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Life-Cycle Cost of Buildings

Coût global d'un bâtiment

Über die gesamten Kosten eines Gebäudes

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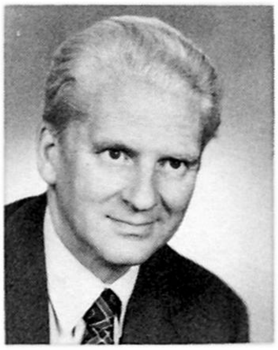

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SUMMARY

The operations and maintenance costs of a building are considerable as compared to the investment costs. Both should therefore be treated together in the form of life-cycle cost. The main parts are the costs for energy, cleaning and maintenance, which are investigated in detail. The conversion of future costs to present worth is a key problem. A new approach with two compound interest rates is presented. The operations and maintenance costs can then be put in a balanced form against the investment costs. The search for the most favourable solution is thus enhanced.

RÉSUMÉ

Les coûts d'exploitation et d'entretien d'un bâtiment sont considérables par rapport aux coûts d'investissement. C'est pour cette raison qu'il faut traiter ces coûts ensemble, comme coût global. Les éléments principaux des coûts d'exploitation sont le chauffage et le nettoyage; ceux-ci de même que l'entretien sont examinés en détail. L'actualisation des coûts futurs est un problème fondamental. Une solution nouvelle avec deux taux d'actualisation est présentée. Ainsi le coût global optimum peut être trouvé.

ZUSAMMENFASSUNG

Die Folgekosten eines Gebäudes sind beträchtlich, verglichen mit den Investitionskosten. Aus diesem Gesichtspunkt heraus sollten beide Kostenarten zusammen behandelt werden. Die Hauptkomponenten der Folgekosten sind Energie, Reinigung und Bauunterhaltung und diese werden eingehend im einzelnen behandelt. Die Umwandlung der künftigen Kosten in Zeitwert ist ein Schlüsselproblem. Eine neue Lösung mit zwei Diskontierungszinssätzen wird vorgeschlagen. Die Folge- und Investitionskosten können in dieser Weise optimiert werden.

This paper deals with a thesis presented at the Technical University Vienna under the title "Optimierung der Bau- und Folgekosten von Gebäuden".

The life-cycle cost (LCC) consists of the original investment and the operations and maintenance costs. The operations and maintenance costs can amount to ten percent of the gross national product in a country [1]. This is one aspect of the costs. Another is that the operations and maintenance costs have increased rapidly during the 1970's, especially regarding fuel.

To cope with the situation a search for improved techniques and control methods is taking place in many countries. Findings from USA, Great Britain, France, Germany, Austria and Sweden are presented in the thesis. The international emphasis is interesting as various solutions to existing problems are shown at the same time it demonstrates what kind of solutions are acceptable to the parties concerned.

A systems approach is used in the thesis to account for all relevant factors of the long life of a building. It is generally the long life of 50 years or more that creates the specific problems. There is a lack of statistics, the available data are not complete and it is not known what is contained in the data.

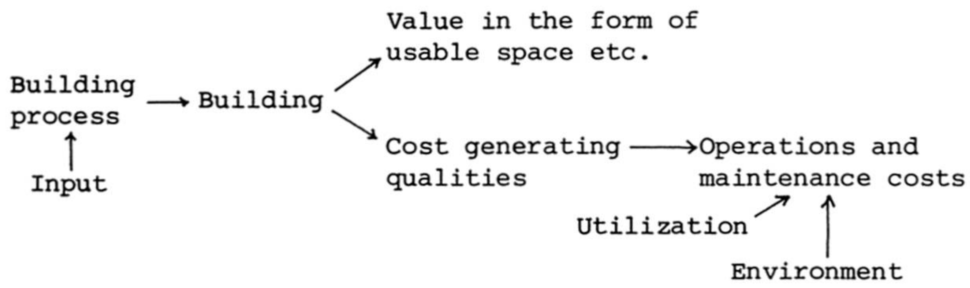

Figure 1. The relations between building qualities and the operations and maintenance costs

The operations and maintenance costs are a function of three parameters: the cost generating qualities of the building, the utilization of the building and the environment. These relations are fundamental to the analysis of the operations and maintenance costs and for their calculation i. e. the synthesis. What do these parameters mean? An example from the heating-side is illustrative. The cost generating quality stems from lack of insulation or air-tightness. In order to be able to utilize the building a certain temperature is called for. The environment is in this case represented by the outdoor temperature. The resulting heat flow through the walls has to be compensated by heating. Thus the three parameters together generate the costs.

The most important cost generating factors are the net floor area and the ratio between the net and the gross floor areas as well as the ratio of external cladding elements to net floor area. The complexity of the air-conditioning and other technical equipments do also contribute to high operations and maintenance costs.

Reverting to the concept of LCC the following items ought to be considered when calculating the LCC:

- I The original investment including costs for raising the capital.
- O Operations costs containing only the energy and cleaning costs.
- M Maintenance costs including repair, replacement and inspection.
- F Costs for increasing the flexibility of the building.
- D Costs for the disturbance of the operation of the user including costs for arranging replacement of activities.
- Z Other costs relevant to an investment decision.

The general formula is

$$LCC = I + \sum_{x} \sum_{t=0}^{t=n_h} C_{xt} \cdot \beta_{xt} \tag{1}$$

where

- I : Investment
- C_{xt}: Costs for the object of expenditure x
- β_{xt}: Conversion factor of C_{xt} costs to present worth (see table 1)
- n_h : Horizon (end of life-cycle) in number of years

It should be noted that there are different conversion factors for thermal energy, electrical energy, cleaning work, maintenance work and the operation of the user.

The costs for each component could be presented in a matrix as follows:

Component	year 1	2	3	4	5	6	etc. to the end of the life-cycle
I							
Thermal energy							
Electrical energy							
Cleaning							
M							
F							
D							
Z							

Figure 2. Matrix for LCC

The costs entered should be multiplied by the appropriate conversion factors.

The components which dominate are the energy, the cleaning and the maintenance, amounting each to about 30 % of the total operations and maintenance costs.

When processing alternatives only those costs, which are specific to the alternatives, need to be considered. Take as an example the covering of an office floor with linoleum (alt. 1) or a wall to wall carpet (alt. 2). The basic data are:

	Alt. 1		Alt. 2	
	costs in monetary units	interval years	costs in monetary units	interval years
investment	829	20	1008	10
repair	112	10	112	5
removal	224	20	224	10
cleaning	80	annually	105	annually

Alt. 1

years	0	1 through 9	10	11 through 19
investment repair cleaning	829	 80 annually	 112 80	 80 annually
Total	829	80 annually	192	80 annually

The conversion factor is assumed to be 1 for all components and both alternatives. In case of other conversion factors the costs of each component have to be multiplied by the pertinent conversion factor for each year.

The costs for Alt. 1 are 2461 monetary units under the given assumptions.

Alt. 2

years	0	1 through 4	5	6 through 9	10	11 through 14	15	16 through 19
investment repair removal cleaning	1008	 105 annually	 112 105	 105 annually	1008 224 105	 105 annually	 112 105	 105 annually
Total	1008	105 annually	217	105 annually	1337	105 annually	217	105 annually

The costs for Alt. 2 are 4459 monetary units under the given assumption.

The relative costs would most likely vary from country to country and the outcome of the comparison will change accordingly.

Economizing with energy has for several reasons got a high priority. The costs have gone up rapidly since 1973 leading to a search for new economic solutions. It can be shown [2] that under certain conditions the optimum insulation is determined by the formula

$$U_{opt} = \sqrt{\frac{P \cdot \lambda}{Q \cdot E_o \cdot \gamma}} \tag{2}$$

where

U_{opt} = the optimum thermal transmittance of the structure (W/m² °C)
P = marginal cost for the insulation layer (monetary units/m³)
λ = thermal resistance of the insulation layer (W/m °C)
Q = degree-hours in thousands (1000 h °C)
E_o = current energy price (monetary units/kWh)
γ = transformation factor of equal yearly amounts to present worth (year) (see table 2)

A more practical way of arriving at the optimum insulation has been presented by professor Adamsson of the University of Lund [3]. The formula utilized is

$$\frac{I}{B \cdot \gamma} \leq E_o \tag{3}$$

where

I = cost of the additional insulation (monetary units/m²)
B = energy saving achieved through the additional insulation (kWh/m² year)

The additional insulation is increased step by step so that $\frac{I}{B \cdot \gamma}$ reaches but does not exceed E_o.

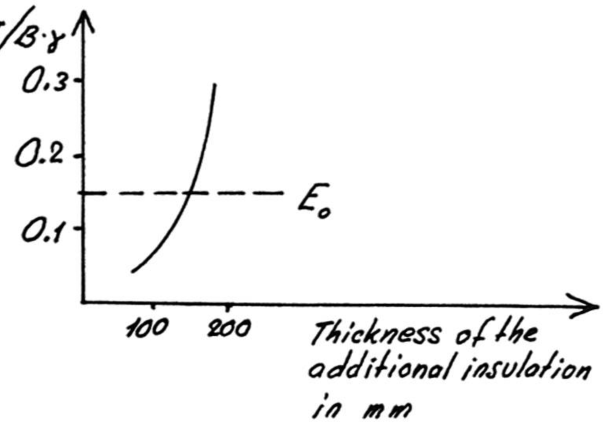

Figure 3. The factor $I/B \cdot \gamma$ as a function of the thickness of the additional insulation

The same result is attained by the two formulae when the insulation qualities and the costs follow each other closely which, however, in practice is not always the case. The second formula can also be used for other measures to reduce consumption of energy. Still more insulation will be justified if the formulae are corrected for the effect of decreased need for heating capacity.

Consideration should be given to the gain of heat through the sun and other heat sources. The effects on the conservation of energy can best be calculated if the temperature conditions are studied hour by hour.

There are beside the technical aspects also economical factors which have to be examined. The unpredictable price developments on the energy market do not provide a firm basis for choosing the optimum insulation design which will remain the optimum during the life of the building. A good help could here be given by the authorities in laying down the rules for calculating the energy conservation. Should the predicting of the price developments be left with the design teams then the result would be a spectrum of assumptions making comparisons and decisions within the energy conservation area more difficult.

Improvements can be recorded by comparing energy performance data for various buidings. A quality performance form ought for this purpose to be presented for each building.

The costs for cleaning deserve a lot of attention. The main parameter is space to be cleaned and this can be broken down into

- net usable floor area for the purpose of the client (R_u)
- communication area e. g. corridors, entrance, halls (R_c)
- "hygienic" area e. g. toilet, changing room, kitchenette (R_h)
- other areas of the gross floor area (R_o)

The operations costs for cleaning will be minimized if the ratio net to gross floor area is as big as possible. There are however other relations which are of interest. Let us as an example [4] take an office building:

	R_u	R_c	R_h	R_o
Area m²	1295	810	85	850
Cleaning time per month in minutes	1602	3048	1885	881
Cleaning time per m² and months in minutes	1.24	3.76	22.18	1.04

It is evident that the cleaning of the "hygienic" area takes more time than the cleaning of the whole net usable floor area. It takes in this example about 18 times longer to clean one m² of R_h as compared to one m² of R_u. The conclusion to be drawn is that the allotting of space has to be watched closely. Further the choice of materials on the floors and the cleaning methods have a major influence on cleaning costs. The cleaning is labour intensive in that 85 to 90 % of the costs are for labour. As a consequence cleaning costs increase more rapidly than what can be explained through the average inflation.

Building maintenance is characterized by its many small jobs and that it often is financed by several sources of funds. It is difficult to get a complete picture of building maintenance and of all the factors which have an influence e. g. utilization, environment, modernization and use for new purposes. It would be of advantage if one could follow the effect of these factors and thus arrive at appropriate intervals for maintenance. The amount of emergency maintenance could be lowered and replaced by planned actions adjusted to the actual needs of maintenance, so called condition-based maintenance. The result should be lower costs, improved service to the user of the building and a better feedback of information. Further, planned execution makes it possible to place fixed price contracts for maintenance work.

It has been noted that a lot of defects occur during the first five to six years of the life of a building [5].

The relationship can be illustrated by the wellknown "bath-tub"-curve. It should be the task of design teams and the contractor to lower the first part of the "tub"-curve to an acceptable level. The client can insist on this by asking for extended responsibility covering the first five to six years.

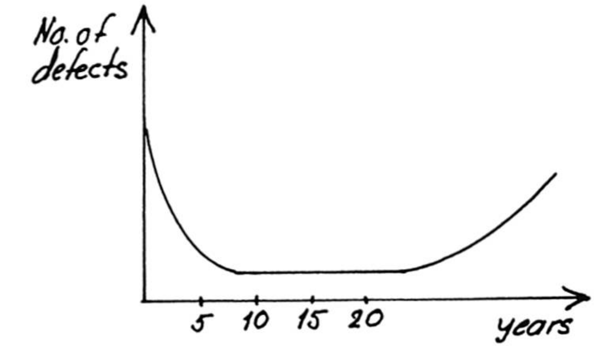

Figure 4. "Bath-tub"-curve for a building

As to information, measures should be taken to ensure that all valid information is registered. This can be done by giving each building or unit a unique identification number to be used in reporting and in the accounts (cost carrier). The job ticket is one of the main means of bringing information together. All relevant details should be recorded on the job ticket and in the accounts where possible.

Regarding other LCC a few words should be said about costs for flexibility measures. It is often argued that a certain amount of flexibility should be provided for in a building. The question is to what extent and at what costs. Investigations have shown that the measures taken sometimes do not lead to any cost savings and further that the user is unaware of the measures undertaken in the building [6].

One of the key issues of the processing of operations and maintenance costs is the calculation of present worth. The traditional way with compound interest leads to such a degrading of future costs that they loose almost all impact on the decision to invest in more durable designs and materials. Thus it does not pay to introduce designs with lower operations and maintenance costs when the interest rate is high. This fact has been recognized and given rise to doubts about the usefulness of such formulae [7]. In seaking a solution to the problem those involved have chosen low discount rates (free from inflation). Further reductions have been attained by considering the extraordinary cost increase for e. g. fuel and labour.

The conversion of operations and maintenance costs to present worth should be made through a decision model. The following factors ought to be considered in the model

- the limited availability of capital
- development of costs for fuel
- development of labour costs for maintenance and operation of the building
- the employment situation

- the horizon of the decision
- the risk that a technical solution does not pay off
- the difficulty to rationalize the maintenance and operations jobs
- the social time preference rate (STPR).

The additional capital needed to lower the operations and maintenance costs ought to be included in the decision to build a house. This should not present a major problem as the increase normally is fairly limited if the energy conservation efforts are left aside. The latter should be financed through separate means.

A factor which deserves special attention is the horizon. When using discounting methods with high interest rates the horizon has little influence on the issue. The situation is different with low interest rates or other decision models. Then a horizon of e. g. 100 years as compared to 50 years may have a great influence on the extent to which operations and maintenance costs should be replaced by investments. The proper selection of horizon is specifically pertinent when dealing with energy conservation measures.

Another factor which needs to be considered is the STPR. It is assumed that there will always be a time preference for goods and services delivered in the near future as compared to deliveries in the distant future. The STPR could amount to 3 - 4 % per annum. From this rate the extraordinary increases in labour or fuel costs could be deducted which often leads to interest rates around zero. As an interim decision model a discount procedure with two rates is put forward. A rate that corresponds to STPR (with some correction for the social opportunity cost rate, SOCR) should be used for the first period of the life time. After a certain number of years (switchpoint n_s) a second rate would be applied. In the proposed version the second rate is zero. Under these conditions the present worth of one monetary unit as a function of time is illustrated in figure 5 and table 1.

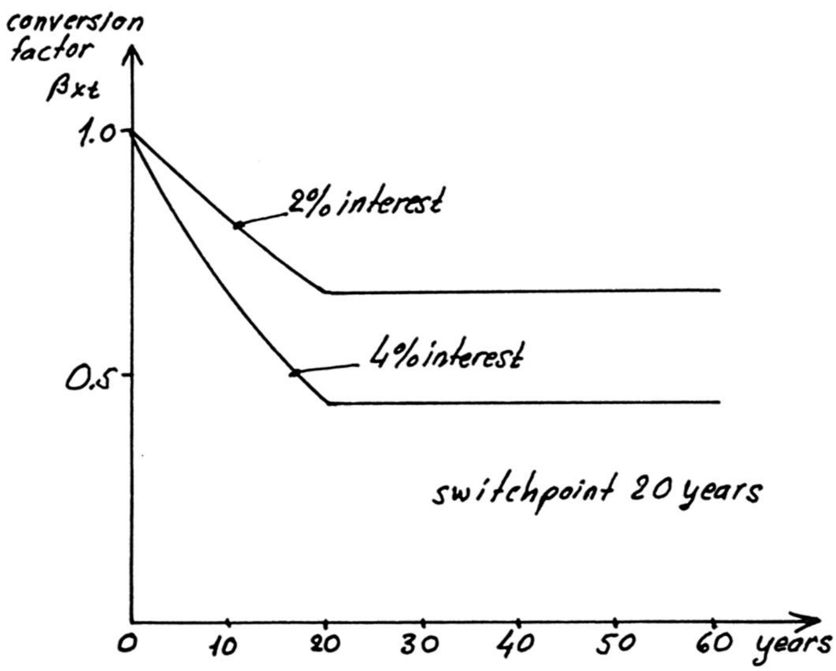

Figure 5. Conversion factor as a function of time

The parameters, first and second rate and the swithpoint can be varied to suit the requirements of the client. Note that it should be the task of the client to fix the parameters.

The present worth of operations and maintenance costs plus investment can be established for each alternative containing substitution of operations and maintenance costs with investment. On this basis a ranking list of the alternatives can be established.

The conversion factor (present worth factor) ß for continuous payment of interest is

$$\beta = e^{-nq} \qquad (n \le n_s)$$
$$\beta = e^{-n_s q} \qquad (n \ge n_s) \qquad (4)$$

where n : years
q : interest rate

year	interest rate 2 %	3 %	4 %
5	0.905	0.861	0.819
10	0.819	0.741	0.670
15	0.741	0.638	0.549
20	0.670	0.549	0.449
25 etc.	0.670	0.549	0.449

Table 1. Conversion factor β_{xt} when switchpoint is at 20 years.

The transformation factor for continuous payment of interest and annually equal amounts of payments is

$$\gamma = \frac{1-e^{-qn}}{q} \quad (n \le n_s) \qquad (n \le n_s)$$
$$\gamma = \frac{1-e^{-qn_s}}{q} + \frac{n-n_s}{e^{n_s q}} \qquad (n \ge n_s) \qquad (5)$$

year	interest rate 2 %	3 %	4 %
5	4.8	4.6	4.5
10	9.1	8.6	8.2
15	13.0	12.1	11.3
20	16.5	15.0	13.8
25	19.8	17.8	16.0
30	23.2	20.5	18.3
35	26.5	23.3	20.5

Table 2. Transformation factor (present worth factor) γ when switchpoint at 20 years.

The cost increases for labour and fuel have in the last decade been substancial and there are indications that this development will continue. Indices based on statistics could be used for the forecast of future prices. Unfortunately statistics are not available respectively not reliable for all the relevant items thermal energy, electricity, building maintenance and cleaning. In France the CSTB, a Government building research institution, has proposed a building maintenance index based on the average of the construction cost index and the construction salary index [8]. The result seems to be recommendable.

The architects and the building trade have often paid attention to the operations and maintenance costs but what has been missing is the systematic approach. To be able to steer not only the investment through cost targets but also the operations and maintenance costs is a challenge. The original purposes of cost control [9]:to give the client good value for money, to achieve the required balance of expenditure between the various parts of the building and to keep expenditure within the amount allowed by the client, need to be supplemented as follows:

- Only the items which the designers can influence should be included in the calculations.
- The lowest LCC should be aimed at.
- The scope of the LCC calculations should be defined especially regarding the borderline between the operation of the building and the costs of staff etc., required to perform the function of the organization using the facility.
- The rules for calculating the present worth of operations and maintenance costs should be laid down.
- The assumptions about the use of the building should be clearly expressed, especially concerning flexibility.

The steering of the costs to arrive at the lowest LCC is a different procedure to the control of investment costs. In the latter case we had only to satisfy the minimum requirements regarding value. When striving to lower the LCC we have to increase the value of the building by improving the qualities to save energy and to economize with cleaning and maintenance resources. The expressions energy goodness, cleaning goodness and maintenance goodness stand for the qualities wanted. They have to be optimized against the additional investment needed and this is the specific feature of LCC control. How this optimization is done for energy goodness has been shown above (formulae (2) and (3)). The process is complex for cleaning and maintenance as more factors come into play (see alt. 1 and alt. 2 above).

All three goodness factors can be expressed as future costs by making hypothesis about the impact of utilization and environment. Thus we have the situation that values can be expressed as future costs and optimization carried out by minimizing the sum of investment and present worth of future costs. This is different to the normal treatment where the maximum of the expression value divided by costs is looked for.

Value and investment can be handled in three ways:

	Value	Investment
a.	The value is kept constant	The design is changed so as to achieve the minimum investment
b.	The design is changed to reach the maximum value	The investment is kept constant
c.	The design is changed so that the relation value to investment is optimized	

The alternative a. is closest to the previous cost control. The other alternatives constitute a new approach. There will be compromises e. g. alternative c. with an upper limit for the investment.

Reverting to the resources for energy, cleaning and maintenance we find that they are proportional to the size of surfaces in the building.

The most efficient way to steer the operations and maintenance costs is thus to steer the use of space. It has been shown that a good utilization of space [6] can lead to low specific building costs. This results indirectly in lower operations and maintenance costs as there is less space to heat, clean and maintain. Another way of steering is to make comparisons with key-data from other buildings. It is important to develop statistics over such key-data (goodness data) e. g. transmission losses per net floor area, cleaning time per net floor area, maintenance costs per net floor area.

The operations and maintenance costs can be lowered not only through design measures but also by rationalizing the operation of the building. The condition-based maintenance mentioned above is here an effective means. Figure 6 shows how the total operation may look.

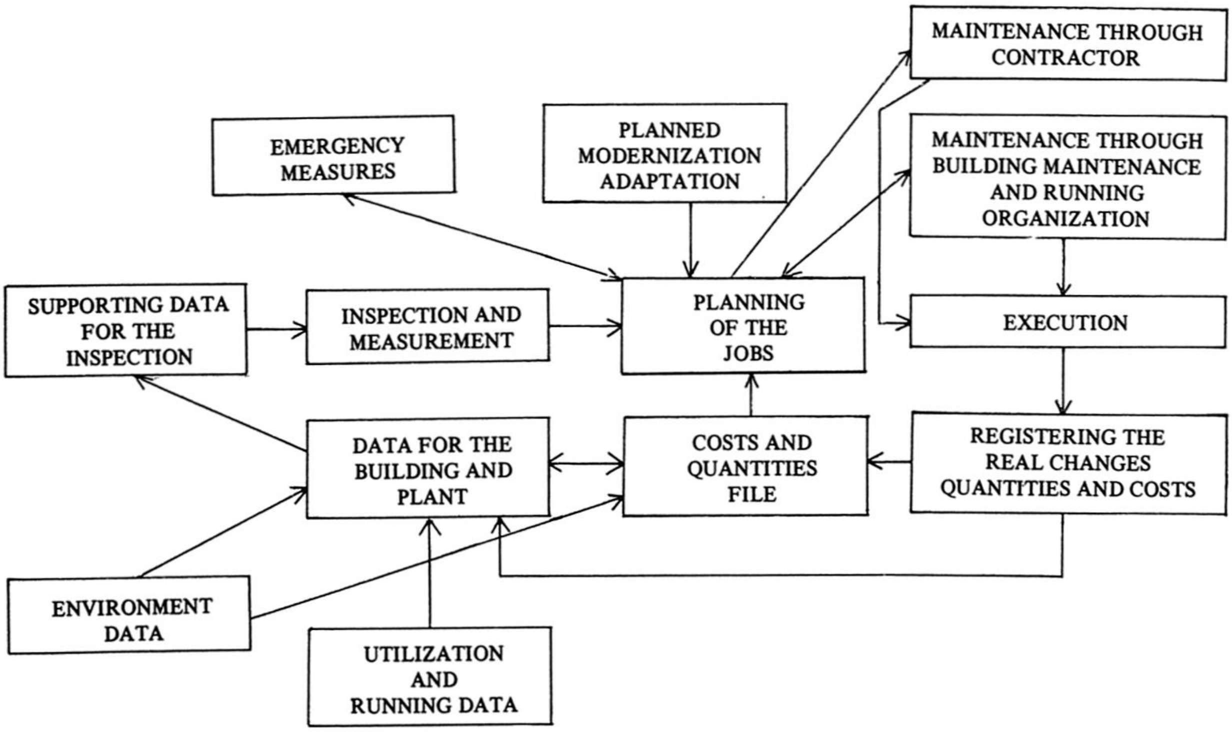

Figure 6. Maintenance and operation of a building

The figure illustrates how the data are collected and filed for each building unit. The inspection provides one part of the information needed for condition-based maintenance. The other part of the data, supplied by various measurement devices, shows the degree of deteoration of the building parts.

The improved way of operating the building will no doubt provide more accurate and reliable information. It will however take years to build up the data bank needed for forecasts and optimization calculations.

The following suggestions for decisions and development are proposed:

- the presentation of LCC should be made in a uniform way preferably as in figure 2,
- the conversion of future costs to present worth should be investigated whereby a solution like the one in figure 5 should be aimed at,
- the question about indices for energy etc. should be investigated so they can be used in the process of conversion to present worth,
- the process of collecting data should be investigated and norms proposed. The job ticket would be the main vehicle to accomplish this task. The information gathered should be computerized in a segmented way where the hierarchy could be built up according to needs through programming. It should be possible to trace information by using a thesaurus and not only through codes,
- the most up-to-date and simple methods to calculate and optimize energy conservation should be published (see e. g. formula 3),
- the field of cleaning of buildings should be explored and norms for usage of resources suggested,
- maintenance costs should be investigated in the light of modern rationalizing methods and dependence of usage and environment,
- development of a set of goodness factors and means to collect data about them is suggested.

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