Economic Analysis of Water Efficient Appliances and Fixtures in the Residential Sector

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1 Introduction

Only 0.5% of the freshwater on earth is readily available in the form of surface water and accessible groundwater [2]. Therefore, it is important to aid in the conservation of this natural resource, especially as water scarcity becomes an increasing threat in countries around the globe. The best way of conserving this asset is reducing its consumption. In addition to behavioral changes such as flushing less often and turning the faucet off while washing dishes, the employment of water efficient appliances can aid in the reduction of water consumption.

The United States Environmental Protection Agency (EPA) launched the WaterSense program that aims to reduce water consumption through water consciousness campaigns as well as offering a label to appliances and fixtures operating within certain standards. However, for many looking to incorporate these appliances and fixtures into their homes to help reduce their water consumption, the initial costs of these products may cause some hesitation. Despite the promise of future savings in water bills, the temptation to save money at the time of purchase may persuade consumers to opt-out of the water efficient products.

Life-cycle cost analysis (LCCA) is an economic technique that is helpful in determining whether a higher initial investment may be recouped by reduced future recurring costs. By examining various points of cost data, LCCA can make determinations such as net savings, cost–benefit ratio, as well as payback periods to better inform consumers on all costs across the lifespan of a product. LCCA is rooted in sustainability measures, as it was first used by the United States government to evaluate cost savings from water and energy conservation techniques.

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This research aims to determine the necessary parameters for determining the financial feasibility of water efficient appliances and fixtures used in the residential sector to reduce the consumption of water. Using guidelines from the Federal Energy Management Program (FEMP) from the U.S. Department of Energy, this research will provide a framework for performing an LCCA on water efficient products.

2 Literature Review

The works presented in this review all deal with the topic of conducting LCCA, water conservation and efficiency, and the applications of LCCA on green building, sustainability measures, or otherwise water-efficient alternatives to a traditional project.

The literature review is subdivided into three sections as to keep related topics together. The sections are as follows: (A) LCCA Standards and Techniques, this section contains information on the process, requirements, and various techniques of conducting a LCCA. The information contained in this section is sourced from a variety of federal and state government publications. (B) Water Efficiency and Conservation, this section reviews literature regarding water-efficiency practices, topics regarding water conservation, and water consumption habits in the U.S. (C) Application of LCCA on Residential Green Building, the final section of the reviewed literature contains the collected works centered on LCCA applied to residential green building projects.

2.1 LCCA Standards and Techniques

The use of LCCA in the government was first brought about by Sect. 4.1 of Executive Order 13,123, for evaluating products, services, construction, and other investments to lower the federal government's spending as well as reducing water and energy consumption [7]. LCCA is useful in the comparison of design alternatives that have differing initial and recurring costs (such as operating costs, or costs of utility bills), and can help decision makers determine which alternative to choose based on the net savings [8]. The primary output value of the LCCA is the life-cycle cost [8]. Life-cycle costs (LCC) are defined as "the sum of present-values of investment costs, capital costs, installation costs, energy costs, operating costs, maintenance costs, and disposal costs over the life-time of the project, product, or measure" [19].

Apart from the LCC output there are various supplementary measures that are calculated in to add nuance and determine the validity of the LCC output. These "supplementary measures are the net savings (NS), savings-to-investment ratio (SIR), adjusted internal rate of return (AIRR), and the discounted payback (DPB)" [8]. Some publications discuss the treatment of uncertainty in LCCA, citing that because these studies often encompass several years that the analysis leaves much room for variation in the estimates. LCCA uses estimated or average values as input, therefore output quality can only be as accurate as the quality of the input data (Stanford University [18].

LCCA is exceptionally well suited to being applied to evaluating building projects. Considering the costs involved in initial investments, operating costs, and utility bills, savings accrued from project alternatives may add up quickly and noticeably. LCCA considers all the costs over the lifetime of a project and generates estimations of the future costs and savings using cost information that is important to investors [17].

2.2 Water Efficiency and Conservation

With an increasing global population and therefore an increasing demand for potable water, prioritizing water efficiency and conservation is more of a necessity than ever before. It is important for humans to start developing short-term and long-term measures that increase the supply of water while reducing its demand [16]. However, resource shortages, aging infrastructure, and population growth has led governments at local, state, and national levels to face utility budget cuts that require the adoption of cost-efficient water conservation methods.

Ratna Reddy [15] suggests that the adoption of LCCA could enhance the efficiency and effectiveness of governmental budget allocations to appropriate departments. In order to adopt this methodology, it would require the assessment of the cost of water consumption supplies in an LCCA framework and the estimation of the expenses of different cost components [6]. The average single-family in the United States consume water both directly and indirectly through appliances and fixtures that have been installed in their residence. Direct water consumption includes water used to drink, cook, and shower, while indirect consumption is the water used in the production of goods and services [20]. The amount of water consumed in a home is dependent on several factors such as the number, age, and water use patterns of the occupants, as well as the appliances and fixtures owned [3]. Additionally, as stated by EPA, "the average U.S family uses approximately 300 gallons of water per day at home", 70% of this water consumption occurs indoors [4].

2.3 LCCA in Green Building and Product Selection

With the rise of efficient and other "green" alternatives has come the belief that these alternatives are notably higher in cost than their traditional counterparts. In the case of green building, this price tag may seem even higher. Niemeyer [14] found that approximately 52% of respondents would not be able to afford energy-efficient changes to their home on their own. However, other studies have found that the cost premiums attached to green or efficient buildings can be relatively low. Fuerst [5] found that the mark-up on green building costs could range from 2–10%.

An evaluation of LEED (Leadership in Energy and Environmental Design) silver-certified homes in Kentucky found that the cost of building and attaining a silver LEED rating had a payback period of less than 30 years [9]. The use of LCCA to evaluate green building design is not without precedent as it has been used to evaluate zero-energy housing in Melbourne [13], as well as a Beijing office building [10]. Despite the high initial costs involved with green and sustainable building choices, in the long run there may be notable benefits in terms of cost savings.

LCCA can also be applied to the process of product selection, a 2014 study details multiple applications of LCCA in product selection [1]; LCCA has seen heavy application in the topic of flooring choice. An Australian study evaluating flooring alternatives used LCCA and found that timber floors were the most cost-effective choice [21]. In 2017 an algorithm was developed specifically for conducting LCCA on flooring products, with the purpose of informing decision-makers about the lifetime costs associated with different flooring types [11]. A study in Sweden using LCCA to evaluate the environmental impact of flooring alternatives found wood to be the best option [12].

3 Methodology

An extensive review of the literature was the first phase of the methodology of this research. The literature included information on the published standards required to complete an LCCA, ways that LCCA has been applied to areas such as sustainable and green building, as well as discussions of water conservation and efficiency. Necessary information such as input parameters, data types, and equations for carrying out a comprehensive LCCA were retrieved from the review of the literature. The literature also aided in identifying the output values and supplementary measures generated by the LCCA process. Using the information collected from the literature, this report provides a detailed description of the model used to conduct an LCCA and offers a succinct aggregation of the outputs, supplementary measures, and parameters.

4 Model Description

The following subsections contain information regarding the required input parameters, cost data, assumed values, equations, and the cash flow used for conducting an LCCA.

4.1 Input Parameters

The LCCA technique requires many input parameters such as (1) cost data, (2) rates, (3) time data, and (4) assumed values. Each will be discussed within this section.

4.1.1 Cost Data

In LCCA there are (1) initial costs and (2) recurring costs. Initial costs occur once on the cash flow timeline, these costs are often the investment cost of the project, in the case of this study: the purchase and installation of appliances and fixtures. Recurring costs are those that occur multiple times within the study period. Recurring costs may be costs associated with maintenance and repair, utility bills, and replacement costs. Finally, the residual value of all appliances and fixtures should be accounted for.

4.1.2 Rates

The first rate considered in an LCCA is the nominal discount rate. This value can be obtained from FEMP or other government publications and is chosen based on the base-year of the study. The nominal discount rate is used to account for interest in many of the equations which calculates life-cycle costs and supplementary measures. The second rate is the utility rate increase, water and sewer escalation rates will be utilized to account for the increase of municipal water and sewage rates over the lifetime of the study. These escalation rates are available from the FEMP publication, "Water and Wastewater Annual Price Escalation Rates…".

4.1.3 Time Data

LCCA is an accurate tool of estimation because it accounts for the time-value of money, therefore there is time data that must be considered. The base date is the point in time that all project costs are discounted to [7]. The base date can also be thought of as the time at which the project "starts". In the case of this research, base date is the time after the purchase and installation of all appliances and fixtures. The next piece of time data is the study period. The study period is the period of time for which the costs are accumulated. For performing an LCCA to FEMP standards, the FEMP recommends a study period of 25 years. Finally, there is the service period. The service period is the period of time for which all costs associated with daily operations take place. FEMP guidelines define the service period as 25 years.

4.1.4 Assumed Values

In conducting an LCCA some values may not be as concrete as others. In particular, water and sewage usage may be difficult to accurately ascertain because water usage can be highly seasonal depending on the part of the country. Due to this variability, water consumption values may need to be estimated with water usage calculators.

4.2 Equations

All equations required for calculating life-cycle costs and all supplementary measures will be discussed within each subsection.

4.2.1 Life-Cycle Costs

The life-cycle cost (LCC) is the essence of the LCCA output. The LCC value is verified by various supplementary measures that will be discussed within their own subsections. The LCC is the total cost of a project over the entire study period expressed in present-value dollars. LCC can be found using the following formula:

$$\mathrm{LCC} = \mathrm{I} + \mathrm{Repl} - \mathrm{Res} + \mathrm{W} + \mathrm{S} + \mathrm{OM\&R} \tag{1}$$

Equation 1 is a summation of the present-value of all costs less any residual values occurring along the cash flow of the study period. '*I*' is the present-value of the investment costs, also known as the principal; generally this cost occurs at time zero on the cash flow and thus does not need to be discounted. '*Repl*' is the present-value of all replacements that occur during the study period. The one value that must be subtracted in this equation is '*Res*'. This is the present-value of any residual values retained by appliances and fixtures at the end of the study period. The parameters '*W*' and '*S*' are the present-values of the monthly costs of water consumption and sewage usage. It should be noted that '*W*' and '*S*' must be discounted to present-value by using a uniform gradient series. Finally, '*OM&R*' is the present-value of all operations, maintenance and repair costs occurring throughout the study period.

4.2.2 Supplementary Measure: Net Savings

Net savings is a way of measuring the financial performance of a project or alternative. It measures the expected savings of a project or alternative in present-value dollars. Net savings may be found using the following formula:

$$\mathrm{NS}_{\mathrm{A:BC}} = [\Delta\mathrm{W} + \Delta\mathrm{S} + \Delta\mathrm{OM\&R}] - \left[\Delta\mathrm{I}_{\mathrm{o}} + \Delta\mathrm{Repl} - \Delta\mathrm{Res}\right] \tag{2}$$

Equation 2 measures the economy of a project alternative (subscript '*A*') against a base case (subscript '*BC*'). This equation has two parts, the first is a summation of operational savings of the project alternative relative to the base case less the additional investment costs of the alternative compared to the base case. 'ΔW' and 'ΔS' is the savings in water and sewage utility bills that can be attributed to the alternative. Both 'ΔW' and 'ΔS' are found by subtracting the present-value of water and sewage costs of the base case from the present-value of water and sewage costs from the alternative. '$\Delta OM\&R$' is the savings in operations, maintenance, and repair and is found by finding the difference in the present-value OM&R costs between the base case and the alternative. The second part of the net savings equation calculates additional costs related to the alternative. 'ΔI' is the additional investment cost required for the alternative as compared to the base case. The costs of additional replacements attributable to the alternative is given as '$\Delta Repl$' and is found by subtracting the present-value of the replacement costs incurred by the alternative from the replacement costs associated with the base case. Finally, 'ΔRes' is the additional residual values that can be attributed to the alternative. 'ΔRes' is determined by subtracting the present-value of residual values of the alternative from the present-value of residual values of the base case.

4.2.3 Supplementary Measure: Savings-To-Investment Ratio

The savings-to-investment ratio (SIR) is another measure of financial performance. It expresses savings to investment costs (in present-value dollars) as a ratio. SIR may be found using the following relationship:

$$\mathrm{SIR}_{\mathrm{A:BC}} = \frac{\Delta \mathrm{W} + \Delta \mathrm{S} + \Delta \mathrm{OM\&R}}{\Delta \mathrm{I_o} + \Delta \mathrm{Repl} - \Delta \mathrm{Res}} \tag{3}$$

Equation 3 measures the ratio of savings to investments from the alternative (subscript 'A') against a base case (subscript 'BC'). 'ΔW', 'ΔS', and '$\Delta OM\&R$' are the present-value savings in water consumption, sewage usage, and operations, maintenance, and repairs of the alternative relative to the base case, respectively. 'ΔI_o', and '$\Delta Repl$' are the present-value additional costs attributable to the alternative relative to the base case. 'ΔRes' is the present-value of additional residual values associated with the alternative.

4.2.4 Supplementary Measure: Adjusted Internal Rate of Return

Adjusted Internal Rate of Return (AIRR) is another measure of financial effectiveness that measures the yearly percentage yield from the initial investment that occurs over the study period. AIRR can be found with the following formula:

$$\mathrm{AIRR} = (1 + \mathrm{r}) * (\mathrm{SIR})^{1/\mathrm{N}} - 1 \tag{4}$$

Equation 4 uses the calculated '*SIR*' value to determine the annual percentage yield generated by the alternative. The '*r*' value is the reinvestment rate which is generally accepted to be the same as the discount rate used for the LCC. Finally, the '*N*' value is equal to the length of the study period, generally expressed in years.

4.2.5 Supplementary Measure: Payback

The final supplementary measure in LCCA is the payback period. The payback period is the length of time it takes for the accrued savings to equal the initial investment costs. An accurate LCCA should use the discounted payback period as it requires that all costs and savings be discounted to present value. Payback can be found with the following formula:

$$\sum_{t=1}^{y} \frac{[\Delta W_t + \Delta S_t + \Delta OM\&R_t - \Delta Repl_t + \Delta Res_t]}{(1 + d)^t} \geq \Delta I_o \quad (5)$$

'ΔW_t', 'ΔS_t', and '$\Delta OM\&R_t$' are the present-value savings of the cost of water, sewage, and OM&R in year '*t*', respectively. '$\Delta Repl_t$' is the difference in replacement costs in year '*t*' and 'ΔRes_t' is the difference in residual value in year '*t*'. The value '*d*' is equal to the discount rate used in the LCC analysis, and 'ΔI_o' is the additional cost of investment [7].

4.3 Cash Flow Diagram

The cashflow diagram is illustrated below using a general form to illustrate cash inflows and outflows associated with a LCCA. The initial investment cost is represented by the black arrow at $t = 0$ on the cash flow diagram. Water and Sewage usage costs are shown as two upwardly sloping curves to represent the gradual increase in water and sewage rates as the study period progresses. The replacement costs are represented by the black arrow occurring at $t = N$ years, as each appliance and fixture will have its own lifespan, after which it will require a replacement. The initial investment cost, water and sewage costs, and replacement costs are illustrated using downward facing arrows to represent money spent over the study period, or cash outflow. Finally, the residual value is represented by the red arrow pointing upwards. The upwards arrow represents the retained value of the appliances and fixtures at the end of the study period, or cash inflow.

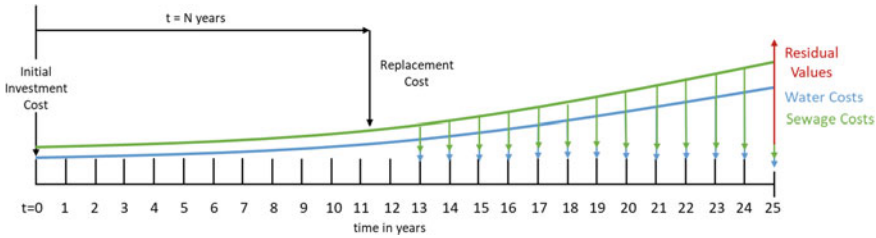

Fig. 1 An illustration of the cash flow diagram in its most basic form

4.4 Statement of Limitations

Finally, the limitations of this research should be discussed. This research is limited to establishing a framework for conducting a LCCA that can be applied to water efficient appliances and fixtures- it does not perform an analysis nor make conclusions about the economy of water efficient appliances and fixtures. As of publication, the model remains untested. Additionally, this paper is focused on the U.S. and references U.S. federal publications for the sources of various financial rates (Fig. 1).

5 Discussion

In the following subsections each LCCA output value and its benefit to the analysis will be discussed in detail.

5.1 Life-Cycle Costs

LCC is the primary and most important output value of an LCCA. LCC is the computation of the present value of each cost that is incurred during the study period by using the Department of Energy (DOE) discount rate then adding those values to each alternative. When comparing various project alternatives, the alternative with the lowest LCC is considered the most cost-effective for the application that is being studied. In order for such accurate comparisons to be made all project alternatives must meet the established minimum performance requirements and must use the same base date, study period, service period and discount rate in their respective analysis. The LCC output values can be verified with calculated supplementary measures.

5.2 Supplementary Measure: Net Savings

Net Savings (NS) is a variation on the Net Benefits (NB) technique of measuring the financial performance of a project. While the NB technique measures the difference that exists between the present-value benefits and the present-value costs for the study period, the NS technique measures the net value of money (in present-value dollars) that a project is expected to save over the life of the study. The NS is a relative performance measure and can only be calculated in respect to a "base case". When comparing project alternatives, the project with the NS value greater than zero is considered the most cost-effective. It should also be noted that the project alternative with the highest NS will be the project with the lowest LCC [7].

5.3 Supplementary Measure: Savings-To-Investment

The Savings-to-investment ratio (SIR) is a variation of the cost–benefit ratio that just as the NS approach, is a relative performance measure. The SIR is a calculation that involves dividing the projected energy costs savings over the finance term by the total cost of the assigned project (including financing, installation, and cost of equipment). Overall, it is another measure of economic performance towards a project alternative that demonstrates the existing relationship of the increased investment cost and savings. A project with a SIR greater than 1 is considered cost-effective [7]. Please note that a project with the lowest LCC is not necessarily the project with the highest SIR. SIR should also not be used to choose between mutually exclusive alternatives as it is more useful as a tool of ranking alternatives.

5.4 Supplementary Measure: Adjusted Internal Rate of Return

AIRR is a method of determining the annual yield from a project's investment expressed as a percentage. Just as the SIR and the NS approach, the AIRR is another relative performance measure. When determining the economy of a project using AIRR it must be compared against the discount rate being used in the study. If the AIRR is higher than the discount rate, a project is economically acceptable. On the other hand, if the AIRR is lower than the discount rate, then it is unacceptable, but if they are equal it is considered to be economically neutral. It should be noted that AIRR cannot be used to choose between mutually exclusive alternatives.

5.5 *Supplementary Measure: Payback*

Payback determines the length of time between the start of the service period and the time it takes for accumulated savings to exactly equal initial investment costs. It should be noted that payback should not be used to select between mutually exclusive project alternatives. Payback is useful for determining a lower bound on the useful life of a project.

6 Conclusion

The demand for water will persist as both the economy and the population continue to grow, making water quality management, water conservation, and reduction of water consumption a growing challenge. The existing literature supports the use of LCCA in the evaluation of green building projects and product selection. This research proposes the use of LCCA to evaluate water conserving appliances and fixtures should be equally appropriate. Adopting the LCCA technique can aid in residential water conservation by providing a tool for use in a comprehensive water resource management program at both the residential and municipal level.

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