# 2. METHOD

## 2.1 RANKING CRITERION

In order to find an optimal retrofit strategy it is necessary to have an accurate ranking criterion. The life-cycle cost is such a criterion, and below this is discussed in more detail. However, before this can be done, it is necessary to explain the terminology used in this thesis.

### 2.1.1 Net Present Value

When investing money into something, this is done because of the benefit that comes out from the investment. Renovation of a building is made because the old house does not give you back as much as you wanted from your earlier investments in the house. Maybe the roof is bad and water leaks into the apartments. It is obvious that a person does not want to pay very much for living under such circumstances. The landlord has to repair the roof because otherwise he will not get any tenants for his apartments. If the cost for mending the roof seems to be lower than the cost for loosing the tenants the roof will be repaired. Many times these costs can not be expressed in monetary terms e g esthetic reasons. Nevertheless, this "cost-benefit analysis" results in a choice,

In this thesis the costs come from investing in energy conserving measures e g insulation on an external wall. The benefit is the diminution in the energy cost that comes from heating the apartments to a suitable temperature.

The problem in evaluating this analysis is the lag of time between the cost and the benefit.

Fortunately, there is a method that solves this, called the Net Present Value, NPV, method.

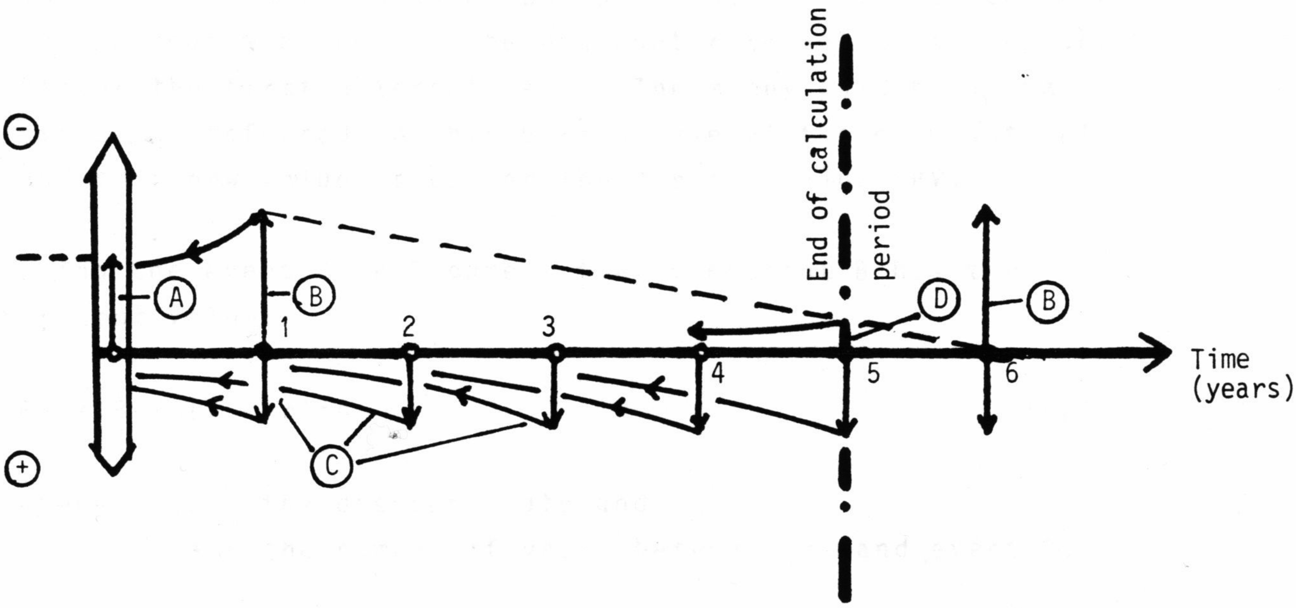


Figure 1. Net Present Value method.

In Figure 1 we have three different types of monetary events (the terminology from (8))

- o A Initial investment or first cost
- o B Recurring costs, which recur on a periodic basis throughout the life of a project
- o C Annual recurring costs which are incurred eachurring costs which are incurred each year in an equal amount or in an amount that is increasing/decreasing at a constant rate throughout the study period.

Some examples from the retrofitting terminology can be the cost for extra insulation to an external wall as a type A investment. A type B investment could be the change of boiler because its performance becomes very bad after say 20 years. The energy cost for heating the house could be an example of the type C investment. In our figure these "costs" are on the positive side of the graph, so in this case they could be the savings of energy costs entailing a retrofit.

It is easy to understand that an amount of money paid today is better than the same amount paid the next year. According to the economic theory, the discount rate tells us how much better the first alternative is. The money paid next year can be transferred to this year by use of the discount rate and this new value is called the Present Value, PV.

Using the event B in Figure 1 the investment B has the Present Value:

$$PV = B \cdot (1 + r)^{-a} \qquad (F2)$$

where $r$ = the discount rate and
$a$ = the number of years between now and event B.

The expression $(1 + r)^{-a}$ is also called the discount factor. For annual recurring events the formula is

$$PV = C \cdot \frac{1-(1+r)^{-b}}{r} \qquad (F3)$$

where $b$ = the number of years in the calculation period.

The letter D in Figure 1 shows us the remaining value of investment B when the calculation period has come to an end. This value is called the salvage value and is transferred to the base year with the method in (F2).

The formulas (F2) and (F3) gives us the possibility to calculate the NPV = the sum of PV´s for the events in Figure 1. The event A occurs this year and shall therefore not be converted. (In our case the base year = year 0)

$$NPV = -A - B(1 + r)^{-1} + C \times \frac{1-(1+r)^{-5}}{r} - \frac{1}{5} B \times (1+r)^{-5}$$

If the NPV has a positive value then the PV of the investments and costs are less than the PV of the savings. In such cases the investment is profitable, in other cases not.

### 2.1.1.1 Discount rate

Unfortunately, it is not so easy to choose the proper discount rate. Using a high rate makes investments less profitable and the reverse is valid for low rates.

Normally, the effect of inflation is removed from the rate, but this is not necessary. The theory still works with inflation included.

In the economic literature it is possible to find the most conflicting advice about the proper rate. In ((8) p 43) 10 % is specified for government projects. In Sweden it has been ordered to calculate with 4 % when considering national energy measures (9) (10). In (9) and (10) there are also referred to other investigations where higher rates are recommended, up to 10 %. More information about this subject can be found in (8) p 56), in (11) and in (12).

In this thesis I have chosen to calculate with a rate of 5 % as a basic alternative. This because of the effects when calculating with a constant rate of increase in energy cost. (See further down in the theses chapter 8.3.) Examples are, of course, also given from calculations with lower and higher rates.

### 2.1.1.2 Optimization time

As is the fact about the discount rate there is no ultimate choice of the proper optimization time or life-cycle period.

In (13) - (17) this problem is treated for different building materials. In fact buildings and machinaries never becomes "worn out" with proper maintenance. Instead the life of a building is determined of its obsolescence. The building is obsolete when a new building gives a higher performance to the owner than the old one. It is more the economic life of a building that has to be considered (18). Therefore, I have chosen a 50 year period in the basic alternative. Calculations are after that made with other life-cycle periods to find out if the retrofit strategy changes.

## 2.1.2 Life-Cycle Cost

There are a number of methods to be used ranking different investment strategies. In ((8) p 14) some of these are mentioned, i e savings-to-investment ratio, the internal rate on return on investment, the NPV, the discounted payback period and some variaties of "the quantity of energy saved per investment dollar spent".

The two first methods are technically correct when having a limited amount of money to invest, but the methods do not give an optimal solution for the entire house without a cumbersome iterative procedure.

In (18) some other similar methods are mentioned e g the return on investment (ROI) method. These are here called the revenue-to-cost methods.

In my case, where I shall try to find the best possible retrofit strategy for a house without considering how much money the initial investment cost, the method of the NPV seems to be the best. The house is a system with many different details and equipment which are depending on each other. The method used, thus, has to be superpositional i e the different cost values must be possible to sum and this sum should show the total cost for the house. Only the NPV-method does this.

The sum of all the costs for the house, during its life-cycle period, is called the LCC, or the NPV for the entire house. Having a lot of retrofit alternatives we therefore should choose those which give the house the lowest possible LCC. In (19) a more theoretical approach is made to this subject.

## 2.2 THE COST FUNCTIONS

Having found a suitable method for evaluating and ranking different combinations of retrofit measures, i e the minimized LCC, it is necessary to find the different values of the parts in the NPV function. As is shown in (18) and (19) the NPV for the whole house, considering energy retrofits, only consists of costs. No benefits are parts of the function or this part can be considered as constant. Of course, also the energy retrofits influence on the welfare in the house and thus, it could be possible to take out higher rents from the tenants. Such effects are very hard to quantify and in this thesis they are neglected. (Some efforts have been made by other authors to find such links between the welfare and the will to pay for the living in the house (20).)

In this part of the thesis I shall show how mathematical expressions can be found in order to calculate the LCC. This is here done from a principal view and further down the actual expressions for a fictional multi-family house is evaluated.

### 2.2.1 Building costs

As mentioned before, it is necessary to find a mathematical expression for how the building cost varies with the ability of the components to save energy. This ability raises when e g more insulation are put on the external walls, attic floor etc, and therefore, it would be a proper way trying to express the building cost as a function of the thickness of the thermal insulation.

For each insulation material it is also possible to calculate how much a certain amount of insulation costs, when it is added to e g the attic floor.

Plotting these figures in a graph shows the procedure.

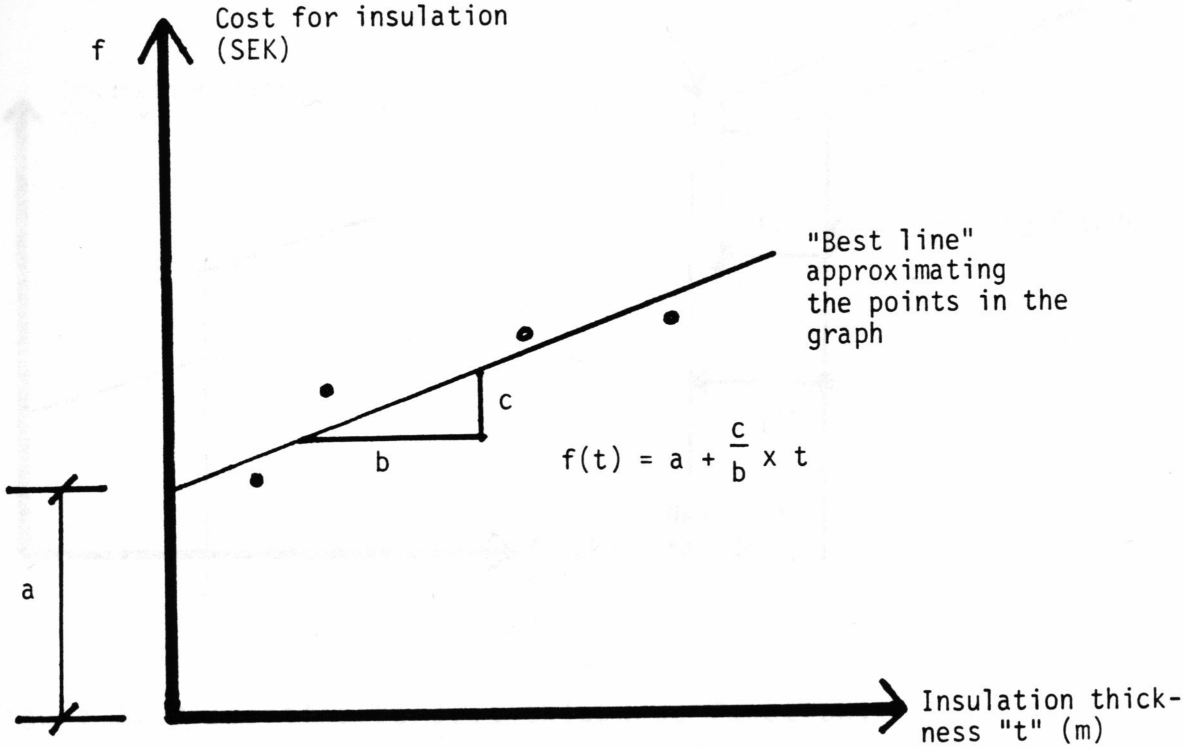


Figure 2. The cost for insulation as a function of the insulation thickness.

As is shown later it is also possible to leave the insulation thickness "t" as a variable during the calculations and find a mathematical expression without a best line fitting procedure. Then it is estimated that the cost-thickness function really is continous. Because of marketing reasons this is not exactly true, but my calculations show that the errors made, calculating on e g insulating an attic floor, are very small. Of course, the appearance of the existing house also can make the function discontinuous, e g insulation of an external wall on a house with a very small overhanging roof. This is shown in Figure 3.

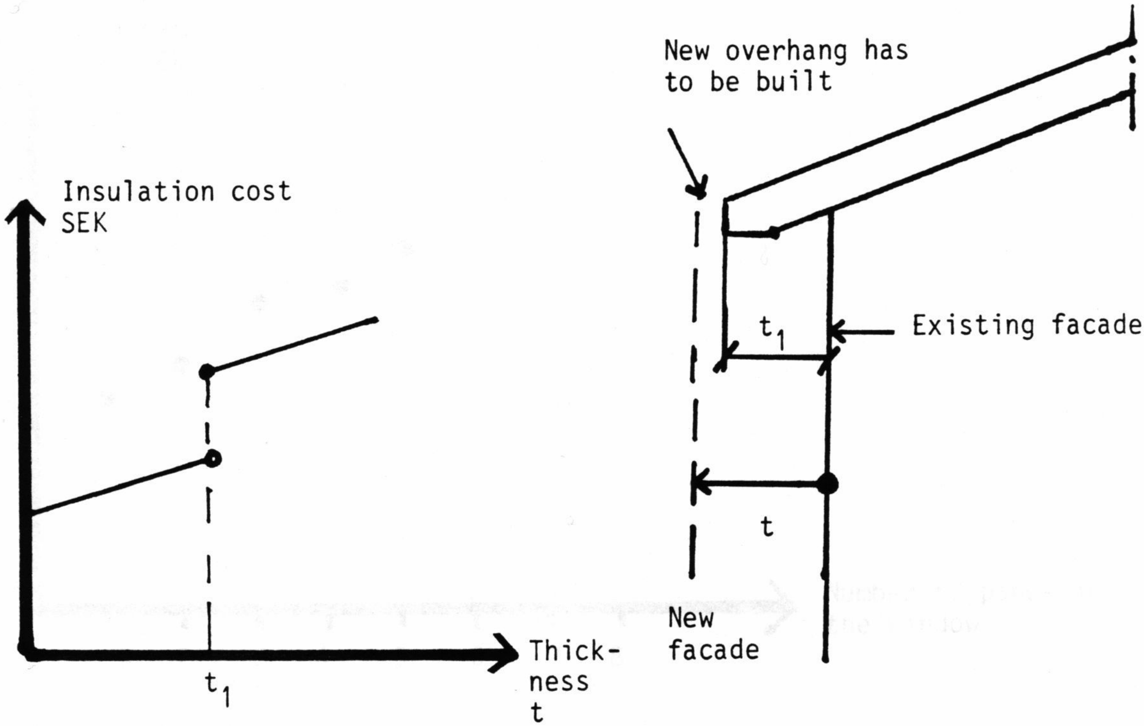


Figure 3. Discontinuous cost-thickness function.

The problems are bigger trying to find mathematical expressions for windows. The thermal performance of windows is influenced by many variables and it is not possible to describe this in an easy way. In fact (21) shows that the difficulties are great trying to solve the thermal insulation performance of windows during darkness in an analytical way. The problem increases when the influence of solar radiation also shall be considered. This is discussed more in Chapter 4.1.4, where some calculations have been made for Swedish conditions.

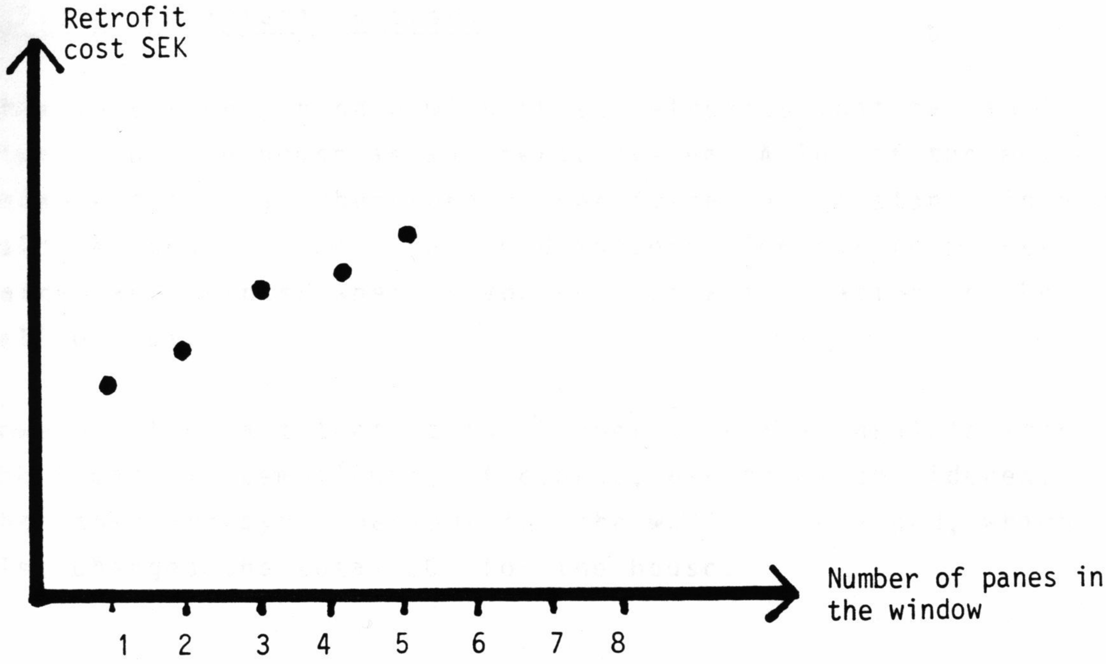


Figure 4. Retrofit cost function with discrete values.

I have found that it is suitable to use the discrete values for each type of window during the optimization process and Figure 4 shows this cost function from a principal view.

## 2.2.2 Acquisition costs, heating equipment etc

In the same manner it is possible to find mathematical expressions that approximately reflect the real cost for buying and installing heating equipment, ventilation facilities etc. Investigating the pricelists for e g boilers, the costs to a great deal depend on the power that has to be installed. The cost for installing the equipment depends to some extent on the weight of the boiler, which also depends on the power. An expression that describes the cost as a function of the installed power therefore seems suitable. The cost for ventilation equipment in the same way can have the flow of air as a variable.

### 2.2.3 Maintenance costs

This thesis only handle with those retrofits that has an influence on the house as an energy system. A lot of the maintenance costs can therefore be considered as constants in our calculations. A facade very bad in condition has to be repaired and painted whether you put extra insulation on the wall or not.

However, the fact that it is cheaper to extra-insulate when the facade is demolished, of course, has to be considered. Then the life-cycle periods for the wall are changed, which also changes the total LCC for the house.

### 2.2.4 Energy or running costs

In order to get lower energy costs we can act in two different ways. One is to retrofit the house with energy conserving measures. The other is to make the energy losses cheaper. The heat transmitted through e g the external wall can be diminished by adding more insulation to it. See (F1) Another way to lower the costs is to install a heat producing equipment with lower running costs than the existent heating system have. An example of this is to install heat pump that takes the major part of its energy from a lake or the earth. Combinations of these two different strategies can, of course, be the solution to the optimization problem. As before it is necessary to find mathematical expressions for the energy losses and the energy production costs in the house. An example using the external wall is described in Figure 5.

A very thick wall with a low U-value (thermal transmittance) implies a very low energy cost. We can see that the function energy cost to thickness of insulation are non-linear. (Using the linear expression energy cost to the U-value makes the building cost U-value function nonlinear, so this will not solve this inconvenience.) Later in this thesis a more elaborated discussion will take place about the thermal performance of walls etc. (22) also gives an easy understandable review about this.

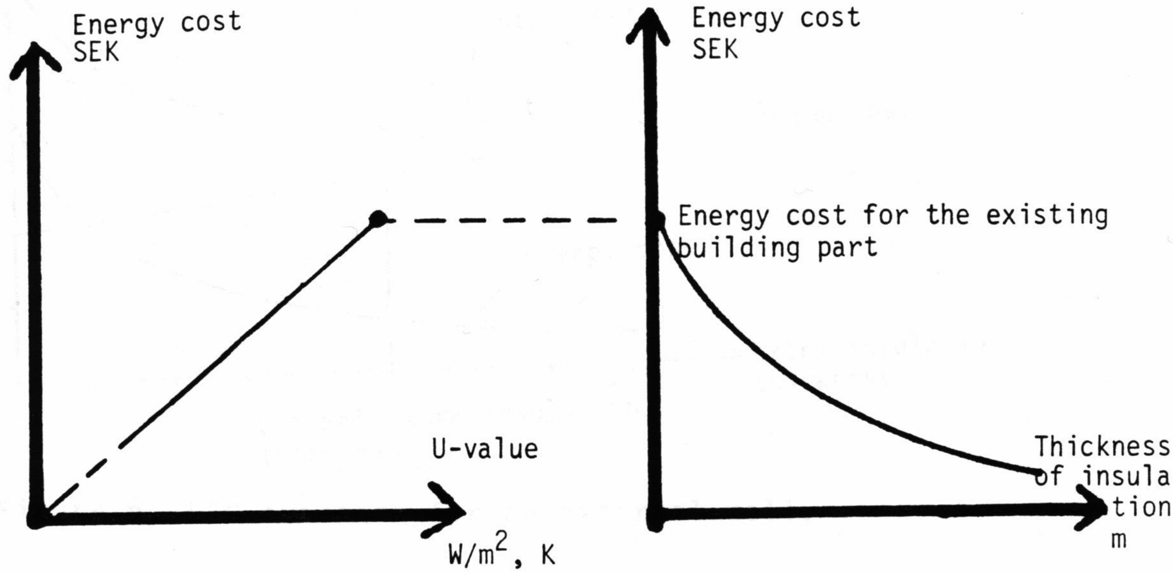


Figure 5. The energy cost function.

Changing the heating equipment in order to get lower running costs can be done in two ways. Number one is to choose a system with higher efficiency, changes in (F1) Number two is to choose other "fuels" for the heating system, e g fire wood instead of oil. It might also be cheaper to produce the energy somewhere else, e g electricity or district heating systems.

### 2.2.5 Life-cycle cost function

Having found mathematical expressions for the building-, maintenance- and running costs we "only" have to calculate their present values for the base year and sum them to find the NPV or the LCC. Figure 6 shows the procedure for the external wall.

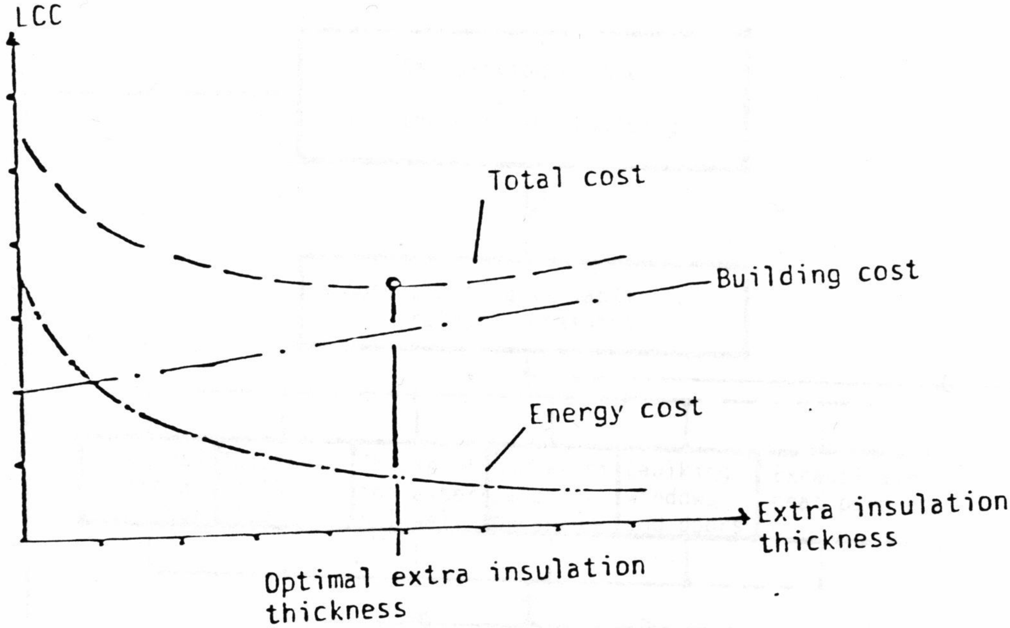


Figure 6. LCC-function for an external wall.

Finding the LCC for the whole house, however, is a little more complicated because the energy cost depends on the heating system, and the proper heating system depends on the amount of insulation on the walls. One way to solve this problem is to calculate the LCC for a number of discrete varieties of thermal insulation and other retrofits, and simply choose the lowest found LCC.

This procedure is shown in Figure 7.

Of course, it is a very cumbersome method to find the lowest possible LCC and the optimal retrofit strategy. Even with the use of modern computers this will take a lot of time, and the fact is, that by examining the mathematical performance of the house and the intervals, where the optimal parameters usually emerge, it is possible to reduce the process substantially.

The optimization technique used in this thesis varies for different retrofits and it is not fruitful to describe this before adequate mathematical expressions have been presented. It is also necessary to elaborate the mathematical problem in a form that is easy to handle. This is described under the headline "The Model" further down in the thesis.

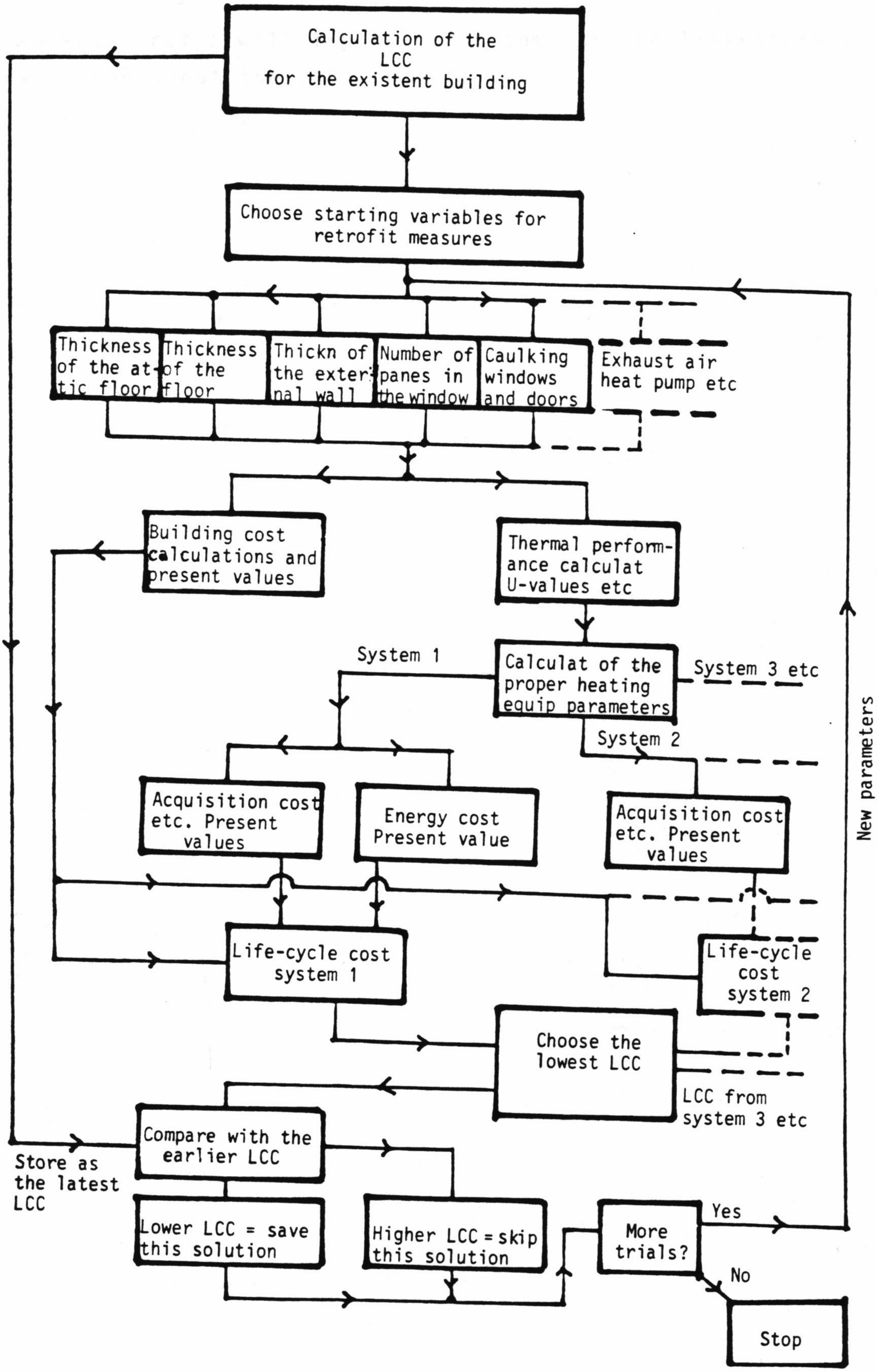


Figure 7. Trial and error procedure in order to find an optimal retrofit strategy.

However, first I will try to brief some of the literature I have found about the LCC subject.