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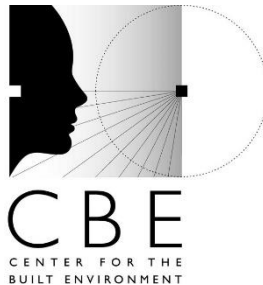
CBE UFAD COST ANALYSIS TOOL: LIFE CYCLE COST MODEL, ISSUES AND ASSUMPTIONS

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I INTRODUCTION

This report, a companion to the first cost model assumptions report [Webster et. al. 2008] documents the issues and assumptions upon which the CBE UFAD life cycle cost (LCC) modeling tool were based. In this first section we provide an overview of the model structure and a brief description of its main parts. In Section 2 we summarize highlights of the literature search that we conducted to inform our model development work. Section 3 summarizes the major issues and assumptions for the model approach as well as pertinent LCC elements. Section 4 contains more detailed descriptions of the model elements as implemented in the accompanying tool.

The issues and assumptions provide a wealth of information about what things need to be considered when constructing a tool but also serve as a guide for considerations important to any LCC methods that attempt to compare system types.

Our intent in designing this tool was to provide a comprehensive tool with flexibility to not only allow users options but provide the ability to conduct analyses on a broad range of building types in both private commercial and public buildings.

1.1 LCC MODEL OVERVIEW

For the life cycle model, we adopted the same overall approach as the first cost model, namely, to compute the differences in life cycle costs between UFAD and conventional overhead systems for the key factors most affected by the decision to use a UFAD system. Through a review of methods and discussions with industry sources it became clear that the following elements are the most important factors to that affect this difference on a life cycle basis. The overall structure of the model is shown in Figure 1.

Maintenance & Repair

This is an operating expense element that depends on the difference between UFAD and OH specifications for the first cost affected elements (AE) associated with HVAC alone. The model covers differences between mechanical components of UFAD and OH systems. Though there may be other differences in Maintenance and Repair costs of other components, they are less quantifiable and more likely to vary on a case-by-case basis.

Utility Expense

This element depends on the difference in energy performance between UFAD and OH and will be different for each UFAD alternative. To our knowledge, there is very little applicable measured data so simulation ultimately looks to be the best option. As reliable energy simulation tools for UFAD systems are still in development, we will prepare this section to accept future energy simulation results. An EnergyPlus module is in development and may serve this purpose in the near future.

Churn Expense

This element addresses the turnover associated with office reconfiguration and restructuring. Data is used regarding churn types and associated churn *rates* and difference between UFAD and OH *costs* for the different churn types.

Fixed Expense (Accelerate Depreciation Tax)

According to the tax code, some of the construction costs in UFAD systems could use accelerate depreciation methods and therefore reduce the tax at the beginning of the system's useful life. As the use of this advantage may vary by local tax code interpretation, the model allows the user to turn this feature on or off. This covers reduction in LCC due to tax deductions associated with tenant equipment that can be claimed as personal property for tax purposes. This section uses

data on tax rates and the types of equipment that will qualify for this deduction and is to be implemented with user's discretion as to whether these incentives will be approved by the local tax authority.

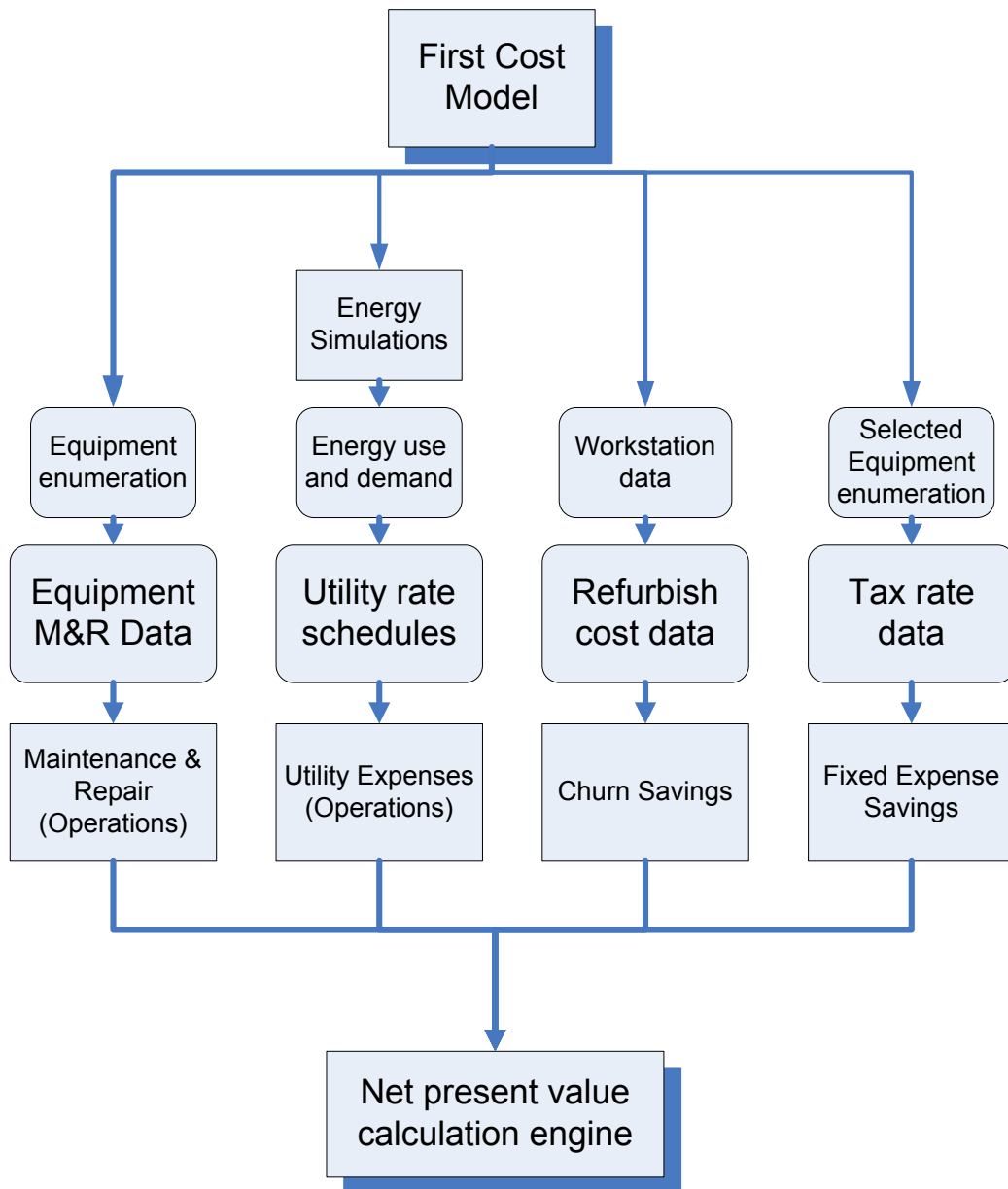


Figure 1: LCC Model Flow Chart

2 INFORMATION SOURCE REVIEW

To assist our decision making process, we conducted a literature review to uncover appropriate sources of information and data on LCC affected elements. Below we summarize highlights of what we found.

2.1 BUILDING LIFE CYCLE COST METHODS

2.1.1 BUILDING LIFE CYCLE COST (BLCC)

This method and associated software based on NIST Handbook 135 is used extensively within Federal agencies such as DOE as well as in private industry for certain types of LCC analyses to analyze life cycle performance of energy related projects. [NIST 1995] The software tool calculates lowest life-cycle cost (LCC) as well as supplementary measures such as Net Savings (NS), Savings-to-Investment Ratio (SIR), Adjusted Internal Rate of Return (AIRR), Simple Payback (SPB) and Discounted Payback (DPB). Users input the different costs, including construction, energy and operation costs. The program will help you summarize the data and output with different analyses.

2.1.2 ASTM METHODS

ASTM supports extensive LCC methods embodied in Standard E917 [ASTM 2005]. These methods appear to be favored by non-governmental commercial interests but are consistent with NIST Handbook 135.

2.1.3 BUILDING FOR ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY (BEES)

BEES measures the environmental performance of building products by using the life-cycle assessment approach specified in ISO 14000 standards.

In this method, economic performance is measured using the ASTM standard life-cycle cost method, which covers the costs of initial investment, replacement, operation, maintenance and repair, and disposal. Environmental and economic performance are combined into an overall performance measure using the ASTM standard for Multi-Attribute Decision Analysis. For the entire BEES analysis, building products are defined and classified according to the ASTM standard classification for building elements known as UNIFORMAT II. [ASTM]

BEES 3.0 contains environmental and economic performance data for nearly 200 products across 23 building elements including beams, columns, roof sheathing, exterior wall finishes, wall insulation, framing, roof coverings, partitions, ceiling finishes, interior wall finishes, floor coverings, chairs, and parking lot paving.

2.2 MAINTENANCE AND REPAIR (M&R) DATA

In the following, we outline data sources related to M&R LCC analyses.

1. Whitestone Research : Independent source for M&R data.[Whitestone 2006] “The most comprehensive source of life-cycle cost profiles and M&R cost statistics.” Fifty one building models; 210 metropolitan areas; over 450 components and more than 1,200 associated maintenance tasks. The reference supplies data for each piece of equipment including frequency of replacement, labor hours and costs, material costs, equipment hours and costs. The model uses multiple sources of data. For the Maintenance & Repair section, cost data is a combination of first cost data (for equipment replacement) and data from Whitestone for frequency and cost of maintenance for the closest possible equipment matches. [Whitestone, 1999]

Conversations with Whitestone (Marcel) on the phone indicated that:

- Costs are estimated using real building data in combination with a regularly updated computer simulation for costs.
- Assumptions include that in-house staff covers regular maintenance, minor repairs and contract labor covers replacement and unexpected repair.

We purchased this database in February 13, 2006

This database seems to be the most comprehensive for our purposes but it does not contain comparable data for underfloor components. The question remains, how to obtain UFAD specific data.

2. ASTM: The ASTM website shows a link to an M&R database (DMDB) that is an adjunct to Standard E917 [ASTMb 2005] but with virtually no description of its contents. Our research indicates that it contains was based on "constructed" rather than "historic" information. We did not explore this further.
3. RS Means: Data in this book is based on two sources; *Life Cycle Cost Data* published by the author in 1982 and the DMDB program by ASTM. [Means 2007] Detail breakdown of common equipment, but no specific information about OH or UFAD systems. We did not explore this one further.
4. CERL: CERL supports the BUILDER M&R system aimed primarily at maintaining an inventory of inspections; it does not appear to include cost data. It does not seem appropriate for our use. [CERL 2007]
5. ASHRAE (2005 winter meeting seminar): Tom Webster attended an ASHRAE seminar for this ASHARE research project and made contact with the authors. They are just beginning collection of data and are refining the database front end; it will be several years before this is ready for general use. We suggested that they add UFAD equipment to the database.

3 LIFE CYCLE MODEL ISSUES AND ASSUMPTIONS

3.1 GENERAL ISSUES

3.1.1 COMPARISON APPROACHES

Question: How should we handle each of the LAEs in terms of determining the difference between OH and UFAD?

Discussion: We could adopt a strategy that uses a sensitivity approach where we establish an OH baseline for each LAE and assume UFAD is some fraction of this baseline; the user would select exercise his judgment as to which level of offset is appropriate. The primary problem with this approach is that there is no "objective" way to decide on the appropriate differences. It also is not consistent with the systematic approach we took for the first cost model.

Decision: To be comprehensive and offer objectivity consistent with our first cost model approach we will develop detailed procedures appropriate for each LAE. We will strive to use qualified industry sources of data to populate these methods.

3.1.2 LCC METHODS

Question: Which methods should we base our LCC analyses on?

Discussion: Based on our literature review and discussion with experts we found that the two most common and well developed methods for LCC analyses appear to be the NIST Handbook 135 and ASTM Standard E917. However, since the NIST methods were developed to be entirely consistent ASTM standards, there does not seem to be much difference between the two when applied systematically; differences are more related to the emphasis placed on certain formulations of the same basic concepts that suit the needs of the different organizations using them.

We interviewed an outside consultant [Carroll, 2005] who has extensive experience with LCC methods applied to energy saving retrofits. His opinion was that we should look no further than the methods described in NIST Handbook 135.

Decision: Since the underlying methods for these approaches are essentially the same and we are using the same methods for both OH and UFAD models (and computing the differences) the particular method used is of lesser importance. In our opinion and experience, the methods contained in the NIST Handbook 135 are straightforward and adequate for our purposes. Also, most government methods (at least for purposes such as these types of analyses) are based on Handbook 135, therefore these methods would be more appropriate for GSA analyses.

These methods could be expanded in the future to include more comprehensive evaluations suitable for speculative commercial ventures. [Gross 2005]

3.1.3 LCC MEASURES

Question: Which LCC parameters are appropriate expressions of life cycle cost for our use?

Discussion: Present value (PV) is the most common measure life cycle analysis. There are still some supplementary measures – Net Savings (NS), Saving-to-Investment Ratio (SIR), Adjusted Internal Rate of Return (AIRR), and Discounted and Simple Payback.

AIRR is a measure of the annual percentage yield from a project investment over the study period. Like the NS and SIR measures, the AIRR is a relative measure of cost effectiveness.

Still another method is the BEES model. BEES measures economic performance by computing the product life-cycle cost as Present Value (PV):

LCC_j = total life-cycle cost in present value dollars for alternative j ;

C_t = sum of all relevant costs, less any positive cash flows, occurring in year t ;

N = number of years in the study period;

d = discount rate used to adjust cash flows to present value

The UFAD modeling software that Tate Access Floors has developed contains a LCC model but it only uses the first year life cycle cost as an indicator.

Decision: We will use the present value method consistent with Handbook 135 methods.

3.1.4 TIME HORIZON AND RESIDUAL VALUE

Question: What time horizon should we use?

Discussion: The study period for an LCC is the time over which the costs and benefits related to a capital investment decision are of interest to the decision maker. Sometimes the study period will coincide with the useful life of the project, and sometimes it will not, depending on the time horizon of the investor. The shorter the study period, the more critical becomes the estimate of the residual value.

There are two basic approaches:

1. Study period determined by expected system life: The LCC analysis may focus on the system itself in determining an appropriate common service period and study period for evaluating system alternatives.
2. Study period determined by investor's time horizon. The time horizon of the investor should be considered especially for leased buildings and for buildings that are expected to be sold or

extensively renovated before the end of the service period based on the expected life of the alternatives.

In the BEES model, economic performance is measured over a 50-year study period. The residual value is computed by prorating the purchase and installation cost over the product life remaining beyond the 50-year period. For example, a product with a 40 year life that costs \$10/ft² to install would have a residual value of \$7.50/ft² in year 50, considering replacement in year 40.

In the BLCC Model a Planning / Construction period (if any) is added to a specified maximum 25-year service period.

Carroll suggested that we consider other options for changing the time horizon for the calculation. Also, due to technology obsolescence, time horizons much longer than 30 years are unrealistic. Carroll also recommended that we allow the ability to enter a different discount rate every year and a different escalation rate for other items (not just energy).

Decision: If we make sure that we use the longest time horizon we will want to study (e.g., 30 years) than we can simply report the LCC cost at different increments less than that, and not have to introduce the extra complication of vary rates over the time horizon. We will neglect the residual value at the end of the period.

3.1.5 LIFE CYCLE CASH FLOW ASSUMPTIONS AND INFLATION, DISCOUNT RATE

Question: What are typical discount rates and do they vary with type of ownership?

Discussion: Although the discount rate used will likely have a minimal impact since we are comparing differences between OH and UFAD, we wish to use rates methods commonly used for building life cycle projects.

There are two ways to arrive at constant dollar amounts in an LCC; when applied properly, both approaches yield the same LCC results.

1. First, a *real* discount rate may be used with *constant-dollar* (e.g., cost referenced to a given year) costs. Real discount rates reflect that portion of the time value of money attributable to the real earning power of money over time independent of price inflation. Even if all future costs are expressed in constant dollars, they must be discounted to reflect this portion of the time value of money.
2. Second, a *market* discount rate may be used with *current-dollar* amounts (e.g., actual future prices). Market discount rates reflect the time value of money stemming from both inflation and the real earning power of money over time.

Examples of how rates are used in standard LCC approaches are:

- The BEES model computes LCCs using constant 2002 dollars and a real discount rate. As a default, the BEES tool uses a real rate of 3.9 %, the 2002 rate mandated by the U.S. Office of Management and Budget for most Federal projects.
- The BLCC5 model computes LCCs using constant dollars and a real discount rate.

The current DOE discount rates (real and nominal) are published in the Annual Supplement to NIST Handbook 135 [OMB 1992; OMB 2008]

Decision: Since we are using the Handbook 135 methods we will use nominal rates for everything except energy which will use energy escalation rates published in the annual supplement.

3.1.6 CONSTRUCTION BIDDING AND MARKET ENVIRONMENT

Question: *Do we need to account for differences in market conditions that might affect differences between OH and UFAD?*

Discussion: CBE design professionals maintain that there are significant factors associated with the bidding climate for UFAD jobs. For example, in some localities UFAD is so new that contractors will bid it up by adding premiums as a safety factor or because they think it is a class A system. Also, construction timing issues may lead to differences in costs due to coordination of trades etc. In additions, sub contractor bids can be influenced by market conditions and availability of resources.

Do we need to include a offset factor to account for market and bidding factors?

Decision: While this may end up being an important issue, it has much to do with how the market responds to nascent technologies. Over time, when UFAD design and installation practices are well established, these factors will be more easily evaluated and probably less of a differentiating issue. Due to the difficulties inherent in determining these factors we will neglect them for now.

3.2 LCC ELEMENTS

3.2.1 M&R COST

Question: *Are M&R cost difference between UFAD and OH system is so significant that we should include a detailed analysis?*

Discussion: There are two fundamental ways to approach this topic: Bottom-up or Top Down. In the following we discuss the pros and cons of each of these.

3.2.1.1 Bottom-up

The most accurate approach is the bottom-up approach. In this method, we would calculate the detail M&R cost for all the equipment and add them up to see the difference.

However, some of the fundamental data about M&R are very limited, in particular for UFAD systems. For instance, intuition tells us that the maintenance cost for the ductwork in the OH system should be higher than that of a UFAD system. However, UFAD systems are so new that it is virtually impossible to find verifiable data on M&R for diffusers, underfloor fan coil units (FCU), etc. that are different from OH system components. However, VAV boxes and FCUs are very similar between UFAD and OH; most of these units are OH units that have been adapted or resized for UFAD purposes but the basic components and controls are virtually the same. The one primary difference is that UFAD FCUs typically have variable speed drives (VSD), typically ECMs, while fan powered VAV boxes (FPB) do not. One could argue that these motors require less maintenance since they are a higher quality motor.

3.2.1.2 Top-down

Another approach is to estimate the cost difference via a top down approach. This gives us a way to evaluate the relative magnitude of different M&R factors.

According to RS Means “*Life Cycle Costing for Facilities*”, LCC could be broken down to Initial Energy Costs, M&R Costs, Alteration and Replacement Costs, and Associated Costs.

The M&R costs range from \$2.75 to \$6.00 per gross square foot per year, which includes the costs of regular custodial care and repair, annual maintenance contracts, and salaries of facility staff performing maintenance tasks. A typical breakdown [RS Means 2004] of the total cost is shown in Table 1.

Table 1: Percentage breakdown of total M&R costs

Foundation	Substructure	Superstructure	Exterior Closure	Roofing	Interior Construction	Conveying System
0.25%	0.75%	0.25%	10%	1.5%	19%	4%

Mechanical Plumbing	HVAC	Fire Protection	Electrical	Equipment	Sitework
16%	21%	0.25%	13%	11%	3%

* Resource: RS Means “Life Cycle Costing for Facilities”

If we first assume 60% of the M&R cost is for infrastructure maintenance and Mechanical Plumbing, HVAC and Electrical make up the building systems portion, Table 1 shows that the latter make up about 50% of the total. Then we further assume that for the building systems portion, the OH and UFAD difference is about 20%, the difference between OH and UFAD is about $(\$2.75-6.00) * (1-60%) * 50% * 20% = \$0.12 - 0.24 \text{ ft}^2/\text{yr}$

The problem with this approach is it only gives us a magnitude check between M&R data but does not capture its relative magnitude to the other LCC components.

Decision: Since the Top-Down simplified annual cost example shows a small effect, overall it depends on how the LCC calculation comes out relative to other components of energy, churn, and taxes. To settle this issue we decided to embrace the Bottom-up approach so we have a more accurate way to understand the elements and to allow for future modifications when more UFAD data might be available. Furthermore, we will base our cost estimates on Whitestone reference for annual maintenance costs but use the same costs as the first cost model for full replacement of components.

3.2.2 UTILITY EXPENSES

Question: How do we model energy use?

Discussion: At this point, no energy simulation software is fully capable of accurately modeling the energy use of an UFAD system (both perimeter and interior conditions). As such, the most accurate form of life cycle costing that we can achieve here is to provide the annual energy cost for OH, with the assumption that this remains constant every year (subject to inflation and energy escalation rates). We then allow the user to investigate two possibilities for evaluating the energy used by a UFAD system relative to an OH system.

3.2.2.1 Method 1: Relative to OH

This method relies on establishing baseline annual energy use for the OH system and then creating “savings scenarios” by apply a percentage savings (or increase) to the OH baseline. This has the obvious flaw of not knowing what the real savings are, but it does allow a sensitivity study to be done.

3.2.2.2 Method 2: Full simulations

This method is based on conducting full energy simulations for both OH and UFAD systems once accurate simulation models can be developed (i.e., EnergyPlus UFAD now being developed [Bauman 20]). This is potentially more accurate but relies on having a robust and accurate simulation tool as well as a way to port the first cost options into simulation input files easily.

3.2.2.3 Method 3: Lookup tables

To improve on the first method and reduce the complexity inherent in the second one, we would create look up tables of energy savings (possibly for just cooling and fan energy, the major

factors impacted by using a UFAD system) using a simulation tool capable of simulating UFAD systems accurately for typical ranges of design options.

Decision: Since EnergyPlus UFAD development is well under way, set up a structure to accept simulation output for both UFAD and OH. For interim purposes, the OH simulation energy use could be offset using percentages as described in Method 1.

Question: How do we estimate utility rates?

Discussion: If we are going to allow this program to calculate life cycle costs in each of 53 cities, how do we accurately reflect utility costs in each of the cities? For example, EnergyPlus does not calculate utility costs – it exports energy use data by fuel type to Excel to which we would have to apply utility rate structures. This would mean we would have to obtain rate structures and find a way to incorporate those in into the LCC model along with the energy use data (the form of which would depend on the energy estimating method used). However, under the Tariff Analysis Project (TAP), LBL has developed a database of over 400 tariffs that is accessible via a website.

Decision: We will use tariff structures from TAP. For the near term these will be user supplied by accessing the TAP database for the city specified. In the future, these could be catalogued to allow automatic updating based on the city selected in the Design Options. Apply energy escalation rates based on Handbook 135 Annual supplement.

Question: Do we consider peak demand charges?

Discussion: In order to have the utility rate files accurately reflect energy cost, we will need to accurately reflect peak power demand. However, the peak demand depends on more than just the HVAC component. We need to determine the impact of HVAC system type on overall building peak demand.

Decision: Include demand costs in the energy cost estimate structure but conduct a study to determine the impact of HVAC system type on whole building demand.

3.2.3 FIXED EXPENSES

Question: Should we include accelerated depreciation in our LCC methods?

Discussion: According to the tax code [IRS 2005], some portions of the tenant costs in UFAD systems can use accelerate depreciation methods and therefore reduce the tax at the beginning of the system's useful life. Anecdotal comments by UFAD practitioners indicate that this method is actively used in private commercial projects where appropriate and allowed by local tax authorities and that it is an important vehicle to help defray any cost premium for UFAD. To our knowledge, it is not used in governmental projects.

Decision: Although it is unclear to what extent this procedure can be widely applied, practitioners indicate it should be included as an option so it is available to those who want to include it. We will include the methods but allow it to be turned off or on.

4 LCC MODEL METHODS

This section outlines the approach and methods used for each of our LCC affected elements (LAE).

4.1 LIFE CYCLE COST CALCULATIONS

The current model follows procedures and default discount rates from NIST Handbook 135 and the Annual Supplement to Handbook 135. The model allows the user to choose discount factors and inflation rates but defaults to energy escalation rates recommended by the Annual

Supplement. This allows for the flexibility for the user to test the influence of different discount rates on the relative performance of different system options but also defaults to the government standard values. The calculations use the Nominal discount rate that includes general inflation.

The life cycle cost calculations are based on equations and factors derived from NIST Handbook 135 and the Annual Supplement to Handbook 135. [NIST 2008] The present value of a single future cost is calculated using the equation:

$$P = F \times SPV_N = F \times 1/(1+d)^N$$

Where:

F = single future cost

D = discount factor (including general inflation)

N = year

In the model, this process is simplified by multiplying the single future cost by the pre-calculated factor SPV_N .

Following this calculation for each year, the annual life cycle costs are summed for the study period of 30 years and reported on the summary page on a per square foot basis.

The LCC calculation is performed in this simple manner for the Churn, Maintenance & Repair, and Miscellaneous cost sections. Inflation is not included for the Accelerated Depreciation section.

Life Cycle Costs for the Utility cost section are calculated using lookup values from Tables B0-B5 in the Annual Supplement to Handbook 135 for combined energy escalation and present value factors for various fuel types and regions. These calculations are based on the region within which the city chosen on the Design Options page is located. The model selects the appropriate factors from these tables and multiplies the annual cost difference by the factors. Again, these annual costs are summed and reported for the 30 year period.

4.2 WORKSTATION CHURN METHODS

4.2.1 OVERVIEW

The workstation churn analysis focuses on the life cycle cost impacts of space reconfiguration. In the LCC model, as in the First Cost Model, we focus on the difference between overhead (OH) and UFAD systems. We have defined the following four workstation churn move scenarios:

1. Box Move,
2. Furniture Move,
3. Minor Construction
4. Major Construction

These scenarios are described in detail below. In addition, we have defined a set of “churn affected elements” that we use to estimate the cost differential between OH and UFAD.

4.2.2 DEFINITIONS

4.2.2.1 Type of Churn

Through literature searches and interviews of industry professionals, we have concluded that the following types of churn capture the renovation landscape in sufficient depth to represent the life cycle impact of churn.

Box Move: (Employees moving to existing workspaces) – No furniture moved, no new wiring or telecommunication systems. Files, and supplies moved. This type of move will not be included in the Lifecycle Cost Model since its costs are the same with either a UFAD or traditional OH system.

Furniture Move: (workstation/furniture moves) - Reconfiguration of existing furniture and/or furniture moved or purchased. Includes the move and setup of individual computer workstation and telephone. Minimal telecommunication reconfiguration needed and no hard wall changes.

Minor Construction: Some new or modified hard walls (less than 20% of walls), new or additional wiring, new telecommunication systems or other minor construction needed to complete move. Includes ducting for OH and perhaps some for UFAD. No difference between OH and UFAD for lights, ceiling or walls construction.

Major Construction: New or modified hard walls (more than 20% of walls) new or additional wiring, new telecommunication systems, and moving and relocating VAV boxes and diffusers or other minor construction needed to complete move.

4.2.2.2 Churn affected elements

We define churn affected elements to be those factors that are most affected by refurbishment in a comparison between UFAD and OH. We have assumed that the only ones of significance to the cost difference are Electrical, HVAC, Telecom, and Furniture. We assume that wall and ceiling lighting and finishes, construction costs are equal for UFAD and OH. Table 2 shows a breakdown of how each element is used for each move type for UFAD and OH. An estimating format for creating the unit values for these elements is shown in Table 3.

Electrical: Relocation of electrical outlets. For powered furniture the cost is only for power pole relocation. For UFAD open plan we assume that power/voice/data (PVD) terminals are used for non-powered furniture configurations in open plan (OP). The first cost model allows for either PVD or wall mounted outlets for private offices (PO).

HVAC: We assume that HVAC changes are primarily associated with moving supply diffusers. For UFAD this means moving a panel to a new location which will result in carpet tiles being disturbed so they have to be rearranged. This is only true for non-aligned (not aligned with edges of the floor panels (ie. Non-Positile) carpet. For OH we assume that (1) HVAC changes occur only in the interior; (2) a minor move only involves moving the diffusers and its associated flex ducting; and (3) for a major move some fraction of the VAV boxes will be moved as well.

Telecom & Data: We assume that only the phone and data jacks are relocated. In the case of powered furniture we assume they are embedded in the workstation system. For non-powered furniture they are embedded in the PVDs so only the cost of the connections to the PVD are accrued since the PVD relocation cost is included in electrical. For private offices

with wall mounted receptacles we assume voice and data are combined in a separate wall plate from the electrical.

Furniture: We only consider the open plan workstation furniture since private office furniture move costs would be the same for UFAD and OH. This is the cost to move and reconfigure either powered or non-powered furniture. It also includes setting up the computer systems and task lighting.

4.2.3 CHURN SCENARIO BUILDER

The unit cost information spreadsheet contains device level detailed estimates on a unit cost basis for the churn affected elements described above. In the following two-step process, we build a churn scenario that is used to determine the life cycle impact of churn:

First we take the unit cost data from the spreadsheet that our consultants helped us create for each of the devices included in an element. From this data we construct a method for applying the information contained in the first cost analysis (e.g., number of workstations and PVDs per workstation) associated with the detailed device estimates.

In the second step we provide a table that allows a user to assign on a percentage basis a mix of the types of churn that best represents their churn situation using the following definition:

Percentage of Churn due to. ...: The percentage of Churn due to Furniture Move, Minor Construction Move and Major Construction Move. The inputs for these values should sum to 100%. Percentage of churn is used to provide a view into the type of churn scenarios that a particular company will engage. For example: a company may have a workstation churn rate of only 5%, but the type of churn when it does occur is 70% Major Construction. Both of these ratios is important to accurately calculate churn costs.

The overall magnitude of churn is set by another user assignment of the overall level of churn expected based on the following definition:

Workstation Churn: The average percentage of workstations that are moved in a given year.

4.2.4 COST DATA

WE obtained detailed cost data for the churn affected elements from relocation specialist [Bergman 2007] based on examples of real buildings. Data was originally based in Houston but numbers were converted based on city indices to the appropriate area. All data has been broken down on a material and labor basis and labor costs referenced to actual prevailing rates in the region where the experience was derived. Other assumptions are list below:

1. Estimates based on OH baseline configuration using powered furniture workstations and conventional wiring.
2. Assume no perimeter HVAC changes, except for diffusers. Thus the primary impact will be due to interior space reconfigurations.
3. No difference between UFAD system types except for HVAC UFAD A that uses interior FPBs.
4. Assume no change in conference rooms. Since conference rooms are a small percentage of the floor space and most likely would only be affected in a major move their overall impact would be small.

5. No difference between modular wiring and conventional for PVD moves. We assume that the changes to extend a whip would be similar for MC cable and modular extenders for the total of labor and materials.
6. No receptacles are changed for moving powered furniture either for OH or UFAD. These changes are incorporated in the furniture move.
7. For all electrical work an electrical contractor is used. In some areas (e.g., Houston, New York) only a licensed electrician can install or reconfigure modular power although this is not the case in other parts of the country.
8. For all underfloor mechanical work, the work would be performed by the raised floor contractor but for all overhead mechanical work, the work would be performed by a mechanical contractor.
9. Carpet tile work is done by the raised floor contractor
10. Furniture work is performed by a contract furniture dealer.
11. The unit costs data provided to us from our consultant assumed non-union labor at the customer level which includes direct cost, benefits and markup. Typical assumptions for breakdown of these would allocate benefits at 20% additional to direct wages and overhead and profit at 20% on top of the loaded costs. Material does not include tax but does include contractor markup.

LIFE CYCLE COST MODEL ISSUES AND ASSUMPTIONS

Table 2: Churn affected elements application schedule – showing applicability to churn type and devices involved

		UFAD			OH		Comments
		Open Plan	Private Office	Cost add for carpet tile	Open Plan	Private Office	
Electrical							
	Reconfigure Electrical Receptacles	All	Minor/Major	All	All	Minor/Major	
	Modular - Non powered	PVD	PVD/Wall	Yes	NA	NA	
	Conventional - Non powered	PVD	PVD/Wall	Yes	NA	NA	
	Modular - powered	NA	PVD/Wall	No	NA	NA	
	Conventional - powered	NA	PVD/Wall	No	PP only	Wall	OH: Power pole (PP) relocation only, other in Furniture
HVAC							
	Relocate Supply Diffuser	All	incl	Yes	Minor	Minor	OH: No main ductwork relocation
	Relocate VAV box and Supply Diffuser	NA	NA	NA	Major	Major	OH: With branch ductwork and VAV box reconfiguration
Telecom & Data							
	Relocate Voice/Data Jack	All	Minor/Major	All	All	Minor/Major	
	Modular - Non powered	PVD	PVD/Wall	Incl in electrical	NA	NA	For PVDs only the cost of the connections to the PVD, the PVD relocation cost is included in the electrical
	Conventional - Non powered	PVD	PVD/Wall	Incl in electrical	NA	NA	
	Modular - powered	NA	PVD/Wall	Incl in electrical	NA	NA	
	Conventional - powered	NA	PVD/Wall	Incl in electrical	NA	Wall	
Furniture							
	Move Non-powered Workstation	All	NA	NA	NA	NA	
	Move Powered Workstation	All	NA	NA	All	NA	

Table 3: Unit cost for Churn affected elements

		Cost Per Unit (\$)				
		UFAD			OH	
		Open Plan	Private Office	Cost add for carpet tile vs non-Positile	Open Plan	Private Office
Electrical						
	Reconfigure Electrical Receptacles (Powered furniture)					
	Materials	\$0.00	\$0.00	\$11.10	\$0.00	\$0.00
	Labor	\$42.19	\$42.19	\$51.46	\$102.19	\$0.00
	Reconfigure Electrical Receptacles (Non-Powered furniture)					
	Materials	\$0.00	\$0.00	\$11.10	\$16.65	\$11.10
	Labor	\$25.31	\$25.31	\$51.46	\$170.63	\$110.63
	Install New Electrical Receptacles					
	Materials	\$94.38	\$94.38	\$11.10	\$55.52	\$38.86
	Labor	\$42.19	\$102.19	\$51.46	\$255.94	\$110.63
HVAC						
	Relocate Supply Diffuser (minimal ductwork reconfiguration)*					
	Materials	\$0.00	\$0.00	\$11.10	\$0.00	\$0.00
	Labor	\$10.89	\$10.89	\$51.46	\$109.92	\$109.92
	Relocate Supply Diffuser (with ductwork and VAV box reconfiguration)*					
	Materials	\$0.00	\$0.00	\$11.10	\$83.27	\$83.27
	Labor	\$10.89	\$10.89	\$51.46	\$558.62	\$558.62
Telecom & Data						
	Relocate Voice/Data Jack					
	Materials	\$0.00	\$0.00	\$11.10	\$27.76	\$38.86
	Labor	\$15.00	\$15.00	\$51.46	\$75.00	\$250.00
	Install New Voice/Data Jack					
	Materials	\$94.38	\$94.38	\$11.10	\$83.27	\$83.27
	Labor	\$25.00	\$25.00	\$51.46	\$175.00	\$250.00
Furniture						
	Move Non-powered Workstation					
	Materials	\$0.00	\$0.00	n/a	\$0.00	\$0.00
	Labor	\$1,086.42	\$1,940.03	n/a	\$1,086.42	\$1,940.03
	Move Powered Workstation					
	Materials	\$0.00	n/a	n/a	\$0.00	0
	Labor	\$2,420.57	n/a	n/a	\$2,420.57	0

All	All move types: Furniture, minor, major
PVD	Power, voice, data floor terminal unit
Wall	Wall outlets, power and voice/data
PP	Power pole
NA	Not applicable

4.3 MAINTENANCE AND REPAIR METHODS

4.3.1 OVERVIEW

The Maintenance and Repair analysis focuses on the difference in cost to maintain individual pieces of HVAC equipment that is unique to the OH or any of the UFAD systems. We have not attempted to quantify differences in cost due to the location of the equipment, carpet wear, cleaning of the ductwork or underfloor plenum, central system differences or any other difference that would be totally contingent upon the operation and setup within each individual building. Instead, the analysis uses data from the Whitestone Research [Whitestone 2006] M&R cost reference to assign each piece of equipment for each system as designated by the first cost model to derive yearly maintenance, occasional repair and ultimate replacement of each piece of equipment. This data is then used to determine the 30 year life cycle cost of all HVAC maintenance for each system design option (OH, UFAD A, UFAD B, etc.).

4.3.2 DATA AND PROCESS

Each piece of equipment that exists in the first cost model is assigned a series of costs for preventative maintenance, repair and replacement along with frequencies at which these events must occur. All the data is derived from the closest matching piece of equipment included in the Whitestone Cost Reference. This means that underfloor equipment is equated to traditional comparable overhead equipment. Frequency numbers are based on location within the country and are assigned based on the location chosen by the user in the design options page. Replacement costs are equivalent to the first cost (material as well as labor) of the given piece of equipment whereas replacement frequencies are taken from the Whitestone reference. These numbers are then used to create three arrays that map the M&R costs (preventative maintenance, repair, and replacement) for a single instance of each piece of equipment.

Information is also imported from the first cost model to enumerate the quantity of each piece of equipment that occurs within each system design option (OH, UFAD A, UFAD B, etc.). These quantities are then multiplied by the arrays of each type of maintenance to produce a total yearly cost for each system design option, for the 30 year time horizon. These sums are reflected in the M&R Summary page.

Finally, the totals for each year from the M&R Summary are sent to the life cycle cost engine where they are subject to the discount and escalation rates defined by the user in Design Options (with defaults being equal to those values given in the Annual Supplement to Handbook 135, updated every April).

4.3.3 ASSUMPTIONS

Unfortunately the Whitesone reference only includes two types of equipment relevant to our purposes: VAV boxes and Fan Coil Units (FCU). Furthermore, these are not defined in any detail and in fact some of the entries seem wrong, e.g., Variable volume box, 50,000 cfm. However, the data for the smaller sizes seems reasonable. For these reasons we use the following equipment correspondence between our model and the Whitestone database as shown in Table 4.

Table 4: M&R equipment correspondence

Parallel and series FPB: Titus DTQP, DTQS	Proportionally ratio down from 1800 cfm one-pipe FCU for labor and materials based on size using the range shown in Whitestone for two-pipe fan coil; e.g., PM 0.8 hr at 400 cfm to 3.3 hr at 1800 cfm. (Used for both UFAD and OH)
UFAD FCU, York MFT	Use 400 cfm FCU figures derived from above.
UFAD FCU, Greenheck UFT	Use 1800 cfm figures for Whitesone one-pipe FCU for all UFAD FCU sizes.
VAV reheat boxes: Titus DESV	Use the non-rated VAV box figures for all sized of OH VAV boxes. (Not used for UFAD)
Ductwork and central system components	Ignore; these differences are likely to be small. Assume UFAD FCUs tend to have insulated perimeter unit ducting as well as OH.
Diffusers	Ignore and differences, no data to suggest and differences.

In addition, we assume that there are no differences between low- and high-height equipment.

4.4 ENERGY METHODS

At this time, no complete and reliable energy estimation method exists for UFAD systems. Though a number of simulation programs are currently in development, none are ready at this time to be incorporated into this cost model.

The current model allows for the user to enter energy use (electricity and natural gas) and peak demand for the building as a whole for the OH and each UFAD system for each month of a typical year. These values may be estimated at this point from either simulation programs or sample energy use data from real projects. These values are then converted into life cycle costs assuming the same depreciation rate as for the remainder of the modules, and an energy escalation rate from the annual supplement to ASTM Handbook 135 and would require periodic updating. The model applies the appropriate escalation rate based on the region in which the project is located.

Currently, utility rates must be manual inserted for summer and winter periods based on demand and use tariffs determined from <http://tariffs/tbl.gov> for the city of choice.

4.5 FIXED EXPENSES

One of the areas in which life cycle costs of an underfloor air distribution system have the potential to differ from those of a conventional overhead system is that of accelerated depreciation under the US income tax code. Under the Modified Accelerated Cost Recovery System,[IRS 2007] in effect since the passing of the Tax Reform Acct of 1986 (TRA-86), all assets are classified into categories that dictate the number of years over which, and thereby the method by which, the value of these assets may be depreciated.

Traditionally, *non-residential real property* is assigned a life of 39-years with zero recovery value at the end of its life, and is then depreciated using the straight-line method, thus decreasing its value by a consistent percentage each year for the 39-year time horizon (see below). There are

elements involved in the UFAD system, however, that may be classified as *other than non-residential real property*, and as such, other depreciation regulations may apply.

The accelerated depreciation model may be turned on or off on the initial user input page to allow for the inclusion of these calculations in the overall life cycle cost summary or not. This method for depreciation of underfloor related property has been used successfully in the past, though it is at the discretion of the local tax authority what may be included and what classification may be used.

If it is the intention of the owner to apply for accelerated depreciation for underfloor air systems, the less attachment of the system to the building itself, the more likely it will be to have the deduction approved. It will have to be demonstrated that the raised floor and any other components for which the deduction is taken are not critical building elements and the building may indeed function in their absence (Gould, personal communication, 2007).

4.5.1 NON-RESIDENTIAL REAL PROPERTY

This category includes all other property, in particular anything fixed and integral to the building.

This model uses MACRS percentage tables for depreciation established by the IRS in Publication 946. [IRS 2007] In order to use these tables, we have assumed that the percentages are applied to unadjusted costs – or rather that the percentages are applied without deducting for the depreciation of previous years. The model assumes values from Table A-7a of Publication 946 for these assets.

4.5.2 ACCELERATED DEPRECIATION

MACRS includes a half-year convention to simplify the first and final years of a property's recovery life. This method also assumes zero recovery value at end of an asset's life. In contrast to the straight line depreciation method used for non-residential real property, MACRS allows for a greater depreciation rate towards the beginning of the life of the capital asset (similar to the double declining balance method), which may make the life cycle of such assets more favorable when return on investment calculations are done with shorter time horizons. Under the MACRS assets are categorized and assigned service lives; we use Table A-1 of Publication 946 for these assets.

In order for these regulations to be used, the following conditions must be met [IRS 2007]:

- The asset must be owned by the entity claiming the depreciation value
- The asset must be used in business or income-producing activity
- The asset must have a useful life substantially more than the year that you place it in service.
- Depreciation begins when the asset is ready and available for a specific use
- The basis of the asset value is its cost plus tax, freight and installation and testing fees

MACRS includes the use of one of two depreciation systems; the General Depreciation System (GDS) or the Alternative Depreciation System (ADS). GDS is the more common method and is used unless law specifically requires ADS. Since UFAD systems do not qualify under the ADS criteria, the cost model uses the GDS.

Within this system, assets are assign to a variety of classes as described below. The model currently assumes that the following components of the building may be depreciated at an accelerated rate:

- Carpeting
- Access flooring
- HVAC Ductwork
- HVAC Underfloor plenum dividers
- Electrical equipment
- Voice and data
- Furnishing and workstations

These components are all currently assumed to be depreciated as 5-year property:

- Automobiles, taxis, buses, and trucks.
- Computers and peripheral equipment
- Office machinery (such as typewriters, calculators, and copiers).
- Any property used in research and experimentation
- Breeding cattle and dairy cattle
- Appliances, carpets, furniture, etc., used in a residential rental real estate activity.
- Any qualified Liberty Zone leasehold improvement property.
- Certain geothermal, solar and wind energy property.

The following lists property classified as 7-year for tax purposes:

- Office furniture and fixtures (such as desks, files, and safes)
- Agricultural machinery and equipment
- Any property that does not have a class life and has not been designated by law as being in any other class.
- Certain motorsports entertainment complex property
- Any natural gas gathering line placed in service after April 11, 2005.

5 ACKNOWLEDGMENTS

Please see first cost assumptions report.

6 REFERENCES

ASTM. 2005. "Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems." Standard E917-05, ASTM International, West Conshohocken, PA

ASTMa. 2005. "Standard Classification for Building Elements and Related Sitework-UNIFORMAT II." Standard E1557-05, ASTM International, West Conshohocken, PA

ASTMb. 2005. "Practice for Measuring Life-Cycle Costs of Buildings and Building Systems Building Maintenance Repair and Replacement Database (DMDB) for Life-Cycle Cost Analysis." Adjunct to Standard E917-05, ASTM International, West Conshohocken, PA

CERL. 2007. "BUILDER Engineered Management System." US Army Construction Engineering Research Laboratory, Champlain IL.

<http://www.cecer.army.mil/td/tips/product/details.cfm?ID=64&TOP=1>

Carroll, W. 2006. Personal communication, Consultant, Berkeley CA.

Gross, G. 2005. Personal communication. President, CII, Tempe AZ.

IRS 2007. "How to Depreciate Property." U.S. Department of Treasury, Internal Revenue Service, Publication 946. Washington, DC.

Means. 2007. "Means Facilities Maintenance & Repair 2007 Book, 14th Edition." RS Means, Kingston MA.

MACRS http://taxpoint.swcollege.com/taxpoint_2001/student/m10/m10-2.html

NIST. 1995. "Life-Cycle Costing Manual for the Federal Energy Management Program." NIST Handbook 135. National Institute for Standards and Technology, Gaithersburg MD
(<http://www.eere.energy.gov/femp/program/lifecycle.cfm>).

NIST. 2008. "Energy Price Indices and Discount Factors for Life Cycle Cost Analysis." Annual supplement to Handbook 135. National Institute for Standards and Technology, Gaithersburg MD. April

RS Means. 2004. "Building Construction Cost Data." RS Means, Kingston MA.

OMB. 1992. "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs." Circular A-94. Office of Management and Budget, . Washington DC.
<http://www.whitehouse.gov/omb/circulars/index.html>

OMB. 2008. "Discount Rates for Cost-effectiveness, Lease purchase, and related analyses." Office of Management and Budget, Circular A-094, Appendix C. Washington DC.
http://www.whitehouse.gov/omb/circulars/a094/a94_appx-c.html

Whitestone. 2006. "The Whitestone Building Maintenance and Repair Cost Reference." Whitestone Research, Santa Barbara CA.
<http://www.whitstoneresearch.com/>

Webster, T., R. Pinto, B. Elgamil, C. Benedek, F. Bauman, J. Wallis and H. Lin. 2008. "CBE UFAD Cost Analysis Tool: UFAD First Cost Model, Issues and Assumptions." Center for the Built Environment, University of California, Berkeley CA