Life-Cycle Cost Analysis of Energy Efficient Single Family Homes in Pakistan

Salman Azhar, Kamal Ahmed, Amna Salman
McWhorter School of Building Science, Auburn University, Auburn, Alabama, USA

Abstract

This paper is a companion of our first paper titled "Development and Testing of Energy Efficient Designs for Single Family Homes in Pakistan" which is also published in this conference proceedings. It presents results of Life-Cycle Cost Analysis (LCCA) of baseline and improved designs with energy efficiency measures for single family detached homes in Pakistan. The LCCA is an important tool to determine the feasibility of any energy efficient measure in the design process. It takes into account all costs of acquiring, owning, and disposing of a building or building system. By comparing LCCA of an existing design with a proposed design we can find out if the design updates are going to be economical in the long run. It includes initial investment, operating and maintenance, and disposal costs. The efforts made to minimize the life-cycle costs are not only beneficial for building owners but also for the society and economy. In our research, the LCCA results showed that, over the lifetime of the building, four measures namely Lighting Power (LEDs usage), White Paint on Roof, Roof Insulation and Exterior Wall Insulation are economically feasible. The LCCA results further indicated that the combined initial investment for these energy efficiency measures can be recovered within 7 to 10 years of building's service life. It is strongly recommended that various energy efficiency measures should be implemented in residential designs in Pakistan. The Implementation process will require continuous effort from government, housing authorities, designers, contractors and homeowners. The LCCA results produced as part of this research can be used as a benchmark. In addition, the LCCA for more energy efficient products should be carried out in an effort to fully understand their economic impact as well as short and long-term feasibility.

Keywords

Life-cycle, Life-Cycle Cost Analysis (LCCA), Life-Cycle Costing (LCC), Return on Investment (ROI), Energy efficient design, Residential construction

1. Introduction

The Life-Cycle Cost Analysis (LCCA) is considered as an important decision tool in the planning and designing process of the buildings. This tool is used to analyze the effectiveness of different Energy Efficient Measures (EEMs) in the building. In the construction of buildings, the initial investment in production cost is commonly set to minimum which does not necessarily results in a decrease in the life-cycle cost of a building. It becomes very important to show to the clients and owners of the building the relationship between efficient design choices and resulting life-cost of the building (Leckner and Zmeureanu, 2011). This issue becomes even more prudent when it comes to residential buildings. Owner of residential buildings and homes are most concerned with the initial investment they have to make for the completion of the project. In doing so, they tend to ignore the life-cycle cost of the building which often rises if initial planning is not very well thought out.

The LCCA is an important tool to determine the feasibility of any energy efficient measure in the design. "Life-Cycle Cost Analysis (LCCA) is a method for assessing the total cost of facility ownership. It takes into account all costs of acquiring, owning, and disposing of a building or building system" (WBDG website, 2016). By comparing LCCA of an existing design with a proposed design one can find out if the design updates are going to be economical in the long run. It includes initial investment, operating and maintenance, and disposal costs. The efforts made to minimize the life-cycle costs are not only beneficial for building owners but also for the society and economy. However, regardless of its importance, Life-Cycle Costing (LCC) has found limited applications so far. The reason for lack of applications of LCC is two barriers that include the complexity of the LCC technique and shortage of LCC data (Motuzienė et al., 2016). LCCA is being extensively used for industrial products nowadays (Levander et. al 2014). The goal is to minimize the production cost and maximize the profit. There are several differences between industrial products and buildings or homes. One of the major difference is the life length of a building compared to the industrial product. These factors can make the initial LCCA more difficult in the case of buildings or homes (Leckner and Zmeureanu, 2011).

The consumption of energy in an office building over a 25-year span will be almost three times the initial cost, but still more attention is paid to initial capital cost. The important point to note here is that a higher production cost can decrease the LCC. It is very important in the planning phase to show the relation between design choices and resulting life-cycle costs so that the owner can make appropriate decisions before the construction process starts (Schade, 2007). The execution of energy efficiency measures is becoming ever more important considering the amount of energy buildings are utilizing. An LCCA was conducted on residential buildings in Romania. The goal of this LCCA was to analyze the cost effectiveness of initial investment in renewable energy resources. The study was conducted on houses having low energy demand. It studied the impact of using photovoltaic panels on a passive house. The initial investment increased by 9.1% after incorporating photovoltaic cells. The results of this study showed that the application of photovoltaic cells is a cost-effective solution for electricity production leading to a payback period of 8-11 years. In studies considering the use phase, the life length of the house is an important consideration. The life length is generally determined by how long the residents tend to stay in a house, the functional lifetime of the house/building itself, or the length of time for a generation to pass. The Life length varied from 25 – 100 years in the literature assessed, most falling between 30-50 years (Leckner and Zmeureanu, 2011).

2. Aim and Scope

The aim of this paper is to conduct and compare LCCA of baseline designs and improved designs with energy efficiency measures for single family detached homes in Pakistan. The key question for this study is as follows: "Are initial investments for energy efficient design and construction feasible considering life cycle costs of a building?". This research is limited to design development of single family detached homes in Pakistan. Size of these homes ranges from 800 to 6000 sq. ft. The weather conditions considered for this research are of hot climate areas. Moreover, the focus city for this research is Lahore (31° 32′ 59″ N, 74° 20′ 37″ E) which is the 2nd largest city of Pakistan and lies in hot climatic region where summer season dictates the type of design. It is important to note that this paper is a companion of our first paper titled "Development and Testing of Energy Efficient Designs for Single Family Homes in Pakistan" which is also published in this conference proceedings (see Azhar *et al*, 2018a). Please refer to the first paper to learn about various Energy Efficiency Measures (EEMs) proposed in the base designs.

3. Literature Review

A short literature review in the form of three case studies was conducted. The three case studies discussed three different aspects involved in the LCCA. The first case study was focused on data uncertainties involved in the LCCA and how this data can impact the final results (Giuseppe et. al., 2017). Economic parameters like inflation rate, interest rate and energy price evolution play an important role in the determination of life-cycle cost of any energy efficient measure. The authors suggested that the probabilistic LCC methodologies could provide powerful decision support for undertaking building energy efficiency measures and should be used in the LCCA (Giuseppe et. al., 2017).

In the second case study, implications of different roofing and floor designs are considered on the life-cycle cost of the building (Islam et. al. 2015). The researchers divided the life of the building into four phases; construction, operation, maintenance, and disposal. The results showed that after incorporating the design improvements, the overall cost is reduced in the first three phases of the building whereas in the disposal phase the costs were increased. However, the overall life-cycle cost remained below the life-cycle cost of the base design.

In the third case study, building orientation and passive heating/cooling techniques were analyzed to determine their cost impact over the life-cycle of the building (Satori and Hestnes, 2006). The research compared results of 60 different houses from different climatic conditions. The LCCA results showed that houses incorporating passive techniques were more energy efficient over the entire life-cycle. In conclusions, all the three case studies indicated that a higher initial investment in energy efficient measures is economically feasible over the course of life-cycle of the building.

4. Research Design and Methodology

The research design is outlined in Figure 1. The first two phases of research are already explained in the first paper (see Azhar *et al*, 2018a). In the last phase, the LCCA was conducted to evaluate the feasibility of a design feature over the course of life span of a house (steps marked in bold) and final recommendations are made.

Figure 1. Research design

The LCCA was performed using data from energy simulations of existing and proposed design solutions. The results of the LCCA indicate if a design solution is effective and beneficial over the course of its life cycle. The first step in LCCA is to determine the economic impact of an alternative design or improved design. The Life cycle costs include initial cost, energy and water usage costs, operation and maintenance costs, replacement costs, residual value and other costs like taxes etc. After determining all these costs, one can calculate the life cycle costs (Dell'Isola, 1997).

For LCCA, the Present Value method was used. In the Present Value method, all present and future costs are converted into baseline of today's costs. Initial costs are expressed as present worth. Net present value is the difference between the present value of cash inflows and the present value of cash outflows that occur as a result of undertaking an investment project (Dell'Isola, 1997).

The following formula is used for Present Value calculations (Dell'Isola, 1997):

$$PV = \frac{FV}{(1+i)^n} \qquad \text{(Equation 1)}$$

Where:
- *PV* is Present Value
- *FV* is Future Value
- *i* is the interest rate (as a decimal)
- *n* is the number of years

The unit rates of all design items were collected from open market and vendors in Pakistan. Interest rate is assumed to be 6% (Trading Economics Website, 2017).

5. Results and Discussion

As mentioned in the first paper (see Azhar *et al*, 2018a), the following design measures were found to be most effective for achieving maximum energy savings:

1. Lighting Power (LEDs usage)
2. White Paint on Roof
3. Roof Insulation
4. Exterior Wall Insulation

Hence the LCCA was conducted for these measures only.

5.1 Lighting Power (LEDs Usage)

Replacing CFLs with LEDs resulted in the most savings in electricity bills. Price of CFL and LED light fixtures were collected from vendors in Pakistan. The manufacturer used for pricing of lighting fixture was Philips. The prices were PKR 175 and PKR 240 for one 24W CFL and one 9W LED respectively. The number of lighting fixtures per space were assumed based on the common practices used in Pakistan. The extra cost of LEDs from CFLs was considered as initial investment for this measure. For replacement costs, it was assumed that CFLs will be replaced every 2.5 years and LEDs will be replaced after every 10 years. Table 1 shows initial investment, annual savings and lifetime savings for each home. The replacement costs for CFLs were higher than the LEDs, this difference in replacement costs was added to Net Lifetime Savings. The LCCA results indicate that the initial investment for the LED usage will be recovered during the first year of building's service life for all homes.

Table 1: Lifetime Savings from LEDs Usage

z	I		Y		L		N=L-I+ Replacement Costs	
	Initial Investment		Yearly Savings		Lifetime Savings		Net Lifetime Savings	
	PKR	USD	PKR	USD	PKR	USD	PKR	USD
Home A	1,950	19	6,639	63	524,867	4,999	543,048	4,980
Home B	3,575	34	7,841	75	619,895	5,904	653,226	5,870
Home C	5,200	50	14,202	135	1,122,784	10,693	1,122,965	10,644
Home D	8,775	84	42,869	408	3,389,145	32,278	3,470,957	32,194

(Currency exchange rate: 1 US$ = PKR 105.4 as in July 2017).

5.2 White Paint on Roof

The second energy efficiency measure considered for the LCCA was the application of white paint on roof. In the calculations, it was assumed that applied paint is white weather resistant paint by *Master Paints.* Two coatings of paint were applied with 0.0172 liter paint per square foot. The total initial cost for paint was calculated using total roof area and price per liter. It was also assumed that the roof surface will be re-painted after every 3 years over the lifetime of building. All future replacement costs were converted into present values for the LCCA. The initial investment and replacement costs for paint application were PKR 44,777, PKR 72,796, PKR 137,351 and PKR 280,195 for Home A, B, C and D respectively. The yearly savings in electricity bills were PKR 5,464, PKR 6,242, PKR 9,205 and PKR 21,435 for Home A, Home B, Home C, and Home D respectively. Table 2 shows initial investment, annual savings and lifetime savings for each home. The LCCA results indicates that initial investment and replacements costs for paint usage will be recovered during the 10th, 13th, 16th and 13th year of building's service life for Home A, B, C, and D respectively.

Table 2: Lifetime Savings from White Paint on Roof

Home	I		Y		L		N=L -I + Replacement Costs	
	Initial Investment		Yearly Savings		Lifetime Savings		Net Savings	
	PKR	USD	PKR	USD	PKR	USD	PKR	USD
Home A	44,777	426	5,464	52	431,974	4,114	387,197	3,688
Home B	72,796	693	6,242	59	493,481	4,700	420,685	4,007
Home C	137,351	1308	9,205	88	727,731	6,931	590,380	5,623
Home D	280,195	2669	21,435	204	2,010,845	19,151	1,730,650	16,482

(Currency exchange rate: 1 US$ = PKR 105.4 as in July 2017).

5.3 Roof Insulation

The third energy efficiency measure considered for LCCA was installation of 2 inch roof insulation. In the calculations, it was assumed that installed insulation product is *Diamond Jumbolon*®. The total initial cost for roof insulation was calculated using total roof area and insulation price per square foot. The initial investment for roof insulation was PKR 74,980, PKR 121,900, PKR 230,000 and PKR 469,200 for Home A, B, C and D respectively. The yearly savings in electricity bills were PKR 2,884, PKR 2,571, PKR 4,603 and PKR 8,548 for Home A, B, C and D respectively. LCCA was carried out using the PV method. Table 3 shows initial investment, annual savings and lifetime savings for each home. The LCCA results indicate that initial investment for roof insulation will be recovered during the 16th, 28th, 24th and 25th year of building's service life for Home A, B, C and D respectively.

Table 3: Lifetime Savings from Roof Insulation

Home	I		Y		L		N=L-I	
	Initial Investment		Yearly Savings		Lifetime Savings		Net Savings	
	PKR	USD	PKR	USD	PKR	USD	PKR	USD
Home A	74,980	714	2,884	27	228,004	2,171	153,024	1,457
Home B	121,900	1161	2,571	24	145,230	1,383	23,330	222
Home C	230,000	2190	4,603	44	363,905	3,466	133,905	1,275
Home D	469,200	4469	8,548	81	675,789	6,436	206,589	1,968

(Currency exchange rate: 1 US$ = PKR 105.4 as in July 2017).

5.4 Exterior Wall Insulation

The last energy efficiency measure considered for the LCCA was installation of insulation on exterior walls. In the calculations, it was assumed that the installed insulation product is *Diamond Jumbolon*®. The total initial cost for insulation was calculated using total surface area of walls and insulation price per square foot. The initial investment for exterior wall insulation was PKR 30,814, PKR 61,628, PKR

136,462 and PKR 181,618 for Home A, B, C and D respectively. The yearly savings in electricity bills were PKR 175, PKR 1,840, PKR 1,736 and PKR 2,762 for Home A, B, C, and D respectively. Table 4 shows initial investment, annual savings and lifetime savings for each home. The LCCA results indicate that initial investment for exterior wall insulation will be recovered during the 19th, 30th and 28th of building's service life for Home B, C, and D respectively. For Home A, It was observed that although wall insulation had some annual savings but its life cycle cost was more than the cumulative savings. It was due to the reason that Home A had very low exterior wall area for wall insulation which contributed to lower savings.

Table 4: Lifetime Savings from Exterior Wall Insulation

Home	I Initial Investment		Y Yearly Savings		L Lifetime Savings		N=L-I Net Savings	
	PKR	**USD**	**PKR**	**USD**	**PKR**	**USD**	**PKR**	**USD**
Home A	30,814	293	175	2	13,835	132	-16,979	-162
Home B	61,628	587	1,840	18	145,467	1,385	83,839	798
Home C	136,462	1300	1,736	17	137,245	1,307	783	7
Home D	181,618	1730	2,762	26	218,359	2,080	36,741	350

(Currency exchange rate: 1 US$ = PKR 105.4 as in July 2017).

5.5 Combined LCCA Results for Energy Efficiency Measures

In the last step, the LCCA was conducted to see the combined impact of following energy efficiency measures.

1. Lighting Power (LED usage)
2. White Paint on Roof
3. Roof Insulation
4. Exterior Wall Insulation

The combined initial investment for all energy efficiency measures was PKR 116,155, PKR 200,777, PKR 397,462 and PKR 712,225 for Home A, B, C, and D respectively. The yearly savings in electricity bills were PKR 15,162, PKR 18,494, PKR 29,746 and PKR 75,614 for Home A, B, C and D. Table 5 shows initial investment, annual savings, and lifetime savings for each home whereas Figures 2, 3, 4 and 5 show LCCA charts for Home A, B, C and D respectively. The LCCA results indicate that combined initial investment for all energy efficiency measures will be recovered during the 7th, 9th, 10th and 8th year of building's service life for Home A, B, C, and D respectively.

Table 5: Combined Lifetime Savings from Energy Efficiency Measures

Home	I Initial Investment		Y Yearly Savings		L Lifetime Savings		N=L-I Net Savings	
	PKR	**USD**	**PKR**	**USD**	**PKR**	**USD**	**PKR**	**USD**
Home A	116,155	1106	15,162	144	1,198,680	11,416	1,082,525	10,310
Home B	200,777	1912	18,494	176	1,462,102	13,925	1,261,325	12,013
Home C	397,462	3785	29,746	283	2,351,665	22,397	1,954,203	18,611
Home D	712,225	6783	75,614	720	5,977,906	56,392	5,265,681	50,149

(Currency exchange rate: 1 US$ = PKR 105.4 as in July 2017).

Home A Home B

Home C Home D

Figure 2: Combined LCCA Results for Energy Efficiency Measures

6. Conclusions and Recommendations

This paper presented Life-Cycle Cost Analysis (LCCA) of energy efficient designs for typical single family detached homes in Pakistan. The energy simulation results (see Azhar et al., 2018a) showed that all energy efficiency measures resulted in some reduction in electricity consumption. However, the LCCA results showed that, over the lifetime of the building, four measures namely Lighting Power (LEDs usage), White Paint on Roof, Roof Insulation and Exterior Wall Insulation are economically feasible. The LCCA results further indicated that the combined initial investment for these energy efficiency measures can be recovered within 7 to 10 years building's service life. It is strongly recommended that various energy efficiency measures are implemented in residential designs in Pakistan. The implementation process will require continuous effort from government, housing authorities, designers, contractors and homeowners. Some of the energy efficiency measures like LED usage and White Paint on roof can be made mandatory in house construction as they have lower initial cost and biggest savings. Moreover, homeowners and builders should consider these energy efficiency measures in the planning phase because they will save their money in the long run and also save country's electricity production. The LCCA results produced as part of this research can be used as a benchmark. In addition, the LCCA for more energy efficient products should be carried out in an effort to fully understand their economic impact as well as short and long term feasibilities.

This research study provides an initial data for future studies. Future research studies can explore more areas of a residential home where electricity can be saved. Moreover, future research is needed on incorporating energy efficiency measures in housing codes and examine their implementation. After residential sector, commercial sector should also be considered so that electricity can be saved from those sectors. Future research can be conducted to study the impact of miscellaneous electricity loads on overall electricity consumption. These loads mainly include appliances like televisions, computers, microwave ovens, washer and dryers. There is potential for saving electricity if these appliances can be made more energy efficient.

7. Acknowledgment

This research study is funded by the US Department of State and the Higher Education Commission of Pakistan (HEC) under the joint Pakistan-U.S. Science and Technology Cooperation Program (Phase 6).

8. References

Azhar, S., Ahmed, K., and Salman, A. (2018a). "Development and Testing of Energy Efficient Designs for Single Family Homes in Pakistan." *Proceedings of the 10th International Conference on Construction in the 21st Century (CITC-10)*, July 2nd-4th, 2018, Colombo, Sri Lanka.

Dell'Isola, A. (1997). *Value Engineering: Practical Applications for Design, Construction, Maintenance & Operations*. RS Means Company Inc., Kingston, MA.

Giuseppe, E.D., Massi, A., D'Orazio, M. (2017). "Impacts of Uncertainties in Life Cycle Cost Analysis of Buildings Energy Efficiency Measures: Application to a Case Study." *Energy Procedia, 8th International Conference on Sustainability in Energy and Buildings*, SEB-16, 11-13 September 2016, Turin, Italy 111, 442–451. doi:10.1016/j.egypro.2017.03.206

Islam, H., Jollands, M., Setunge, S., Haque, N., Bhuiyan, M.A. (2015). "Life cycle assessment and life cycle cost implications for roofing and floor designs in residential buildings." *Energy and Buildings* 104, 250–263. doi:10.1016/j.enbuild.2015.07.017

Leckner, M., Zmeureanu, R. (2011). "Life cycle cost and energy analysis of a Net Zero Energy House with solar combisystem." *Applied Energy* 88, 232–241. doi:10.1016/j.apenergy.2010.07.031.

Motuzienė, V., Rogoža, A., Lapinskienė, V., Vilutienė, T. (2016) "Construction solutions for energy efficient single-family house based on its life cycle multi-criteria analysis: a case study." *Journal of Cleaner Production* 112, Part 1, 532–541. doi:10.1016/j.jclepro.2015.08.103

Sartori, I., and Hestnes, A.G. (2007). "Energy use in the life cycle of conventional and low-energy buildings: A review article" *Energy and Buildings*, 39, 249-257, doi:10.1016/j.enbuild.2006.07.001.

Schade, J. (2007). "Life cycle cost calculation models for buildings" *Proceedings of the Nordic Conference on Construction Economics and Organsiation* June 14-15, Lulea a tekniska universitet, pp. 321–329.

Trading Economics Website. (2017). https://tradingeconomics.com/

WBDG. (2016). "Life-Cycle Cost Analysis." *WBDG Website*, URL: https://www.wbdg.org/resources/life-cycle-cost-analysis-lcca