Probabilistic Life cycle Cost Model for Sustainable Housing Retrofit Decision-Making

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ABSTRACT

Sustainable housing retrofitting is an effort to convert a house to a low energy facility, to analyze the deconstruction techniques, and to evaluate the alternatives for installing reused/recycled materials. In order to make the decision of both designing and pursuing a green housing refurbishment approach, there is a need to perform a life cycle cost assessment to evaluate how each alternative influences the cost of construction, long-term costs (e.g., maintenance, utilities) and environmental impacts. This study presents a Monte Carlo simulation for estimating life cycle costs (LCC) of a case study house built in the 1960's. The study identifies the significance of proposed retrofit activities on the house's LCC. The results show that the cost of building may increase if we select a sustainable retrofit approach, but that the long-term costs would decrease. This paper also concludes that an optimum selection of retrofitting activities could minimize the life cycle cost of a project.

INTRODUCTION

The building sector, including building construction and operation, consumes almost 50% of the total energy each year (Kansal and Kadambari 2010; Wang et al. 2010). In addition, most of this amount of energy is consumed by a building during its life cycle period (Menassa 2011). The cost of energy also plays an important role in long-term exploitation costs (Gasic et al. 2012). One way to reduce the adverse impacts of buildings on the environment and target the energy efficiency is through green building retrofitting.

The capital costs of a building only represent half the total cost during its whole life, and are only slightly higher than the total costs of cleaning and care-taking, replacement and maintenance, and routine servicing (Wang et al. 2012). Unfortunately, most public funding decisions are often made on the basis of initial cost and without any consideration of life cycle costs (Arditi and Messiha 1999; Salem et al. 2003). Life cycle cost (LCC) is an evaluation technique that takes into consideration all costs that emerge during the life cycle of a project (Ammar et al. 2013) from initial planning and design, through construction, including all operations and maintenance, and then concluding with building demolition and disposal. Therefore, in order to make the decision of both designing and pursuing a green housing refurbishment approach, there is the need to perform a life cycle cost assessment of the alternatives, in order to evaluate how each alternative influences the cost of building, and long-term costs (e.g., maintenance, utilities, and disposal).

The widely used cost estimate method for life cycle cost estimate is still the deterministic model in practice. However, Because of the uncertainties in cost elements of buildings, the deterministic models cannot model life cycle costs properly (Ammar et al. 2013; Salem et al. 2003). Either overestimating or underestimating the life cycle assumptions are risks in life cycle costing which may cause the project to be under funded in future (Wang et al. 2012). To deal with such uncertainty, this study presents a probabilistic model for estimating life cycle costs. The developed life cycle cost model employs the use Monte-Carlo simulation to evaluate the competing alternatives. A case study of the green retrofit of a house built in 1960’s is presented in order to demonstrate the use of the developed model.

LITERATURE REVIEW AND BACKGROUND

Green Building Retrofit. A green building is a healthy facility designed and built in a resource-efficient manner, using ecologically-based principles (Kibert 2008). There are many benefits of green buildings such as: reduced energy consumption, reduced damage to natural, reduced water consumption, limited waste generation due to recycling and reuse, reduced pollution loads, and enhanced image and marketability.

Sustainable retrofit is a capital improvement with an associated cost that resets the building life, improves performance, and makes the building’s use more predictable for an extended period of time (Menassa 2011).

Previous Research on LCCA. Most of the research in the field of LCCA utilization is devoted to transportation projects, including highways, bridges, and pavements, among others. It also reveals that some theoretical non-deterministic models have been developed for estimating life cycle cost of buildings.

Making accurate assumptions is the most difficult step in life cycle costing due to the complex cost breakdown structure and uncertainties in predicting future events at the long term (Wang et al. 2012). Assumed factors in previous studies on life cycle cost analysis on construction projects include: Initial capital costs, Operating and maintenance costs, Special Repairs costs, Replacements cost, Cleaning costs, Energy cost, Administration costs, Renovation, and Disposal cost (Ammar et al. 2013; Bromilow and Pawsey 1987; Gasic et al. 2012; Kansal and Kadambari 2010; Menassa 2011; Wang et al. 2012).

This study contributes to LCCA by applying Monte-Carlo simulation to model the life cycle cost assessment of a housing retrofit project. The model considers uncertainty in all cost elements and replacement periods.

CASE STUDY

The University of New Mexico is working with the Associated General Contractors (AGC) of New Mexico and the Central New Mexico Home Builders Association to remodel an existing home as a demonstration project. The project is intended to gather data and demonstrate the effectiveness of various green remodeling techniques. The house being studied was originally constructed in 1964 as a ranch style home in Albuquerque, New Mexico. The home is a 1600 square feet 3 bedroom 2 bath concrete block and adobe facility constructed on a slab-on-grade. There is a relatively flat gable roof with a 1:12 pitch. The current heating is by gas furnace and cooling is provided by an evaporative cooling system.

METHODOLOGY

As shown in Fig. 1, the methodology of this research includes a six-step approach:

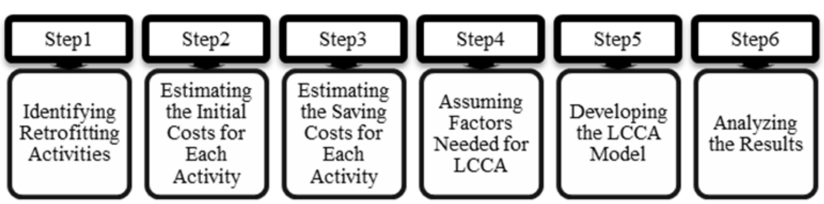

Figure 1. The research methodology

Step 1: Identifying Retrofitting Activities. To determine the sequence of areas to be retrofitted, this study starts identifying the basic least expensive items from the building and works up through more complex items to finish with on-site renewable energy systems. The "Build Green New Mexico criteria for a Green Building" (BGNM 2012) document is used to evaluate the steps that could be taken to renovate the house. Table 1 summarizes of the planned activities for retrofitting of the house.

Table 1. Planned retrofitting activities

Classification	**Activities**
Low Cost	01. Programmable Thermostat
	02. HVAC tune up
Lighting	03. Replace all lighting with CFLs
Appliances	04. Replace with Energy Star for Refrigerator
	05. Replace with Energy Star for Clothes washer
	06. Replace with Energy Star for Dishwasher
Insulation	07. Insulate Ceilings
	08. Insulate walls
	09. Insulate Attic
Windows and doors	10. Replace doors with insulated core
	11. Replace windows with energy efficient glass
Heating and Cooling	12. Install ground source heat exchanger
	13. Evaporative Cooler
Water Heating	14. Solar Thermal
Renewable Options	15. Solar electric

Step 2: Estimating the Initial Costs for Each Activity. The initial cost of each activity is estimated by the following sources: RS Means: Green Building Cost Data (RSMeans 2012), Housing and Urban Development Website: Energy Efficient Rehab Advisor (HUD 2013) , and a cost estimator profession. For each activity, three point of cost are estimated according to the estimation sources.

Step 3: Estimating the Saving Costs for Each Activity. The annual savings of each activity is estimated by the following sources: (1) eQuest (Quick Energy Simulation Tool) software (DOE2 2013), version 3.65 , (2) Housing and Urban Development Website: Energy Efficient Rehab Advisor (HUD 2013), (3) Energy Star website (EnergyStar 2013).

Step 4: Assuming Factors Needed for LCCA. There are two main factors:

Discount Rate (r): the LCCA process uses an economic technique known as 'discounting' to convert different costs and benefits occurred at different times at a common point in time (Ferreira and Santos 2013). This technique applies a financial variable called discount rate (r) to represent the time value of the money. This rate is not a constant term and may vary over the service life of the project. A discount rate of 2 or 3% above inflation is considered an appropriate value (Hojjat 2002). For the purpose of demonstrating the proposed methodology, a discount rate of 3% is assumed in this study.

Service Life (n): expected service life of a building depends on the client's expectations and the characteristics of the project. It may vary from 25 to 50 years (Wang et al. 2012), and also may be expanded to more than 70 years (Ammar et al. 2013). In this study, a service life of 50 years is assumed.

Step 5: Developing the LCCA Model. This study uses Monte-Carlo Simulation for LCCA. Monte Carlo simulation uses computing power to explore all of the possible outcomes to a problem given certain bounds of variability expressed in the model (Wang et al. 2012). The main advantage of this method over the deterministic models is that it allows the uncertainty and risks during the long-term operation stage of buildings to be involved in cost analyses. The software @RISK, which can handle a large number of variables in a Monte Carlo simulation, has been employed to carry out the calculations.

Several cost items can be considered over its service life; from initial cost to salvage values. In this study, two main items are used in LCCA:

1. Initial Cost (IC): Initial costs refer to cost of implementing a retrofitting activity including materials, equipments, labors and etc. These costs are estimated in 3 points for each activity: optimistic (x_{min}), most probable (m), and pessimistic (x_{max}) expected costs. These values are then used to construct a PERT distribution for initial cost of each activity. Initial costs do not need to be discounted. It should be mentioned that maintenance costs are neglected in this study.

2. Annual cost of Utilities (UC): These costs are benefits of each activity considering the annual cost of utilities. According to the estimated energy saving for each activity, the annual cost of utilities in the house as a result of performing each activity can be calculated. A PERT Distribution is considered for annual utilities bill as well. All annual bills have to be discounted first as present value as given by Eq. 1:

$$\mathrm{PVUC_i} = \frac{\mathrm{UC_i}}{(1+r)^i} \quad (1)$$

Where PVUCi is the present value of the annual utility bills in year i, UC_i is the current value of the annual utility bills in year i, and r is the discount rate. Since it is assumed that the annual bills will be the same at the end of each year, the total present values of annual bills can be as given by Eq. 2:

$$\mathrm{PVUC} = \sum_{i=1}^{n} \mathrm{PVUC_i} = \sum_{i=1}^{n} \frac{\mathrm{UC_i}}{(1+r)^i} = \mathrm{UC}\left(\frac{1-(1+r)^{-n}}{r}\right) \quad (2)$$

Where PVUC is total amount of present value of the annual bills in whole service life, n is the service life of the project, and UC is the annual bill for utilities. Therefore the whole life cycle cost of the house retrofitting can be calculated as given by Eq. 3:

$$\mathrm{LCC} = \mathrm{IC} + \mathrm{UC}\left(\frac{1-(1+r)^{-n}}{r}\right) \quad (3)$$

Where LCC is life cycle cost of the retrofitting project, IC is the total initial cost of implemented retrofitting activities, and UC is the annual utility bills according to the implemented activities.

Step 6: Analyzing the Results. Step 6 includes the following three main parts: (1) The results of the eQuest software for calculating energy savings, (2) Calculating of payback period for each activity according to initial cost and annual savings, (3) Calculating the life cycle cost and selecting the retrofit activities that minimize the life cycle costs for 50 years for service life of the project.

RESULTS AND DISCUSSION

eQuest Software. eQuest is a user friendly software that can step through the creation of a detailed building model, which allows automatic parametric simulations of the design alternatives, and provides graphics that compare the performance of the alternatives. In this research, the study home is modeled by eQuest v3.65. First, the house is modeled as it is, without consideration of any retrofitting activities. Figure 2 shows the output of the study house in terms of electricity and natural gas consumption. The building has been occupied by a family of three for the last two years. During that time, the annual utility usage has been approximately 9,000 kWh of electricity and 70 MBtu of gas. As the results show, the annual electric and gas consumption of the study house is simulated to be 9,550 KWh and 73.42 MBtu, respectively. Therefore, the simulated energy consumption for the home is directly in line with the average actual usage of utilities. Considering the unit price of 0.113 $/KWh and 10.6 $/MBtu for the electricity and natural gas, respectively, the annual utilities bill of the study house would be $1857.2. In the next step, each retrofitting activity is included into the LCC model and the result on annual utilities bill is evaluated.

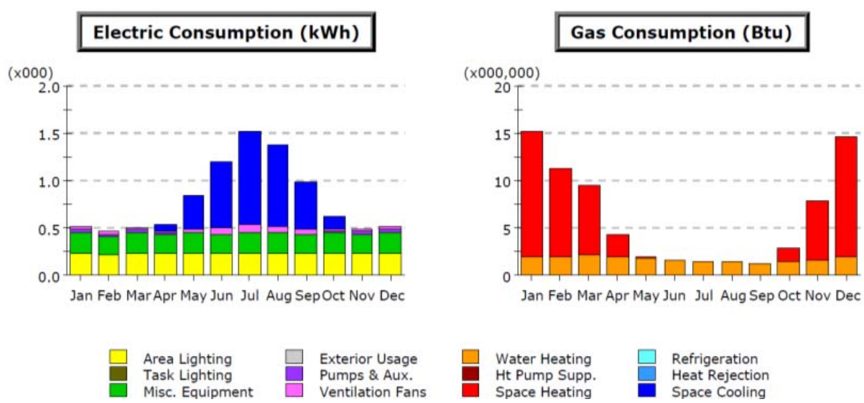

Figure 2. Energy consumption of the house as it is

Payback Periods. After estimating the initial cost and annual saving for each retrofitting activity, the payback period for each activity is calculated. The payback period is the length of time required for an activity to recover its initial costs by considering expected savings. Using the Monte-Carlo Simulation and @Risk software, the payback period of each activity is calculated, as a distribution. Table 2 summarizes the results.

Table 2. Summary of the payback periods for each retrofitting activity

No.	Activity	Payback Period (Year)			Rank
		Percentile5	Percentile95	Mean	
1	Programmable Thermostat	0.4	1.0	0.6	2
2	HVAC tune up	0.6	0.8	0.7	3
3	Replace all lighting with CFLs	0.2	0.3	0.3	1
4	Replace with Energy Star for Refrigerator	14.8	103.2	42.9	11
5	Replace with Energy Star for Clothes washer	7.9	23.5	14.5	7
6	Replace with Energy Star for Dishwasher	27.9	133.7	64.5	14
7	Insulate Ceilings	9.2	12.0	10.2	5
8	Insulate walls	7.9	33.0	17.4	8
9	Insulate Attic	8.8	13.5	11.1	6
10	Replace doors with insulated core	31.5	145.6	74.7	15
11	Replace windows with energy efficient glass	43.0	97.7	63.7	13
12	Install ground source heat exchanger	30.3	41.6	35.4	10
13	Evaporative Cooler	4.9	8.6	6.7	4
14	Solar Thermal	21.5	50.1	32.4	9
15	Solar electric	47.6	62.4	54.4	12

Calculating the life cycle costs. The life cycle cost of the project (including initial retrofitting costs and utilities costs) for 50 years of service life of the building is evaluated. The evaluation options include:

- The study house as it is (the initial cost is zero but the utilities costs are considered to be at its maximum because there is no retrofitting)
- The study house when implementing all retrofitting activities (the initial cost is increased but the cost of utilities bill is zero because the house does not need more outsource energy)
- The study house with implementing a specific group of retrofitting activities (the initial cost is increased but not as much as implementing all retrofitting activities; however the cost of utilities bill is decreases but would not be zero)

As the results show, the mean of LCC of the study house for not having the retrofitting and having the retrofitting is equal to $46,988 and $63,852, respectively. Therefore, performing all retrofit activities is not cost effective. That is because by implementing all retrofitting activities, the house could generate more energy than it needs and therefore, the result would be inefficient.

Although the main purpose of the house retrofit is to decrease the LCC, the results show that having an excessive investment for retrofitting can increase the LCC. The optimization approach includes the following steps:

- Each activity is defined as a binary decision variable.
- If the value of the activity decision variable is 0, it means that there is no initial cost and no effect on energy consumption of the house. If the value is 1 for an

activity, that means the initial cost of the activity and its effect on annual utilities bill are considered in LCC.

- The goal of the optimization problem is to minimize the total LCC. Using @Risk optimizer, the minimum value of the average of distribution for LCC can be reached by considering the decision variables as adjustable cells.
- After finding the minimum value for the LCC, the activities with decision variable equal to 1 are part of the optimum combination of retrofitting activities for the study house.

The results illustrate that the average LCC for retrofit cost would be $27,134, if the best combination of retrofit activities are selected. The optimum LCC for retrofitting the house is less than performing all retrofit activities ($63,852) and not performing any retrofit activities ($46,988). The final results show that by having the best combination of activities to retrofit the house, the LCC would decrease to less than 40%. In other words, by selecting the best retrofit options the LCC of the building decreases significantly.

CONCLUSION

This research introduces an approach to determine and optimize the LCC for retrofitting houses and to determine how the best alternative for retrofitting of a house can be selected. This study presented a probabilistic approach to estimate life cycle costs (LCC) of a sustainable housing retrofitting. The developed LCC model employed the use of probability theory and Monte Carlo simulation to evaluate the competing alternatives. A study of the green retrofit of a house built in 1960's is presented in order to demonstrate the use of the developed model.

The results showed that the three best retrofitting activities that have the shortest payback periods are: replace all lighting with CFLs, install a programmable thermostat, and perform a HVAC tune up.

The results also showed that although the main purpose of retrofitting a house is decreasing the LCC, having excessive investment for retrofitting could increase the LCC. Therefore, it is the responsibility of the decision maker to select the best combination of retrofit activities to minimize the LCC of a project. In addition, by having the best combination of activities to retrofit the studied house, the LCC would decrease to more than 40%. In other words, by selecting the best retrofit options the LCC of the building decreases significantly.

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