Analysis of Life Cycle Cost Methods for Heating, Ventilation, and Air Conditioning Systems in Hospitals

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1 Introduction and Background

The purpose of this research was to evaluate the current body of knowledge related to life cycle costing of heating, ventilation, and air conditioning systems (HVAC) systems in hospitals. Life cycle cost (LCC) is the total cost of procuring, designing, owning, operating, maintaining, and disposing of a building over its useful life (including its fuel and water, energy, labor, and replacement components), determined on the basis of a systematic evaluation and comparison. Both government and private hospitals were studied. Hospitals have several interesting characteristics that made them useful to consider. They are:

- typically owned by either governments or large corporations
- regulated as a class
- subject to special tax situations
- owned by owners who often own more than one building
- not driven solely by profitability or return on investment
- financed over the long-term by bonding or taxes.
- expected to have long service lives
- not likely to change building use and functions over time.
- often procured through processes open to public scrutiny
- operated by decision makers who are not facilities specialists.

Evaluation of life cycle costs is important because the true costs of ownership of a facility are much larger than the initial construction cost investment. Initial cost is typically the subject of intense scrutiny during design and planning and HVAC systems represent significant portions of the initial cost of a facility and consequently involve significant design choices and trade-offs. Figure 1 shows that facilites require significant ongoing operating expenses especially in maintenance and utilities, and thus influence future costs of ownership. Accurate life cycle cost information is helpful in decision making for initial investment in projects, replacement options, repair options, and for assessing the true costs of ownership of a building. Life cycle costing uses historical and tabular data as well as rules of thumb to make estimates and assessments of the costs involved in different design and construction choices before making a final business decision. The quality of the results of life cycle cost analysis depends on both the computation method and the input data.

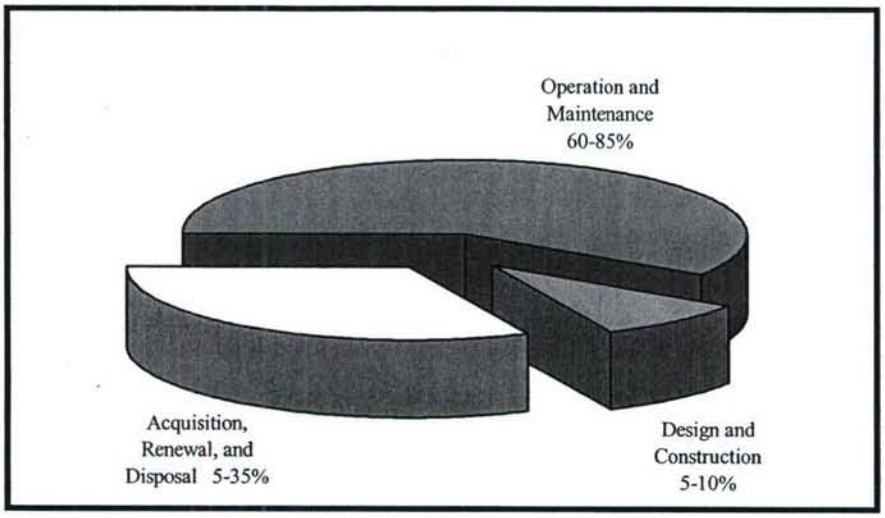

Figure 1 - Life Cycle Cost Elements: 30-year period for Federal Facilities ASHRAE (2003)

This research will serve many useful purposes. Evaluating and quantifying the process of life cycle cost planning for hospitals enables more effective and efficient decision-making on current and future projects. In addition, the capabilities and limitations of life cycle costing can be defined. First, the state of the art in life cycle modeling for institutional HVAC was determined to define the preferred practice. Then, the life cycle models were evaluated for usefulness in design and selection of HVAC systems, including economic analysis (annualized costs, present value). Evaluation was based on underlying models and assumptions; complex commercially available proprietary tools were not examined. The models are widely available with clearly visible mathematical algorithms.

Analysis included determination of the variability and reliability of the models based on the known or expected variability in inputs: interest rates, energy costs, operation costs, etc. Sensitivity to changing variables of interest was also determined. Trends or anomalies in the models were defined and checked. The scope of the study included economic analysis, energy analysis, present cost, replacement cost, life span, maintenance, operation, and other relevant factors for life cycle costs.

In Chapter 2, the literature review describes the current state of the art in life cycle costing. Chapter 3 defines the research methodology and assumptions. Chapter 4 compares and contrasts the two life cycle cost methods of interest: one from the American Society of Heating Refrigeration and Air-conditioning Engineers (ASHRAE) and the other from the Federal Energy Management Program (FEMP). Chapter 5 evaluates the available input data for use in life cycle costing for three hospitals. Chapter 6 states the conclusions and recommendations of the analyses.

2 Literature Review

Most current writings and resources for life cycle costing are from professional organizations and government entities, not from academic or research sources. There are two main manual techniques available and adaptable for analysis of HVAC life cycle costing, ASHRAE (2003) and FEMP (1996). These methods allow engineers and facilities planners to perform economic analyses and evaluate design decisions prior to construction or extensive design.

Other models for LCC do exist such as those developed by the American Institute of Architects (1977), Dell'Isola and Kirk (1981), and Logistics Management Institute (1976) but these models were designed for different purposes than HVAC life cycle cost analysis.

There are two main computer code life cycle models available: *Building Life Cycle Cost* (BLCC) from the National Institute of Standards and Technology (NIST) and Department of Energy (DOE) and *Life Cycle Cost in Design* (LCCID) from the US Army Civil Engineering Research Laboratory at the University of Illinois Champaign-Urbana. BLCC and LCCID are both nearly identical to the FEMP model. The FEMP manual model includes an extensive handbook and instructions, which make LCC analysis simpler. Computer code energy forecasting models such as ERATES, HPEAK, and HEAT, from NIST (2004), automate the cost acceleration and inflation factors available in the manual model and in the context of this analysis do not add additional analytical value. The computation of life cycle costs relies heavily on the quality of the available data, which is typically historical or based on estimates. Some required data are readily available from R.S. Means and Company, ASHRAE, and the U.S. Government.

2.1 ASHRAE Cost Model

The ASHRAE method of analysis compares the cumulative total of design, construction, acquisition, operating, maintenance, and disposal costs. The total costs are discounted over the life of the system or over the loan repayment period. The costs and investments are both discounted and displayed as total combined life-cycle cost at the end of the analysis period. Table 1 shows the input data used in the whole building analysis under the ASHRAE (2003) model. Many of these data are not appropriate for building system analysis, but they are exhaustive and can help lead the analyst to include all relevant information. These data are then used as the inputs for a cash flow analysis of costs, which leads to the life cycle cost. Life cycle cost is determined using current value analysis of the data, a simple economic analysis, using either uniform series or single payments and is expressed as Net Present Value (NPV).

Table 1 –Life-Cycle Cost Elements
Source: ASHRAE (2003)

Pillars Of Life Cycle Cost	**Elements**	**Sources Of Data**
Operating And Maintenance Cost	Utilities	DOE (2004)
		FEMP (1996)
		ASHRAE (2003)
		ASHRAE (2001)
	Consumables	Not readily available
	Fuel	DOE (2004)
	Waste	Not readily available
	Lost Production	Not readily available
	Spares	Not readily available
	Equipment Life	ASHRAE (2003)
		Manufacturer Data
	Planned Maintenance	ASHRAE (2003)
		MEANS (2002A)
	Unplanned Repair	MEANS (2002A)
	Labor Costs	Department of Labor
	Cost Of Parts And Stores	Manufacturer
		MEANS (2002A)
	Maintenance Management	Means (2002A)
	• Insurance	Not readily available
	• Property Taxes	Not readily available
	• Income Taxes	Not readily available
	• HAZMAT Handling	Not readily available
	• Financing Costs/Interest	Not readily available
	• Depreciation	Not readily available
	• Permits & Fees	Not readily available
Design And Construction Cost	Engineering	MEANS (2002B), Army (1994)
	Installation	MEANS (2002B), Army (1994)
	Training	Not readily available
Acquisition, Renewal, And Disposal Costs	Procurement	Not readily available
	Administration	Not readily available
	Environmental	Not readily available
	Demolition	MEANS (2002B)
	• Recycling	Not readily available
	• Removal	MEANS (2002B)
	• Salvage	Army (1994)
	Replacement	MEANS (2002A)

Note: Sources of data are not provided in ASHRAE (2003). Some data are "not readily available" due to dependence on either locality, organizational business practice, market conditions, and internal management data or they are unpredictable.

2.2 FEMP Cost Model

This model assists in decision making for whole building projects, but is easily adaptable for sub-system analysis. ASTM (2002) describes recommended procedures for life cycle costing, which are the basis for this FEMP (1996) life cycle costing model. FEMP (1996) is a very deep and broad treatment of life cycle costing, including background, theory, and examples. The FEMP model is the required method for life cycle costing for U. S. Federal Facilities. The key steps in life cycle cost analysis process are defined in FEMP (1996). They are to:

- define problem and state objective
- identify feasible alternatives
- establish common assumptions and parameters
- estimate costs and times of occurrence for each alternative
- discount future costs to present value
- compute and compare LCC for each alternative
- compute supplementary measures if required for project prioritization
- assess uncertainty of input data
- account for effects for which dollar costs or benefits cannot be estimated.

The FEMP (1996) method requires all of the input items in Table 2 such as initial investment cost, capital replacement cost and period, residual value, electricity cost, fuel cost, operations, maintenance, and repair, and study period. The input values are multiplied by an appropriate factor to compute a present value and then summed to compute the total life cycle cost. The uniform present value (UPV) factors provided for energy costs (electricity and fuels) include an additional cost acceleration factor to account for expected increases in energy costs over time. The sum of all the factored costs gives the Net Present Value.

Table 2 - FEMP Life Cycle Cost Computation
Source: FEMP (1996)

Cost Items	Cost	Year of Occurrence	Discount Factor
Initial Investment Cost	$/event	Initial	None needed, unless procured over a long period
Capital Replacement	$/event	Year of Replacement	Single Present Value (SPV)
Residual Value	$/event	Year of Disposal	SPV
Electricity Cost	$/year	Annually	Uniform Present Value(UPV)
Fuel Cost	$/year	Annually	UPV
Operations, Maintenance, and Repair	$/year	Annually	UPV

2.3 Data Sources for Life Cycle Cost

There is significant dependence in all LCC methods on the quality of data used for evaluation. Thus, before evaluating the life cycle cost method, appropriate data must be obtained from several sources. ASHRAE (2003) includes data for planning and design, but other sources of HVAC data are available, especially MEANS (2002B) and Army (1994). Table 1 shows how the data are broken down into categories, as well as the expected data sources for each.

R.S. Means cost data manuals are popular and widely accepted sources of information for construction costs. They address operations and maintenance costs, demolition and disposal costs, but do not include salvage values. Square foot unit costs for construction is available the Means cost data, and lists typical values for construction of HVAC systems in new facilities. These values exclude Architect fees and land costs. This data is useful only for conceptual design cost estimation. MEANS (2000) also offers assembly costs for simple complete HVAC systems. Means (2002A) provides detailed cost breakdowns for repair, replacement, and maintenance of HVAC systems in a detailed and adaptable format.

The Facilities Pricing Guide, DoD (2003), provides lists of initial construction costs and annual sustainment costs for facilities, including hospitals. This unit cost database uses a 367,838 ft^2 standard sized hospital for reference, which is particularly relevant to this work. This database provides total **like new** sustainment costs, which are not well defined in other sources.

2.4 Life Cycle Costing in Peer-Reviewed Literature

There is very little published research addressing life cycle costing in the peer-reviewed literature, which reveals opportunities for additional contributions.

The available literature helps reveal research opportunities especially in the area of HVAC system level analysis of life cycle costing for hospital facilities. Woodward (1998) gives a deep and thorough treatment of the theory and terminology of life cycle costing. Warren and Weitz (1994) describe slightly different theory and terminology. These papers show that recent efforts are still refining the theory of life cycle costing. I found two specific examples of HVAC subsystem analysis: Lu et al (2004) focuses on optimizing the condenser water loop for optimal efficiency, providing useful information on power consumption, controls, and operations and Asiedu et al (2000) highlighted the life cycle cost impacts of duct design. Gustafsson (2000) focuses tightly on the cost-benefit analysis of retrofit vs. repair, showing the impact on the annualized costs on a specific actual building in Sweden. Khan and Haddara (2003) described risk based maintenance for scheduling and planning purposes. Thus, there has been significant interest in the general field of life cycle cost analysis, but no investigation into the life cycle costing of HVAC systems for hospitals and this lack of specific research is the primary motivation for further study and this report.

3 Research Methodology

The two life-cycle cost models that were studied were ASHRAE (2003) and FEMP (1996). These two manual techniques were chosen based on their availability, acceptance by practitioners, and their well-described computational methods as compared to computer programs. This research will involve determining the effects of input data on the LCC models and determining the quality of available data for producing an accurate LCC estimate.

The model analysis was performed to evaluate implementation of the ASHRAE and FEMP models. Simulated data were input into the models and life cycle costs computed. Data values were varied to determine the most important input data as well as the sensitivity of the models to the input data. The input data values were determined from recommended or available sources and each source is indicated where the data are used. The types of data necessary for evaluation of life cycle cost using the FEMP and ASHRAE methods fall into two main categories annual costs and one-time costs. The one-time costs include the initial construction cost, periodic replacement costs over the life of the supported facility, and salvage and disposal costs. The annual costs include maintenance and repair, operations, and the cost of energy consumed by operations. Each of these major categories of costs were investigated and then evaluated within two life cycle cost models. Additionally, the use of discount rates for economic analysis of future costs is important and this choice represents a management decision relative to alternative investment options.

3.1 Effects of Input Data on LCC Models

Simulated inputs were performed and analyzed to determine the impact of different parameters on each model. Base case data were either provided with the model's literature or recommended (as in the FEMP model recommending MEANS construction cost data). The results of this analysis are shown in Chapter 4. Life cycle cost computations were made for both the ASHRAE and FEMP models using estimated data for two sample hospitals.

The first step of the analysis was to define hospital models as the basis for analysis. The sample hospitals were based on the 55,000 square foot and 200,000 square foot hospitals in Means (2002). The second step of the analysis was to estimate costs for construction, heating, cooling, and ventilation based on procedures and data from ASHRAE (2003) and Means (2002) manuals. The third step of the analysis was to estimate replacement costs and replacement period for the HVAC systems based on the literature available as well as estimates factors available. The fourth step of the analysis was to estimate maintenance and operations costs, which were based on the expected costs provided especially in ASHRAE (2003). The fifth step of the analysis was to determine the values of discount rate and study period to be used in economic analysis, which were based on representative values found in literature and in the models themselves. The sixth step of the analysis was to compute life cycle cost using each of the ASHRAE and FEMP models as well as by direct comparison of the models. The seventh and final step of the analysis was to conduct sensitivity analysis of the input variables to each life cycle cost model, using the values computed in step 6 as the base case; assessing the list of variables and their importance and impact on the model.

3.2 Quality of Available HVAC LCC Data

In order to validate the use of either model in hospital facilities, HVAC system data and other required data was obtained from several publicly owned and privately owned hospitals in the Central Texas Region. This real-world data permitted a comparison of publicly available data to actual facility costs. Results are reported in Chapter 5.

The first step for analyzing the quality of available data was to develop a survey instrument (Appendix E) incorporating all of the pertinent information on each facility, its HVAC system, and associated cost histories and operating procedures. The second step was to establish contacts with hospitals in the central Texas region, where ten hospitals were contacted and four agreed to provide data for the study. The third step was to distribute and administer the survey, which was accomplished electronically, by mail, by phone, and in person according to the desires of the subjects. The fourth step was to conduct follow-up phone interviews to clarify any unclear or missing data. The fifth step was to compute life cycle costs for real hospitals using provided data and the ASHRAE and FEMP methods. The sixth step for analyzing the quality of available data was to compare tabular, sample, and real life cycle cost computations. The seventh and final step was to determine the most vital data for accurate life cycle costs by comparing the quality of data available with the most sensitive variables from the sensitivity analysis.

4 Model Analysis Results

Initial construction cost is one of the most significant and visible costs of an HVAC system. There are some difficulties in determining the true initial cost of an HVAC system for a hospital, with the most important being the use of lump-sum contracts for construction of large capital projects. The use of lump-sum costs in construction means that the actual cost of the HVAC system is buried and has to be artificially extracted from the aggregate cost. To illustrate the level of variability in costs, Tao (2001) gives the range of the cost of mechanical and electrical systems as 30-50% of total building cost in research hospitals and 25-35% of total building cost in clinical hospitals. This level of variability complicates the computation of reasonable system costs. Means (2002B) provides an alternative method for determining HVAC system costs using data for sample representative hospitals. Costs were estimated for the two sample hospitals. The data that were used are based on those available from common sources as shown in Table 1.

4.1 Estimated Sample Costs for Hospitals

The sample hospitals were taken from the illustrated models in the Means (2002B). Details of these samples, abbreviated for the uses of this research are listed in Table 3 below. Both hospitals have oil-fired hot water, wall fin radiators, chilled water-cooling, and fan coil units. Both DoD (2003) and Means (2002B) lists similar area cost factors for central Texas, with DoD having an average value of 0.82 and Means (2002B) listing 0.81. The 0.81 area cost factor from Means was used to maintain consistency with the other construction costs from the same source. Sample hospitals are in central Texas for climate purposes.

Table 3 - Sample Hospital Characteristics

3 Story Hospital	**6 Story Hospital**
55,000 Square foot floor area Cost per square foot $150.70 Building Initial Cost $8,300,000 HVAC/total building cost 11.0% Heating system construction \$3.06/ ft^2 Cooling system construction \$9.15/ ft^2 HVAC system initial cost $911,700 Location Adjustment factor 0.81 HVAC initial adjusted $739,000 • Heating $ 136,000 • Cooling $ 408,000 • Ventilation & Controls $195,000	200,000 Square foot floor area Cost per square foot $123.70 Building Initial Cost $24,740,000 HVAC/total building cost 5.7% Heating system construction \$3.06/ ft^2 Cooling system construction \$2.08/ ft^2 HVAC system initial cost $1,410,000 Location Adjustment factor 0.81 HVAC initial adjusted $1,142,000 • Heating $ 496,000 • Cooling $ 337,000 • Ventilation & Controls $309,000

The derivation of the annual energy consumption of an HVAC system is a significant factor in determining life cycle costs, but is often impossible to separate from the other energy costs of building operation, especially lighting and tenant equipment. As such, a nominal value was derived to show its impacts on the life cycle cost models, rather than as an attempt to predict the cost of HVAC operation in a real facility. Energy costs were taken from DOE (2004) and a hypothetical building heat and cooling load was derived from ASHRAE (2003) tables and Means (2002B) estimates.

Average representative energy costs were obtained from the U.S. Department of Energy, FEMP (2004), and several assumptions used in calculation are listed below:

- $0.06/kWh is the Federal average electricity price in the U.S.
- $0.04/therm is the Federal average gas price in the U.S.
- $0.66/gallon is the Federal average fuel oil price in the U.S.
- Future electricity price trends and a discount rate of 3.2% are based on Federal (DOE) guidelines. This item was only used in the FEMP model, where there is a separate energy conversion factor.
- The average heating value for No. 2 oil is 1.4×10^5 Btu/gallon.
- The average heating value for natural gas is 10^5 BTU/therm.

Heating, cooling, and ventilation loads were determined using the 1995 Commercial building energy consumption listed in ASHRAE (2003). The data were adjusted from the aggregate data to approximate realistic values for the model hospitals based on size and location. ASHRAE (2003) listed heating, cooling, and ventilation values for many categories of buildings; average (all buildings in the study), sorted by location, height, floor area, and building function. A detailed explanation of the method for deriving this data is in Appendix A. The total annual costs for heating, cooling, and ventilation for the sample hospitals is included in Table 4. The annual operating cost data vary greatly between the models, reflecting the differing sources of information. The

Means values will be used in the FEMP model and varied substantially from the ASHRAE values. The closest agreement between the sources was for ventilation and the Means derived ventilation costs were more than twice as large as ASHRAE costs for the three-story hospital but was within 5% for the six-story hospital. Heating costs had a higher difference between the sources and the Means derived heating costs were over twice the ASHRAE costs for the three-story hospital and almost 30% higher for the six-story hospital. The worst agreement between the data was in cooling costs and the Means derived cooling costs were over 25 times higher than the ASHRAE costs for the three-story hospital and over 16 times higher for the six-story hospital.

Table 4 – Annual HVAC Operating Costs for Sample Hospitals.
Sources: Means (1999), ASHRAE (2003), and FEMP (2004).

	Means values/year	ASHRAE values/year	Means $/Year	ASHRAE $/Year
Heating				
3 Story Hospital	9,447 MBTU	4,030 MBTU	$44,500	$19,000
6 Story Hospital	28,760 MBTU	22,270 MBTU	$135,500	$105,000
Cooling				
3 Story Hospital	6,265 MWh	249 MWh	$376,000	$15,000
6 Story Hospital	22,780 MWh	1,418 MWh	$1,370,000	$85,000
Ventilation				
3 Story Hospital	36,666 CFM 196 MWh	1.62 kWh/ ft^2 89 MWh	$12,000	$5,400
6 Story Hospital	133,333 CFM 712 MWh	3.44 kWh/ ft^2 688 MWh	$43,000	$41,000

Total annual HVAC Maintenance costs for the FEMP model based on DoD (2003) were estimated as $25,250 and $47,500, for the three and six-story hospitals respectively. For a full explanation of the computations and assumptions for maintenance costs, see Appendix A. The ASHRAE (2003) maintenance cost equation was based on 1983 dollars and is shown in equation (1) below.

$$C = 0.338 + 0.0018(n) + h + c + d \qquad (1)$$

The inputs to Equation (1) are C, which is the annual HVAC maintenance cost ($/ft2), n is age of the system in years, h is the heating system adjustment factor, c is the cooling system adjustment factor, and d is the distribution system adjustment factor. ASHRAE (2003) makes disclaimers about the age and accuracy of this cost model because of a failure to account for climate, location, facility type, etc. Annual inflation-corrected maintenance costs for the three-story hospital is $52,600 and for the six story hospital $191,000. This value does not include periodic replacements, which are addressed separately. In addition, administrative costs were estimated as a 10% overhead on maintenance and operating costs to permit the inclusion of this cost in the analysis, despite the lack of data. Additional explanation of maintenance costs is in Appendix A.

The average age of health care facilities is 23.5 years and the average age of all buildings is 30.5 years, ASHRAE (2003). FEMP (1996) discounting tables only go up to 30 years, with 25 years the expected useful life of any facility and the remaining five years accounting for planning, procurement, and construction. The FEMP limit on 25 years is not consistent with the ASHRAE (2003) data, which suggests that the actual life of a health care facility extends well beyond the average of 23.5 years, and that a maximum of 50 years is not out of the question. For FEMP models, the maximum of 30 years was used, while for the ASHRAE model a 50-year maximum life was used despite the unequal comparison that results. The DoD (2003) sustainment data for the FEMP model will replace the need for a separate replacement cost over the life of the system because the DoD definition of sustainment includes periodic replacement of worn-out components.

The service lives of all the components were compared within the subsystems and weighed by percentage of cost to arrive at an aggregate cost weighted service life for heating, cooling, and ventilation components. ASHRAE (2003) lists service lives for components, and replacement costs were based on a most conservative 100% initial value replacement of worn out components. Based on Means (1999), the breakdown of costs in the heating system is as shown in Table 5. In addition, the breakdown of costs in the cooling system is as shown in Table 6. No weighting was necessary for ventilation components because they all have a twenty year expected service life, ASHRAE (2003), and the replacement period for the ventilation system will be 20 years.

Table 5 - Heating Component Service Life
Sources: ASHRAE (2003) and Means (1999).

Component	% of Cost	Service Life (Years)
Oil Fired Boiler	61.0%	30
Circulating Pump	4.2%	20
Expansion tank	5.2%	30
Storage tank	4.9%	30
Tubing	9.3%	20
Radiators	6.9%	25
Insulation	8.6%	20
Total	**100.0%**	***28 - Weighted Average***

Table 6 - Cooling Component Service Life
Sources: ASHRAE (2003) and Means (1999).

Component	% of Cost	Service Life (Years)
Rooftop multi-zone unit	70.9%	15
Ductwork	29.1%	30
Total	**100%**	***19 – Weighted Average***

Salvage and disposal represent significant unknowns in both sign and magnitude, where negative salvage value would indicate a disposal cost. For the purposes of this model, salvage value was taken as 5% of initial cost, to account for scrap value of metal equipment and ductwork. This value was used mainly to facilitate further analysis of the life cycle model based on sensitivity to salvage value.

FEMP (1996) uses the Department of Energy (DOE) rate of 3% for discount rate. This low discount rate reflects a conservative assessment, because a lower discount rate will increase the life cycle cost of future payments. The FEMP model uses an energy cost acceleration factor, included in the present value factor for fuel and electricity costs only. ASHRAE (2003) offers various discount rates, reflecting the commercially relevant concept of return on investment, which is not a factor in the governmental focus of the FEMP method. For the purposes of this analysis, a 10% discount rate was used. The ASHRAE model was also run using a 3% discount rate to compare more directly with FEMP. Depreciation is not addressed in these models.

Cash flow analyses were performed in accordance with the method specified in the ASHRAE (2003). This method uses end of year cash flows with all values discounted to present value. In a comparison of FEMP Method to ASHRAE Method, minor differences were noted because the discounting method used in the FEMP model is a mid-year cash flow, while the ASHRAE uses the year-end cash flow typical of economic analysis.

Table 7 shows the input data and life cycle costs computed for the sample hospitals using the ASHRAE cost model based on a 50-year useful life using both a 10% and 3% discount rates. Tables 8 and 9 show the input data and results for the FEMP model. These data are the base case for the sensitivity analysis, which follows. The full computations are in Appendix B because of their size and repetition.

Table 7 – ASHRAE Model Sample Cost Summary

Owning Costs	**3 Story Hospital**	**6 Story Hospital**
Initial Cost Of System	$739,000	$1,142,000
Total Replacement Costs	$739,000	$1,142,000
-Cooling Replacement (19 yrs)	$408,000	$ 337,000
-Heating Replacement (28 yrs)	$136,000	$ 496,000
-Ventilation Replacement (20 yrs)	$195,000	$ 309,000
Salvage Value (5%)	$ 37,000	$ 57,000
Operating Costs		
Annual Utility, Fuel, Water, Etc Costs	$ 39,400	$231,000
Annual Maintenance Allowances/Costs	$ 52,600	$191,000
Total	$ 92,000	$422,000
Annual Administration Costs	$ 9,200	$ 42,200
Total Annual Operating Costs	$101,000	$464,000
NPV of 50-year HVAC Life Cycle Cost (10% Discount Rate)	**$1,860,000**	**$5,893,000**
NPV of 50-year HVAC Life Cycle Cost (3% discount)	**$3,922,000**	**$13,852,000**

Table 8 - FEMP LCC Sample – 3-Story Hospital

Cost Items	**Base Date Cost**	**Year of Occurrence**	**Discount Factor (DOE 3%)**	**Present Value**
Initial Investment Cost	$739,000	Initial	None needed	$ 739,000
Residual Value (5%)	$37,000	Year 30	0.412	$ 15,200
Fuel/Electric Cost	$432,500	Annually	21.23	$ 9,182,000
(Sustainment)	$ 25,250	Annually	19.60	$ 494,900
NPV of HVAC Life Cycle Cost				**$10,431,100**

Table 9 - FEMP LCC Sample – 6-Story Hospital

Cost Items	Base Date Cost	Year of Occurrence	Discount Factor	Present Value
Initial Investment Cost	$1,142,000	Initial	None needed	$ 1,142,000
Residual Value (5%)	$57,000	Year of Disposal (30)	0.412	$ 23,500
Fuel/Electric Cost	$1,548,500	Annually	21.23	$32,875,000
Operations, Maintenance, and Repair (Sustainment)	$ 47,500	Annually	19.60	$ 931,000
NPV of HVAC Life Cycle Cost				**$34,970,000**

The total life cycle costs from the previous tables for the sample hospitals is compiled in Table 10, and are listed by which sample hospital, method, and discount rate was used. Table 10 includes an additional computation using the FEMP model data in the ASHRAE computation to check the models against each other more directly. This led to a comparison of the computations and resulted in life cycle costs within 20% of each other for the same hospital. Most of the variability in the life cycle costs between models can be attributed to the effects of data rather than the choice of model. This variability between the FEMP model and the ASHRAE model with FEMP input data is well within the range of expected accuracy for all but the most detailed estimates as determined by the Construction Industry Institute and the American Association of Cost Engineers, shown in Table 11. Thus, for the purposes of life cycle costing either model will produce reasonably consistent results given the same input data.

Table 10 - Summary of LCC Computations for Sample Hospitals
(See Appendix B for detailed computations)

Sample Hospital	Model Variant	Life Cycle Cost
3-Story	ASHRAE 10%	$ 1,860,000
3-Story	FEMP	$ 10,431,100
3-Story	ASHRAE 3%	$ 3,922,000
3-Story	ASHRAE w/FEMP data	$ 12,508,360
6-Story	ASHRAE 10%	$ 5,893,000
6-Story	FEMP	$ 34,970,000
6-Story	ASHRAE 3%	$ 13,852,000
6-Story	ASHRAE w/FEMP data	$ 42,193,701

Table 11 - Accuracy Ranges of Estimates
Source: Referenced in Oberlender (2000)

	Organization producing standards	
Estimate Class	**AACE**	**CII**
Concept Screening	-50% to + 100%	N/A
Study or Feasibility (Order of Magnitude)	-30% to + 50%	±30 to 50 %
Budget, Authorization, Control (Factored Estimate)	-20% to + 30%	±25 to 30 %
Control, Bid Tender	-15% to + 20%	±10 to 15 %
Check Estimate (Detailed/Definitive)	-10% to + 15%	± <10%

4.2 Variables and sensitivity

In order to evaluate the different variables, their contribution to life cycle cost, and their sensitivity to changes, the Table 12 data attribute table shows all the relevant variables for life cycle cost calculation. The **state** variables are random or unpredictable, the **nominal** values have a recommended value, and the

decision variables are dependent on a choice. In addition, the expected range of values and the principle or recommended source of data is also listed.

Table 12 - Data Attribute Table for Life Cycle Cost
Format from O'Connor (2004).

Cost Element	Variable Type	Unit of Measure	Model	Value or Range	Best Source	Source Reliability
Admin	Calc Qty	$/Year	ASHRAE	0-∞	Guess	Poor
Discount Rate	Decision	%	ASHRAE	0-25	Inst. Decision	Good
OM&R	Calc Qty	$/Year	ASHRAE	0-∞	ASHRAE Means	Fair
Replace-ment	Calc Qty	$	ASHRAE	0-∞	Means	Good
Replace-ment Freq.	State	Years	ASHRAE	10-30	ASHRAE	Good
Electric	State	$/Year	Both	0-∞	ASHRAE, DOE, FEMP	Fair
Fuel	State	$/Year	Both	0-∞	ASHRAE, DOE, FEMP	Fair
Initial	Calc Qty	$	Both	0-∞	Means, DoD	Good
Residual value	State	$	Both	-∞ to ∞	No good source	Poor
Study Period	Decision	Years	Both	05-50	Choice	N/A
Sustain-ment	Nominal	$/ ft^2/Year	FEMP	$5.09	DoD	Good

The table of ASHRAE sensitivity, Table 13, shows the effects of changing each input variable by ±10%, while holding all other variables constant. All of the changes were simple changes in the values, except for replacement period. The change in replacement period changed each of the elements of the system based on the service lives shown in Tables 5 and 6. For example, a ten percent change in period for heating was 2.8 years, for cooling 1.9 years, and for ventilation 2.0 years. The varying periods affected the cash flow timing for replacement costs. Full computations are in Appendix B.

Table 13 – Sensitivity Analysis of ASHRAE Model

Changes in Life Cycle Cost	**3 Story**		**6 Story**	
Changes from Expected Values	**10.0%**	**-10.0%**	**10.0%**	**-10.0%**
Initial Cost Of System	4.0%	-4.0%	1.9%	-1.9%
Replacement Cost	0.6%	-0.6%	0.3%	-0.3%
Replacement Period	-1.3%	1.7%	-0.5%	0.7%
Salvage Value	0.0%	0.0%	0.0%	0.0%
Annual Utility, Fuel, Water, Etc Costs	2.1%	-2.1%	3.9%	-3.9%
Annual Maintenance Allowances/Costs	2.8%	-2.8%	3.2%	-3.2%
Annual Administration Costs	0.5%	-0.5%	0.7%	-0.7%
Discount Rate	-5.9%	7.2%	-7.4%	8.9%
Study Period	0.2%	-0.3%	0.3%	-0.4%

The sensitivity plots visually highlight the most sensitive variables as the steepest lines. As can be seen in Figure 2 and Figure 3, the most sensitive variable is and discount rate for both the 3-story and 6-story samples. The remaining cost elements had much lower sensitivity, with initial cost, annual maintenance, and annual utility and energy costs having the largest effects. Replacement period had a small effect on life cycle cost. Salvage value, study period, administrative costs, and replacement costs had almost no effect on life cycle cost. There was no difference in the most sensitive variables between the two sample hospitals in the ASHRAE model.

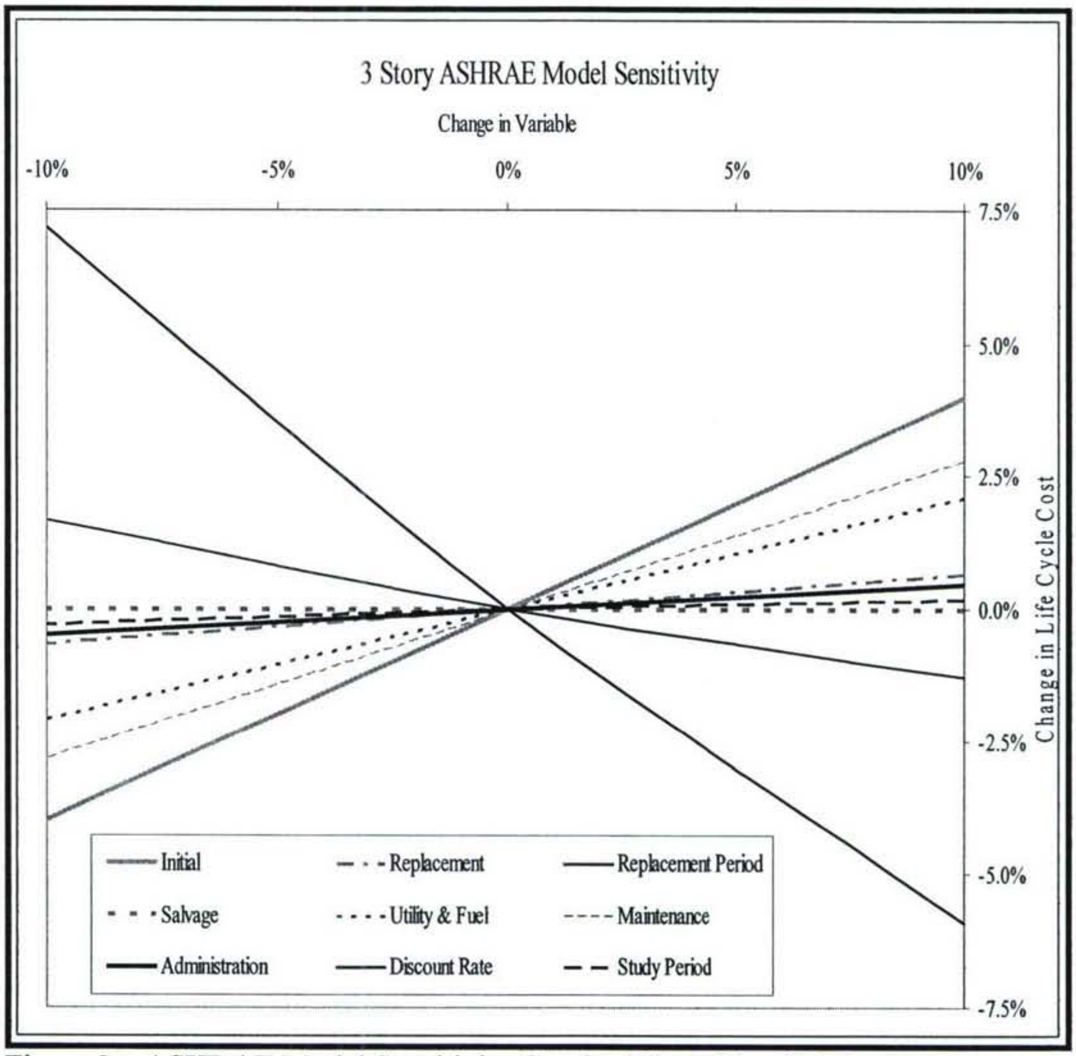

Figure 2 – ASHRAE Model Sensitivity Graph, 3-Story Hospital

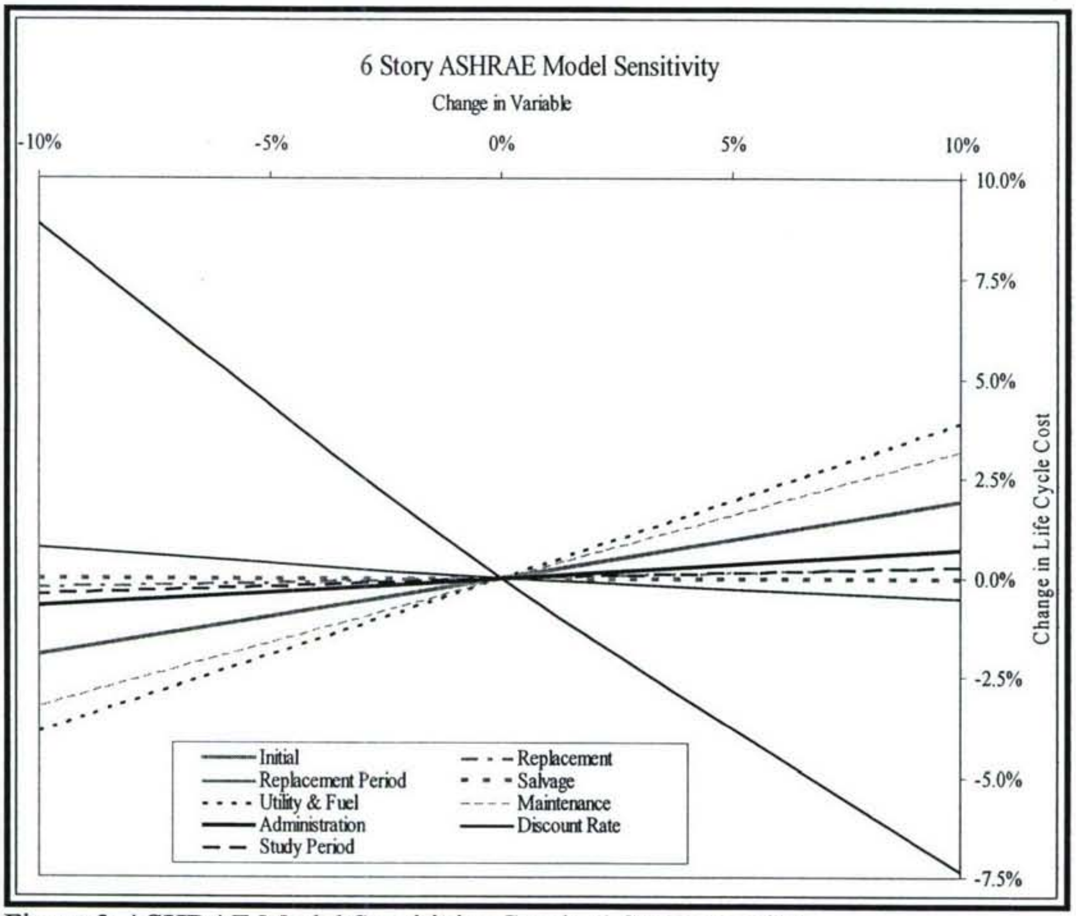

Figure 3-ASHRAE Model Sensitivity Graph, 6-Story Hospital

The FEMP model was evaluated for sensitivity as shown in Table 14 using a 10% change from the expected value. In order to shorten the study period by a 5-year increment, a 16% change in duration value was recorded. In addition, the study period was not extended using FEMP data, because the 30-year timeline initially used was the maximum available in the FEMP discount factor tables.

Table 14 - FEMP Model Sensitivity by Changing Variables

% Change of NPV	**% Change in Variables**		
3 Story	**10%**	**-10%**	**-16%**
Initial Investment	0.71%	-0.71%	
Residual Value	0.01%	-0.01%	
Fuel & Electric	8.80%	-8.80%	
Sustainment	0.47%	-0.47%	
Study Period			-7.39%
6 Story			
Initial Investment	0.33%	-0.33%	
Residual Value	0.01%	-0.01%	
Fuel & Electric	9.40%	-9.40%	
Sustainment	0.27%	-0.27%	
Study Period			-7.64%

The relative sensitivities of the variables in the FEMP model are shown in Figure 4 and Figure 5. The fuel and electric costs were the most sensitive components of the FEMP model. The choice of study period also had a significant impact on life cycle cost. All other factors, including initial investment, residual value, and sustainment cost had minor impacts on life cycle cost. There was no difference in the ranking of the sensitivity of the variables between the two samples.

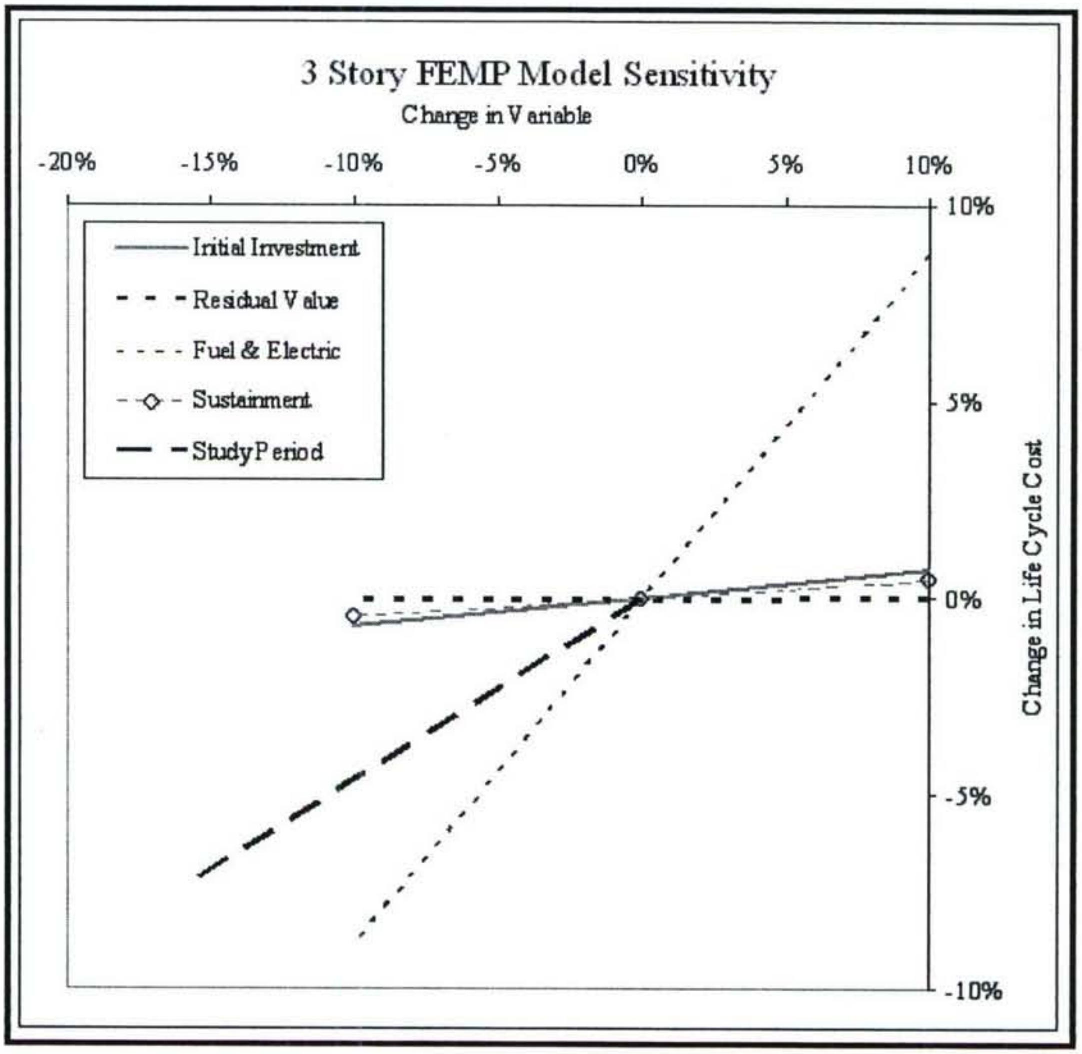

Figure 4 – FEMP Sensitivity Graph, 3-Story Hospital

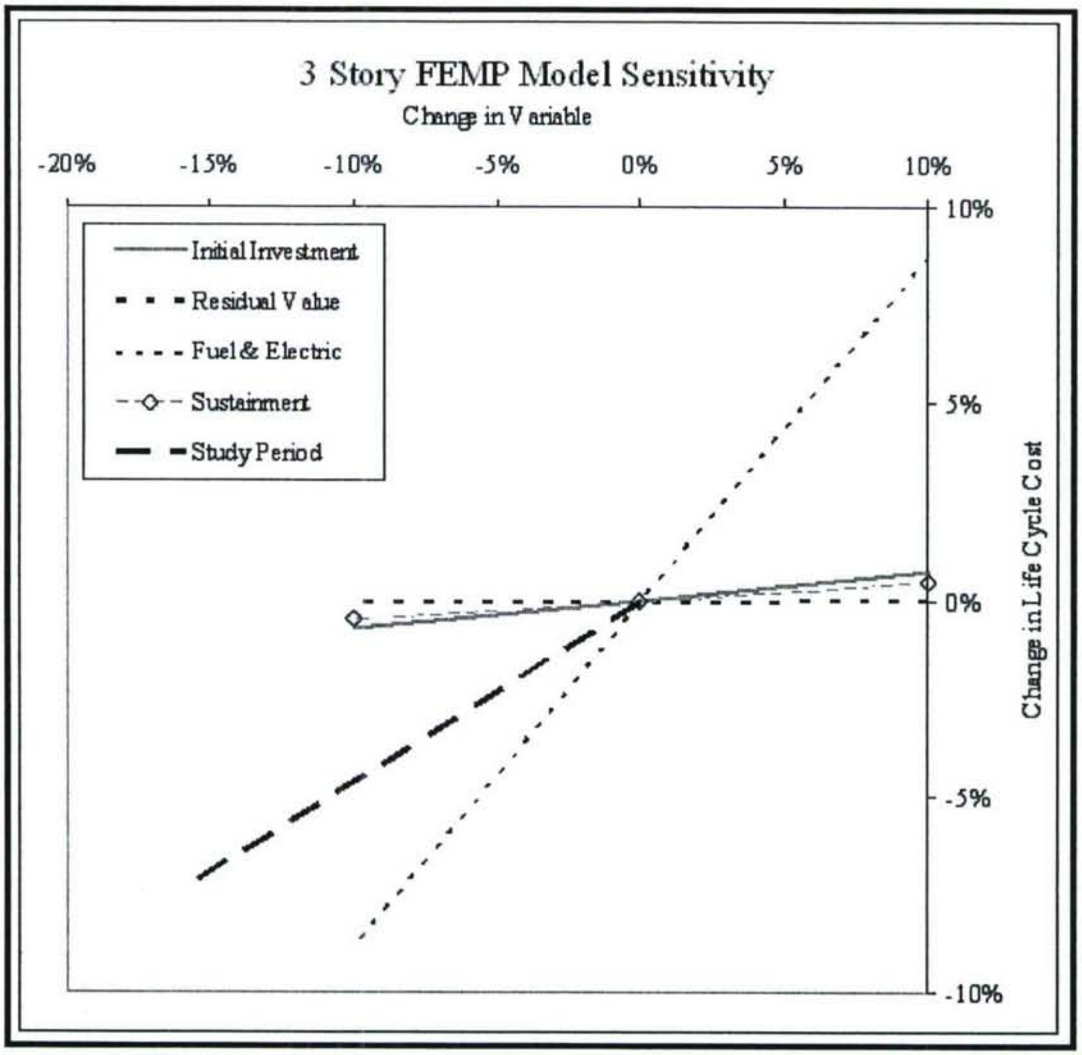

Figure 5 - FEMP Sensitivity Graph, 6-Story Hospital

The ASHRAE (2003) model analysis shows that fuel, electricity, and maintenance costs, while very important to the accuracy of the model have only fair definition as input variables to the model as shown in Table 12. Initial cost, while having a strong relative influence on life cycle cost, is a well-defined quantity at the start of a project. The most significant variable is the choice of discount rate, reflecting the business decision of risk and rate of return. Discount rate is not an unknown but is a choice, and thus is not a significant accuracy factor for the model.

The FEMP (1996) model analysis shows that fuel and electric costs over the life of the facility are the most sensitive variables, while also being poorly defined at the start of a project. Life cycle cost is also relatively sensitive to the study period, but this represents a business decision as to the owner's planning horizon, and is choice not a true variable. The FEMP model always uses a 3% discount rate, so the discount rate is not a factor in this sensitivity analysis. There is no recommended discount rate for the ASHRAE model because the discount rate depends on the analysts assumptions about the current value of future payments.

Annual energy and maintenance costs are the most important variables in either model. Both the ASHRAE (2003) and FEMP (1996) models are most sensitive to annual costs, especially energy and maintenance costs, more than any other unknown quantities. The choice of discount rate and study period has strong impacts, but these are owner choices and not unknowns. Despite the models' sensitivity to initial cost, this variable has a smaller effect on model accuracy because of the quality of data available.

5 Model Application Results

The ASHRAE and FEMP models are not notably different in their output if the same input data are used in the calculation, as shown in Chapter 4. Therefore, the data used in the life cycle cost analysis is important to the accuracy and precision of life cycle cost determinations. The accuracy and precision of input data was assessed based on both a compilation of computed sample data based on tables and references and a detailed survey of real hospitals in Texas. Evaluation of data sources available either in each model's literature or recommended (as in FEMP recommending MEANS construction data), were useful in checking forecasted input data against real world data. Real world costs are from four hospitals:

- Naval Hospital Corpus Christi, Corpus Christi, TX
- Darnall Army Medical Center, Killeen, TX
- Heart Hospital of Austin, Austin, TX
- Brooke Army Medical Center, San Antonio, TX

The form used in the survey is provided in Appendix E and the entire responses are provided in Appendix D. The data obtained from the four hospitals is in Table 15 alongside data from the example hospitals described in Chapter 4. Army (1994) was the only source of salvage costs and is included for reference and its initial cost data is proportional to the FEMP sample case, making an additional useful comparison point for those values. However, the Army (1994) salvage value data were based on a value of half the initial cost rather than any more substantial basis and thus cannot be assumed any more accurate than the sample values. The survey data from Brooke Army Medical Center do not include annual energy costs and life cycle costs for this facility were computed, but the available data from this facility were used in the individual data element analyses whenever possible. Brooke Army Medical Center was an order of magnitude larger than any of the other hospitals or data reference points and the inclusion of its information was helpful in expanding the range of square foot area values considered in the analysis.

Table 15 lists the combined data from the sample and real hospitals, which were used in the life cycle analysis that follows. The real hospital data did not have itemized costs for the HVAC system and the expected value of the initial cost was extracted from the whole building cost using the cost fractions listed in MEANS (1999) and were between 5.7 and 11 percent. The average of these two limits was used as the assumed initial cost of the HVAC system.

Table 15 – HVAC Cost Data from Samples and Real Hospitals

Values/Ranges	ASHRAE Sample	ASHRAE Sample	FEMP Sample	FEMP Sample	Army (1994)
Square Foot Basis	55,000	200,000	55,000	200,000	367,838
Administrative Costs	$9,200	$42,200			
Discount Rate	10%	10%	3%	3%	
OM&R	$52,600	$19,1000			
Replacement Costs	$739,000	$1,142,000			
Replacement Frequency	19-28 yr	19-28 yr			
Electric & Fuel Cost	$39,400	$231,000	$432,500	$1,548,500	
Initial Cost (2004 US$)	$739,000 (HVAC)	$1,142,000 (HVAC)	$739,000 (HVAC)	$1,142,000 (HVAC)	$2,490,000 (HVAC)
Residual value	$37,000	$57,000	$37,000	$57,000	($1,250,000)
Study Period	50 yrs	50 yrs	30 yrs	30 yrs	
Sustainment			$25,250	$47,500	

	Corpus Christi	Heart Hosp. of Austin	Brooke Army	Darnall Army
Square Foot Basis	221,292	140,000	3,500,000	504,202
Initial Cost (2004 $US)	$26,910,000 (Building)	$36,000,000 (Building)	$420,000,000 (Building)	$32,500,000 (Building)
HVAC Low (5.7%) Means	$1,530,000	$2,050,000	$23,940,000	$1,850,000
HVAC High (11%) Means	$2,960,000	$3,960,000	$46,200,000	$3,580,000
OM&R	$2,120,000	$6,000	$625,639	$2,377,000
Replacement Costs	$53,001,123 (Building)	Unknown	$420,000,000 (Building)	$76,000,000 (Building)
Replacement Frequency	15	10	25	25
Electric Cost	$8,216	$52,000	Unknown	$1,968,958
Fuel Cost	$1,000	$6,000	Unknown	$137,416
Residual value	Unknown	Unknown	Unknown	Unknown

5.1 Real Hospital Life Cycle Cost Computation

Life cycle cost computations using the real data in Appendix C and summary data are in Table 16. Figure 6 shows the side-by-side comparison of the life cycle costs depending on method. The FEMP 3% and ASHRAE 3% values show little difference between the two life cycle costing methods. Corpus Christi and Heart Hospital values differ by less than 3% and the Darnall Army Medical Center values differ by less than 8%. In addition, these differences fall well within the 10% expected tolerance of the highest level of cost estimate in Table 11, and therefore either model will provide the expected level of accuracy and precision for these estimates. This is important because the choice between the two life cycle cost models is immaterial. Thus, there is no reason to choose one model over the other in establishing life cycle costs.

Table 16 – NPV Life Cycle Costs of Real Hospitals' HVAC

LCC Model	**Discount Rate**	**Darnall Army Medical Center**	**Heart Hospital of Austin**	**Naval Hospital Corpus Christi**
ASHRAE	3%	$102.3 Million	$5.6 Million	$43.5 Million
ASHRAE	10%	$53.5 Million	$4.3 Million	$33.0 Million
FEMP	3%	$95.0 Million	$5.4 Million	$44.8 Million

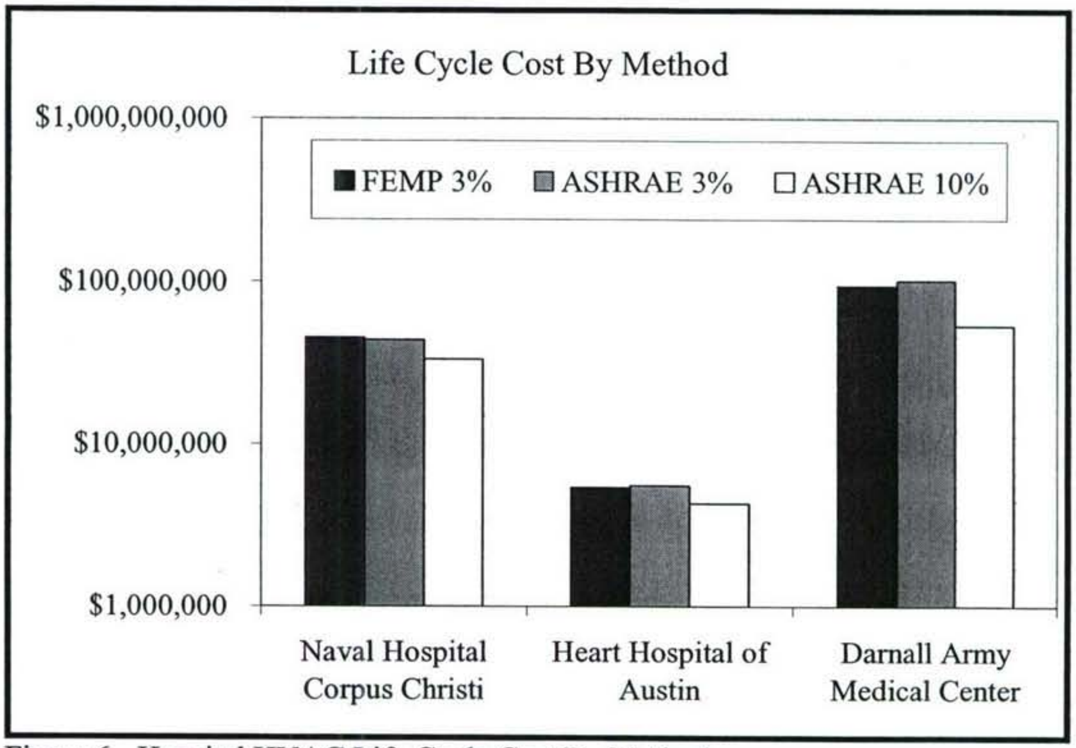

Figure 6 - Hospital HVAC Life Cycle Cost By Method

5.2 Data Source Analysis

Data sources will be an important factor in producing useful results with a model, but will not aid much in differentiating between models. Compilation of useful data for design and planning will be a function of time and resources available to owner organizations. The real world data and data obtained from references and tables were compared on a per square foot basis to allow for more appropriate comparisons in the following tables.

The data for actual initial cost shows a linear relationship on a log-log plot of cost versus square foot area in Figure 7. The use of log-log plotting is to allow the display of all the different hospitals and sample data on the same scale while retaining reasonable representations. This display of initial cost confirms the assumptions in the data attribute table, Table 12, that data for initial cost are well defined. In addition, the general agreement between estimates and actual data show that available data allow accurate estimates of initial cost. No linear regression or trend analysis was reasonable given the small number of data points available, however a weak proportional agreement is visible on the square foot comparison.

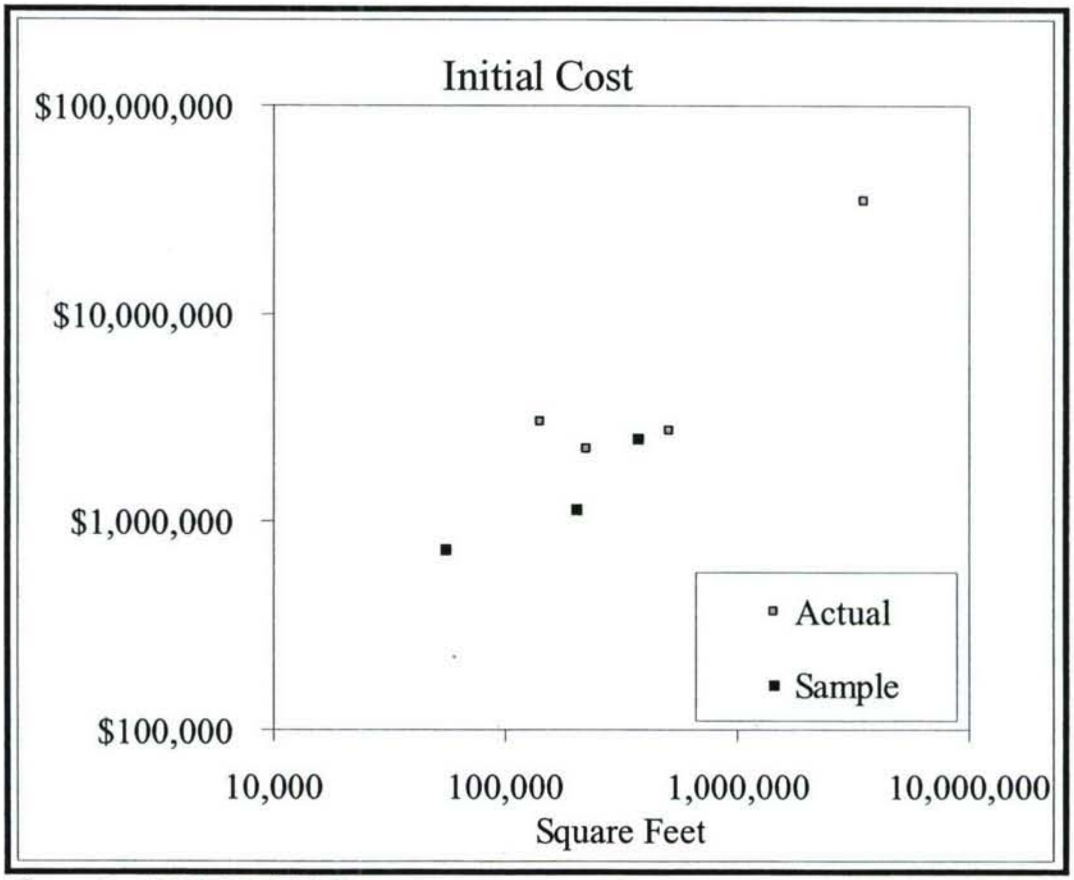

Figure 7 – HVAC Initial Cost Data

Salvage and residual value cannot be determined accurately until system demolition and removal. Only Army (1994) provided an actual value and assumed that removal costs are 50% of the initial costs. None of the real hospitals provided any data concerning salvage value or cost. Energy and fuel costs show the absence of a definite linear relationship on the log-log plot in Figure 8, reflecting many of the expected uncertainties in these costs.

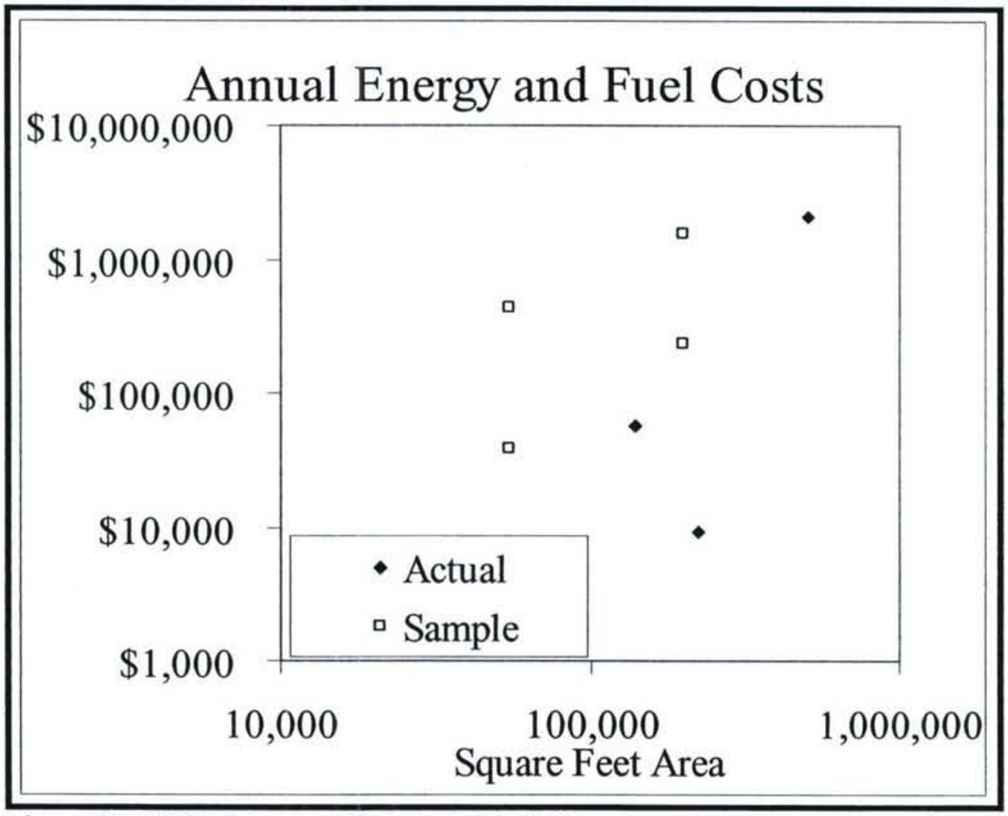

Figure 8 – HVAC Annual Energy & Fuel Cost

The choice of replacement period has little effect on life cycle cost, as shown in Chapter 4. Figure 9 shows the range of replacement periods used by different real facilities. All of the values represent owner choices based on perception of the expected life of each HVAC system. These data represent planning assumptions and expectations rather than actual replacement experience. Based on the sensitivity analysis in Chapter 4, this variability would have an important impact on the life cycle costs computed using the ASHRAE method.

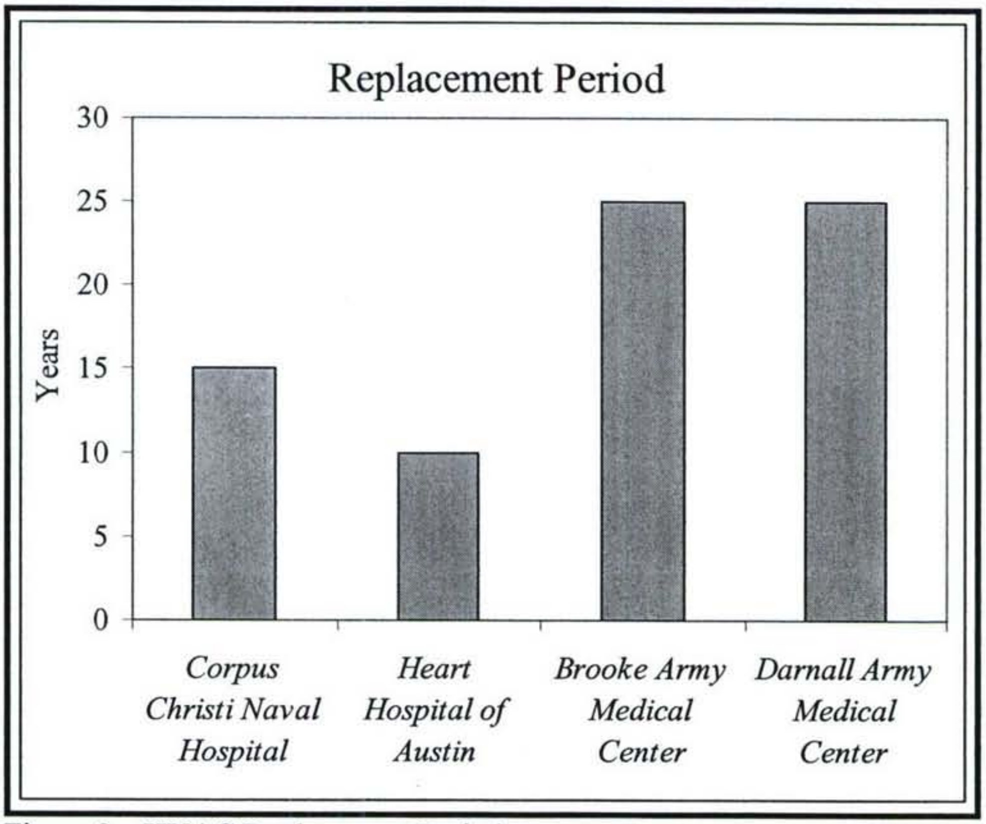

Figure 9 – HVAC Replacement Period

Operations maintenance and repair (called sustainment in DOD 2003) costs for the model samples and the actual hospitals had a no definable linear agreement on the log-log scale in Figure 10, reflecting that these data have significant variability that is not explained by changes in square foot floor area. Based on the sensitivity analysis in Chapter 4, this variability would have an important effect on the computation of life cycle cost in the ASHRAE model, and a weaker effect on the FEMP model. This sensitivity, combined with the poor quality of data available for the ASHRAE model as shown in Table 11 gives this data element an important negative impact to life cycle cost accuracy.

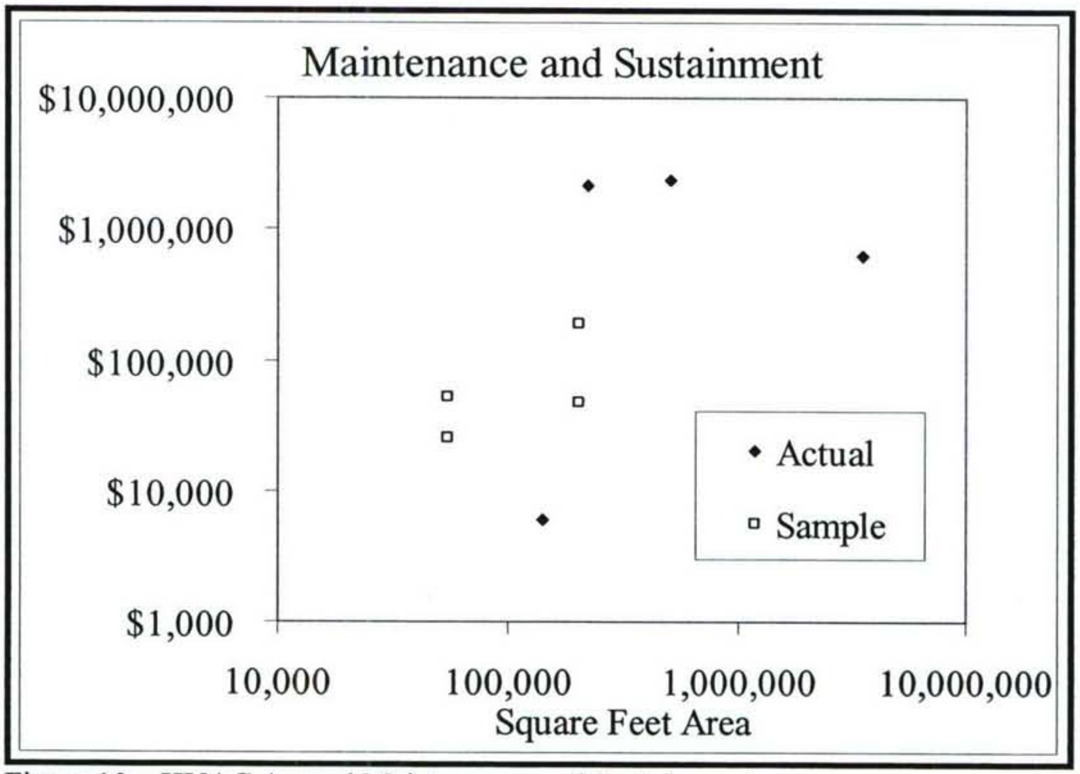

Figure 10 – HVAC Annual Maintenance and Sustainment

6 Conclusions and Recommendations

The most important variables to address for improving the quality of life cycle cost analysis are discount rate, maintenance costs, and electric & fuel costs with replacement frequency and study period also having important effects. These elements all relate to the future cost of operating and maintaining the system and reflect the expected importance of future costs to life cycle cost shown in Figure 1. Elements with poor data availability such as administrative, replacement, salvage, and sustainment costs are not sensitive elements in the models and better information is not valuable for these items since they are already within the desired range for estimates. Replacement frequency is only of medium importance and depends on the design and operation of the system. Improved information on replacement frequency will not improve the life cycle cost computation significantly. Study period is an artificial representation of the analytical assumptions of the useful life of the system before complete replacement. Study period represents a choice based on assumptions and further data gathering will not improve the value of the analysis.

Table 17 shows all of the data elements and their importance relative to the models, their consistency, and the importance of improving information in each category. Both discount rate and study period are based only on the choices of the analyst and do not change based on design, construction, or operation of the system. Data that are not important for improving accuracy are administrative costs, replacement costs, initial costs, residual value, and sustainment. Any effort to improve the accuracy of life cycle costing should begin with those variables with both a strong influence on life cycle cost and a current low quality of available data.

Table 17 – Importance of HVAC Data Elements

Variable or Data Element	Chapter 4 ASHRAE Sensitivity	FEMP Sensitivity	Chapter 5 Consistency of Data	Chapter 6 Value of Better Information
Administrative Costs	Low		Not available	Low
Discount Rate	Very High		Choice	Very High
Maintenance	Medium		Low	High
Replacement Costs	Low		Low	Low
Replacement Frequency	Medium		Medium	Medium
Electric & Fuel	Medium	Very High	Low	High
Initial Cost	High	Low	High	Low
Residual value	Low	Low	Not Available	Low
Study Period	Low	High	Choice	Medium
Sustainment		Low	Low	Low

HVAC system operators do not track costs sufficiently to allow for cost assessment separate from the whole facility, specifically:

- There is no justification for choosing either the ASHRAE or FEMP life cycle cost model over the other. For the purposes of estimating costs at any practical level of detail, they produce identical results.

- Important cost elements are buried within aggregate costs. Initial costs for HVAC systems are hidden in single-sum construction contract amounts and are extracted only using rules of thumb such as percentage of total cost. Operating costs, utility, and fuel costs are for the whole facility based on utility billing. These aggregate costs need to be decomposed to extract HVAC costs. Separating component costs will allow better assessments of the life cycle costs of the HVAC systems. Specifically, separate cost tracking through utility sub-metering and detailed maintenance cost accounting will improve the ability to predict costs.
- Maintenance costs are typically tracked as the cost of a maintenance contract, accurately reflecting the market value of maintaining the systems. However, they do not reflect the actual cost of work performed.
- The hospitals surveyed do not track maintenance effectiveness and maintenance costs are not a consideration in design decisions.
- There is no urgent demand for HVAC Life Cycle Costing among the facilities managers surveyed, despite its significant impact on initial cost of a facility, cost of operations and maintenance, and its importance to occupants and their productivity. The only need is for initial planning estimates as mandated in Title 10, Code of Federal Regulations, for the federal (military) hospitals only.

The value of life cycle cost determinations to facility managers would be improved through the tracking and management of data , allowing for reasonably accurate values to be provided to decision makers. These improvements would require changes in several owner processes including cost accounting, utility usage tracking, maintenance management, and historical data tracking. These improvements would permit more informed business decisions with regards to HVAC systems.

Glossary

Acquisition

This is the process of gaining effective access to a needed facility or system for operational business use through construction, purchase, leasing, or other contractual arrangement.

Aggregate Costs

This is a cost representation that combines similar but separable costs into a single sum for purposes of evaluation.

Annualized Cost (Annual Value)

The time-equivalent value of past, present, or future cash flows expressed as an annual recurring uniform amount over the study period. FEMP (1996).

Base Year

This is the first year of the Study Period, generally the year in which the Life Cycle Cost Analysis is conducted. FEMP (1996).

Benchmark

A fixed value for a variable representing a point for comparison either obtained as a historical or time related base value or as the expected value based on an assessment of similar conditions elsewhere.

Calculated Quantity Variable

A variable affecting the objective function whose value is determined from mathematical operations on one or more other variables. O'Connor (2004).

Cost Accounting

The tracking of costs associated with a business enterprise based on categorization and attribution of costs to activities.

Cost of Perfect Data

The increased value to a decision maker that would be obtained if a given unknown variable's expected value or expected range could be better defined.

Decision Variable

A variable affecting the objective function whose value is defined based on a decision and is not random. O'Connor (2004).

Heating, Ventilation, And Air Conditioning Systems (HVAC)

Any mechanical system for the control of the air conditions inside a building, including heating, cooling, ventilation, mechanical, electrical, electronic, pneumatic, controls, and incidental structural systems (such as supports and ductwork).

Importance of Better Data

The added decision making benefit to be expected from improvements in accurate estimation of variable values.

Initial Cost (Initial Investment Costs)

This is the initial cost of design, engineering, purchase, and installation, exclusive of "Sunk Costs," all of which are assumed to occur as a lump sum at the beginning of the base year or phased in during the planning/construction period. FEMP (1996).

Life Cycle Cost (LCC)

The total discounted dollar costs of owning, operating, maintaining, and disposing of a building or building system over the appropriate study period. FEMP (1996)

Life Cycle Cost Analysis (LCCA)

A general approach to economic evaluation that encompasses several economic evaluation measures, including Life Cycle Cost (LCC), net benefits (NB) or net savings (NS), Savings-to-investment Ratio (SIR), and Adjusted Internal Rate of Return (AIRR), all of which take into account all dollar costs related to owning, operating, maintaining, and disposing of a project over the appropriate study period. FEMP (1996).

Like New

A material condition closely resembling the initial condition of a facility or system when new, achieved through continuous repair and maintenance of systems, finishes, and structures over its useful life.

Lump Sum Cost

A single cost presented for consideration, usually representing a combination of subordinate costs, for the purposes of bidding in a sealed bidding procedure.

Nominal Variable

A variable affecting the objective function whose value is typically a specific quantity. O'Connor (2004).

Objective Function

The mathematical representation of the basis for deciding between several compared options; examples are cost, return on investment, minimal risk, etc.

Owning Costs (Costs of Ownership)

All costs, exclusive of operating and maintenance costs, which are required to acquire and put a building or system into initial operational use.

Present Value (Present Worth)

This is the time-equivalent value of past, present, or future cash flows as of the beginning of the base year. FEMP (1996).

Procurement

Purchasing, arranging, or contracting for the provision of some product or service especially for a company, government, or other organization.

Salvage Value (Residual Value)

The estimated value, net of any disposal costs, of any building or building system removed or replaced during the study period, or remaining at the end of the study period, or recovered through resale or reuse at the end of the study period. FEMP (1996).

Sensitivity Analysis

This is the testing the outcome of an evaluation to changes in the values of one or more system parameters from the initially assumed values. FEMP (1996)

Single Payments

Unique payments made at a specific time.

State Variable

A variable affecting the objective function whose value is unknown or random. O'Connor (2004).

Study Period (Planning Horizon)

This is the length of the time covered by the economic evaluation. This includes both the planning/construction period and the service period. FEMP (1996).

Sub-Metering

This is the division of utility metering among the various subsystems of a building to allow more detailed accounting of usage.

Sustainment

These are the maintenance and repair activities necessary to keep a typical inventory of facilities in good working order over a 50-year service life. It includes regularly scheduled adjustments and inspections, preventive maintenance tasks, and emergency response and service calls for minor repairs. It also includes major repairs or replacement of facility components (usually accomplished by contract) that are expected to occur periodically throughout the facility life cycle. This work includes repairing and replacement of heating and cooling systems. (http://www.whitestoneresearch.com/fsm/).

Uncertainty

Describing the unknown value of a variable based on expected value and a range of variation to be expected. This concept is often expressed as a probability distribution.

Uniform Series of Payments

Repeated identical payments made at regular frequency.

Variability

This is a range of expected values for a variable encompassing all possible outcomes.

Appendices

A. Sample Data Computation References

Heating, cooling, and ventilation loads and costs.

Health care facilities (nearest category for Hospital) used an average of 2.65 times the average end energy use compared to average buildings. This factor was used to adjust the average east south central regional consumption of 24,400 BTU per square foot per year for Space Heat up to 64,800 BTU per square foot per year. Additionally, electric consumption for Space Heat was converted upward from 3,200 BTU per square foot per year to 8,480 BTU per square foot per year. In order to simplify comparisons, these were combined to give the total 73,280 BTU per square foot per year used in the table. Finally, the average fuel cost in the taller building was 1.51 times the smaller building, based on a comparison of average cost by height.

ASHRAE Cooling load was determined using the same formulas as heating, except with the use of electric costs for cooling. The electricity cost scales at a rate of 1.97 times higher than average to increase the tabulated data of 7,800 BTU per square foot per year to 15,420 BTU per square foot per year (or 4.518 kilowatt hours per square foot per year). In this case, the height factor is less significant than for heating, with the taller building being only 1.3 times the lower building, yielding 7.09 kilowatt hours per square foot per year. The differences between the Means and ASHRAE kilowatt-hours per year are over one order of magnitude.

ASHRAE (2003) ventilation energy load was determined using the same formulas as heating and cooling, except with the use of electric costs for ventilation, and the electricity scaling of 1.97 times higher than average was used again. 2,800 BTU per square foot per year scales to 5,516 BTU per square foot per year (or 1.616 kilowatt hours per square foot per year). In this case, the height factor is 2.13 times the lower building, yielding 3.44 k kilowatt-hours per square foot per year. Means (2002B) values used a ventilation requirement of five air changes per hour. Calculation of the Means ventilation energy required uses the power expenditure of a commercially available air handler, the Trane model TTB530CA00A, which has a fan power at 1000 CFM totaling 610 Watts, from Trane (2004).

Maintenance and Administration Costs

Annual HVAC maintenance costs range between 0.9% and 4.5% of system replacement value in manufacturing facilities. In addition, a stores inventory of .5%-1.9% of plant replacement value is listed, with inventory turns of 1-3 per year being common. This leads to an expected materials cost of .5%-5.7% of plant replacement value per year, from Rosaler (1998).

Thus, a reasonable range of annual HVAC maintenance and materials cost would be 1.4%-10.2% of plant replacement value. Using the HVAC initial cost for a 55,000 square foot hospital of $740,000, the annual maintenance cost should be $10,000 to $75,000, or between $0.19 per square foot and $1.37 per square foot. This data was used to establish a reasonable range for the ASHRAE (2003) and DoD (2003) data.

DoD (2003) hospital sustainment (maintenance, repair, and replacement required to maintain 'like-new' condition) costs are $5.09 per square foot per year. The area cost factor of 0.81 leads to total annual maintenance costs for the 3-story hospital of $229,559 per year and $834,760 per year for the 6-story hospital. HVAC Maintenance costs are assumed to be proportional to construction costs (11% and 5.7% of total) yielding $25,250 and $47,500, respectively. These costs were used only in the FEMP model, as ASHRAE has its own maintenance cost equation.

ASHRAE Maintenance cost equation

The ASHRAE (2003) maintenance cost equation was based on 1983 dollars and is shown in equation (1) below.

$$C = 0.338 + 0.0018(n) + h + c + d \qquad (1)$$

The inputs to equation (1) are C, which is the annual HVAC maintenance cost (dollars per square foot), n is age of the system in years (10 years), h is the heating system adjustment factor (.0077) , c is the cooling system adjustment factor (.1925), and d is the distribution system adjustment factor (-.0466). ASHRAE (2003) makes disclaimers about the age and accuracy of this cost model because of a failure to account for climate, location, facility type, etc. The two sample hospitals vary only in size as far as this model is concerned; a simplified equation for maintenance cost was formulated for the hospital samples. For the 3 story building, *C 3-story=$ 28,045* and for the 6 story building, *C 6-story= $101,980.*After correcting for inflation to 2004 using the Consumer Price Index (CPI) of 187.6 from US Department of Labor (2004) yields corrected maintenance costs for the three-story hospital of $52,600 and for the six story hospital $191,000. This maintenance cost is an order of magnitude smaller than the DoD (2003) data, but it does not include periodic replacements. In addition, it falls within the reasonable range determined using benchmark information from Rosaler (1998). However, the age correction is an interesting addition to the maintenance cost model, accounting for the expected increase in maintenance costs for older systems. In addition, administrative costs were estimated as a 10% overhead on maintenance and operating costs to permit the inclusion of this cost in the analysis, despite the lack of data.

B. *Sample Model Computation Tables Referenced In Text.*

Table 18: LCC for 3 Story Hospital – ASHRAE 10% Discount Rate

Year	Purchase	Annual Cost	Net Cash Flow	Net Present Value
0	$ 739,000		$ 739,000	$ 1,860,425
1		$ 101,000	$ 101,000	NPV per Square Foot
2		$ 101,000	$ 101,000	$ 34
3		$ 101,000	$ 101,000	Discount Rate
4		$ 101,000	$ 101,000	10%
5		$ 101,000	$ 101,000	Square Foot Floor Area
6		$ 101,000	$ 101,000	55,000
19	$ 408,000	$ 101,000	$ 509,000	
20	$ 195,000	$ 101,000	$ 296,000	
21		$ 101,000	$ 101,000	
28	$ 136,000	$ 101,000	$ 237,000	
29		$ 101,000	$ 101,000	
38	$ 408,000	$ 101,000	$ 509,000	
39		$ 101,000	$ 101,000	
40	$ 195,000	$ 101,000	$ 296,000	
41		$ 101,000	$ 101,000	
50	$ (37,000)	$ 101,000	$ 64,000	

Table 19: LCC for 6 Story Hospital – ASHRAE 10% Discount Rate

Year	Purchase	Annual Cost	Net Cash Flow	Net Present Value
0	$ 739,000		$ 739,000	$ 1,860,425
1		$ 101,000	$ 101,000	NPV per Square Foot
2		$ 101,000	$ 101,000	$ 34
3		$ 101,000	$ 101,000	Discount Rate
4		$ 101,000	$ 101,000	10%
5		$ 101,000	$ 101,000	Square Foot Floor Area
6		$ 101,000	$ 101,000	55,000
19	$ 408,000	$ 101,000	$ 509,000	
20	$ 195,000	$ 101,000	$ 296,000	
21		$ 101,000	$ 101,000	
28	$ 136,000	$ 101,000	$ 237,000	
29		$ 101,000	$ 101,000	
38	$ 408,000	$ 101,000	$ 509,000	
39		$ 101,000	$ 101,000	
40	$ 195,000	$ 101,000	$ 296,000	
41		$ 101,000	$ 101,000	
50	$ (37,000)	$ 101,000	$ 64,000	

Table 20: LCC forFor 6 Story Hospital – ASHRAE 10% Discount Rate

Year	Purchase	Annual Cost	Net Cash Flow	Net Present Value
0	$ 1,142,000		$ 1,142,000	**$ 5,893,253**
1		$ 464,000	$ 464,000	NPV per Square Foot
2		$ 464,000	$ 464,000	$ 29
3		$ 464,000	$ 464,000	Discount Rate
4		$ 464,000	$ 464,000	10%
5		$ 464,000	$ 464,000	Square Foot Floor Area
6		$ 464,000	$ 464,000	200,000
19	$ 337,000	$ 464,000	$ 801,000	
20	$ 309,000	$ 464,000	$ 773,000	
21		$ 464,000	$ 464,000	
28	$ 496,000	$ 464,000	$ 960,000	
29		$ 464,000	$ 464,000	
38	$ 337,000	$ 464,000	$ 801,000	
39		$ 464,000	$ 464,000	
40	$ 309,000	$ 464,000	$ 773,000	
41		$ 464,000	$ 464,000	
50	$ (57,000)	$ 464,000	$ 407,000	

Table 21: LCC For 3 Story Hospital – ASHRAE 3% Discount Rate

Year	Purchase	Annual Cost	Net Cash Flow	Net Present Value
0	$ 739,000		$ 739,000	$ 3,921,823
1		$ 101,000	$ 101,000	NPV per Square Foot
2		$ 101,000	$ 101,000	$ 71
3		$ 101,000	$ 101,000	Discount Rate
4		$ 101,000	$ 101,000	3%
5		$ 101,000	$ 101,000	Square Foot Floor Area
6		$ 101,000	$ 101,000	55,000
19	$ 408,000	$ 101,000	$ 509,000	
20	$ 195,000	$ 101,000	$ 296,000	
21		$ 101,000	$ 101,000	
28	$ 136,000	$ 101,000	$ 237,000	
29		$ 101,000	$ 101,000	
38	$ 408,000	$ 101,000	$ 509,000	
39		$ 101,000	$ 101,000	
40	$ 195,000	$ 101,000	$ 296,000	
41		$ 101,000	$ 101,000	
50	$ (37,000)	$ 101,000	$ 64,000	

Table 22: LCC for 6 Story Hospital – ASHRAE 3% Discount Rate

Year	Purchase	Annual Cost	Net Cash Flow	Net Present Value
0	$ 1,142,000		$ 1,142,000	**$ 13,851,998**
1		$ 464,000	$ 464,000	NPV per Square Foot
2		$ 464,000	$ 464,000	$ 69
3		$ 464,000	$ 464,000	Discount Rate
4		$ 464,000	$ 464,000	3%
5		$ 464,000	$ 464,000	Square Foot Floor Area
6		$ 464,000	$ 464,000	200,000
18		$ 464,000	$ 464,000	
19	$ 337,000	$ 464,000	$ 801,000	
20	$ 309,000	$ 464,000	$ 773,000	
27		$ 464,000	$ 464,000	
28	$ 496,000	$ 464,000	$ 960,000	
29		$ 464,000	$ 464,000	
38	$ 337,000	$ 464,000	$ 801,000	
39		$ 464,000	$ 464,000	
40	$ 309,000	$ 464,000	$ 773,000	
41		$ 464,000	$ 464,000	
50	$ (57,000)	$ 464,000	$ 407,000	

Table 23: LCC for 3 Story Hospital – ASHRAE Model With FEMP Data 3%

Year	Purchase	Annual Cost	Net Cash Flow	Net Present Value
0	$ 739,000		$ 739,000	**$ 12,508,360**
1		$ 457,750	$ 457,750	NPV per Square Foot
2		$ 457,750	$ 457,750	$ 227
3		$ 457,750	$ 457,750	Discount Rate
4		$ 457,750	$ 457,750	3%
5		$ 457,750	$ 457,750	Square Foot Floor Area
6		$ 457,750	$ 457,750	55,000
49		$ 457,750	$ 457,750	
50	$ (37,000)	$ 457,750	$ 420,750	

Table 24: LCC for 6 Story Hospital - ASHRAE Model With FEMP Data 3%

Year	Purchase	Annual Cost	Net Cash Flow	Net Present Value
0	$ 1,142,000		$ 1,142,000	**$ 42,193,701**
1		$ 1,596,000	$ 1,596,000	NPV per Square Foot
2		$ 1,596,000	$ 1,596,000	$ 211
3		$ 1,596,000	$ 1,596,000	Discount Rate
4		$ 1,596,000	$ 1,596,000	3%
5		$ 1,596,000	$ 1,596,000	Square Foot Floor Area
6		$ 1,596,000	$ 1,596,000	200,000
49		$ 1,596,000	$ 1,596,000	
50	$ (57,000)	$ 1,596,000	$ 1,539,000	

Table 25 - FEMP LCC Sensitivity – 3&6 Story Hospitals

Cost Items	Base Case Value	Initial Cost 10%	Initial Cost -10%	Residual 10%	Residual -10%
3 Story					
Initial Investment Cost	$ 739,000	$ 812,900	$ 665,100	$ 739,000	$ 739,000
Residual Value	$ 15,244	$ 15,244	$ 15,244	$ 16,768	$ 13,720
Fuel/Electric Cost	$ 9,181,975	$ 9,181,975	$ 9,181,975	$ 9,181,975	$ 9,181,975
Sustainment	$ 494,900	$ 494,900	$ 494,900	$ 494,900	$ 494,900
Total Life Cycle Cost	$ 10,431,119	$ 10,505,019	$ 10,357,219	$ 10,432,643	$ 10,429,595
	0.00%	0.71%	-0.71%	0.01%	-0.01%
6 Story					
Initial Investment Cost	$ 1,142,000	$ 1,256,200	$ 1,027,800	$ 1,142,000	$ 1,142,000
Residual Value	$ 23,484	$ 23,484	$ 23,484	$ 25,832	$ 21,136
Fuel/Electric Cost	$ 32,874,655	$ 32,874,655	$ 32,874,655	$ 32,874,655	$ 32,874,655
Sustainment	$ 931,000	$ 931,000	$ 931,000	$ 931,000	$ 931,000
Total Life Cycle Cost	$ 34,971,139	$ 35,085,339	$ 34,856,939	$ 34,973,487	$ 34,968,791
	0.00%	0.33%	-0.33%	0.01%	-0.01%

	Fuel/Electric 10%	Fuel/Electric -10%	Sustain 10%	Sustain -10%	Years -16%
3 Story					**(25 years)**
Initial Investment Cost	$ 739,000	$ 739,000	$ 739,000	$ 739,000	$ 739,000
Residual Value	$ 15,244	$ 15,244	$ 15,244	$ 15,244	$ 17,686
Fuel/Electric Cost	$ 10,100,173	$ 8,263,778	$ 9,181,975	$ 9,181,975	$ 8,464,025
Sustainment	$ 494,900	$ 494,900	$ 544,390	$ 445,410	$ 439,603
Total Life Cycle Cost	$ 11,349,317	$ 9,512,922	$ 10,480,609	$ 10,381,629	$ 9,660,314
	8.80%	-8.80%	0.47%	-0.47%	-7.39%
6 Story					
Initial Investment Cost	$ 1,142,000	$ 1,142,000	$ 1,142,000	$ 1,142,000	$ 1,142,000
Residual Value	$ 23,484	$ 23,484	$ 23,484	$ 23,484	$ 27,246
Fuel/Electric Cost	$ 36,162,121	$ 29,587,190	$ 32,874,655	$ 32,874,655	$ 30,304,145
Sustainment	$ 931,000	$ 931,000	$ 1,024,100	$ 837,900	$ 826,975
Total Life Cycle Cost	$ 38,258,605	$ 31,683,674	$ 35,064,239	$ 34,878,039	$ 32,300,366
	9.40%	-9.40%	0.27%	-0.27%	-7.64%

C. Real Hospital LCC Computations

ASHRAE Model

Table 26: LCC for Naval Hospital Corpus Christi 3%

Year	Purchase	Annual Cost	Net Cash Flow	Net Present Value	
0	$ 23,000,000		$ 23,000,000	**$ 43,475,206**	
1		$ 1,068,802	$ 1,068,802	NPV per Square Foot	
2		$ 1,068,802	$ 1,068,802	$ 196	
3		$ 1,068,802	$ 1,068,802	Discount Rate	
4		$ 1,068,802	$ 1,068,802	3%	
5		$ 1,068,802	$ 1,068,802	Square Foot Floor Area	
6		$ 1,068,802	$ 1,068,802	221,292	
7		$ 1,068,802	$ 1,068,802	Replacement value	$ 53,000,000
8		$ 1,068,802	$ 1,068,802	Annual Costs	
9		$ 1,068,802	$ 1,068,802	Energy	$ 8,802
10		$ 1,068,802	$ 1,068,802	Maintenance (est.)	2.00%
11		$ 1,068,802	$ 1,068,802	Annual Maintenance Cost	$ 1,060,000
12		$ 1,068,802	$ 1,068,802	Annual Costs	$ 1,068,802
13		$ 1,068,802	$ 1,068,802	Annual Costs/SF	$ 4.83
29		$ 1,068,802	$ 1,068,802		
30	$ (1,150,000)	$ 1,068,802	$ (81,198)		

Table 27: LCC for Darnall Army Medical Center 3%

Year	Purchase	Annual Cost	Net Cash Flow	Net Present Value	
0	$ 8,360,000		$ 8,360,000	**$ 102,303,583**	
1		$ 4,792,932	$ 4,792,932	NPV per Square Foot	
2		$ 4,792,932	$ 4,792,932	$ 203	
3		$ 4,792,932	$ 4,792,932	Discount Rate	
4		$ 4,792,932	$ 4,792,932	3%	
5		$ 4,792,932	$ 4,792,932	Square Foot Floor Area	
6		$ 4,792,932	$ 4,792,932	504,202	
7		$ 4,792,932	$ 4,792,932	Replacement value	$ 76,000,000
8		$ 4,792,932	$ 4,792,932	Estimated HVAC Fraction	11%
9		$ 4,792,932	$ 4,792,932	HVAC replacement Value	$ 8,360,000
10		$ 4,792,932	$ 4,792,932		
11		$ 4,792,932	$ 4,792,932	Annual Energy Cost	$ 2,142,932
12		$ 4,792,932	$ 4,792,932		
13		$ 4,792,932	$ 4,792,932	Annual Maintenance Cost	$ 2,650,000
14		$ 4,792,932	$ 4,792,932	Annual Costs	$ 4,792,932
15		$ 4,792,932	$ 4,792,932	Annual Costs/SF	$ 9.51
16		$ 4,792,932	$ 4,792,932	Salvage Value	$ 0
17		$ 4,792,932	$ 4,792,932		
18		$ 4,792,932	$ 4,792,932	Note: Energy costs includes total electricity,	
19		$ 4,792,932	$ 4,792,932	not just for HVAC, inflating the HVAC cost	
20		$ 4,792,932	$ 4,792,932	considerably.	
29		$ 4,792,932	$ 4,792,932		
30	$ 0	$ 4,792,932	$ 4,792,932		

Table 28: LCC for Heart Hospital of Austin 3%

Year	Purchase	Annual Cost	Net Cash Flow	Net Present Value	
0	$ 3,300,000		$ 3,300,000	**$ 5,553,711**	
1		$ 64,000	$ 64,000	NPV per Square Foot	
2		$ 64,000	$ 64,000	$ 40	
3		$ 64,000	$ 64,000	Discount Rate	
4		$ 64,000	$ 64,000	3%	
5		$ 64,000	$ 64,000	Square Foot Floor Area	
6		$ 64,000	$ 64,000	140,000	
7		$ 64,000	$ 64,000	Initial Cost	$ 30,000,000
8		$ 64,000	$ 64,000	Estimated HVAC Fraction	11%
9		$ 64,000	$ 64,000	Est. Initial HVAC Cost	$ 3,300,000
10	$ 770,000	$ 64,000	$ 834,000		
11		$ 64,000	$ 64,000	Annual Energy Cost	$ 58,000
12		$ 64,000	$ 64,000		
13		$ 64,000	$ 64,000	Annual Maintenance Cost	$ 6,000
14		$ 64,000	$ 64,000	Annual Costs	$ 64,000
15		$ 64,000	$ 64,000	Annual Costs/SF	$ 0.46
16		$ 64,000	$ 64,000	Salvage Value	$ 0
17		$ 64,000	$ 64,000		
18		$ 64,000	$ 64,000		
19		$ 64,000	$ 64,000	Replacement Value	
20	$ 770,000	$ 64,000	$ 834,000	Compressors	$ 210,000
21		$ 64,000	$ 64,000	Cooling Towers	$ 540,000
22		$ 64,000	$ 64,000	Boiler	$ 20,000
23		$ 64,000	$ 64,000	Total major components	$ 770,000
24		$ 64,000	$ 64,000		
25		$ 64,000	$ 64,000	Note: Energy costs includes total electricity,	
26		$ 64,000	$ 64,000	not just for HVAC, inflating the HVAC cost	
27		$ 64,000	$ 64,000	considerably.	
28		$ 64,000	$ 64,000		
29		$ 64,000	$ 64,000		
30	$ 0	$ 64,000	$ 64,000		

Table 29: LCC for Naval Hospital Corpus Christi 10%

Year	Purchase	Annual Cost	Net Cash Flow	Net Present Value	
0	$ 23,000,000		$ 23,000,000	**$ 33,009,600**	
1		$ 1,068,802	$ 1,068,802	NPV per Square Foot	
2		$ 1,068,802	$ 1,068,802	$ 149	
3		$ 1,068,802	$ 1,068,802	Discount Rate	
4		$ 1,068,802	$ 1,068,802	10%	
5		$ 1,068,802	$ 1,068,802	Square Foot Floor Area	
6		$ 1,068,802	$ 1,068,802	221,292	
7		$ 1,068,802	$ 1,068,802	Replacement value	$ 53,000,000
8		$ 1,068,802	$ 1,068,802	Annual Costs	
9		$ 1,068,802	$ 1,068,802	Energy	$ 8,802
10		$ 1,068,802	$ 1,068,802	Maintenance (est.)	2.00%
11		$ 1,068,802	$ 1,068,802	Annual Maintenance Cost	$ 1,060,000
12		$ 1,068,802	$ 1,068,802	Annual Costs	$ 1,068,802
13		$ 1,068,802	$ 1,068,802	Annual Costs/SF	$ 4.83
29		$ 1,068,802	$ 1,068,802		
30	$ (1,150,000)	$ 1,068,802	$ (81,198)		

Table 30: LCC for Darnall Army Medical Center 10%

Year	Purchase	Annual Cost	Net Cash Flow	Net Present Value	
0	$ 8,360,000		$ 8,360,000	**$ 53,542,560**	
1		$ 4,792,932	$ 4,792,932	NPV per Square Foot	
2		$ 4,792,932	$ 4,792,932	$ 106	
3		$ 4,792,932	$ 4,792,932	Discount Rate	
4		$ 4,792,932	$ 4,792,932	10%	
5		$ 4,792,932	$ 4,792,932	Square Foot Floor Area	
6		$ 4,792,932	$ 4,792,932	504,202	
7		$ 4,792,932	$ 4,792,932	Replacement value	$ 76,000,000
8		$ 4,792,932	$ 4,792,932	Estimated HVAC Fraction	11%
9		$ 4,792,932	$ 4,792,932	HVAC replacement Value	$ 8,360,000
10		$ 4,792,932	$ 4,792,932		
11		$ 4,792,932	$ 4,792,932	Annual Energy Cost	$ 2,142,932
12		$ 4,792,932	$ 4,792,932		
13		$ 4,792,932	$ 4,792,932	Annual Maintenance Cost	$ 2,650,000
14		$ 4,792,932	$ 4,792,932	Annual Costs	$ 4,792,932
15		$ 4,792,932	$ 4,792,932	Annual Costs/SF	$ 9.51
16		$ 4,792,932	$ 4,792,932	Salvage Value	$ 0
17		$ 4,792,932	$ 4,792,932		
18		$ 4,792,932	$ 4,792,932	Note: Energy costs includes total electricity,	
19		$ 4,792,932	$ 4,792,932	not just for HVAC, inflating the HVAC cost	
20		$ 4,792,932	$ 4,792,932	considerably.	
29		$ 4,792,932	$ 4,792,932		
30	$ 0	$ 4,792,932	$ 4,792,932		

Table 31: LCC for Heart Hospital of Austin 10%

Year	Purchase	Annual Cost	Net Cash Flow	Net Present Value	
0	$ 3,300,000		$ 3,300,000	**$ 4,314,646**	
1		$ 64,000	$ 64,000	NPV per Square Foot	
2		$ 64,000	$ 64,000	$ 31	
3		$ 64,000	$ 64,000	Discount Rate	
4		$ 64,000	$ 64,000	10%	
5		$ 64,000	$ 64,000	Square Foot Floor Area	
6		$ 64,000	$ 64,000	140,000	
7		$ 64,000	$ 64,000	Initial Cost	$ 30,000,000
8		$ 64,000	$ 64,000	Estimated HVAC Fraction	11%
9		$ 64,000	$ 64,000	Est. Initial HVAC Cost	$ 3,300,000
10	$ 770,000	$ 64,000	$ 834,000		
11		$ 64,000	$ 64,000	Annual Energy Cost	$ 58,000
12		$ 64,000	$ 64,000		
13		$ 64,000	$ 64,000	Annual Maintenance Cost	$ 6,000
14		$ 64,000	$ 64,000	Annual Costs	$ 64,000
15		$ 64,000	$ 64,000	Annual Costs/SF	$ 0.46
16		$ 64,000	$ 64,000	Salvage Value	$ 0
17		$ 64,000	$ 64,000		
18		$ 64,000	$ 64,000		
19		$ 64,000	$ 64,000	Replacement Value	
20	$ 770,000	$ 64,000	$ 834,000	Compressors	$ 210,000
21		$ 64,000	$ 64,000	Cooling Towers	$ 540,000
22		$ 64,000	$ 64,000	Boiler	$ 20,000
23		$ 64,000	$ 64,000	Total major components	$ 770,000
24		$ 64,000	$ 64,000		
25		$ 64,000	$ 64,000	Note: Energy costs includes total electricity,	
26		$ 64,000	$ 64,000	not just for HVAC, inflating the HVAC cost	
27		$ 64,000	$ 64,000	considerably.	
28		$ 64,000	$ 64,000		
29		$ 64,000	$ 64,000		
30	$ 0	$ 64,000	$ 64,000		

FEMP Model

Table 32 - FEMP LCC Naval Hospital Corpus Christi

Cost Items	Base Date Cost	Year of Occurrence	Discount Factor (DOE 3%)	Present Value
Initial Investment Cost	$2,960,000	Initial	None needed	$2,960,000
Residual Value (5%)	$148,000	Year 30	0.412	$61,000
Fuel/Electric Cost	$9,216	Annually	21.23	$196,000
(Sustainment)	$2,120,000	Annually	19.60	$41,600,000
Total Life Cycle Cost				**$ 44,817,000** **$203/ ft^2**

Table 33 - FEMP LCC Heart Hospital of Austin

Cost Items	Base Date Cost	Year of Occurrence	Discount Factor	Present Value
Initial Investment Cost	$3,960,000	Initial	None needed	$3,960,000
Residual Value (5%)	$198,000	Year of Disposal (30)	0.412	$82,000
Fuel/Electric Cost	$59,000	Annually	21.23	$1,250,000
Sustainment	$6,000	Annually	19.60	$118,000
Total Life Cycle Cost				**$5,410,000** **$39/** ft^2

Table 34 - FEMP LCC Darnall Army Medical Center

Cost Items	Base Date Cost	Year of Occurrence	Discount Factor	Present Value
Initial Investment Cost	$3,580,000	Initial	None needed	$3,580,000
Residual Value (5%)	$179,000	Year of Disposal (30)	0.412	$74,000
Fuel/Electric Cost	$2,106,374	Annually	21.23	$44,720,000
Sustainment	$2,377,000	Annually	19.60	$46,590,000
Total Life Cycle Cost				**$94,964,000** **$188/** ft^2

D. Hospital Survey Response Data

Table 35- Response Data from Naval Hospital Corpus Christi

Date Survey Completed	26-Jul-04
Facility Name	**Naval Hospital Corpus Christi**
Facility Cost	$23,000,000
Year Built	1974
Facility Replacement Value	$53,001,123
Location of Facility (State/City)	Texas/Corpus Christi
ft^2 Floor Area	221,292
Height (Stories)	5
Owner/Agency	Navy, Bureau of Medicine
Operator/Tenant	Navy, Bureau of Medicine
Contact Name	Rudy Salazar
Contact Title	Head, Facilities Management Department
Contact Phone/E-mail	(361) 961-3103

B. Design Details of HVAC System

	Type	Make	Model	Quantity	Year Installed	Expected Life
Heating Source (ex. 55 MBTU oil fired boiler)	100 HP Gas-fired steam boiler	HURST		2		
Cooling Source (ex. 100 ton air-air chiller)	2 Water Cooled 650-ton Chillers	TRANE		2	1983	Near end of life
Ventilation/ Air Handling (ex. 1000 CFM Air Handlers with 200 VAV boxes)	AHU1- 17,210CFM AHU2-30,210CFM AHU3A -22,130 CFM AHU3B - 14,825 AHU4- 14,825CFM AHU5-36,235CFM AHU6 43,735CFM AHU7-35,840CFM AHU8-3,555CFM AHU 9 - 17,670CFM AHU 10 - 13,790CFM AHU 11- 29,290 CFM AHU 12- 6,895CFM AHU 13 - 1,500 CFM			14		15 Years

Controls System (zones, digital controls, manual controls, etc.)	AHU1- 4 zones AHU2-6 zones AHU3A -21 zone AHU3B - 3 zones AHU4- 2 zones AHU5-9 zones AHU6 7 zones AHU7-5 zones AHU8-1 zone AHU 9 - 7 zones AHU 10 - 6 zones AHU 11- 7 zones AHU 12- 4 zones AHU 13 - 1 zone	14	15 Years
HVAC year designed/ or Retrofit	Retrofit 1997		
Year of HVAC System Installation	1974		
Years of major HVAC work (if any)	1997		

Did you use LCC in the design of the HVAC system?	No
Who does life cycle costing or system planning functions?	Facilities Management
Who are the decision makers in the planning process?	Hospital Leadership Team, Regional Support Office, BUMED
Who defines the policies used in your organization?	Commanding Officer

	Annual Consumption	Units of Measure	Method for Estimate
Electricity	136,935	KWH	Reported by management
Natural Gas	1,428,572	CU FT	Reported by management
Water/Sewer	1,286,500	GALS	Reported by management
Maintenance Cost	$2,120,000	Annual	4% of replacement Value
Preventive- Periodic maintenance functions are performed on schedule.			

Table 36- Response Data from Heart Hospital of Austin

HOSPITAL HVAC LIFE CYCLE COSTING SURVEY 2004						
A. GENERAL INFORMATION						
Date Survey Completed				04 Aug 2004		
Facility Name				**Heart Hospital of Austin**		
Year Built				1998		
Facility Cost				$30,000,000		
Location of Facility (State/City)				Austin, Texas		
ft^2 Floor Area				140,000		
Height (Stories)				3		
Owner/Agency				Heart Hospital 4, LP		
Operator/Tenant				Heart Hospital 4, LP		
Contact Name				David Clemons		
Contact Title				Team Leader, Support Services		
Contact Phone/E-mail						
B. Design Details of HVAC System						
	Type	Make	Model	Quantity	Year Installed	Expected Life
Heating Source (ex. 55 MBTU oil fired boiler)	HW - Gas	HURST		2		
Cooling Source (ex. 100 ton air-air chiller)	300 Ton dual screw chiller	York		3	1997	
Ventilation/ Air Handling	110,000 CFM					
Initial Cost of HVAC System	Unknown					
HVAC System Replacement Cost	6@$35k Chiller Compressors	3 @ $180K Cooling Tower	1 @ $20K Segmented Boiler	(No other major components are itemized)		
HVAC year designed/ or Retrofit			1996			
Year of HVAC System Installation			1997			

Years of major HVAC work (if any)	None	
Frequency of Replacement of Major Components		10 Years
Other details of system components (Online spares, excess capacity, plans for expansion) Low Bid project, with lots of trouble – especially the compressors		
C. Life Cycle Costing Process		
Did you use LCC in the design of the HVAC system?	No	
Who does life cycle costing or system planning functions?	Contractor, using Manufacturer's Info	
Who are the decision makers in the planning process?	CEO with Support Services Team Leader Input (Direct Report)	
Are copies of any past LCC analyses available for review?	No	
E. Annual Utility, Fuel, Water, Etc Costs		
	Annual Consumption	Method for Estimate
Electricity	$52,000	Reported by management
Natural Gas	$6,000	Reported by management
Preventive Maintenance Contract	$6,000	Reported by management
Salvage Value	Scrap Only	Reported by management
Additional Maintenance Cost	0.25 man-year in house	Reported by management

Table 37- Response Data from Darnall Army Hospital

<table>
<tr><td colspan="6">HOSPITAL HVAC LIFE CYCLE COSTING SURVEY 2004</td></tr>
<tr><td colspan="6">A. GENERAL INFORMATION</td></tr>
<tr><td>Date Survey Completed</td><td colspan="5">09 Aug 2004</td></tr>
<tr><td>Facility Name</td><td colspan="5">Darnall Army Medical Center</td></tr>
<tr><td>Year Built</td><td colspan="5">1964</td></tr>
<tr><td>Facility Cost</td><td colspan="5">$5,368,000</td></tr>
<tr><td>Plant Replacement Value</td><td colspan="5">$76,000,000</td></tr>
<tr><td>Major Renovation 1987</td><td colspan="5">$41,320,403 (whole building)</td></tr>
<tr><td>Major Renovation 2004</td><td colspan="5">$12,000,000 added 40K ft^2</td></tr>
<tr><td>Major Renovation 2005</td><td colspan="5">$13,500,000 added 40K ft^2</td></tr>
<tr><td>Location of Facility (State/City)</td><td colspan="5">Ft. Hood, Texas (Adjacent to City of Killeen, TX)</td></tr>
<tr><td>ft^2 Floor Area</td><td colspan="5">504,202</td></tr>
<tr><td>Height (Stories)</td><td colspan="5">6</td></tr>
<tr><td>Owner/Agency</td><td colspan="5">US Department of Defense</td></tr>
<tr><td>Operator/Tenant</td><td colspan="5">Ft. Hood, US Army</td></tr>
<tr><td>Contact Name</td><td colspan="5">Chris Snodgrass</td></tr>
<tr><td>Contact Title</td><td colspan="5">Facilities Manager</td></tr>
<tr><td>Contact Phone/E-mail</td><td colspan="5">(254) 286-7313
christopher.snodgrass@cen.amed.army.mil</td></tr>
<tr><td colspan="6">B. Design Details of HVAC System</td></tr>
<tr><td></td><td>Type</td><td>Make</td><td>Model</td><td>Quantity</td><td>Year Installed</td></tr>
<tr><td>Heating Source (ex. 55 MBTU oil fired boiler)</td><td>10.3 MBTU Oil/Gas Boiler</td><td colspan="2"></td><td>1</td><td>~1995</td></tr>
<tr><td>Cooling Source (ex. 100 ton air-air chiller)</td><td>3@600 Ton 1@300 ton chillers</td><td colspan="2">3@600 cost $2.7M in 2001</td><td>3</td><td>2001</td></tr>
<tr><td>Ventilation/ Air Handling</td><td colspan="5">24 Air Handlers
18/24 cost $4.3 million to replace recently($6.45 for all)
Unknown Total Volume</td></tr>
<tr><td colspan="3">Initial Cost of HVAC System</td><td colspan="3">Unknown</td></tr>
<tr><td colspan="3">HVAC year designed/ or Retrofit</td><td colspan="3">2000</td></tr>
</table>

Year of HVAC System Installation	2001
Years of major HVAC work (if any)	2001

C. Life Cycle Costing Process

Did you use LCC in the design of the HVAC system?	No
Expected Replacement Frequency of HVAC	25 years

E. Annual Utility, Fuel, Water, Etc Costs

	Annual Consumption	Method for Estimate
Electricity	$1,968,958	2003 Actual
Natural Gas	$137,416	2003 Actual
Water	$36,558	2003 Actual
Sewage	$6,830	2003 Actual
Preventive Maintenance Contract	$2.65 Million (Includes $273K boiler operations)	2003 Actual
Salvage Value		
Additional Maintenance Cost		

G. Additional Information

Preventive- 75% PM, 25% work order (breakdown). Some IR and vibration testing used.

Table 38 - Brooke Army Medical Center Data

Facility Name	**Brooke Army Medical Center**
Date survey completed	20-Aug-04
Year Built	1992-96
Facility Cost	$350 Million
Facility Replacement Value (if tracked)	$420 Million
***Location of Facility (State/City)**	Fort Sam Houston, Texas
*** ft^2 floor area**	3.5 Million (Including IBS)
***Height (stories)**	Various - up to eight stories
Owner/Agency	US Government
Operator/Tenant	US Army Medical Command
Years of Major structural Renovations/additions	N/A
***Contact Name**	Mr. Roy Hirchak
***Contact Title**	Facility Engineer/Manager
***Contact Phone/email**	210-916-2551

B. Design Details of HVAC System	Type	Make	Model	Qty	Year Installed	Expected Life
Heating Source	Steam	Kewanee	H35-600-602	3	1992	25+ years
Cooling Source	Centrifugal	York	YKQ2Q18ZDBA	4	1992	25+ years
Ventilation /Air Handling	97 Units of Various Sizes	York	Various	Countless VAV Boxes	97	1992 to present
Controls System	Digital	York	Custom	1	1992	15 Years

***HVAC year designed/or Retrofit**	**1992-96**
***Year of HVAC System Installation**	**1992-96**
Years of major HVAC work (If Any)	1999 (York 5th Chiller, Model # YQHHHBJ2CBE)
Did you use LCC in the design of the HVAC system?	No

Who are the decision makers in the planning process?	Facilities Management
Who defines the policies used in your organization?	Dept of Army -- Army Corps of Engineers
Expected useful life in planning	25+ Years
On-Site Generation Of Electricity	Emergency Power Generation Only
Annual HVAC Maintenance costs by who performs the tasks.	$ 440K Assumes 8 FTE's working full time on the air handlers and the controls
In-House Maintenance Materials Expended annually	$124,134.00
Maintenance Materials Inventory value (consumables, spares, etc.)	$61,505.00
Breakdown - Maintenance is essentially through repair of noted discrepancies or failures.	**Yes**
Preventive - Periodic maintenance functions are performed on schedule.	**Yes**

E. *Data Collection Tool*

HOSPITAL HVAC LIFE CYCLE COSTING SURVEY 2004

Survey by: Christopher Krus, PE — *Lieutenant Commander, Civil Engineer Corps, U. S. Navy*

Graduate Student Research Project — *Construction Engineering and Project Management*

Requested Completion Date: Friday July 30, 2004

Contact Information: c_krus@mail.utexas.edu

The University of Texas at Austin — (847) 571-7589

Christopher Krus — (E-mail response is preferred)

Civil Engineering - (CEPM)

This information is requested to allow follow on data to be correlated between facilities, as well as to evaluate data against benchmarks, rules of thumb, and published standard values; to allow for improvements in facilities management processes, especially in the public sector.

Items in Red (also *) are Necessary for useful analysis, all other information is for supporting more detailed computations and background understanding of HVAC system and local processes.

Target: Facilities Managers, Facilities Engineers, Maintenance Managers tasked with the design, construction, maintenance and operation of HVAC systems in Hospitals.

A. General Information

Date survey completed			
Facility Name			
Year Built			
Facility Cost			
Facility Replacement Value (if tracked)			
***Location of Facility (State/City)**			
***SF floor area**			
***Height (stories)**			
Owner/Agency			
Operator/Tenant			
Years of Major structural Renovations/additions			
***Contact Name**			
***Contact Title**			
***Contact Phone/email**			
Additional Contact and Facility Information:			

B. Design Details of HVAC System	Type	Make	Model	Replacement or Initial Cost	Qty	Year Installed
Heating Source (ex. 55MBTU oil fired boiler)						
Cooling Source (ex. 100 ton air-air chiller)						
Ventilation/Air Handling (ex. 5 @ 1000 CFM Air Handlers with 200 VAV boxes)						
Controls System (zones, digital controls, manual controls, etc.)						
***Initial Cost of HVAC System**						
***HVAC year designed/or Retrofit**						
***Year of HVAC System Installation**						
Years of major HVAC work (If Any)						
% of Total Facility Cost						
Other details of system components (Online spares, excess capacity, plans for expansion)						

C. LIFE CYCLE COSTING PROCESS		
Did you use LCC in the design of the HVAC system?		
Method used for LCC? (ASHRAE, FEMP, Other?)		
***Discount rate used on LCC**		
Source of Economic Information Used (DOE, OMB, Other?)		
***Inflation rate assumed (if any)**		
Other LCC assumptions (if any)		
Who does life cycle costing or system planning functions?		
Who are the decision makers in the planning process?		
Who defines the policies used in your organization?		
Are copies of any past LCC analyses available for review? (either straight estimates or option comparisons)		*PLEASE PROVIDE IF AVAILABLE*

D. Other Operating Details ($ cost per year)			
Taxes, permits, or fees related to HVAC (EPA, local, etc.)			
Property Taxes (Value of HVAC improvements, such as chiller buildings, etc.)			
Insurance on HVAC (liability, casualty, or other)		*May be a portion of overall building insurance, with fraction base or replacement value? (It is possible that this value is not tracked*	
Rent on HVAC equipment (portable chillers/boilers)			
Depreciation method (if any)			
Expected useful life in planning			
Other Periodic Costs of HVAC system			
***Total Periodic Costs (ANNUAL)**			*Sum of above values*
***Replacement Cost (if tracked)**			
***Frequency of replacement of entire system or major components**		*Add additional comments as necessary to clarify.*	
***Salvage Value (if tracked/estimated)**			
Additional Comments:			

E. Annual Utility, Fuel, Water, Etc Costs	Price per Unit	Annual Consumption	Units of measure	Method for Estimate	
Other Utilities					Electrical F Factor
Electricity					
Natural Gas					
Water/Sewer					
Purchased Steam					
Purchased Hot/Chilled Water					
Propane					
Fuel Oil					
Diesel					
Coal					
Other Fuels Cost					
On-Site Generation Of Electricity					
Other Utility, Fuel, Water, Etc. Costs					
***TOTAL HVAC FUEL & UTILITY COSTS (ANNUAL)**					

F. Annual Maintenance Allowances/Costs	In House (labor only)	Contract (all)	Mix
Annual HVAC Maintenance costs by who performs the tasks.			
In-House Maintenance Materials Expended annually		*assumes that contract maintenance would incude these amounts.*	
Maintenance Materials Inventory value (consumables, spares, etc.)			
In-House Maintenance Equipment Inventory Value (including digital data systems and diagnostic equipment, vehicles and other durable assets.		*assumes that contract maintenance would incude these amounts.*	
In-House Maintenance Equipment Operating costs		*assumes that contract maintenance would incude these amounts.*	
Other Maintenance Allowances/Costs			
Annual Admin/Mgmt Costs related to HVAC			
***Total Annual Maintenance Allowances/Costs**			
Specify breakdown of maintenance tasks if any: (.ie. Repair - in house, Filters - contract)			

G. Additional Information

Which of the following best describes overall maintenance practices:

Breakdown - Maintenance is essentially through repair of noted discrepancies or failures.	
Preventive - Periodic maintenance functions are performed on schedule.	
Predictive/Analytical - Maintenance is performed based on measuring performance factors to detect trends, such as increasing vibration, noise , pressure losses, or other gradual degradation.	
Proactive - systems are designed/repaired to effectively eliminate failure modes and failure prone components, engineering out performance problems.	

Other notes on HVAC system maintenance and operation:	
Extra space for comments:	

H. Evaluate this Survey:

Things to Change Δ	
Things to Add +	

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VITA

Christopher James Krus was born in New York, New York in October 1970. After completing his work at Mineola High School, Garden City Park, New York, in 1988, he entered the University of Virginia in Charlottesville, Virginia. He received the degree of Bachelor of Science in Aerospace Engineering from the University of Virginia in May 1993 and a commission in the United States Navy. He earned his Naval Flight Officer wings in 1995 and reported to Fleet Air Reconnaissance Squadron ONE at Naval Air Station Whidbey Island, Washington, in January 1996. He earned qualifications as an electronic warfare office, navigator, and senior evaluator, and accumulated over 1700 flight hours. In 1999, he reported to the staff of Joint Forces Command in Norfolk, Virginia. He transferred into the Navy's Civil Engineer Corps and completed the civil engineer basic course in May 2000. In May 2000, he reported to Engineering Field Activity Midwest in Great Lakes, Illinois, as assistant resident officer in charge of construction, where he managed construction projects and earned the Contracting Officer qualification. In May 2002, he reported to Public Works Center Great Lakes in Great Lakes, Illinois, as deputy production officer where he managed personnel and operations in maintenance, utilities, material, and transportation. In August 2003, he received the degree Master of Engineering in Mechanical and Aerospace Engineering from the University of Virginia. In January 2004, he earned his Professional Engineer license from the State of Illinois. In January 2004, he entered The Graduate School at the University of Texas at Austin.

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