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Life Cycle Cost Analysis: Is it Worth the Effort?

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ABSTRACT

Life cycle cost analysis (LCCA) is often considered important for both new and retrofit building construction projects but is rarely implemented, often because it is perceived to be "not worth the effort." Is an LCCA worth the effort? This paper can help you answer this question for yourself. It is important to know what the benefits are, and to be clear about what constitutes the effort. The paper demonstrates that, when used in place of a simple payback approach, an LCCA can lead to far different energy-efficiency recommendations. In addition, the paper provides an overview of how to do an LCCA, including non-conventional LCCA steps called "establishing the baseline" and "bundling measures."

A simple payback underestimates the value of an energy-efficiency investment because it only accounts for annual energy cost savings and capital cost. It ignores other significant costs and benefits (rebates, maintenance savings, avoided immediate and future capital investments, etc.) as well as savings that accrue beyond the timeframe of the simple payback period. Because the inclusion of additional cash flows or the impact on long-term operating costs can significantly alter the decision to include or exclude a particular measure, a simple payback metric is not ideal. In sharp contrast, a comprehensive LCCA gives decision-makers the full financial implications of various design decisions to make better decisions.

The most time intensive part of an LCCA is gathering the data inputs. The paper explains how this data can be collected in the most efficient way. Also, the paper presents a case study of how this data was gathered for a small, retail building. The effort to collect data for this project is shown to be significant, but perhaps not as large as one would expect.

INTRODUCTION

Life cycle cost analysis (LCCA) is a financial tool that uses discounted cash flows to evaluate a project given a set of constraints, which include time period and discount rate. LCCA takes into account all possible cash flows and generates financial metrics: net present value (NPV) and internal rate of return (IRR). In the context of building design, LCCA is used to evaluate energy efficiency measures (EEMs), conventionally only considering capital and energy costs, although other costs such as operation & maintenance, rebates or incentives, or even projected revenue changes may affect the outcome.

A simple payback analysis is often used in lieu of an LCCA. For the purpose of this discussion, a simple payback analysis is the process of determining the capital cost and energy cost savings of an EEM, and dividing one by the other to determine the number of years it takes for the EEM investment to be repaid. While a simple payback analysis may be convenient and less time-intensive, we argue that this metric is incomplete and results in sub-optimal design choices, especially when used in the context of a "deep energy-efficiency retrofit," or a retrofit that dramatically reduces a building's energy operating costs. An LCCA is more comprehensive and enables decision makers to make more informed decisions.

LIFE CYCLE COST ANALYSIS FUNDAMENTALS

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In order to understand why a simple payback analysis is inferior to life cycle cost analysis, it is necessary to fully understand the LCCA process. A conventional LCCA determines energy savings and other cash flows for a set of energy efficiency measures and calculates financial metrics on which to base a decision for each measure. This conventional process, while it provides a more comprehensive analysis than simple payback, overlooks some key opportunities to achieve greater savings and improve the accuracy of the analysis. We advocate a four-step process for LCCA that targets the realization of all cost saving opportunities:

1. Establish the Baseline *(additional step beyond conventional process)*
2. Define the Energy Efficiency Measures (EEMs)
3. Calculate the Financial Metrics
4. Bundle Measures (*additional step beyond conventional process)*

The additional steps of establishing the baseline and bundling measures explicitly require the analyst to consider all possible cash flows, including any cost avoidance resulting from a highly integrated design (e.g., avoiding a chiller plant expansion). In the following sections, we will show that these additional steps are useful tools to reduce both fossil fuel consumption and life-cycle costs.

Establishing the Baseline

An important, but often not taken, first step in an LCCA is establishing the baseline. For new construction, this means defining the building design that minimally meets all of the owner's needs. Examples of such baselines can be found in the federal standards set forth in NIST Handbook 135, the current Annual Supplement to NIST Handbook 135, and the Office of Management and Budget Circular A-94.

However, for deep energy-efficiency retrofits, a different baseline is required. We define this baseline as the set of ongoing building maintenance and renewal projects that help meet non-efficiency goals – such as safety, occupant comfort, reliability, functionality, and aesthetics. We consider these baseline projects to be inevitable and part of business-as-usual.

Establishing a baseline for building retrofits helps analysts clearly differentiate between the cost of efficiency (i.e., what they are selling) and cost of business-as-usual (i.e., building expenses that would occur without the increased efficiency). To focus the analysis on efficiency measures, the business-as-usual capital cost should be subtracted from the full cost of efficiency measures. For example, if a boiler must be replaced because it has reached the end of its life, the business-as-usual cost is to maintain functionality by replacing it with a standard unit that meets code. An efficiency measure may call for a boiler that is much more efficient. To justify the investment in this efficiency measure, the energy cost savings (and other financial benefits) should only have "to pay for" the marginally higher cost of the higher efficiency unit, not its full cost.

It is often extremely difficult to establish the baseline, which should extend into the future as long as the LCCA analytical period. In many small buildings (less than 30,000 square-feet), replacements are not planned at all and only occur upon system or component failure. For larger buildings, maintenance and replacement are rarely planned more than a few years in advance. Moreover, facility managers are sometimes unwilling to be forthcoming about what they are planning to replace as it may skew an energy auditor's replacement recommendation. In such a case, it is advisable to explain to the owner and facility manager that an accurate baseline will improve the financial analysis.

Even when there is no capital improvement plan in place, it is still vital that an appropriate baseline be established. There are at least two ways to project business-as-usual costs:

1. A <u>facility condition assessment</u> consists of a third party assessor who evaluates building systems and components, and estimates time until replacement, typically assigning replacements a high, medium or low priority. It is important to ask the assessor to forecast these placements at least as long the LCCA analytical period, as the recommendations commonly only cover a few years.
2. <u>Analysts themselves can estimate replacements</u> by using various published sources. Chapter 36 of the 2007 ASHRAE Handbook of HVAC Applications provides service life estimates for mechanical systems. Life-cycle costing handbooks provide estimates for envelope, lighting, and other systems (see Kirk, et al 1995). When possible, analysts should further justify these resources with their own professional experience.

In addition to making the LCCA more accurate, establishing the baseline can help you find the best time for a deep energy-efficiency retrofit. Owners who are planning to implement a major business-as-usual renewal project would likely be more receptive to deep retrofits. This is because a deep energy-efficiency retrofit that is planned in conjunction with a major renewal, done well, and uses integrative design (see www.10xe.org), can create enormous energy savings for minimal incremental capital cost (Fluhrer et. al. 2010). For buildings with no planned improvements, a deep energy-efficiency retrofit will have greater net present value at certain times in its life. This is ultimately a function of anticipated building improvements, but a full discussion of how to time retrofits is a discussion for another paper.

Defining Energy Efficiency Measures

After the baseline has been established, the energy efficiency measures (EEMs) should be defined and their costs and benefits must be estimated. The following costs and benefits should be considered when evaluating EEMs:

Capital Costs. Capital costs cover the initial cost of equipment including installation, replacement costs that fall within the timeframe of the analysis, and any salvage or residual value of the equipment.

Energy Costs. Energy operating costs for a measure are typically taken from an annual energy model of the building. These costs are subtracted from the baseline energy operating costs to obtain the marginal annual savings for the measure.

Maintenance Costs. Maintenance costs include all planned equipment maintenance, such as cleaning and repair.

Miscellaneous Costs. This category incorporates all costs that do not fall under any of the three previous categories. This can include utility rebates, tax benefits, and increased revenue.

Non-Quantitative Benefits. Non-quantitative benefits are defined as any positive effect of the measure that cannot objectively be assigned a cost benefit. An example of this is increased worker productivity from a daylit and thermally comfortable space. If the financial merit of the measure under consideration is questionable, these benefits may provide the determining factor. Per section 4.6.4.3 of NIST Handbook 135 (1996), these items are by nature external to the LCCA, and thus do not directly affect calculations, but they should be considered in the final decision and should be included in the project documentation. Muldavin (2010) provides guidance on considering these benefits during analysis.

When gathering cost data, two different approaches may be taken: absolute costing or marginal costing. Absolute costing is to calculate the absolute life-cycle cost of each measure and the baseline, accounting for every cash flow. Marginal costing, on the other hand, is to subtract the cost of the baseline from each measure to determine the net value of the measure relative to the baseline.

Since maintenance costs and others can be no different between the efficiency measure and baseline, marginal costing can be a simpler analysis than absolute costing because such costs do not have to be estimated (since they would subtract to zero). For all dissimilar costs, we find absolute costing to be more transparent and easier to work with.

Calculating Financial Metrics

After all of the costs of the measure have been defined, the calculation of financial metrics may begin. Some common metrics of life cycle cost analysis are net present value (NPV) and internal rate of return (IRR), which is also known as return on investment (ROI). A measure's NPV is the value in today's dollars of its implementation over the specified timeframe. If the NPV is positive, then the measure is generally considered to be beneficial. The IRR is a rate of return used to compare profitability of investments. If the IRR is greater than the owner's stated discount rate, the measure is considered beneficial. The methods for calculating these metrics have been documented at length elsewhere and will not be repeated. See, for example, Chapter 36 of the ASHRAE Handbook of Applications (2007) or Kirk and Dell'Isola (1995).

After financial metrics are calculated, a conventional life cycle cost analysis typically ends and a decision is made on a measure-by-measure basis. However, an added step of combining measures into bundles can lead to different conclusions.

Bundling Measures

A bundle is a combination of individual energy efficiency measures. The purpose of bundling is to evaluate the synergistic benefits of measures. This practice supports integrative design and allows for more cost-effective measures to absorb the cost of measures that do not "pay for themselves," leading to a more efficient design with more non-quantitative benefits. Bundling measures also often leads to downsizing mechanical systems because a specific collection of measures can greatly reduced heating and cooling loads. Fortunately, these benefits can be achieved through a relatively straightforward bundling process.

Evaluating measures in a bundle is intrinsic to integrative design, which, in our view, is iteratively seeking the optimization of the whole building rather than its individual parts and creating multiple benefits from single expenditures (see www.10xe.org for a fuller explanation). In addition, the benefit of an integrated design is a better performing and more cost-effective building (Lewis 2004).

Considering measures individually cannot always support integrative design. Take, for instance, a concept-phase evaluation of a new chilled beam system for an existing high-rise building. Replacing a traditional variable-air-volume (VAV) system one for one with a chilled beam system will result in a large capital-cost increase for the chilled beams above a baseline VAV replacement, and would probably not meet the client's ROI threshold. However, if the measure is combined with an efficient glazing retrofit and lighting fixture upgrade, the loads, and therefore the capital cost of the chilled beams, are dramatically reduced. Moreover, the load reduction allows for the purchase of more efficient chillers that are only available in sizes now suitable for the building.

If these measures were not bundled together and their interactions not analyzed, it is likely that the glazing retrofit and chilled beams would be rejected and the lighting replacement may have been the only measure implemented – resulting in a less efficient and more costly building.

As noted in the example above, downsizing mechanical systems is a possibility when bundling measures. Indeed, it is a widely known, if not widely talked about, fact that these systems are often greatly (50 percent or more) oversized. In order to capture the full opportunity of bundling measures, the entire design team should agree at the outset of design to attempt to downsize systems. Teams should plan to address barriers to downsizing systems, which include the following:

1. Liability. The mechanical engineer does not want to be responsible for an undersized system (no engineer has ever been sued for making a mechanical system too big!).
2. Lack of team collaboration. When mechanical engineers do not consider the exact lighting power density or what types of windows were specified, they often compensate for the uncertainty by oversizing.
3. Conventional practice: "infectious repetitis." Engineers often rely on imprecise assumptions, such as 400 square-feet per ton of cooling, which are based on obsolete technology and energy prices.
4. Lack of incentive. Typically, design teams are not financially rewarded for appropriately sized systems (in fact, it is often just the opposite: a larger system provides a larger fee).

An "integrated project delivery" (IPD) approach can help overcome these barriers; for more information see the "Trapelo Road" case study at www.10xe.org.

The method of selecting measures using a bundle approach is not as obvious as the conventional approach of selecting all measures with an acceptable simple payback. One should start by determining the synergies between EEMs. Often, a few EEMs bundled together to reduce loads will affect the capital cost and energy savings of an HVAC measure. It is important to capture such a synergy in at least one bundle, which could be called the "minimum energy use" bundle. After accounting for synergies, you may find a list of EEMs that have minimal impact on others. In this case, you can sort the measures by NPV from most positive to most negative; then, select additional measures until the NPV of the bundle is near zero or otherwise acceptable.

After making a preliminary bundle of measures, the mechanical systems should be resized, and the energy operating cost savings and capital cost of the bundle must then be re-evaluated. This re-evaluation will not require as much as effort as was required to create the initial estimates, because measures can be combined with relative ease using parametric runs in energy modeling and the initial cost estimates can be revised without much added effort.

Two or three alternative bundles should be created for evaluation. It is often useful to create packages that satisfy specific goals, such as optimizing NPV or minimizing fossil fuel consumption. Non-quantitative benefits (see above) and carbon emissions reduction could also be considered. It is important to not create many more than three bundles, as it is easy to overwhelm the client with too many options. It is possible to create preliminary bundles that may include alternative daylighting schemes or HVAC systems, with the expectation that some of the schemes and systems could be mixed and matched by the client to create a new bundle. If such mixing and matching does occur, it is important to ensure that valuable synergies between measures are not lost.

ADDITIONAL EFFORT OF LCCA

Clearly, the life cycle cost analysis outlined above requires more effort than a simple payback calculation. However, the magnitude of this additional effort is not as large as one would expect at first glance. The largest efforts required in the process are usually the energy modeling and capital-cost estimating – both of which are often required for a simple payback anyway. Additional cost estimating of business-as-usual costs (the “baseline”) will require some additional research and consultation.

The discounted cash flow analysis required by the LCCA to calculate financial metrics can be very time intensive if produced from scratch, but there are many software tools available that are built specifically for life cycle cost analysis that reduce this effort considerably. Once the individual measure analysis is complete, bundle analysis is simple because the majority of the data has already been compiled. Up until now, tools commonly used for LCCA have not had the capability to easily bundle measures. However, Rocky Mountain Institute has recently developed a free, open-source tool that makes it easier to analyze individual measures and then combine them into bundles. This tool is currently available for download at http://www.rmi.org/rmi/EMIT-LCCA-ModelingTools.

The additional resources required for LCCA will depend on the scope of the project being evaluated, but in general, the cost of professional design services is very small relative to the life cycle costs of a building – on the order of 0.2% of total cost of ownership, including personnel costs and assuming a design fee of 10% of construction costs (Public Technology, Inc. 1996). Considering all the added benefits of LCCA and bundling, the increase in building life cycle cost efficiency is well worth a small increase in design services.

TAKING THE LCCA STEPS: FICTIONAL EXAMPLE

Consider the replacement in January 2011 of an old 500-ton centrifugal chiller that runs for the equivalent of 2000 full load hours per year. We will assume the following project requirements:

Table 1. Project Requirements for Simple LCCA

Category	Value
Timeframe	10 years
Discount Rate	8%
Electricity Rate	$0.12/kWh
Demand Charge	$10/kW/mo (for 8 months out of the year)

The key to establishing the baseline in this example is to estimate the remaining life of the chiller and account for the capital expense required to replace it at the end of its useful life. Suppose the chiller is estimated to have a remaining life of 5 years, after which it will no longer function. In 2016, the baseline will need to include the cost of a replacement chiller, which we will assume to be ASHRAE Standard 90.1 compliant.

Now that the baseline has been established, the measure must be defined. Table 2 lists the critical information:

Table 2. Chiller Data

Category	Baseline Existing Chiller	Baseline Replacement Chiller	New Efficient Chiller
Efficiency	0.65 kW/ton	0.577 kW/ton	0.50 kW/ton
Year Service Starts	2011	2016	2011
Year Service Ends	2015	2020	2020

Electricity Used (kWh/yr)	650,000	576,557	500,000
Demand (kW)	325	288.3	250
Electricity Cost ($/yr)	$78,000.00	$69,186.88	$60,000.00
Demand Charge ($/yr)	$26,000.00	$23,062.30	$20,000.00
Capital Cost	n/a	$230,000 (RS Means)	$287,500 (25% premium)

We will also assume that replacing the old chiller now with an efficient chiller will save $5,000/yr in maintenance for the first 5 years. The savings end at year 6 because at that point the old chiller would have been replaced. The LCCA yields the annual discounted cash flows, shown in Table 3.

Table 3. Discounted Cash Flows Over Time

2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
-$258,500	$27,074	$25,276	$23,598	$22,032	$165,296	$8,194	$7,663	$7,166	$6,702

As one can see, the annual savings are large for the first five years and reduce significantly after the installation of the code-compliant chiller. Also, the discounted cost of this chiller can be clearly seen in 2016. Summing up the discounted cash flows results in a net present value of $34,501 (ROI of 11.2%).

Now let's do the same analysis using a simple payback approach. We divide the capital cost of the efficient chiller by the reduction in annual energy cost ($104,000 – $80,000 = $24,000) to get:

$$Simple\ Payback = \frac{\$287{,}500}{\$24.000/yr} = 12.0\ years$$

Since the simple payback is greater than the timeframe of the analysis, this measure would not be accepted. However, the more comprehensive LCCA shows that the project has a positive NPV and makes financial sense.

TAKING THE LCCA STEPS: REAL PROJECT EXAMPLE

This section provides an example of using the LCCA method described above in an actual project. The example illustrates how establishing the baseline and bundling measures can lead to far different results for manageable added effort.

In 2009, an RMI-led team conducted a deep energy-efficiency retrofit of a 20,000 square-feet retail store in a hot and humid climate. Using the LCCA method described above, we found that the store could save 72% of its annual utility cost and surpass the client's hurdle rate of 20% IRR by 6%. If we had not established the baseline, the project IRR would have been cut to 19%, forcing the removal of one or more cost-saving measures in order to meet the hurdle rate. And if we did not bundle the measures, the utility cost savings would have dropped to 55% – equivalent to a staggering 60% increase in the client's utility bill. Were these benefits of establishing the baseline and bundling measures worth the effort?

Establishing the baseline

During the Level-III audit conducted at the outset of the project (Thumann et all 2009), we interviewed the building owner about planned renewal projects. As one may expect from the owner of a smaller commercial building, there were no plans. Thus, during the audit, we made our own assessment of equipment and components that were nearing the end of their lifecycle, in need of repair, or simply not up to current codes. This assessment was later confirmed with the general contractor and the owner.

We considered items for the baseline that were directly linked to energy use as well as those that were not. We examined everything from paint on the walls to the rooftop units. This is because we would later do integrative design, where EEMs can range from interior finishes to less-tonnage, super-efficient cooling units.

We used our own collective professional experience as well as published sources to anticipate business-as-usual replacements, as shown in Table 4. Six out of the 8 rooftop units (RTUs) were 7–8 years old and in poor condition. While RTUs can last up to 20 years, these were clearly not going to last that long due to a growing frequency of breakdowns. In addition, one RTU was grossly undersized and responsible for an uncomfortable office space. If it were to be replaced with no changes to the load, the 5-ton RTU would need to be replaced with an 8-ton unit, therefore requiring additional structural support. The built-up roofing was 40 years into its roughly 30–50-year lifecycle and thus seemed ready for replacement. Smaller items such as a broken condensate removal system and a thermostat were also recommended, despite their comparatively minor cost. The windows had roughly 10 years left in their lifecycle and would have been included in the baseline, but given the short, 10-year LCCA analytical period requested by the owner, they did not qualify.

Table 4. Anticipated business-as-usual replacements

Building component	Age (yrs) and Condition	Expected service life (yrs)	Source
Rooftop unit air conditioners	7–8, poor	15	Chapter 36, ASHRAE Handbook 2007
Built-up roof	40, fair	30–50	Kirk and Dell'Isola 1995
Condensate removal; thermostat	N/A, Items are broken	N/A	N/A
Windows	30, fair	40	Kirk and Dell'Isola 1995

During a meeting to discuss possible efficiency measures, the owner and his general contractor (with whom he valued a trusting relationship) both confirmed our assessment that the RTUs were due for replacement, and that the one RTU would require additional structural support. They also confirmed the minor items. The general contractor thought the roof probably had a few more years left, but since other disturbance would be taking place in the building anyway for the RTU replacements, he advised the owner to move the roof's replacement cycle up. We accounted for this move by defining in the baseline a roof replacement in 5 years. This conversation with the owner and general contractor was honest and benefitted from professional experience and published data. Table 5 presents the mutually agreed-upon baseline.

Table 5. Replacements defined in the mutually agreed-upon baseline

Building component	Baseline replacement schedule	Baseline replacement description
Six rooftop unit air conditioners	Immediate	Code-compliant RTUs; additional structural support for one RTU
Built-up roof	Year 5	Replacement in kind
Condensate removal; thermostat	Immediate	Replacement in kind

Bundling measures

After the team developed EEMs and estimated their utility cost savings and capital cost, a simple payback was calculated for each. Next, the measures were bundled. The team considered non-quantitative benefits as well as overarching IRR to select measures. By selecting a bundle of measures, we were able to account for reduced loads on the HVAC equipment and implement measures that did not reach a 20% IRR on their own.

Daylighting EEMs were very attractive to the client because he felt his products were viewed better in daylight. However, the daylighting EEMs only had a 10% IRR. Moreover, after taking into account the greatly reduced lighting power density (LPD) provided by the lighting designers, the daylighting had an even less IRR. Despite the low IRR, we still managed to justify the daylighting EEMs financially in addition to justifying them by their non-quantitative benefits.

Two very cost-effective measures helped finance the less cost-effective daylighting and other EEMs. The first cost-effective measure was the lighting retrofit, which was a complete redesign for a 30% IRR. This high IRR was accomplished simply through good design techniques and an inefficient existing system. The second measure was the replacement of air conditioners, which had a negative capital cost. How was a negative cost possible?

After combining load-reducing EEMs, we were able to downsize the air-conditioning units, reducing their baseline capital cost and avoiding the added cost of structural support. In addition to saving cost, the downsizing enabled us to specify split-system units (more common in residential applications) that are available with greater efficiency than RTUs. The negative air-conditioner cost drove down the cost of the entire bundle and, along with the cost-effective lighting, helped pay for the less cost-effective measures.

Figure 1 indicates the two efficiency bundles we presented to the client. We heard from the client that IRR and carbon savings were important, so we created one bundle with a maximum IRR and other with maximum CO2 savings. Both bundles had daylighting, which the client greatly desired.

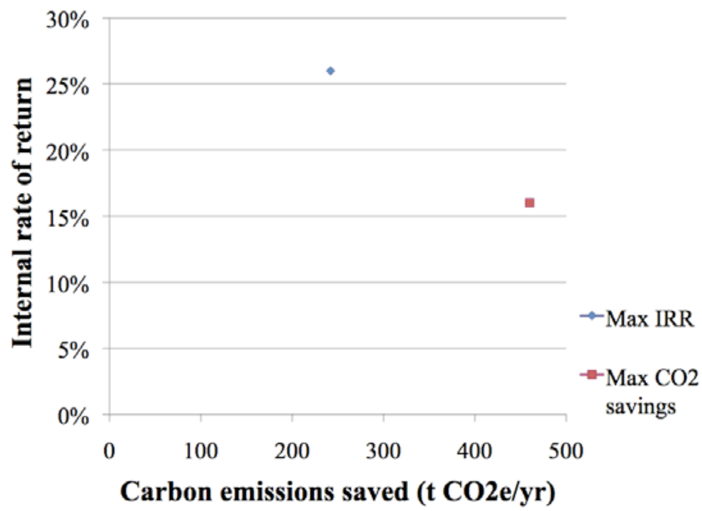

Figure 1 *Evaluating two bundles of efficiency measures. Our analysis indicated that over 450 tonnes of carbon emissions could be saved each year, but for an IRR less than the hurdle rate of 20%. Another bundle could achieve as high as a 26% IRR.*

CONCLUSION

In this paper, we posed an important question for analysts of new and retrofit building construction projects: Is an LCCA worth the effort? A comprehensive LCCA includes the four steps of (1) establishing the baseline, (2) defining EEMs, (3) calculating financial metrics, and (4) bundling measures. We showed that such an LCCA requires significant effort beyond what is required for simple payback analysis. However, we also identified instances when a simple payback would have led to far different and inferior results. Given the manageable effort required for an LCCA and the possible benefits, which include energy cost savings and carbon emission reduction, we argue that it warrants consideration on any project.

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