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Time effects of green buildings on energy use for low-income households: A longitudinal study in the United States

Dong Zhao[a,b,*], Andrew P. McCoy[c], Philip Agee[c], Yunjeong Mo[a], Georg Reichard[c], Freddy Paige[d]

[a] School of Planning, Design, and Construction, Michigan State University, East Lansing, MI, 48824, United States
[b] Department of Civil and Environmental Engineering, Michigan State University, East Lansing, MI, 48824, United States
[c] Myers-Lawson School of Construction, Virginia Tech, Blacksburg, VA, 24061, United States
[d] Department of Civil and Environmental Engineering, Virginia Tech, Blacksburg, VA, 24061, United States

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ABSTRACT

The U.S. government has included green building policy in affordable housing programs for years. However, little to no evidence is available to elucidate this policy's efficacy in the context of energy performance and financial savings. This paper reports a longitudinal study that investigates time effects of such policy on the energy performance in low-income housing units. The researchers collected monthly energy use data over three years from 310 residential units and conducted profile analysis and MANOVA. Results indicate that (1) green buildings' energy performance is consistent across years; (2) construction type, technology level, and apartment size significantly and consistently affect energy use; and (3) occupant type inconsistently affects energy use. Results suggest financial savings of $648 per year due to reduced energy usage in green buildings. The savings equate to 9.3%, 5.6%, and 3.5% of annual income for extremely low-income, very low-income, and low-income families, respectively. Savings represent a 26.6%–37.5% reduction of energy expenditure for low-income households. Findings strongly suggest that green building incentives and the diffusion of green building practice is resulting in affordable housing systems.

1. Introduction

Affordable housing has long been a national effort in the United States. In the early decades of the implementation of the Housing Act of 1937 (Mo, Zhao, McCoy, Du, & Agee, 2017; Vale, 2007), the federal government's involvement was directly funding affordable housing development including construction costs; while state and local public housing authorities (PHA) covered the operational and maintenance costs. In return, PHAs owned the properties and controlled the design, construction, and tenant selection. Beginning in the 1960s, the U.S. Department of Housing and Urban Development (HUD) started to prioritize public-private partnerships that encouraged private developers to develop affordable housing by offering subsidies and vouchers to offset development and construction costs. To date, the Low Income Housing Tax Credit (LIHTC) program has become the largest and most significant federal program for the production and preservation of affordable housing for low-income families in the nation (Collinson, Ellen, & Ludwig, 2015). Eligible LIHTC-assisted projects require that 20% or greater of residents have incomes below 50% of the area median income (AMI) and 40% or greater of residents have incomes below 60% of AMI. The federal government annually earmarks $6 billion to the LIHTC program which has supported more than 2 million residential units and retained a large tax credit portfolio (Khadduri, Climaco, Burnett, Gould, & Elving, 2012).

Over the same 40–50 years, building energy use reduction has also been a national effort. In the U.S. residential buildings account for at least 21% of energy consumption and carbon emissions based on the U.S. EIA (2016). This usage represents 20 quadrillion British thermal units (BTU) and US$218 billion in energy expenditure. Many low-income families are involved in energy poverty since they must allocate significantly more of their household income to energy expenditures than other households (Bird & Hernandez, 2012). Low-income households often live in homes that are not energy efficient and they are unable to afford energy-saving measures (Guerra Santin, 2011; Langevin, Gurian, & Wen, 2013). The broad concept of green building can be defined as aspects of energy efficiency, sustainability, and environmentally friendly products (Adomatis, 2012; Hodges, 2005; Tucker, Pearce, Bruce, McCoy, & Mills, 2012). In this research, the authors focus on human-centered energy efficiency to measure the performance of green building (McCoy, Zhao, Ladipo, Agee, & Mo, 2018). The focus on energy performance is consistent with LIHTC policy.

* Corresponding author at: 552 W Circle Drive, East Lansing, MI 48824, United States.
E-mail address: dzhao@msu.edu (D. Zhao).

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To improve building energy efficiency, the architecture, engineering, and construction (AEC) industry has engaged in R&D for building technologies. These technologies range from enclosure systems advancements (e.g. spray-applied insulation and weather resistant barriers, air sealing techniques, and high-performance glazing systems) to sub-system advancements (e.g. inverter-driven heat pumps, efficient lighting and appliances, and low-flow water fixtures). Green buildings also provide a healthier built environment, addressing indoor environmental quality (IEQ) and occupant quality of life (Amiri, Mottahedi, & Asadi, 2015; Baughman & Arens, 1996; Hoskins, 2003; Singh, Syal, Grady, & Korkmaz, 2010; Singh, Syal, Korkmaz, & Grady, 2010; Spengler & Sexton, 1983). The U.S. Department of Energy (DOE) has set long-term goals toward 50% energy reduction in buildings and committed to catalyzing green buildings at a national level through model building codes and supporting third-party green rating systems (e.g. LEED, Energy Star, and EarthCraft).

As a part of this national effort, HUD and local housing finance agencies (HFAs) have integrated green building rating systems into state-led LIHTC programs. Financial support from the LIHTC programs address essential barriers to green building implementation, including higher initial costs of design and construction (Beheiry, Chong, & Haas, 2006; Lee, Chin, & Marden, 1995; Zhao, McCoy, & Smoke, 2015). At the federal level, the LIHTC program does not mandate green building rating programs for apartment development; however, the U.S. Internal Revenue Service (IRS) specifies that energy efficiency shall be considered in state-level requirements for LIHTC development. In practice, HFAs provide financing for affordable housing and are the agencies that award the IRS credits. The IRS credits are distributed to developers based on the Qualified Allocation Plan (QAP).

To date, all state PHAs have incorporated some form of green building policy (e.g. discrete green building measures and/or green building rating systems) into their QAPs. As listed in Table 1, the QAP either requires LIHTC applicants (e.g., the developer or builder) to participate in a green building rating system or encourages them to achieve green building certification by offering additional scoring points.

LIHTC is an ideal platform to gauge home energy efficiency; however, little to no research has fully utilized this platform to investigate green homes' energy performance and economic impact. This knowledge gap prevents policymakers from a better understanding of green building efficacy, particularly for low-income households. To address part of this gap, as shown in Fig.1, this study has two objectives: (1) to identify energy performance of LIHTC-assisted green buildings over time, and (2) to determine economic impacts on low-income households as a result of these green buildings. In reaching the objectives, the authors have conducted a longitudinal study on energy consumption of LIHTC-assisted green buildings over 36 consecutive months from 2013 to 2016. Unlike cross-sectional studies that only reveal static homogeneity and heterogeneity, longitudinal study uncovers dynamic trends of energy use and time effects of energy efficiency (Diggle, 2002). In other words, this study focuses on whether or not energy performance is stable, durable, and consistent over time in these green buildings. Energy use trends and time effects unveiled from this study contribute to the robust long-term decision-making for both energy and housing policymakers. In this regard, the authors also discuss data-driven policy implications based on analytical results.

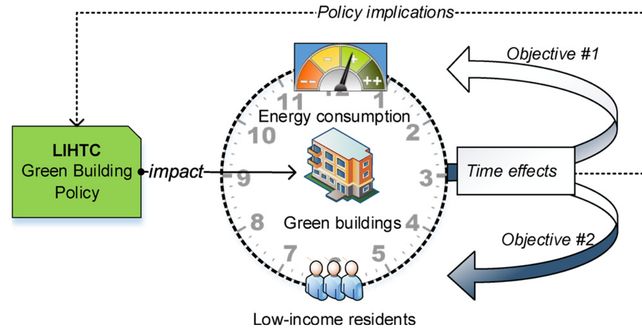

Fig. 1. Diagram of research design and objectives.

2. Materials and methods

2.1. Data

Fig. 2 displays the 310 residential units across 16 developments in the state of Virginia from which energy use data were collected. Apartment-level electricity data were collected on a monthly basis from May 2013 to April 2016 using an online benchmarking software. The authors applied a method of geographic cluster sampling (or termed area cluster sampling). The cluster sampling technique has been widely used in research by many statistic agencies including the World Bank (Himelein, Eckman, & Murray, 2013) and U.S. Department of Agriculture (2016). In this research, the geographic clusters are based on the metropolitan statistical area (MSA), a geographical region with a relatively high population density at its core and close economic ties throughout the area (U.S. Census Bureau, 2016). MSA is a result of national standards for statistical purposes and has been adopted by many federal agencies including the Census Bureau and HUD. The sampling strategy aligns with the referenced national standards and, therefore, allows for representing a larger population in each statistical area and producing more accurate analytical results (Himelein et al., 2013). To minimize the disturbance from missing data (Everitt, 1998; Molenberghs & Verbeke, 2000), the study used longitudinal data with complete records during the whole 3-year period.

Virginia is selected for data collection because it contains a large number of LIHTC-assisted green apartments with considerable quality. Since 2007, the Virginia Housing Development Authority has integrated

Table 1
Summary of state-level LIHTC green building programs in the United States.

Certification	Require Certification by State	Encourage by State
• LEED for Homes • Home Energy Rating System • EarthCraft House • Enterprise Green Communities Criteria • National Green Building Standard • ENERGY STAR appliances • Green Point Rated Multifamily Guidelines • Green Globes • LEED for Neighborhood Development	Alaska, Arkansas, Arizona, California, Colorado, Connecticut, District of Columbia, Delaware, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Nebraska, North Carolina, Louisiana, Massachusetts, Maryland, Michigan, Minnesota, Missouri, Mississippi, Montana, New Hampshire, New Jersey, Nevada, New York, Ohio, Oklahoma, Oregon, Rhode Island, South Dakota, Tennessee, Texas, Utah, Virginia, Washington	Hawaii, North Dakota, New Mexico, Pennsylvania, South Carolina, Vermont, Wisconsin, West Virginia, Wyoming