE), hence the name.
- EnergyPlus [6] is an advanced whole building energy simulation tool, developed on the basis of work carried out on DOE-2. It incorporates the same functionality as DOE-2, producing hourly (or sub-hourly) energy costs of a building given system input information. It also incorporates many advanced features not available in DOE-2, such as multi-zone airflow and extensive HVAC specification capabilities.
- TRNSYS [7] is a transient system simulation program with a modular structure which implements a component-based simulation approach. Components may be simple systems like pumps or fans, or complex systems such as multi-zone buildings.
- ESP-r [8] is an integrated modelling tool for the simulation of the thermal, visual and acoustic performance of buildings. Similar to EnergyPlus and DOE-2, ESP-r requires user-specified information regarding building geometry, HVAC systems, components and schedules. It supports explicit energy balance in each zone and at each surface as well as incorporating inherent uncertainty and sensitivity analysis capabilities.

The above four simulation programs represent the most common tools encountered in conducting this review. However, many more tools are available, some of which are tailored specifically to certain tasks (e.g., HVAC simulation, solar gain, daylighting etc.). Crawley et al. [9] presents a comparison of the main features and capabilities of the top 20 tools available at the time of publication.

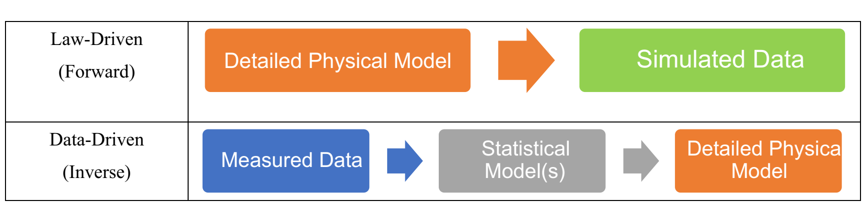

Fig. 1. Law-driven (forward) models vs. data-driven (inverse) models.