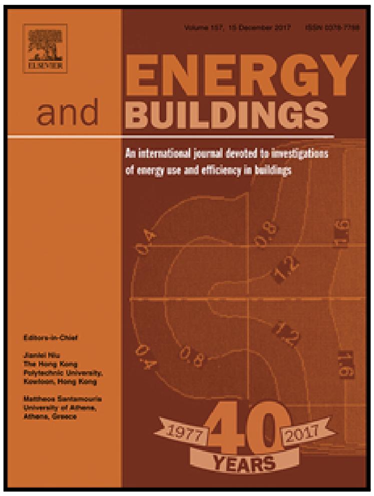

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Bayesian verification of an energy conservation measure

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Abstract

Most building owners eventually invest in energy conservation measures for their buildings. Faced with a variety of options, ranging from trivial (replacing light bulbs) to major (better façade insulation), they want to know which measure will yield the highest return on investment—and with what confidence. Moreover, once the measure has been applied, they will want to know how well it performs and whether their money was well spent—also known as Measurement & Verification (M&V).

But conventional M&V mandates the establishment of a baseline. The building should be instrumented during a year or more before applying the measure, driving the costs of M&V to sometimes unacceptable levels. Furthermore, a typical M&V study will report a single number for the measure's efficiency, ignoring any uncertainty surrounding that estimate.

To solve these two problems (expensive baseline and absence of uncertainty), we have developed a method, based on Bayesian statistics, that will 1) rely on historic utility bills and climate data to establish the baseline, and 2) estimate, with confidence intervals, how effective the energy conservation measure was.

We have tested this method after installing, in March 2016, a model-predictive controller for space heating for a medium-sized (about 2700 m^2) office building in Switzerland. The baseline was established from historic oil tank refill records and climate data from a nearby weather station. The total heat loss coefficient of the building was assessed 46 days after the installation and found to have decreased by 31.9 %, with 17.8 percentage points standard error.

Keywords: Bayesian inference, heating degree days, base temperature, balance point temperature, total heat loss coefficient

1. Introduction

Many energy conservation measures (ECMs) can reduce the energy consumption of existing buildings, but they vary widely in cost and effectiveness. Faced with a variety of options, ranging from trivial (replacing light bulbs) to major (better façade insulation), building owners need to know which measure is likely to yield the highest return on investment—and with what confidence. Moreover, once the measure has been applied, the owner needs to know how well it performs and whether their money was well spent—an activity known as Measurement & Verification (M&V).

This is a growing problem for Swiss firms that have publicly committed to reducing their greenhouse gas emissions. The majority of these emissions can be traced to large portfolios of legacy buildings [1], in particular to the fossil fuels used for heating. Reducing the heating energy for legacy buildings (while maintaining user comfort) can help such companies achieve their objectives—provided those energy savings can be proven. This is frequently a stumbling block for building managers who may prefer spending their budget on traditional (but perhaps less effective) energy conservation projects, and avoid riskier (but more effective) solutions.

Proving the effectiveness of any ECM is hard. Many factors influence the energy consumption of a building, and must be accounted for before and after the installation. Proper M&V typically involves establishing a "baseline" model of the building's energy consumption, ideally covering at least one year. After the installation, the energy consumption is measured again and compared with the prediction from the baseline model, yielding the energy savings. But in our experience, it would appear that many M&V projects ignore the uncertainties surrounding the baseline model and report a point estimate for the energy savings, giving a false sense of accuracy.

Lack of confidence in the effectiveness of ECMs hinders their adoption [2]. To convince building owners to undertake more ECM projects we must address three concerns: 1) the risk that the ECM might not be as effective as advertised, 2) the risk that, although effective, the benefits will turn out to be difficult to prove, and 3) the risk of a poor return on investment. The latter depends not only on the effectiveness of the ECM, but also on the fluctuating energy prices throughout the lifetime of the building, as discussed by Kumbaroglu and Madlener [3]. Mitigating risks 1) and 2) is the goal of M&V, currently perceived

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