Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 142 (2017) 2541–2546

Energy Procedia

www.elsevier.com/locate/procedia

9th International Conference on Applied Energy, ICAE2017, 21-24 August 2017, Cardiff, UK

Method for visualizing energy use in building information models

Hanh Truong[a], Abigail Francisco[b], Ardalan Khosrowpour[a], John E. Taylor[b,*], Neda Mohammadi[b]

[a] *Department of Civil and Environmental Engineering, Virginia Tech, 113B Patton Hall, Blacksburg, VA 24061, United States*
[b] *School of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Dr NW, Atlanta, GA 30313, United States*

Abstract

While technology advancements are increasingly improving the energy efficiency of buildings, occupant behavior remains a critical factor in ensuring the effectiveness of such enhancements. To this end, numerous eco-feedback systems have been developed to reduce building energy use through adjusting occupants' behaviors. The information represented in an eco-feedback system affects the users' engagement, motivation, and interpretation. In this paper, we introduce a new information representation method in which a building information model (BIM) is integrated with energy use information to enhance visual representation of energy use. The BIM-integrated energy visualization approach developed in this paper allows users to visualize energy consumption values of each building room through a color-coding scheme in an as-built BIM. Colors correspond to the levels of energy consumption in individual rooms compared to other rooms in a building, which enables a visually intuitive normative comparison for building eco-feedback systems. This representation may lead to increased user engagement in and improved interpretation of eco-feedback systems.

Peer-review under responsibility of the scientific committee of the 9th International Conference on Applied Energy.

Keywords: building information modeling; eco-feedback; energy efficiency; information representation; normative comparison.

1. Introduction

The efficient use of energy resources has gained global attention as scarce resources are being depleted, energy costs rise, and greenhouse gas emissions continue to increase. In the United States, approximately 39% of the total energy consumption and its associated CO_2 emissions are attributed to building-related activities [1]. Occupant

* Corresponding author. Tel.: +1-404-894-8021.
E-mail address: jet@gatech.edu

Peer-review under responsibility of the scientific committee of the 9th International Conference on Applied Energy.
10.1016/j.egypro.2017.12.089

behaviors in buildings are known to be critical to building energy efficiency [2-5], providing the potential to offset up to 7.4% of the associated CO_2 emissions, according to one study [6]. Recently, researchers have examined eco-feedback systems, which provide energy feedback to building occupants on individual or group behaviors with a goal of reducing environmental impact [2, 6-8]. The use of eco-feedback systems is based in part on the premise that people lack awareness and understanding of how their everyday consumption behaviors affect the environment. Eco-feedback systems may bridge this gap by automatically sensing these behaviors through computerized means and communicating behavioral impacts to occupants [9, 10]. Although there are numerous factors attributed to the effectiveness of an eco-feedback system, an efficient user interaction with the system is an essential factor in achieving the goal of energy conservation [11, 12]. The efficacy of this interaction depends on two main factors: information content and visualization, and researchers continue to explore ways to create more effective and impactful information visualization techniques in eco-feedback systems. One recent promising trend is the combination of energy use information into building information models (BIMs) [13]. In the current practice, BIM is a widely used form of information storage and visualization in the architecture, engineering and construction (AEC) industry [14]. Most previous studies have focused on using BIM for energy efficiency in the early design phase [15-17], however, the potential of using BIM for energy efficiency and energy use visualization in the building operation phase is unexplored, beyond efforts involving simulated data [13]. This study explores employing BIMs as an energy use visualization framework in eco-feedback systems to achieve improved energy conservation outcomes.

2. Background

To evaluate the effectiveness of residential and commercial building eco-feedback systems, the effects of underlying components such as information representation methods, psychological motivators, and interface design have been explored. These components have improved system effectiveness and resulted in energy savings, ranging from 5% to 55% [7, 18]. For example, normative comparison is a type of social comparison feedback method in which an individual or a group is compared to a norm (i.e., a reference value or benchmark), thereby using social norm as a motivation to encourage the conservation of energy. Several studies have demonstrated that the normative comparison component of eco-feedback systems can drive energy efficient behavior from users through competition and public perception [2, 10].

However, the results of eco-feedback studies are not entirely consistent regarding the effectiveness of information representation methods on occupants' behaviors. For example, studies found people tended to understand the representation of energy in monetary units [19], however, other studies found monetary representation is not an effective approach to increase the occupants' energy efficiency [20, 21]. In addition, studies show that building occupants often have difficulty in interpreting charts and understanding energy units [22, 23]. Recognizing the limitations of existing energy information representation, recent studies have used color-coding techniques to represent energy use [24]. Color-coding has been shown in other research domains to provide effective learning and interpretation due to increased retention and cognition performance [25-27]. In eco-feedback research domains, Bonino et al. [24] conducted interviews to assess users' reactions to color-coded 2D floor plan energy consumption visualizations and found this color-based and spatial visualization helped 71.77 % of respondents understand energy consumption. However, this study had several shortcomings, including the lack of a control group and statistically validated results. Based on the findings and shortcomings in the Bonino et al. study, there is a compelling opportunity to evaluate user understanding of eco-feedback systems that incorporate color-based representations of energy use integrated into spatial building layouts, such as BIM, that are statistically evaluated with a control group. However, to address these opportunities, we first need methods to integrate energy consumption information into BIM, as well as methods to automate the representation of color-coded energy use information in BIM.

Many studies have combined BIM with building energy simulation programs (e.g. EnergyPlus) to optimize the energy efficiency decision-making process and develop sustainable designs [15, 16, 28]. However, most of these studies have mainly focused on implementing BIM for energy efficiency in the design phase, whereas energy consumption during the operation phase is also critical. The operations phase is usually between 20 – 50 years and accounts for approximately 80% – 95% of the total energy consumption during building's life [29]. Costa and colleagues [30] developed an integrated toolkit for building energy managers that links BIM and the monitoring, analysis and optimization of energy in a building during its operational phase. But we still lack a method to link