A Systematic Approach to Quantifying Energy Savings Potential due to Improved Operations of Commercial Building Stocks

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ABSTRACT

In an effort to achieve large-scale energy savings, governments have been developing energy conservation policies that target large numbers or stocks of commercial buildings. While actions performed by occupants and facility managers significantly impact building energy performance, current policies overlook the importance of human actions and the potential energy savings from a more efficient operations of buildings. This slow policy adoption is mainly attributed to the absence of energy modeling tools and frameworks that evaluate non-technological drivers of energy use and quantify energy savings for large stocks of buildings to support policy-making efforts. Such an evaluation is in fact essential to help policy-makers set specific energy conservation targets, highlight the need for operation-focused policy tools, and justify corresponding investment costs. Therefore, this study proposes a systematic approach to quantifying the energy savings potential due to improved operations of any stock of commercial buildings. The proposed framework is general and combines energy modeling, existing studies on human actions in buildings, and surveying methods. The framework’s capabilities are illustrated in a case study performed on medium-sized office buildings in the United States (US). Results indicate a potential 18 percent reduction in the current energy use levels of these buildings through realistic changes in the operation pattern of different building systems.

INTRODUCTION

The worldwide growing demand for energy is urging developed countries to reduce energy consumption in different sectors of the economy (EIA 2013). A specific emphasis has been lately put on commercial buildings, which have witnessed the fastest growth in demand for energy and have been identified by the United States (US) and the European Union as the most promising targets to achieve large-scale energy savings (EIA 2013).

Consequently, governments have been developing energy policy tools (e.g., appliance standards and building energy codes and labeling) that can help conserve energy in thousands of commercial buildings (Lopes et al. 2012; Levine 2007). Traditionally, these tools have used a one-dimensional approach to energy

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Consequently, governments have been developing energy policy tools (e.g., appliance standards and building energy codes and labeling) that can help conserve energy in thousands of commercial buildings (Lopes et al. 2012; Levine 2007). Traditionally, these tools have used a one-dimensional approach to energy
conservation by mainly promoting ‘technological’ solutions including efficient building envelopes; office equipment; lighting systems; heating, ventilation and air conditioning systems (HVAC); to name a few (EPA 2010; Escrivá-Escrivá et al. 2010).

On the other hand, recent studies show that human actions (both by occupants and facility managers) are major determinants of energy use, and could hinder optimal operations of buildings, leading to excessive energy use and defeating the purpose of ‘technological’ investments (Azar and Menassa 2012; Levine et al. 2007). As a result, designers, facility managers, researchers, and policy makers are becoming increasingly aware of the need to improve building operations within the field of energy conservation and integrate operation-focused solutions in energy policy frameworks (Lopes et al. 2012; Ucci et al. 2012). These solutions can include (1) energy management strategies by facility managers and engineers to optimize the performance of the different building systems (e.g., regular maintenance, energy audits, and energy monitoring) (Colmenar-Santos et al. 2013), or/and (2) occupancy interventions that encourage occupants to adopt energy conservation practices (e.g., energy education and training, feedback techniques, and incentives) (Azar and Menassa 2012; Carrico and Reimer 2011). However, such solutions have been rarely integrated in energy policies, limiting their adoption on large-scale levels and leaving their potential energy conservation benefits unexplored (Lopes et al. 2012; Urge-Vorsatz et al. 2009; Levine et al. 2007).

Several studies have highlighted the key factors for the development of successful large-scale energy policy tools, which typically target a large stock of commercial buildings (e.g., in a city, state, or country) (Lopes et al. 2012; Urge-Vorsatz et al. 2009). These include the need to: (1) identify and quantify specific energy savings potential for different building characteristics and energy systems, (2) scale the projected benefits on the whole targeted population of buildings to support policy adoption and justify corresponding investment costs, and (3) set specific and measurable energy reduction goals and pave pathways to reach them through operation-focused solutions.

The task of quantifying and scaling energy savings potential to a given building stock is challenging for several reasons. First, building energy modeling tools adopt a systems-focused approach to energy use analysis in buildings and typically overlook the important role that human control can have in determining building energy performance (Azar and Menassa 2012; Hoes et al. 2009). Second, studies that considered human drivers to energy conservation were mostly qualitative, and did not integrate a quantitative energy calculation aspect that generates measurable results for energy policy purposes (Lopes et al. 2012; Ucci et al. 2012). Third, research on quantifying energy savings potential in commercial buildings is limited to few observational case studies with results that are hard to generalize due to the small sample size used (Masoso and Grobler 2010; Webber et al. 2006).

This paper fills the gap in literature by proposing a general framework capable of quantifying the energy savings potential from an improved operation of a stock of commercial buildings. The contributions of this work are significant as different types of decision-makers can use the framework to support and drive their energy conservation efforts. For instance, policy-makers can use the framework to highlight
the need for an improved operation of a stock of commercial buildings, set energy savings targets, and promote operation-focused solutions through large-scale policies. Utility companies can also benefit from the framework to better understand their energy demand profile and devise operation-focused interventions that help reduce and level that demand (i.e., educate customers to reduce high peak-hour energy demand). Finally, owners such educational institutions can also benefit from the framework to guide their efforts to reduce the carbon footprint of their building stock.

METHODOLOGY

In order to evaluate the energy savings potential from an improved operation of a stock of buildings, the proposed methodology combines three areas that have rarely been integrated in literature: energy modeling, existing studies on operation-related drivers of energy use, and surveying methods that allow scaling results on a large stock of buildings. The different phases of the methodology are presented in Figure 1 and detailed in the following sub-sections.

**Figure 1. Methodology**

**Phase I – Data gathering and stock aggregation**

The goal of Phase I is to gather the required information on the stock of buildings of interest in order to later develop building energy models that emulate the actual performance of these buildings (Phase II). First, Step I-a starts by setting the scope of the building stock to study. Next, information needs to be gathered on the stock of buildings of interest such as building characteristics (e.g., size, location, age, type and size of mechanical and electrical systems), operation-related characteristics (e.g., building schedule, settings of HVAC systems, lighting, and equipment), and weather data. As shown in Figure 1, the needed information can be obtained in two ways. First, when available, existing databases can be used such as the US Commercial Buildings Energy Consumption Survey (CBECS) (EIA 2003) (Phase I-b), or through surveys to obtain the needed information (Phase I-c).
Then, since it is impractical to model every building in the population, Step I-d consists of choosing and defining a number of theoretical ‘typical’ buildings that represent a large number of buildings in the population of interest. These buildings vary according to main buildings characteristics that have an important influence on energy use. The choice of characteristics can be determined through a pilot study where preliminary energy models are developed and building characteristics are varied to track their influence on building energy performance. Typical building characteristics considered are building size, location, and age, but other characteristics can also be used such as building orientation, construction materials, type of HVAC system, and the proximity of other buildings.

In Step I-e, the actual number of buildings represented by each ‘typical’ commercial building is calculated to obtain ‘weighting factors’ (NREL 2011). These factors are essential to scale the results observed from ‘typical’ buildings to the entire stock of buildings they represent, as discussed in Phase III. They are determined based on the sampling process used for data collection (e.g., simple random sample, cluster sampling), and the number of ‘typical’ buildings considered (Lohr 2010).

In this paper, a case study was performed to illustrate a practical application of the framework. Starting with Step I-a, the scope was first set to US medium-sized office buildings. CBECS was then used to gather the data required on the stock of buildings of interest to be used in the subsequent phases. In Step I-d, a combination of pilot studies performed by the authors and from literature (Azar and Menassa 2012; NREL 2011) determined that building size, location, and age, are the main building characteristics with the most influence on building energy performance. As a result, 32 ‘typical’ medium-sized buildings were identified combining 16 US climate zones (DOE 2010) and 2 building age categories (pre-1980 and post-1980).

In Step I-e, CBECS was also used as a starting point to obtain weighting factors for the ‘typical’ buildings identified in the previous phase. However, while 16 weather zones are considered in the choice of ‘typical’ buildings (DOE 2010), CBECS simplifies US climate zones to only 5 zones (EIA 2003), which complicates the weight calculation process. A three-step process is therefore used to overcome this limitation and spread the weights of the 5 CBECS weather zones on the 16 US Department of Energy (DOE) weather zones (DOE 2010). First, a visual comparison is made between the two weather maps to determine how the zones overlap (e.g., CBECS Zone 3 corresponds to DOE Zones 4A, 4B, and 4C). Next, data from Jarnagin and Bandyopadhyay (2010) is used to determine how buildings in each CBECS Zone (e.g., Zone 3) are spread between the corresponding DOE zones (e.g., 30% in Zone 4A, 20% in 4B, and 50% in 4C). The final step consists of using the obtained results to spread the CBECS weights on the 32 considered ‘typical’ buildings, which are later presented in the results section.

Phase II – Energy modeling and back casting

This phase consists of developing and calibrating building energy models to emulate the actual energy performance of the ‘typical’ buildings identified. This results in one building energy model for each ‘typical’ building, to be used in the parametric variation of Phase III. Step II-a therefore consists of developing building energy models where commercial software tools can be used such as EnergyPlus,
eQuest, and TRNSYS (Crawley et al. 2008). The inputs for these models correspond to the building and operation characteristics information collected in Phase I, while weather information are typically integrated in most software programs. Calibration is then performed in Step II-b. Different methods can be found in literature for this purpose, most of which use the mean bias error (MBE) as a calibration reference, calculated by averaging the errors between the models’ predicted energy use and the actual energy use data of the buildings (Azar and Menassa 2012; Yoon et al. 2003).

In the case study, the authors make use of benchmark energy models developed by the DOE “Commercial Building Initiative” in conjunction with three national laboratories (DOE 2013). The initiative used CBECs data to develop benchmark building energy models for a multitude of commercial buildings using EnergyPlus. It is important to mention that a similar base case model development process has been covered in details in a previous work by the authors (Azar and Menassa 2012) and in NREL (2011). An initial calibration was performed by the DOE initiative on the technical building design parameters (DOE 2013; NREL 2011). However, given the focus of this paper on building operation, the authors used existing studies and building codes to initialize the operation-related parameters of the models to values that emulate the actual operation of the buildings represented. For instance, in order to determine the actual after-hours lighting use in the buildings, the CBECs variable “LTNHRP8 - Percent lit when closed” was analyzed (EIA 2003), showing that on average, office buildings in the US have 10 percent of their lights on after-hours. A summary of the considered parameters is shown in Table 1.

Phase III – Parametric variation

After developing and calibrating the base case models, the goal of this phase is to simulate the building performance under alternative operation conditions that can result in lower energy use levels. For example, this could be achieved by setting thermostat temperature set points to levels that avoid excessive cooling or heating loads, reducing equipment and lighting use for unoccupied periods, using natural ventilation, blinds and shades when possible, among other measures (Azar and Menassa 2012; Moezzi 2009). Therefore, Step III-a consists of determining alternative building operation while (1) not affecting the work tasks of occupants (e.g., reducing working hours cannot be used), (2) meeting building energy standards, and (3) maintaining good indoor conditions and high occupancy comfort levels.

Next, the collected information is used in Step III-b as alternative input parameters for the energy models, hence customizing the models to emulate alternative and more efficient operation conditions. Step III-c consists of running the energy models under the two sets of parameters, base case and alternative, and observing any differences in building energy performance. Then, if the alternative run predicts energy levels 10 percent lower than the base case’s one, this would mean that the proposed improved operation characteristics for this type of buildings results in 10 percent energy savings. In Step III-d, the weights obtained from Step I-e are used to scale the results observed in the individual models (Phase III-c) on the entire stock of buildings using equation 1:

\[
Total\ Energy\ Savings\ Potential = \frac{\sum_{i=1}^{n} (Energy\ Savings\ Potential_{model_i} \times Weight_{model_i})}{\sum_{i=1}^{n} Weight_{model_i}}
\]  

(1)
In the case study, an extensive review of literature is performed to determine alternative building operation settings that energy management strategies or occupancy interventions can help promote in commercial buildings. In parallel, ASHRAE building energy standards such as ASHRAE 90.1-2007 and ASHRAE 55-2007 are reviewed to ensure that the proposed settings do not violate building standards and maintain occupants’ comfort (ASHRAE 2007a, 2007b). Three operation-related parameters, which typically have high impacts on building energy performance (Azar and Menassa 2012), are varied to determine the alternative energy use profile as shown in Table 1: (1) thermostat temperature set points for occupied and unoccupied periods (i.e., after-hours), (2) equipment use for unoccupied periods, and (3) lighting use for unoccupied periods.

As an example of the process used to determine alternative values, the ‘Thermostats temperature set points during occupied hours’ are set at 27°C for cooling and 19°C for heating for two main reasons. First, they fall within the recommended building design temperatures dictated by standard ASHRAE 90.1-2007 (ASHRAE 2007a), and provide a good comfort level for occupants according to standard ASHRAE 55-2007 (ASHRAE 2007b). This is also in accordance with the building codes of several countries such as the United Kingdom, Spain, and Holland (HSE 2009). Finally, it is important to mention that due to the absence of literature regarding alternative after-hours equipment and lighting use, reduction targets of 50 percent from base case values were set based on engineering judgment following discussions with energy modeling and design professionals.

Table 1. Summary of operation-related input parameters

<table>
<thead>
<tr>
<th>Input Parameters</th>
<th>Base case values</th>
<th>Alternative values</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermostat temperature set points - Unoccupied</td>
<td>Cooling: 26.7°C (80.1°F) Heating: 15.6°C (60.1°F)</td>
<td>Cooling: 32.2°C (90.0°F) Heating: 12.8°C (55.0°F)</td>
<td>ASHRAE (2007a, 2007b)</td>
</tr>
<tr>
<td>After-hours equipment use</td>
<td>Weekdays: 40% running Weekends: 30% running</td>
<td>Weekdays: 20% running Weekends: 15% running</td>
<td>EIA (2003)</td>
</tr>
<tr>
<td>After-hours lighting use</td>
<td>10% running</td>
<td>5% running</td>
<td>EIA (2003)</td>
</tr>
</tbody>
</table>

RESULTS

This section presents the results obtained from applying the proposed methodology on the case study of medium-sized US office buildings. Table 2 summarizes the results including: (1) the characteristics of the 32 ‘typical’ office buildings modeled using EnergyPlus, namely the location and age of the buildings, (2) the calculated weights for each model, and (3) the total energy saving potential for each model from applying the parametric variation proposed in Table 1.

As shown in Table 2, Model 32, which represents buildings constructed before 1980 and located in weather Zone 8A, shows the lowest potential in energy savings with 10 percent. On the other hand, Model 17, representing buildings constructed before 1980 in Zone 1A, shows the highest energy saving potential with
22 percent. Such information can be very beneficial to policy makers as it highlights the type of buildings that would benefit the most from improved operations and could be the first target of operation-focused energy conservation initiatives. For instance, owners of buildings with high energy savings potential can be required by the DOE to have annual energy audits performed to ensure that their buildings are operating with acceptable operation efficiency levels. Also, once additional strategies (e.g., energy trainings for building managers, feedback techniques) are promoted to achieve energy savings, the numbers in Table 2 can serve as benchmark against which progress is evaluated and adjustments are made.

As for the overall energy saving potential in the considered stock of buildings, a value of 18 percent is obtained by applying the individual energy savings from Table 2 in Equation 1. Here again, this quantification can assist the policy making process as it confirms the importance of improving operations and supports the need to integrate operation-focused solutions in large-scale energy conservation policies.

Table 2. Summary of energy saving potential by typical building

<table>
<thead>
<tr>
<th>Energy Model Characteristics</th>
<th>Weight</th>
<th>Total Energy Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1A</td>
<td>Post1980</td>
</tr>
<tr>
<td>2</td>
<td>2A</td>
<td>Post1980</td>
</tr>
<tr>
<td>3</td>
<td>2B</td>
<td>Post1980</td>
</tr>
<tr>
<td>4</td>
<td>3A</td>
<td>Post1980</td>
</tr>
<tr>
<td>5</td>
<td>3B</td>
<td>Post1980</td>
</tr>
<tr>
<td>6</td>
<td>3C</td>
<td>Post1980</td>
</tr>
<tr>
<td>7</td>
<td>4A</td>
<td>Post1980</td>
</tr>
<tr>
<td>8</td>
<td>4B</td>
<td>Post1980</td>
</tr>
<tr>
<td>9</td>
<td>5A</td>
<td>Post1980</td>
</tr>
<tr>
<td>10</td>
<td>5B</td>
<td>Post1980</td>
</tr>
<tr>
<td>11</td>
<td>6A</td>
<td>Post1980</td>
</tr>
<tr>
<td>12</td>
<td>6B</td>
<td>Post1980</td>
</tr>
<tr>
<td>13</td>
<td>7A</td>
<td>Post1980</td>
</tr>
<tr>
<td>14</td>
<td>8A</td>
<td>Post1980</td>
</tr>
<tr>
<td>15</td>
<td>8B</td>
<td>Post1980</td>
</tr>
<tr>
<td>16</td>
<td>8C</td>
<td>Post1980</td>
</tr>
</tbody>
</table>

Next, in accordance with the objectives of this study, the energy savings potential of each ‘typical’ building is broken down by end-use, which helps develop targeted and specific energy conservation goals. As shown in Figure 2, results are divided between (1) equipment, (2) HVAC, and (3) lighting energy use. In almost all cases, HVAC shows the highest share of energy savings, especially in buildings located in hot weather zones due to the high resulting cooling loads (i.e., close to Zone 1A). Equipment shows the second highest potential in energy savings, with relatively consistent values across the different buildings. Finally, lighting shows the least potential for energy savings, which can be attributed to the already low value of 10 percent after-hours lighting use in base case buildings. Such results can assist decision makers in targeting their interventions on the building systems with the highest potential for energy savings. For instance, utility companies serving commercial buildings in hot weather zones would highly benefit from sending out educational information with energy bills (e.g., brochures or emails) on how to
optimize HVAC controls to avoid high peak-hour energy demands. This would help avoid overloading the grid during peak-hours while reducing energy bills for building owners.

![Energy Savings Potential by End-Use](image)

**Figure 2. Energy savings potential by end-use for typical buildings**

**CONCLUSION**

This paper presents a framework capable of quantifying the energy savings potential from an improved operation of a commercial buildings’ stock. Prior to this study, it was challenging to measure operation-related energy conservation opportunities, contributing to the low adoption of techniques such as energy management and occupancy interventions in commercial buildings. The proposed framework is general and can be applied on any group of commercial buildings as illustrated in a case study performed on US medium-sized office buildings.

The contributions of this paper to energy policy are significant as they fill several gaps identified in literature. First, the proposed methods can be used by policy makers to set clear energy conservation goals and develop a pathway to reach them. Second, the framework provides detailed information about the potential energy savings by building system, hence allowing detailed and targeted objectives to be set. Third, the scalability potential of the framework provides policy makers with the ability to aim and plan for large-scale energy savings initiatives. In addition, other stakeholders can also benefit from the framework such as utility companies (e.g., energy load leveling) or educational institutions (e.g., energy conservation efforts).

In addition to the discussed benefits, quantifying the every savings potential of operation-related actions is also expected to increase interest and boost research on the different techniques that can be used to achieve those energy savings. Future research includes investigating, testing, and optimizing different energy management strategies and occupancy interventions. This type of research typically requires a large amount of resources and is beyond the scope of this study. However, with the proposed framework’s ability to evaluate a building stock’s energy conservation opportunities, researchers can now motivate and focus their efforts on specific energy
conservation goals and methods, increasing their chances in successfully reaching their energy savings targets.

Finally, as discussed by Levine et al. (2007), governments can provide funding for potentially high-impact non-technological energy conservation measures as part of their broader support for energy innovation. In the US, a bill was introduced in 2009 (HR 3247) to establish the first program at the DOE to understand “behavioral factors that influence energy conservation” and speed the adoption of promising initiatives. While this particular bill failed to be enacted, it can still serve as an example of the next step that needs to be taken to promote and eventually integrate operation-focused solutions in energy policies.

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