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LIFE CYCLE COST ANALYSIS OF ENERGY EFFICIENT SINGLE FAMILY RESIDENCE

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Residential and commercial buildings account for more than half of the electricity consumption in the United States. There are numerous practical solutions to make buildings more energy efficient and sustainable. Although it is well-established that green buildings are socially, environmentally, and economically beneficial, there is still a lack of green buildings in the residential sector. The installation and upfront costs for these houses are very high. This research aims to facilitate a broader understanding of the cost benefits of energy efficient and sustainable residences. The Life cycle cost analysis (LCCA) approach and energy simulation tools have been utilized and integrated for assessing the traditional single-family residence in the United States. A comparative study has been carried out including passive and net-zero energy through energy simulation software. This analysis will benefit academic researchers and industry practitioners to analyze and evaluate challenges and opportunities in energy efficient and sustainable residences.

Keywords: Residential, Upfront cost, Energy efficient, Energy simulation, Passive, Zero energy.

1 BACKGROUND

The life cycle energy used by buildings in their operation and maintenance phase is between 80-90% of the total life cycle energy (Ramesh *et al.* 2010). Thus, management and reduction of this energy during its operation phase should be of utmost importance and a major factor in play during the design phase of the project. There is growing awareness regarding the need for energy conservation and it is reflected in the way we now design buildings (Hoque 2007). However, Developers, owners, and tenants are reluctant to jump into the investments involved with Net zero energy buildings. New technologies often have high installation costs, which is one of the major reasons why there is a lack of energy-efficient buildings. Moreover, despite the numerous benefits of Life cycle cost analysis (LCCA), its adoption in the green building industry, especially for low rise residential buildings, is relatively slow. Most of the studies are limited to commercial building (Ryghaug and Sørensen 2009). There is need to expand LCCA into the residential sector, where its growth is hampered by inconsistent data and insufficient collaboration between stakeholders (Ramesh *et al.* 2010).

The purpose of this research is to explore the potential of current LCCA procedures as an evaluation tool for single-family residences; it will also seek to provide suggestions to improve its adoption for green building strategies.

The residential sector in the US accounts for a majority of energy consumption in the country. The supporting data has been published by the U.S. Energy Information Administration

(EIA) for the residential sector and the commercial sector (US Energy Information Administration 2015).

In recent studies conducted by U.S. Energy Information Administration (EIA), it was published that "Estimates from the most recent Residential Energy Consumption Survey (RECS), collected in 2010 and 2011 and released in 2011 and 2012, show that 48% of energy consumption in U.S. homes in 2009 was for heating and cooling (US Energy Information Administration 2017)". However, in 1993, the share of space heating and cooling in energy consumption in households was 58% (US Energy Information Administration 2017) suggesting that over the years, this share has declined. An explanation for this trend could be the increased use of newer heating systems or better insulation (Kansal and Kadambari 2010). On the other hand, there has been a steady increase in energy consumption through other electronic appliances (US Energy Information Administration 2017). Figure 1 gives us a better idea of the residential end use of electricity.

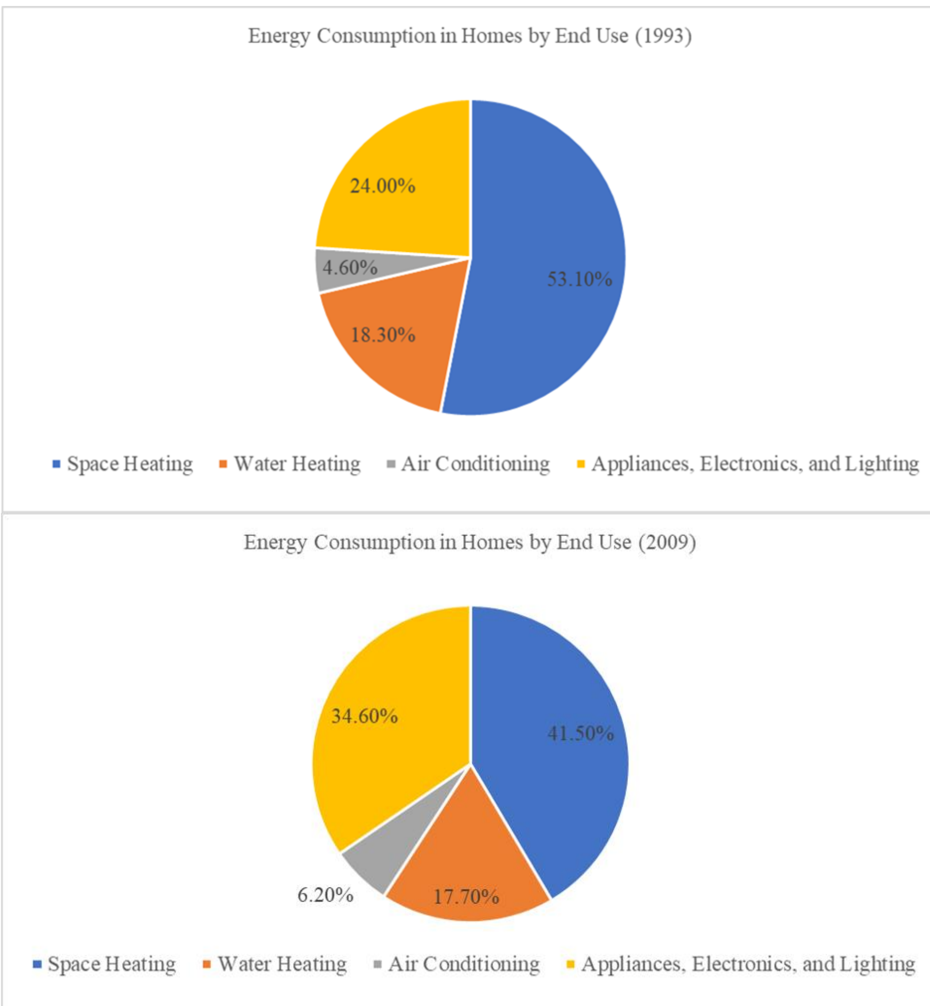

Figure 1. Energy consumption. (US Energy Information Administration, 2015).

3 CHALLENGES FACED BY PASSIVE AND ZERO ENERGY BUILDINGS

Today, only a few net-zero energy buildings (NZEB) exist around the world and they show that the design, construction, and operation have been challenging for many reasons (Butera 2013). We can conclude that energy efficiency is still deeply retrained in the construction industry. Some of the major reasons for this are:

- Lack of public policies to develop energy efficiency strategies (Ryghaug and Sørensen 2009)
- Limited or no government efforts in regulating green building and the construction industry (Ryghaug and Sørensen 2009)
- A rigid and conservative construction industry (Ryghaug and Sørensen 2009)
- Lack of knowledge of new technologies amongst the stalk holders (Kshirsagar *et al.* 2010)
- High installation costs (Marszal and Heiselberg 2011)
- Lack of consumer (home owner) understanding
- Lack of a quantitative approach to calculating the cost benefits of NZE houses (Perlova *et al.* 2015)
- Lack of renewable sources at some locations.

4 DESIGN OF NET ZERO ENERGY RESIDENCE

When we look at the construction of a building, it is often realized in a three-step process.

- Architecture design
- Mechanical/electrical system design
- Construction

In his work, Butera (2013) concluded that energy consultants must step in before any construction begins to provide optimum energy and cost-efficient alternatives. Thus, a new process was developed.

(i) Architecture design
(ii) Mechanical/electrical system design
(iii) Energy analysis
(iv) Construction

The process can be repeated until an appropriate design solution is proposed. This design process coupled with technological advances can be used to improve on strategies that make a building truly net-zero energy.

5 ASSESSMENT OF ZERO ENERGY BUILDINGS - LCCA

Buildings, in general, are increasingly evaluated to meet norms related to sustainability, cost-effectiveness, comfort and safety (Dwaikat and Ali 2014). However, zero energy buildings are a relatively new concept and haven't been fully developed. Thus, an optimum combination of measures has to be developed that are cost beneficial. Life cycle cost analysis (LCCA) is a great tool that helps the owner and stakeholders investigate the most cost-effective solution.

Life cycle cost analysis method was first developed by the Department of Defense (DOD) as an analytical method for evaluation of federal projects (Fernholz *et al.* 2013). "It is a method of determining the entire cost of a structure, product, or component over its whole life" (Snodgrass 2003). Because it includes operation and maintenance costs over a product's lifetime, it is considered a more appropriate evaluation measure when compared to only investments costs.

5.1 Net Present Value (NPV)

NPV is a method to calculate life-cycle cost (LCC) of a building while factoring in the time value of money. This is the most common tool used for life-cycle cost analysis (LCCA). However, it is not the most effective method for comparing buildings that have different lifespans. Additionally, this method does not include the user or owner's perspective (Marszal and Heiselberg 2011). The formula developed by Kaufman (1970), is the most widely used method for Life cycle cost calculation as shown in Eq. (1).

$$NPV = C + R - S + A + M \tag{1}$$

Where C is the investment cost, R is the Replacement costs, S is the Resale value A is the annually occurring costs and M is the non-annually occurring costs.

Life cycle cost analysis can serve as a great benchmarking tool for Green buildings, as it quantifies the benefits of one. Hoque (2007) writes, "It is useful for the comparison of different alternatives which satisfy the desired level of performance". Additionally, it is a great tool to access the performance of a green building.

6 RESEARCH METHODOLOGY

The researcher aims to develop green building strategies for a single-family residence through software and analyze the total cost of building through life-cycle cost analysis (LCCA).

The initial stage of the study would include a case study of a single family unit located in central Indiana. For this, energy data will be calculated from monthly energy bills. Energy modeling for a redesigned unit will be performed on an energy simulation software. The design would be of the following type:

- Passive Building design for a high-performance building
- Active Building equipment for a high-performance building
- A mixture of passive design and active building equipment for a net zero energy building.

The next steps in the research would be the cost and energy data calculations. Energy data from eQUEST would be used to evaluate operation and maintenance costs for the house. These costs along with other variables will be used to calculate the life cycle cost of the building using the net present value method.

7 DATA COLLECTION

The researcher will collect energy and cost data for the single-family residence and the energy modeling data. Based on previous studies and literature, following data variables will be included in this study.

(i) Occupancy Data- functionality, hours of use and specific features of building use
(ii) Physical Data- the number of floors, floor areas, HVAC systems, fenestration details, and water & sanitary data
(iii) Building performance data- Maintenance & cleaning cycles, electricity consumption, gas consumption
(iv) Cost Data- acquisition cost, taxes, inflation, management costs, replacement costs, salvage value

These variables have been determined from the larger pool of data depicted in the Figure 2.

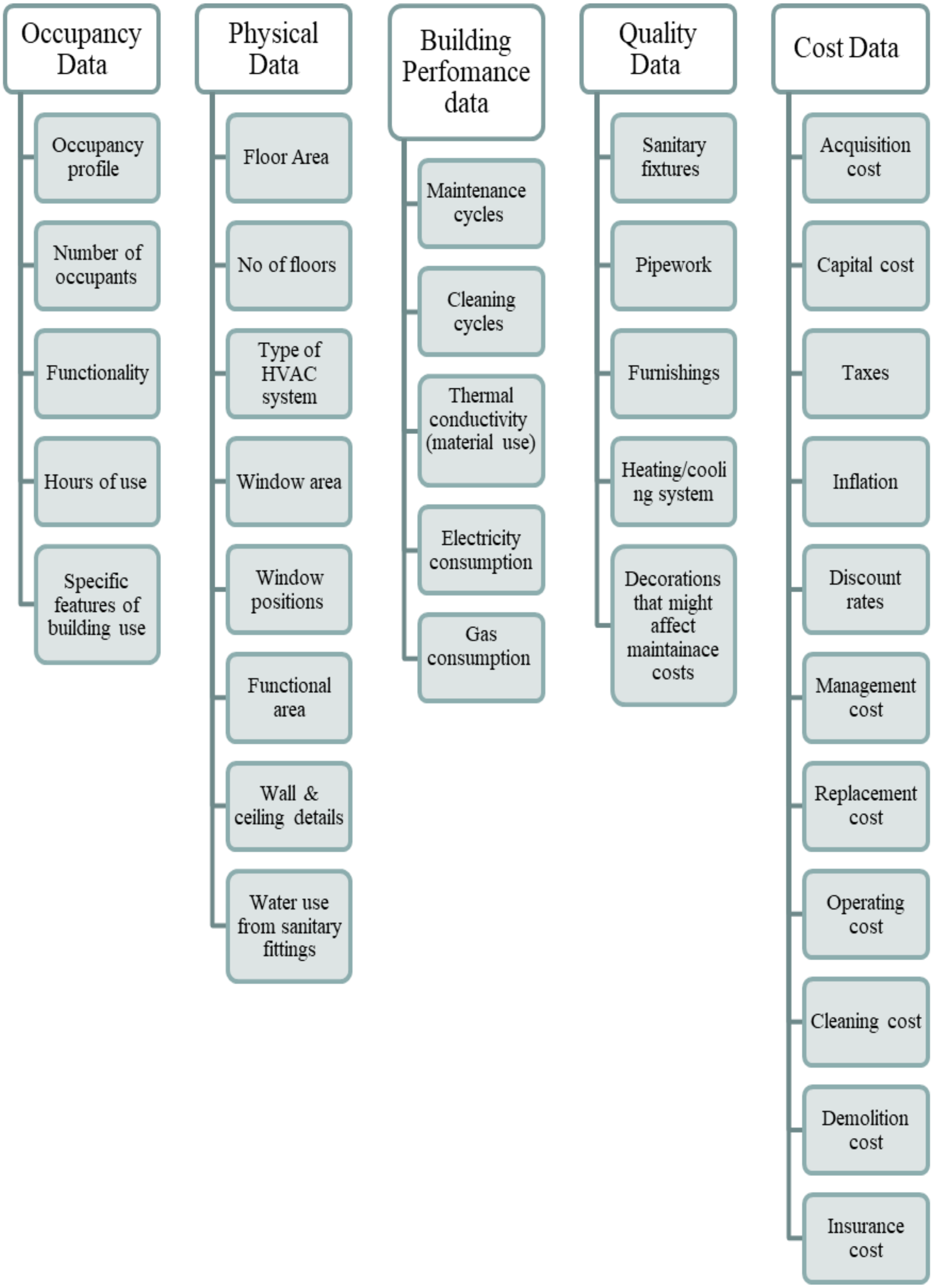

Figure 2. Data collection summary.

8 CONCLUSIONS

The study is ongoing. The data has been collected and analyzed data for a single residential home in Central Indiana.

While there has been tremendous growth in the design and implementation of sustainable practices, there is a dearth of efficient residential buildings in the United States. Energy efficient residential buildings form the core of implementable sustainability practices and a lack of research in the residential sector is prescient of bigger problems ahead. The cost benefits of energy efficient housing are far-reaching.

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