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Life Cycle Assessment of Building Projects

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Course Content

INTRODUCTION

Investment in a building project entails significant capital investment and associated costs over the economic life of the project. It is a mistaken notion that the buildings costs have to be expensed once. The buildings like any other industry have running expenses in a way that they consume lot of energy and require water & disposal facilities that accounts for significant recurring costs. The security provisions, state taxation, administration expenses and insurance premiums are other indirect cost elements. All costs which may occur at various times such as first cost, installation costs, maintenance costs, replacement costs and any miscellaneous expenditure should also be treated as any other capital investment.

Bringing all of these costs, which occur at different times, to a common point in time, allows for selecting the right alterative to the cost effective building and maximizing its value. The principle underlying all types of investment is the net return expected from the proposed investment. This net return must be evaluated and compared with the overall investment in the project. An economic technique used to compare various design alternatives by projecting (discounting or compounding) associated costs over the economic life of the project is known as "Life Cycle Analysis (LCC)".

There are separate methods of analysis for

a) Projects, which do not involve major capital investment such as small residential, shopping & office blocks
b) Projects involving major capital investments such as hospitals, airports, hotels and big commercial complexes.

In the first case, simple payback period analysis is sufficient while in the second case, more detailed methods of analysis are required.

What contributes to the building cost?

Each building is different. The building designs, types and materials will vary per the applications, usage requirements, environment, local culture, local codes, capital costs and the whims and fancies of the owner. The owner shall always be interested to get best out of his money and shall be concerned for reducing costs and maximizing value. The facilities provided in the buildings may have a very significant influence on costs.

The principle elements of direct capital costs to the building projects could be contributed to:

1. Common civil engineering parameters such as- architectural design, configuration, bay sizes, structural loads, flatness & tolerance rating of slabs, clear interior height, single v/s multistoried structure, concrete v/s steel structure, building materials etc
2. Requirements for cooling, heating and air-conditioning
3. Requirements for safety and fire protection systems
4. Requirements for water supply and disposal systems
5. Requirement for the security systems
6. Requirement of electrical distribution

7. Requirement of telecommunication and control distribution
8. Requirement of acoustics and sound insulation
9. Plant room spaces, location of utility equipments
10. Quality of facade materials and roofing
11. Extent of glazing and lighting through roofs and walls

Costs can often be influenced by the owner's/company's insurers and risk managers. The tragedy of September 11 has heightened awareness of the need to consider security risks. This has resulted in significant growth in insurance premiums. The buildings well equipped with the advanced security surveillance systems shall demand low premium.

Cultural leaning will influence costs. Other than the architectural aspects, in US, buildings are considered more disposable, whereas in Europe the tendency is towards greater flexibility. Europeans prefer the buildings to be column free or at least they use longer spans than typical in the US. Floor slabs in Europe are also often thicker than the US, to allow greater flexibility in floor loading.

The environmental factors such as scarcity of water shall demand the use of air-cooled air-conditioning systems. For instance in Middle East environment the most of the HVAC applications run on air-cooled refrigeration machines.

The local codes having jurisdiction have influence on the building costs. The requirements are different state to state and in one country to the other. For instance, while in Europe, it may not be mandatory to provide fire sprinkler system up to 4 storied structure whereas in US the codes requirements insist on the these provisions.

The course here with shall provide a generic reading on the life cycle costing aspects with an eye to mechanical stream and air-conditioning.

FUNDAMENTAL TERMINOLOGY & CONEPTS

What is Life Cycle Assessment?

Life Cycle Assessment (LCA) or simply the life cycle analysis is a method, which allows owners, agencies, engineers, or any competent person to evaluate different alternatives of infrastructure or building projects. This analysis method is based on the estimated or calculated costs of each alternative over its design life. LCA identifies the economic, environmental, design, performance, cultural and legal consequences of a product or facility through its entire life cycle. The LCA information is beneficial because it compares initial capital costs to ownership and maintenance costs over a specified lifetime.

Why Use Life Cycle Assessment?

The LCA provides the basis to accept or reject different options to facilitate management decisions. With the strong trend in the Heating, ventilation and Air-conditioning (HVAC) industry emphasizing energy savings, there is an equally a concern from the owners & operators that the installed costs of new and replacement systems be as economical as possible. In applying this concept to the buildings, the designer and owner should consider not only the initial (first) costs but also the maintenance costs, rehabilitation costs, user costs, and reconstruction costs. The designer must also make sure that the different cost effective building alternatives are considered for maximizing value.

Initial cost + Energy + Maintenance/Repair + Replacement/Modernization – Salvage/Resale = Total cost

Where Life Cycle Assessment could be applied?

The building cost is influenced by each discipline, be it the civil, mechanical or the electrical. Technically the LCA could be performed to each and every aspects of the building, but it may not be worth to do so. For some cases a simple payback analysis or return on investment analysis may suffice but for larger cost contributing elements, the management could decide for the LCA. Each functional discipline shall perform the cost analysis to their specific areas.

Many a times, the use of specialized technology may have an increased cost impact to one discipline but that could be advantages to the other discipline. For instance providing high quality heat resistant glazing facade to the building outdoors and/or using energy efficient lighting indoor shall reduce the demand on air-conditioning. Higher capital expenses to the civil and electrical discipline shall be offset by reduced capital cost on the air-conditioning plant. It shall also result in lowering the recurring energy utility in future due to downsized air-conditioning plant.

It is important to co-ordinate with inter-disciplines to check the overall economics. Say in above example, if the electrical discipline also performs the LCA for providing the energy efficient lighting, which comes out negative, it shall suggest against using this alternative. But if the same thing is re-looked along with the savings to the air-conditioning system, it may turn out to be positive.

- An LCA could be applied to every engineering discipline associated with building design & construction. LCA shall be helpful in determining whether a building with a higher initial capital cost would save money in the future because of improved durability of decreased operating & maintenance (O&M) costs. A balance though has to be arrived at before detailing any project to reduce overall energy consumption and sacrificing installed first-cost savings.
- LCA might be applied to check the very decision itself to whether at all to go for a new project or other alternatives such as leasing may be the best option.
- LCA could be applied to the direct costs of a building such as energy and water costs, building renewal and replacement, and operation and maintenance (O & M) costs.
- LCA could be applied to the indirect costs such as salaries, budget allocation, productivity, cost of time, insurance, downtime etc that are not directly related to cost of the building.
- LCA shall be useful for comparison of long-term costs such as cleaning, maintenance and replacement with short-term costs that include the initial capital cost of the building itself.

In essence the LCA can be applied to every function. Refer to the drawbacks beneath for understanding limitations.

How Is Life Assessment Done?

The concept of money having a time value is fundamental to understanding any economic or financial analysis of investments. Money has a time value since it can be invested at some particular interest rate and will grow in value over time. This is technically called the “Present Value” analysis that uses the discounting technique.

But before going into the mathematical or accounting aspects of LCA, let's understand the sequence of events.

Define Core Area: The core area has to be defined first. This focuses on the element of the building that account for the significant initial capital and/or recurring cost. During the start of project, a preliminary costing is determined. The break up is analyzed to check the potential elements that have significant influence on the first and the recurring costs. For instance the mechanical air-conditioning is one area that has significant first and the recurring cost. Larger the project, bigger is the cost saving potential and more is the need for detailed LCA to justify the selection of right system.

Select Alternatives: involves identification of possible technologies alternatives and system configuration. There may be several ways or alternatives to handle a design aspect. The type of alternatives may arise from the experience; lesson learnt on past projects, success stories of other projects, historical information, manufacturer's recommendations etc. It is always beneficial to discuss the ideas and alternatives among the project team members drawn from a wide range of backgrounds, perspectives and past experiences.

For example a building demanding roughly 1800-ton air-conditioning plant could have following alternatives.

1. ***A single unit of 1800 ton, 2 x 900 ton machines, 3 x 600 ton machines…***

   A continuous duty operation without much variation in the heat duty conditions may opt for 2 x 900 ton where as for the situations where the air-conditioning system is operated mostly on part load (lesser than the installed capacity) shall opt for 3 x 600 ton machine. A single unit shall be avoided, as it does not provide flexibility and redundancy even though the initial investment shall be low.

2. ***Vapor compression machine v/s Absorption technology:***

   Absorption technology may be cost effective in the industrial plants where there is a scope of tapping waste heat or where the fuel is cheaper than using electricity.

3. ***Centrifugal machines v/s Screw machines v/s Reciprocating machines:***

   Screw chiller may be most advantageous up to 750 tons and beyond this centrifugal machine may be more economical. Reciprocating machines may be used for below 100-ton capacity.

4. ***Water cooled v/s Air cooled Machines:***

   Air-cooled machines shall be more economical for the smaller plant configurations up to 200 ton and where water is scarce.

5. ***Type of cooling tower alternatives:***

The type of cooling tower, materials of construction etc. influence cost. Detailed breakup is provided in the sections below.

6. ***The condenser temperature range to reduce piping costs:***

Higher is the temperature differential across the condenser, lower shall be the flow and hence lower shall be the pipe sizes, pumps and cooling tower sizes. The initial cost of condenser shall be high on high temperature ranges, but it shall offset by reduction elsewhere. The plus point is that the cost to operate shall be significantly lower due to downsized pumps and cooling tower.

7. ***The low temperature air distribution system:***

Lower is the supply air distribution, smaller shall be the air-handling equipment and lower shall be the ducting and insulation requirement.

8. ***Providing advanced Building management systems (BMS):***

The BMS other than providing monitoring and security surveillance functions are beneficial in optimum utilization of energy. A high initial capital on the BMS system is usually having a payback of 3 to 4 years, when optimally utilized.

Assess costs: The above alternatives could be analyzed for capital costs (CAPEX), operating costs (OPEX) or the life cycle analysis (LCA). CAPEX are the non-recurring costs that appear as lump sum cost in the present or at the fixed point in the future. The capital cost could also be spread out over periodic payments. OPEX are the recurring costs that are paid out periodically over the lifetime of the facility. The OPEX costs occur on a regular basis and include the utility (electricity + fuel) bills, repair & replacement costs. Benefits are accounted for as negative costs. For example, energy savings arising from a high-energy efficient chiller are considered negative costs.

Net present value: To evaluate the alternatives, all the costs and benefits have to be normalized to common platform of ‘present value of money’. Bringing all of these costs, which occur at different times, to a common point in time, allows the analyst to compare various design alternatives and select the alternative with the lowest total cost. The principle underlying all types of investment is the net return expected from the proposed investment. This net return must be evaluated and compared with the overall investment in the project. To accomplish this, the costs and benefits are converted to either present value or annual value. Once the costs and benefits have been normalized, a comparison is performed by summing the costs and benefits to arrive at a total cost.

Select Alternative: The results from the present value computation are analyzed to facilitate management decisions. A positive net present value indicates an accepted project. A negative NPV indicates that a project should not be considered. However, other criteria might include the reliability factors, risk minimization, timely implementation, company's policies, client preferences and other intangibles

PRINCIPLES OF TOTAL LIFE CYCLE COST (PRESENT VALUE)

When the total life cycle cost (present value) method is used all expenditures, regardless of when they are incurred, are compared during a common year i.e. Base year. Future expenditures are properly discounted to reflect their time value. Once these future expenditures are discounted, they may properly be compared to expenditures incurred "today" or during the "base year". After discounting, all expenditures are weighted on a common basis and may be added together to obtain a total present worth or value.

Example:

If $100 is invested today at a 5% nominal annual rate, it will be worth $ 105 one year from now. In other words, the present worth of the $ 105 to be received next year is $ 100. If the investor leaves his or here money in the account for another year, the account balance shall grow to $ 110.25. An additional $ 0.25 has accrued over and above the first year's interest because the account has accumulated (compounded) interest on interest.

The present worth of any amount of money due in the future is calculated by a process known as "discounting".

The discounting process is important in LCC analysis because it facilitates the translation of future values to present values, which makes investment decisions simpler. If the total cost of owning an asset is its initial cost and all subsequent costs, the latter must first be discounted to the present value before they are combined with the initial cost to obtain the life cycle cost. It would be wrong to ignore the timing of the future costs and merely add them to initial cost.

All LCC analysis must be performed in terms of compatible dollars. The computing equations are as follows:

$$PV = FV \left[\frac{1}{(1+i)^{n}} \right]$$

In many instances, investments are made more often than just at the beginning of the analysis period. Sometimes investors deposit periodic payments into an account, which greatly adds to the effect of compounding. When the same amount of money is paid, or received, periodically it is referred to as an "Annuity". When the money is invested or received at the end of the period it is referred to as an ordinary annuity. To calculate the Future value of an ordinary annuity (A), the following formula may be used:

$$PV = A \left[\frac{(1+i)^{n} - 1}{i\,(1+i)^{n}} \right]$$

This factor is used to determine the present amount P that can be paid by equal payments of A (uniform annual payment) at (i %) interest, for n years. If you know A (uniform annual payment) and want to find PV (present value of all these payments), then

Example:

What single sum, deposited today at 8 percent interest compounded annually, would enable you to withdraw $ 7760.67 at the end of each of the next 3 years? In other words we are looking for the "present value of a future annuity".

$$PV = 7760.67 \times \left[\frac{(1+0.08)^3 - 1}{0.08\ (1+0.08)^3} \right]$$

$$= 7760.67 \times 2.57709 \quad = \$\ 20000$$

Thus the present value of a 3-year annuity of $7760.67 at interest of 8% compounded annually is $ 20000

Example:

How much money you need to deposit today to grow it to $ 20000 in 10 years from now for your child's education. The bank is offering you a fixed deposit for 10 years @ 6.5% interest compounded annually.

$$PV = 20000\left[\frac{1}{(1+0.065)^{10}} \right] = 20000 \times [0.5327] = \$10,654.52$$

NET PRESENT VALUE (NPV)

The net present value method discounts all of the cash flows of a project to a base year. These cash flows include, but are not restricted to equipment costs, maintenance expenses, energy savings, and salvage values. The cash flows are discounted to reflect their time value. Once all of the cash flows are discounted to a base year, the cash flows are weighted on a common basis and may be added together to obtain a 'total net present value'. A positive net present value indicates an accepted project. A negative NPV indicates that a project should not be considered.

The NPV method is similar to the total life cycle cost method presented earlier, but includes the ability to compare projects with varying benefits.

The positive NPV for one project can become multiplicative when other similar projects are considered.

SENSITIVITY ANALYSIS

[Limitations of LCA and How to Overcome]

The LCA analysis, many a times is based on educated guess or estimation. An erroneous data could nullify the LCA results. A few instances when the LCA results can go wary are:

1. Authentic & reliable data on all the required parameters of the comparative alternatives is not available. For example uncertainty about the life of a project, the quantity of energy it will save, energy costs, and/or its future replacement costs may raise doubts about its cost effectiveness.
2. Sometimes educated guess is desired but it may not always possible to make right assumption on the data figures. Particularly the life span and the performance ratios of say air-conditioning chiller machine.
3. Manufacturer's catalogue information or statements may be wrongly interpreted. Many a times one has to rely on the manufacturer's statements if the equipment is not certified by a listed organization.
4. The performance issues may vary over a period of time. Sometimes the conditions beyond control for instance environment conditions; operation and maintenance (O&M) practices impact the performance.
5. Data analyzed on historical comparison may not hold good. Each building is different and their location and functionality may be different. It might be possible to use historical data on past projects but even slight differences between buildings can affect the lifetime analysis significantly.
6. Time & budget constraints may discourage the in-depth economic analysis.
7. Company's accounting policies might discourage or inhibit the application of LCA. For instance, a company purchasing a standard protocol over years might not allow expenditure for any alternate consideration.

Sensitivity analysis is a technique for evaluating a project when there is considerable uncertainty about appropriate values to use in performing the evaluation. For example, to assess the impact of these factors, several evaluations of the project can be made, using a range of values for the parameters. By using upper and lower estimated values of each parameter, a clearer picture of a project's potential cost effectiveness can be seen.

EXAMPLES & ILLUSTRATIONS

Example #1

An HVAC system is expected to cost $ 125,000. A one-time replacement is expected after 15 years at a cost of $ 500,000. Annual operating costs are to be $ 125,000 per year. The system is expected to have a salvage value of $ 250,000 after 30 years.

Using a 10 percent discounted rate, what is the total present value of the system over 30 years?

Solution:

Present value = PV

Note in the solution below, the cash outflows (expenditure) are expressed in parentheses and the cash inflows (e.g. salvage value) are not

PV initial cost	=$ 125000.00
PV of one time replacement	= $ 500000 x 0.239393
	= 119695.00
PV of operating costs	= $125000 x (PV/A, 30 years, 10%)
	= 125000 x 9.42691
	= (1178363.75)
PV of salvage	= 250000 x (PV/F, 30 years, 10%)
	= 250000 x 0.05731
	= 14327.50

Total PV of system ($ 2533841.25)

ILLUSTRATION # 2

Capital Cost (CAPEX) and Operating Cost (OPEX) Analysis For Cooling Towers

The table below provides cooling tower information gathered on real time project. The relative costs of cooling towers demanding specified criteria shall be different but it is fair to assume these comparisons to a range of cooling towers. Especially for the modification and renovation projects, the engineer can analyze broadly the cost elements.

This table is for preliminary analysis & not recommended for detailed LCA.

Remember it is possible to upgrade the performance of your tower with simple repairs and upgrades, or replace it with the latest technologies. The cost comparisons are beneficial during such situations.

Designing and optimising a cooling tower is not a small job. Be sure to consider which materials of construction, fill type and sizing choices best suited to your application. Expert advice is recommended.

COOLING TOWER COST COMPARISONS			
Tower Alternatives	***Capital Cost Factors***	***Operating Cost Factors***	***Remarks***
Cooling Tower Types:			Counter-flow towers are compact, low in operating weight and the maintenance is easy, though have high capital & operating expenses on energy.
Cross-Flow	1	1	
Counter-Flow	1.25	1.15	
Materials:			Any of these materials is suitable for tower construction. Generally big field erected cooling towers rely on usage of
Douglas Fir	1	1	
Redwood	1.15	1	
Concrete	1.4	0.90	
Steel	1.35	0.95	

FRP	1	0.95	lumber in combination of concrete & steel. For small package towers, steel and FRP is the best choice.
Internals:			Internals dictate the performance of cooling tower. The performance is high with film fill but the maintenance is high due to clogging of internals.
Without Fill	1	1	
Splash Fill	1.2	1.5	
Non-fouling Film Fill	1.1	1	
Drift losses			Important where health & safety regulations are stringent and water is scarce
0.008%	1	1	
0.004%	1.05	1.05	
0.001%	1.1	1.1	
Plume Abatement			Alternate considered to meet the statutory requirements
Without Plume Abatement	1	1	
32 Dry Bulb Temperature (ambient)	4	1.2	
20 Dry Bulb Temperature (ambient)	5	1.3	
12 Dry Bulb Temperature (ambient)	6	1.4	
Noise			Reduction desired depends on statutory requirements
Standard rating; 80 dBA @ 1m	1	1	
5 dBA reduction	1.1	1.02	
10 dBA reduction	1.3	1.07	
30 dBA reduction	3	1.12	

ILLUSTRATION # 3

Capital Costs (CAPEX) And Operating Costs (OPEX) of Chiller Packages

The installed cost of chiller package is an important economic parameter for selection of HVAC system. The Chiller package is a single most costly item of the HVAC system and is therefore need careful cost evaluation.

As an example, consider an application of chiller based on 700 kW (~200 TR) cooling capacity for a critical facility building. A decision has been made to utilize a chilled water system. The engineer has considered three alternate electric chiller packages with reciprocating, screw and centrifugal compressors, in air-cooled and water-cooled configurations.

Vapor absorption machines are also been included in CAPEX/OPEX analysis for comparison with electrical machines and to check for its commercial viability.

The remainder of the HVAC system components are assumed to be the same for each chiller, i.e. air handling units, ductwork, inlet/outlet air terminals, heating equipment, electrical and control service.

The cost data (in US$) for all the alternatives have been compiled and tabulated below:

Cost Components	Water Cooled Chiller with different Compressor Configuration			Air Cooled Chiller with different Compressor Configuration		Vapour Absorption Machine (VAM)
	Reciprocating	*Screw*	*Centrifugal*	*Reciprocating*	*Screw*	*Direct Fired (2 stage)*
Purchase Costs						
Compressor	58410	61155	67950	58410	61155	104000
Cooling tower	12320	12320	12320	0	0	18480
CHW pump/piping	4410	4410	4410	4410	4410	4410
Condenser water pump/piping	3675	3675	3675	0	0	5510
Condensing Unit	0	0	0	23210	23210	0
Installation Costs						
Chiller package	11870	20170	23730	11870	20170	25000
Cooling Tower	1340	1340	1340	0	0	2010
CHW water pump and piping	2520	2520	2520	2520	2520	2520
Condenser water pump/piping	2100	2100	2100	0	0	3150
Condensing unit	0	0	0	2430	2430	0
Total Initial Investments	**96645**	**107690**	**118045**	**102850**	**113895**	**165080**
Operating Costs						
Electrical	210240	183960	170820	210240	183960	Low electricity use but use heat energy @ 1000 kcal/hr/KW cooling (Refer note 2)
Water	19060	19060	19060	0	0	28000
Total operating costs per annum	**229300**	**203020**	**189880**	**210240**	**183960**	

Purchase costs for all equipment and installation labor were obtained from "RSmeans guidebook", Mechanical cost data, 19th Edition, 1996. (Refer www. Rsmeans.com/). These figures and the cost estimating data are derived from surveys of the construction industry in USA. It may not be reflective of the local conditions of other countries, but is good for relative cost comparison and evaluation of various type of equipment.

(Note: The centrifugal machines are not available in air-cooled version and therefore not included in comparison table above.)

Operating costs are based on continuous operation of 8760 hours a year.

Electrical consumption rates are based on electrical power @ $0.15/KWH. The full load chiller efficiencies of the different compressors is considered as follows:
Reciprocating compressor: 0.8 KW/TR
Screw compressor: 0.7 KW/TR
Centrifugal compressor: 0.65 KW/TR
(Note: 1 TR = 3.5 kW of cooling)

Water costs have been based on cooling water flow @ 0.68m^3/hr per 3.5 kW (3 GPM per ton) of cooling and 2% water loss. The cost of processing the cooling water from desalination plant is considered @ $ 0.8/ m^3. The VAM uses approx 1.0 m^3/hr of cooling water per 3.5 kW (4 GPM per ton) of cooling with similar 2% water loss in cooling water circuit.

Notes:

1. The energy consumption of water-cooled and air-cooled systems has been assumed same for simplicity. It may be noted that the water-cooled chiller options consume lower energy than the air-cooled configuration, but it is largely offset by the additional energy costs on pump and cooling tower operation in case of water-cooled machines. In addition the water treatment costs in water-cooled configuration shall be significant. For larger capacity machines, it is recommended to compute on the actual data figures. The illustration above is just an example to go about the analysis.

2. The vapor absorption system, operating costs shall depend on the type of fuel used. The vapor absorption machines can run on steam or could be direct-fired machines operating on LPG, diesel, CNG, Naphtha ….The operating costs are largely varies on the fuel pricing. The co-efficient of performance of the vapor absorption machine is a little less than or approaching 1, implying that the energy usage shall be close to 700 KW equivalent of heat value. Dividing this by the calorific value of fuel provides the fuel consumption figures. It is recommended to use the actual figures from manufacturer’s data.

Analysis of Comparison Chart

1. Capital costs are considered first. The reciprocating compressors are the cheapest both in air-cooled and water-cooled variants. The screw compressor is the next best option and is less expensive than a centrifugal compressor by 10-15%. The total initial investment of electric chillers is significantly lower than the heat driven VAM.

2. The water-cooled variant of the chiller has an extra cost of water processing, weighing approx. 20% of the installed cost and is a recurring expense every year. Hence the water-cooled variant machine is not an economic option.

3. Among the air-cooled variant, the operating cost of screw compressor is approx. 12.5% lower than the reciprocating compressor. This indicates that the high initial investment cost of screw compressor shall have a payback of less half a year or around 5 months.

Conclusion

The air-cooled screw compressor chiller package has low initial investment, which is comparable to the reciprocating machine and is 10-15% cheaper than the centrifugal compressor. The operating cost of the screw compressor is the lowest that provides a payback of less than 6 months against air-cooled reciprocating compressor.

Technically, the screw chillers are most superior with advantages such as high reliability, low maintenance, low noise, and availability in environmentally friendly R-134a refrigerant and high efficiency. (Refer to technical analysis of the chiller machines in a separate course titled " HVAC made easy- Selection tips for chiller compressors"

Therefore air-cooled screw compressor chiller is techno-economically the best choice followed by air-cooled reciprocating compressor in 200 TR duty condition.

Course Summary

The course presents the basic understanding of the fundamental concepts and terminology used to compute the life cycle assessment specific to building projects. The procedure may be greatly simplified by the use of readily available software programs, but understanding of these concepts remains vital particularly for the individuals who have not had any previous experience in this area.

Life cycle assessment (LCA) is a decision making process that is applied to large scale building projects for evaluating the appropriate selection. The LCA takes into account all capital costs, recurring operation & maintenance (O&M) expenses, replacement costs, energy, environment and the code issues for the life cycle of equipment.

LCC are summations of cost estimates from inception to disposal for both equipment and projects as determined by an analytical study and estimate of total costs experienced during their life. The objective of LCC analysis is to choose the most cost-effective approach from a series of alternatives so the least long-term cost of ownership is achieved.

Related Reading

Glossary and Acronyms

The course *HVAC made easy – 'Glossary and Acronyms of HVAC systems'* is a compilation of most common HVAC terminology and is a recommended reading. The abbreviations and terms that may be unfamiliar to someone exploring HVAC systems for the first time have been carefully selected and presented in alphabetical order.

Cooling Water Systems

HVAC system is a significant proportion of the overall building costs and the cooling water system is one of the major cost elements. The air-conditioning systems on the big infrastructure-building projects generally use cooling towers for heat rejection. A 4-hour study course title "Cooling Water System- Overview of Cooling Towers" presents fundamentals and technical analysis of the various cooling water system options.

Chiller package

The chiller package comprising of refrigerant compressor is a heart of main cooling system. The chiller is a single most expensive item of the air-conditioning system that influences the life cycle economics of the air-conditioning system. The chillers have been discussed exclusively in another course *HVAC made easy – 'Selection tips for chiller compressors'.* This 2-hour course summarizes briefly the technical merits and demerits of using different compressors.