## 5. OPTIMIZATION TECHNIQUE

Considering the model, as it is shown in (F40) and (F41), it is nonlinear in the expressions for the insulation parts, i e attic floor, external walls and the floor. The rest of the model is an integer problem, where the variables H, Y and X only can have binary values 0 or 1. Further, all of the constants only contain the binary variables and if the insulation expressions could be transformed to linear expressions the model could be solved using a mixed integer programming method. As is shown in (7 p 315) a nonlinear function can be piecewise linearized. The nonlinear function will then transform to an expression like: $f(a) \times \lambda_1 + f(b) \times \lambda_2 + f(c) \times \lambda_3$ .....

The function values f(a), f(b) .... etc has to be calculated from the nonlinear function for the values a, b ..... The first part of the model will then look like $H_1(Y_1(A \times \lambda_1 + B \times \lambda_2 + C \times \lambda_3.....)$, where A, B and C etc are constants, and $\lambda_1$, $\lambda_2$ are normalized to one or zero. However, a linear program, LP, cannot solve expressions like $Y_1 \times A \times \lambda_1$ because $Y_1$ and $\lambda_1$ are variables that are multiplied with each other. This is so even in this case, where $Y_1$ and $\lambda_1$ are binary variables and only can have the values 0 or 1. In (7 p 470) one method is mentioned to transform the $H_1 \times Y_1$ expression to a linear expression in the case both the variables is binary.

Solving integer problems is possible using the branch-and--bound method discussed in (7 p 472) or in (32 p 150). This is done by first solving a continuous LP problem that can be exactly solved, e g by the simplex method. After this solution is reached a new LP problem is constructed using the solution from the first one. Examining all of these new solutions to the constructed LP problems it is obvious that a lot of those will have higher objective function values and thus can be excluded, and the integer problem is solved after some iterations.

However, this is a rather cumbersome method solving my own problem. In fact, looking at the process calculating all the constants to the final problem, piecewise linearization etc makes this a very unwieldy method. It is obvious that it is easier to start the optimization when the constants are calculated exactly as is done in the Chapter 4. The main work is to calculate the constants and when this is done it is easy to compare these and see which has the lowest value. My method to solve the problem is therefore to calculate the total LCC for the existing house as is shown in Chapter 4.1.6.2.2. After this is done I introduce one of the retro-fit measures and calculate the new LCC for the house. If this new LCC is lower the measure is chosen by the program if not, the original LCC still is the best one. All the envelope retrofit measures are tested in this way and the total optimal strategy thus can be chosen. After this is done a new heating equipment is chosen and all the envelope retrofits are tested and so on. Of course, there has to be an immence amount of calculating, but by the use of modern computers, in my case a NORD 570 machine, the process only takes about 30 seconds. Then 8 envelope retrofits and 7 heating systems are tested. It is obvious that the integer programming method described above will be a more cumbersome method. The process I have chosen can be depicted as shown in Figure 26.

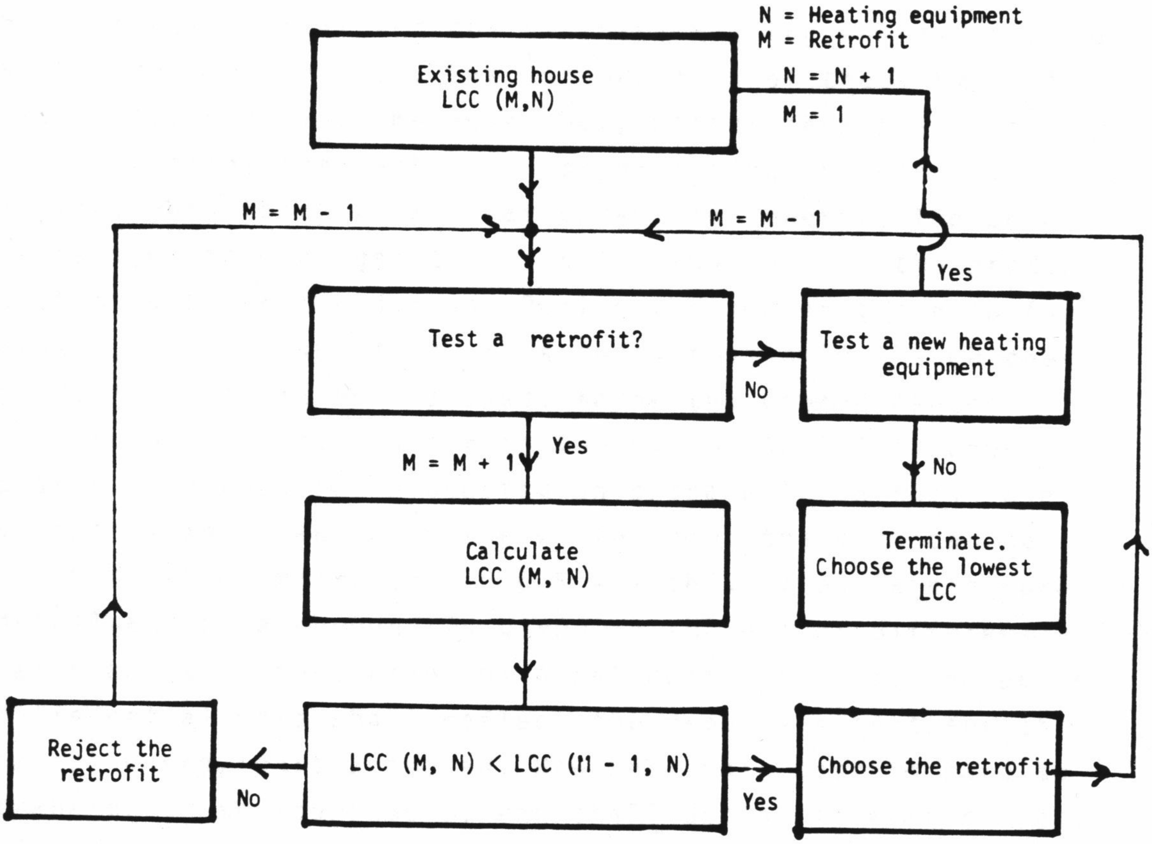


Figure 26. Optimization technique.

Before showing some results from my calculations I will discuss the use of differential rates for energy.

## 6. DIFFERENTIAL RATES FOR ENERGY

During the latest years a new type of rate for energy has been introduced from the power companies. As mentioned before both the electrical and the district heating energy cost thus varies during the year. The introduction of these type of rates have been made because they, better than the other types, reflect the real cost for producing the energy. In the winter, when there is a great demand for energy, the power company maybe uses gas turbines "on the top" of the producing system to cover the demand. During the summer the need for heating is very small and this means that only the cheapest producing facilities are used. Maybe the demand can be covered by redundant water in the hydro electrical power plants. The cost for producing an extra unit in this case almost is zero, while in the winter time the cost can be 0.5 SEK/kWh or more. In (70 p 5 - ) this is explained more in detail and a background is given to the use of differential rates and the short range marginal cost theories. The perfect differential rate shall reflect the producers cost for the latest energy unit produced. However, this cost is hard to transfer to the consumers, who shall decide if more or less energy shall be consumed. Some efforts have been made to build such equipment, but these are not in common use. The power companies, thus, have introduced the next best differential rate, the time of use rate, where the consumer is in-informed of the energy cost by the time of the year and the hour of the day.

The electrical rates for Malmö for our energy demand is 8 400 SEK in annual and an energy price of 0.345 SEK/kWh during November - March, Monday to Friday 06.00 - 22.00 and 0.16 SEK/kWh during other periods. To these prices the energy taxes 0.072 SEK/kWh shall be added. (71).

For district heating the prices are shown in Chapter 4.1.6.3.2.

It is easier to calculate the LCC for the district heating because the time-of-use rate has a different price depending on the month and there is a possibility to use the monthly mean temperatures shown in Table II.

The electrical rate differs also during the day, which means that it is necessary to examine the climate, not only for the different months but also the variation during the day. Thus, these types of electrical rates have to be excluded from this thesis and are left for future research.

## 7. THE INFLUENCE OF THERMAL CAPACITIES IN THE BUILDING

Using the LUT-concept, earlier discussed, makes it possible to calculate the demand of power in the house, because of the proposed lowest possible outside temperature. In (89) the background to the LUT concept is discussed and some calculations are made for different climate periods con-cerning the time constant in a building. In our case the temperature chosen was LUT 1 = -16 °C. If my building could be considered as heavy, LUT 5 could be used, and -12 °C then is proposed. When retrofitting a building, i e putting more insulation to the walls, better windows or making the ventilation system not so energy consuming, of course, the influence of very short periods, with low outside temperatures deminutes. In this thesis I will only give a brief view of this problem of finding the "thermal answers" from the inside climate, when fluctuating the outside temperature.

In (26 p 107 - ) there is some analytical solutions for some simple cases. Assuming a single-lump heat capacity, where the temperature in the lump is considered the same through the lump, the temperature can be calculated as:

$$\frac{T-T\infty}{T_0-T\infty} = e^{-(hxA/\rho xcxV_0)x\tau} \qquad \text{(F44)}$$

where $T\infty$ = The surrounding temperature

$T_0$ = The temperature when the time = 0

$V_0$ = The volume of the lump whith the density and the heat capacity = c and

$\tau$ = The time

when $\tau = \rho xcxV/(hxA)$ the expression (44) will become $T - - T = T_0 - T \; e^{-1} = T_0 - T \times 0.3679$.

$\rho \times c \times V_0/h \times A$ is called the time constant because it has the dimension time. However, the conditions in a building are not very similar to a lump, and the author also shows a solution for a two lumped system, when the walls could be considered as one lump and the air inside the building another. Unfortunately, the air has a very low thermal conductivity and the temperature throughout the lump will differ a lot. The assumption that the air is a lump will thus not work very well.

Using the method in (26 p 110 "one lump method") it can be found that:

$$\frac{T-T_o}{T_i-T_o} = e^{-(\Sigma(U \times A)+V \times c_{pa})/m_b \times c_{pb}))\times\tau} \qquad (F45)$$

and the time constant = $\dfrac{m_b \times C_{pb}}{\Sigma(U \times A)+V \times C_{pa}}$

Here $T$ = The temperature in the building at the time

$T_i$ = The starting inside temperature

$T_o$ = The outside temperature

$\Sigma U \times A$ = The sum of all U-values multiplied with the corresponding area

$V$ = The mass flow of ventilation air in kg/h

$c_{pa}$ = Heat capacity for air in Wh/kg K

$m_b$ = The mass of the building

$c_{pb}$ = Heat capacity of the building

In (73 p 26) the process is explained more elaborate.

It shall also be noted that this solution also considers a transient increase/decrease in the temperature, which never happens in reality. Using (45) will thus probably not give very accurate results.

In (73 p 27 - ) the author uses a mathematical model, where also the heating equipment is considered, however, with the lumped capacity concept. In (74) several models are discussed using data from real houses. The time constants have been calculated from temperature measurements in the houses. Unfortunately, only single-family houses have been examined. The estimated time constants in these varied from approximate 100 to 200 hours.

There have also been calculations about using the building construction to store heat. The climate from a test year with temperature measurements every hour has been used to compute if the mass in the construction has any influence on the energy demand in the building. No retrofit measures, however, are discussed (75). In (83) the effect of the thermal mass influence is calculated to 1 - 3 % of the total annual heat demand.

In (76) a rather thorough discussion is made about the time constant subject. Some measurements from real buildings are also mentioned. The constants varied from 30 - 100 hours. Further, there are several theoretical solutions to the differential equations that solves the assumed model of a building. Another report concerning this subject is (77) dealing with heat losses to the earth under the house. In my thesis it is out of the scope to solve such equations and, furthermore, there are so many assumings made that differs from the reality that the results probably will be inaccurate. In (90 p 216) a slightly different method is used. The model consists this case of a slab of material that has one of the sides adiabatic and the other in a fluid. In (92) the author deals with the model in a mathematical way.

The subject is also treated in (95).

However, the consideration of the time constant of the building makes it possible to calculate with a higher "lowest outside temperature". In (78) the Dimensioning Outside Temperature for a light building in Malmö can be calculated, according to the National Board of Planning and Building. Unfortunately, this is only valid for single family houses. However, the DOT can differ up to approximately 10 °C with this method. Assuming this is relevant also for multi-family buildings, the LUT 1 used in Chapter 4.1.6 could be changed to -6 $^{o}C$ for a highly insulated building with ventilation retrofit. Using this temperature on the attic floor retrofit with the existent oil boiler in Chapter 4.1.6.1.3 the power cost expression changes from $729/(0.04 + 0.8 \times t_{af})$ to $527/(0.04 + 0.8 \times t_{af})$, which, however, can be neglected when calculating the optimal insulation thickness.

For other heating equipment with high "power costs", e g the heat pump in Chapter 4.1.6.4.3, the influence of a lower outside temperature will change the expression from $8\,988/$ $/(0.04 + 0.8 \times t_{af})$ to $6\,491/(0.04 + 0.8 \times t_{af})$.

$$\text{The } t_{af} = -\frac{0.04}{0.8} + \sqrt{\frac{12\,224}{300\,000 \times 0.8}} = -0.050 + 0.226 = 0.176 \text{ m}$$

The LCC becomes 1 137 365 or approximately 25 000 SEK cheaper than the earlier calculation in Chapter 4.1.6.4.2. It is obvious that in some cases there can be a different retrofit strategy considering the heat capacity and time constant of the house, but mostly the strategy will not change because of this.

As mentioned above I have changed the optimization technique a little in order to find the true optimal retrofit strategy. Using the model I have developed, it is easy to change some of the input data for the building or the boundary conditions, and I will thus in the last chapter of this thesis give examples from some of these sensitivity calculations and case studies.