Puts You In Touch With Innovative Energy Technologies

LCC Application Manual for Construction Clients and Project Managers

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1. Introduction

Public and private buildings comprise a substantial part of every nation's capital. Financing needed for the construction and the maintenance of the buildings is competing against financing, which is needed for other private and public investments as well as for industrial production. Therefore it is important to get the most out of the money invested in the building, which leads to the direction of sustainable construction.

In sustainable construction the economical thinking, which is based only on first cost idea, has been given up. Parallel to the first cost, i.e. construction costs, money needed also for operating, maintenance and repair or for changing the purpose of use of the building during its life cycle, is taken into consideration. This doesn't mean that the competition in construction phase will be reduced, but in the first place conduct design to solutions, which are economical long-term investments.

<u>Benefits of LCCA thinking in service life and performance</u>

Operational and energy costs usually exceed the first cost. That translates to obvious benefits of the LCCA thinking.

It leads to good energy performance and durability with lower maintenance costs. This brings good financial balance through the years and also gives some insurance against possible increases in energy price and service personnel costs. It also indicates good environmental performance.

It leads to long service life. The first cost is divided in to more years and thus reducing yearly cost. Furthermore, the additional renovation costs are postponed further.

<u>Benefits of LCCA thinking in flexibility</u>

In long term the future purposes of use of the buildings can be expected to change. With thorough planning the design can be realised with only marginal extra expenses to accommodate change of use with significantly lower cost than new building. Flexible building base is an effective tool for preparing of future changes.

Economical life cycle management requires defined real-estate strategy to its support in order to be effective and rational. Specific decisions in building projects will be done based on to this strategy.

As key decisions and guidelines for any project are determined usually in briefing phase (at least the budget), regular methods of cost estimation based on the statistics, are not sufficient.

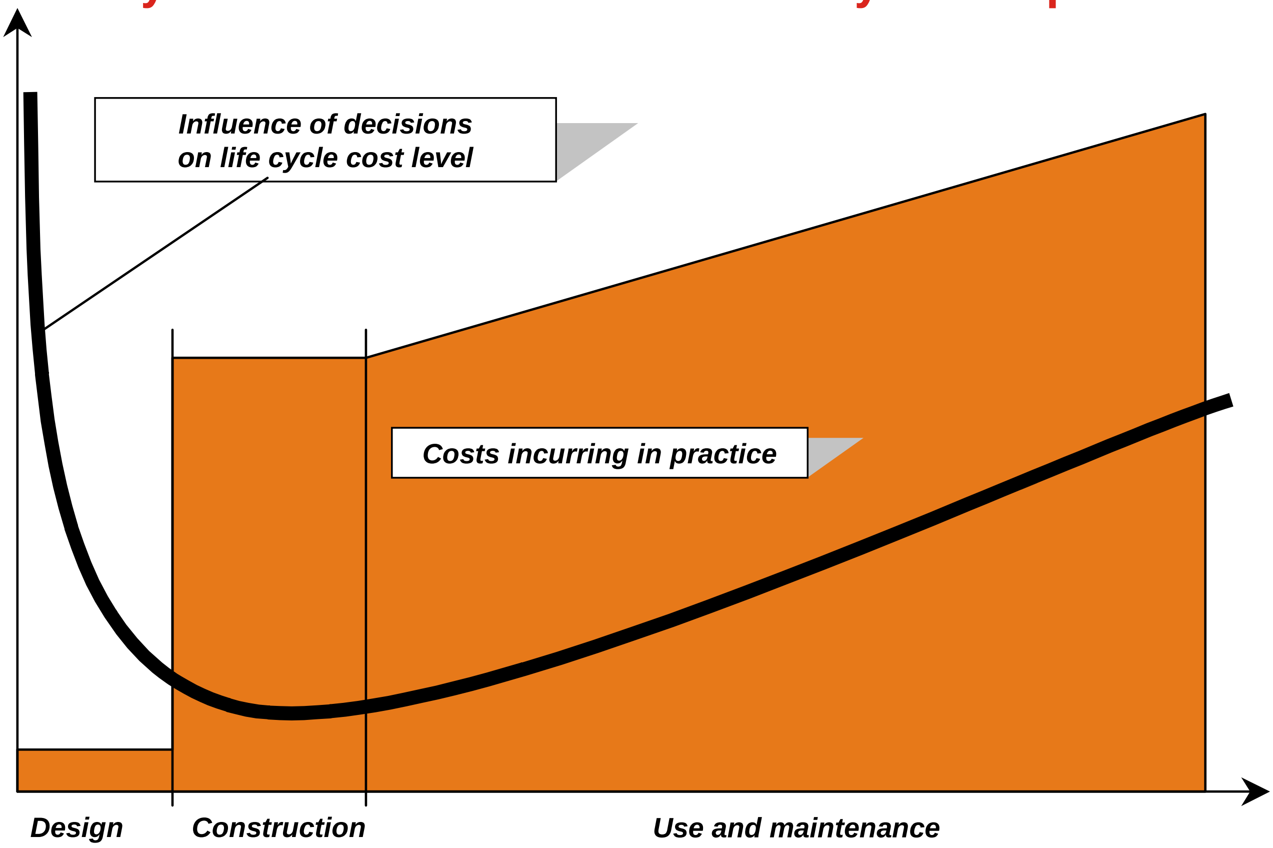
Life cycle optimisation frequently asks for higher investments (first cost) to favour low maintenance and energy costs in the long run. This easily conflicts with budgets estimated by regular methods. Projecting by LCCA principles is demanding from the cost control point of view. The authority of life cycle strategy should be adequate for reasonable financial arrangements.

The key targets for LCCA strategy set in briefing phase are suggested to include

- Energy performance
- Flexibility class / service life
- Indoor climate

The life cycle costs of building and its functions are closer examined in different phases. It is important, that targeted performance is not lost during the whole process. This guide suggests practical possibilities for instructing and controlling the life cycle costs on building design and management.

Life cycle costs are determined early in the process



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2. Defining life cycle objectives

2.1. Guidance on service life

The life cycle goals of a building should be issued from life cycle strategy set by the building owner. Though the perspectives of spatial use of the buildings or social development in society cannot anticipate the average life cycle of a building, long life cycle should be the main goal of the building design.

This is supported by the use of energy in construction and manufacturing, as well as impediments and pollution from construction on site. Additionally disturbing impact in city environment, costs of demolishing buildings and also the value of city milieu are the factors, which support the strategy to build buildings for long term use.

Anyhow, it is worth to combine flexibility with multipurpose use of buildings for long life cycle. That is presented further in the following chapter.

The purpose of use of the building might anticipate the actual life cycle; as for example in case of resale shops the situations can vary during few years due to competition reasons.

In Appendix 2 the targets for service times are presented for different buildings and building components.

The selected flexibility grade influences life cycle targets as well. Therefore if the flexibility grade is high in spatial and technical solutions, the life cycle targets of stationary parts of the building such as structural frame, facade and roof can be raised.

2.2. Flexibility

Flexibility as minimum means capacity of a building to adapt spatial changes, and in the broadest sense to adapt the changes of the use.

The probability of the building to face spatial changes is so high, that it should be taken into consideration during the design phase. Getting prepared for space changes is a minor cost factor in the modern future oriented building project.

The principles of the flexibility are defined in the feasibility phase of the project. The grade of spatial changes is relatively easy to decide. More difficult is to determine the long-term changes such as different use and users. The development of surrounding area as well as social development shall be taken into consideration.

There are two different types of flexibility can be seen in a building. Flexibility on building level and flexibility on work place level.

Flexibility on building level

Flexibility on building level can be determined according to the multipurpose use of the building as follows:

- Basic type of the building is an office building, which provides premises for laboratory needs for the companies in electronic or biotechnology etc. business
- The building will later be used as a school
- The building will later be used as a hotel or old-age home with in-house services for elderly people

Other flexibility functions are:

- Basic building can be extended by building an extension on one side of the building
- Basic building can be extended by building an additional floor on the top of the building
- The floor area of basic building should be possible to use as a whole or divided into small offices depending on how much office space different users need

On building level flexibility of building services means mainly space requirements for routing of pipes, ducts and cables. The other factor is to dimension the main distribution networks so that reasonable capacity of services is always available.

On building level following factors are necessary to take into consideration.

- The basic layout with the location of stairs and elevators as well as load bearing walls and columns should not restrict space planning
- Structural possibilities for additional vertical and horizontal routings (shafts for ducts, pipes and cables)
- Structural possibilities to make new openings for installations
- Space to enlarge mechanical and electrical rooms and shafts
- Dimensioning of floor to floor height so that there is space enough for additional horizontal installations
- Possibilities to build new bathrooms with waterproof floors and walls
- Dimensioning of main vertical and horizontal ducting and piping as well as electrical and telecommunication cabling according to the flexibility needs
- Possibilities to measure different users’ energy consumption

The changes of use as it comes to structures and technique are more challenging alternative and don’t always stay within reasonable limits.

Building owners with large quantity of property, should aim at the situation where a certain part of the building space can be changed for another use. With this buffer against future changes in social system can be faced without the risk that a large volume of properties should be useless/demolished. On the other hand being prepared for changes of use means more costs compared to changes of space.

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Sensible and researched changes are, for example, the following:

Change ↓	Apartment house	Office building	Hotel	Commercial building	School
Apartment		X	X		
Office	X		X	X	X
Hotel	X	X			
Commercial		X			X
School		X		X	

2.3. Flexibility on workplace level

Flexibility levels are:

- No flexibility
- Limited flexibility
- Full flexibility

The following actions can be foreseen:

- Change the layout of the working place
- Change the type of furniture etc. used in the working place
- Change the size of an working place
- Change the type of the working place (office room, open office etc)
- Change the indoor air quality level

For building services installations on workplace level following factors should be considered:

- Location of outlets and inlets of services based on general module used in the layout design
- Different thermal and daylight requirements for the modules located next to facade compared to those in inner zones of the floor plan
- Space for additional electrical and communication outlets per module is needed
- Additional capacity in heating, cooling and ventilation should be considered
- Flexibility to control indoor climate in different layout situations is needed
- Building services components on work place level should be movable

Normally there is no need to require flexibility in every room. For example kitchens, bathrooms, toilets and all technical rooms will remain in the same location. Of course they can also be removed, but the moving costs are higher compared to normal working spaces.

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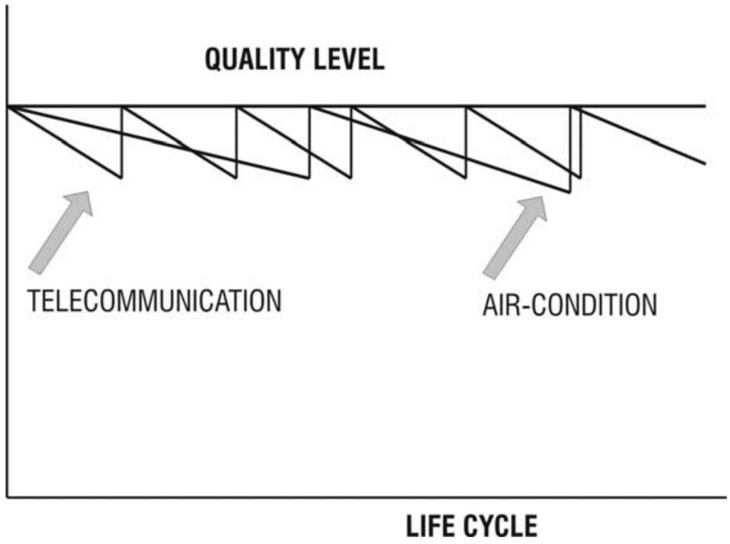
2.4. Principles for maintenance and refurbishment

Even the buildings, which are designed with sustainable solutions, need continuous service and maintenance. Surfaces wear out, technical systems brake down and structures get old. Although the service life for a system or building part is defined, there are always components, whose life cycle is shorter than the expected life cycle of the whole system. Also within one system service and maintenance needs of the components vary.

The principle of maintenance and refurbishment is to maintain the quality standards of the building, which have been set at the beginning. Of course new quality standards can be set during the refurbishment design. Normally that means of updating the standards according to modern requirements.



The main task for maintenance organisation, including building owner, is to determine the kind of policy to be used to maintain the building. The options are the so-called continuous maintenance and long refurbishment cycle, and minimum maintenance and shorter refurbishment cycle. The set length of life cycle doesn't determine the demolition date for the building. At that point major refurbishment must to be carried out to meet still the set quality standards of the building.

The management of life cycle policy is quite difficult today, because there are no standards or guidelines, and only little experience of buildings' life cycle applications. Evaluation between different materials and systems can be done on the basis of expected life cycles and costs. Large maintenance companies have obviously got experience and done experiments during recent years.

The technical systems' life spans can be assorted according to

- Technical life span
- Functional life span
- Economical life span

These three spans are very often different. Technically well working device or system can *de facto* according to standards become functionally poor. Functionally well working system can be economically unprofitable because the lack of technical support or pricing policy of the spare parts. Also the new alternative technology can make an old well functioning system uneconomical to run. This applies to all systems in the building but especially electrical **IT** and **AV** systems.

Typical maintenance cycles for building services components are presented in appendix 3.

2.5. Environmental objectives

The environmental factors effecting to the building project are:

- Use of natural resources
- Emissions
- Quality of indoor conditions
- Age span
- Society and nature

The most important of these factors is the use of natural resources. It can be divided into three categories:

- Use of energy
- Use of water
- Use of raw materials

All these are used both in construction process (manufacturing, transportation and on site activities) and during life cycle use of the building.

Building owner will set the target values for annual consumption of heating energy and electricity. Actual figures are set based on reference information of similar buildings. In addition to reference figures the building owner can set special energy saving target or targets to use renewable energy sources.

During its life cycle the use of a building causes emissions mainly to the air. Most of the emissions are related to energy consumption. The most common of them are CO_2, SO_2 and C_2H_4. The amount of these depends on type of energy used for heating the building and for producing electricity.

Other pollutants caused by the use of the building are waste of materials and wastewater.

Life cycle priorities in practice

• Efficient use of materials	• Optimised service life • **service life planning** • **flexibility and adaptability** • **systematic maintenance** • Closed material loops • **Reuse and recycling, renewable and recycled materials** • **Design for deconstruction and reuse**
• Minimising harmful emissions	• Energy use in buildings • **minimising energy demand** • **renewable energy supply** • Design decisions and induced transportation needs • **personal transportation** • **supply of goods**

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2.6. Targets for indoor environment (climate) and health

The indoor climate employs most often the thermal conditions, odour intensity, noise levels, ventilation and indoor air pollutants. Target values for indoor climate and health can be described according to performance specification. The performance approach concerned depends on the requirements for the building, not on description of the technical solutions.

In most countries there are minimum demand levels set by authorities. For different quality levels, there are systematic methods.

In appendix 4 the Finnish indoor climate classification is presented. It is based on three different quality levels of indoor air. The higher categories correspond to better indoor air quality and the lowest ones to the minimum requirements for the quality, which are very much the same requirements as in the official building regulations and codes.

It is equally important to determine the target values and odour emissions for building materials as it is for indoor air conditions. It is evident that the cleanliness of building materials is as important as is good ventilation for a comfortable and healthy indoor air.

The guidelines for design and construction, how to maintain the cleanliness in the construction, comprises of principles and procedures for the main stages of construction works.

The targets, requirements and instructions shall be taken into consideration at all stages of the construction project. This means that the building owner decides on the target values for the indoor climate together with the design team. Then he controls planning by explicitly defining the desired indoor-air targets and making them known to all designers. Each member of the design team makes sure that the decisions made concerning the selected indoor air class are presented in all necessary contract documents. Additionally this includes the cleanliness of construction work and ventilation systems as well as the emission for building materials and the cleanliness of ventilation components. The contractor will include all these requirements in the quality control plan of the construction site.

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3. Life cycle cost management

3.1. Objectives and possibilities of management

Life cycle aspect should be included in the planning at the feasibility-planning phase. The project cost estimate should include factors, which have effects on reasonable life cycle expectancies and project costs.

The feasibility study is carried out without any design of the building and all the issues are handled on general level, therefore only the most important factors concerning management of sustainable solutions should be considered.

The factors being:

- Energy consumption during life cycle
- Flexibility in building and workplace level
- Indoor climate

Since project costs are usually agreed during the feasibility study phase, the resources should be appropriately allocated for more effective energy use, flexible design solutions and quality of indoor climate. This should be done in spite of the fact that in feasibility study phase it is uncertain how these key issues will be carried out in design process.

3.2. LCC management in different project phases

LCC management is carried out in every phase of the building project. Project managers should realise that LCC design is not a separate item in design task list, but a great number of “normal” design task include also LCC design elements.

LCC design will be carried out in two different levels. The first one is to handle the building as a whole. The second one is to design every detail according to set sustainable target. Co-operation within design team is very important especially in level one, thus energy, flexibility and indoor climate targets can be met in architects’, structural engineers’ and building services engineers’ design.

The guidelines for LCC management in different phases of a building project are given in the following table. The guidelines are divided in three groups concerning architects, structural engineers and building services engineers’ tasks.

The guidelines table presents reference in which phase of the project certain activities are required. These give the project manager opportunity to follow activities in chronological order also. It is important not only check that reasonable action has been taken by the designers but also document the content of actions and its background.

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LCC MANAGEMENT, CHECK LIST

Feasibility study

Energy consumption

	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
• Setting the target level of energy consumption	O	X	X	X			
• Building's location on the site taking solar and wind conditions as well as trees into consideration		X					
• Influence of altitude of the ground floor to sewer and drain water pumping		X					

Indoor climate

Quality of indoor air

	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
• Setting the target level of indoor climate	O			X			
• Selection of building materials according to emissions (M1 classified materials	O	X	X				

Sound

	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
• Sound insulation of building envelope	O	X	X				
• Sound insulation between rooms, apartments and floor	O	X	X				

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Use of the building

	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
Life cycle • Setting the target life cycle of the building	O	X	X				
Flexibility • Setting the target level of multipurpose use and flexibility	O	X	X	X			
Durability • Setting the target of durability of materials and components	O						
LC Cost Reservation for cost calculation according to previous set targets	O						

Conceptual design

Energy consumption

	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
• Verifying energy usage calculations	O			X			
• Necessary compensation calculations of thermal behaviour of building envelope, so that requirements of Finnish energy code are fulfilled		X					
• Minimising the area of building envelope		X					
• Directions of windows		X					
• External shading against solar energy, including trees		X		X			
• Possibilities to utilise natural lighting		X					

Indoor climate

Item	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
Indoors air quality							
• Verifying indoor climate level in specifications and dimensioning	O	X	X	X			
• Verifying the specifications of building materials according to emissions (M1 classified materials)	O	X	X				
Thermal conditions							
• Verifying thermal insulation of building envelope	O	X	X				
Sound							
• Verifying sound insulation in specifications	O	X					

Use of the building

Item	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
Flexibility is verified from the drawings							
• Multipurpose use	O	X					
• Dimensioning of load bearing structures according to future use of the building	O		X				
• Optimisation of spans and floor heights	O	X					
• Reasonable space for building services installations	O	X		X			
• Possibilities to build new shaft in future	O	X	X	X			
Durability is verified from the drawings and specifications							
• Service life of the building	O	X	X	X			
• Bearing structure	O		X				
• Facades	O	X	X				
• Roof	O	X	X				

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Detailed Design

Supervising design targets in LCC point of view

	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
Energy consumption	O			X			
• Demand based ventilation				X			
• Heat recovery from extract air				X			
• Utilising solar energy and energy from internal loads		X		X			
• Efficient systems and their controls				X			
• Energy efficient components and products		X		X			
• Selection of ventilation units according to specific fan power figures				X			
• Room by room temperature control (winter/summer)				X			
• Measurement of energy (heating, electricity) consumption separately for each user				X			
• Humidification				X			
• Control of lighting according to natural light				X			
• Measurement of water consumption separately for each user				X			
• Sanitary appliances with low water consumption				X			

Indoor climate
Indoor air quality

	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
• Location of air intakes		X		X			
• Exhaust efficiency of filters				X			
• Demand based ventilation with CO_2 control				X			
• Cleanliness classified ventilation units and components (M1 classified products)				X			

Thermal conditions

	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
• Selection of thermal conditions, room temperatures (winter/summer), temporary deviations from set values, vertical temperature differences, floor temperatures, air velocities and relative humidity according to indoor climate category system (S1, S2 and S3)				X			

Item	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
Lighting							
• Lighting power		X		X			
• Lighting efficiency		X		X			
Sound							
• Sound insulation of building services systems and equipment and components taking requirements for future needs into consideration				X			
Use of the building							
Flexibility							
• Multipurpose use, flexibility to move walls and compoundable of space		X					
• Common spaces		X					
• Floor height		X					
• Reasonable space for technical rooms, shafts and routing for building services systems		X		X			
Durability							
• Durability of materials and components		X	X	X			
• Materials and components with different age spans will be installed so that they can be maintained and changed without damaging each other		X		X			
• Building services components with short or limited lifespan such as pipes and cables should not be installed in or behind the long life span material such as concrete.				X			
• Service and maintenance manuals		X		X			
• Training of users.		X		X			

Construction

Supervising design targets in LCC point of view in systems and components

Item	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
Supervising design targets in LCC point of view in systems and components	O						
Energy consumption							
• Demand based ventilation					X		
• Heat recovery from extract air					X		
• Utilising solar energy and energy from internal loads					X		
• Efficient systems and their controls					X		
• Energy efficient components and products					X		
• Selection of ventilation units according to specific fan power figures					X		
• Room by room temperature control (winter/summer)					X		
• Measurement of energy (heating, electricity) consumption separately for each user					X		
• Humidification					X		
• Control of lighting according to natural light					X		
• Measurement of water consumption separately for each user					X		
• Sanitary appliances with low water consumption					X		

Indoor climate
Indoor air quality

Item	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
• Location of air intakes					X		
• Removal efficiency of filters					X		
• Demand based ventilation with CO_2 control					X		
• Cleanliness classified air handling units and components (M1 classified products)					X		

Thermal conditions

Item	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
• Selection of thermal conditions, room temperatures (winter/summer), temporary deviations from set values, vertical temperature differences, floor temperatures, air velocities and relative humidity according to indoor climate category system (S1, S2 and S3)					X		

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	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
Lighting							
• Lighting power					X		
• Lighting efficiency					X		
Sound							
• Sound insulation of building services systems and equipment and components taking requirements for future needs into consideration					X		
Use of the building							
Flexibility							
• Multipurpose use, flexibility to move walls and compoundable of space					X		
• Common spaces					X		
• Floor height					X		
• Reasonable space for technical rooms, shafts and routing for building services systems					X		
Durability							
• Durability of materials and components					X		
• Materials and components with different age spans will be installed so that they can be maintained and changed without damaging each other					X		
• Building services components with short or limited lifespan such as pipes and cables should not be installed in or behind the long life span material such as concrete					X		
• Service and maintenance manuals					X		
• Training of users					X		

Commissioning

	Project manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
Supervising commissioning procedures in LCC point of view	O						
Energy consumption							
• Demand based ventilation					X		
• Heat recovery from extract air					X		
• Utilising solar energy and energy from internal loads					X		
• Efficient systems and their controls					X		
• Energy efficient components and products					X		
• Selection of ventilation units according to specific fan power figures					X		
• Room by room temperature control (winter/summer)					X		
• Measurement of energy (heating, electricity) consumption separately for each user					X		
• Humidification					X		
• Control of lighting according to natural light					X		
• Measurement of water consumption separately for each user					X		
• Sanitary appliances with low water consumption					X		
Indoor climate							
Indoor air quality							
• Location of air intakes					X		
• Removal efficiency of filters					X		
• Demand based ventilation with CO_2 control					X		
• Cleanliness classified air handling units and components (M1 classified products)					X		
Thermal conditions							
• Selection of thermal conditions, room temperatures (winter/summer), temporary deviations from set values, vertical temperature differences, floor temperatures, air velocities and relative humidity according to indoor climate categories (S1, S2 and S3)					X		

	Project Manager	Architect	Structural Engineer	Building services	Contractor	Checked	Documented
Lighting							
• Lighting power					X		
• Lighting efficiency					X		
Sound							
• Sound insulation of building services systems and equipment and components taking requirements for future needs into consideration					X		
Use of the building							
Flexibility							
• Multipurpose use, flexibility to move walls and compoundable of space					X		
• Common spaces					X		
• Floor height					X		
• Reasonable space for technical rooms, shafts and routing for building services systems					X		
Durability							
• Durability of materials and components					X		
• Materials and components with different age spans will be installed so that they can be maintained and changed without damaging each other					X		
• Building services components with short or limited lifespan such as pipes and cables should not be installed in or behind the long life span material such as concrete					X		
• Service and maintenance manuals					X		
• Training of users							

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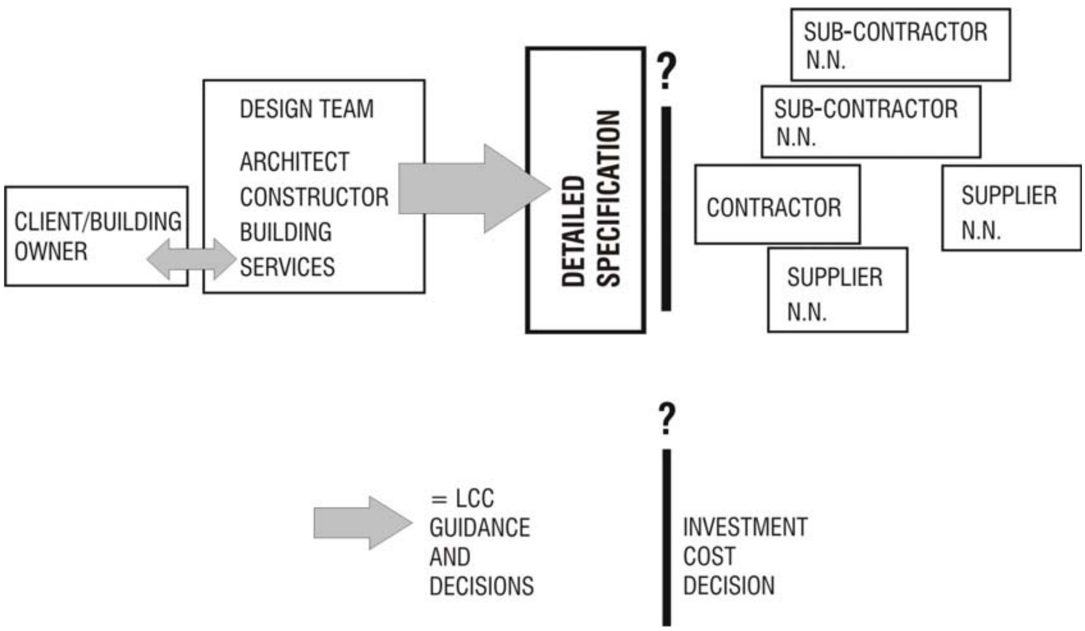
3.3. LCC management in different contract types

As mentioned before, LCCA management is carried out in every design phase of the building project. When it comes to contracting, there are several ways to realise them. Building owners possibilities to influence LCCA decisions vary from contract type to another. There are numerous types of contracts, but main differences can be classified with the basic contract types:

- Lump sum contract
- Design build contract
- Project management contract

These three contract types demonstrate the different place of cost decisions. There is an unwritten rule, that after cost decisions it is much more difficult to influence on the content of a contract.

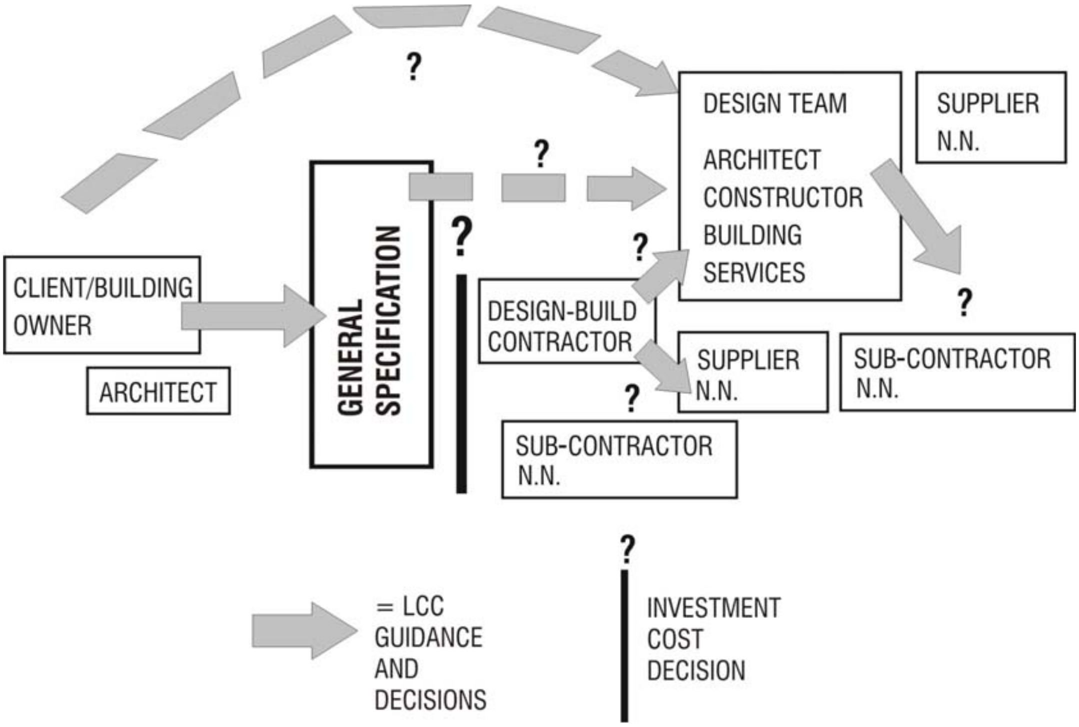


Picture 2. Lump sum contract, detailed LCCA decisions beforehand

In lump sum contract, which is the most traditional way of contracting, the client/building owner can control the design phase up to the detailed specification, thus enabling himself to introduce any LCCA policy he is committed to. With a LCCA oriented design team this can achieve good LCCA results. All possibilities can be discussed and evaluated, and there is the expertise available. The results are included in detailed specifications, which the selected contractor must follow.

In most cases detailed specification doesn't mean a named product, as there should always be opportunity for supplier tendering. Although there is often a site supervisor commissioned by the building owner, who supervises that contractor follows the contract it is in practice quite demanding to verify the performance of every offered product or system.

On the other hand, there are no possibilities to cut corners, as good performance can easily be paralysed with wrong product selections.



Picture 3. Design-build contract, detailed LCCA decisions in contractors' team

In design-build contract financial agreement is done in early phase, at least when related to detailed design. Contract is normally made with a general level specification. Actual detailed design is done within the contractor's organisation.

From LCCA point of view, key factor is the ability to include LCCA targets in a measurable way in the general specification. It is up to contract, which are the possibilities of the building owner to influence on the contractors design team and suppliers in more detailed questions.

There have been development projects (Helsinki University, Viikki Information Centre Building) where the performance level of HVAC-systems has been agreed on beforehand, on measured basis during 5 years after hand-over. Although simple as an idea, it raises many questions as

- The amount and behaviour of occupants
- Weather (temperature, sunshine, wind)
- User related equipment
- Working hours (in different building parts)
- Actual level of indoor climate

A lot of work is needed to clear out (if even possible) for every "out of contract" situation to accommodate conditions for a fair final deal. No standardised methods are available at the moment.

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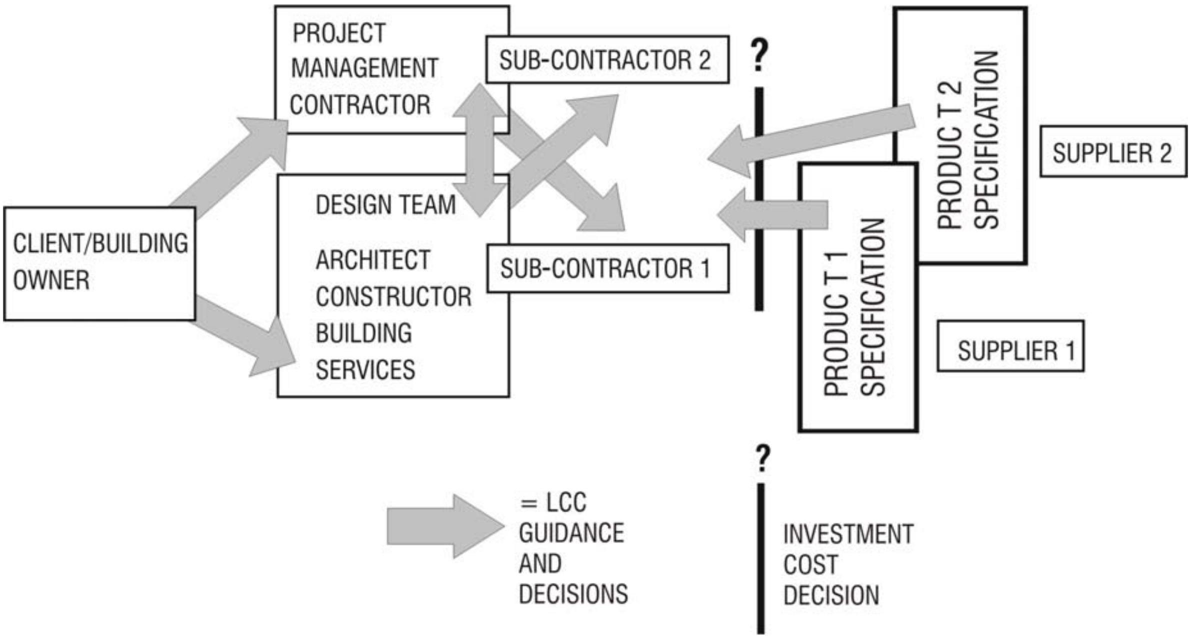


Picture 4. Project management contract

In project management contract client/building owner is principally present in every design and product purchase decision. This allows full LCCA decision possibilities but also creates a demand of high involvement to the process all the way. This must be done with a good expertise, otherwise being useless.

4. LCC methods and tools

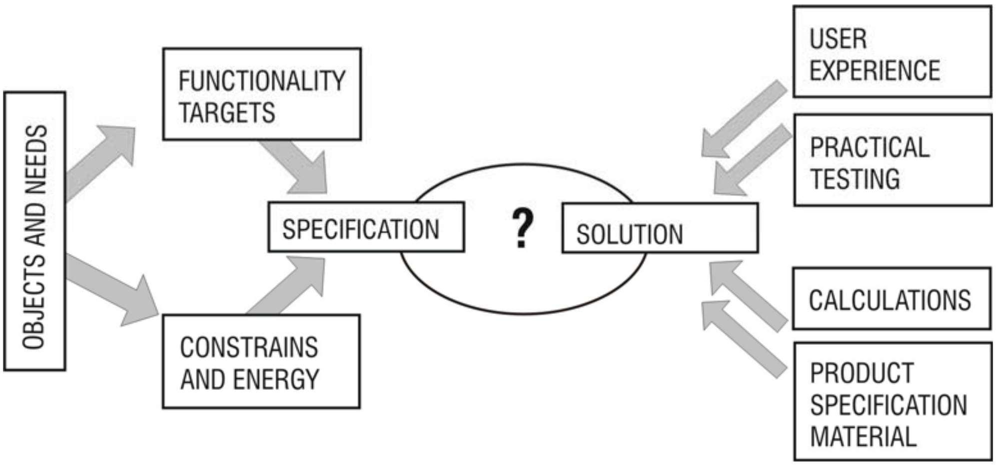
4.1. Methods

Theoretically life cycle cost management is based on the following formula:

$$K = A + \sum_{t=0}^{n} \frac{D_t + e_0(1+q)^t E_t}{(1+r)^t}$$

An	investment
D_{ot}	maintenance cost year t
E0	initial energy cost
Q	energy price increase against inflation
E_t	energy usage year t
N	life cycle (calculation period)
R	interest rate (real)

Decision procedure is described in picture 5. In practice the product specifications seldom produce sufficient and reliable knowledge for decision-making. Additionally, practical testing, calculations and pure experience are needed.



Picture 5 Life cycle cost optimisation decision procedure. Does the product match the specification?

There is also the question of open competition. No problems occur if specification is for a named product previously known by design team. In most projects product and system purchases must follow the public tendering procedure, and then all the methods in picture 5 may be necessary.

4.2. Cost of different life cycles

In practice a life cycle cost estimate as described in Chapter 4.1 does not apply to the systems, which have a shorter life cycle than the building itself. This means most of the building services systems, especially HVAC.

Starting a new life cycle of e.g. piping means considerable interruption for building's normal life (waste, dust, noise, break-ups etc.). In many cases the tenants have to leave the building for the worst periods. That together with creating of a building site and organisation, mean considerably higher costs than the system renovation itself.

The formula for a subsystem renovated n times during building life cycle

$$K_{total} = K +(K_1+R_1) + \ldots+(K_n+R_n)$$

K_1 = system cost in first renovation
R_1 = renovation additional cost in first renovation

Many building owners find this very critical, especially having the tenants to leave, and therefore tend to postpone technical renovations far beyond their technical life cycle. They try to combine different type of renovations time wise together to save additional costs or divide them to many systems. Unfortunately that easily leads to poorly performing systems.

To object this problem the design solutions, which give good flexibility, accessibility and forehand designed methods of replacements can remarkably reduce additional costs of renovation. A good idea also is to estimate the major cycles shorter than buildings life cycle (e.g. 20...30 years), and try to designate them as partial renovation points for several systems.

4.3. Software

No standardised software is available. Methods differ from software to software and country to country. Basically all software deal with costs, time and interest rate. Additional software is often needed for energy calculations etc. Software packages available are presented in appendix 5.

Appendixes

1. LCC management, checklist
2. Examples of life cycles of building parts, systems and components
3. List the typical maintenance cycles for building services components.
4. Classification example of indoor climate (Finland)
5. Example of LCCA software (Finland)

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Appendix 1. LCC management, check list

Feasibility study

Energy consumption

- Compensation calculations are needed if window area exceeds 50 % of the total façade area. Extra energy consumption can be compensated using better thermal insulation values of building parts such as windows, walls or roof, or better heat recovery from the extract air compared to the requirements in the code. Also compensating the consumed extra energy by improving the thermal behaviour of the façade can leave out heat recovery from the extract air.
- The shape of the building should be as compact as possible. The energy, which is lost through the façade and roof varies 30…50 % of the total heating energy consumption of the building depending of building type.
- In the urban conditions it is not often possible to locate the building on the site so that microclimate round the building is optimised. Nevertheless, protecting the building from direct sunlight and heavy winds by taking conditions on site into consideration can effect substantially to the energy consumption.
- When determining the altitude of the ground floor of the building in addition to other factors, the need to pump sewage or drain water should be studied. The pumping of sewage or drain water means continuous consumption of electricity.
- Thermal characteristics of the windows both in winter and summer conditions are factors, which should be carefully studied. In summer conditions external solar shading is in most cases needed to prevent direct sunlight entering the space to overheat it or cause direct glare.
- One third of the electricity consumed in a commercial building is used for artificial lighting. Therefore it is necessary to utilise natural lighting as much as possible. The natural lighting should be handled in connection with windows thermal properties and shading against external solar radiation, as well as direction of windows.

Indoor climate

Quality of indoor air

- Socles of the building must be designed so that snow does not cause any water leakage into the building. Recommended minimum socle height in northern climatic conditions is 60 cm.
- Every roof should be provided with gutters. This is necessary to prevent walls getting wet and being destroyed by combined influence of water and ice.
- All the rooms, where water is used for showers etc. must be built of water-resistant materials to prevent mould and other compounds to grow.
- Only low emission building materials should be specified. Use classified materials if available.
- Every room should be provided with operable window to make airing possible.
- Building materials should be selected so that they are easy to keep clean. Also design should be developed so that all the surfaces can be cleaned.

Thermal conditions

- Thermal conditions such as room temperatures (winter, summer), temporary deviations from set values, vertical temperature differences, floor temperatures, air velocities and relative humidity should be specified. The document called “Classification of indoor climate" can be used to select the indoor climate category.
- Solar shading for windows is necessary. It can be arranged by windows solar characteristics, Venetian blinds between the panes and external shading devices. Also direction of windows

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should be studied. Trees with leaves are good solar shades. They prevent direct sunshine in summertime and allow utilisation of solar radiation in wintertime.

Lighting

- People feel better in natural light than in artificial light.

Sound

- The building envelope should be designed to prevent traffic and other outdoor noises from disturbing people inside the building.
- Sound insulation requirements between the rooms, apartments and floors should be specified.

Use of the building

Flexibility

- Flexibility targets of the building should be discussed. Flexibility both on building and work place level should be considered and specified.

Common spaces

- Floor height should be determined based on functional requirements and flexibility targets
- Basic design of building services systems should be carried out in order to be able to determine spatial needs for building services (technical rooms, shafts and vertical routing). Flexibility requirements are important to decide.

Durability

- Life cycle of the building and different systems should be determined. Durability requirements for building materials and components should be specified accordingly.

Appendix 2. Examples of life cycles of building parts, systems and components

Structure/System	Public Building	Office Building	Commercial Building	School Building
Structures				
- Load bearing structures	100	50	50	50
- Structure of facade	100	50	30	50
- Surface of facade	50	30	20	30
- Windows, doors	35	30	20	30
- Partition walls and finishing	35	20	10	30
Building services systems				
Heating	50	50	30	50
- Piping	100	50	50	50
- Heat exchangers	35	25	25	35
- Pumps and valves	15	15	15	15
- Radiators	50	50	30	50
Plumbing	35	25	25	35
- Copper and cast iron pipes	35	25	25	35
- PVC pipes and wells	50	50	50	50
- Sanitary fixtures	35	25	25	25
Air-conditioning	35	25	20	35
- Ventilation units	35	25	20	35
- Ducts and accessories	50	50	50	50
- Controls	15	10	10	15
- Water chillers	35	25	25	35
Electricity	35	25	20	35
- Cables	50	30	30	50
- Distribution boards	20	20	20	20
- Luminaries	35	25	10	35
- Tele networks	20	20	20	20
- IT networks	10	10	10	10

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Appendix 3. List the typical maintenance cycles for building services components

Heating systems:

Component	Life span (years)	Maintenance cycle (years)
Gas boilers	30	1
Burners	10	1
Flues and chimneys	30	1
District heating sub-station	20	5
Pipes, black steel	50	50
Pipes, polyethylene	80	80
Valves	20	2
Piping accessories	20	2
Pumps	20	2
Radiators	50	20
Electric heaters	20	2
Floor heating	80	20
Controls	10	1

Ventilation and air-conditioning systems:

Component	Life span (years)	Maintenance cycle (years)
Ventilation units	30	1
Air-conditioning units	30	1
Exhaust air fans	30	5
Air ducts	50	5
Duct accessories	20	5
Exhaust hoods	20	1
Kitchen hoods	20	1
Supply air devices	25	10
Exhaust air devices	25	5
Water chillers	30	1
Condensers	30	1
Controls	20	1

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Plumbing:

Component	Life span (years)	Maintenance cycle (years)
Water pipes, copper	25	5
Water pipes, polyethylene	80	80
Sewers, cast iron	40	40
Sewers, polypropylene	80	80
Valves	20	2
Pipe accessories	20	5
Pumps	20	2
Hot water heaters	20	1
Hot water storage tanks	20	1
Sanitary fixtures	30	5
Mixers and taps	20	5
Floor drains	50	1
Roof drains and outlets	30	1
Fire hydrants	50	5
Fire extinguishers	20	2
Controls	20	1

Electrical components:

Component	Life span (years)	Maintenance cycle (years)
Main switchboard	50	5
Sub-centrals	50	5
Cable routes	50	10
Cables	50	5
Luminaries	30	5
Electrical equipment	30	5

Telecommunication:

Component	Life span (years)	Maintenance cycle (years)
Telephone network	20	5
TV/Radio aerial system	30	5
IT Data cable system	20	5

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Appendix 4. Classification example of indoor climate (Finland)

Parameter	Quality level 1	Quality level 2	Quality level 3
Thermal conditions			
-Room temperature, summer	23-24 °C	23-26 °C	22-27 °C
-Room temperature, winter	21-22 °C	20-22 °C	20-23 °C
-Temperature gradient	2 °C	3 °C	4 °C
-Floor temperature	19-29 °C	19-29 °C	17-31 °C
Air flow (draft)			
- Air velocity, summer (24 °C)	0,20 m/s	0,25 m/s	0,30 m/s
- Air velocity, winter (21 °C)	0,14 m/s	0,17 m/s	0,20 m/s
Humidity			
-Relative humidity, summer	-	-	-
-Relative humidity, winter	25-45 %	-	-
Climate control			
- Temperature deviation from set value	0,5	1,0	2,0
-Individual control of room temperature, summer	Yes	No	No
- Individual control of room temperature, winter	Yes	Yes	Yes
Indoor air quality			
Maximum concentration of indoor air pollutants			
- CO_2	700 ppm	900 ppm	1200 ppm
- TVOC	200 µg/m^3	300 µg/m^3	600 µg/m^3
- CO	2 mg/m^3	3 mg/m^3	8 mg/m^3
- Cigarette smoke in smoke free areas	Not discernible	Not discernible	Not discernible
- Mass concentration of airborne particulate matter (PM_{10})	20µg/m^3	40 µg/m^3	50 µg/m^3
Acoustic conditions			
Max noise level produced by mechanical equipment	30 dB	33 dB	33 dB

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Appendix 5. Example of LCCA software (Finland)

SAKU

Saku is a Microsoft Excel application programme, by which the life cycle cost of two alternatives can be calculated. Saku is a tool to compare life cycle costs of building services systems and installations. Because it is an Excel based calculation method other comparisons can also be made, also those of the whole building.

Software is based on annual spreadsheet of the life cycle of the building or a system. First costs (building costs), annual service and maintenance costs, refurbishment costs and demolishing costs are the needed inputs. Furthermore, the same costs for alternative systems are needed. A print sheet of the software is being presented in Enclosure 1.

Other instruments when using this software shall define both information of costs and energy consumption. The basic level of cost information can be defined for example by Haahtela-Kiiras –method using Wintaku software and the comparison costs using designer's own cost estimate. WinnEtana, Motiwatti or IDA-ICE –software can be used to estimate energy consumption.

The software can be shortly evaluated:
+ Fine base to input information
+ Comparison of different options by graphic printing
+ Easy to change interest rate and energy price (sensitive analysis)

- Information of costs and energy should be formed by other instruments
- Primarily for building services systems calculations

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RAE

RAE is a Microsoft Windows based application, which can be used to calculate buildings life cycle costs and required rent profit by given capital income and interest rate.

This is supported by cost analysis, which compares the figures of existing building to those of a reference building. Every cost item can be dealt separately. The shares of costs are based on classification and percentage of reference building. Service and maintenance figures and costs are based on actual consumptions according to KH databank. The databases are up-dated annually based on published actual statistics.

Either actual cost distribution or that of reference building can be used in calculations. At least the total cost (€/m^2) of actual building must be known as well as its energy consumption.

The software has been developed to define the right rent level of existing buildings and to estimate maintenance costs. It is also suitable for close examination of life cycle costs, when by means of calculation energy savings and cost effects of investments can be observed indirectly by rent level.

The software can shortly be evaluated:

+ Good instrument to find balance of costs
+ Up-dated cost file of maintenance
+ Easy to change interest rate and price of energy (sensitive analysis)

- Cost and energy information have to be created by other software
- Indirect life cycle calculation
- No collection of comparable printing

The software includes a separate part, which analyses economical ways to maintain building which is not in use.

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