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A comprehensive framework to quantify energy savings potential from improved operations of commercial building stocks

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HIGHLIGHTS

- Human actions highly influence energy performance of commercial building stocks.
- It is challenging to quantify operation-related energy savings potential.
- The proposed framework quantifies potential energy savings from improved operations.
- The framework can be applied on any stock of commercial buildings.
- Applications include support for operation-focused solutions in energy policies.

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ABSTRACT

While studies highlight the significant impact of actions performed by occupants and facility managers on building energy performance, current policies ignore the importance of human actions and the potential energy savings from a more efficient operation of building systems. This is mainly attributed to the lack of methods that evaluate non-technological drivers of energy use for large stocks of commercial buildings to support policy making efforts. Therefore, this study proposes a scientific approach to quantifying the energy savings potential due to improved operations of any stock of commercial buildings. The proposed framework combines energy modeling techniques, studies on human actions in buildings, and surveying and sampling methods. The contributions of this study to energy policy are significant as they reinforce the role of human actions in energy conservation, and support efforts to integrate operation-focused solutions in energy conservation policy frameworks. The framework's capabilities are illustrated in a case study performed on the stock of office buildings in the United States (US). Results indicate a potential 21 percent reduction in the current energy use levels of these buildings through realistic changes in current building operation patterns.

1. Introduction

Global demand for energy has been rising at accelerating rates over the past decade while fossil fuels are becoming scarce with soaring prices (US Energy Information Administration (EIA), 2013a). The resulting energy crisis, coupled with global warming repercussions, is motivating developed countries to reduce their energy consumption and carbon emissions. In the United States (US) for instance, the building sector presents an important opportunity for large-scale energy savings. Commercial buildings in particular account for 19 percent of national energy consumption and their energy demand is growing at a rate higher than any other sector of the economy (US Energy Information Administration (EIA), 2013a; Yudelson, 2010). Similarly, the European Union has identified buildings as the most promising target to improve energy efficiency with commercial buildings again providing the highest potential for energy use reduction (Commission of the European Communities (CEC), 2006).

In an effort to achieve large scale energy savings, governments typically rely on energy policy tools that can help conserve energy in thousands of commercial buildings such as appliance standards, building energy codes and labeling, and demand-side management programs (Lopes et al., 2012; Jennings et al., 2011; US Environmental Protection Agency (EPA), 2010; Levine and Urge-Vorsatz, 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

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systems; heating, ventilation and air conditioning systems (HVAC); to name a few (Daouas, 2011; US Environmental Protection Agency (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; Augenbroe et al., 2009; Levine and Urge-Vorsatz, 2007). In fact, the lack of understanding and account of human actions has significantly contributed to the observed differences between desired and actual energy levels even when 'technological' strategies are implemented in the building (Augenbroe et al., 2009; Levine and Urge-Vorsatz, 2007; Henze, 2001). As a result, designers, facility managers, researchers, and policy makers are becoming increasingly aware of the need to improve building operations through energy conservation, and integrate the corresponding operation-focused solutions in energy policy frameworks (Lopes et al., 2012; Ucci et al., 2012; Cabinet Office, 2011). 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; Escrivá-Escrivá et al., 2010), 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 Riemer, 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;Allcott and Mullainathan, 2010;Urge-Vorsatz et al., 2009; Levine and Urge-Vorsatz, 2007).

In an effort to identify and overcome the barriers behind the mentioned slow policy adoption, studies have highlighted key factors for the development of successful large-scale energy policy tools, which typically target a large stock of commercial buildings (e.g., city, state, or country) (Lopes et al., 2012; Jennings et al., 2011; Allcott and Mullainathan, 2010;Urge-Vorsatz et al., 2009;Intergovernmental Panel on Climate Change (IPCC), 2007). These include the need to:

(1) Identify and quantify specific energy savings potential for different building characteristics and energy systems (Lopes et al., 2012; Urge-Vorsatz et al., 2009; Intergovernmental Panel on Climate Change (IPCC), 2007).
(2) Scale the projected benefits on the whole targeted stock of buildings in order to explore and support the need for policy adoption, and justify the corresponding investment costs (Allcott and Mullainathan, 2010).
(3) Set specific and measurable energy reduction goals and pave pathways to reach them through operation-focused solutions. This will also form a benchmark against which the success of the adopted energy policy can be evaluated and improved (Jennings et al., 2011).

Despite the identified importance of quantifying and scaling energy savings potential for a given building stock, this task remains challenging to perform for operation-focused solutions due to several reasons (Lopes et al., 2012; Urge-Vorsatz et al., 2009; Intergovernmental Panel on Climate Change (IPCC), 2007; Levine and Urge-Vorsatz, 2007). First, building energy modeling tools adopt a systems-focused approach to energy use analysis in buildings, typically overlooking the important role that human actions can have in determining building energy performance (Azar and Menassa, 2012; Hoes et al., 2009; Turner and Frankel, 2008). Second, studies that considered human drivers to energy conservation are mostly qualitative, and do not integrate a quantitative energy calculation aspect that generates measurable results for energy policy purposes (Lopes et al., 2012; Ucci et al., 2012; Zhang et al., 2011). For instance, Ucci et al. (2012) developed a theoretical framework of the mechanisms affecting pro-environmental behaviors but did not translate the findings into quantitative energy savings values for a large number of buildings that can motivate energy conservation efforts. Finally, 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; Sanchez et al., 2007; Webber et al., 2006). As an example, Webber et al. (2006) found that more than half of office equipment are typically left running in commercial buildings, highlighting the potential energy savings that can be achieved from an improved operation of the buildings. However, the small sample size of 12 buildings limits the generalization of the results.

In summary, there is a growing and significant need for a general framework that quantifies and illustrates the energy savings potential from improved operations of a commercial building stock. Such a framework is essential to support policy-making efforts with clear energy conservation targets, which are essential to the integration of operation-focused solutions in energy policy frameworks and the justification of any investment costs (Lopes et al., 2012; Allcott and Mullainathan, 2010; Urge-Vorsatz et al., 2009; Levine and Urge-Vorsatz, 2007). In addition, other decision-makers such as energy utility companies or building stock owners (e.g., universities) can also benefit from the framework to identify energy conservation opportunities in their buildings and develop appropriate and targeted energy conservation strategies (e.g., educational campaigns).

2. Objectives

The main goal of this research is to fill the identified gap in literature and develop a framework capable of quantifying the energy savings potential from an improved operation of any given stock of commercial buildings. The proposed framework helps answer the following research questions, which are integral to promote operation-focused solutions in energy conservation policies and initiatives that target a large stock of commercial buildings:

(1) How much energy can be saved if more efficient operation patterns are adopted in the studied building stock (e.g., commercial buildings in the US)? Such an evaluation is essential to prove that an improved operation of the buildings can be very beneficial in terms of energy savings and deserves to be further researched and promoted through operation-focused solutions.
(2) Within the stock, what type of buildings exhibit the largest energy savings potential (e.g., buildings with specific size, location, age)? The answer to this question helps set priorities on the type of buildings that needs to be targeted first in order to achieve fast and important energy reductions.
(3) How is this potential spread on different building systems (e.g., lighting, HVAC, equipment) and different energy sources (e.g., electricity, natural gas)? This additional level of granularity helps policy-makers set specific energy saving goals (e.g., 10 percent reduction in lighting energy use) and avoid setting general targets that are typically harder to achieve and verify. Also, this could help other decision-makers (e.g., utility companies) to better understand and control the demand for specific energy sources such as natural gas.

In order to answer those questions, the proposed framework quantifies the impact of human control and actions on the energy performance of different building systems. The framework is scalable to cover all buildings in the studied