Two Days International Seminar on Theorizing Sustainable Architecture: Sustainable Building Design (SBD09)
12-13 August 2009, Edge Hill University, Lancashire UK

Life Cycle Costing Applications in Sustainable Building

Rusdy Hartungi, Christopher John Pye
School of Built and Natural Environment
University of Central Lancashire,
Preston PR1 2HE, Lancashire, UK
Email: RHartungi@uclan.ac.uk

ABSTRACT

Life Cycle Costing (LCC) which is defined ISO 15686-5:2005 is used to assess the sustainable and renewable technology used in building. The results indicate that the premium cost of sustainable/renewable technology in building is surprisingly lower than many have expected. The life time saving benefits are mainly coming from energy savings. However benefits might also come from improved indoor environmental quality, greater employee comfort/productivity, reduced employee health costs and lower operations and maintenance costs. These benefits will normally greatly exceed any additional upfront premium costs.

The information derived from this study will assist people to be aware of the life cycle cost and benefit of sustainable and renewable technology in building. It will also provide the architect/engineer the information about energy conservation potential acquired via energy saving and conservation.

Keywords: Sustainability, Sustainable Building, Life Cycle Costing, LCC

BACKGROUND

The adoption of green concept into a construction project by using sustainable and/or renewable technology in building is commonly perceived as a major undertaking since it requires significant initial investment. Undisputedly, sustainable building will incur a premium above the costs of traditional building. However, it also provides an array of financial and environmental benefits that conventional buildings do not. Those benefits might include future energy savings, improved indoor environmental quality, greater employee comfort/productivity, reduced employee health costs and lower operations and maintenance (O&M) costs. Since these benefits are predicated on the understanding that they are accrued over the life of the building, it is important to use a tool which accounts for the actual distribution of costs incurred over the life cycle of the building such as LCC. Life Cycle Costing (LCC) of a sustainable building project is a tool that accounts for the total cost/benefit of ownership of the project in question over its complete life including the cost elements incurred from initial investment, through ownership and operation to subsequent disposal of building materials or product.

In sustainable building, LCC is an important tool as it informs the decision making in the selection of various competing options such as the choice between the conventional or sustainable/renewable technology in building by comparing all of the significant differential costs of ownership over a given time period. It is also applicable to various types of building materials, products, systems and technologies when the focus is on determining the least-cost alternative for achieving a given level of performance (Johnson, 1990; Ruegg and Marshall, 1990).

Many studies have shown that the premium cost of sustainable building is much lower that the operations and maintenance cost that will occur during the life cycle of the equipment. A study of over a dozen of LEED certified building in the US for instance revealed that an average reduction in energy use of 30% per year (Kats, G., 2003). Flanegan *et al*., (1989) study confirms that if the accounting approach is applied where costs of operation and maintenance over life cycle of the building are included these can account to about 55-75% % of the total cost seen over 40 years. Further significant long term cost saving comes from reduced annual maintenance costs.

Moreover, often the premium in investment cost of sustainable/renewable technology in building is surprisingly lower than many have expected. This premium will continue to fall in the future as the numbers of sustainable buildings continue to rise and the increased experience of manufacturing and applying sustainable/renewable technology in buildings will make such sustainable technology more accessible. Berman (2001), in interviewing six US developers, found that the developers found that sustainable building has a cost premium of 10 to 15%. Another study on the cost of sustainable buildings was undertaken by New Ecology and the Tellus Institute in 2005. It is comprised of 16 case studies of affordable housing projects from around the country. The green projects reviewed in the report had a total development cost that ranged from only about 9-18% above the costs for comparable conventional affordable housing. In the US, Kats (2003) looked at 33 USGBC certified LEED projects and found an average 2% cost premium for sustainable buildings. Warnke (2004) also found a similar 2% premium for green building in the Department of Defense. Morris *et al.* (2005) concluded there was no significant difference in the cost of constructing a sustainable building as compared to a conventional building.

The cost of green design has dropped in the last few years and this will continues to drop in the future. The trend of declining costs can be observed through completed LEED Silver buildings, which were finished in 1995, 1997, and 2000. They incurred cost premiums of 2%, 1% and 0% respectively. Also, in the US, the cost of LEED Silver buildings has dropped from 3-4% several years ago to 1-2% (Kats, G, 2003).

The LCC will demonstrate how the sustainable/renewable technology in building which seems to be high in terms of initial investment will eventually be the most attractive option in cases where the whole life cycle costs are accounted for since the highest investment will be later recouped from the future savings coming from the energy and O&M cost saving. In the future, LCC will gain importance as the price difference between sustainable/renewable and conventional technology in buildings will continue to drop and there will be more sustainable/renewable technology coming into the market which will make it possible to carry out total integration.

AIMS

This paper applies the Life Cycle Costing (LCC) tool to analyse the different options for sustainable and/or renewable technology in buildings. It offers an overview of theoretical methods for LCC analyses and their practical application to sustainable and/or renewable technology in buildings. In addition, this paper will look into the limitation and constraints of LCC if it is applied to sustainable and/or renewable technology in buildings.

METHODOLOGY

LCC as described in ISO 15686-5:2005 will be used to evaluate the cost and benefit of sustainable sustainable/renewable technology in building in comparison to traditional technology. For this purposes a spreadsheet has been created to help with the calculation and analysis. In terms of validation, the stages and procedures used in the spreadsheet follows the stages and procedures prescribed by the U.S. EPA and U.S. DOE. The main sources of the data for analyzing life cycle cost and benefit of energy efficient sustainable building are mainly coming from

- The manufacturers, suppliers, contractors and testing specialists
- Data from utility company, statistics in the UK
- Data from trusted sites/organizations, (e.g. EIA, EPA, Carbon trust, CIBSE BRE, etc.).
- Historical data (From where?)

HISTORICAL DEVELOPMENT OF LCC

Table 1: Summary of Various Life Cycle Accounting Concepts in Building

Concept	Description
Full-Cost Accounting or Cost-Benefit Analysis	Cost-Benefit Analysis is an economic tool for supporting decisions on larger investments from a social viewpoint (Moberg et al., 1999). The attempt is to internalise the externalities, such as social costs, so that the company producing the environmental impact brings the costs into the costing system (Epstein, 1996). Future costs and benefits are discounted to take the time horizon of effects into account.
Total-Cost Accounting or Life-Cycle Cost	Total cost accounting; synonymously with whole-life costing and life-cycle cost is an approach where the systematic consideration of all relevant costs and revenues associated with the acquisition of an asset are considered. For construction this is expected to take into account all the relevant costs for capital or procurement during the whole life-cycle (Clift and Bourke, 1999). A standard methodology for whole-life costing is currently being developed by ISO (ISO/TC 59/SC 14N). Moreover the ISO standard for lifecycle costing is ISO 15686-5-2005
Life-Cycle Profit	The linkage between initial investment cost and income is sometimes expressed as life-cycle profit (LCP). This includes the whole income after all life-cycle costs have been deducted (Bejrum, 1991).

Previous studies suggested that the accounting for distribution of costs and/or benefit incurred over the life cycle of a building had been used under various names or variations for different purposes. For instance, originally the term "*cost in used*" (Should this be "Cost in use?") was introduced to describe to total life cycle cost of ownership throughout building life cycle (Stone, 1967). But not until 1978 the life cycle accountancy for the building became popular when the US Department of Commerce (DOC, 1978) introduced a guide for selection of energy conservation projects based on life-cycle costs for public and later state laws demand life-cycle costs to mandate or encourage energy conservation in building (Ruegg, 1980). The term which is later known as "*Life Cycle Costing, LCC*" was then standardised by the American Standard for Testing Material, ASTM E917 (1989) and since then has become the most commonly used term (Flanegan and Norman, 1983; Robinson, 1986; Bromilow and Pawsay, 1987; Kirk and Dell'Isola, 1995).

Table 2: Goals of the Project's LCC

Goal	**Very important**	**Somewhat important**	**Not important**
Reduce operation/ maintenance costs	55	8	0
Extend useful life/durability	47	12	4
Increase occupant productivity/comfort	31	24	8
Conserve natural resources	27	29	7
Future facility alteration	17	37	9
Lower construction costs	16	36	9
Meet government mandates	15	25	21

Source: Various sources on reference list.

Apart from the above terms, the studies from around the world have shown that other various methods and terms have been used for the life cycle accountancy of a sustainable building. Table 1 provides a summary of some other life cycle accounting concepts that have been used so far to account for the actual distribution of costs and/or benefit incurred over the life cycle of a sustainable building.

But recently the terms of "*Whole Life Cycle Costing* (WLC/WLCC)" (Clift and Bourke, 1999) and "*Whole Life Appraisal* (WLA)" are also used (Flanagan and Jewell, 2005). However, the use of this term has been limited in practice due various things such as scarce input data (Clift and Bourke, 1999; Larsson and Clark, 2000).

Though various terms exist, the LCC term used in this paper refers to the most commonly agreed definition which is used in ISO 15686-5:2005. The ISO 15686-5 which is adopted from the American Standard for Testing Material, ASTM E917 (1989), states that:

"Life Cycle Costing is a method to facilitate choices where there are alternative means of achieving the clients or key stake holders objectives and where those alternatives differ not only in their initial costs, but also in their subsequent operational and renewal costs over the service life time in the asset. "

Nowadays LCC has been widely used in sustainable building for various goals such as: to evaluate the competing options of energy efficiency and control technology in building to reducing operation and maintenance (O&M) costs, more accurate cost forecasting for construction. Table 2 above shows the surveys results of how construction professionals see the level of importance of using LCC for various goals.

LCC APPLCATION IN SUSTAINABLE BUILDING

Life Cycle Costing (LCC) in sustainable building is a tool to account for the total cost of ownership that addresses all the elements of the anticipated non-recurring and recurring costs and/or cash flow over the building life-span. It takes into account discount/compounding factors and cash flow during the entire life-span of the sustainable building system.

In this paper there are two LCC techniques that will be used. The first one is to add together all the present and future anticipated non-recurring and recurring costs and cash flows up to end of the anticipated life of the sustainable building system. The anticipated LCC accumulated value of a sustainable building system will then be calculated and compared for each project. Certainly, the alternative with the lowest LCC is the most attractive option in case the selection criteria are based solely on the economics term.

The second technique is borrowing a concept which is frequently used in economics and finance, the Net Present Value (NPV). The NPV expresses the sum of the present value (PV) of non-recurring and recurring costs and cash flows occurring during the life-span of the sustainable building system. It starts with a discount rate, followed by finding the present value of the cash proceeds expected from the investment, then followed by finding the present value of the outlays: the net of this calculation is the net present value. In mathematical term it is expressed as

$$NPV = \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}$$

Where C_t is the sum of all costs incurred at time *t; i* is the discount rate and n is the life cycle of the sustainable building system. The alternative with the greatest NPV is the most attractive one in financial terms.

The key factor for accurate LCC analysis is the ability to identify the cost and future cash flow that might be generated by the sustainable building system during its entire life-cycle. In this paper, the anticipated costs and cash flow that might be generated from the use of sustainable building have been identified and then put into the spreadsheet.

Initial Investment Costs

Initial investment costs are the costs that will occur prior to the use of the sustainable and renewable energy technology in building. Because sustainable and renewable energy technology in sustainable building is operated for a longer life with less operational and maintenance costs, during their life span, the initial cost is normally not the major cost of the sustainable building life cycle.

Operational Costs
The operational costs are annual costs, excluding maintenance and repair costs, involved in the operation during the life cycle of the equipment. All operational costs are to be discounted to their present value prior to the application of LCC analysis. The operational cost of sustainable and renewable technology in building is mainly the electricity energy consumption As the sustainable and renewable energy technologies in buildings consume less energy, are more efficient and have a longer life span, their operational costs are much less in comparison with conventional technology.

Maintenance Costs
Maintenance costs are scheduled costs associated with the upkeep of the equipment to maintain it in good working order. The maintenance cost of sustainable and renewable energy technology in buildings might be the repair costs, inspection and cleaning costs, the cost of labour and equipment required to upgrade and prolong the life of the equipment without replacing the system. An example is the cost for replacing any faulty components or carrying out annual inspections. For the LCC analysis the maintenance and repair costs should be treated as annual costs. .

Replacement Costs
Replacement costs are anticipated expenditures on major components required to maintain the operation of the equipment. Replacement costs typically come from replacement expenditure on some of the components of the sustainable and renewable energy technology equipment during their life cycle.

Understanding the characteristics of the sustainable and renewable energy technology in buildings is the key feature to understanding the likely maintenance and replacement cost behaviour.

Residual Value and Disposal Cost
Residual value is the net worth of the equipment at the end of the LCC analysis study period. Disposal costs are the cost of disposing of the equipment or components when they have failed or are no longer required for any reason. Some equipment may contain materials that could contaminate groundwater or cause toxin build-up in soil; therefore they must be disposed of properly at a licensed hazardous waste site. In some countries this is already mandatory; therefore in this case there is a disposal cost that needs to be added to the total LCC. The residual value of some equipment is in many cases less important, as the net worth value at the end of LCC analysis is minimal or can not be estimated. But the disposal cost of sustainable building is important when evaluating the sustainable building solution that might have different life expectancies.

Total LCC
The LCC is the sum of Initial Investment which is also known as Cost of Capital (I_0) Operations Cost (O), Maintenance (M) and Replacement (R) Cost, Disposal Cost (D) minus

Salvage Value (S). All of the cash in/out flow must be brought to the same time reference (Should this be 'time frame'?) which is either present value (PV) or future value (FV). An example of the mathematical expression in the case of all cash flows being brought to the present value (PV) is

$$LCC = I_0 + \sum_{t=0}^{n} O.PV_{sum} + \sum_{t=0}^{n} M.PV_{sum} + \sum_{t=0}^{n} R.PV_{sum} + \sum_{t=0}^{n} D.PV_{sum} - S.PV$$

Where

$$PV_{sum} = \frac{(1+i)^t - 1}{i(1+i)^t} \qquad PV = \frac{1}{(1+i)^t}$$

LIFE CYCLE COST AND BENEFIT ANALYSIS OF SUSTAINABLE BUILDING

The main cost barrier to sustainable and renewable technology in buildings is the upfront cost of investments. Undisputedly this investment cost incurs a premium above the costs of traditional technology. However, when evaluated over the entire life cycle of the building, the life time saving benefits coming from energy savings, improved indoor environmental quality, greater employee comfort/productivity, reduced employee health costs and lower operations and maintenance costs will normally greatly exceed any additional upfront premium costs.

Life Cycle Operations and Maintenance (O&M) Benefit

Life cycle operations benefit is mainly the saving that could be realised from reducing electrical energy consumption. It is widely recognised that energy efficiency will improve greatly through the intensive use of energy saving and control technology in building. In turn, this will reduce the life cycle operational cost. But it is important to recognise here that the saving in operational cost is not just the saving from reducing energy consumption, because the use of energy control technology in building will also allow the reduction of peak energy demand.

The operational saving from using energy efficient technology in buildings is well documented. Kats (2003) investigated the actual energy saving in the US state office building and revealed that the actual savings for a 100,000 ft^2 of office spaces is worth US $60,000 per year, with a 20-year present value of expected energy savings at a 5% real discount rate, is worth about three quarters of a million dollars of life cycle savings (Kats, G, 2003)

In terms of benefit from peak energy demand, it is important to recognise that the price of energy during peak periods is higher than the energy price during the off peak season. Therefore reducing the peak demand will result a life cycle cost saving. A study for over a dozen of LEED certified buildings revealed that an average peak reduction of about 40% is achieved by the sustainable buildings. A study of various public buildings in the US confirm that a 10% reduction in peak demand for one million square feet of state prisons, hospitals or office buildings amounts to about $24,000 savings per year (Kats, G, 2003). A further review of 60 LEED rated buildings throughout the US demonstrated that green buildings, compared to conventional buildings are on average 25-30% more energy efficient and are characterized by lower electricity peak demand through the use of onsite renewable energy production (Kats, G, 2003).

Table 3 below shows a detailed breakdown of efficiency improvements and onsite renewable energy production for each of the four LEED certification levels based on United States Green Building Council (USGBC) Observation.

TABLE 3: Reduced energy use for buildings of different LEED certification levels.

	Certified	**Silver**	**Gold**	**Average**
Energy Efficiency (above standard code)	18%	30%	37%	28%
On-Site Renewable Energy	0%	0%	4%	2%
Green Power	10%	0%	7%	6%
Total	28%	30%	48%	36%

Source: USGBC & Capital E Analysis

Beside operational benefits from energy saving, further benefit might come from less water consumption and water conservation. Sustainable building water conservation strategies typically fall into four categories:

- Efficient use of potable water through better design technology.
- Capture of gray water, which is the non-fecal waste water from bathroom sinks, bathtubs, showers, etc, and re-use for irrigation.
- On-site storm water retention for use as groundwater recharge.
- Recycled water use. (Is this category number 4? Is this reuse of storm water for irrigation as opposed to groundwater recharge?)

Taken together, these strategies can reduce water use below common practice by over 30% indoors and over 50% for landscaping. Of 21 reviewed green buildings submitted to the USGBC for LEED certification, all but one used water efficient landscaping, cutting outdoor water use by at least 50%. Seventeen buildings, or 81%, used no potable water for landscaping. Over half cut water use inside their buildings by at least 30%." This also translates into big savings for the building. Taking all factors into account, including the avoided cost of water and extra cost for new marginal water supply, the California Analysis calculated a 20-year present value of $0.5 1/ft2 for water savings from green buildings (Kats, G. 2003).

Other Life Cycle Benefit.

Another life cycle benefit of sustainable building is waste reduction. Waste reduction strategies, such as reuse and recycling, help to reroute some waste from being disposed of in landfills. These strategies help save on disposal costs as well as costs to society for creating new landfills and maintaining the existing ones. Estimating life cycle benefits of waste reduction, diversion and recycling for sustainable buildings relative to conventional ones is not a straight forward process, as minimal data exists regarding the actual diversion and disposal rates, thus making it hard to estimate the waste reduction cost benefits.

Some other life cycle benefits may be better indoor environmental quality which might improve employee's productivity, reduced employee ill health and improved retention rates. Other life cycle benefits might include environmental aspects such as reducing pollution and global warming. These are some of the more difficult benefits to quantify, but if enough databases are available to convert these into monetary units, they could still be incorporated into LCC analysis.

CASES PRESENTATION ANALYSIS AND RESULTS

The following cases are presented and analyzed using the LCC framework to demonstrate how sustainable technology in a proposed lighting scheme which may seem to be most expensive solution in terms of the initial investment, might in fact the least expensive solution if the future costs occurring during its lifetime are considered.

The building is a refurbished office, naturally ventilated with a reasonable number of corridors and circulation areas. Along the corridors and circulation areas there is an option of using tungsten incandescent, halogen, fluorescents, or LED lighting. The lighting solution needs to be acceptable in terms of visual comfort but more importantly needs to be cost effective in terms of energy efficiency too. The following data has been input into the LCC spreadsheet:

<u>*Project General Information*</u>

Name/location	: UK
Rooms or spaces	: Building Corridor and Circulation Areas
Days used per week	: 6 Days
Hours of use per day	: 10 hours
Total usage per week	: 60 hours
Total of week per year	: 52 Weeks

<u>*Basic Parameters*</u>

Energy rate (£/kWh)	: £0.13
Labour/technician rate (£/hr)	: £20.00
Electricity increase rate	: 3.00%
Inflation rate per year	: 2.00%
Interest charge	: 4.00%
Time to install each lamp (hour)	: 0.25 lamp/hour
Time to install each ballast per hour (if any)	: 0.50 ballast/hour

The result showed that in term of the initial investment cost, LED lighting system is the most expensive solution, among any other alternatives, reaching approximately 186% in comparison to the investment cost of tungsten incandescent lighting. This figure is followed by the halogen and fluorescent which is about 169% and 160% respectively. However, owing to the future cost of operation and maintenance that will occur during the life time of the LED lighting system, it is reasonably to suspect that the high investment cost might be offset by future saving that could be made. The maintenance cost relevant to this project is mainly the cost for re-lamping which includes the cost of materials (e.g. ballast/control gears, lamps, etc), and the cost of labour/technicians to do the re-lamping work. On the top of maintenance cost, there is still the operational cost which is related to the buildings energy consumption throughout the life cycle of the lighting system. In terms of the annual energy cost, the figure indicates that LEDs consume as little as 17% of annual energy cost of the incandescent lamps. The full result and spreadsheet of this study have been published (Hartungi & Jiang, 2009).

Life cycle analysis has also been applied in various sustainable building projects throughout the world. The application of LCC as a tool for life-cycle accountancy for various building materials and systems have shown varied results, with positive pay-off and varying accuracies these are shown below in tables 4 & 5.

A key requirement for accuracy in LCC projections/estimations is the availability of accurate information on the significant cost drivers of the alternatives under consideration. Much of this data come from the manufacturers, suppliers, contractors and testing specialists, from utility companies, statistics from trusted sites/organizations, (e.g. EIA, EPA, Carbon trust, ASHRAE, CIBSE BRE, etc.) and historical data from these companies.

The LCC tools that are normally used are Energy-10 from the National Renewable Energy Laboratory (NREL). Other tools mentioned were DOE-2, BLCC, LCCID, BEES, and Trane. The majority of these software tools deal directly with energy modelling and resource efficiency.

Table 4: LCC and its Application in Sustainable Building

Building component	***Always applied***	***Sometimes applied***	***Seldom applied***	***Never applied***	***Positive Pay-Off***
M & E Systems in Building					
HVAC system	41	23	1	0	94%
Sustainable building/day-sustainable building	27	30	7	0	75%
Drainage & Water conservation	19	27	16	2	45%
Renewable energy	17	25	19	2	13%
Operations and maintenance	27	26	8	2	59%
Building Materials					
Windows	23	29	9	2	50%
Insulation	21	31	10	1	45%
Exterior finishes/Roofing	23	22	15	4	34%
Interior finishes	10	21	17	16	17%
Foundation/structural elements	4	13	30	16	3%
Other Purposes					
Size of building	11	14	20	16	22%
Disposal/deconstruction	5	20	19	20	11%

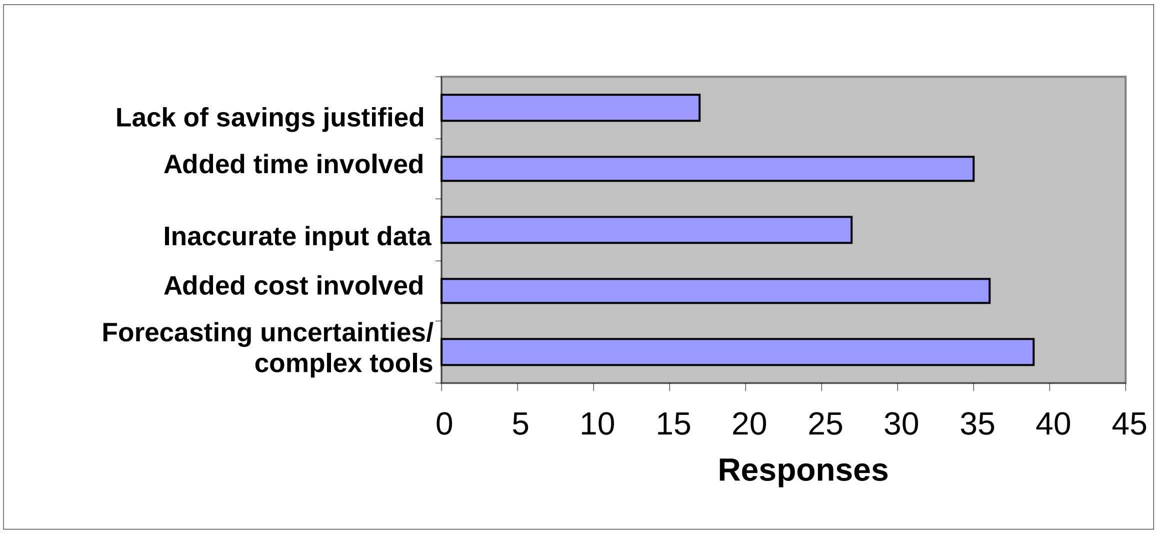
Source: Taken from various sources as shown on the list of reference

Table 5: Accuracy of Projections/Estimations using LCC

Building Component	***Better than or Equal to Projected Result***	***Less Than Projected Result***	***No Post Construction Follow-Up***
M & E Systems in Building			
HVAC system	29	12	13
Sustainable building/day-sustainable building	26	7	20
Drainage & Water conservation	21	8	23
Renewable energy	7	14	24
Operations and maintenance	20	8	20
Building Materials			
Windows	13	4	33
Insulation	13	9	29
Exterior finishes/Roofing	9	2	38
Interior finishes	7	3	34
Foundation/structural elements	3	4	37
Other Purposes			
Size of building	9	4	35
Disposal/deconstruction	4	6	33

Source: Taken from various sources as shown on the list of reference

DISCUSSION AND CONCLUSION



Source: Nornes (2005) **Figure 1. Constraints Encountered in LCC**

LCCs have been successfully applied throughout the world to demonstrate how sustainable/renewable technology in buildings which seem to be high in terms of initial investment will be eventually be the most attractive option in economic terms.
In the future, LCC will gain importance as the price difference between sustainable/renewable and conventional technology in buildings continues to drop and new sustainable/renewable technologies come onto the market which will need to be economically assessed.

Despite its importance, LCC has found limited application so far in the construction sector (Bakis et al., 2003). Various constraints and limitations of LCC have been identified from various studies. LCC techniques depend heavily on forecasts about the future but some of the forecasts will be no more than expert judgment, best guesses or hunches (Flanagan et al., 1989). Moreover the accuracy of the forecast is heavily reliant on the availability of the data for investment, operating / maintenance and replacement costs. The availability of the databases for LCC today is still rather limited. One reason is the lack of any framework for collecting and storing data (Bakis et al., 2003).

Kelly and Hunter (2005) and Flanagan and Jewel (2005) cite the same basic data sources as: data from specialist manufacturers, suppliers and contractors, predictive calculations from computer modelling of buildings and historic data.
All authors highlight the danger associated with the data used for whole life costing; Flanagan and Jewel state:

- Data is often missing.
- Data can often be inaccurate.
- People often believe they have more data than actually exists.
- It can be difficult to download data for subsequent analyses and for data sharing by a third party.
- There will be huge variation in the data, sometimes for the same item.
- Data is often not up to date.
- Data input can be unreliable: the input should be undertaken by those with a vested interest in getting it right.

Thus, data collection brings difficulties; however, LCC analysis is only accurate if the collected data is reliable (Emblemsvag, 2003). Existing databases have their limitations; they do not record all necessary context information about the data being fed into them (Kishk *et al*., 2003). Furthermore, people may have a detailed knowledge of the performance and characteristics of the material and components of sustainable technology used in the projects, but do not have knowledge of the ways in which facilities are used. Here again it will be difficult to gather the correct data. (Flanagan and Jewell, 2005). Another issue that may arise is that LCC analyses can be time consuming, which may translate into higher professional costs needed to assess the LCC. The driver for change is that clients should recognise the added value being provided by LCC and, as a result, pay for this service. Until this is done, the professional fees might provide another barrier to applying LCC to sustainable building. It has also been highlighted that in practice, LCC remains a set of techniques that are not applied in a consistent manner within EU member countries, let alone across the EU as a whole. An important consideration therefore in the development of an LCC methodology is to identify a sort of ‘common denominator’ (essentially a simplified basis) that can provide a recognizable framework for using LCC and also provide the basis for future development. The approach to this might be to take account of the most essential and commonly used scenarios and instances in which LCC may be applied, whilst allowing for country-specific approaches in line with local standards and guidelines

Nevertheless, apart from these limitation and constraints, Life cycle costing techniques still provide an acceptable definition of the economic effectiveness of different sustainable/renewable technologies in sustainable building.

REFERENCES

ASTM E917-89. Standard practice for measuring life-cycle costs of buildings and building systems. American Society for Testing Material (ASTM), Washington D.C., U.S.

Bakis, N., Kagiouglou, M., Aouad, G., Amaratunga, D., Kishk, M. & Al-Hajj, A., (2003), An Integrated Environment for Life Cycle Costing in Construction.

Bejrum, H. (1991). (Life-cycle economic appraisal for buildings and real estates). Institute of Technology, Stockholm, Sweden.

Berman, Adam (2001) “Green Buildings: Sustainable Profits from Sustainable Development,” Tilden Consulting. Report July 30, 2001.

Bromilow, F.J., Pawsay, M.R. (1987). Life cycle cost of university buildings. Construction management and economics, 5, 3-22.

Clift, M., Bourke, K. (1999). Study on Whole Life Costing. Report prepared for DETR, February 1999, Report Number CR 366/98. UK.

Epstein, M. J., (1996). Measuring corporate environmental performance. Irwin Professional Publishing, Chicago, U.S.

Flanagan, R. & Jewell, C. (2005), Whole Life Appraisal for construction. Oxford: Blackwall Publishing Ltd.

Flanegan, R., Norman, G. (1983). Life cycle costing for construction, Quantity Surveyors Division of The Royal Institution of Chartered Surveyors, London, UK.

Flanegan, R., et al. (1989). Life cycle costing, theory and practice. BSP Professional books, Oxford, London, UK.

Hartungi, Rusdy, Liben Jiang (2009) “Life Cycle Cost and Benefit of Energy Efficient Lighting” Proceeding of 1st International Exergy, Life Cycle Assessment, and Sustainability Workshop & Symposium (ELCAS), 4 - 6 June, 2009, Nisyros – Greece.

ISO 15686 Part 5 (:2006). Buildings & constructed assets – Service life planning – Part 5: Life cycle costing

Johnson, R. (1990). The Economics of Building: A Practical Guide for the Design Professional. New York: John Wiley and Sons Inc.

Kats, Gregory (2003). "The Costs and Financial Benefits of Green Buildings." California, October 2003.

Kirk, S.J., Dell’Isola, A.J. (1995). Life cycle costing for design professionals. McGraw-Hill, Inc. New York, U.S.

Kishk, M., Al-Hajj, A., Pollock, R., Aouad, G., Bakis, N. & Sun, M. (2003) Whole life costing in construction: a state of the art review. RICS Foundation.

Larsson, N.K, Clark, J. (2000). Incremental costs within the design process for energy efficient buildings. Building research and information, 28 (5/6), 413-418.

Moberg, A, et al. (1999). System analytical environmental tools, an introduction to decision making context). Report 251, Swedish EPA, Stockholm

Morris, Greeg of Future Resources Associates based on A-6 Schedule (Figure IV-1) indicates a range of $0.026 -$0.039/ft2/year, indicating that the $0.025/ft/year estimate is conservative (this analysis is available upon request, gmorris@emf.net).

Ruegg, R. T. & Marshall, H. E. (1990). Building Economics: Theory and Practice. NewYork: Van Nostrand Reinhold.

Robinson, J.R.W. (1986). Life cycle costing in buildings: a practical approach. Australian Institute of building papers, 1, 13-28.