A STUDY COMPARING THE ELECTRIC CONSUMPTION OF SITE-BUILT HOMES AND MOBILE HOMES IN MONTGOMERY AND WALKER COUNTY, TEXAS

A Thesis

By

CHARMY MANISHBHAI SHAH

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Chair of Committee,	Ben F. Bigelow
Committee Members,	Manish Dixit
	Juan Carlos Baltazar
Head of Department,	Patrick Suermann

December 2018

Major Subject: Construction Management

ABSTRACT

The housing sector accounts for roughly 21% of energy consumption in the United States. The homeownership rate in the United States is growing, and with that the demand for affordable manufactured houses is also increasing. The construction industry and U.S. Department of Energy (DOE) are becoming more aware of their impact on the environment. Every year, there is an expansion in the number of mobile homes, yet the question about how energy efficient these homes are compared to site-built homes, to a great extent, remains unanswered. According to a 2017 IBIS World Report, the demand for mobile homes is predicted to grow over the next five years. With the government constantly trying to upgrade the technology and codes used to make these homes energy efficient, it becomes important to discover which of the two types of housing tends to have lesser electricity consumption. This study compares the electric consumption of site-built and mobile homes in Montgomery and Walker County, Texas, to determine which one of them is more energy efficient. The results were drawn after comparing the electric consumption of two types of housing for the year 2016. The analysis concluded that there was no major difference in the electric consumption of mobile homes and site built homes that did not have a building code enforced.

Keywords: residential sector (homes), energy efficiency, electric consumption, manufactured/mobile homes, site-built homes, HUD codes.

DEDICATION

To my parents Manish and Parul Shah and my uncle Deepak Shah and Hitesh Shah.

ACKNOWLEDGEMENTS

I would like to show my sincere appreciation and deepest gratitude to the following persons without whom completing this research would have not been possible. I am grateful to Dr. Bigelow, my thesis chair, for his time, effort and patience in guiding me throughout this research. .My committee members, Dr. Manish Dixit and Dr. Juan Carlos Baltazar for their valuable comments and suggestion. My parents and family for their consistent help, encouragement and support. And finally, all the members of COSC department especially Ms. Liz Smith and support staffs for helping me and making sure that I am headed towards the right direction.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

The study conducted was supervised by a thesis committee consisting of Dr. Bigelow and Dr. Dixit of the Department of Construction Science and Dr. Baltazar of the Department of Architecture.

The data analyzed for Chapter 3 was provided by Mid-South Synergy.

All other work conducted for the thesis was completed by the student independently.

Funding Sources

There are no external funding contributions to acknowledge for this study.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER I

INTRODUCTION, PROBLEM STATEMENT, RESEARCH QUESTIONS, RESEARCH OBJECTIVES AND RESEARCH CONTRIBUTIONS

INTRODUCTION

In the United States, approximately 21% of all energy consumption (natural gas, biogas, and electric) comes from the residential sector, which also accounts for 37% of electrical demands in the country. According to the U.S. Department of Energy Report 2009, electrical consumption is anticipated to increase by 39% between 2010 and 2020 (Hassel et al. 2009).

Most homes in the U.S. are built by a builder onsite. This approach is usually referred to as "site-built" construction. This technique of home construction has been the predominant approach for residential construction since the late nineteenth century and constitutes a major part of the housing sector (Kawecki, 2010). Manufactured housing refers to factory-built houses which have been built and manufactured in a factory-type environment and then transported to a site. These types of homes are built in accordance with the U.S. Department of Housing and Urban Development Construction and Safety Standards (HUD codes) (Beamish, Goss, Atiles, & Kim, 2001).

In the last 50 years, the construction sector has investigated various industrialization procedures to develop construction techniques. Industrialization procedures are also referred to as pre-fabrication or modularization procedures. These are employed to enhance conventional construction methods and are now preferred, by some, over site-built homes because of their affordability (Kawecki, 2010).

Environmental performance is one of the most important measures when sustainability is taken into account. The trend of manufactured housing is growing, and the Department of Energy (DOE) is now making significant efforts to make factory-built housing more energy efficient by upgrading the federal HUD codes. A study conducted by Lee and Onisko (1994) states that mobile homes are distinctive since they are exempted from local building codes, including the region-wide model conservation standards (MCS), which were established as a section of the plan for site-built houses released by the U.S. Department of Housing and Urban Development. These HUD codes are markedly less rigorous than local building codes for site-built homes, which result in less energy efficiency (Lee, Onisko, Sandahl, & Butler, 1994).

According to Jacob Talbot's 2012 report submitted to the American Council for an Energy Efficient Economy, nearly 19 million people in the U.S. reside in mobile homes. This is problematic as energy efficiency in manufactured housing lags behind that of site-built homes. As a result, Talbot proposed cost-effective energy efficiency improvements. However, hardly any studies have been conducted to actually compare the electric consumption of site-built homes and mobile homes, and the ones that have been conducted are outdated.

With new strategies being formed, the DOE is trying to make more stringent HUD policies for energy efficiency in manufactured housing, and with the increasing demand of mobile housing (Manufactured Housing Institute, 2017) it is necessary to explore energy consumption between site-built homes and manufactured homes to determine if one results in lower energy consumption

PROBLEM STATEMENT AND RESEARCH QUESTIONS

Manufactured construction practices could be used as an alternative to traditional on-site construction in the housing sector. While factory-built construction has certain benefits in terms of material and time efficiency, it involves a different kind of framework than traditional house construction. The environmental trade-offs between these two types of construction are unclear. As per the report published by the U.S. Energy Information Administration, Texas led the country in energy utilization in 2015. The number of mobile homes in Texas is expanding (Manufactured Housing Institute, 2017), yet research about the energy performance of mobile homes compared to site-built homes is limited and outdated. The application of various codes for mobile homes is meant to improve their performance and make them energy efficient; they should utilize less electricity compared to the site-built homes, but the information related to this is also limited. Furthermore, the data on the correlation of electric consumption per square footage in kWh between site-built and mobile homes is insufficient. So this study attempts to answer the following questions: 1) Do the improvements in HUD codes (Manufactured Home Construction & Safety Standards) and technologies result in less electric consumption for mobile homes? 2) What is the correlation between the electric consumption of site-built homes and mobile homes in kWh per square footage?

RESEARCH OBJECTIVES

To address these issues, this study compares mobile homes to site-built homes. In the study of home construction, site-built and mobile homes in Montgomery and Walker

County will be evaluated in terms of energy efficiency and electric consumption per square foot. The main objective of this research is to determine if one type of housing (Mobile or Site Built) is more energy efficient.

RESEARCH ASSUMPTIONS

The following assumptions were made during this study:

1. Houses used for this study were built in the year listed by the Montgomery and Walker County Appraisal District.
2. Electricity consumption data is accurate.

DELIMITATIONS

The following delimitations were made in order to increase the reliability of the study:

1. The sample consisted of mobile and site-built homes between 1000-1800 square feet.
2. Energy data collected was based on monthly electrical consumption for each house over a one-year time period (the year 2016).
3. Remodeled houses were not included in the study.
4. Only mobile and site-built housing units were considered.
5. The study was limited to Montgomery and Walker County in the state of Texas.

RESEARCH CONTRIBUTIONS

Prefabrication and modularization procedures are becoming widespread and trendy for building homes. As these procedures are developing and becoming more common, it is vital to determine how prefabricated and factory-built homes function environmentally and how houses built with these procedures contrast with conventional home building techniques. Mobile homes constitute about 6% of the homes in the U.S. (Berg & Taylor, 1994). As per the Electric Power Research Institute report, approximately 13% of new houses are mobile homes (Berg & Taylor, 1994). This may be because mobile housing is a substantial option for increasing affordable homeownership possibilities for people in the U.S. Since 1991, the production of manufactured housing has increased an average of about 17% per year (Beamish et al., 2001). According to a 2017 report by the Manufactured Housing Institute, 93,000 mobile homes were produced in 2017, which was about 9% of the new single family homes; these mobile homes are contributing about $3 billion to GDP/yr.

The average electricity utilization per Texas house is 26% higher than the country's average, and the Texas housing sector utilizes an average of 77 million Btu annually (RECS, 2009). Considering the fact that buildings account for a massive portion of environmental burdens, determining which type of housing unit (a mobile home vs. a site-built home) is more energy efficient in the state of Texas is important. There is very limited information available on performance effectiveness for existing mobile homes compared to site-built homes. Since the U.S. government emphasizes enhancing HUD codes and developing strategies to make mobile homes more energy

efficient, a study exploring how effective these homes are when compared with conventionally built homes is important. It contributes to the existing body of knowledge by delivering a deeper look into the energy performance of mobile homes and site-built homes. It will give the results for the mobile homes located in Montgomery and Walker County in the state of Texas. From these results, future studies in different states can be conducted.

CHAPTER II

LITERATURE REVIEW

LITERATURE REVIEW

Buildings in the U.S. represent 72% of electricity utilization, 39% of energy usage, about 38% of total CO2 emissions, 40% of raw material usage, 30% of waste yield, and 14% of consumable water utilization (U.S. Green Building Council, 2008). They additionally are responsible for about 46%, 19%, and 10% of the sulfur dioxide, nitrogen oxide, and particulate emission, respectively. Buildings are also responsible for about 33% of energy utilization and 40% of material usage in the global economy. A positive aspect of factory-built homes is that they considerably reduce the environmental impact of projects. This is partially because of decreased time in field construction and a reduction in on-site labor demands. Trends in construction operations, comprising of increased automation and factory-based production, tend to generate less waste than in the field. Challenges in the availability of natural resources and the environmental impact at the local and global levels are resulting in notable changes in the construction sector. For example, more consideration is being given to environmental and social issues in the building atmosphere. Similarly, greater attention is being given to standard project goals such as cost, quality, safety, and time. Buildings utilize one-sixth of the world's fresh water, one-fourth of the world's wood production, and 40% of the world's material flow. One way or another, buildings and related construction phenomenon contribute to about 54% of U.S. energy utilization (Kawecki 2010).

Utilization of non-renewable natural assets, materials, and energy in buildings and the related supply chain operations leads to environmental impact by contaminating the land, air, and water, as well as health issues. The Department of Energy (DOE) has set an aim of energy consumption reduction in the constructed environment. Twenty-first century structures will reduce the annual U.S. energy utilization by reducing the carbon emanation by 32 million metric tons annually. The Environmental Protection Agency (EPA) is intending to develop pollution prevention strategies wherein they or their contractors assist the builders to enhance their manufacturing procedures. This in turn will help eliminate potential pollution at the source. The EPA's pollution prevention program may result in less waste generation, reduced disposal cost, and decreased input of materials (Kawecki, 2010).

Energy is one of the most critical resources used in our everyday life. According to Omer (2008), not much attention was given to the energy consumption levels before 1992. However, due to the current concerns about the shortage of natural assets, efficient use of energy has received extra interest from academia and project officials. As stated in the United States Energy Information Administration (EIA) evaluation, the residential sector in the U.S. consumed about 23% of energy in 2015. Further, the U.S. Housing Census record states that 65% of households in the U.S. are single-family housing units (USEIA, 2016).

Discussion about the development and evolution of the residential sector is important in order to understand the improvements made in the phase of the mentioned challenges of energy performance of the houses. The residential sector is characterized

by the variety of its products, in terms of quality, construction methods, materials, and costs. As the other sectors of construction, residential contractors have also been consistently assessing innovative materials and design techniques to enhance the proficiency, sustainability, and cost-effectiveness of the residential market. Because of these early attempts and endeavors, prefabricated manufactured homes were presented as an efficient and reasonable housing option that can be manufactured in substantial volumes in facility controlled environments (H. Said & Bartusiak, 2016).

Historically, the typical site-built way of house construction has predominated. However, now the factory-built houses, particularly manufactured homes constructed in accordance with the Federal HUD code, also contribute a significant role in the housing sector. The substantial increase in the production of manufactured houses could have both short and long-term consequences for the residential sector as a whole. Traditionally, manufactured housing—also known as "HUD-code homes"—has not competed with site-built homes because of the considerable dissimilarity between the two kinds of homes. The current HUD-code sector shows a growing market overlap, especially in the entry-level affordable housing sector. With the demand for manufactured units more than doubling between 1991 and 1996, the mobile units have improved significantly. They went from being large in size and well-equipped to appearing quite similar to the standard ranch-style houses (de Souza Briggs, 1998).

Manufactured houses, or mobile homes, are quite different from modular houses. Despite the fact that manufactured homes are also built in a factory, they are commonly fabricated with an attached permanent steel framework and comply with the HUD

building code (Kawecki, 2010). Mobile homes or trailers, give a low priced housing option for many low- and moderate-income families (Beamish et al., 2001).

Mobile homes follow HUD codes, which are not stringent. Because of this, we need to determine how they perform in terms of energy efficiency. As we know, buildings constitute about 40% of the entire U.S. energy consumption, including 2/3 of the nation's electricity (Kawecki, 2010). Since the HUD code imposes comparatively low energy efficiency standards, new mobile homes represent a noteworthy risk to the energy efficiency objectives of local electric utility grids, as they may stimulate the requirement for more power plants in some locations. The local utilities are thus challenged to determine a strategy that will enhance the energy efficiency of the mobile homes, resulting in decreased regional electricity needs. As a part of the solution to this challenge, an acquisition strategy or approach was formed which was named as the Manufactured Housing Acquisition Program (MHAP). According to this program, people who constructs an energy efficient home in the region of Bonneville and a few other Pacific Northwest parts of the country will get a pay of $2,500 from utilities in place of costs they would pay for a new power supply (Lee et al., 1994).

With energy efficiency being considered, the air distribution system would play a major role for mobile homes. Nearly all mobile home units in the country use forced air systems for heating and cooling distribution. An evaluation done in 1996 indicates that the air distribution system (ADS) in these houses wastes a huge amount of energy. This evaluation showed average energy losses owing to ADS cause leakage, conduction, and

infiltration, which constitutes about 40% of the entire heating energy utilization and 15% of the entire cooling energy utilization. These results are significant and state a huge and easily available chance to enhance the energy efficiency of mobile homes by updating ADS performance. Previous accomplishments indicate that ADS losses can be reduced to a limit of 5% to 11%. Implemented to the average mobile home, such a decrease would trim the annual utility bills by about 20%. Unquestionably, enhancing ADS efficiency is the most crucial approach for saving energy in mobile housing. A substantial part (at least half) of this strategy of enhancing the ADS performance can be achieved by minimizing ADS leakage (Manufactured Housing Research Alliance, 2003).

Texas and the states that construct the most houses (Florida, California, North Carolina, Georgia, and South Carolina), have energy codes like the International Energy Conservation Code (IECC) for site-built homes. On the other side, the "HUD CODE" which is developed by the Department of Housing and Urban Development for governing the energy standards in mobile housing has not changed considerably since 1994 (Lowell Ungar, 2016).

In 2007, Congress decided to take action and instructed the DOE to set energy principles for manufactured houses based on the latest IECC. The DOE was supposed to submit a draft of new standards set for mobile homes in 2011, but there were no upgrades proposed by the DOE during that time. In 2014, the DOE met with the partners to decide upon the rules, and in October 2014, they came to compliance and agreed upon

the key terms. After a year, the DOE presented the proposed set of principles to the Office of Management and Budget Review, and in June, after over eight years, the DOE released the draft. This standard is predicted to have an actual effect on landlords and rural electric lines. The DOE performed an evaluation that anticipates that a standard mobile home will reduce the energy consumption by 27% compared to a home that meets the present HUD Code. Average energy saving for homeowners during their entire lifespan is assessed to be nearly $4,000 net present value. Total national energy savings would include about 2.3 quadrillion Btu — a value close to the energy consumed in one year by all houses in New York and Florida, combined. (Lowell Ungar, 2016).

Two-story HUD-code homes are currently being produced and most are being stationed on personal properties rather than on leased sites. Moreover, builders of mobile and site-built homes are establishing alliances among one another that suggest industry-extensive shifts in the housing industry may be in progress (de Souza Briggs, 1998). A significant development over the same time frame has been advanced production of industrialized homes — most remarkably for factory-built mobile homes that are manufactured under a federal regulatory system and dispatched throughout the nation. Advancements in mobile homes or the “HUD-code” sector have been especially rapid (de Souza Briggs, 1998).

These advancements clearly trigger questions about such solid performance in the mobile homes industry. Furthermore, those inquiries lead to other questions. These include the potential for continuation of this pattern, long-term consistency of

industrialization in the new house development and its correlation to the "affordable housing" industry, and the future prospects of traditional site-built construction and various kinds of factory-built homes within the new home sector as a whole. Essentially, new mobile homes are advancing into a new era with a variety of interior layouts, plus the arrival of the two-story model, high-pitched roofs, cathedral ceilings, permanent foundations, and the addition of site-built extras like garages, porches, decks, and exterior trim (Wherry, 2009).

Modular and mobile home manufacturers have an outstanding and ever-developing array of strong, green construction materials available to the clients who seek better-functioning, energy-efficient houses. The fact that manufactured/mobile homes are constructed under controlled facility conditions and have superior quality contributes to their capability of having better energy performance (Wherry, 2009). Efforts are being made to upgrade the energy efficiency of mobile homes, but research and studies show that their performance is actually limited when compared to site-built homes.

Manufactured homes encountered a remarkable development over the 60-year period. In 1940, the number of mobile homes was so low that they were not computed independently; rather they were incorporated in the “Other” category with boats and tourist cabins. In 1950, manufactured homes constituted just 0.7 percent of the stock and by the year 2000 had expanded to 7.6 percent of the entire housing shares (Census Bureau, 2000). Typically, “trailer” or “mobile homes” are perceived as the home to “newlywed or nearly dead;” however, the truth is that 2 out of every 10 new single-family homes are mobile homes, and new proprietors constitute all age groups and every

economic status and lifestyle. Of all the new single-family homes that began construction that year, mobile homes constituted about 20.7 % (Beamish et al., 2001).

Mobile housing is growing in popularity among Texas homebuyers. Mobile home sales constitute more than 30 percent of total housing sales in Texas in 2003. (Harris et al. 2003).

Off-site construction has attained considerable attention from both academia and the construction industry in the previous few years (Kamali & Hewage, 2016). Table 1 shows the details of shipments of manufactured homes over the course of 5 years. Texas had the most shipments, with 17,676 homes being shipped (Manufactured Housing Institute, 2017).

Table 1 - Shipments of Mobile Homes over the Last 5 Years

Year	2013	2014	2015	2016	2017
Total	60,210	64,344	70,519	81,169	92,891

Table 2- Shipments of Mobile Homes over the Last 5 Years in Texas

Year	2013	2014	2015	2016	2017
Total	10,309	12.048	13,926	13,592	17,676

One of the traits of the HUD code homes sector is that a few firms produce a huge share of the houses. In 2001, there were 69 firms with 263 operating facilities, fabricating 193,229 houses, or about 735 homes per facility. The top ten mobile housing manufacturers sold approximately 155,000 homes in 2001, constituting about an 80.1% share of the entire industry shipment (Manufactured Housing Research Alliance, 2003). Innovative and technological developments, improved designs and plans and an emphasis on conveying quality homes that people can afford are the major forces within the manufactured housing sector. That is the reason people are choosing the mobile homes, to have homes that fit their necessities and needs, at costs they can bear (Manufactured Housing Institute, 2018).

In 1989, the mobile housing industry constituted 21.5% of all new single-family homes sold, but from 2002-2005 due to market imbalance, the sales declined by 57%. The mobile housing sector rose afterward and contributed about 25% of sales in 2011. According to the Manufactured Housing Institute in 2011, because of the rise in population, the demand for single-family homes will grow as well (Manufactured Housing Institute, 2012).

Mobile homes constitute about 6% of the total occupied U.S. housing sector. It is about 7% for Texas (Bureau, 2014). Prefabrication and factory-built homes are an example of a major change in the perspective of the construction industry structure, procedures, and techniques, and it enhances the value for customers, industry organizations, and the general public. Industrialized home building (IHB) has advanced

as a cost-effective key in many developed nations for the growing population (H. M. Said & Bartusiak, 2017).

In a study conducted by H. Said & Bartusiak in 2017, manufactured homes were the subject of various research studies that analyzed the construction processes and operations of these homes along with the occupant's behavior. The first series of studies evaluated factors for advancing construction systems and fabrication processes of manufactured homes. The second group of researchers analyzed the factory-built homes operations and mass customizations, and the third group conducted studies related to market structure, stakeholders, and historical performance (H. Said & Bartusiak, 2016). Despite the contributions of earlier research studies, there is still a need to analyze whether or not mobile homes are more energy efficient than site-built homes. Such analysis would expand the current understanding of energy efficiency in manufactured homes.

As the literature review suggests, there is a shift in the industry towards manufactured housing, and public acceptance of this type of housing is rapidly growing. The application of various codes on mobile homes is meant to improve their performance and make them energy efficient, and, consequently, they should utilize less electricity compared to site-built homes; however, no research concerning this topic has been performed, thus this theory remains unclear (Kawecki, 2010). This study will analyze the electric consumption of mobile homes compared to site-built homes and evaluate which type of housing is more energy efficient compared to other.

CHAPTER III

RESEARCH PROCESS

RESEARCH METHODOLOGY

The purpose of this study is to compare the electrical consumption of mobile homes and site-built homes in Montgomery County and Walker County, TX. Monthly electricity consumption of site-built homes and mobile homes for the year 2016 were used to quantify the difference in electrical consumption between the two types (mobile VS. site built of housing units. Houses built during the period of 1990-2000 were considered for the study.

Electrical company, Mid-South Synergy, provided the electrical consumption data. This data consisted of kWh used per month from each house selected in 2016. The company considered for the study, uses smart meters to quantify the electric consumption of homes and so consumption data is considered highly accurate.

Data Information: The total data consisted of total 247,252 homes and mobile homes in 6 counties. Walker County had data of total 50,330 units (6573 mobile homes) and Montgomery had 115,845 units (8,813 mobile homes).

For all the units in Montgomery (115,845) and Walker (50,330) County, the year built and square footage data was obtained from respective appraisal district web database. The data of Montgomery and Walker Counties was filtered according to the year built and size of the house. For this study, the sample of 100 mobile homes and 100 site built homes were drawn from all the data available, after filtering them by their respective square footage and year built. Mobile homes and site-built houses similar in

area (1000-1800 square feet) were selected. Electric consumption of these sampled homes was compared monthly for the year 2016.

A multi-step procedure was employed in order to determine which homes were to be selected in the sample for the study. First, the electrical consumption data of mobile homes and site built homes for Montgomery and Walker County was obtained from Mid-South Synergy Company. Secondly, web based data from Montgomery and Walker County Appraisal district was used to determine the year the houses were built. The square footage of each home was also obtained from the appraisal district county data. Once all the data regarding the square footage and year built of each homes was obtained the filter of square footage of 1000-1800 and year built to be from 1990-2000 was applied. Once the data was filtered down as per the mentioned criteria we had 100 mobile homes and 100 site built homes. Table 1 shows the square footage, year built and sample sizes for mobile and site built homes used for this study.

Table 3: Square Footage, Year Built and Sample Size (1990-2000)

Square Footage	Year Built	Sample size Mobile homes	Sample size Site Built homes
1000-1800	1990-2000	100	100

THE HYPOTHESIS TESTED FOR THIS RESEARCH IS:

$$\boldsymbol{H_0: \mu_1 = \mu_2} \qquad \boldsymbol{H_a: \mu_1 \neq \mu_2}$$

Where μ_1 is the average electric consumption of site built homes and μ_2 is the average electric consumption of mobile homes. H_0- Null hypothesis - the average electric

consumption of mobile homes is same as site built homes. H_a is the alternative hypothesis which is the average electric consumption of mobile home is different than site built homes. The average monthly electric consumption used for the test was obtained from electrical consumption during year 2016. A 95% certainty was used when conducting a two sample independent t-test.

Also, in order to have a better understanding of the relationship between the electric consumption of the two types of housing over the time period, the houses built in the period of 2000-2016 were also tested. The data available for the homes built in this time period was limited, so a sample of only 38 homes for each type of housing, built in the period of 2000-2016 and with a square footage of 1000-1800, was compared. The same methodology as previous was employed for the comparison. Homes built in the year 2000-2016 and with a square footage of 1000-1800 for Montgomery and Walker County were filtered from the overall data and two sample t-test was performed comparing the electrical consumption in that time.

CHAPTER IV

FINDINGS AND CONCLUSIONS

ANALYSIS AND RESULTS

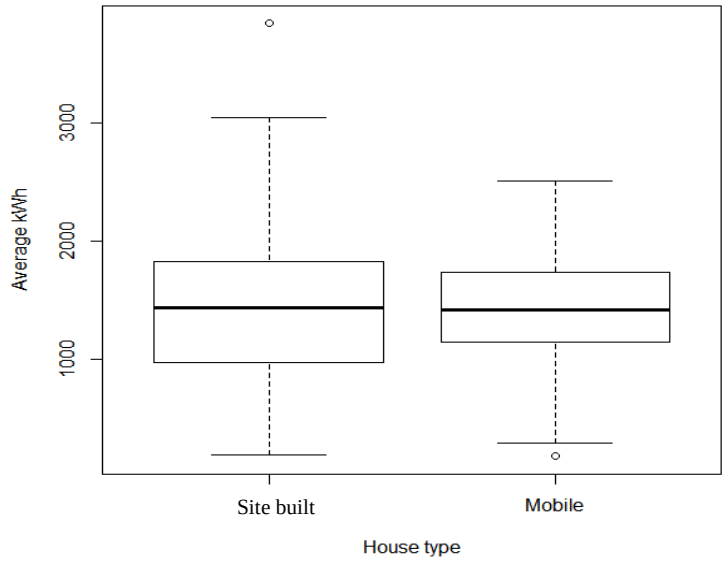
The primary interest of this study was to compare average electrical consumption of site built homes and mobile homes. Since these are two different types, t-test is used to compare average electricity consumption per square foot. For t-test, we usually check two assumptions, normality and variance. However, if sample size is large enough (as in this case, 99 samples) normality assumption does not matter for the validity of the test due to the central limit theorem. For equal variance assumption, two sample independent t-tests with unequal variance assumption were used, so that it will be enough to mention the variances for each group.

For the analysis two test results for the homes built in 1990-2000 are presented, one is using overall average from January to December. The other one is individual monthly comparisons between site built and mobile homes.

1. Overall average (Results for the homes built in 1990-2000)

    1) Boxplots of each average electricity consumption by house type

Figure 1 - Boxplots of each average electricity consumption by house type



2) Descriptive statistics

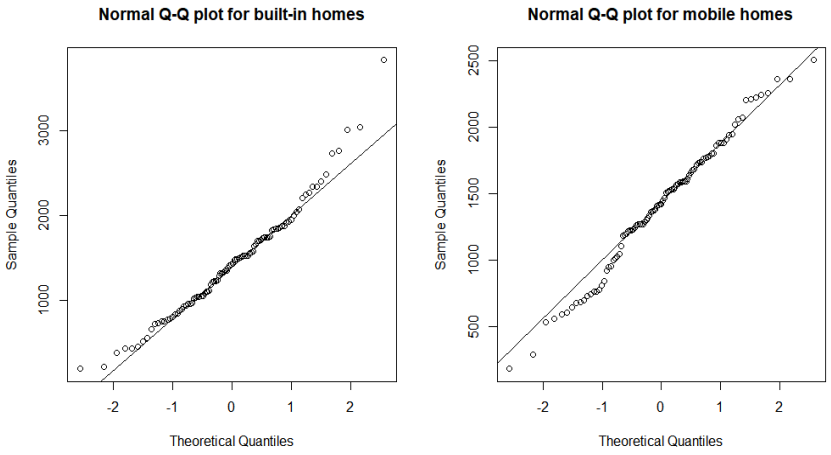
Table 4: Overall statistics for electrical consumption of each house type(1990-2000)

	Site Built	Mobile
Mean	1441.753	1411.239
SD	647.74	490.31

Variances for site built homes are about 2 times of mobile homes. So, it is reasonable to assume unequal variance.

3) Normal Q-Q plots

Figure 2 – Normal Q-Q plot of residual for site built and mobile homes



Except few samples, points are along with the real line which indicates normality assumption is true.

T-test result (unequal variance t-test)

t-test statistic is 0.3725 and corresponding p-value is 0.709. There is no evidence that the electricity consumptions are different using overall average data.

2. Monthly data (For year 1990-2000)

1) Descriptive statistics (total consumption and per square footage)

Table 5: Monthly statistics for electrical consumption of each house type (1990-2000)

	Site built		Mobile homes	
Month	Mean kWh	SD	Mean kWh	SD
January	1484.8	872.4	1519.5	595.2
February	1675.3	1083.4	1650.1	693.6
March	1221.1	721.7	1181.0	501.8
April	1038.5	547.5	1026.7	436.0
May	1104.8	548.7	1043.6	462.8
June	1280.9	591.2	1221.9	545.8
July	1735.9	745.8	1762.7	745.9
August	1999.1	850.9	1949.3	784.1
September	1799.9	786.7	1754.8	739.3
October	1577.4	717.6	1537.1	634.5
November	1248.1	562.9	1158.6	489.9
December	1135.4	574.4	1129.6	500.4

Per Square footage

Table 6: Monthly statistics for electrical consumption of each house type per square footage (1990-2000)

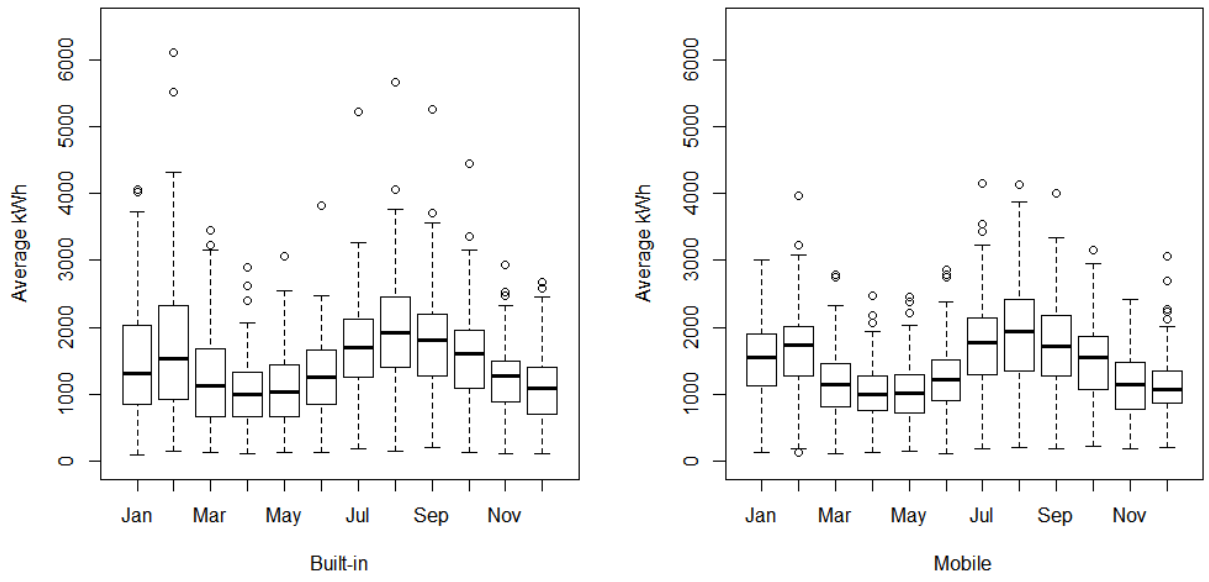
Month	Site Built Homes		Mobile Homes	
	Mean kWh	SD	Mean kWh	SD
January	1.032	0.608	1.182	0.45
February	1.156	0.719	1.284	0.506
March	0.843	0.494	0.913	0.345
April	0.723	0.397	0.794	0.307
May	0.771	0.396	0.807	0.334
June	0.891	0.408	0.951	0.416

Table 6 Continued

Month	Site Built Homes		Mobile Homes	
	Mean kWh	SD	Mean kWh	SD
July	1.207	0.518	1.376	0.592
August	1.386	0.58	1.511	0.573
September	1.242	0.519	1.359	0.532
October	1.09	0.479	1.196	0.477
November	0.865	0.397	0.903	0.368
December	0.792	0.413	0.883	0.386

2) Boxplots for monthly data

Figure 3 - Boxplots of average electricity consumption per month by house type



3) t-test using monthly data

Table 7: Monthly test statistics values and P-value (1990-2000)

	Test statistic	p-value
January	-0.325	0.745
February	0.194	0.846
March	0.451	0.652
April	0.167	0.867
May	0.845	0.399
June	0.726	0.468
July	-0.252	0.801
August	0.427	0.669
September	0.415	0.678
October	0.417	0.677
November	1.189	0.236
December	0.074	0.940

Per Square Footage Values (1990-2000)

Table 8: Monthly test statistics values and P-value per square footage (1990-2000)

	Test Statistic	p-value
January	-1.983	0.054
February	-1.445	0.152
March	-1.164	0.247
April	-1.406	0.163
May	-0.703	0.484
June	-1.009	0.315
July	-2.145	0.034
August	-1.532	0.129
September	-1.557	0.123
October	-1.560	0.122
November	-0.696	0.488
December	-1.608	0.111

95% certainty was assumed while conducting the tests. To reject the null hypothesis, the p-value should be smaller than 0.05 (5%). For the period 1990-2000, all

p-values are greater than .05, indicating that there is no evidence of statistically significant difference of electricity consumption between two types of housing on a monthly basis when overall consumption is considered. While when the data per square footage was compared, the p-value for the month of July was smaller than 0.05 and also for the month of January the p value is very close to 0.05. The averages of two types of housing are close to each other.

Following are the analysis for the houses built in the period of 2000-2016, for this analysis following parameters were used:

Table 9: Square Footage, Year Built and Sample Size (2000-2016)

Square Footage	Year Built	Sample size Mobile homes	Sample size Site Built homes
1000-1800	2000-2016	38	38

For overall consumption (2000-2016):

Overall averages:

Table 10: Overall statistics of electrical consumption for each house type (2000-2016)

	Site Built	Mobile
Mean	1168.529	1398.193
SD	715.511	664.414

Descriptive Statistics:

Table 11: Monthly statistics for electrical consumption of each house type (2000-2016)

	Site Built		Mobile homes	
Month	Mean kWh	SD	Mean kWh	SD
January	1150.30	814.42	1489.76	619.72
February	1203.16	944.05	1593.65	698.68
March	914	575.19	1216.94	559.83
April	835.32	486.18	1071.68	455.38
May	897.79	473.92	1093.94	466.72
June	1094.10	590.15	1219.44	512.46
July	1506.68	818.69	1713.63	714.40
August	1610.08	776.29	1907.05	805.24
September	1471.68	702.09	1745.86	788.68
October	1332.52	627.71	1512	622.71
November	1049.73	548.60	1127.65	457.25
December	956.737	613.93	1086.65	422.00

Consumption per square footage (2000-2016):

Overall Averages per sq. ft.

Table 12: Overall statistics for electrical consumption of each house type per square footage (2000-2016)

	Site Built	Mobile
Mean	0.833	1.054
SD	0.536	0.50

Table 13: Monthly statistics for electrical consumption of each house type per square footage (2000-2016)

Month	Site Built		Mobile homes	
	Mean (kWh)	SD	Mean (kWh)	SD
January	0.813	0.587	1.124	0.464
February	0.856	0.684	1.209	0.541
March	0.654	0.433	0.917	0.416
April	0.601	0.374	0.808	0.354
May	0.641	0.359	0.818	0.345
June	0.776	0.438	0.916	0.397
July	1.076	0.642	1.300	0.584
August	1.151	0.598	1.436	0.614
September	1.048	0.531	1.301	0.549
October	0.951	0.479	1.139	0.475
November	0.747	0.408	0.859	0.379
December	0.688	0.495	0.821	0.339

T-test using monthly data

Table 14: Monthly test statistics values and P-value per square footage (2000-2016)

	Test statistic	p-value
January	-2.564	0.014
February	-2.494	0.017
March	-2.688	0.010
April	-2.484	0.017
May	-2.196	0.034
June	-1.459	0.152
July	-1.590	0.120
August	-2.051	0.047
September	-2.044	0.048
October	-1.713	0.095
November	-1.247	0.220
December	-1.363	0.181

For the period of 2000-2016, when the electric consumption per square footage of the two types of housing were compared, the p-values for the months January, February, March, April, May, August and September were less than .05 (95% certainty), indicating that there is a statistically significant difference in the electric consumption of

the two types of housing for these months. The descriptive statistic table for consumption per square footage shows the value of mean of electric consumption for these months and that indicates that mobile homes have statistically higher electric consumption than site built homes for the months of January, February, March, April, May, August and September. The reason mobile home had higher electric consumption during those months is because the weather and poor thermal insulation of mobile homes. Mobile homes do not offer too much thermal protection resulting in higher energy consumption during winter, because the temperature difference indoor and outdoor during winters is higher than during summer.

The study conducted by Bigelow and Cedillo (2017) compared the average electric consumption of the site built houses that were built during different decades for past 44 years in Montgomery, Texas. Their study found that the site built homes built without a building code enforced have not seen a significant change in electrical consumption over the last 40 years. However when those homes were compared to site built homes built with a building code enforced; there was as much as a 62% reduction in electrical consumption compared to the homes in areas with absence of codes. This is important, because this study compared the mobile homes to site built houses built in area without code enforcement. As such it would suggest that although this study did not find a statistically significant difference between mobile and site built homes, the site built homes compared in this study were not built with a code enforced. As such the data suggests that mobile home performance is comparable only to site built homes

where a building code is not enforced (the site built homes used in this study are not built with the code enforced).

CONCLUSIONS

For the period of 1990-2000, the results and analysis of the study indicated that there is no significant difference in the electric consumptions of the mobile homes and site built homes, except for the month of July when per square footage data was compared. When the same comparison was performed on the houses built in the period of 2000-2016, practical and statistical differences emerged, suggesting that site built homes are more efficient. The difference in the consumption for the period of 2000-2016 was because of the poor thermal insulation of the mobile homes. However, the small sample size (only 38 houses) means these results should not be generalized and should be interpreted with caution. The data suggests that performance of mobile homes and site built homes in terms of energy efficiency is approximately same for the time period 1990-2000 while the performance of site built homes performed better in terms of energy efficiency compared to mobile homes for the period 2000-2016. However, the results are valuable and for more accurate results smaller range of square footage should be used. Also, data for various time period should be collected and analysis for various time period and with smaller range square footage groups should be conducted to better understand the performance of the two type of housing in comparison to each other over the period of time. The data available for these study was limited. When groups with smaller range of square footage and period built were formed, the sample data available

was very small to be considered for statistical analysis for this study and so the analysis was done for two time periods with the square footage range of 1000-1800.

With the construction industry becoming more and more aware of sustainable development and with manufactured housing becoming a popular choice among the consumers; this study plays a vital role in determining the energy performance of the two types of housing compared to each other. Since, the mobile homes are assumed to perform poorly in terms of energy efficiency compared to site built home (because of less stringent HUD codes), the Manufactured Housing Division (regulates the manufactured housing industry) is continuously making efforts to improve the energy standards of the mobile homes, to make improve their energy performance compared to the site built homes.

This study gives a better insight on the energy efficiency of manufactured housing compared to site built homes, to carry out the future research regarding mobile homes energy performance. One of the major areas of improvement can be the thermal insulation of the mobile homes, to make them perform better in terms of energy consumption. There are still several areas that need to be explored to better understand the relation between mobile homes and site built homes in terms of energy efficiency. They include: A study comparing the electric consumption of two types of housing during different time period, which will help understand how well the codes have been enforced and how efficient is the performance of the mobile homes under those codes.

An analysis comparing the energy performance of the site built homes built with the codes enforced compared to mobile homes. The mobile homes built after June 2015 will follow the updated energy efficiency standards, and also Montgomery County adopted the 2015 IRC to be in effect January 2016 for the site built homes. It will be interesting to conduct a similar study on the site built homes and mobile homes built with this new codes enforced, which will help to evaluate the energy performance of the two types of housing compared to each other with all the updated codes and standards enforced. Studies can be conducted for other counties and states for a better idea of the performance of manufactured homes compared to site built homes in terms of energy efficiency throughout U.S.

REFERENCES

Beamish, J. O., Goss, R. C., Atiles, J. H., & Kim, Y. (2001). Not a trailer anymore: Perceptions of manufactured housing. *Housing Policy Debate, 12(2), 373-392.*

Berg, S. V., & Taylor, C. (1994). Electricity consumption in manufactured housing. *Energy Economics, 16(1), 54-62.*

Bigelow, B., F., and Cedillo (2017). An Evaluation of the effect of age of house construction on electrical energy consumption in Montgomery County, Texas

Bureau, C. F. P. (2014). "Manufactured-housing consumer finance in the United States." September, available at http://files. consumerfinance. gov/f/201409_cfpb_report_manufactured-housing. pdf.

de Souza Briggs, X. (1998). Factory and Site-Built Housing. A Comparison for the 21st Century. *Environmental and Energy Stud Institute (2009, June).*

Energy Use in Mobile Homes Retrieved from Environmental and Energy Stud Institute.

Harris, J., Evans, J., Chris, P. (2003). "Manufactured Home Buyer's Guide."

Texas A&M University.

Hassel, S., Blasnik, M., and Hannas, B. (2009). "Houston Home Energy Efficiency Study.*" Advanced Energy.*

IBISWorld Report (2017). Manufactured Home Wholesaling in the US. Retrieved From IBISWORLD Report.

Jacob Talbot (2012). Mobilizing Energy Efficiency in the Manufactured Housing Sector. Retrieved from The American Council for an Energy-Efficient Economy (ACEEE).

Kamali, M., & Hewage, K. (2016). Life cycle performance of modular buildings: A critical review. *Renewable and Sustainable Energy Reviews, 62, 1171-1183*.

Kawecki, L. R. (2010). Environmental performance of modular fabrication: Calculating the carbon footprint of energy used in the construction of a modular home: *Arizona State University*.

Lee, A., Onisko, S., Sandahl, L., & Butler, J. (1994). Everyone wins-a program to upgrade energy efficiency in manufactured housing. *Electricity Journal;(United States), 7(2).*

Manufactured Housing Research Alliance (2003, January 02) Improving Air Distribution System (ADS) Performance in Manufactured Homes. Retrieved from Manufactured Housing Research Alliance.

Manufactured Housing Institute (2017). Manufactured Housing Facts Industry Overview Retrieved from Manufactured Housing Institute.

Manufactured Housing Institute (2018). Manufactured Housing Facts Industry Overview Retrieved from Manufactured Housing Institute.

Said, H., & Bartusiak, J.(2016). “Detailed Analysis of Texas's Manufactured Housing Growth and Competition.”

Said, H. M., & Bartusiak, J. (2017). Regional Competition Analysis of Industrialized Homebuilding Industry. *Journal of Construction Engineering and Management, 144(2), 04017108.*

The American Council for an Energy-Efficient Economy (ACEEE), Lowell Ungar (2016, August 03). Mobile homes move toward efficiency. Retrieved from The American Council for an Energy-Efficient Economy (ACEEE).

The Residential Energy Consumption Survey (RECS) Program (2009). Household Energy Use in Texas. Retrieved from The Residential Energy Consumption Survey (RECS) Program.

United States Census Bureau (2018). Historical Census of Housing Tables. Retrieved 20 December 2017, from United States Census Bureau.

Wherry, G. D. (2009). Trends and Diversification in the Factory-Built Home Industry. *Virginia Tech.*