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# Experimental verification of an energy consumption signal tool for operational decision support in an office building

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ABSTRACT

This paper demonstrates an energy signal tool to assess the system-level and whole-building energy use of an office building in downtown Denver, Colorado. The energy signal tool uses a traffic light visualization to alert a building operator to energy use which is substantially different from expected. The tool selects which light to display for a given energy end-use by comparing measured energy use to expected energy use, accounting for uncertainty. A red light is only displayed when a fault is likely enough, and abnormal operation costly enough, that taking action will yield the lowest cost result. While the theoretical advances and tool development were reported previously, it has only been tested using a basic building model and has not, until now, been experimentally verified. Expected energy use for the field demonstration is provided by a compact reduced-order representation of the Alliance Center, generated from a detailed DOE-2.2 energy model. Actual building energy consumption data is taken from the summer of 2014 for the office building immediately after a significant renovation project. The purpose of this paper is to demonstrate a first look at the building following its major renovation compared to the design intent. The tool indicated strong under-consumption in lighting and plug loads and strong over-consumption in HVAC energy consumption, which prompted several focused actions for follow-up investigation. In addition, this paper illustrates the application of Bayesian inference to the estimation of posterior parameter probability distributions to measured data. Practical discussion of the application is provided, along with additional findings from further investigating the significant difference between expected and actual energy consumption.


## 1. Introduction and motivation

There is increasing concern with the energy performance of the built environment [1]. Growing commitment to energy efficiency, cost-minimal retrofits, and renewable energy integration has led to the availability of both commercial and open source building energy simulation engines [2–5]. Model-based building design approaches have become the norm. Model-based approaches can be extended beyond design applications to improving energy performance over a building's multi-decade life cycle [6,7]. A model-based approach is valuable because tradeoffs in comfort and energy consumption can be hidden and the establishment of '*normal behavior*,' as distinguished from '*faulted behavior*,' is nontrivial. This paper represents a demonstration of the application of data-driven models for operational decision-making processes which are flexible, adaptable, and can evolve with the building as it changes.

The ultimate goal of the energy signal tool research presented in detail in [8,9] and applied herein is to enable owners and operators of commercial buildings to quickly, i.e., in a matter of a few seconds, attain insight into how their building's energy use compares against the likely range of expected energy consumption over a given time period (days, weeks, months, or years). The output of the energy signal tool is a simple stoplight indicator which summarizes energy consumption relative to model based expectation. In order to find the appropriate value of the indicator, the energy signal tool carries out an analysis of building energy use, taking uncertainty and misclassification cost into account.

As described in detail in [8,9] and illustrated in Fig. 1, the energy signal tool process begins with an operational energy model of a building to provide expected energy performance but recognizes that any model only approximates reality. Previous research explored how gray-box models are obtained and calibrated from noisy

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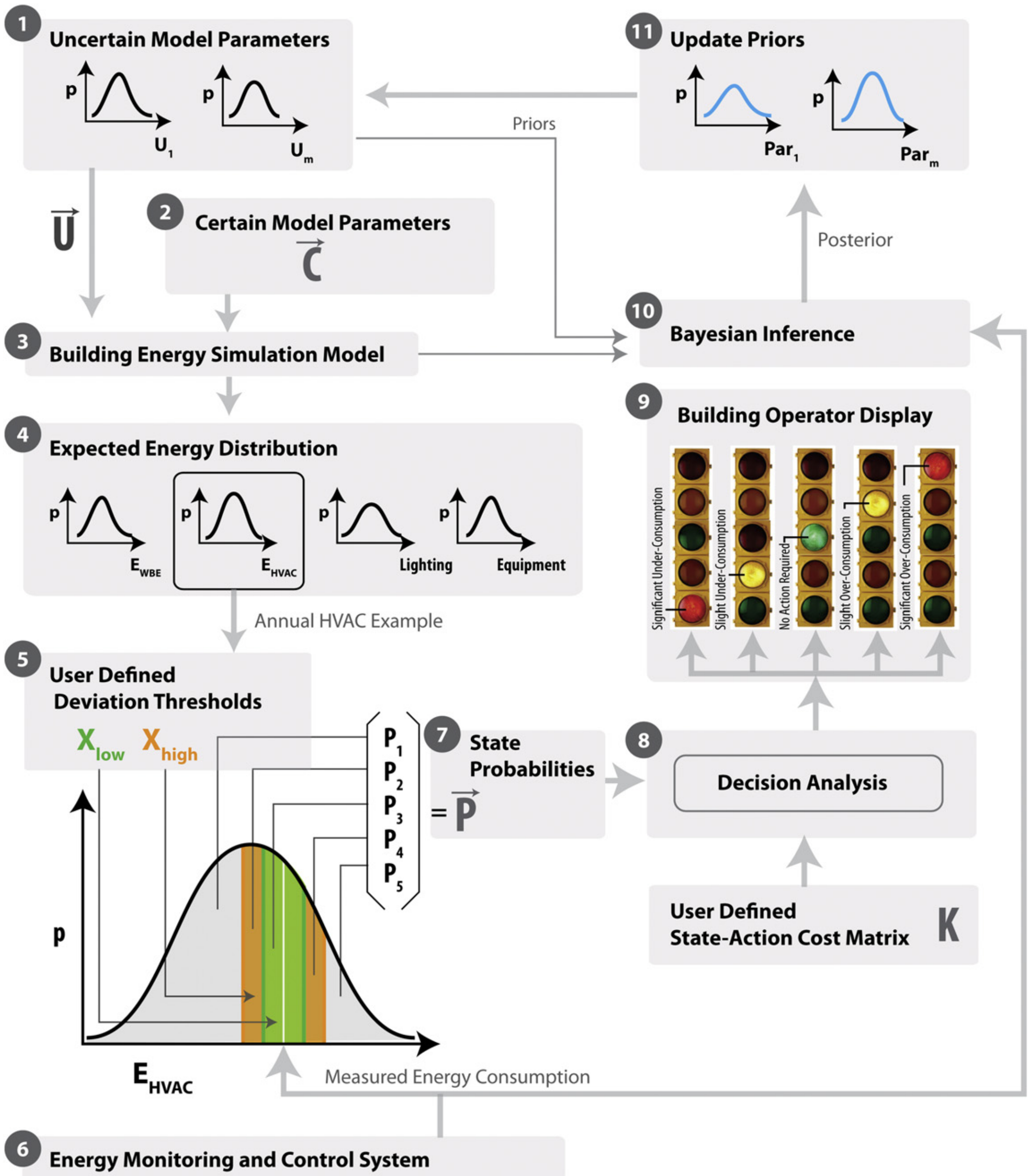


**Fig. 1.** Energy signal tool flowchart.

data [10], and results are extended here to include heating, ventilation, and air-conditioning (HVAC) systems. The term 'operational' derives from the desire to consider only a few influential variables within the model and to use it in real-time applications while learning from data as they are gathered. We believe that simplified operational models are sufficient when coupled to uncertainty analysis and misclassification costs of sufficiently simple building types. Currently, work is underway to develop an open-source tool based on the OpenStudio development effort that would allow the decision analysis to be applied to arbitrarily complex buildings modeled with detailed, dynamic simulations like EnergyPlus.

Over time, the energy signal tool learns from the building's energy data, updating input parameter expected values and their uncertainties in a Bayesian inference process. Unobserved variables are inferred from data and physical modeling. The range of all possible values of expected energy consumption is divided into five exhaustive and mutually exclusive intervals, labeled 1–5 in the figure, which represent predicted energy use substantially lower, somewhat lower, more or less the same, somewhat higher, and substantially higher than observed.

The probability that energy use, either at the whole-building or end-use level, falls into a given bin is computed as the integral under the curve for that bin; user-defined thresholds determine the tool's sensitivity and are driven by the operator's risk appetite. We then apply utility theory [11] to find the most appropriate action, comparing the net benefits of selecting a particular stoplight signal with the costs of possible misclassification and choosing the lowest cost option.

For a description of the salient literature preceding the energy signal tool, its development, and performance assessment in a range of simulated cases, the reader is referred to [8,9]. While the previous references develop the theory and software tool, the point of departure of this publication is the experimental verification and demonstration to an actual commercial building.

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