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Life-Cycle Cost Analysis of the Efficient Water Fixtures and Electric Appliances Used to Minimize Water and Energy Consumption in Homes in the U.S

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LIFE CYCLE COST ANALYSIS OF THE EFFICIENT WATER FIXTURES AND ELECTRIC APPLIANCES USED TO MINIMIZE WATER AND ENERGY CONSUMPTION IN HOMES IN THE U.S.

A Thesis
by
MIRANDA N. GARCIA

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Requirements for the Degree of
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December 2021

LIFE-CYCLE COST ANALYSIS OF THE EFFICIENT FIXTURES & APPLIANCES USED TO MINIMIZE WATER AND ENERGY CONSUMPTION IN HOMES IN THE U.S.

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ABSTRACT

Garcia, Miranda, Life Cycle Cost Analysis of the Efficient Water Fixtures and Electric Appliances Used to Minimize Water and Energy Consumption in Homes in the U.S. Master of Science (MS), December, 2021, 128 pp., 34 tables, 43 figures, references, 118 titles.

Consumer interest in incorporating sustainability and efficient appliances into daily life has been growing in the past several years. Programs such as WaterSense and Energy Star not only offer certified efficient appliances and fixtures but they may also certify water- and energy-efficient homes. Additionally, the United States Green Building Council (USGBC) offers the LEED program (Leadership in Energy and Environmental Design) which certifies homes in a similar manner.

This research aims to evaluate the financial feasibility of following the recommendations of these different green building certifications (LEED v4 for Homes, Energy Star and WaterSense). To accomplish this task, a life-cycle cost analysis (LCCA) will be conducted to determine the feasibility of each of these systems. Using different types of analyses that utilize the costs of purchasing, installation, operation, replacement, and monthly utilities, both traditional (non-efficient) and efficient appliances are compared via an LCCA. The LCCA will be applied to the five most populous cities in the U.S. to draw final conclusions about the feasibility of investing in efficient appliances and fixtures by comparing the net savings, the cost-benefit ratio, adjusted internal rate of return, and the payback period. This study should prove useful to a wide range of stakeholders including homeowners and construction practitioners.

DEDICATION

I would like to dedicate this work to my mom and dad for their support of me, my work, and my education, for their tolerance with my periods of irritability, and for letting me live in their house rent-free.

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I would like to acknowledge the help of my thesis committee chair and faculty mentor, Dr. Mohamed Abdel-Raheem, who knew what work I was capable of, even when I wasn’t. I would also like to acknowledge my thesis committee for lending their time and expertise to the review of my work.

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CHAPTER I

INTRODUCTION

General Overview

The United States is among the top countries in per-capita energy consumption, the BP Statistical Review estimated that the U.S. per-capita primary energy consumption was almost 80 mWh (BP, 2021). Of the estimated 92.94 quadrillion BTU's of energy consumed in the United States, approximately 20.45 quadrillion BTU's are consumed by the residential sector, or about 22% (U.S. Energy Information Administration, 2021). Potable water is one of, if not the most, precious resource on Earth- even though approximately 71% of the surface of the Earth being covered in water only 0.5% of that is readily available fresh water (U.S. Bureau of Reclamation - Central California Area Office, 2020). The USGS estimated that approximately 322 billion gallons of water are used per day in the United States, or approximately 1.18E+14 gallons per year (Dieter, et al., 2015). Of this volume of water consumed in the U.S., an estimated 8% is used in the domestic sector (U.S. Bureau of Reclamation - Central California Area Office, 2020). The EPA estimates that, on average, American families are consuming a volume of approximately 300 gallons of water per day- 70% of which occurs indoors (U.S. Environmental Protection Agency, 2020).

With droughts in the U.S. increasing in frequency and severity, and as concerns regarding the greenhouse gas emissions associated with energy use rise among the general population, the conservation of freshwater resources and the reduction of energy consumption in the U.S. has become a top priority.

While reducing their carbon footprint may be a draw to some, many homeowners are enticed by the promise of seeing long-term savings in their utility bills by making the switch to water- and energy-efficient appliances (Niemeyer, 2010). For those committed to taking larger steps towards reducing water and energy consumption and, potentially, see even greater savings in their bills, the United States Environmental Protection Agency (EPA) as well as the Department of Energy (DOE) offer programs such as WaterSense and Energy Star. And the United States Green Building Council (USGBC) offers the LEED program (Leadership in Energy and Environmental Design).

Headed by the EPA, WaterSense was founded in 2006 with the goal of informing Americans about their water usage (U.S. Environmental Protection Agency, 2020). Through outreach programs that increase awareness of water conservation, WaterSense has saved an estimated 5.3 trillion gallons of water from its inception through to 2020 (U.S. Environmental Protection Agency, 2020). WaterSense not only promotes awareness but also offers a voluntary program through which fixtures proven to be operating within a determined standard may receive the WaterSense label- certifying that these fixtures are indeed water efficient (U.S. Environmental Protection Agency, 2020). In addition to the fixture-labeling program, WaterSense now also certifies entire homes as water efficient. By following the required specifications, the EPA estimates that a WaterSense certified home may save up to 50,000 gallons of water annually (U.S. Environmental Protection Agency, 2020).

Energy Star, a program run by both the DOE and EPA, was founded in 1992 with an ethos not unlike the WaterSense program. Energy Star offers clearly explained information on energy efficiency that consumers can use to inform their decision-making processes (Energy Star, 2021). Much like the WaterSense program, Energy Star not only raises awareness about behavioral changes that can save energy but also labels products and appliances operating within specified criteria as energy efficient (Energy Star, 2021). Energy Star, as well, can now certify homes as energy efficient. Homes meeting the Energy Star certification criteria are estimated to be at least 10% more efficient than built-to-code homes (Energy Star, 2020). Energy Star estimates that in 2019 nearly 500 billion kWh of electricity was saved through their program and associated partners (Energy Star, 2021).

The USGBC program LEED is one of the most well-known organizations in certifying projects, including homes, as "green"- which includes both water and energy efficiency requirements, among many other ballots. LEED extends beyond just considering overall water- and energy-efficiency of the building system, it also considers the construction materials, as well as the quality of the indoor environment (USGBC, 2021). Each LEED ballot has prerequisites that are necessary to earn a "passing" score for said ballot, however projects may choose which ballots they want to earn points in for their certification (USGBC, 2021). In both water- and energy-efficiency ballots for LEED WaterSense and Energy Star labeled appliances, fixtures, and products are required items.

Each of these home certification programs require, at the least, the use of water- and energy-efficient appliances and fixtures in order to meet program specifications. The cost of investment in these items is not insignificant and can be a major hurdle to homeowners looking to either attain a "green" home certification or, at the very least, save money on utility bills. For many, the cost may be perceived as prohibitive and deemed "not worth" the future savings. In this instance, the life-cycle cost analysis (LCCA) method may be used to help evaluate the cost of purchasing, owning, and disposing of these appliances and fixtures (Kneifel & Webb, 2020). LCCA is an economic method of evaluating projects and project alternatives, this method uses economic principles to evaluate the costs associated with a particular project/alternative and provides an estimation of the ultimate cost of the project/alternative that is incurred over the lifespan of the project (Kneifel & Webb, 2020). LCCA not only provides an estimation of the full project cost, it also provides supplementary measures that can aid in the further evaluation of projects/alternatives. LCCA is a popular method of project evaluation which can be leant to its flexibility in application, LCCA may be applied to large-scale projects, such as the evaluation of entire buildings and building systems, or it may be applied on the micro level, such as product selection. In the case of this study, LCCA is useful due to the difference in investment costs and operating and replacement costs, however one case has reduced future costs (Kneifel & Webb, 2020).

This research aims to evaluate the financial feasibility of following the recommendations of these different green building certifications (LEED v4 for Homes, Energy Star, and WaterSense). To accomplish this task, a life-cycle cost analysis will be conducted to determine the feasibility of each of these systems. Using different types of analyses that utilize the costs of purchasing, installation, operation, replacement, and monthly utilities, both traditional (non-efficient) and efficient appliances are compared via an LCCA. The LCCA will be applied to the five most populous cities in the U.S. and a sensitivity analysis will be performed to draw final conclusions about the feasibility of each of these three guidelines by comparing the net-savings, savings-to-investment ratios, adjusted internal rates of return, and the payback periods.

Problem Statement

The review of the literature demonstrated that while there are a multitude of papers regarding energy-efficiency measures many are focused on commercial/industrial building systems. Studies that evaluated home systems or appliances often centered around singular system aspects, and in the case of studies on appliances, were often concerned with refrigerator and freezer systems. In addition to this, many studies that performed some form of the life-cycle costing method of analysis did so in a markedly different way than is being posited by this research. Most studies on energy efficiency determined that energy efficiency measures yielded positive net benefits, both fiscally and environmentally.

While there were numerous studies regarding energy efficient building systems, there were notably fewer studies of water efficiency and water efficient appliances/fixtures used in homes. The scope of these papers ranged from commercial/industrial water systems for whole buildings, to water recycling systems, to the evaluation of the performance of "green" certified buildings. In further restricting the search criteria and focusing on studies of water efficiency that also utilized some form of life-cycle costing, there were even fewer studies. Once again, studies that did both examine water efficiency through the life-cycle cost analysis lens did so in a different manner than is being proposed by this research.

As the review of the literature demonstrates, there is a noted lack of studies evaluating both water- and energy-efficient home appliances and fixtures through the lens of a comprehensive life-cycle cost analysis. This study differs from others like it for the following reasons: (1) this study evaluates multiple appliances and fixtures simultaneously rather than a single appliance/appliance type, fixture/fixture type, (2) this study not only calculates life-cycle costs but four additional supplementary measures to verify and add nuance to the final life-cycle cost finding, and (3) this study provides an evaluation of the financial feasibility of following the requirements of “green” home certifications.

Objective

The ultimate goal of this research is to develop a model that is capable of assessing the financial feasibility of water- and energy-efficient fixture and appliances. There are several steps intermediate to this final goal that are necessary for the construction of a model of this scale. The following points are a summarization of these intermediate steps.

1) **Identify Input Parameters & Determining Appliance & Fixture Life Expectancies:** A comprehensive LCCA requires several key points of data that can be broken down into a few major categories such as cost data, time data, and rates. These data points are necessary for an accurate calculation of life-cycle costs and all supplementary measures. Another crucial part in developing the cashflow necessary for this study is knowing the life expectancy of all appliances, devices, and fixtures used. This data allows for the accurate organization of replacement costs along the timeline of the study. However, most of this information is not readily accessible from reliable sources (e.g., manufacturer website, owner’s manuals, etc.). Thus, these values must be determined to perform a comprehensive analysis.

2) **Identify Supplementary Measures:** A comprehensive LCCA requires more than the calculation of LCCs. There are four other measures that are calculated using the same input parameters that allows for a more precise and nuanced interpretation of the feasibility of

water- and energy-efficient appliances and fixtures. Measures such as Net Savings, Savings-to-Investment Ratio, Adjusted Internal Rate of Return, and Payback Period can provide greater insight into the overall feasibility and economy of these investments.

3) **Construction of the Model:** Conducting a comprehensive LCCA for multiple appliances and fixtures over their useful lifetimes as well as over the full study period is a complex undertaking and requires a model to accurately calculate values and organize data. The model will account for numerous points of data to aid in the calculation of the payback period, net savings, savings-to-investment ratio, etc. that will be necessary in evaluating the cost effectiveness of traditional versus efficient appliances and fixtures.

4) **Quantifying Savings** is a large portion of the work involved in this research that must be accounted for. The study must account for savings accrued over the lifetime of the appliances and fixtures as well as the duration of the study period. The first step in this is establishing a base case to understand the water and energy consumption rates of traditional appliances. Once the base case has been established, the efficient alternatives may be measured against it to begin to determine the value of savings, if any, attributed to the reduction in water and energy consumption.

Methodology

Chapter 3 – Methodology of this thesis presents a more in-depth and detailed description of the methodology used to meet the objectives outlined in this manuscript. What follows is a summarization of the methodology used to create the model necessary for conducting a LCCA is as follows:

1) **Literature Review:** Knowing what existing works are relevant to this study are important in understanding how to conduct and direct this research. The literature review for this study involved the topics of LCCA’s of green building techniques, official resources regarding the green building certification processes, studies of water- and energy-efficient measures, appliances, fixtures, and technology, and the application of LCCA in product selection.

2) **Establish a Base Case:** By establishing a base case, this will create a benchmark against which the energy and water efficient alternatives will be measured. This requires knowing the energy and water consumption of each appliance and fixture, the amount of time these items will be used per day to establish the amount of energy and water consumed per month, per appliance/fixture. In addition to knowing the consumption habits of the considered appliances and fixtures, the estimated life expectancy of these items will be necessary for establishing the cash flow.

3) **Create Cash Flow:** Using the life expectancy of the considered appliances and fixtures, the replacement costs will be distributed along the study period. This will establish the costs associated with each appliance and fixture involved in the study, e.g., appliances with longer life expectancies will have less frequent replacement costs and vice versa.

4) **Modeling:** The model will be built using information from both the base case as well as the cash flow. In addition to this information, water, sewer, and electrical rates will be added to determine the costs incurred by the consumption rates of each appliance and fixture. The model will use this data to perform present worth analyses on the cashflows of traditional efficient appliances and fixtures to determine which appliances and fixtures are cost effective in which city. In turn, this will aid in concluding which programs are most cost effective.

Thesis Organization

This thesis is organized into six major chapters. Each chapter is subdivided into appropriate content areas to keep similar concepts and items together to preserve the flow of ideas as well as lend to the navigability of the finished manuscript. The following list presents the chapters as they appear, as well as provides a brief description of what may be found within each chapter.

1) **Chapter 1 – Introduction:** This chapter provides a general overview of the background of this study, the problem statement, an outline of objectives necessary to complete the work proposed, a brief outlining of the methodology used to meet the objectives presented, and the thesis organization.

2) **Chapter 2 – Literature Review:** This chapter presents a review of the relevant literature tangential to the concepts utilized in this research. The reviewed literature includes topics on the evaluation of “green” certified buildings, studies of both water and energy efficiency, life-cycle cost analysis standards and techniques, as well as instances of life-cycle cost analysis applied to product selection.

3) **Chapter 3 – Methodology:** This chapter provides a detailed explanation of the methodology employed in this research. Subsections of this chapter include a statement of study rationale and scope of work, study limitations, impact on green building, model description, and a detailed explanation of the model framework.

4) **Chapter 4 – Water Fixture Analysis:** In this chapter the water fixtures are analyzed, the results for life-cycle cost and all supplementary values are presented.

5) **Chapter 5 – Electrical Appliance Analysis:** In this chapter the electrical appliances are analyzed, and the results of the life-cycle cost and all supplementary values are presented. The sensitivity analysis is performed, and the results are presented.

6) **Chapter 6 – Conclusion:** This chapter includes final conclusions about the feasibility of these appliances and fixtures.

CHAPTER II

LITERATURE REVIEW

Life-cycle Cost Analysis Standards & Techniques

The life cycle cost analysis (LCCA) method utilizes economic principals to evaluate and make estimations of costs and potential values of projects and project alternatives (Kneifel & Webb, 2020). LCCA can draw conclusions about the economic feasibility of a project and its proposed alternatives using the costs incurred from the ownership, maintenance, and operation of a building across its lifetime- from construction to demolition (Kneifel & Webb, 2020). The popularity of this method of analysis can be attributed to its flexibility. LCCA can be applied to a myriad of applications on both macro and micro scales. It is especially useful in instances where a proposed project's alternative has significantly higher initial investment costs, but lower future recurring costs (Kneifel & Webb, 2020). Due to LCCA's particular usefulness in these scenarios it has become increasingly popular in the evaluation of "green" building systems, as well as the study of water- and energy-efficiency measures. In fact, LCCA has been adopted by many federal offices such as the Environmental Protection Agency, The Department of Energy, and the Federal Highway Administration- among others.

Simply, LCCA is the summation of all costs associated with the construction, ownership and operation, and ultimate disposal of a project and project alternatives (Kneifel & Webb, 2020). LCCA uses numerous points of cost data to make estimations of the cumulative cost of projects and draw conclusions about the financial feasibility of proceeding with a project or project alternative. The supplementary measures calculated alongside the LCC are the Net Savings (NS), Savings-to-Investment Ratio (SIR), Benefit Cost Ratio (BCR), Adjusted Internal Rate of Return (AIRR), Discounted Payback (DPB), each of these measures is discussed in-depth in Chapter 3 of this paper.

In the context of building evaluation, most costs can be sorted into one of the following broad categories: (1) Initial Investments, (2) Operation, Maintenance, and Repair, (3) Energy/Water/Fuel, (4) Replacement, and (5) Residual Values (Fuller, S., 2016). Depending on the specific context and scope of the study there may be additional categories such as loan payments and potential non-monetary costs and/or benefits (Fuller, S., 2016). The ultimate outcomes of the LCCA are, of course, the life-cycle cost (LCC) and the supplementary measures. Not only are supplementary measures used to validate the findings of the calculated LCC, but they also help in adding nuance and detail to the LCC, and they may additionally be requirements that must be met according to regulations (Fuller, S., 2016).

The University of Stanford utilizes the LCCA method so often for its evaluation of on-campus building projects that they have a proprietary guideline publication for its use. This publication contains guidance for performing LCCA on the following building systems: (1) Energy, (2) Mechanical, (3) Electrical, (4) Building Envelope, (5) Siting and Massing, and (6) Structural (Reidy, et al., 2005). The Stanford LCCA Process is much like the process detailed in any other government publication regarding the LCCA method (Reidy, et al., 2005). The “Stanford Procedure” includes the broad steps of establishing analysis objectives, outlining evaluation criteria, the identification of project alternatives, obtaining cost data, and completing the LCCA (Reidy, et al., 2005).

LEED, Energy Star & WaterSense Requirements

There are three green home certification programs that are among the most popular, and generally known in the United States, USGBC'S LEED, Energy Star and WaterSense. While there are other green home certification programs in the U.S., this study is using the standards required to obtain a home certification from these programs, as they are the most prominent and well known.

First, the requirements for the Energy Star home certification will be examined. Energy Star offers a modular approach to attaining minimum acceptable performance. There is not any one required measure needed for attaining certification, rather overall home performance must be met (Energy Star, 2020). Areas that Energy Star considers potential areas of performance measure are heating and cooling equipment, building envelope- including doors and windows, water heater, home ductwork and thermostat, and finally lighting and appliances (Energy Star, 2020). Heating and cooling equipment must meet a minimum SEER/EER rating, depending on the climate classification that the home is to be built in. Building envelope must meet specific insulation levels, windows and doors must be Energy Star labeled. Water heaters must also meet a minimum efficiency level depending on energy source and size of the heater. Thermostats must be programmable, and ductwork and air handlers must be within the conditioned space (Energy Star, 2020). Finally, lighting must be Energy Star rated and appliances that must be Energy Star rated are refrigerators, dishwashers, and ceiling fans (Energy Star, 2020).

WaterSense offers a similar method of home certification, however, WaterSense does have a list of requirements to attain home certification. Required items for certification include no detectable leaks, and WaterSense labeled high-use fixtures (WaterSense, 2020). A variety of checks and tests will be performed in order to determine that there are no detectable leaks existing within the water delivery system of the home. There must be no visible leaks from any flush or flow fixtures in the home (WaterSense, 2020). Toilets, bathroom sink faucets and showerheads must all be WaterSense labeled as well (WaterSense, 2020). Homes only meeting these requirements are considered “least efficient”. For a whole-home certification water use must be determined for both indoor and outdoor environments, and must be found to be operating within required performance depending on home classification, and size (WaterSense, 2020).

The LEED certification model is much like a combination of both the certifications for Energy Star and WaterSense. A LEED certification is broken up into “ballots” each focused on a particular building system, a certification is earned by scoring points in each ballot until a minimum threshold of points is met necessary to obtain a LEED rating (McCombs, 2015). Each ballot has its own maximum number of points that may be scored in its respective area. There are four different LEED certification levels, each with a higher number of points necessary to obtain said level. For instance, the two ballots examined here will be the “Water Efficiency” ballot and the “Energy & Atmosphere” ballot. The inclusion of WaterSense labeled appliances is part of the pre-requisites that must be met in order to begin scoring points in the Water Efficiency ballot (McCombs, 2015), much like the WaterSense home certification. Additionally, the inclusion of Energy Star appliances is highly suggested by LEED in meeting requirements for the “Energy & Atmosphere” ballot.

Evaluation of “Green” & Sustainable Buildings

The USGBC’s LEED program has become one of the most popular and most recognizable “green” certification programs in the United States, with many similar programs around the world who are working to promote the social and environmental benefits of green building. With the popularity of “going green” is increasing so has scrutiny regarding the effectiveness of these programs. The continued evaluation of green buildings (LEED-certified or otherwise) has yielded mixed results.

For instance, in this study of the post-occupancy evaluation of key systems of LEED certified homes found that all considered homes performed higher than the national average when these systems were tested to ensure that they were still operating at certification standards (Beauregard, Berkland, & Hoque, 2011). The homeowners of these green homes reported that they did not require any additional maintenance than the average home (Beauregard, Berkland, & Hoque, 2011).

However, on the other hand, there are studies showing that LEED certified buildings do not necessarily operate at a higher level that is statistically significant. This paper was a response to a study commissioned by the USGBC. In this study, the New Building Institute (NBI) found that, on average, LEED buildings are delivering the anticipated savings. However, author Scofield points out that there were found to be two major sources of error in the original NBI study: (1) the authors compare *median* Site Energy Intensity (SiteEI) with *mean* SiteEI for all commercial buildings, (2) the authors also made comparisons between the unweighted average for LEED buildings and compared them to the gsf-weighted averages of all other commercial buildings (Scofield, 2008). Another issue Scofield takes with the NBI study is the use of SiteEI as a measure of efficiency, the report from the NBI uses the difference in SiteEI between LEED and non-LEED certified buildings as proof of beneficial energy performance, however it is SourceEI and not SiteEI that is associated with greenhouse gas emissions (Scofield, 2008). Scofield also states that, statistically, there is no appreciable difference between LEED and non-LEED buildings in measurements of either SourceEI or SiteEI (Scofield, 2008). Since GHG emissions are linked to primary energy consumption (SourceEI), the LEED certification is not useful in reducing the GHG associated with building operations (Scofield, 2008).

Furthermore, in another study, 354 LEED-certified buildings were examined to determine the “water gap” between LEED and non-LEED buildings (Luo, Scofield, & Qiu, 2021). The buildings examined consisted mainly of commercial buildings, but also included a few multi-family homes. The so-called “water gap” is the gap that exists between expected conservation and actual conservation. Through multiple statistical analyses including a weighed regression and 10-fold cross-validation, this study concluded that between LEED and non-LEED buildings there is no statistical significance to the water savings provided by LEED buildings, asserting that “LEED-certified buildings use no less water than non-LEED buildings” (Luo, Scofield, & Qiu, 2021).

Another concern with LEED and green certified buildings and homes is the cost associated not only with building to specification to meet emission and conservation standards, but also with the cost of certification itself. One Kentucky study evaluated the cost-effectiveness of LEED certified homes and demonstrated that there was a negligible cost difference between LEED certified and non-LEED certified homes (Glossner, Adhikari, & Chapman, 2015). This study found that homes having a smaller square footage had the shortest payback periods, additionally the utility costs were significant in determining the cost effectiveness of LEED certified homes (Glossner, Adhikari, & Chapman, 2015). The economic analysis found that the greatest net loss was about $1,200 and the greatest net gain was $1,700, concluding that the added cost of construction for obtaining a LEED certification is essentially negligible (Glossner, Adhikari, & Chapman, 2015).

In a similar study, researchers investigated the premiums associated with homes that had obtained any form of certification of energy-efficiency (Walls, Gerarden, Palmer, & Fang Bak, 2017). This study found that there were price premiums associated with energy efficient certified homes, however this study also found that local energy-efficiency certifications implied greater energy savings than with the national program put forth but Energy Star (Walls, Gerarden, Palmer, & Fang Bak, 2017).

On the international scale, several analyses have been conducted in order to determine the effectiveness of green buildings in various countries around the world. For instance, a case study performed on an existing green building in Andhra Pradesh, India, established a “life cycle budget” for an 80-year horizon (Gopanagoni & Lakshmi Velpula, 2020). This study found that for this particular building 67% of the “life cycle budget” was attributable to the cost of energy for the building (Gopanagoni & Lakshmi Velpula, 2020). This study ultimately concludes that by installing monocrystalline solar panels the total life cycle cost of the building can be reduced by 5% (Gopanagoni & Lakshmi Velpula, 2020).

In this Chinese study, a cost-benefit valuation on an existing green building in China was performed. One of the many important findings reported by this case study was the change in internal rate of return (IRR) when considering only economic benefits as one scenario and considering economic and environmental benefits as another scenario. IRR increased from 0.83% to 7.89% for a 0% annual rate increase of power price (Liu, Guo, & Hu, 2014). One of this study’s conclusions is if only economic benefits are considered, green buildings do not return yields high enough to offset their costs- however, if both economic and environmental benefits were considered the investment becomes feasible (Liu, Guo, & Hu, 2014).

Studies of LCCA & Energy Efficiency

The work proposed by this study is not concerned with the efficiency of building energy systems as a whole, rather with the effect that energy-efficient appliances have on the volume of energy consumed in the home, and how this affects the life-cycle costs. In a 2010 study, 20% of respondents to a survey reported that their utility costs were “somewhat of a problem”, with just as many indicating wanting to make changes to their home’s energy efficiency (Niemeyer, 2010). Over half of respondents indicated that they would need financial assistance or cost discounts to make improvements to their home’s energy efficiency (Niemeyer, 2010). An international study for the European Council for an Energy Efficient Economy conducted in 2007 examined the costs of energy efficient home appliances to determine whether these appliances cost significantly more to the consumer. By comparing historical costs of appliances to their forecasted costs, this study found that not only were the forecasted costs higher than the true costs of these appliances, it was also observed that costs of energy efficient appliances have been decreasing over time (Ellis, Jollands, Harrington, & Meier, 2007). However, it was noted that the most expensive appliances were often the most efficient (Ellis, Jollands, Harrington, & Meier, 2007). This study also reports that for the last ten years (as reported in 2007), in the US, Japan, Australia, and European countries appliances have increased in efficiency and decreased in cost (Ellis, Jollands, Harrington, & Meier, 2007).

However, cost is not the only limiting factor to many who are interested in adopting energy efficient practices, such as maintaining a comfortable indoor environment. In a study conducted for the Institute of Electrical and Electronic Engineers (IEEE), researchers examined ways to optimize energy use in “smart homes” in a way that can prioritize both reducing energy use as well as comfortable living (Anvari-Moghaddam, Monsef, & Rahimi-Kian, 2015). The algorithm posited by this paper has demonstrated an ability to reduce residential energy use, optimize task scheduling, as well as maintain a comfortable interior temperature for residents (Anvari-Moghaddam, Monsef, & Rahimi-Kian, 2015).

Additionally, the overall efficiency of energy-efficient appliances must further be examined in order to effectively examine the potential benefits of adopting them as energy-efficiency measures to be used in the home. A 2020 Swiss (Heidari & Patel) study examined the cost-effectiveness of energy-efficient electronic appliances used in the home using stock modeling. This study found that most electronic appliances have seen significant improvement in efficiency, however the increasing size of the appliances themselves, along with the addition of features (such as wi-fi connectivity) are impeding on the rate at which energy is saved (Heidari & Patel, 2020). The study goes on to report that, despite projected improvements in energy-efficiency technology, energy consumption is not likely to see dramatic reductions due to “counteracting trends” such as larger screens for televisions (Heidari & Patel, 2020). The study concludes that “practically none” of the categories for household appliances can be replaced in a cost-effective manner solely for energy efficiency reasons. Not only is this due to the higher costs of energy-efficient home appliances, but also due to the fact that the reduction in energy consumption is dampened by “counteracting trends”, discussed earlier (Heidari & Patel, 2020). Based on the conclusions reached by this study, the authors recommend that “consumer-oriented” policies are not the best method of reducing energy consumption demand (Heidari & Patel, 2020). In a similar vein, a 2015 study explored the concept of the many “rebound effects” of energy-efficient home appliances through an economic lens. In the ongoing study of energy-efficiency there is a phenomenon known as the “rebound effect”, wherein as the energy-efficiency of a particular product increases, the expected energy consumption of this product does not decrease as anticipated because it is being offset by increased use of this product (Abdessalem & Labidi, 2015). This paper examined direct and indirect rebound effects and found that for both effects, the magnitude of rebounds was high (Abdessalem & Labidi, 2015).

A 2016 Indian study (Parikh & Parikh) investigated the growing rate of adoption of energy efficient appliances. One of the several questions posed by this paper was “What are the savings of electricity and emissions?”. The study created four different scenarios based on the appliance’s efficiency rating. The lowest rated appliances had an average of 13% energy savings, with the highest rated appliances averaging 40% energy savings (Parikh & Parikh, 2016).

A 2011 Brazilian study evaluated both the energy and cost savings of refrigeration systems used in homes. By mathematically modeling the individual components of the refrigerating system, the energy performance of the entire system could then be simulated (Negrao & Hermes, 2011). Using the simulation of the refrigeration system, an algorithm to optimize key energy loss areas in the system was built. Ultimately the study found that refrigeration systems became “less costly” when high efficiency compressors were used in systems with low energy consumption (Negrao & Hermes, 2011).

A Canadian study (Young, 2008) examined the replacement rate of household appliances, an important aspect of estimating energy savings accrued by efficient appliances. This study found that the appliances that were replaced most often were dishwashers, and the ones replaced the least often were freezers (Young, 2008). This study concludes that if the reduction in residential energy consumption can outweigh the costs of material and energy of producing and transporting these appliances, as well as the costs of running energy-efficiency promotion programs, it is likely that there is a net benefit to be seen (Young, 2008).

The work proposed in this study is concerned with single-family homes as renters living in multi-family buildings often do not have much control of the appliances and fixtures in their homes (Davis, 2012). In a book section, author Davis examined the disparity of ownership of energy-efficient home appliances between renters and homeowners. The study utilizes descriptive statistics and regression analysis to examine ownership of energy-efficient appliances and concludes that renters are much less likely to own energy-efficient refrigerators, lighting, dishwashers and clothes washers than homeowners (Davis, 2012).

Studies of LCCA & Water Efficiency

The work proposed by this thesis also includes the effect of water-efficient fixtures on the life-cycle costs of single-family homes. In this Australian study, the effects of water efficient fixtures and appliances in the residential sector were examined with a life-cycle cost analysis (Tam, Kim, & Brohier, 2019). This study found that for all cities examined, water efficient fixtures and appliances generated positive savings, if all appliances were used in combination (Tam, Kim, & Brohier, 2019).

In a similar study, the cost-effectiveness of water efficient fixtures and appliances in a variety of multioccupant buildings were analyzed using both life-cycle assessment and life-cycle cost analysis (Arpke & Hutzler, 2005). This study concluded that for both methods of analysis, water efficient appliances and fixtures were both financially feasible and environmentally justified (Arpke & Hutzler, 2005). This study also identified that the most sensitive cost components in this scenario is the operation, maintenance and repair costs, and costs of replacement (Arpke & Hutzler, 2005).

More numerous, however, were the studies of the life-cycle costs regarding water recycling systems for buildings. Such as this study that focused on the effects of water efficiency measures including rainwater harvesting systems, greywater recycling systems, and water efficient fixtures, this time as applied in commercial buildings (Sousa, Matos Silva, & Meireles, 2019). This study utilized a partial life-cycle cost analysis to determine the effectiveness of these different measures of water efficiency. This study concluded that, based on the calculated life-cycle costs, the most effective water efficiency measure was the grey-water recycling, and the least effective being water-efficient appliances (Sousa, Matos Silva, & Meireles, 2019).

A similar study performed an eco-efficiency analysis of greywater recycling systems, part of this analysis included the use of a life-cycle assessment as well as life-cycle costing. The method used for evaluating life-cycle costs in this study differs notably from the methods to be proposed by this paper. Life-cycle costs were estimated by summing the products of the cost of the component necessary for each scenario and the total quantity of that component in that scenario (Lam, Leng, Chen, Lee, & Hsu, 2017). Additionally, this study evaluates the efficiency of this study not by the costs relating to water consumption, rather by costs of energy associated with water treatment (Lam, Leng, Chen, Lee, & Hsu, 2017). This study ultimately found that an anaerobic greywater reuse system performed most favorably (Lam, Leng, Chen, Lee, & Hsu, 2017).

Another case study examined the effect of water efficiency measures in an apartment building in Lebanon. The measures to be examined included rainwater harvesting, condensate water harvesting, water efficient fixtures, and greywater recycling (Stephan & Stephan, 2017). This study found that the most cost-effective stand-alone measure for this given apartment building was the installation of water efficient fixtures to reduce water demand (Stephan & Stephan, 2017).

Water efficient fixtures were only outdone in cost-effectiveness when all water efficiency measures were combined together (Stephan & Stephan, 2017).

In a similar case study the feasibility of rainwater and greywater systems in a research campus in Japan were analyzed. This study focused exclusively on the utilization of hybrid systems that collect both rainwater and greywater (Chen, Gao, Jiang, Wei, & Wang, 2021). This study concludes that the application of these hybrid systems in non-residential buildings can effectively conserve water, as well as reduce energy consumption compared to traditional methods of water supply for buildings (Chen, Gao, Jiang, Wei, & Wang, 2021). However, this study notes that these hybrid systems may be unfeasible in areas with certain water tariffs due to their high maintenance costs (Chen, Gao, Jiang, Wei, & Wang, 2021).

LCCA as Applied to Product Selection

The flexibility of adapting life-cycle cost analysis to a variety of scenarios has led to instances of this methodology being adopted to evaluate the cost-effectiveness of building and construction materials, as well as being used in a wide array of disciplines. A study in China utilized life-cycle assessment to determine the cost-effectiveness of various pipe materials used in building water and drainage supply systems (Xiong, et al., 2020). This study revealed that replacing conventional metal plumbing pipe materials with PVC-U building energy consumption and environmental impact could be reduced by a significant margin, highlighting the importance of life-cycle assessment in the evaluation of building materials (Xiong, et al., 2020). Life-cycle cost analysis has found notable use in the roadway and transportation engineering discipline. One study states that by modeling the end of life phase of roadway materials, more accurate life-cycle costs are able to be estimated by using the life-cycle cost analysis method (Moins, France, Van den bergh, & Audenaert, 2020). Another review examined methods of using life-cycle cost analysis to model the benefits of using recycled solid waste in pavement design (Li, Xiao, Zhang, & Amirkhanian, 2019). This review identified the particular importance of the study period and discount rate in applications of this method of analysis, and indicated that the most practical expression of economic performance was through Net Present Value analyses (Li, Xiao, Zhang, & Amirkhanian, 2019). Another paper analyzed asphalt alternatives not only utilizing life-cycle costs but also life-cycle assessments (Heidari, Heravi, & Esmaeeli, 2020). This study found that while utilizing concrete pavement instead of asphalt pavements would raise costs, emissions and energy consumption would be drastically reduced, in a way- offsetting the increase of costs (Heidari, Heravi, & Esmaeeli, 2020).

Modifications to the life-cycle cost analysis may also include the evaluation of the environmental benefits of particular building materials in order to evaluate the overall environmental benefit of building materials. Studies evaluating building materials through this lens are more numerous than a traditional life-cycle cost analysis. One such study examined the choice of flooring materials through the lens of environmental impact and determined that solid wood floors outperformed vinyl and linoleum alternatives (Jonsson, Tillman, & Svensson, 1997). In a similar study, building materials in a home were analyzed with this life-cycle assessment lens and found concrete to be the most “energy expensive” material in home building materials (Asif, Muneer, & Kelley, 2007). Another study examined the benefits of building integrated photovoltaics systems, both economic and environmental (Gholami, Rostvik, & Muller-Eie, 2019). By adding social and environmental benefits to an otherwise typical life-cycle cost analysis, this study found that building integrated photovoltaic systems will become financially feasible as replacements for roofing materials and facades (Gholami, Rostvik, & Muller-Eie, 2019).

CHAPTER III

STUDY RATIONALE

Rationale & Scope of Work

This study focuses on single-family residences in the five most populous cities in the United States as of January 2020. Single-family residences were chosen because the residential sector makes up 21% of total energy consumption in the United States (U.S. Energy Information Administration, 2021). The five most populous cities in the U.S. were chosen due to the ease of access and availability of data for these cities. Additionally, the choice in appliances and fixtures used in the model for this study are chosen to be representative of a metropolitan lifestyle.

This study focuses on conducting a comprehensive LCCA of the energy- and water-efficient appliances and fixtures used in homes that are required for obtaining a LEED for Homes, Energy Star, and WaterSense certification. The LCCA will consist of various financial analyses and calculations. Using the outputs obtained from the LCCA will provide for the ability to draw final conclusions about the financial feasibility of obtaining a LEED, Energy Star, and/or, WaterSense home certification. The scope of this study only includes home electrical appliances and water fixtures and is not concerned with alternative energy such as wind or solar. Neither is this study focused on the LEED for Homes certification as a whole, rather with the Water Efficiency & Energy and Atmosphere ballots.

Limitations

While thorough, this study has its limitations. The following is a list of the limitations of this research.

1) **Single Family Homes:** As stated in the "Rationale & Scope of Work" subsection, this study is concerned only with single-family residences, this study does not consider multi-family residences such as apartment complexes and the like. It is assumed that the single-family homes are owned and not rented, as renters rarely have the autonomy to decide which appliances and fixtures are used in the residence (Davis, 2012).
2) **Appliances & Fixtures:** As discussed in the "Rationale & Scope of Work" subsection, this study considers only water- and energy-efficient appliances and fixtures. This study is not concerned with the efficiency of the overall electric or water system of the home, only with the effect of water- and energy-efficient appliances.
3) **Environmental Benefit:** This analysis does not account for any environmental benefit resulting from the decreased energy consumption of efficient appliances. This study only considers the costs directly associated with the reduction in energy consumption.
4) **Rebound Effects & Counteracting Trends:** This analysis does not account for the effect of rebound effects (Abdessalem & Labidi, 2015) and counteracting trends (Heidari & Patel, 2020) resulting from either the increased usage of appliances due to their higher efficiency, or developments in appliance standards that act counteractively to the increased efficiency of said appliances, such as increases in refrigerator size, or added features like wi-fi connectivity.

Impact on Green Building

As interest in green building is growing, homeowners are still unsure of the benefits that green building can have for them. The initial cost of water- and energy-efficient appliances is a large obstacle for many homeowners to surmount (Niemeyer, 2010), despite the promise of savings on utility bills. As this study is focused on the LCCA of water- and energy-efficient appliances and fixtures in single-family residences, this completed work should prove useful to prospective homeowners, contractors, land developers and the like. The outcomes of this study will demonstrate the relative fiscal benefits associated with efficient appliances versus their traditional counterparts. This study hopes to lead more homeowners, investors, and landlords in the direction of adopting water- and energy-efficient fixtures which will not only save money on utilities, but also aid in lessening the impact on the environment by conserving water and lowering greenhouse gas emissions associated with energy consumption.

Model Description

The model used in this study was built using Microsoft Excel, and accounts for multiple points of data to conduct financial analyses using the available information. The Excel model utilizes various economic equations in a dynamic spreadsheet to produce output values of present worth life-cycle costs, net savings, benefit-cost ratios, savings-to-investment ratios, adjusted internal rate of return (AIRR), payback period, and break-even analyses. The outputs from these calculations will aid in the evaluation of the financial feasibility of various green home certification programs.

The data necessary for conducting a comprehensive LCCA can be divided into four general categories: (1) Time Data, (2) Cost Data, (3) Rates, and (4) Assumed Values (Fuller S. , 2016).

Each of these categories contains multiple points of data that each play an important role in the calculation of life-cycle costs as well as all supplementary values.

Time data includes the base date, study period, and service period. The study period is the length of time where all costs and savings related to a project and/or its alternatives is of concern to an investor or otherwise interested party (Kneifel & Webb, 2020). The base date is the start of the study period- the date at which costs and savings of a project and/or its alternatives begin (Kneifel & Webb, 2020). The service period is the time at which the building/project becomes occupied (Kneifel & Webb, 2020).

Cost data refers to items such as the investment costs, replacement costs, recurring costs, and residual values. Investment costs may also be known as initial costs or initial investment costs. Much as the name implies, initial investment costs are costs associated with bringing the project to fruition (Kneifel & Webb, 2020). In the case of this study, initial investments are the costs of purchase and installation of all appliances and fixtures considered in the study. Replacement costs are the cost of replacing appliances and fixtures after they have reached the end of their useful life. Replacement costs are dependent upon both the expected lifetime of the product as well as the length of the study period (Kneifel & Webb, 2020). Recurring costs, also known as operational costs, are expected cost items, often occurring at regular intervals such as monthly, yearly, etc (Kneifel & Webb, 2020). Recurring operational costs are items such as cost of water and energy consumption, as well as any regularly required maintenance and/or repair to keep any machinery operating and required efficiency. Lastly, residual values are the values retained by the project at the end of the study period (Kneifel & Webb, 2020).

The rates used in this study refer to two very critical rates that allow for accurate treatments of the cost data. The first is the nominal discount rate, this allows for the treatment of discounting costs to present-value (Kneifel & Webb, 2020). The second rate is the escalation rate of each the relevant utilities. As LCCA is a method of analysis that requires a lengthy study period, it is imperative that the increase or decrease in utility costs over time is properly accounted for so that the estimations made by the LCCA can be as accurate as possible (Kneifel & Webb, 2020).

Lastly, there are some values that must be assumed or based on an estimated measurement. In the case of this study, the values that are based on estimations are the energy and water consumption of traditional and efficient appliances. The values for energy and water consumption of traditional and efficient appliances are necessary for calculating the monthly cost of energy and water consumption. Each city is expected to have a different value of total kilowatt hours of energy consumed per month due to differences in climate, as well as other restrictions. For instance, most residences in New York City do not have central heating and air conditioning and are reliant on window units for air conditioning.

In order to determine which appliances and fixtures that should be considered in this study a list of standard large home appliances, fixtures, as well as small home appliances and electronics was established. Working from this list each appliance, fixture, and electronic was investigated to determine whether an energy or water efficient alternative was available to the average residential consumer. If an appliance/fixture/electronic was not found to have an energy or water efficient alternative, that item was then excluded from the study. Using the revised list of appliances/fixtures/electronics a representative sample was collected of each to determine average cost of purchase and average estimated energy/water consumption. Tables featuring a comprehensive description of all appliances and fixtures used in this study will follow this sub-section and include the average cost of each appliance and fixture. Cashflow diagrams representing the investment, replacement, and residual value timelines will be within each respective chapter regarding that analysis. The cashflow diagram for the water fixtures and electrical appliances will be in Chapter 4 – “Water Fixture Analysis” and Chapter 5 – “Electric Appliance Analysis” respectively.

Table 1. Comprehensive List of Electrical Appliances Including Cost and Specifications

Appliance Type	Efficient		Traditional	
	Details	Cost	Details	Cost
Central AC	3 – 4 tons	$ 5,405.00	3 – 4 tons	$ 2,842.45
Clothes Dryer	7.3 – 7.5 cu. ft	$ 1,082.33	7.3 – 7.5 cu. ft	$ 810.55
Dishwasher	24 in	$ 739.00	24 in	$ 366.67
Exhaust Fan	ceiling; no light; 50 – 80 cfm	$ 53.53	ceiling; no light; 50 – 80 cfm	$ 22.33
Exhaust Hood	30 in	$ 306.26	-	-
Microwave	30 in; 1.6 – 1.9 cu. ft	$ 169.64	30 in; 1.6 – 1.9 cu. ft with exhaust hood	$ 311.38
Refrigerator	11 – 16 cu. ft	$ 702.47	11 – 16 cu. ft	$ 613.48
Stove/Oven	30 in	$ 903.70	30 in	$ 509.91
Washing Machine	4.5 – 5.5 cu. ft	$ 1,053.93	4.5 – 5.5 cu. ft	$ 696.35
Water Heater	36 – 49 gal	$ 1,215.53	36 – 49 gal	$ 421.88
Window Unit AC	8000 BTU	$ 287.00	8000 BTU	$ 380.17
Ceiling Fan	no light, three blade	$ 505.67	no light, three blade	$ 406.11
Desktop Computer	i7 Intel processor, 16 GB ram	$ 2,139.50	i7 Intel processor, 16 GB ram	$ 1,537.00
Incandescent Bulb	-	-	A 15/19/21	$ 35.01
Laptop Computer	i7 Intel processor, 16 GB ram	$ 1,904.00	i7 Intel processor, 16 GB ram	$ 1,674.99
LED Bulb	60 watt equivalent	$ 47.13	-	-
Television	43” – 55”	$ 1,948.49	43” – 55”	$ 921.98
TV Media	streaming device only e.g., Roku, AppleTV	$ 286.65	Blu-ray player	$ 153.98

Table 2. Comprehensive List of Water Using Fixtures Including Cost and Specifications

Fixture	Description	Efficient Cost	Traditional Cost
Toilet	two piece, chair height, elongated bowl, single flush	$ 277.72	$ 250.92
Showerhead	fixed wall mount, chrome finish	$ 36.73	$ 48.15
Bath Faucets	center mount, chrome finish	$ 66.24	$ 44.67
Kitchen Faucet	center mount, fixed faucet, chrome finish	$ 100.81	$ 87.67

Model Framework

The model evaluates water- and energy-efficient appliances and fixtures separately. All data used in this study is summarized in the Excel model for ease of reference. Evaluating the water- and energy-efficient appliances and fixtures separately not only allows for more accurate calculations but also allows for the ability to identify which appliances and fixtures hold the highest potential for energy and water use reduction. Making the Excel model as dynamic as possible aids in making the calculation process easier to perform sensitivity analyses, as well as update, and implement corrections as necessary.

The following subsections discusses each of the study parameters, and output values. The method of calculation will be detailed as well as the importance of the value in the LCCA method and decision criteria as appropriate.

Cost of Energy

The monthly cost of energy utilities is one of the core cost components needed to determine the cost effectiveness of energy efficient appliances. The rate charged for energy consumption was obtained from the United States Bureau of Labor Statistics. The average energy consumption per state was obtained from reports published by the Energy Information Administration. The amount of energy consumed by traditional appliances is assumed to be equal to the average value of energy consumed per state. To determine the reduction in energy consumption due to efficient appliances a weighted average was calculated. First, the percent difference of energy consumption between traditional and efficient appliances was determined. Then the estimated total time that appliance spends running per day was determined, this value is expressed as a percent. Using each of the previous percentages a weighted average of appliance efficiency can be derived, and an overall efficiency value can be obtained. The cost of energy consumption for each city was determined using Equation 1.

$$E = T_E * R_E \qquad (1)$$

Where 'T_E' is the total amount of energy consumed each month (kWh), 'R_E' is the cost of energy consumption (USD/kWh) and 'E' is the monthly cost for energy consumption (USD).

Cost of Water & Sewerage

The monthly cost of water and sewage utilities are necessary costs needed for determining the cost effectiveness of water efficient appliances and fixtures. The rate charged for water and sewage use was collected from the respective municipalities webpage that contained information on water and sewage billing. The value for water consumption was determined using the home water use calculator provided by the Alliance for Water Efficiency (home-water-works.org). The user answers a questionnaire about home water use and receives an estimation of water consumption. This calculator provided the values for both the traditional and efficient water fixtures and appliances. The amount of water consumed in the home for both traditional and efficient appliances is assumed to be the same for each city in this study. The values for sewage use are assumed to be equal to total water consumed. The cost of water and sewage consumption for each city was determined using Equation 2.

$$W = T_W * R_W \qquad (2)$$

Where 'T_W' is the total amount of water consumed per month (gal), 'R_W' is the rate charged for water consumption (USD/gal), and 'W' is the monthly cost of water consumption (USD).

Present Value of Energy Costs

When discounting the monthly cost of energy consumption to present-value two factors must be taken into consideration: the time-value of money and the increase in the cost of energy utilities over time. To properly account for these factors a geometric gradient series will be utilized for discounting the monthly cost of energy to present-value. This method requires both nominal discount rates as well as a gradient rate. The nominal discount rate for this study has been obtained from Federal Energy Management Program (FEMP) publications. The gradient rate is the rate at which energy costs increase each year. This value may also be obtained from FEMP publications. The method of discounting energy costs to present-value is shown in Equation 3.

$$E_{P.V.} = \frac{E[1-(1+g/1+i)^{n}]}{i-g} \qquad (3)$$

Where 'E' is the monthly cost of energy found using Equation 1, 'g' is the gradient, 'i' is the nominal discount rate, 'n' is the study period, and '$E_{P.V.}$' is the present-value of the monthly cost of energy.

Present Value of Water & Sewerage Costs

When discounting the monthly costs of water and sewerage use to present-value two factors must be taken into consideration: the time-value of money and the increase in the costs of water and sewage utilities over time. In order to account for these factors properly a geometric gradient series will be utilized. This method requires both the nominal discount rate as well as a gradient rate. The nominal discount rate as well as the gradient rate has been obtained from FEMP publications. The method for discounting water and sewage costs to present-value is shown in Equation 4.

$$W_{P.V.} = \frac{W[1-(1+g/1+i)^{n}]}{i-g} \qquad (4)$$

Where ‘W’ is the monthly cost of water or sewage use found using Equation 2, ‘g’ is the gradient rate, ‘i’ is the nominal discount rate, ‘n’ is the study period and ‘$W_{P.V.}$’ is the present-value of the monthly cost of water or sewerage.

Present Value of Cost Parameters

Not only must the costs of energy, water and sewerage use be discounted to present-value, so must the other cost parameters, such as the replacement costs and residual values. Since these costs are not recurring on a regular schedule like the cost of utilities, they may be discounted to present value using the present worth method. The method for discounting all other cost parameters to present-value is shown in Equation 5.

$$P.V. = F(1+i)^{-n} \qquad (5)$$

Where ‘F’ is the future cost, ‘i’ is the nominal discount rate, ‘n’ is the study period, and ‘F.V.’ is the present-value of the given cost parameter.

Life-cycle Costs

As the name would suggest, life-cycle costs are the main output of the LCCA method. The life-cycle cost (LCC) is a measurement of all the costs associated with a project or project alternative(s) throughout the entire lifespan of said project/alternative. This is measured with a summation of all the present-value costs that are expected to occur throughout the study period.

Each output of the LCCA method has its own selection criteria. These selection criteria aid in the ability to make decisions about the cost-effectiveness of a project/alternative. For making decisions about the cost-effectiveness of a project/alternative using the LCC, the project/alternative with the lowest LCC is considered the most cost-effective option. The methods for calculating the life-cycle costs are shown in Equations 6 & 7.

$$LCC = P_0 + E_{P.V.} + Repl_{P.V.} - Res_{P.V.} \qquad (6)$$

$$LCC = P_0 + W_{P.V.} + S_{P.V.} + Repl_{P.V.} - Res_{P.V.} \qquad (7)$$

Where 'P_0' is the initial investment cost, '$E_{P.V.}$' is the present-value of all energy utility costs, '$W_{P.V.}$' is the present-value of all water utility costs, '$S_{P.V.}$' is the present-value of all sewerage utility costs, '$Repl_{P.V.}$' is the present-value of all replacement costs, '$Res_{P.V.}$' is the present-value of residual values, and 'LCC' is the life-cycle cost.

Net Savings

The first supplementary measure in the LCCA method is the Net Savings measure. Net Savings (NS) is a measure of the economic performance of a project/alternative (Kneifel & Webb, 2020). The purpose of the NS method is to determine the savings that are a result of a particular project/alternative. This method measures the difference between the relative benefits and costs of a project/alternative.

The selection criteria for the Net Savings measure is directly related to the LCC output. A project/alternative that is the most cost-effective will have the greatest Net Savings. A project that has the highest Net Savings will also have the lowest LCC (Kneifel & Webb, 2020). The methods for calculating the net savings measure are shown in Equations 8 & 9.

$$NS_{A:BC} = [\Delta E] - [\Delta I_0 + \Delta Repl - \Delta Res] \qquad (8)$$

$$NS_{A:BC} = [\Delta W + \Delta S] - [\Delta I_0 + \Delta Repl - \Delta Res] \qquad (9)$$

Where ‘ΔE’ is the difference in energy costs between the base case and the alternative, ‘ΔW’ is the difference in water costs between the base case and the alternative, ‘ΔS’ is the difference in sewerage costs between the base case and the alternative, ‘ΔI_0’ is the difference in investment cost between the alternative and the base case, ‘ΔRepl’ is the difference in replacement costs between the alternative and the base case, ‘ΔRes’ is the difference in residual values between the alternative and the base case, and ‘$NS_{A:BC}$’ is the Net Savings.

Benefit Cost Ratio

The benefit cost ratio (BCR) is a common measure of economic performance that measures the relationship between the costs and benefits of a particular investment scenario (Kneifel & Webb, 2020). Projects and investments are considered to be beneficial if the BCR returns a value greater than or equal to 1.0. The method for calculating the benefit cost ratio is shown below in Equations 10 & 11.

$$BCR_{A:BC} = \frac{\Delta \mathrm{E}}{\Delta CF} \qquad (10)$$

$$BCR_{A:BC} = \frac{\Delta W + \Delta S}{\Delta CF} \qquad (11)$$

Where ‘ΔE’ is the difference in cumulative energy costs between the base case and the alternative, ‘ΔW’ is the difference in cumulative water costs between the base case and the alternative, and ‘ΔS’ is the difference in cumulative sewerage costs, and ‘ΔCF’ is the difference in cashflows between the alternative and the base case, meaning the difference in costs of principal investment, cumulative replacement, plus any residual values.

Savings-to-Investment Ratio

The savings-to-investment ratio is another measure of economic performance (Kneifel & Webb, 2020). Savings-to-investment ratio (SIR) is a relative performance measure, meaning that alternatives must be measured against a base case. The SIR measures the relationship between the investment costs and savings.

The selection criteria for the SIR is much like the selection criteria for the benefit-cost ratio. A project/alternative that has a SIR greater than or equal to 1.0 is considered cost-effective or beneficial. It should be noted that the project/alternative with the highest SIR may not be the project/alternative with the lowest LCC (Kneifel & Webb, 2020). The methods for calculating the SIR measure are shown in Equations 12 & 13.

$$SIR_{A:BC} = \frac{\Delta E}{\Delta I_0 + \Delta Repl - \Delta Res} \qquad (12)$$

$$SIR_{A:BC} = \frac{\Delta W + \Delta S}{\Delta I_0 + \Delta Repl - \Delta Res} \qquad (13)$$

Where 'ΔE' is the difference in energy costs between the base case and the alternative, 'ΔW' is the difference in water costs between the base case and the alternative, 'ΔS' is the difference in sewerage costs between the base case and the alternative, 'ΔI_0' is the difference in investment cost between the alternative and the base case, 'ΔRepl' is the difference in replacement costs between the alternative and the base case, 'ΔRes' is the difference in residual values between the alternative and the base case, and '$SIR_{A:BC}$' is the savings-to-investment ratio.

Adjusted Internal Rate of Return

The final supplemental measure in the LCCA method is the adjusted internal rate of return. The adjusted internal rate of return (AIRR) is another relative performance measure of economic performance (Kneifel & Webb, 2020). The AIRR measures the annual percentage yield of the investment in a project/alternative.

To draw conclusions about the economic performance of a project/alternative using the AIRR, it must be measured against the minimum acceptable rate of return. The minimum acceptable rate of return is often considered to be equal to the discount rate used throughout the LCCA method (Kneifel & Webb, 2020). In order for a project/alternative to have an acceptable economic performance the AIRR must be greater than the minimum acceptable rate of return. The method for calculating the AIRR measure is shown in Equation 14.

$$AIRR = (1 + r)(SIR)^{1/N} - 1 \qquad (14)$$

Where ‘r’ is the reinvestment rate (or the discount rate used in the LCC analysis), ‘SIR’ is the savings-to-investment rate found using Equations 10 or 11, ‘N’ is the study period in years, and ‘AIRR’ is the adjusted internal rate of return.

Payback Period

The final supplementary method calculated for a comprehensive LCCA is the payback period. The payback period is the measurement of the time that has passed between the beginning of the study period until the accumulated savings offset incurred costs (Kneifel & Webb, 2020). Payback periods for investments with beneficial financial performance will occur within the study period; payback periods occurring earlier during the study period indicate more exceptional performance than payback periods occurring later in the study period. A method for calculating the payback period is shown below using the Discounted Payback method shown in Equations 15 & 16.

$$\sum_{t=1}^{y} \frac{\Delta E_t - \Delta Repl_t + \Delta Res_t}{(1+d)^t} \geq \Delta I_0 \qquad (15)$$

$$\sum_{t=1}^{y} \frac{\Delta W_t + \Delta S_t - \Delta Repl_t + \Delta Res_t}{(1+d)^t} \geq \Delta I_0 \qquad (16)$$

Where 'ΔE_t' is the difference between savings in energy costs accrued between the base case and the alternative, 'ΔW_t' is the difference between savings in water costs accrued between the base case and the alternative, 'ΔS_t' is the difference between savings in sewerage costs accrued between the base case and the alternative. '$\Delta Repl_t$' is the difference in cost of replacement between the alternative and the base case, 'ΔRes_t' is the difference in residual values between the alternative and the base case. 'ΔI_0' is the difference in costs of principal investment between the alternative and the base case, and 'd' is the discount rate.

Break-even Analysis

The break-even analysis is not a supplementary measure necessary for a comprehensive LCCA, however it is one of the preliminary steps taken in conducting a sensitivity analysis. A break-even analysis shows the present-value amount of revenue necessary for the base-case and alternative to become exactly equal. While it is not a part of the "body" of the LCCA, the break-even analysis is still important to investors or other decision makers. The method for calculating the break-even analysis is shown below in Equations 17 & 18.

$$[\Delta E] = [\Delta I_0 + \Delta Repl - \Delta Res] \qquad (17)$$

$$[\Delta W + \Delta S] = [\Delta I_0 + \Delta Repl - \Delta Res] \qquad (18)$$

Where 'ΔE' is the difference between savings in energy costs accrued between the base case and the alternative, 'ΔW' is the difference between savings in water costs accrued between the base case and the alternative, 'ΔS' is the difference between savings in sewerage costs accrued between the base case and the alternative. 'ΔI_0' is the difference in cost of principal investment between the alternative and the base case, 'ΔRepl' is the difference in cost of replacement between the alternative and the base case, and 'ΔRes' is the difference in residual value between the alternative and the base case.

CHAPTER IV

WATER FIXTURE ANALYSIS

This chapter's following subsections will discuss the respective results of the LCCA as it was applied to water using fixtures. All results of the LCCA will be compared to the selection criteria as discussed in Chapter 3, sub-section "Model Framework". The input parameters used for this analysis are summarized in Tables 3-5 and are used in the calculation of each of the following output values. Conclusions about the efficacy of these fixtures will be discussed in Chapter 6. Data used in this section was obtained as discussed in Chapter 3 – "Study Rationale". The water using fixtures considered in this study are based on the LEED v4 for Homes Water Efficiency ballot.

Table 3. Summarization of Water & Sewerage Utility Parameters

Study Parameter		Value
Base Volume of Water		
	New York City	0
	Los Angeles	0
	Chicago	0
	Houston	1000
	Phoenix	5984
Base Rate of Water		
	New York City	$ 14.90
	Los Angeles	$ -
	Chicago	$ -
	Houston	$ 5.24
	Phoenix	$ 4.64
Cost per 1000 Gallons of Water		
	New York City	$ 5.33
	Los Angeles	$ 8.94
	Chicago	$ 4.08
	Houston	$ 5.38
	Phoenix	$ 5.98
Base Rate of Sewerage		
	New York City	$ -
	Los Angeles	$ -
	Chicago	$ -
	Houston	$ 11.14
	Phoenix	$ 7.01
Cost per 1000 Gallons of Sewerage		
	New York City	$ 8.47
	Los Angeles	$ 5.44
	Chicago	$ 4.08
	Houston	$ 11.32
	Phoenix	$ 4.17
Annual Rate of Cost of Water Increase		
	New York City	10.92%
	Los Angeles	7.31%
	Chicago	15.25%
	Houston	2.10%
	Phoenix	0.00%
Annual Rate of Cost of Sewerage Increase		
	New York City	4.40%
	Los Angeles	3.12%
	Chicago	3.83%
	Houston	6.10%
	Phoenix	-2.09%

Table 4. Summarization of Water & Sewerage Consumption, by City

City	Traditional Water & Sewerage Consumption (gal./mo.)	Efficient Water & Sewerage Consumption (gal./mo.)
New York City	4,135.67	2,336.33
Los Angeles	4,135.67	2,471.75
Chicago	3,874.42	2,471.75
Houston	4,658.42	2,471.75
Phoenix	4,135.67	2,471.75

Table 5. Summarization of Cost, Time, and Discount Rate Parameters

Study Parameter		Value
Principal Investment Cost		
	Traditional	$ 775.15
	Efficient	$ 862.19
Cumulative Cost of Replacement		
	Traditional	$ 177.01
	Efficient	$ 233.29
Residual Values of Fixtures		
	Traditional	$ 225.66
	Efficient	$ 150.61
Rates, annual		
	Nominal Discount Rate	2.50%
Study Period, years		
		25

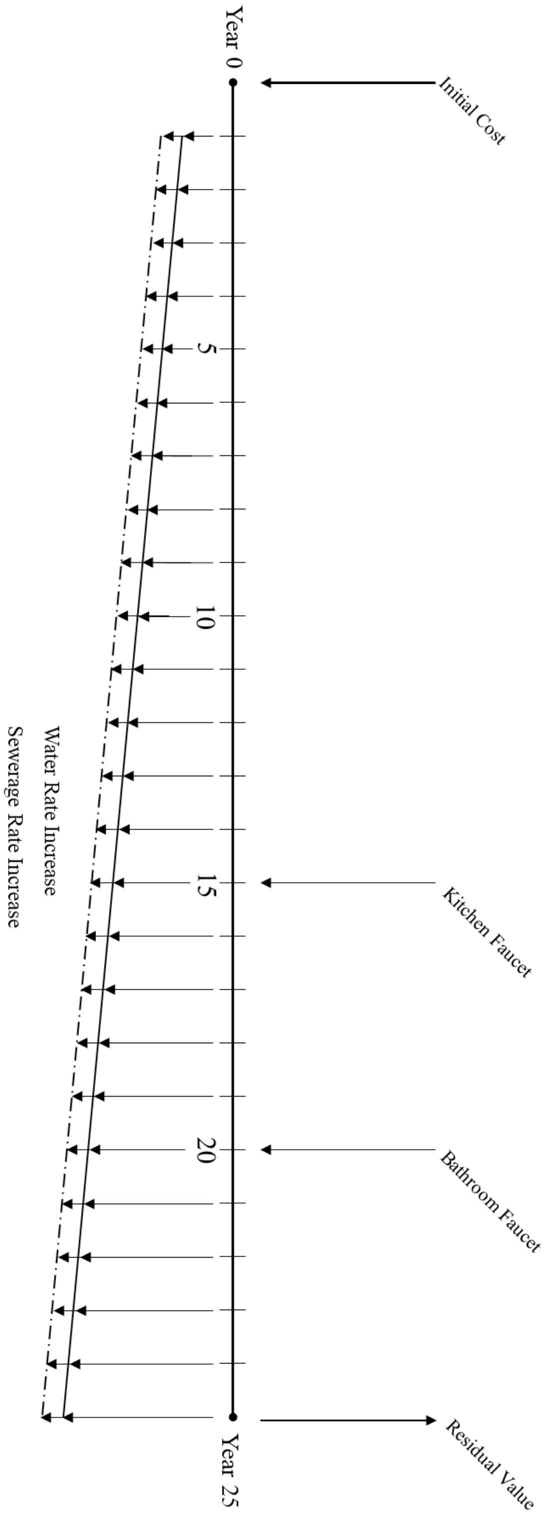

Figure 1. A Cashflow Diagram of Water Fixtures.

Life-cycle Cost

The first, and most pertinent result of the LCCA is the life-cycle cost. This value will be of most interest to investors and financial decision makers as it offers a succinct estimation of the total cost of ownership of an investment. Life-cycle costs were calculated according to Equation 7 as discussed in Chapter 3, sub-section "Model Framework". For all five cities, efficient water fixtures returned the lowest life-cycle cost.

Table 6. Summarization of Life-cycle Cost Output Values

City	Water		Sewerage		Life-Cycle Cost	
	Traditional Monthly Cost	Efficient Monthly Cost	Traditional Monthly Cost	Efficient Monthly Cost	Traditional	Efficient
New York City	$41.55	$30.89	$42.35	$25.41	$ 59,043.32	$ 41,975.66
Los Angeles	$44.70	$26.82	$27.20	$16.32	$ 35,315.51	$ 21,698.28
Chicago	$16.32	$12.24	$16.32	$12.24	$ 41,334.95	$ 31,401.21
Houston	$26.76	$16.00	$67.74	$45.10	$ 41,131.95	$ 27,328.46
Phoenix	$4.64	$5.98	$27.86	$19.52	$ 6,731.95	$ 5,760.88

In accordance with the selection criteria for the life-cycle cost, the efficient water fixtures show favorable economic performance. In four out of five sample cities, the life-cycle costs for efficient fixtures were greater than $20,000, except for Phoenix, AZ where life-cycle costs for efficient fixtures did not exceed $6,000. The reason for such low life-cycle costs for this city can be attributed to the volume of the monthly base supply of water, which exceeded the monthly consumption. In cities where life-cycle costs of efficient fixtures were greater than $20,000, the average life-cycle cost of efficient fixtures was $30,600.90. For cities with efficient life-cycle costs greater than $20,000, the average percent difference between the traditional and efficient life-cycle costs was 31.26%. The results of the life-cycle costing output are summarized in Table 6.

Net Savings

The first calculated supplementary measure in this study is the Net Savings, calculated using Equation 9 as discussed in Chapter 3, sub-section "Model Framework". The Net Savings supplementary measure provides a simple estimation of cumulative dollars saved by the alternative relative to the base case. The results of the Net Savings calculation are summarized below in Table 7.

Table 7. Summarization of Net Savings Output Values

City	Additional Cost of Fixtures	Present-Worth Reduction in Water & Sewerage Costs	Net Savings
New York City	$ (218.37)	$17,286.03	$17,067.66
Los Angeles	$ (218.37)	$13,835.60	$13,617.23
Chicago	$ (218.37)	$10,152.11	$9,933.74
Houston	$ (218.37)	$14,021.86	$13,803.49
Phoenix	$ (218.37)	$1,189.44	$971.07

All five cities have positive net savings, which signifies that the alternative (efficient fixtures) is performing favorably in relation to the base case (traditional fixtures). Four out of the five sample cities had a Net Savings greater than $9,000, except for Phoenix, AZ where Net Savings did not exceed $1000. The reason for this reduced value of savings is the same as was discussed in the preceding sub-section. The average Net Savings in the four cities where Net Savings exceeded $9,000 was $13,605.53.

Benefit Cost Ratio & Savings-to-Investment Ratio

The Benefit Cost Ratio (BCR) and Savings-to-Investment Ratio (SIR) are shown together in one section as they are variations of the same measurement. BCR was calculated using Equation 11, and Savings-to-Investment Ratio was calculated with Equation 13 as discussed in Chapter 3, sub-section "Model Framework". BCR and SIR are succinct expressions of rating project performance, a BCR/SIR greater than or equal to 1 indicates favorable performance. Benefit-Cost Ratio and Savings-to-Investment ratio are summarized below in Table 8.

Table 8. Summarization of BCR and SIR Output Values

City	Additional Cost of Fixtures	Present-Worth Reduction in Energy Costs	Benefit-Cost Ratio	SIR
New York City	$ (218.37)	$ 17,286.03	79.16	79.16
Los Angeles	$ (218.37)	$ 13,835.60	63.36	63.36
Chicago	$ (218.37)	$ 10,152.11	46.49	46.49
Houston	$ (218.37)	$ 14,021.86	64.21	64.21
Phoenix	$ (218.37)	$ 1,189.44	5.45	5.45

The BCR/SIR analysis has demonstrated that water-efficient fixtures perform far more favorably than traditional fixtures in all five sample cities. Four of the five cities returned a BCR/SIR value greater than 40, the outlier being Phoenix, AZ which returned a value of 5.45. For the cities where BCR/SIR were greater than 40, the average rating of efficient appliances was 63.30.

Adjusted Internal Rate of Return

The Adjusted Internal Rate of Return (AIRR) was calculated using Equation 14 as shown in Chapter 3. The AIRR is another measure of relative project performance, projects with favorable economic performance should have an AIRR greater than or equal to the minimum acceptable rate of return. The resulting values of the AIRR analysis are summarized below in Table 9, AIRR values shown are annual rates.

Table 9. Summarization of Adjusted Internal Rate of Return Output Values

City	Additional Cost of Fixtures	Present-Worth Reduction in Energy Costs	AIRR
New York City	$ (218.37)	$ 17,286.03	20.15%
Los Angeles	$ (218.37)	$ 13,835.60	19.25%
Chicago	$ (218.37)	$ 10,152.11	17.99%
Houston	$ (218.37)	$ 14,021.86	19.30%
Phoenix	$ (218.37)	$ 1,189.44	9.31%

The calculated AIRR values shows that all five sample cities greatly exceed the selection criteria for an AIRR analysis, scoring well above the 2.5% annual minimum acceptable rate of return. Four of the five cities returned an AIRR greater than 17% annually, again, Phoenix, AZ returned an AIRR not exceeding 10% annually. For cities with an AIRR greater than 17%, the average AIRR was 19.17%.

Payback Period

The Payback Period of water-efficient fixtures was determined using the concept of discounted payback, defined by Equation 16 in Chapter 3. The Payback Period analysis is used to determine at what point within the study period the cumulative savings offset the investment and recurring costs. Ideally, the Payback Period should fall somewhere within the study period. Well performing investments may have a Payback Period within only a few years or even months after the project base date. The Payback Period results are presented in Table 10, below.

Table 10. Summarization of Payback Period Output Values

City	Life-Cycle Cost		Present-Worth Reduction in Energy Costs	Payback Period (months)
	Traditional	Efficient		
New York City	$ 59,043.32	$ 41,975.66	$ 17,286.03	7.83
Los Angeles	$ 35,315.51	$ 21,698.28	$ 13,835.60	7.83
Chicago	$ 41,334.95	$ 31,401.21	$ 10,152.11	7.83
Houston	$ 41,131.95	$ 27,328.46	$ 14,021.86	7.83
Phoenix	$ 6,731.95	$ 5,760.88	$ 1,189.44	7.83

As shown in Table 10, each sample city had a payback period of nearly 8 months after the project base date. This calculated value of Payback Period displays exceptional project performance.

CHAPTER V

ELECTRIC APPLIANCE ANALYSIS

This chapter's following sub-sections will discuss the respective results of the LCCA as it was applied to the energy using appliances and fixtures. All results of the LCCA will be compared to the selection criteria as discussed in Chapter 3, sub-section "Model Framework". All relevant input parameters used in this analysis are shown in Tables 11-12. Each supplementary measure calculated in this chapter also make use of these same study parameters. The end of this chapter contains a sensitivity analysis to determine which parameters must be changed, and by how much in order to achieve beneficial financial performance. Conclusions regarding the efficacy of these appliances and fixtures will be discussed in Chapter 6 – "Conclusion". Data used in this section was collected as discussed in Chapter 3 – "Study Rationale".

Table 11. Summarization of the Volume of Electricity Consumption, by City

City	Traditional Energy Use (kWh/mo)	Efficient Energy Use (kWh/mo)
New York City	541.67	324.2
Los Angeles	500	299.26
Chicago	732.92	438.67
Houston	1166.67	698.28
Phoenix	1166.67	698.28

Table 12. Comprehensive List of Input Parameters

Study Parameter		Value
Principal Investment Cost		
	New York City - Traditional	$ 8,861.72
	New York City - Efficient	$ 13,344.82
	Traditional	$ 11,324.01
	Efficient	$ 18,462.82
Electricity Cost / kWh by City		
	New York City	$ 0.19
	Los Angeles	$ 0.22
	Chicago	$ 0.15
	Houston	$ 0.14
	Phoenix	$ 0.13
Cumulative Cost of Replacement		
	New York City - Traditional	$ 28,372.47
	New York City - Efficient	$ 38,255.20
	Traditional	$ 30,834.75
	Efficient	$ 43,373.20
Residual Values of Appliances		
	New York City - Traditional	$ 2,895.49
	New York City - Efficient	$ 4,378.68
	Traditional	$ 3,716.25
	Efficient	$ 6,084.68
Rates, annual		
	Nominal Discount	2.50%
	Electricity Increase	1.68%
Study Period, years		
		25

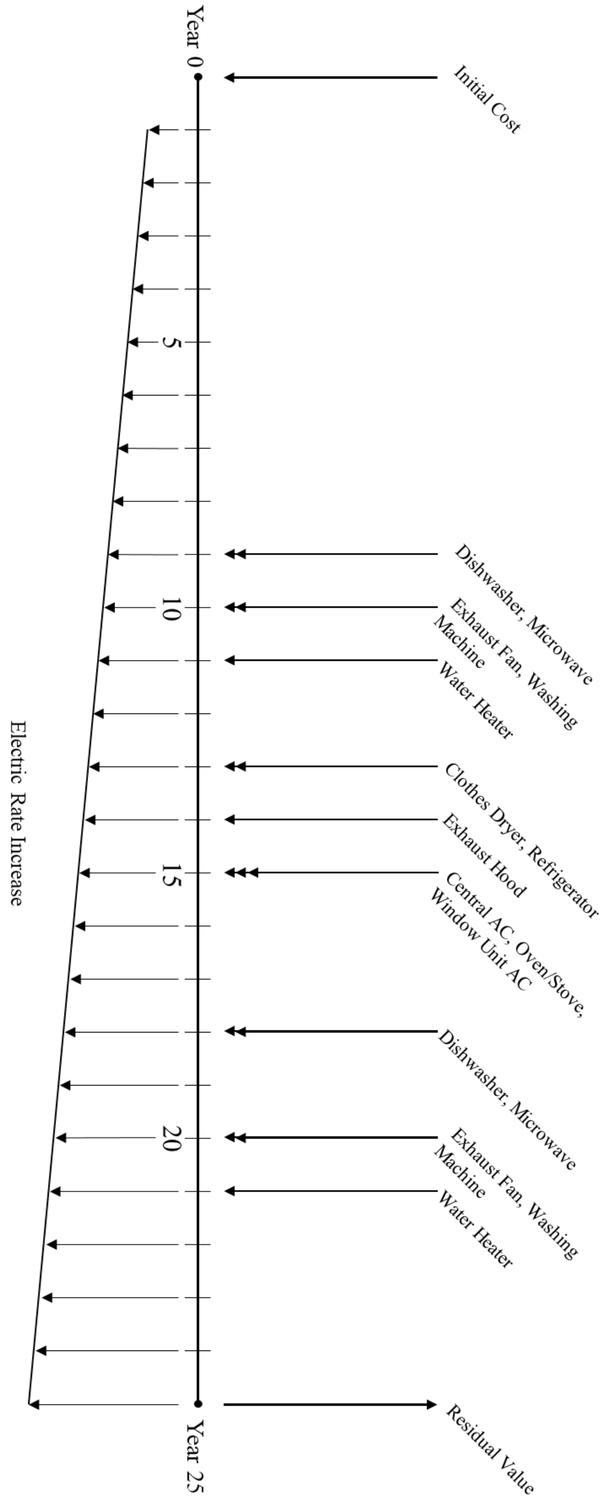

Figure 2. Cashflow Diagram of Large Electric Appliances.

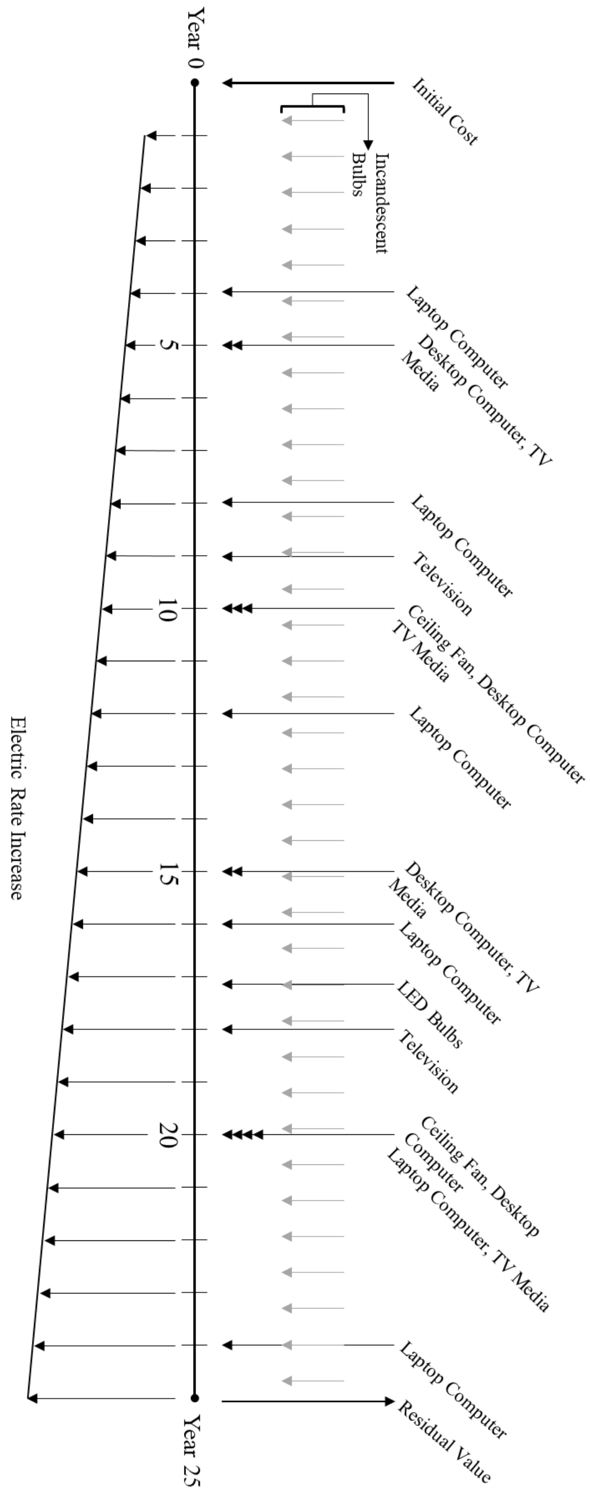

Figure 3. Cashflow Diagram illustrating of Small Electric Appliances.

Analysis

Life-cycle Costs

Life-cycle costs are often the most valuable output of a life-cycle cost analysis to decision-makers. LCCs offer a view of the cumulative costs of ownership of an array of investment/project alternatives, the most favorable project alternative will have the lowest life-cycle cost. Life-cycle costs were calculated according to Equation 6 as discussed in Chapter 3, sub-section "Model Framework". The results of the life-cycle costing calculations are shown below in Table 13.

Table 13. Summarization of the Life-cycle Cost Output Values

City	Energy		Life-Cycle Cost	
	Traditional Monthly Cost	Efficient Monthly Cost	Traditional	Efficient
New York City	$ 102.92	$ 61.60	$ 62,200.76	$ 63,897.49
Los Angeles	$ 110.00	$ 65.84	$ 68,222.01	$ 73,575.12
Chicago	$ 109.00	$ 65.80	$ 68,205.22	$ 73,565.08
Houston	$ 163.33	$ 97.76	$ 82,660.68	$ 82,217.04
Phoenix	$ 151.67	$ 90.78	$ 79,502.24	$ 80,326.63

The only city where LCCs for efficient electrical appliances were lower than traditional electrical appliances was Houston. For the given input parameters, in four of the five sample cities (New York City, Los Angeles, Chicago, and Phoenix), traditional electric appliances returned the lowest life-cycle costs. It should be noted that while both Houston and Phoenix have the same volume of electricity consumption, the cost of electricity per kilowatt-hour differs by one cent.

This difference in utility cost leads to a difference in life-cycle costs of $3,158.44 for traditional appliances and $1,890.41 for efficient appliances.

Net Savings

The next result, net savings, is the first of several supplementary measures. Net Savings is an illustration of the actual amount of money saved by the alternative, expressed in present-value dollars. The project with favorable economic performance will have a positive net savings, indicating that not only does this alternative recoup its costs, but also costs less in the long-run. This measure was calculated using Equation 8 as discussed in Chapter 3, sub-section "Model Framework". The results of the Net Savings analysis are summarized below in Table 14.

Table 14. Summarization of the Net Savings Output Values

City	Additional Cost of Fixtures	Present-Worth Reduction in Energy Costs	Net Savings
New York City	$ (12,882.64)	$ 11,185.91	$ (1,696.73)
Los Angeles	$ (17,308.83)	$ 11,955.72	$ (5,353.12)
Chicago	$ (17,308.83)	$ 11,948.98	$ (5,359.85)
Houston	$ (17,308.83)	$ 17,752.48	$ 443.65
Phoenix	$ (17,308.83)	$ 16,484.44	$ (824.39)

In alignment with the previously calculated output value, four of five cities returned a negative net savings, indicating that the reduced costs of electricity utilities are not sufficient to offset the costs of initial investment and regular replacement. Again, the only city with positive Net Savings was Houston, demonstrating that efficient appliances provide some financial benefit.

However, the margin of benefit in this sample city is rather narrow, over a 25-year period, the reduction in energy costs nets only $443.65 in savings. As noted in the previous section, the only difference between the input parameters for sample cities Houston and Phoenix are the cost of electricity utilities differing by one cent per kilowatt hour. This one-cent variance in energy utility costs is enough to create a difference of $1,268.04 in Net Savings.

Benefit Cost Ratio & Savings-to-Investment Ratio

BCR and SIR output values are shown together in one section as they are variations of the same measurement. Both BCR and SIR offer an intuitive rating of a project based on financial performance, a rating of less than 1.0 indicates a poorly performing investment option; conversely, a rating greater than or equal to 1.0 indicates a positively performing investment option. BCR and SIR were calculated using Equations 10 and 12, respectively, as discussed in Chapter 3, sub-section “Model Framework”. BCR and SIR output values are summarized below in Table 15.

Table 15. Summarization of BCR & SIR Output Values

City	Additional Cost of Fixtures	Present-Worth Reduction in Energy Costs	BCR	SIR
New York City	$ (12,882.64)	$ 11,185.91	0.87	0.87
Los Angeles	$ (17,308.83)	$ 11,955.72	0.69	0.69
Chicago	$ (17,308.83)	$ 11,948.98	0.69	0.69
Houston	$ (17,308.83)	$ 17,752.48	1.03	1.03
Phoenix	$ (17,308.83)	$ 16,484.44	0.95	0.95

Here, the margin of benefit provided by efficient electrical appliances becomes more apparent. This margin is notable not only in the case of Houston, but in the other sample cities as well. The margin of financial benefit in Houston is notably narrow, however the margin of benefit for the next highest ranked city, Phoenix, is almost equally narrow. This method of analysis illustrates how close each city comes to having efficient electrical appliances return beneficial financial performance.

Adjusted Internal Rate of Return

The AIRR analysis provides a succinct look at the rate at which capital is recovered by an investment. Project alternatives that show favorable financial performance will have AIRR values higher than the discount rate used throughout the analysis. The AIRR values were calculated using Equation 14, as discussed in Chapter 3, sub-section “Model Development”. AIRR values are summarized below in Table 16.

Table 16. Summarization of Adjusted Internal Rate of Return Output Values

City	Additional Cost of Fixtures	Present-Worth Reduction in Energy Costs	AIRR
New York City	$ (12,882.64)	$ 11,185.91	1.93%
Los Angeles	$ (17,308.83)	$ 11,955.72	1.02%
Chicago	$ (17,308.83)	$ 11,948.98	1.02%
Houston	$ (17,308.83)	$ 17,752.48	2.60%
Phoenix	$ (17,308.83)	$ 16,484.44	2.30%

Similarly to the previously discussed supplementary measures, this AIRR analysis offers another specific view of project performance. Here it is evident how quickly capital is recouped in each project scenario. Only Houston has an AIRR that exceeds the discount rate used in this analysis. However, just like with the BCR and SIR analysis, the performance of this investment in Phoenix is only marginally lower than is sufficient to see beneficial financial performance.

Payback Period

The Payback Period supplementary measure is an estimation of when the costs of investment and regular replacement are offset by the accrued savings in reduced energy utility bills. An exceptionally to well performing investment will have a payback period within the study period. Payback Periods were calculated using the concept outlined by Equation 15 as discussed in Chapter 3, sub-section “Model Development”. Payback periods are summarized below in Table 17.

Table 17. Summarization of the Payback Period Output Values

City	Additional Cost of Fixtures	Present-Worth Reduction in Energy Costs	Payback Year
New York City	$ (12,882.64)	$ 11,185.91	30.25
Los Angeles	$ (17,308.83)	$ 11,955.72	39.42
Chicago	$ (17,308.83)	$ 11,948.98	39.5
Houston	$ (17,308.83)	$ 17,752.48	25.08
Phoenix	$ (17,308.83)	$ 16,484.44	27.25

This analysis shows that the costs of investment are recouped after the end of the study period for all five sample cities. In seeming contrast to the other calculated performance measures, Houston has a Payback Period just beyond the end of the Study Period. However, closer inspection of these previously discussed performance measures will demonstrate how narrow the margin of benefit is for energy efficient appliances in Houston. Given this, it is not without reason that Houston should have this Payback Period.

For the remainder of the cities, the Payback Period extends well beyond the end of the Study Period. The city with the next shortest Payback Period is Phoenix, extending a little over two years beyond the end of the Study Period; the city with the longest payback period must wait over 14 years to have investment and replacement costs recouped.

Discussion & Summary of Results

As was demonstrated by this life-cycle cost analysis, for a majority of the sample cities, energy efficient electrical appliances did not provide beneficial financial performance. This means that the given input parameters for this analysis were not conducive to beneficial financial performance. It can be observed in the results presented in the previous sub-sections that cities with higher volumes of energy consumption see energy efficient electrical appliances with favorable or nearly favorable economic performance.

Not only is this due to the relationship between higher volumes of energy consumption resulting in higher electricity bills, but also due to the rate charged for electricity. Sample cities Houston and Phoenix have identical volumes of energy consumption, however the rates charged per kilowatt hour differ by one cent, with rates in Houston being higher than rates in Phoenix. This one cent difference in electricity rate results in favorable economic performance in Houston, and unfavorable economic performance in Phoenix.

To build further on this point, the sample city with the third highest volume of energy consumption, Chicago, has the poorest economic performance overall, likely due to its relatively low rate charged for electricity. However, sample city Los Angeles has the lowest volume of consumption, and highest rate charged for electricity but is the second poorest performing sample city.

Additionally, it can be observed from Table 12 that there is a notable disparity in cumulative costs of principal investment and replacement, and residual values. On average, there is a 44% difference in principal investment costs for efficient appliances, 32% difference in replacement costs, and 45% difference in residual values. While the costs of principal investment may be reduced from rebates provided by either the manufacturer, retailer, or even government, there is little room for changes to be made to this input parameter. However, the costs of replacement may be able to be reduced simply by extending the useful life of appliances. It may be much more "realistic" that the average consumer waits until complete failure of the appliance before replacing it with a new model.

Other parameters that may affect the output values are the discount rate, and the annual energy cost escalation rate. A decreased discount rate may lead to increased economic performance of energy efficient electrical appliances. Conversely, an increased annual energy cost escalation rate may also increase the economic performance of these appliances.

Following is Table 18, summarizing all calculated output values that were part of the comprehensive life-cycle cost analysis as described in the NIST Life-cycle Costing Manual (Kneifel & Webb, 2020).

Table 18. Summary of all Calculated Output Values

City	Life-cycle Cost		Net Savings	BCR	SIR	Payback Period (years)
	Traditional	Efficient				
New York City	$ 62,200.76	$ 63,897.49	$ (1,696.73)	0.87	0.87	30.25
Los Angeles	$ 68,222.01	$ 73,575.12	$ (5,353.12)	0.69	0.69	39.42
Chicago	$ 68,205.22	$ 73,565.08	$ (5,359.85)	0.69	0.69	39.50
Houston	$ 82,660.68	$ 82,217.04	$ 443.65	1.03	1.03	25.08
Phoenix	$ 79,502.24	$ 80,326.63	$ (824.39)	0.95	0.95	27.25

Sensitivity Analysis

The preceding sub-sections in this chapter briefly addressed possible sensitive input parameters that could have an influence on the resulting output parameters. This section will further address and evaluate these sensitive input parameters to investigate the interrelationship of these parameters, and what effect they have on all output values. This sensitivity analysis will determine what changes to input parameters are required to attain beneficial financial performance of energy efficient electrical appliances.

Following this sub-section recommendations about these appliances and fixtures will be made based off both the primary analysis and the sensitivity analysis. The following parameters will be examined in their respective sub-sections to follow:

- Rate charged for electricity ($/kWh)
- Principal Investment Cost
- Cost of Regular Replacement
- Nominal Discount Rate
- Electricity Rate Escalation

Prior to performing the sensitivity analysis proper, one preliminary analysis must be conducted: the Break-even Analysis. The Break-even Analysis provides a view of how much additional revenue is required in order to offset the costs of the alternative (efficient appliances). This Break-even value was calculated using Equation 15 found in Chapter 3, sub-section “Model Development”. This analysis provides a crucial piece of information for the sensitivity analysis so that it can be determined how much additional money must be saved by these appliances in order for them to become a financially feasible investment. The calculated Break-even Analysis values are shown below in Table 19.

Table 19. Calculated Break-even Analysis for Electrical Appliances

City	Additional Cost of Fixtures	PW Reduction in Energy Costs	Break-even Analysis
New York City	$ (12,882.64)	$ 11,185.91	$ 1,696.73
Los Angeles	$ (17,308.83)	$ 11,955.72	$ 5,353.12
Chicago	$ (17,308.83)	$ 11,948.98	$ 5,359.85
Houston	$ (17,308.83)	$ 17,752.48	$ (443.65)
Phoenix	$ (17,308.83)	$ 16,484.44	$ 824.39

Here it can be seen that in two of the four sample cities where efficient appliances do not attain beneficial financial performance (Phoenix and New York City), the average additional revenue to offset costs is $1,260.56. However, sample cities Los Angeles and Chicago require far higher additional revenue, with an average of $5,356.49. Finally, sample city Houston does not require any additional revenue to offset costs, however, Houston will still be included in this sensitivity analysis to see how these changes in input parameters may further increase the beneficial financial performance of appliances in this city.

Rate Charged for Electricity

In this section, the effect that the rate charged per kilowatt hour has on output parameters will be explored. The rate charged for electricity for each city will be increased by $0.01 increments to chart the changes made to output parameters as these input parameters are changed. These changes will be made until efficient appliances return results indicating beneficial financial performance. Final values required to achieve beneficial financial performance will be displayed in tabulated form and will be compared to their original input parameter values. For the sake of clarity and brevity, the only output values shown in the main text will be the life-cycle costs. All other supplementary measures will be within the Appendix.

The following table, Table 20. shows the initial input parameter for rate of electricity charged alongside the minimum necessary rate of electricity charged for efficient appliances to attain beneficial financial performance. Table 21. shows the ratios of change in the calculated life-cycle costs of traditional and efficient electrical appliances. These ratios are in relation not only to each other but also in relation to the change in input parameter. These ratios will be useful in determining which input parameters are most effective in helping efficient appliances attain beneficial financial performance. The following figures, Figures 4-8, show an expanded version of what is shown in Table 20.

The following tables and charts provide a clear demonstration of the effect that the rate charged for electricity has on the life-cycle costs of efficient appliances. In the case of sample city Phoenix, a \$0.01 increase in rate charged for electricity leads to 2.35% change in life-cycle cost for efficient appliances, however this same \$0.01 increase leads to a 7.69% change in life-cycle costs for traditional appliances which is sufficient to make efficient appliances attain beneficial financial performance.

The sample city with the next lowest “Minimal Necessary” rate charged for electricity is New York City which required a \$0.03 increase in rate charged for electricity for energy efficient appliances to attain beneficial financial performance. This \$0.03 increase in electricity rate led to a 7.07% change in life-cycle costs for efficient appliances, but a 15.79% change in life-cycle costs for traditional appliances.

Sample cities Chicago and Los Angeles required two of the highest “Minimal Necessary” rates charged for electricity to attain beneficial financial performance, at $0.07 and $0.12 respectively. For sample city Los Angeles this $0.10 increase led to a 19.84% change in life-cycle costs for efficient appliances, but a 45.45% change in life-cycle costs for traditional appliances. The $0.07 increase in sample city Chicago caused an 11.30% change in life-cycle costs for efficient appliances, but a 20.36% change in life-cycle costs for traditional appliances.

As discussed previously in this section, Table 21 shows the ratios of change of the calculated life-cycle costs for all sample cities. The average ratio of change in life-cycle costs relative to each other was 1.75. The average ratio of change in input to change in life-cycle cost of traditional appliances was 2.19, and the average ratio of change in input to change in life-cycle cost of efficient appliances was 3.84- approximately 1.75 times higher.

Table 20. Initial Versus Minimal Necessary Rate of Electricity Charged

Rate of Electricity Charged	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
New York City					
$0.19	$62,200.76	$63,897.49	15.79%	7.07%	4.12%
$0.22	$66,600.03	$66,530.56			
Los Angeles					
$0.22	$68,222.01	$73,575.12	45.45%	19.84%	11.01%
$0.32	$81,758.15	$81,676.85			
Chicago					
$0.15	$68,205.22	$73,565.08	46.67%	20.36%	11.30%
$0.22	$82,094.49	$81,878.16			
Houston					
$0.14	$82,660.68	$82,217.04	0.00%	0.00%	0.00%
$0.14	$82,660.68	$82,217.04			
Phoenix					
$0.13	$79,502.24	$80,326.63	7.69%	3.97%	2.35%

Table 21. Ratios of Change of Calculated Life-cycle Costs of Electrical Appliances

New York City		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.72	2.23	3.83
Los Angeles		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.80	2.29	4.13
Chicago		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.80	2.29	4.13
Houston		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
0.00	0.00	0.00
Phoenix		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.69	1.94	3.27
Average		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.75	2.19	3.84

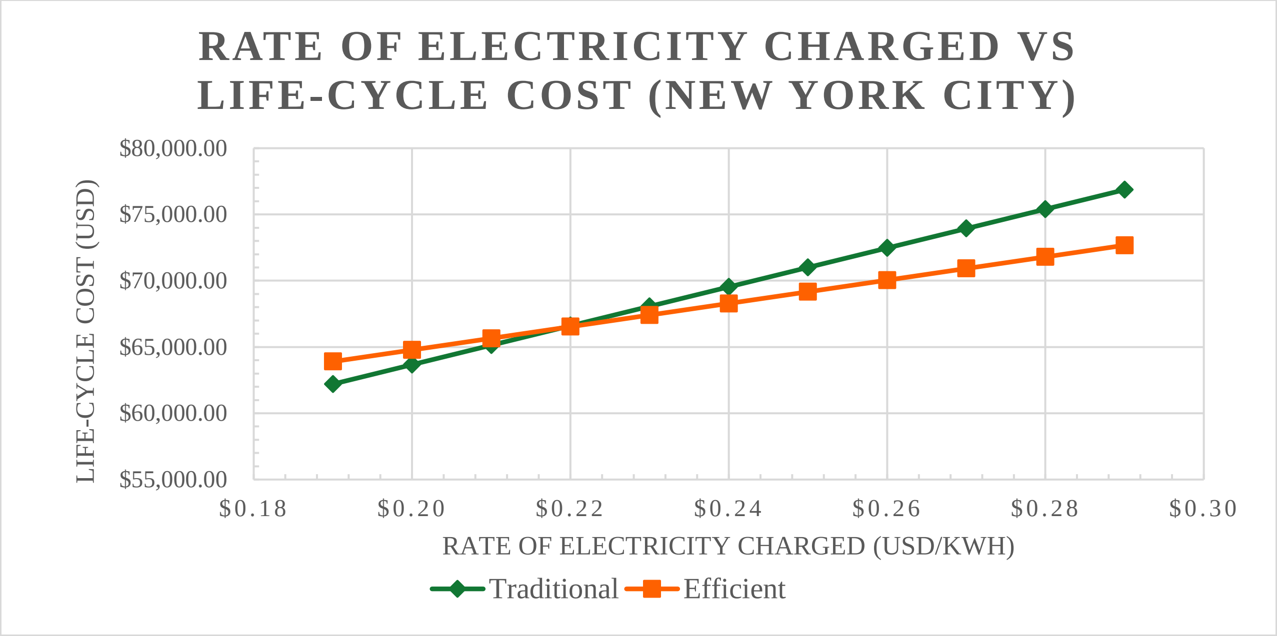

Figure 4. Rate of Electricity Charged vs Life-cycle Cost for New York

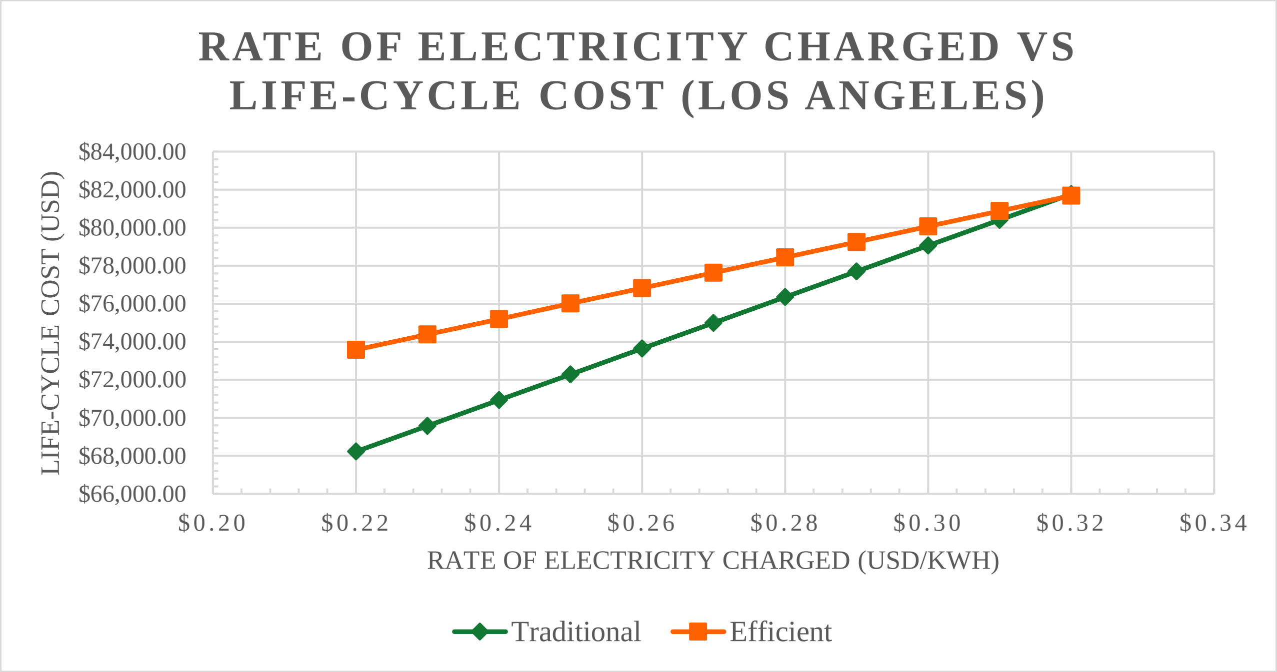

Figure 5. Rate of Electricity Charged vs Life-cycle Cost for Los Angeles

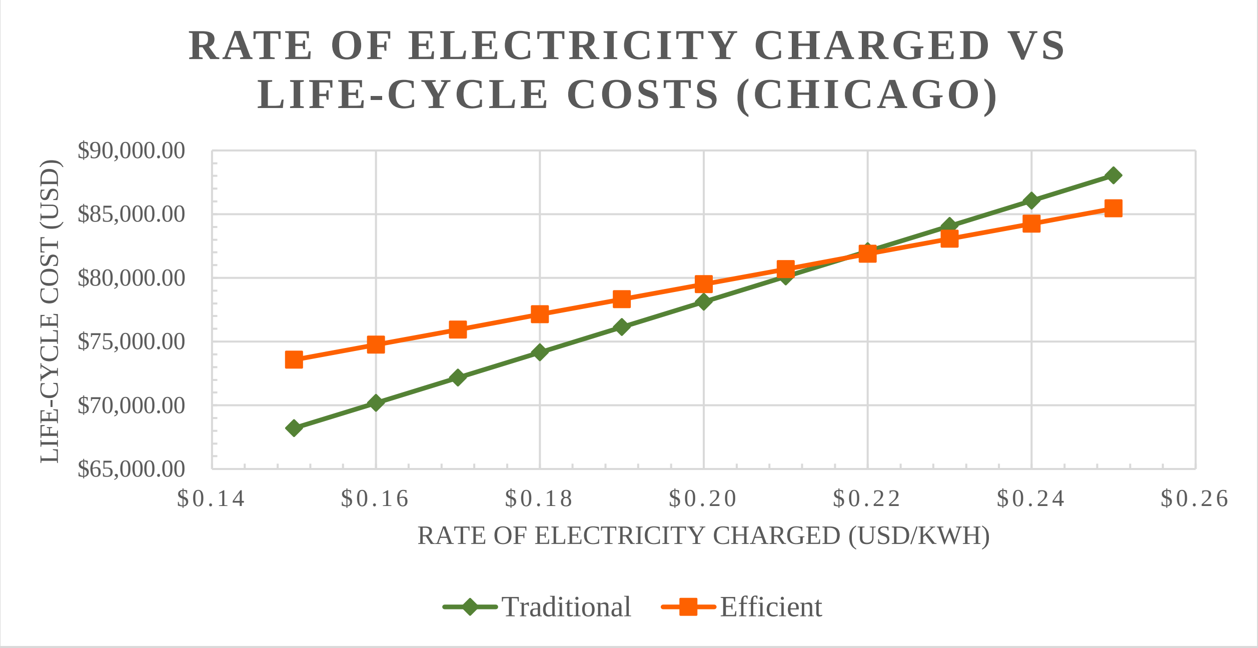

Figure 6. Rate of Electricity Charged vs Life-cycle Cost for Chicago

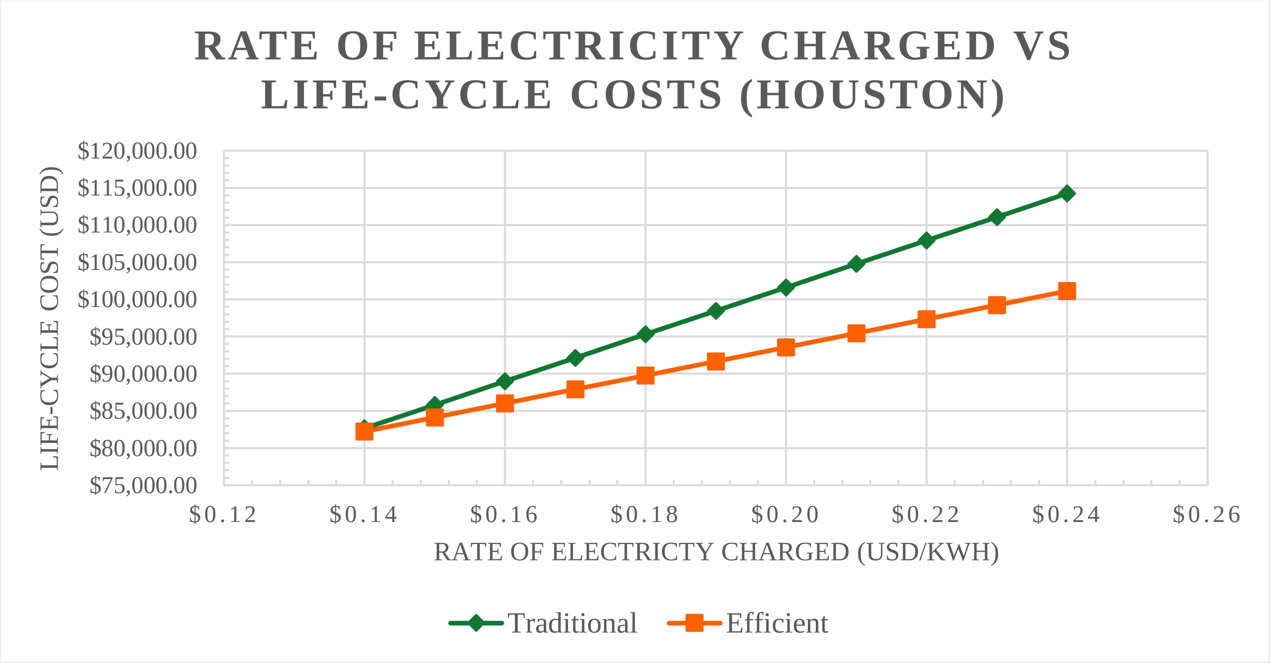

Figure 7. Rate of Electricity Charged vs Life-cycle Cost for Houston

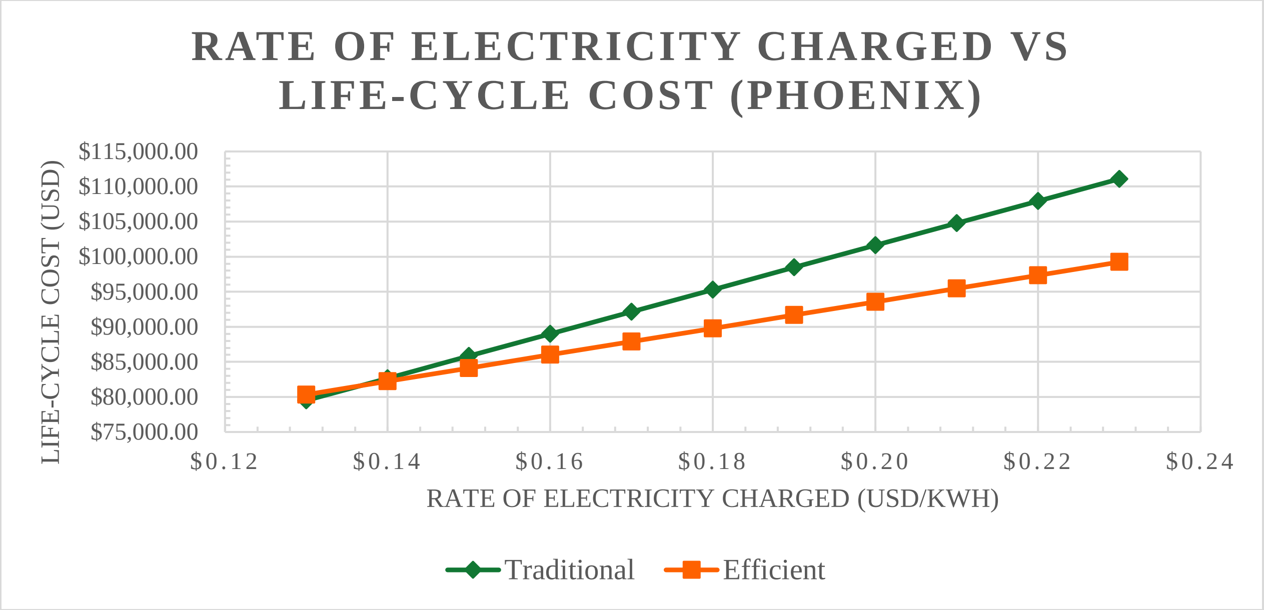

Figure 8. Rate of Electricity Charged vs Life-cycle Cost for Phoenix

Cost of Principal Investment

In this section, the effect that the cost of principal investment of efficient appliances has on output parameters will be explored. The cost of principal investment of efficient appliances for each city will be increased by 5% increments to chart the changes made to output parameters as these input parameters are changed. These changes will be made until efficient appliances return results indicating beneficial financial performance. Final values required to achieve beneficial financial performance will be displayed in tabulated form and will be compared to their original input parameter values. For the sake of clarity and brevity, the only output values shown in the main text will be the life-cycle costs. All other supplementary measures will be within the Appendix.

The following table, Table 22. shows the initial input parameter for cost of principal investment of efficient appliances alongside the minimum necessary cost of principal investment of efficient appliances to attain beneficial financial performance. Table 23. shows the ratios of change in the calculated life-cycle costs of traditional and efficient electrical appliances. These ratios are in relation not only to each other but also in relation to the change in input parameter. These ratios will be useful in determining which input parameters are most effective in helping efficient appliances attain beneficial financial performance. In this case, since the cost of initial investment is only reduced on efficient appliances, the ratio of change in life-cycle costs and ratio of change in input to change in life-cycle cost of traditional appliances cannot be calculated as the percent change in life-cycle cost of traditional appliances is 0%.

The following figures, Figures 9-13, show an expanded version of what is shown in Table 22. The figures show the change in the cost of principal investment as a "% Off Cost" rebate, a feature that is sometimes offered by manufacturers, municipal or state governments that wish to promote the adoption of efficient appliances and fixtures.

The following tables and figures offer an illustration of the effect that cost of principal investment has on the life-cycle costs of efficient electrical appliances. Sample city New York City, for example, a $2,001.72 (15%) reduction in cost of principal investment leads to a 3.13% change in life-cycle costs for efficient appliances. Because the cost of principal investment for traditional appliances does not change, this 3.13% change in life-cycle cost is sufficient to attain beneficial financial performance.

Sample cities Los Angeles and Chicago both had the greatest "Minimal Necessary" change to cost of principal investment to attain beneficial financial performance for efficient appliances. Both Los Angeles and Chicago required a 30% decrease in cost of principal investment to achieve a 7.53% change in life-cycle costs for efficient appliances.

Sample city Phoenix had the lowest “Minimal Necessary” change of cost of principal investment for efficient appliances to achieve beneficial financial performance. A reduction in cost of principal investment of only 5% was necessary to return a 1.15% change in life-cycle costs, which was sufficient to achieve beneficial financial performance.

The average ratio of change in input to change in life-cycle cost of efficient appliances was 4.28 as shown in Table 23.

Table 22. Initial Versus Minimal Necessary Cost of Principal Investment

New York City

Cost of Principal Investment	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
$13,344.82	$62,200.76	$63,897.49	-15.00%	0.00%	-3.13%
$11,343.10	$62,200.76	$61,895.76			

Los Angeles

Cost of Principal Investment	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
$18,462.82	$68,222.01	$73,575.12	-30.00%	0.00%	-7.53%
$12,923.97	$68,222.01	$68,036.28			

Chicago

Cost of Principal Investment	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
$18,462.82	$68,205.22	$73,565.08	-30.00%	0.00%	-7.53%
$12,923.97	$68,205.22	$68,026.23			

Houston

Cost of Principal Investment	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
$18,462.82	$82,660.68	$82,217.04	0.00%	0.00%	0.00%
$18,462.82	$82,660.68	$82,217.04			

Phoenix

Cost of Principal Investment	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
$18,462.82	$79,502.24	$80,326.63	-5.00%	0.00%	-1.15%
$17,539.68	$79,502.24	$79,403.49			

Table 23. Ratios of Change of Calculated Life-cycle Costs of Electrical Appliances

New York City		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
-	-	4.79
Los Angeles		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
-	-	3.99
Chicago		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
-	-	3.98
Houston		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
-	-	0.00
Phoenix		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
-	-	4.35
Average		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
-	-	4.28

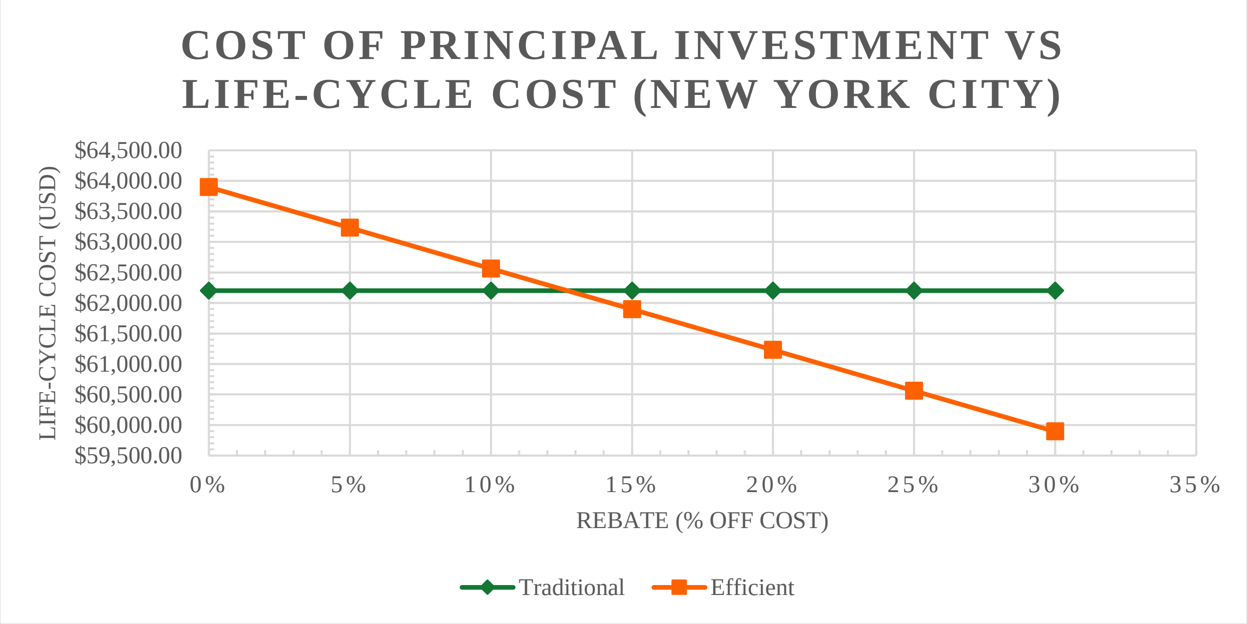

Figure 9. Cost of Principal Investment vs Life-cycle Cost for New York City

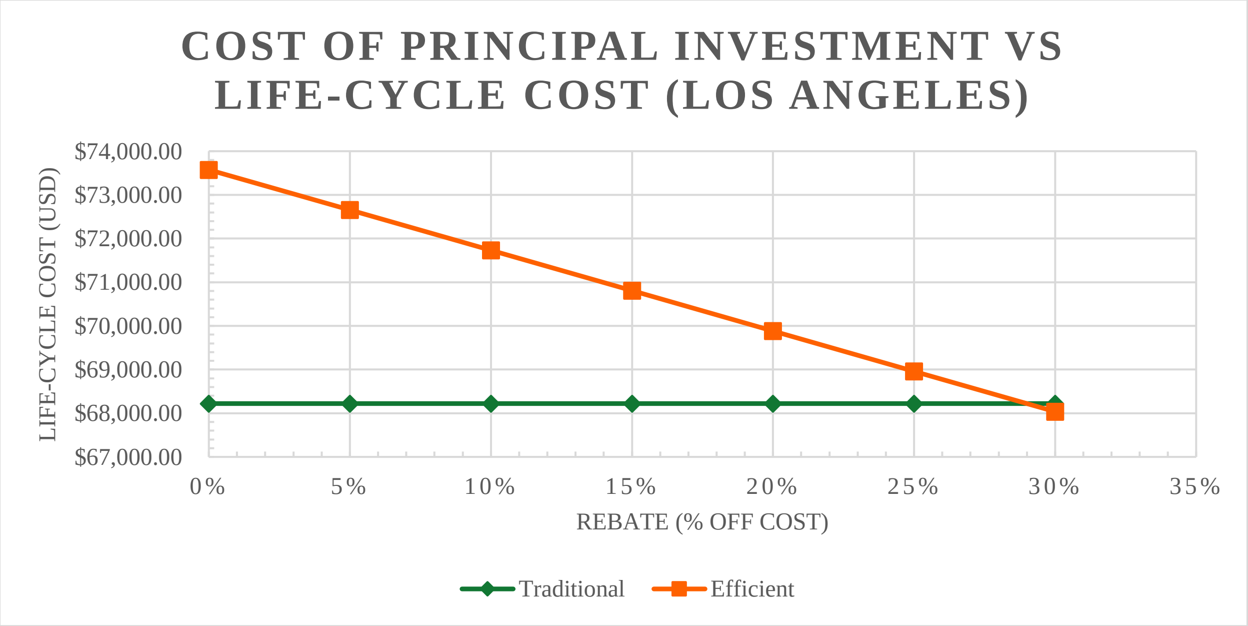

Figure 10. Cost of Principal Investment vs Life-cycle Cost for Los Angeles

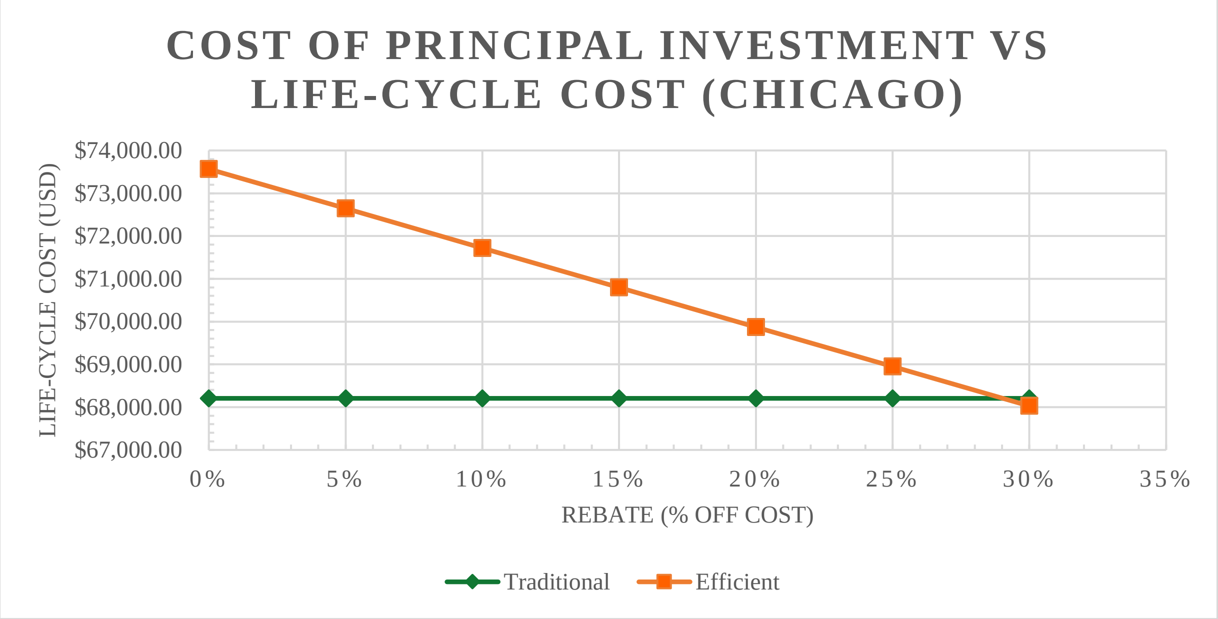

Figure 11. Cost of Principal Investment vs Life-cycle Cost for Chicago

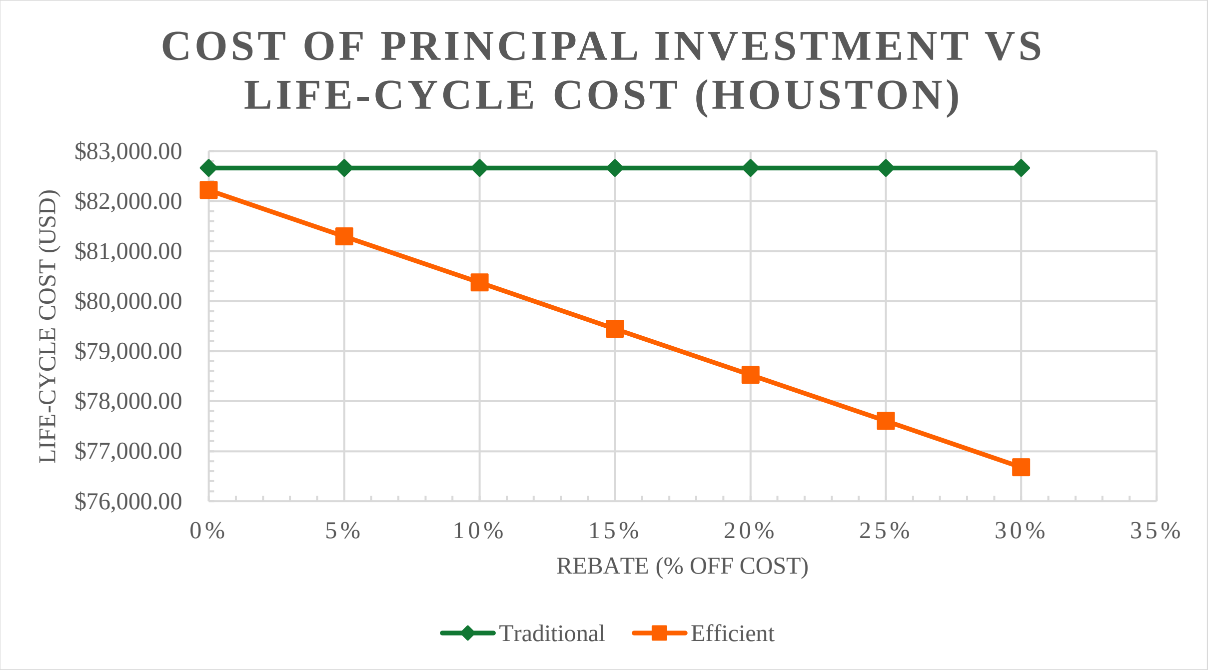

Figure 12. Cost of Principal Investment vs Life-cycle Cost for Houston

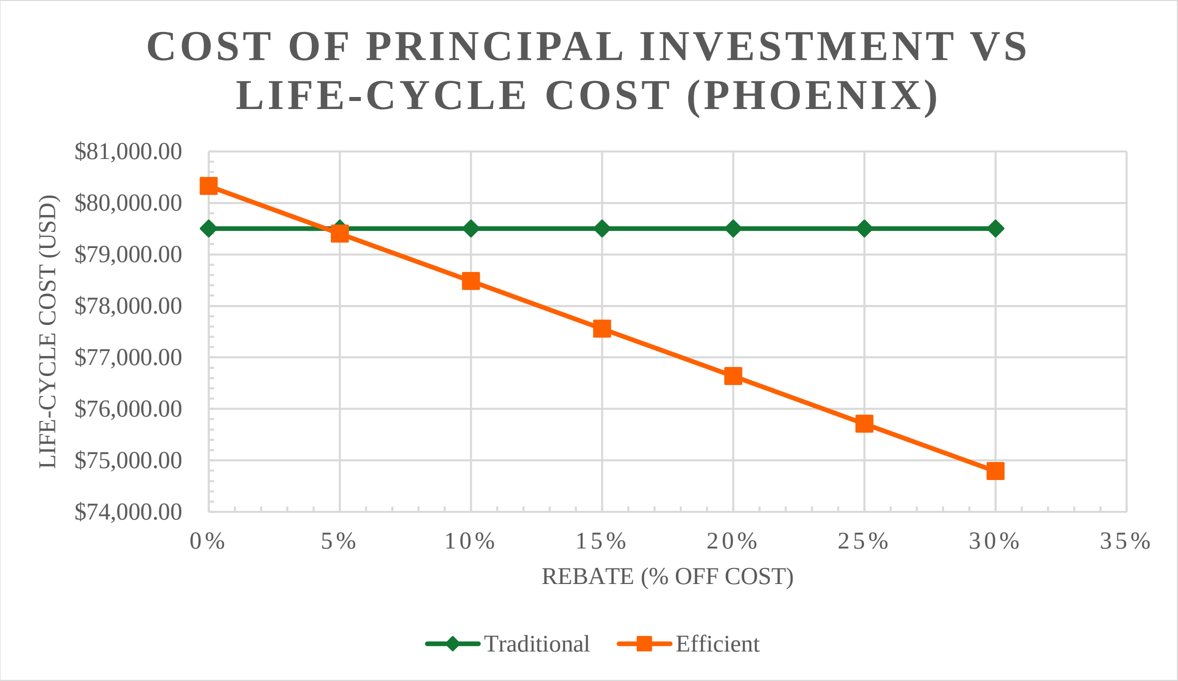

Figure 13. Cost of Principal Investment vs Life-cycle Cost for Phoenix

Cost of Regular Replacement

In this section, the effect that the cost of principal investment of efficient appliances has on output parameters will be explored. The cost of regular replacement for each city will be modified by increasing the appliance life expectancy in 1-year increments to chart the changes made to output parameters as these input parameters are changed. These changes will be made until efficient appliances return results indicating beneficial financial performance. Final values required to achieve beneficial financial performance will be displayed in tabulated form and will be compared to their original input parameter values. For the sake of clarity, the only output values shown in the main text will be the life-cycle costs. All other supplementary measures will be within the Appendix.

The following table, Table 24. shows the initial input parameter for cost of regular replacement alongside the minimum necessary cost of regular replacement to attain beneficial financial performance. Table 25. shows the ratios of change in the calculated life-cycle costs of traditional and efficient electrical appliances. These ratios are in relation not only to each other but also in relation to the change in input parameter. These ratios will be useful in determining which input parameters are most effective in helping efficient appliances attain beneficial financial performance.

The following figures, Figures 13-17, show an expanded version of what is shown in Table 24. The figures show the change in the cost of regular replacement as "Additional Years to Appliance Life Expectancy".

The following tables and figures demonstrate the effect that the cost of regular replacement has on the life-cycle costs of traditional and efficient electrical appliances. In sample city New York City, a $7,153.83 reduction in cost of replacement for traditional appliances and $8,660.30 reduction in cost of replacement led to a change of 11.5% and 13.55% in life-cycle costs respectively. In order for efficient appliances to attain beneficial financial performance in NYC, a necessary minimum of two additional years must be added to appliance life expectancy before replacement.

Once again, sample cities Los Angeles and Chicago required the greatest reduction in cost of regular replacement. In both Los Angeles and Chicago, a $13,244.60 reduction in replacement costs for traditional appliances and an $18,676.23 reduction in replacement costs for efficient appliances led to a change of 19.41% and 25.38% change in life-cycle costs respectively. Efficient appliances were able to achieve beneficial financial performance by extending replacements by an additional four years.

Sample city Phoenix required the lowest reduction in cost of regular replacement. A reduction of $3,365.97 in replacement costs for traditional appliances and $4330.15 for efficient appliances led to a 4.23% and 5.39% change in life-cycle costs respectively. Efficient appliances attained beneficial financial performance after extending the replacement timeline by only one additional year.

The average ratio of change in life-cycle costs for traditional and efficient appliances by modifying the cost of regular replacement was 0.79. The average ratio of change in input to change in life-cycle cost was 2.19 for traditional appliances, and 1.73 for efficient appliances.

Table 24. Initial Versus Minimal Necessary Cost of Replacement

New York City

Cost of Replacement (Efficient)	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
$38,255.20	$62,200.76	$63,897.49	-22.64%	-11.50%	-13.55%
$29,594.90	$55,046.94	$55,237.19			

Los Angeles

Cost of Replacement (Efficient)	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
$43,373.20	$68,222.01	$73,575.12	-43.06%	-19.41%	-25.38%
$24,696.97	$54,977.41	$54,898.90			

Chicago

Cost of Replacement (Efficient)	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
$43,373.20	$68,205.22	$73,565.08	-43.06%	-19.42%	-25.39%
$24,696.97	$54,960.62	$54,888.85			

Houston

Cost of Replacement (Efficient)	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
$43,373.20	$82,660.68	$82,217.04	0.00%	0.00%	0.00%
$43,373.20	$82,660.68	$82,217.04			

Phoenix

Cost of Replacement (Efficient)	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
$43,373.20	$79,502.24	$80,326.63	-9.98%	-4.23%	-5.39%
$39,043.05	$76,136.27	$75,996.48			

Table 25. Ratios of Change of Calculated Life-cycle Costs of Electrical Appliances

<table>
<tr><th colspan="3">New York City</th></tr>
<tr><th>Ratio of Change in LCC</th><th>Ratio of Change in Input to Change in Traditional LCC</th><th>Ratio of Change in Input to Change in Efficient LCC</th></tr>
<tr><td>0.85</td><td>1.97</td><td>1.67</td></tr>
<tr><th colspan="3">Los Angeles</th></tr>
<tr><th>Ratio of Change in LCC</th><th>Ratio of Change in Input to Change in Traditional LCC</th><th>Ratio of Change in Input to Change in Efficient LCC</th></tr>
<tr><td>0.76</td><td>2.22</td><td>1.70</td></tr>
<tr><th colspan="3">Chicago</th></tr>
<tr><th>Ratio of Change in LCC</th><th>Ratio of Change in Input to Change in Traditional LCC</th><th>Ratio of Change in Input to Change in Efficient LCC</th></tr>
<tr><td>0.76</td><td>2.22</td><td>1.70</td></tr>
<tr><th colspan="3">Houston</th></tr>
<tr><th>Ratio of Change in LCC</th><th>Ratio of Change in Input to Change in Traditional LCC</th><th>Ratio of Change in Input to Change in Efficient LCC</th></tr>
<tr><td>0.00</td><td>0.00</td><td>0.00</td></tr>
<tr><th colspan="3">Phoenix</th></tr>
<tr><th>Ratio of Change in LCC</th><th>Ratio of Change in Input to Change in Traditional LCC</th><th>Ratio of Change in Input to Change in Efficient LCC</th></tr>
<tr><td>1.85</td><td>1.00</td><td>1.85</td></tr>
<tr><th colspan="3">Average</th></tr>
<tr><th>Ratio of Change in LCC</th><th>Ratio of Change in Input to Change in Traditional LCC</th><th>Ratio of Change in Input to Change in Efficient LCC</th></tr>
<tr><td>1.06</td><td>1.85</td><td>1.73</td></tr>
</table>

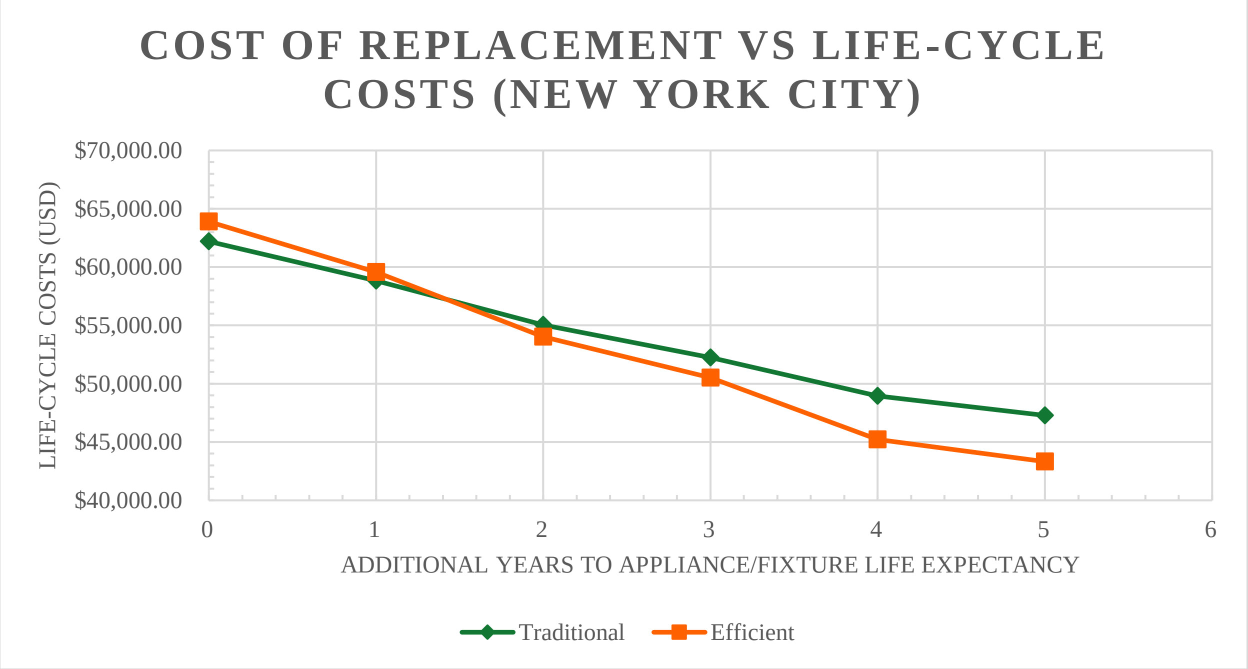

Figure 14. Cost of Replacement vs Life-cycle Costs for New York City

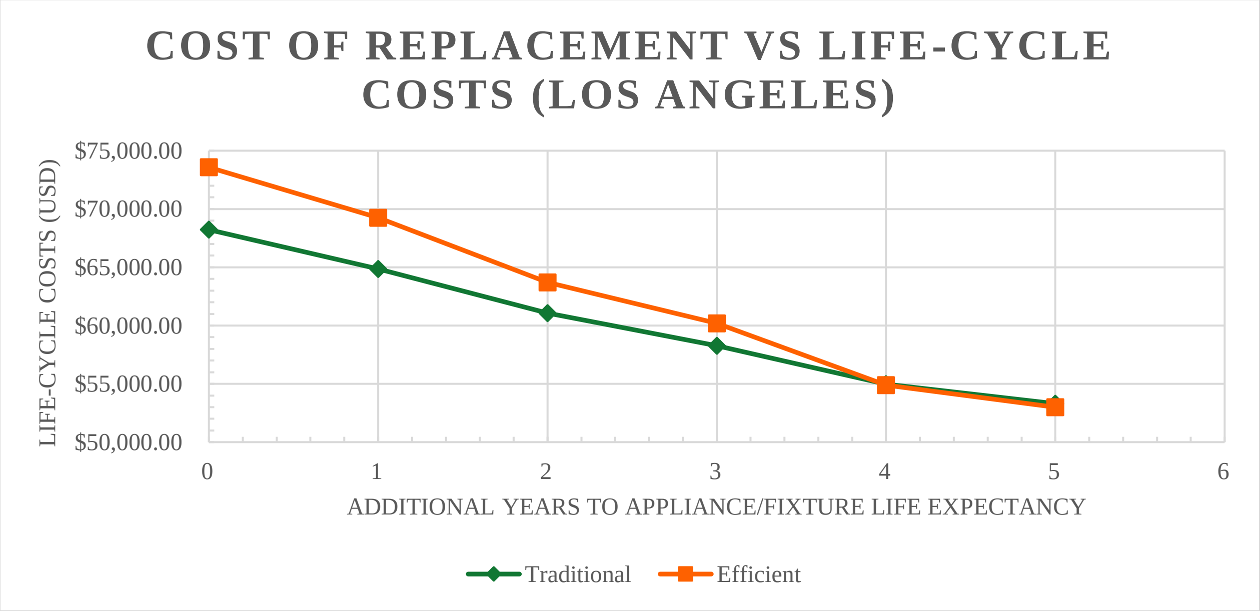

Figure 15. Cost of Replacement vs Life-cycle Costs for Los Angeles

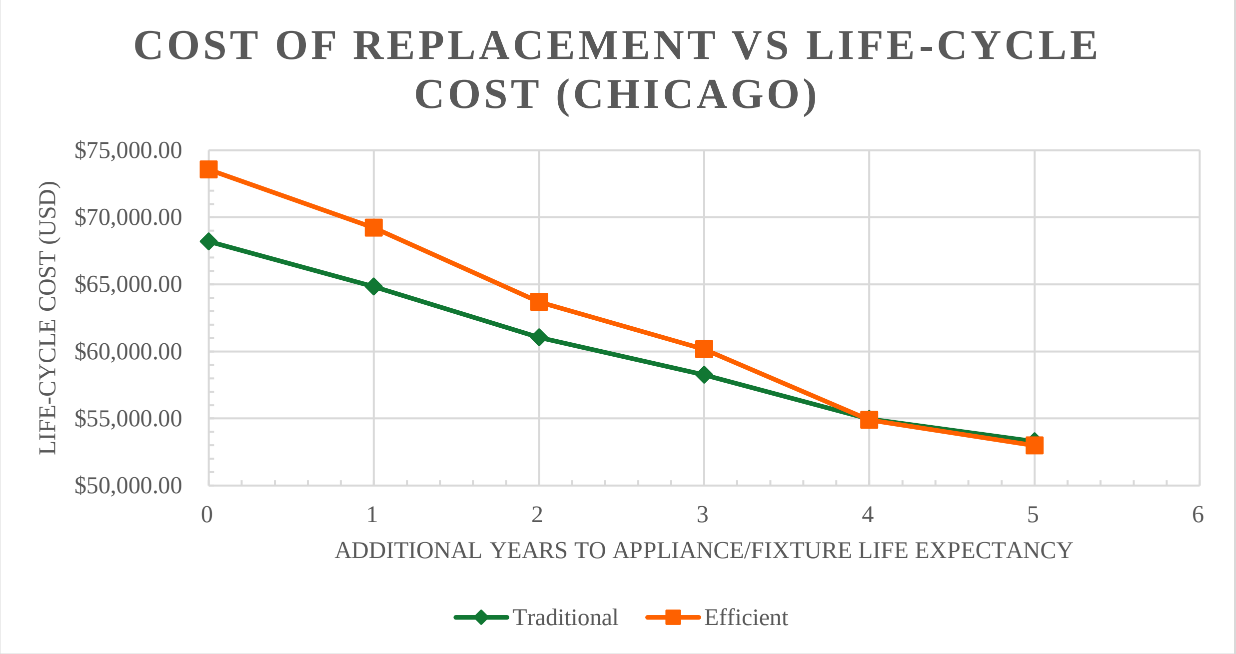

Figure 16. Cost of Replacement vs Life-cycle Costs for Chicago

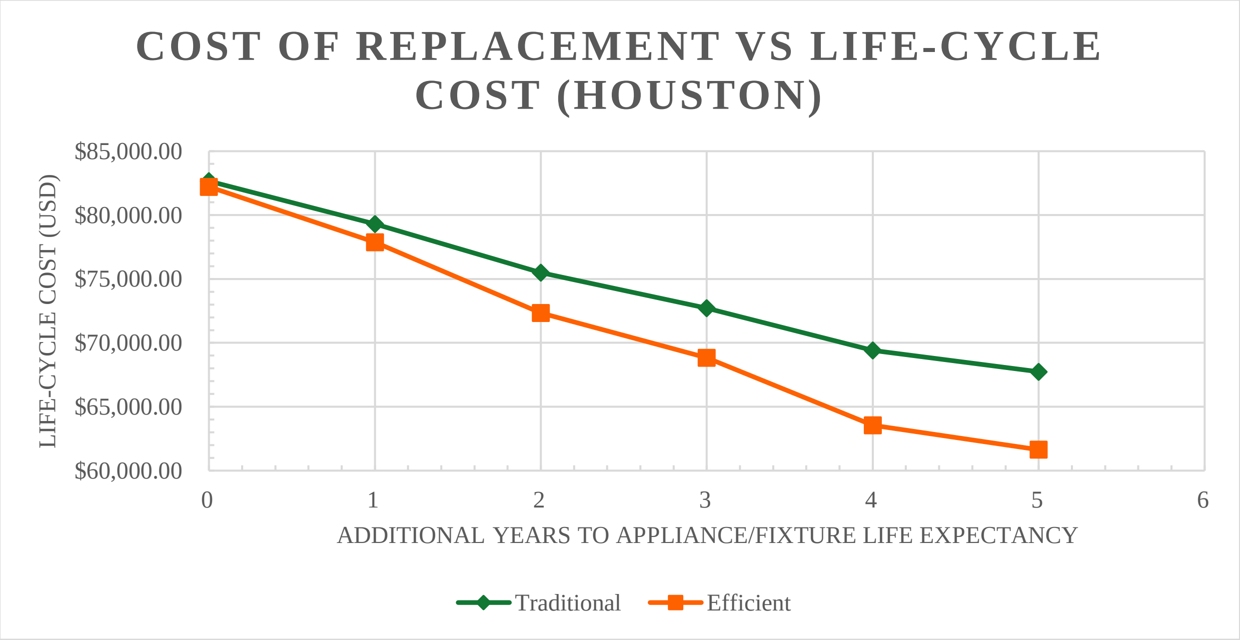

Figure 17. Cost of Replacement vs Life-cycle Costs for Houston

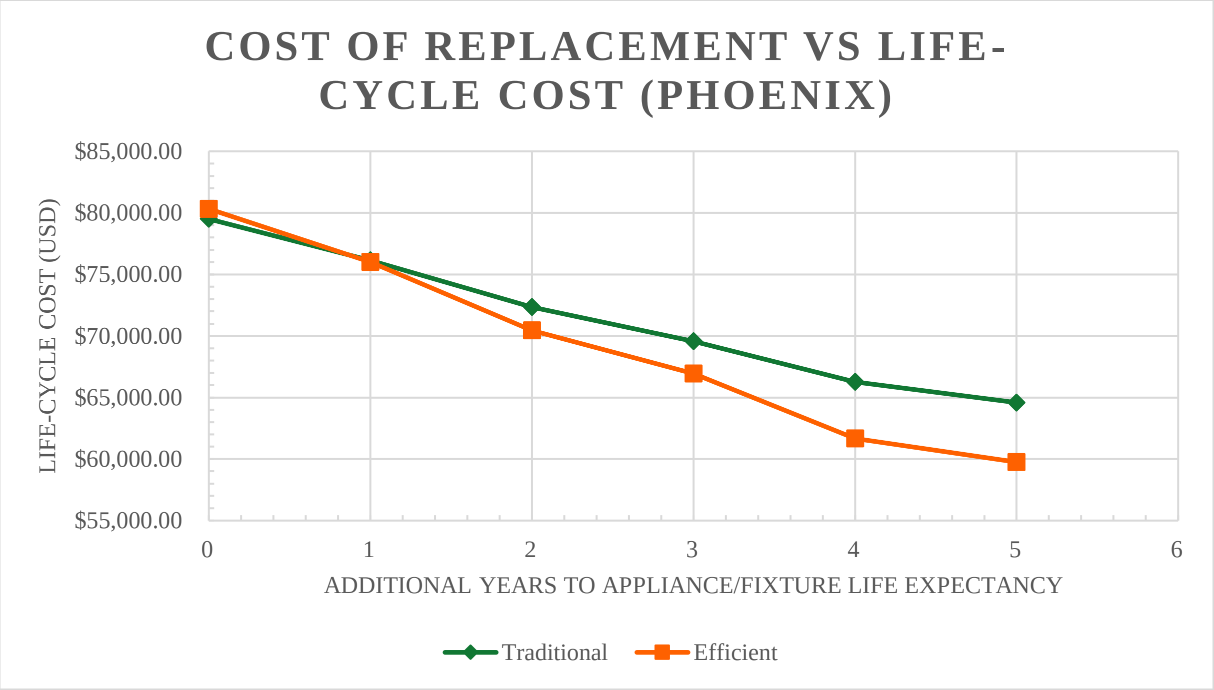

Figure 18. Cost of Replacement vs Life-cycle Costs for Phoenix

Nominal Discount Rate

In this section, the effect that the nominal discount rate has on output parameters will be explored. The nominal discount rate will be modified by increasing and decreasing the nominal discount rate in 0.5% increments to chart the changes made to output parameters as these input parameters are changed. These changes will be made until efficient appliances return results indicating beneficial financial performance. Final values required to achieve beneficial financial performance will be displayed in tabulated form and will be compared to their original input parameter values. For the sake of clarity, the only output values shown in the main text will be the life-cycle costs. All other supplementary measures will be within the Appendix.

The following table, Table 26. shows the initial input parameter for nominal discount rate alongside the minimum necessary nominal discount rate to attain beneficial financial performance. Table 27. shows the ratios of change in the calculated life-cycle costs of traditional and efficient electrical appliances. These ratios are in relation not only to each other but also in relation to the change in input parameter. These ratios will be useful in determining which input parameters are most effective in helping efficient appliances attain beneficial financial performance.

The following figures, Figures 18-22, show an expanded version of what is shown in Table 26.

The following tables and figures provide an illustration of what effect the nominal discount rate has on the life-cycle costs of traditional and efficient electrical appliances. In sample city, NYC by reducing the nominal discount rate from 2.5% to 1%, the life-cycle costs of traditional and efficient appliances saw a 9.23% and 5.38% change respectively. Sample cities Los Angeles and Chicago did not attain beneficial financial performance for any nominal discount rate above 0%, therefore their values for “Percent Change of Input”, “Percent Change of Traditional LCC”, and “% Change of Efficient LCC” cannot be calculated.

Again, sample city Phoenix required the least change in nominal discount rate to attain beneficial financial performance. By reducing the nominal discount rate from 2.5% to 2.0%, the life-cycle costs of traditional and efficient appliances changed by 3.25% and 1.93% respectively.

The average ratio of change in LCC for reducing the nominal discount rate was 1.7, and the ratio of change in input to change in life-cycle cost for traditional and efficient appliances was 6.32 and 10.77 respectively.

Table 26. Initial Versus Minimal Necessary Nominal Discount Rate

New York City					
Nominal Discount Rate	**Traditional LCC**	**Efficient LCC**	**% Change of Input**	**% Change of Traditional LCC**	**% Change of Efficient LCC**
2.50%	$62,200.76	$63,897.49	-60.00%	9.23%	5.38%
1.00%	$67,939.50	$67,332.27			
Los Angeles					
Nominal Discount Rate	**Traditional LCC**	**Efficient LCC**	**% Change of Input**	**% Change of Traditional LCC**	**% Change of Efficient LCC**
2.50%	$68,222.01	$73,575.12	-	-	-
-	-	-			
Chicago					
Nominal Discount Rate	**Traditional LCC**	**Efficient LCC**	**% Change of Input**	**% Change of Traditional LCC**	**% Change of Efficient LCC**
2.50%	$68,205.22	$73,565.08	-	-	-
-	-	-			
Houston					
Nominal Discount Rate	**Traditional LCC**	**Efficient LCC**	**% Change of Input**	**% Change of Traditional LCC**	**% Change of Efficient LCC**
2.50%	$82,660.68	$82,217.04	0.00%	0.00%	0.00%
2.50%	$82,660.68	$82,217.04			
Phoenix					
Nominal Discount Rate	**Traditional LCC**	**Efficient LCC**	**% Change of Input**	**% Change of Traditional LCC**	**% Change of Efficient LCC**
2.50%	$79,502.24	$80,326.63	-20.00%	3.25%	1.93%
2.00%	$82,089.41	$81,875.12			

Table 27. Ratios of Change of Calculated Life-cycle Costs of Electrical Appliances

New York City		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.72	6.50	11.16
Los Angeles		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
-	-	-
Chicago		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
-	-	-
Houston		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
0.00	0.00	0.00
Phoenix		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.69	6.15	10.37
Average		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.70	6.32	10.77

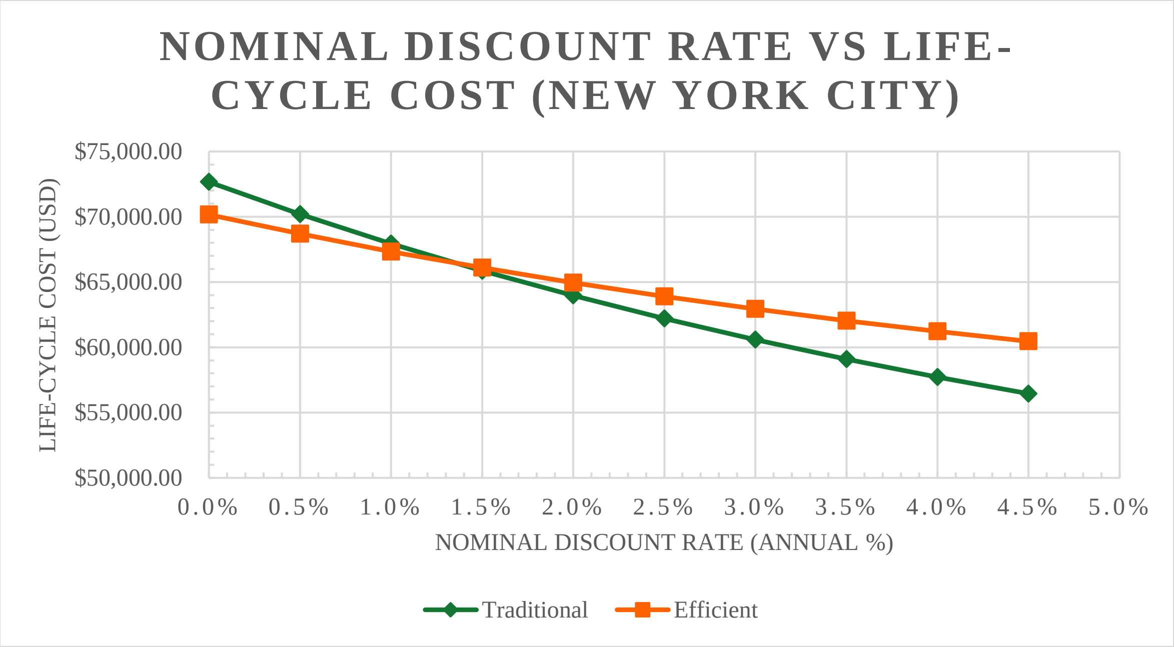

Figure 19. Nominal Discount Rate vs Life-cycle Cost for New York City.

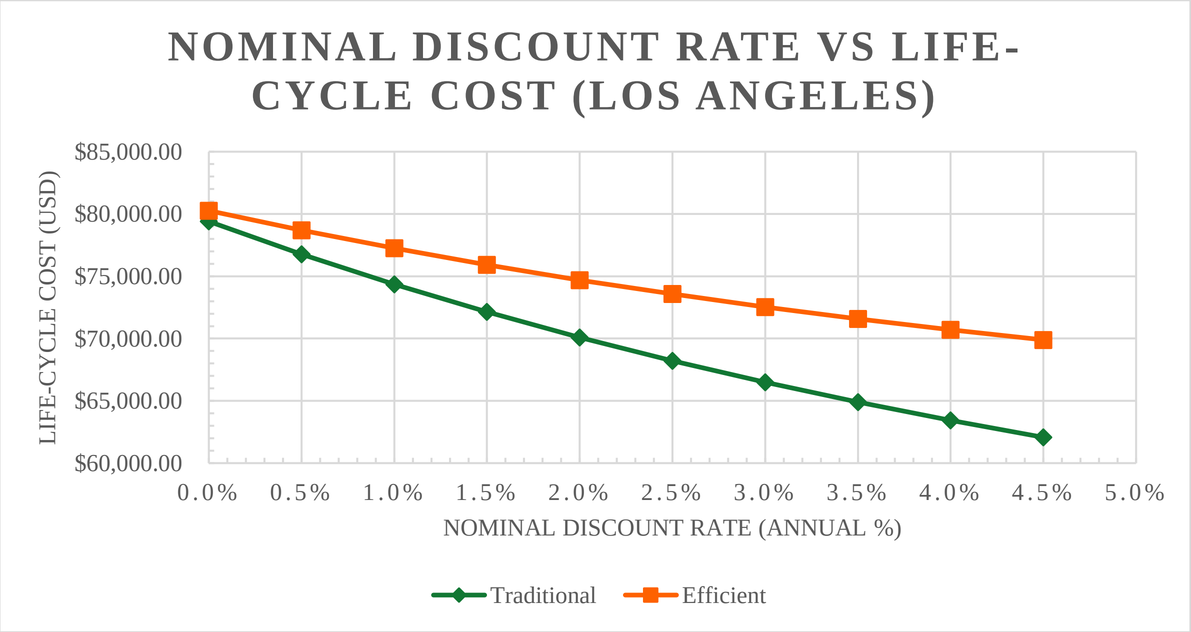

Figure 20. Nominal Discount Rate vs Life-cycle Cost for Los Angeles.

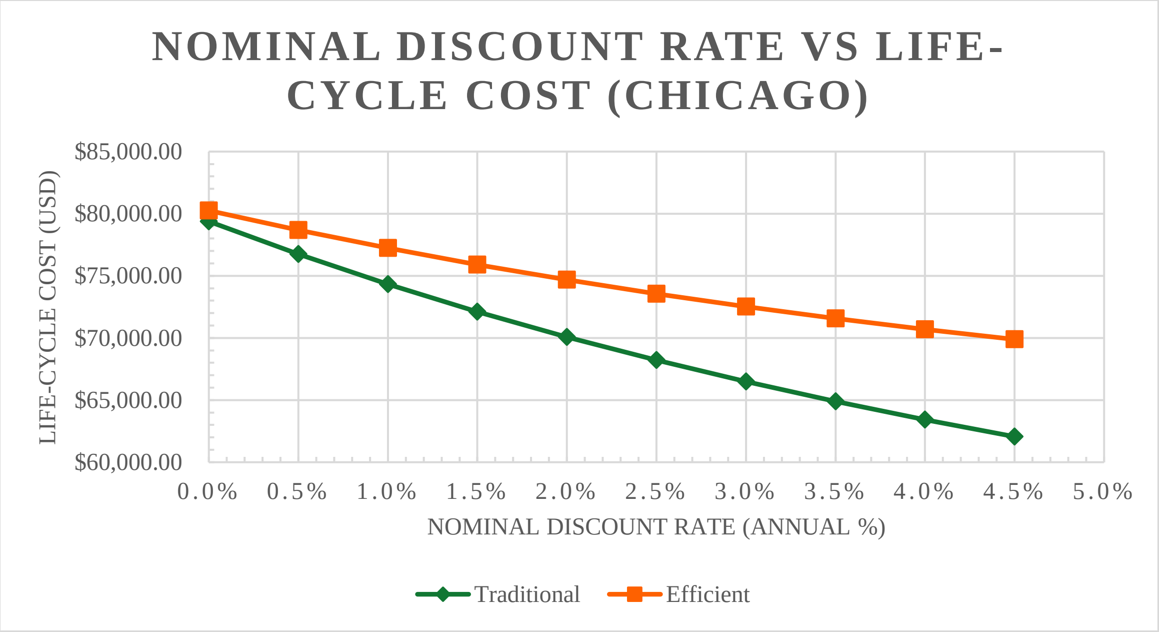

Figure 21. Nominal Discount Rate vs Life-cycle Cost for Chicago.

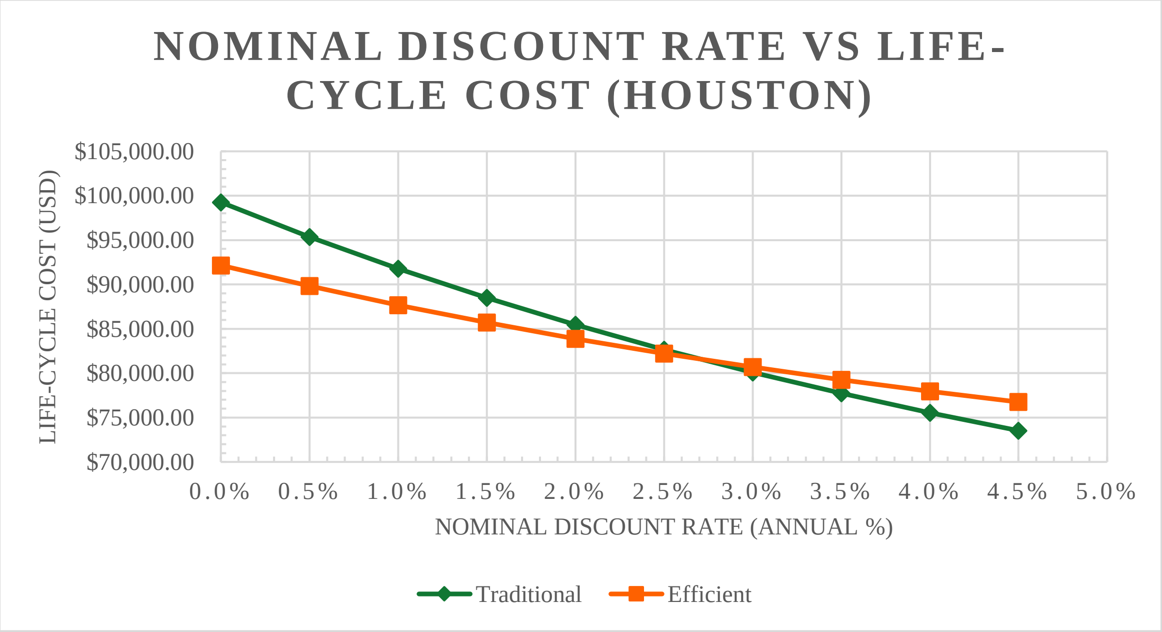

Figure 22. Nominal Discount Rate vs Life-cycle Cost for Houston.

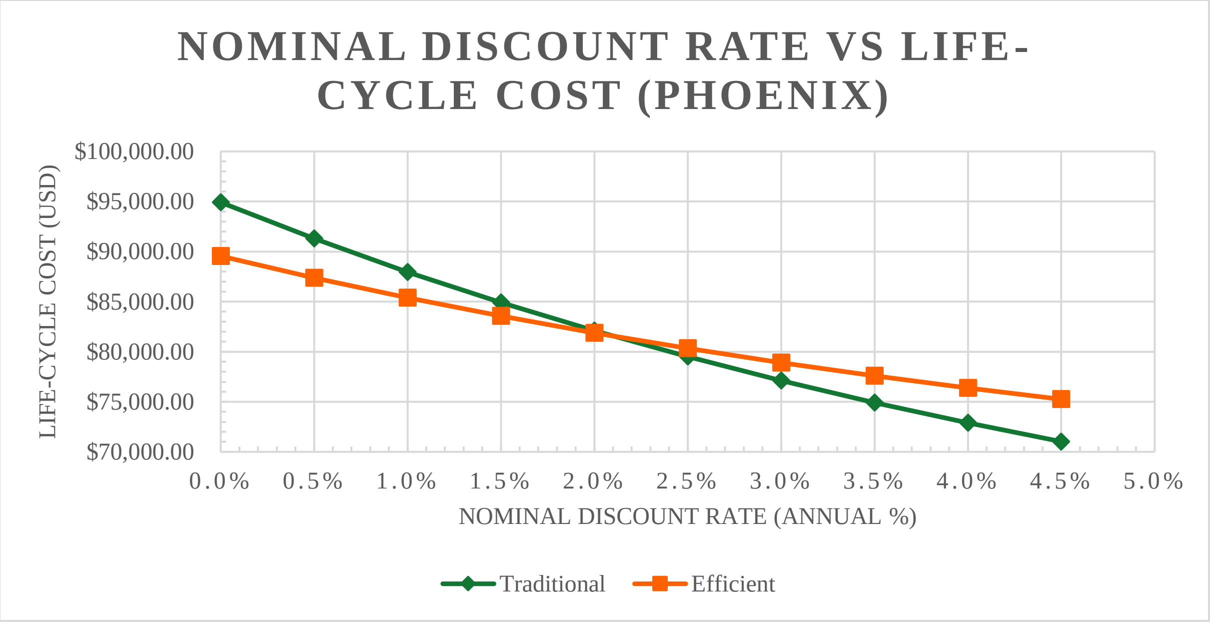

Figure 23. Nominal Discount Rate vs Life-cycle Cost for Phoenix

Energy Rate Escalation

In this section, the effect that the energy rate escalation has on output parameters will be explored. The energy rate escalation will be modified by increasing and decreasing the energy rate escalation in 0.5% increments to chart the changes made to output parameters as these input parameters are changed. These changes will be made until efficient appliances return results indicating beneficial financial performance. Final values required to achieve beneficial financial performance will be displayed in tabulated form and will be compared to their original input parameter values. For the sake of clarity, the only output values shown in the main text will be the life-cycle costs. All other supplementary measures will be within the Appendix.

The following table, Table 28. shows the initial input parameter for energy rate escalation alongside the minimum necessary energy rate escalation to attain beneficial financial performance. Table 29. shows the ratios of change in the calculated life-cycle costs of traditional and efficient electrical appliances. These ratios are in relation not only to each other but also in relation to the change in input parameter. These ratios will be useful in determining which input parameters are most effective in helping efficient appliances attain beneficial financial performance. The following figures, Figures 22-26, show an expanded version of what is shown in Table 28.

The following tables and figures illustrate the effect that energy rate escalation has on the life-cycle costs of traditional and efficient electrical appliances. For example, sample city NYC an increase in energy escalation rate 3.0%, up from 1.68% was necessary to attain beneficial financial performance for efficient appliances. This increase in energy escalation rate led to a change in life-cycle costs for traditional and efficient appliances of 7.95% and 4.63% respectively.

Both sample cities Los Angeles and Chicago required that the energy escalation rate be raised from 1.68% to 5.0% in order for efficient appliances to attain beneficial financial performance. By increasing the energy escalation rate to 5%, the change in life-cycle costs for traditional and efficient appliances was changed by 23.27% and 12.91% respectively.

Once again, Phoenix required the least change to energy escalation rate to attain beneficial financial performance. For an energy escalation rate of 2.75% life-cycle costs for traditional and efficient appliances were changed 7.28% and 4.31% respectively.

The average rate of change in life-cycle costs from increasing the energy escalation rate was 1.75. The average change in input to change in traditional and efficient life-cycle costs was 8.91 and 15.59 respectively.

Table 28. Initial Versus Minimal Necessary Energy Rate Escalation

New York City

Energy Rate Escalation	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
1.68%	$62,200.76	$63,897.49	78.57%	7.95%	4.63%
3.00%	$67,146.59	$66,857.69			

Los Angeles

Energy Rate Escalation	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
1.68%	$68,222.01	$73,575.12	197.62%	23.27%	12.91%
5.00%	$84,094.04	$83,074.94			

Chicago

Energy Rate Escalation	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
1.68%	$68,205.22	$73,565.08	197.62%	23.26%	12.91%
5.00%	$84,068.31	$83,059.54			

Houston

Energy Rate Escalation	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
1.68%	$82,660.68	$82,217.04	0.00%	0.00%	0.00%
1.68%	$82,660.68	$82,217.04			

Phoenix

Energy Rate Escalation	Traditional LCC	Efficient LCC	% Change of Input	% Change of Traditional LCC	% Change of Efficient LCC
1.68%	$79,502.24	$80,326.63	63.69%	7.28%	4.31%
2.75%	$85,288.89	$83,790.09			

Table 29. Ratios of Change of Calculated Life-cycle Costs of Electrical Appliances

New York City

Ratio of Change in LCC	Ratio of Change in Input to Change in Traditional LCC	Ratio of Change in Input to Change in Efficient LCC
1.72	9.88	16.96

Los Angeles

Ratio of Change in LCC	Ratio of Change in Input to Change in Traditional LCC	Ratio of Change in Input to Change in Efficient LCC
1.80	8.49	15.31

Chicago

Ratio of Change in LCC	Ratio of Change in Input to Change in Traditional LCC	Ratio of Change in Input to Change in Efficient LCC
1.80	8.50	15.31

Houston

Ratio of Change in LCC	Ratio of Change in Input to Change in Traditional LCC	Ratio of Change in Input to Change in Efficient LCC
0.00	0.00	0.00

Phoenix

Ratio of Change in LCC	Ratio of Change in Input to Change in Traditional LCC	Ratio of Change in Input to Change in Efficient LCC
1.69	8.75	14.77

Average

Ratio of Change in LCC	Ratio of Change in Input to Change in Traditional LCC	Ratio of Change in Input to Change in Efficient LCC
1.75	8.91	15.59

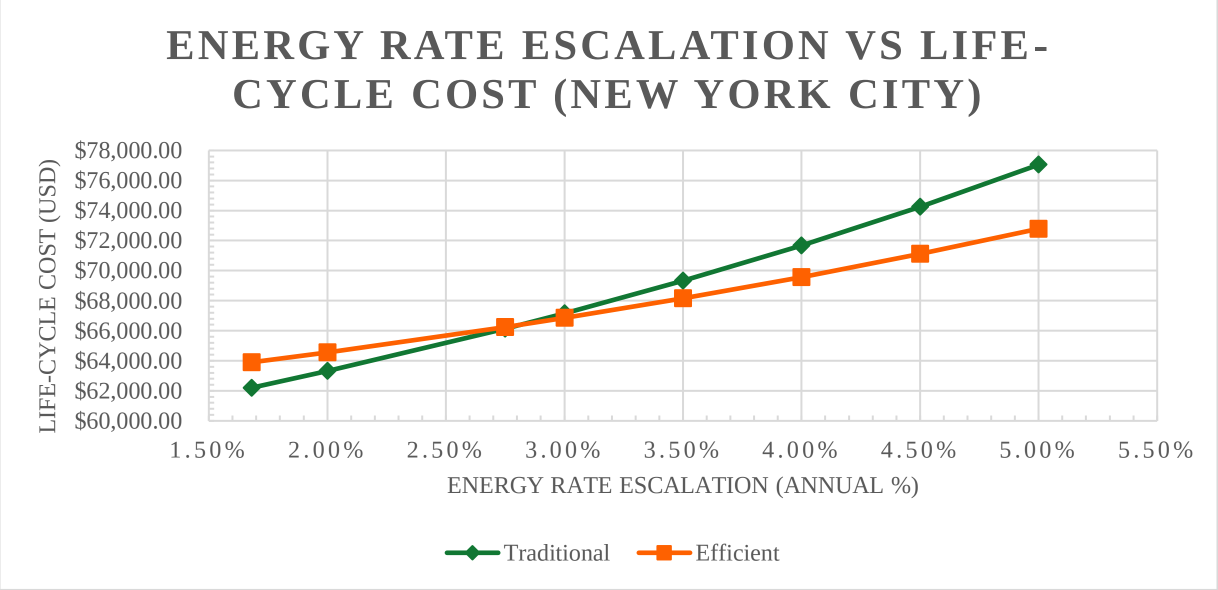

Figure 24. Energy Rate Escalation vs Life-cycle Cost for New York City

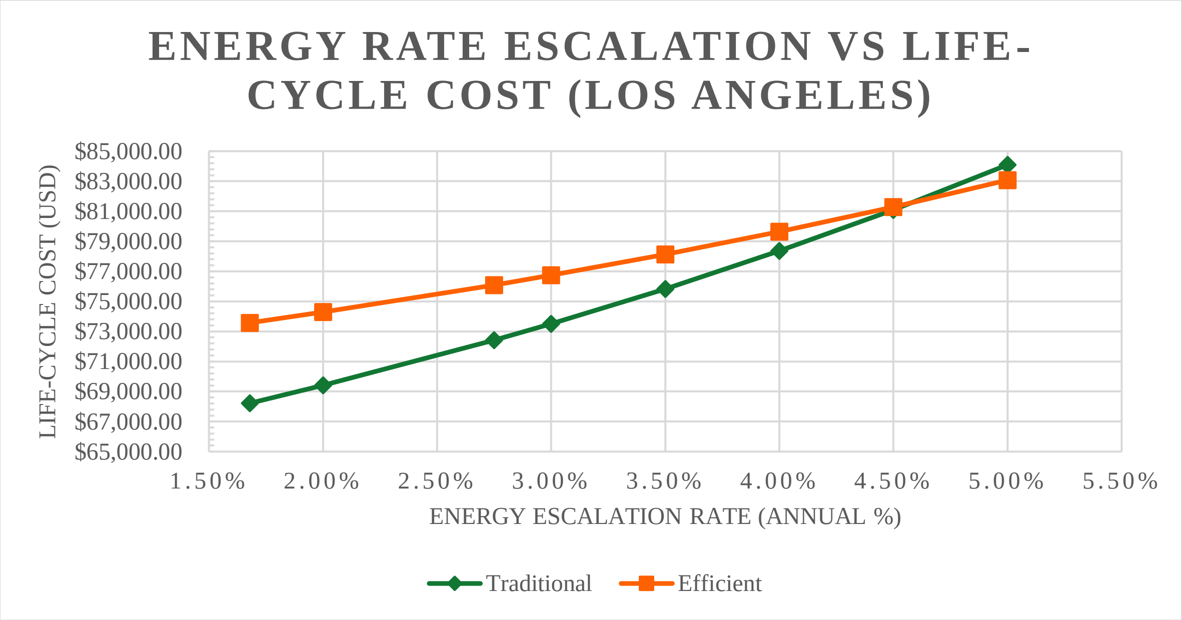

Figure 25. Energy Rate Escalation vs Life-cycle Cost for Los Angeles

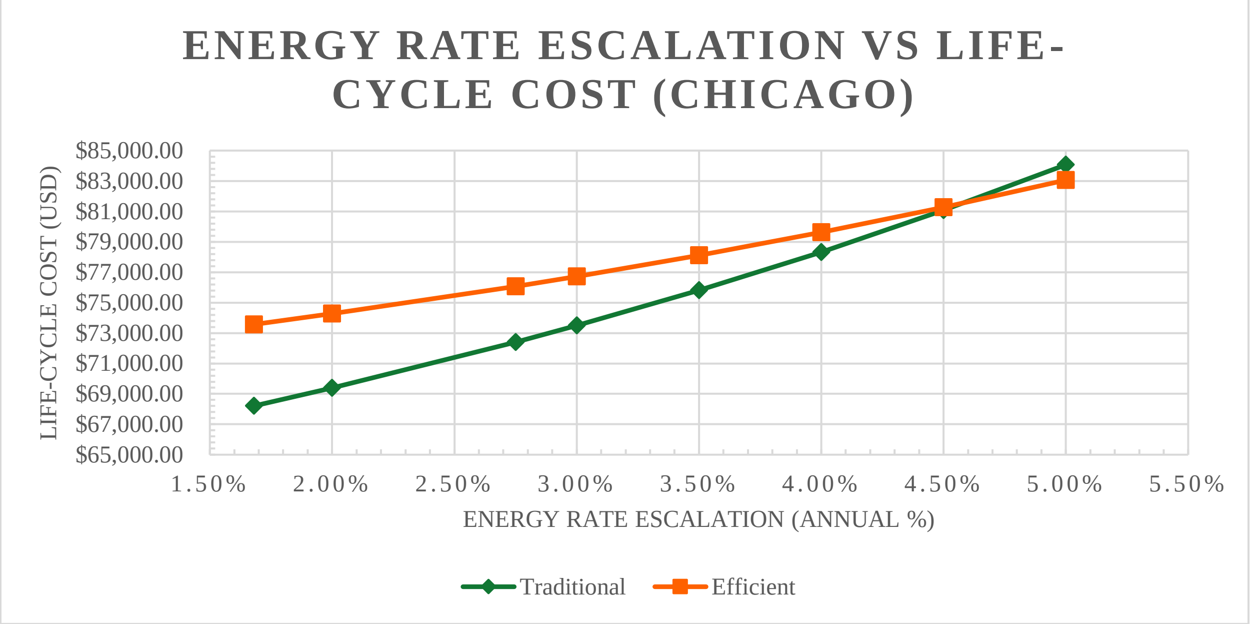

Figure 26. Energy Rate Escalation vs Life-cycle Cost for Chicago

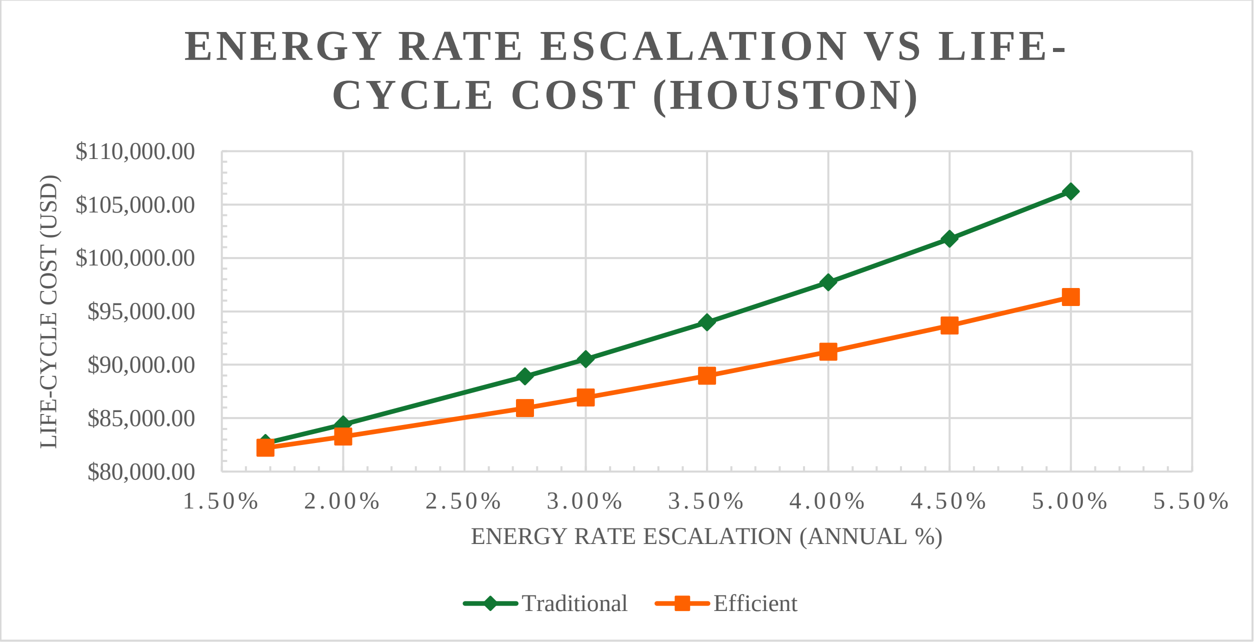

Figure 27. Energy Rate Escalation vs Life-cycle Cost for Houston

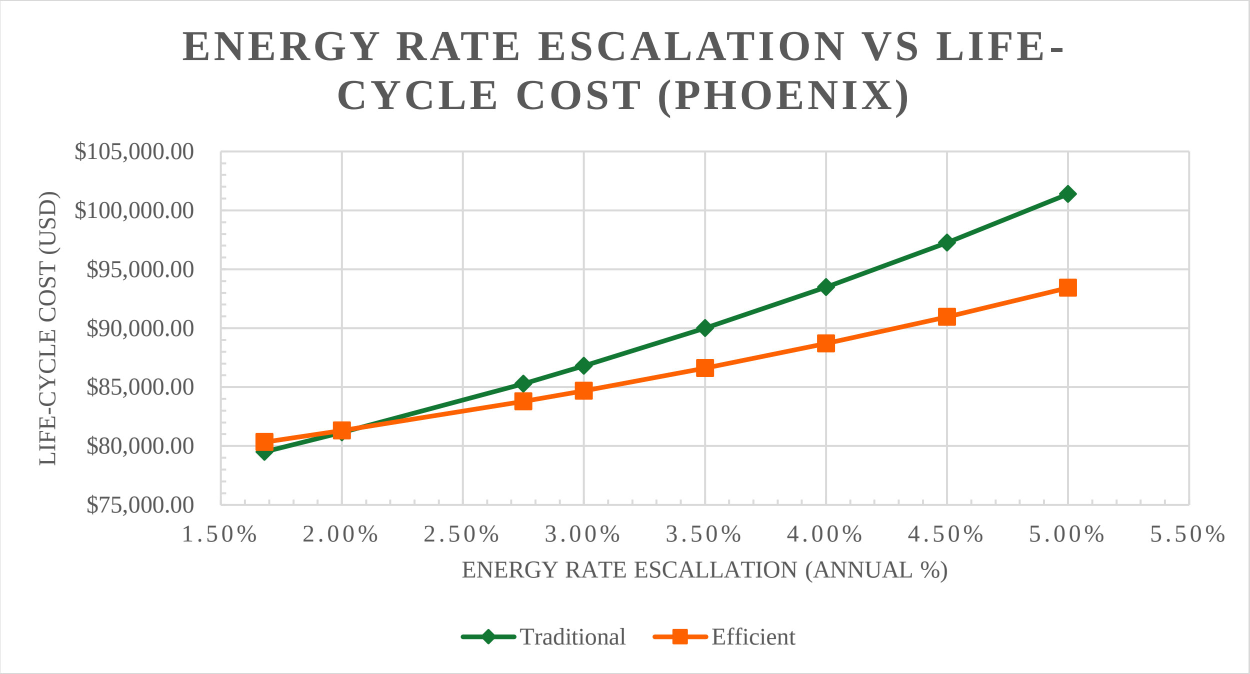

Figure 28. Energy Rate Escalation vs Life-cycle Cost for Phoenix

Summary of Sensitivity Analysis

In the preceding sub-sections, input parameters were modified to gain an understanding of the effect that they have on the output values of the life-cycle cost analysis. This section serves as a point of condensation for the ratios of change calculated for each parameter changed and will be organized by city. Following this section, recommendations will be made for which input parameters are necessary to be changed in order for efficient appliances to attain beneficial financial performance.

Table 30. Ratios of Change for each Input Parameter Modified for New York City

New York City		
Rate of Electricity Charged		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.72	2.23	3.83
Cost of Principal Investment		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
-	-	4.79
Cost of Regular Replacement		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
0.85	1.97	1.67
Nominal Discount Rate		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.72	6.50	11.16
Energy Rate Escalation		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.72	9.88	16.96

Table 31. Ratios of Change for each Input Parameter Modified for Los Angeles

Los Angeles		
Rate of Electricity Charged		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.80	2.29	4.13
Cost of Principal Investment		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
-	-	3.99
Cost of Regular Replacement		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
0.76	2.22	1.70
Nominal Discount Rate		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
-	-	-
Energy Rate Escalation		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.80	8.49	15.31

Table 32. Ratios of Change for each Input Parameter Modified for Chicago

Chicago		
Rate of Electricity Charged		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.80	2.29	4.13
Cost of Principal Investment		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
-	-	3.98
Cost of Regular Replacement		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
0.76	2.22	1.70
Nominal Discount Rate		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
-	-	-
Energy Rate Escalation		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.80	8.50	15.31

Table 33. Ratios of Change for each Input Parameter Modified for Houston

Houston		
Rate of Electricity Charged		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
0.00	0.00	0.00
Cost of Principal Investment		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
0.00	0.00	0.00
Cost of Regular Replacement		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
0.00	0.00	0.00
Nominal Discount Rate		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
0.00	0.00	0.00
Energy Rate Escalation		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
0.00	0.00	0.00

Table 34. Ratios of Change for each Input Parameter Modified for Phoenix

Phoenix		
Rate of Electricity Charged		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.69	1.94	3.27
Cost of Principal Investment		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
-	-	4.35
Cost of Regular Replacement		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
0.79	2.36	1.85
Nominal Discount Rate		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.69	6.15	10.37
Energy Rate Escalation		
Ratio of Change in LCC	**Ratio of Change in Input to Change in Traditional LCC**	**Ratio of Change in Input to Change in Efficient LCC**
1.75	8.91	15.59

Recommendations & Future Work

In this section, recommendations will be made regarding what necessary changes to input parameters must be made in order for efficient appliances to attain beneficial financial performance. Recommendations will be based on the ratios of change summarized in the preceding sub-section, the modified input parameter that results in the greatest ratio of change in life-cycle costs will be considered the most effective method of helping efficient appliances attain beneficial financial performance. Modified input parameters that result in the same value for ratio of change in life-cycle costs will be further broken down by the ratio of change in input to change in efficient life-cycle cost, the higher this ratio, the more effective the modified input parameter is at helping efficient appliances attain beneficial financial performance.

For sample city NYC, the most effective method of helping efficient appliances achieve beneficial financial performance was increasing the energy rate escalation. Increasing the energy rate escalation from 1.68% to 3.0% was sufficient to lead to a ratio of change in life-cycle costs of 1.72, this same modification led to a ratio of change in input to change in efficient life-cycle costs of 16.96, whereas this ratio for traditional life-cycle costs was only 9.88. The second most effective modification of input parameters was reducing the nominal discount rate. Reducing the nominal discount rate from 2.5% to 1.0% was sufficient to lead to a ratio of change in life-cycle costs of 1.72, the ratio of change in input to change in efficient life-cycle cost was 11.16, whereas for efficient appliances this ratio was only 6.5. The least effective modification of input parameters was the cost of regular replacement. By extending the schedule of replacement for appliances and fixture by an additional 2 years, this only led to a ratio of change in life-cycle costs of 0.85, the ratios of change in input to change in efficient and traditional life-cycle costs were 1.67 and 1.97 respectively.

In sample city Los Angeles, the most effective modification of input parameters to help efficient appliances attain beneficial financial performance was, again, increasing the energy escalation rate. However, Los Angeles required a much higher energy rate escalation to attain minimum acceptable performance- energy rate escalation had to be increased from 1.68% to 5.0%. This increase was sufficient to lead to a ratio of change in life-cycle costs of 1.80, modifying this input parameter led to a ratio of change in input to change in efficient life-cycle cost of 15.31, whereas this ratio for traditional appliances was 8.49. Unlike sample city NYC, the second most effective modification of input parameters was not the nominal discount rate, rather the rate of electricity charged was the most effective modification of input parameter. Increasing the rate of electricity charged per kilowatt hour from \$0.22 to \$0.32 was sufficient to cause a ratio of change in life-cycle costs of 1.80. This input modification led to a ratio of change in input to change in efficient life-cycle cost of 4.13, whereas this ratio for traditional appliances was 2.29. The least effective modification of input parameter for Los Angeles was, again, the nominal discount rate, energy efficient appliances in Los Angeles did not attain beneficial financial performance for any nominal discount rate greater than or equal to 0.0%.

For sample city Chicago, the most effective modification of input parameters was again, increasing the energy rate escalation. Much like for Los Angeles, increasing the energy rate escalation from 1.68% to 5.0% was sufficient to lead to a ratio of change in life-cycle costs of 1.80, with a ratio of change in input to change in efficient life-cycle cost of 15.31. This ratio for traditional appliances was only 8.5. The second most effective modification of input parameters was the rate of electricity charged. Increasing the rate of electricity charged from \$0.15 to \$0.22 was sufficient to lead to a ratio of change in input to change in life-cycle costs of 1.80, the ratio of change in input to change in efficient life-cycle costs was 4.13, and this ratio for traditional life-cycle costs was 2.29. In Chicago the least effective modification of input parameter was the nominal discount rate. Just as in sample city Los Angeles, Chicago did not attain beneficial financial performance of energy efficient appliances for any nominal discount rate greater than or equal to 0.0%.

In sample city Phoenix, the most effective modification of input parameter was, again, the energy escalation rate. By increasing the rate from 1.68% to 2.75%, this led to a ratio of change in life-cycle costs of 1.79. The ratio of change in input to change in efficient life-cycle cost for this modified input parameter was 15.59, and for traditional life-cycle costs was 8.91 The second most effective modification of input parameter was the nominal discount rate. Unlike sample cities Los Angeles and Chicago, Phoenix was able to attain beneficial financial performance by decreasing the nominal discount rate from 2.5% to 2.0%. This decrease in nominal discount rate resulted in a ratio of change in life-cycle costs of 1.69. The ratio of change in input to change in efficient life-cycle cost was 10.37 and for traditional life-cycle costs was 6.15 As with every other sample city, the least effective modification of input parameter was the cost of regular replacement. Extending the replacement schedule of appliances and fixtures by only 1 additional year only resulted in a ratio of change in life-cycle costs of 0.79.

Based on the ratios discussed in the sensitivity analysis, it is the recommendation of this author that the most effective modification in input parameters for helping efficient appliances attain beneficial financial performance is by raising the energy escalation rate. This modification of input parameter results in both the highest ratio of change in life-cycle costs as well as the highest ratios of change in input to change in efficient life-cycle cost. For the base set of input parameters used for most sample cities in this analysis, it cannot be reasonably recommended to invest in a full home of energy efficient electrical appliances and fixtures as described in this study.

Future work regarding this topic should include expanding the pool of sample cities will be useful in further investigating the effect that volume of energy consumption has on the cost-effectiveness of efficient appliances. Additionally, obtaining more detailed information regarding the volume of energy consumption through physical measurements and surveys will provide a clearer picture of the effectiveness of energy efficient home appliances.

Additionally, expanding this study to include the environmental benefits of reducing the volume of energy consumption may result in more beneficial financial performance of these appliances and may require less or no modification of input parameters to achieve this level of performance.

CHAPTER VI

CONCLUSION

This analysis examined residential water- and energy-efficiency through the lens of finance. With rising concerns about the effects of climate change, many consumers and homeowners are looking towards water- and energy-efficient appliances and fixtures to aid in mitigating their environmental impact by reducing the volumes of consumption of water and energy in their homes. Not only can these appliances and fixtures help in minimizing the carbon footprint of the residential sector, but they can also help save money on monthly water, sewerage, and energy bills. However, for many, water- and energy-efficient appliances are viewed as an investment with unknown returns; the cost of principal investment may be perceived as prohibitive to those interested in adopting these efficient appliances and fixtures.

The life-cycle cost analysis of water-efficient fixtures found that in all five sample cities, water-efficient fixtures performed exceedingly favorably. Not only did these appliances provide notable savings in monthly water and sewerage bills, but they also provided a notable decrease in the average monthly volume of indoor water consumption (see Chapter IV, Table X). Additionally, water efficient fixtures were able to “pay for themselves” approximately 8 months after the start of the study period. No modifications to the input parameters for the analysis of water-efficient fixtures was necessary to attain beneficial financial performance. Because of the universal excellent performance of these fixtures, investment in these water-efficient fixtures is universally recommended for the sample cities in this analysis.

The analysis of energy-efficient fixtures found that out of the five sample cities, only one, Houston, was expected to attain beneficial financial performance for the input parameters described in this study. Although sample city Phoenix did come close to attaining beneficial performance, the average rate for electricity was just low enough to prevent energy-efficient appliances from performing favorably. It is noted though, that the consumer will experience a reduction in monthly electric utility bills, however, in most cases, this accumulated savings is not enough to offset the incurred costs of investment and replacement. A sensitivity analysis revealed that two of the most effective changes in input parameters to help energy efficient appliances attain beneficial financial performance was by increasing the rate at which energy costs increase per year, or by increasing the cost of electricity charged per kilowatt hour.

For both analyses, this study utilized averages for each city leaving an area of opportunity for better or poorer financial performance depending on each individual’s patterns of water and energy consumption. Individual consumers with higher than average energy consumption may see increased financial performance of efficient appliances in cities whose outputs indicated that efficient appliances were not financially feasible.

While continuing to promote the adoption of water- and energy-efficient appliances and fixtures provides some relief to the carbon footprint left behind by the residential sector, the overall financial feasibility of efficient appliances for the average American returns mixed results.

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APPENDIX

APPENDIX

CONTINUATION OF SENSITIVITY ANALYSIS – SUPPLEMENTARY MEASURES

The following figures are a continuation of the sensitivity analysis performed in Chapter V – “Electric Appliance Analysis”. Figures displaying the effects of modifying input parameters will be organized input parameter modified, followed by the affected supplementary measure.

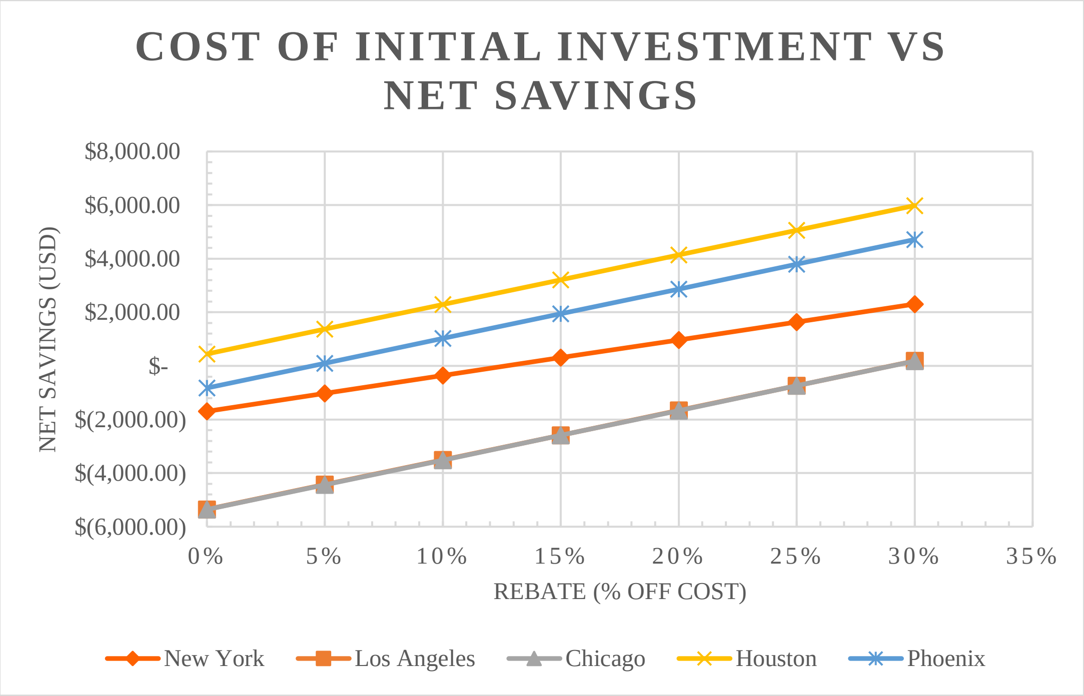

Figure 29. Cost of Principal Investment vs Net Savings for all cities.

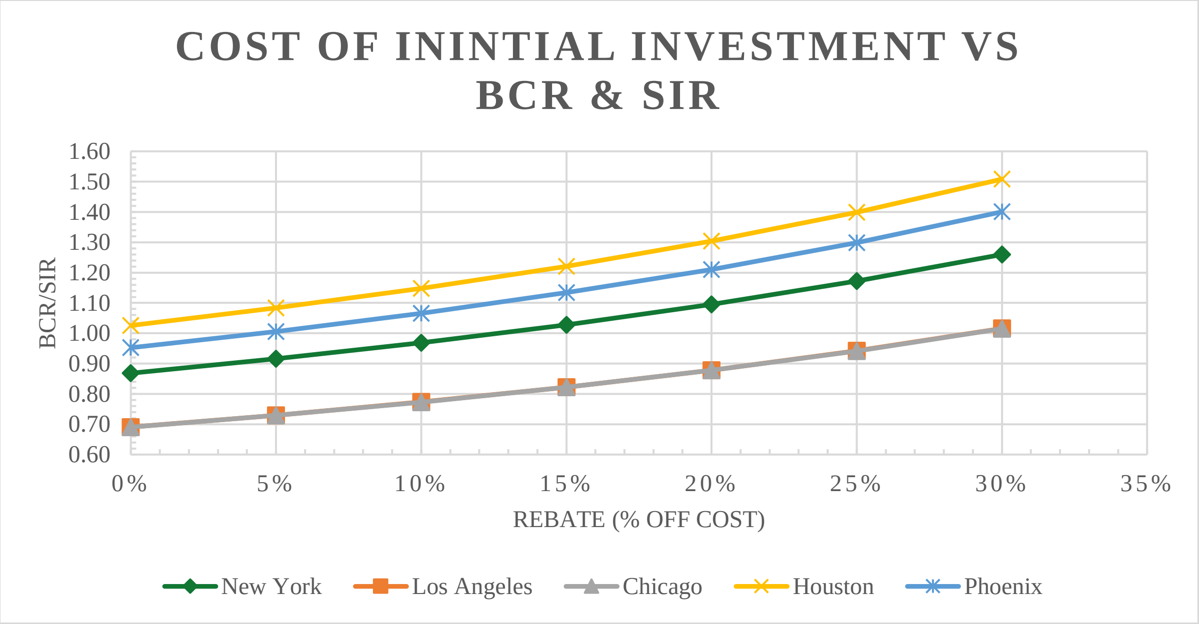

Figure 30. Cost of Principal Investment vs BCR & SIR for all cities.

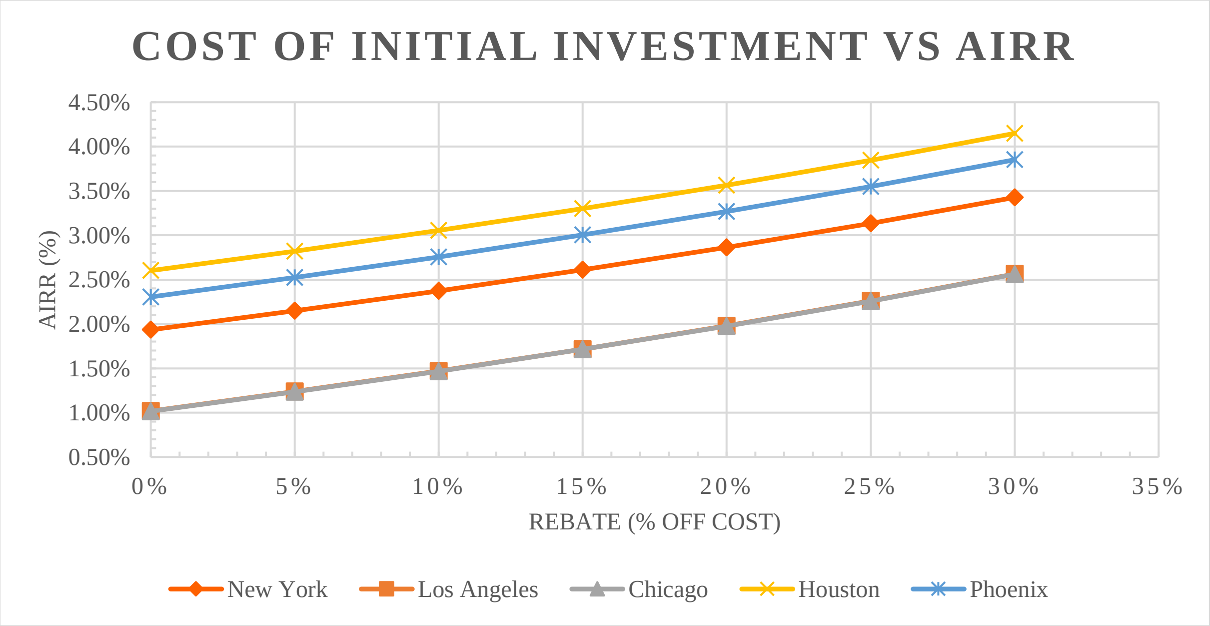

Figure 31. Cost of Principal Investment vs AIRR for all cities.

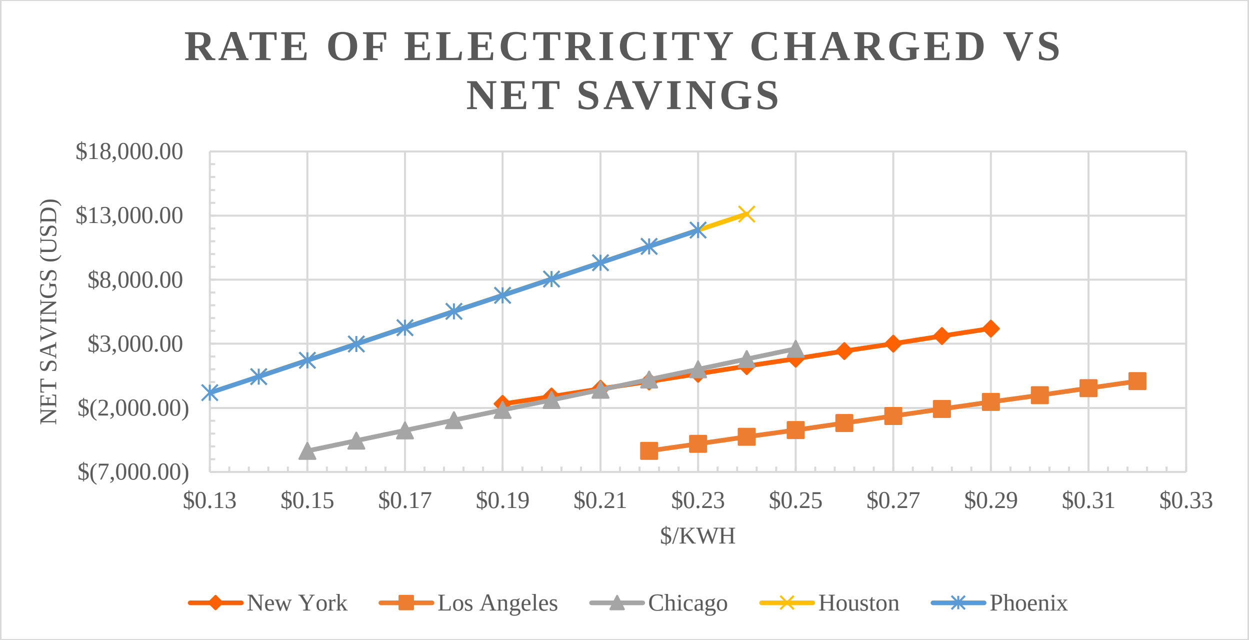

Figure 32. Rate of Electricity Charged vs Net Savings for all cities.

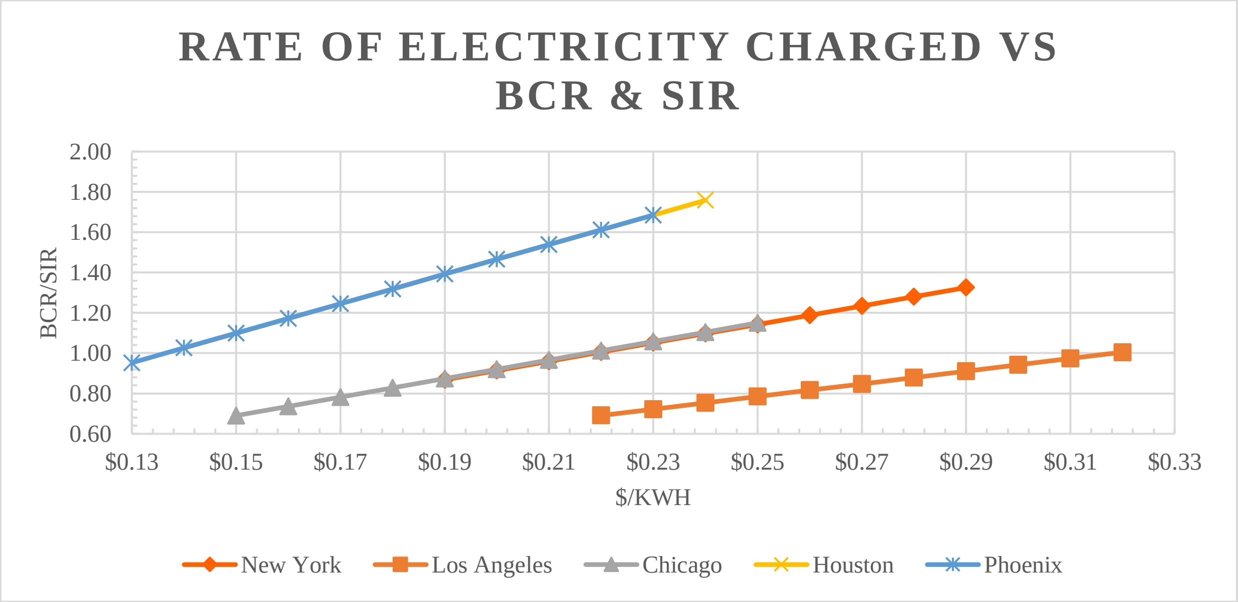

Figure 33. Rate of Electricity Charged vs BCR & SIR for all cities.

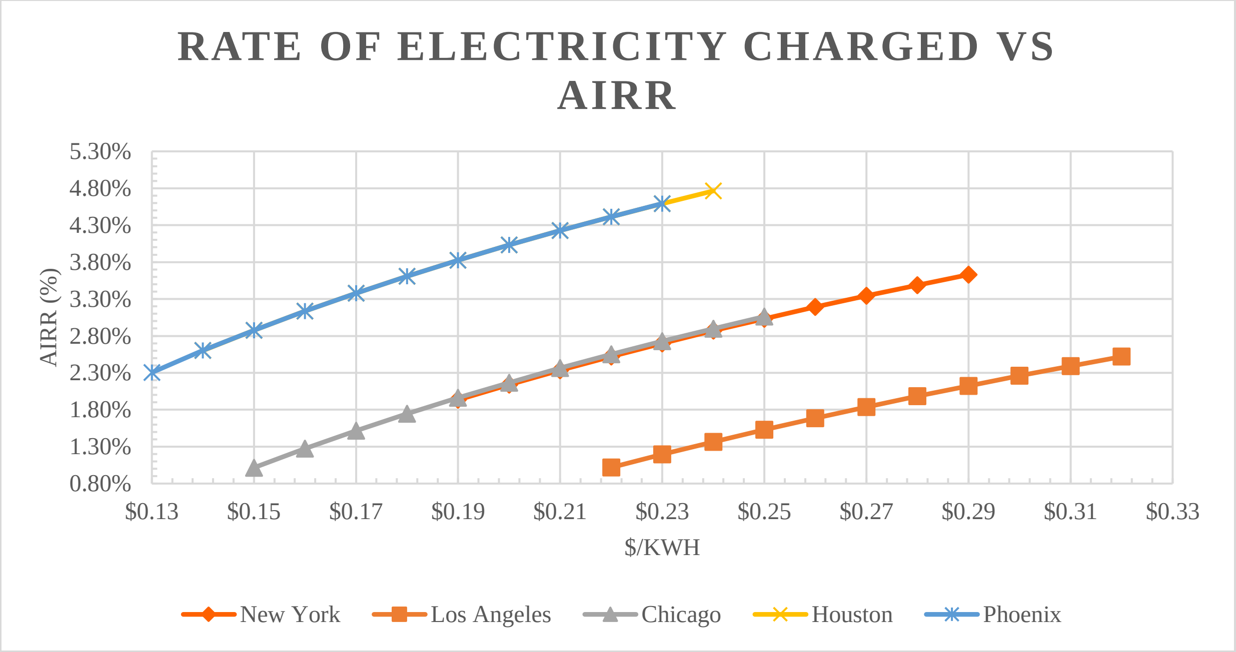

Figure 34. Rate of Electricity Charged vs AIRR for all cities.

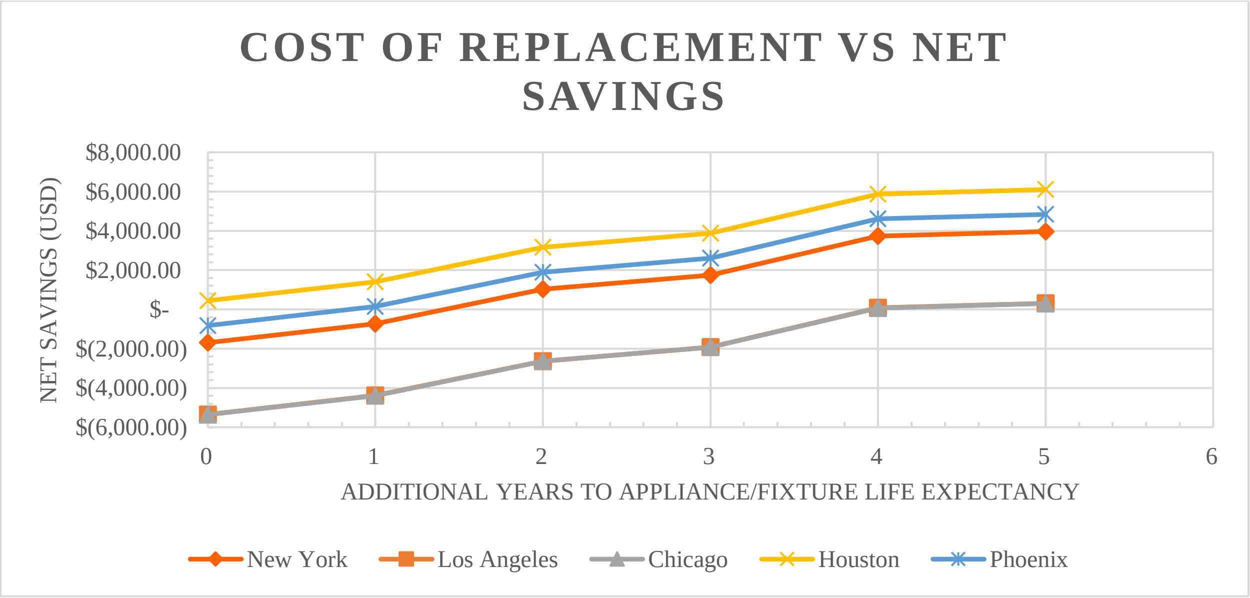

Figure 35. Cost of Replacement vs net savings for all cities.

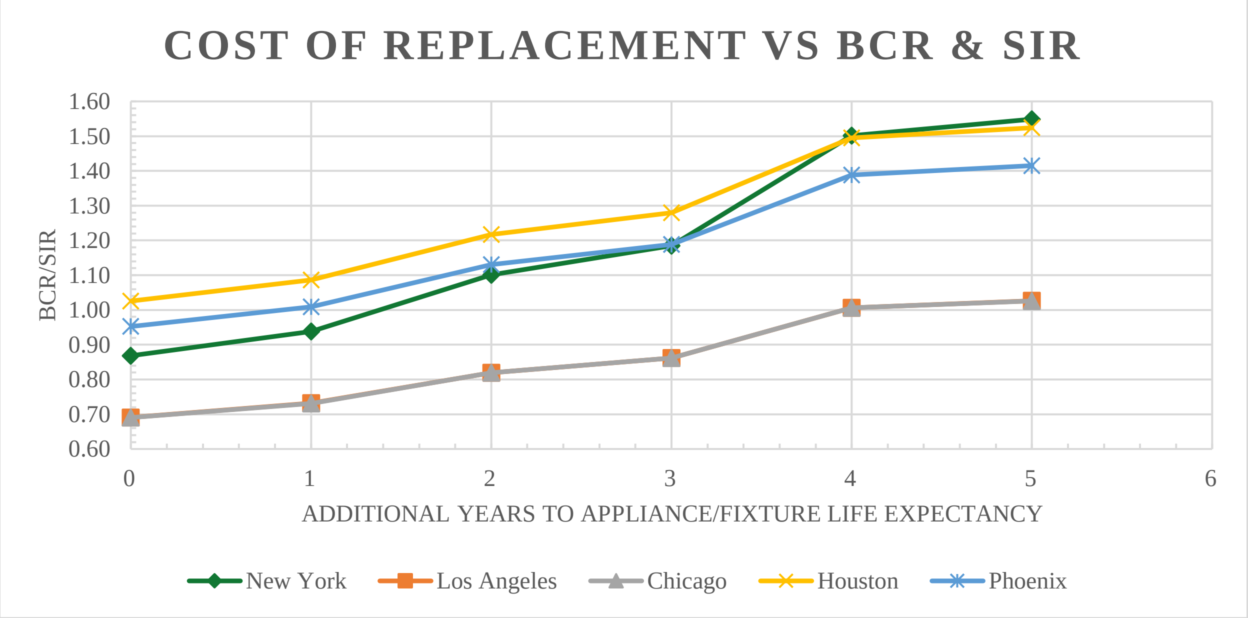

Figure 36. Cost of Replacement vs BCR & SIR for all cities.

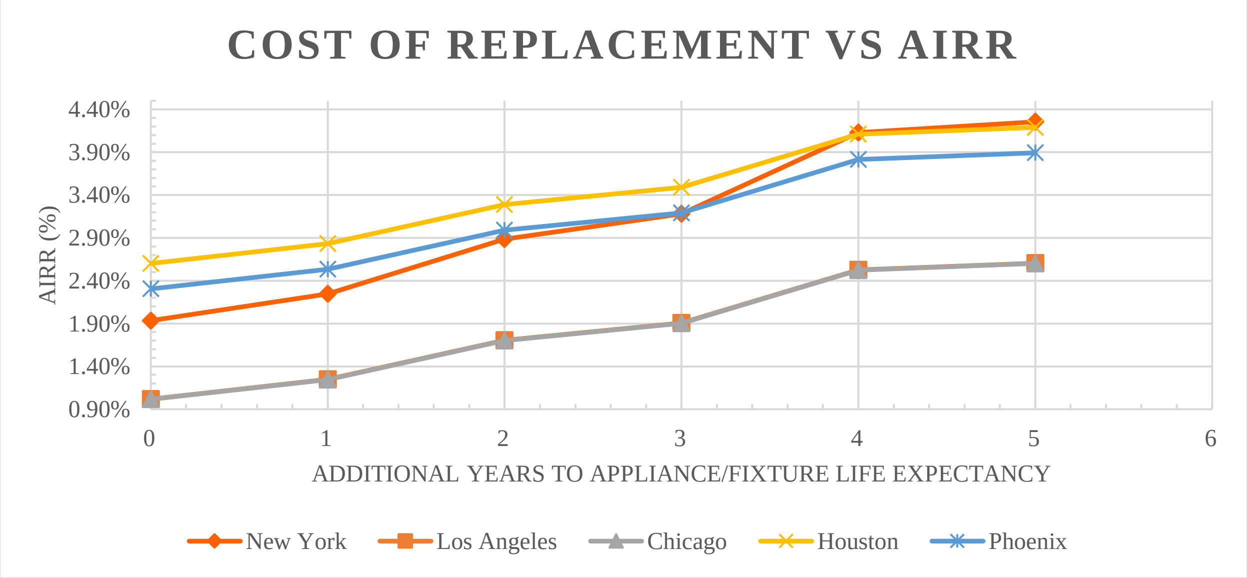

Figure 37. Cost of Replacement vs AIRR for all cities.

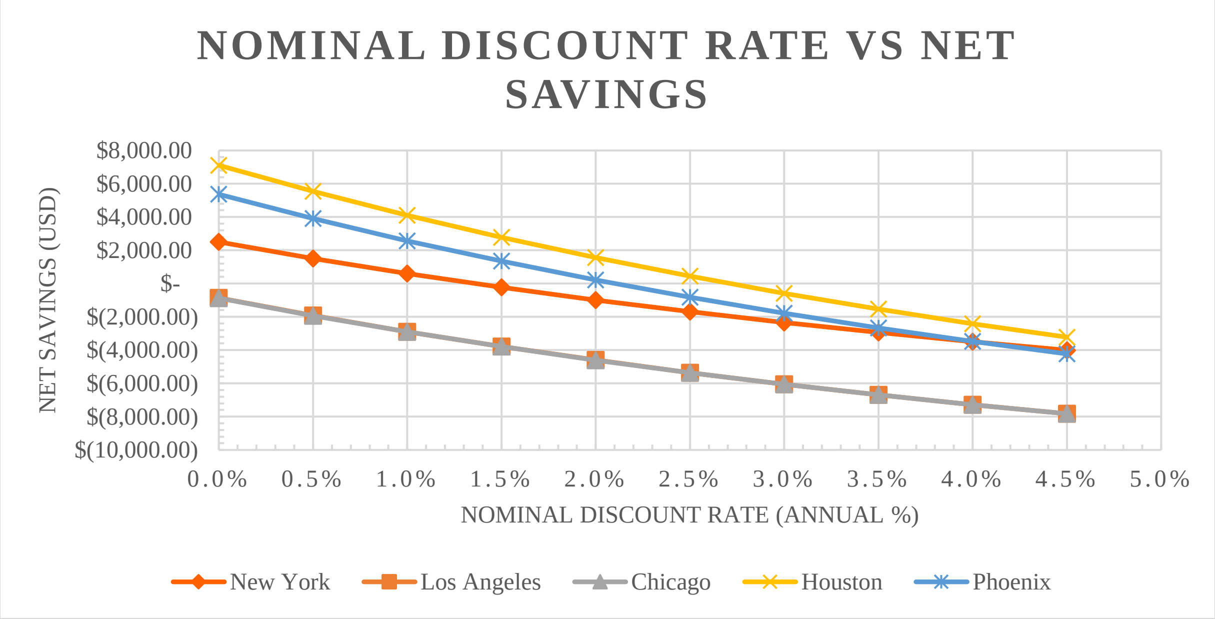

Figure 38. Nominal Discount Rate vs Net Savings for all cities.

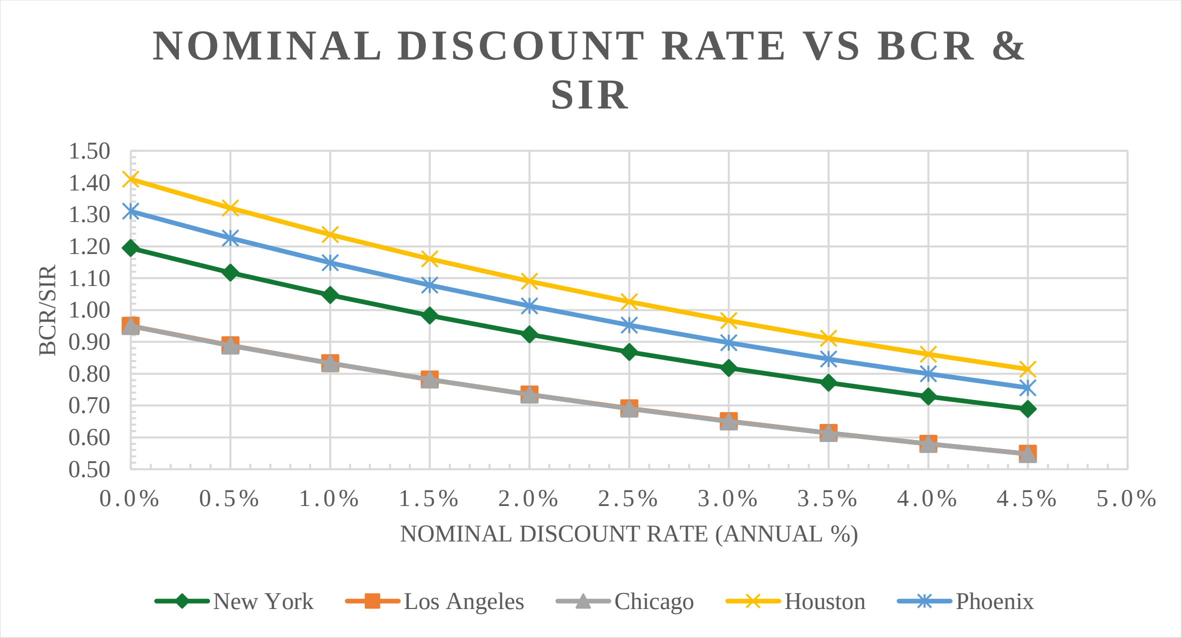

Figure 39. Nominal Discount Rate vs BCR & SIR for all cities.

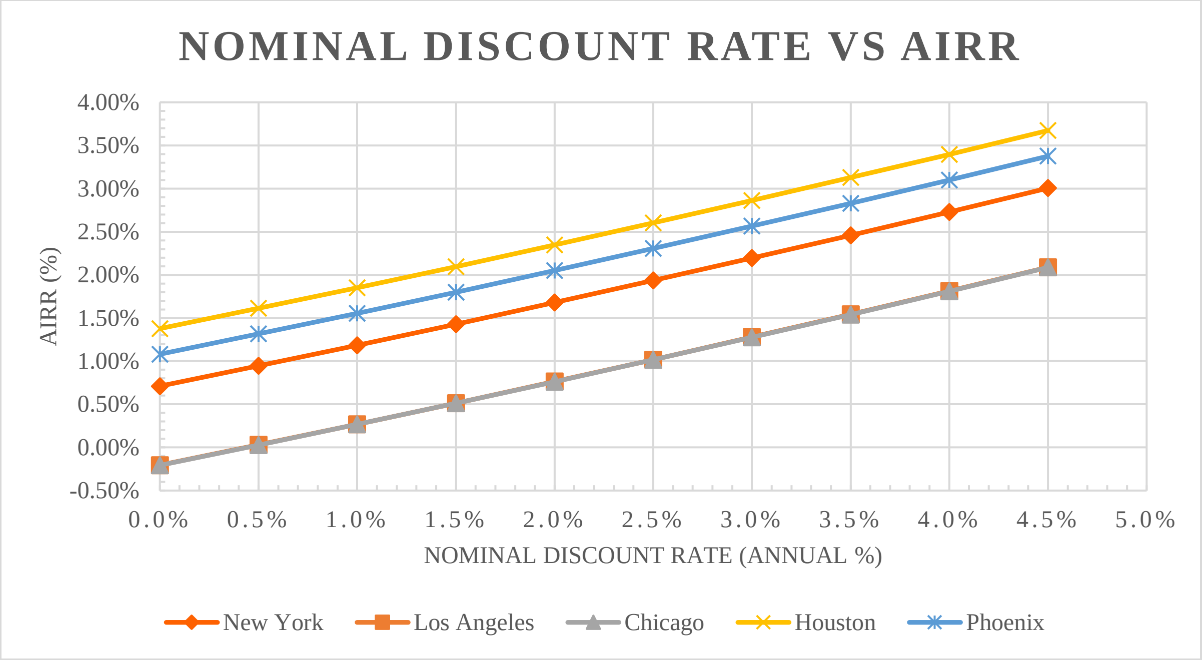

Figure 40. Nominal Discount Rate vs AIRR for all cities.

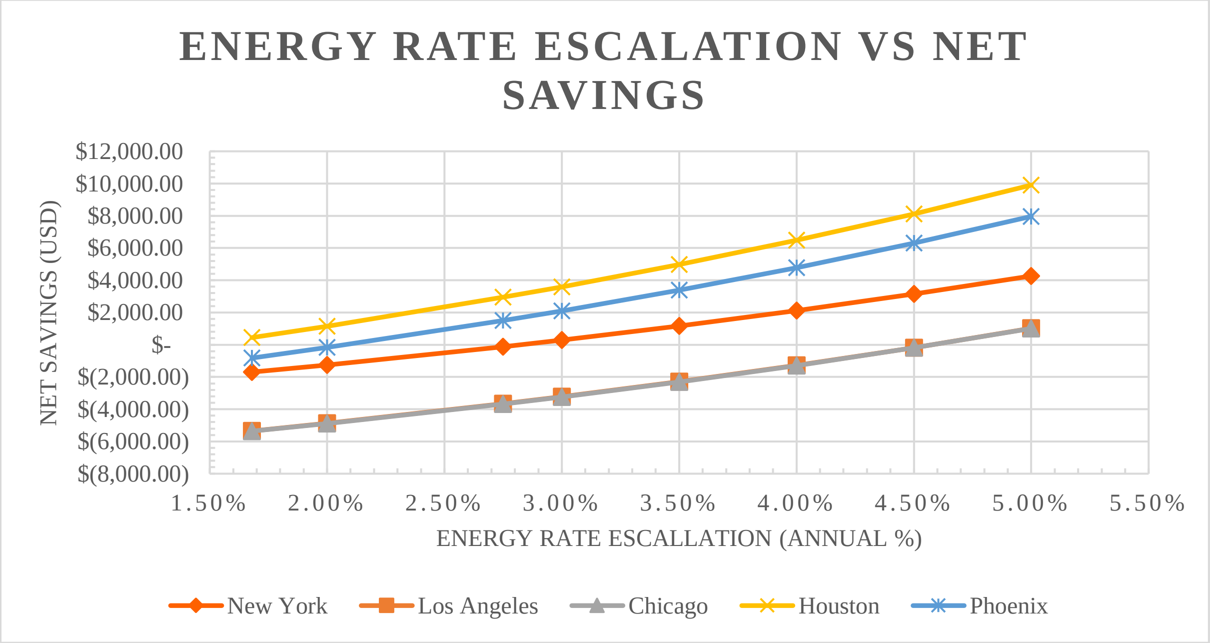

Figure 41. Energy Rate Escalation vs Net Savings for all cities.

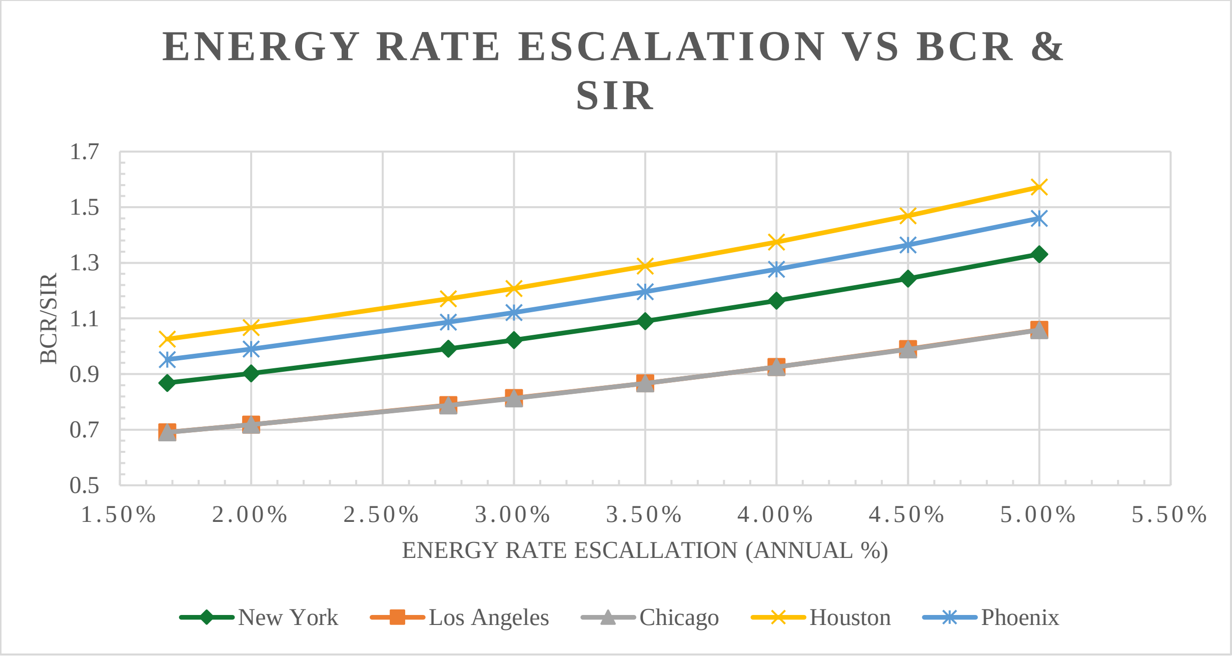

Figure 42. Energy Rate Escalation vs BCR & SIR for all cities.

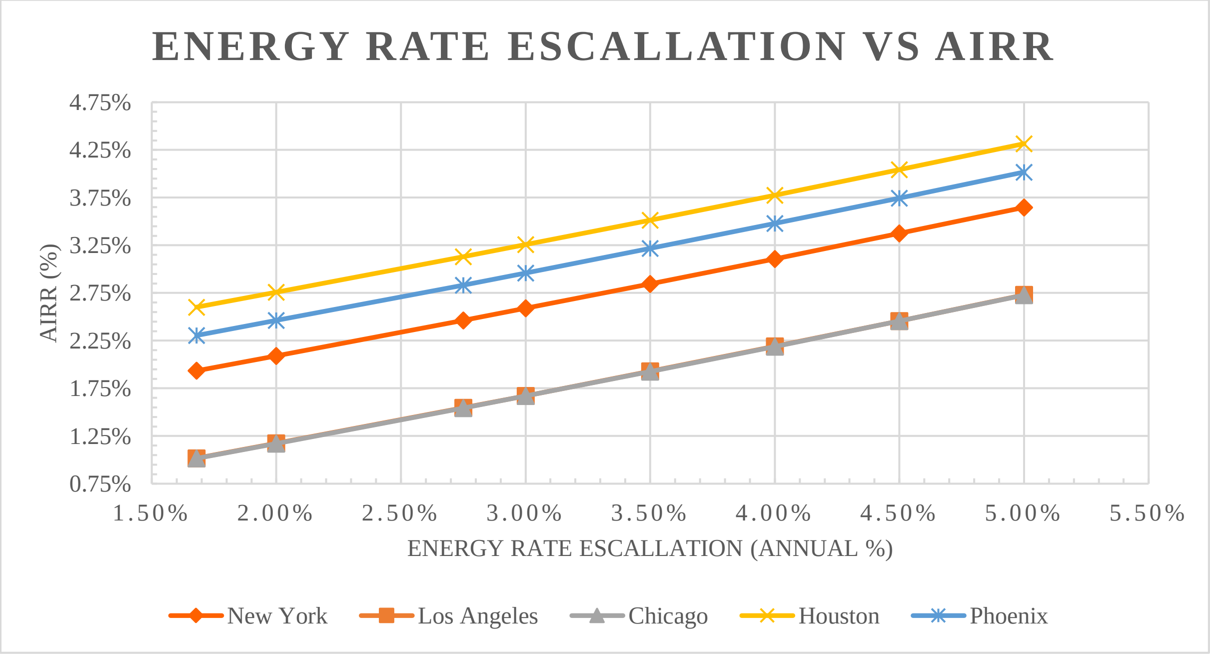

Figure 43. Energy Rate Escalation vs AIRR for all cities.

BIOGRAPHICAL SKETCH

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