APPENDIX III

SOME OPERA SUBROUTINES

The OPERA model has several subroutines following the main program. In this appendix five of those will be presented. The five subroutines are used for calculating:

- The number of degree hours
- The inevitable retrofit cost
- The present values
- The proper energy prices
- The energy balance for the building

AIII.1 THE NUMBER OF DEGREE HOURS

In Sweden it is common to use the degree hour concept in order to calculate the annual energy demand for a building. The degree hours are used in OPERA e g for the energy balance calculations and thus it is convenient to use monthly mean outside temperature values. The equation used for the calculations is:

$$DH = \sum_{n=1}^{12} (T_i - T_{s,n}) \cdot \tau_n \qquad (\text{AIII } 1)$$

where DH = the number of degree hours for one year

n = the number of the month

T_i = the desired inside temperature

$T_{s,n}$ = the mean outside temperature at month n, site s

τ_n = the number of hours in month n

The process is described in detail in [3 p 43].

The numbers of degree hours for each month are also stored in an array for later calculations on e g differential rates or tariffs.
In the subroutine the desired inside temperature is read as an input parameter. Traditionally this temperature has been used to simulate the contribution of free energy, e g solar gains in the building. This can be done by setting this value lower than the desired inside temperature.

In Sweden 20 °C are normally considered as an adequate inside temperature, but 17 °C are used for the energy calculations. Due to this it is assumed that the free heat takes care of the remaining three degrees. A more detailed discussion about the degree hour concept can be found in [22].

In [3] 20 °C was used for the inside temperature and subsequentely the influence from the free energy was neglected. However the calculations were elaborated for a number of different climates and thus for a number of different amounts of degree hours.

Discussions with many interested readers of [3], proposed the use of energy balance calculations instead of using the traditional degree hour concept. The method used in OPERA is presented in [23], where the energy losses and heat production in the building are calculated with an extensive use of energy balances. This also means that it is possible to take solar gains and free energy from appliances into proper consideration.

AIII.2 THE PRESENT VALUE CALCULATIONS

When calculating the LCC it is important to compare the building costs, the energy cost etc on one special occasion, the base year. It does not matter which year this is, but it is essential that the same year is considered for all the costs when adding them together. A method that transfer costs, occurring at different occasions, to one base year, is called the net present value method. The method is described in detail in [3] and is well known from economic literature and will thus not be presented here once again. Only the formulas used in OPERA are shown. For a future non-recurring cost the Present Value can be calculated as:

$$PV = B \cdot (1 + r)^{-a} \qquad (\text{AIII } 2)$$

and for annual recurring costs as:

$$PV = C \cdot \frac{1 - (1 + r)^{-b}}{r} \qquad (\text{AIII } 3)$$

where:
B = The cost for one measure
r = The discount rate
a = The number of years from the base year to event B
C = The annual recurring cost
b = The number of years in the calculation period

If the considered measure has a longer life than the total project, the remaining, so called salvage value, has to be subtracted from the net present value. This value is also calculated by use of expression (AIII 2). This equation is the only one used in the subroutine while the annual recurring costs are calculated in the main program. This is because there is no need to calculate this more than twice for one program cycle. The discount rate and the project life are constants during this calculation.

The input parameters in this subroutine are the cost for measure B and the discount rate r, in equation (AIII 2), but also the total optimization period, b, the number of years before event B happens, a, and how long it takes until it happens again.

The output parameter is the present value for the measure under consideration. In appendix I, page 111 an example is shown using equation (AIII 2).

AIII.3 THE INEVITABLE RETROFIT COST

When calculating the total LCC for the existing building it is necessary to find out how much the inevitable retrofits cost. One example of such a measure is changing windows because of rot in the frames. The retrofit measure in this case, is implemented from other than energy conservation reasons and is thus considered as inevitable. Nevertheless, they have to be taken into proper account, because if an energy retrofit is implemented at the base year, the following inevitable retrofit periods will change, and the cost increases. The savings from the energy conservation thus have to be higher than the increased retrofit cost if the retrofit will be profitable. The subject is discussed in detail in [3 p. 53].

The subroutine serves the main program with the calculations concerning the building envelope, i e the attic floor, the external walls, the floor and the windows. The procedure is depicted in figure AIII 1.

In the subroutine the input parameters are:

- the area of the building part
- the initial cost, i e the inevitable cost, see C_1 in equation (5), page 38, in the main part of the thesis
- the life-cycle for the new building part
- the remaining life-cycle for the existing building part

Each building part has an assigned parameter which runs from 1 to 8. Part number:

1 = the attic floor
2 = the floor or "basement equivalent"
3 = the external wall, outside insulation
4 = the external wall, inside insulation
5 = windows to the north
6 = windows to the east

7 = windows to the south
8 = windows to the west

The subroutine starts with calculations for the attic floor, and calculates the inevitable retrofit cost for one occasion i e " B " in expression (AIII 2). After this is done the present value is calculated by calling the applicable subroutine. The process is repeated until all the building parts are treated. The total present value of the inevitable retrofit cost has then been found.

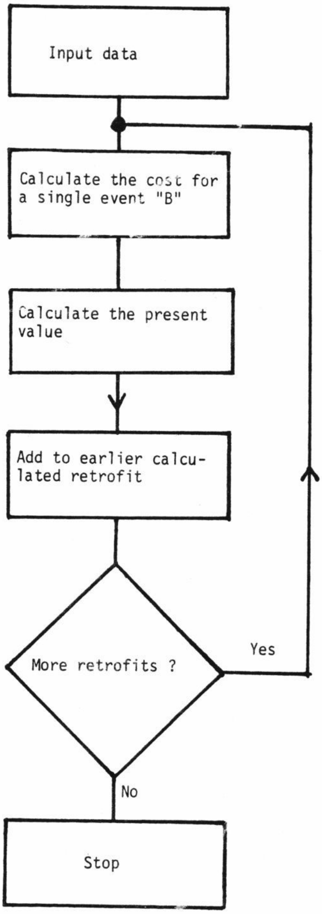

Figure AIII 1. Inevitable retrofit cost subroutine, flow chart.

AIII.4 THE ENERGY PRICE SUBROUTINE

The existing heating system in the building influence the LCC very much. One variable in the input parameters tells the subroutine which energy source that shall be used, i e:

1,2 = Oil
3,5,6 = Electricity
4 = District heating
7 = Differential district heating, time-of-use, rate
8 = Differential electricity, time-of-use, rate
9 = Bivalent oil-boiler, ground coupled heat pump system
10 = Bivalent oil-boiler, outside air heat pump system

In the main part of the thesis the heating systems are dealt with in detail and here it is only explained that the subroutine provides a proper energy price and a connection fee, if applicable.

The energy prices must be given to the model in SEK/kWh, efficiency excluded:

- the price for oil
- the price for electricity
- the price for district heating
- the price for district heating, differential rate
- the price for electricity, differential rate

The first three values are used directly as they appear in the input data file when the heating systems 1 - 6 are considered.For the systems 7 and 8 some calculations must be elaborated in the subroutine, see page 86 - 90. The bivalent systems 9 and 10 only use the subroutine to get the oil and electricity price. In appendix I page 107, and in [29] these systems are treated in detail.

AIII.5 THE ENERGY BALANCE SUBROUTINE

As mentioned above it is necessary to calculate the energy balance for the building in order to find the relevant heating cost. The subroutine uses the values of free energy from appliances and solar gains through windows as input parameters and they are not calculated in the program. Other input parameters are the monthly amount of degree hours from formula (AIII 1) and the sum of the transmission and ventilation factor calculated as:

$$\mathrm{TRANS} = \sum_{n=1}^{m} (U_n \cdot A_n) \qquad (\text{AIII } 4)$$

$$\mathrm{VENT} = H \cdot BA \cdot RN \cdot \rho \cdot cp \qquad (\text{AIII } 5)$$

where n is the building part indices, m the number of building parts, U is the thermal transmittance and A is the area for the building parts. In the formula (AIII 5) H is the distance between the floor and ceiling in an apartment, BA is the net dwelling area, RN the number of air renewals in the apartments, ρ the density of air and cp the heat capacity. A more detailed discussion about formula (AIII 4) and (AIII 5) can be found in [3]. The subroutine is depicted in figure AIII 2.

The calculations start with reading the total amount of free energy from solar gains and appliances. The values are given in monthly mean values for one year. Calculations in the main program provide the subroutine with the total energy losses in the building using the expressions (AIII 1, AIII 4 and AIII 5) above. The total losses are then subtracted from the total gains and the result is tested if negative or not. If it is negative, the gains are bigger than the losses and the heating equipment can be turned off during the whole month for space heating purposes. As is shown in [23] this is important to consider, when deciding the proper optimization values for both the heating system and the envelope retrofits. The heating system shall of course only be optimized for the heat actually produced in the facility and the free energy during the year has to be excluded from the total energy losses in the building.

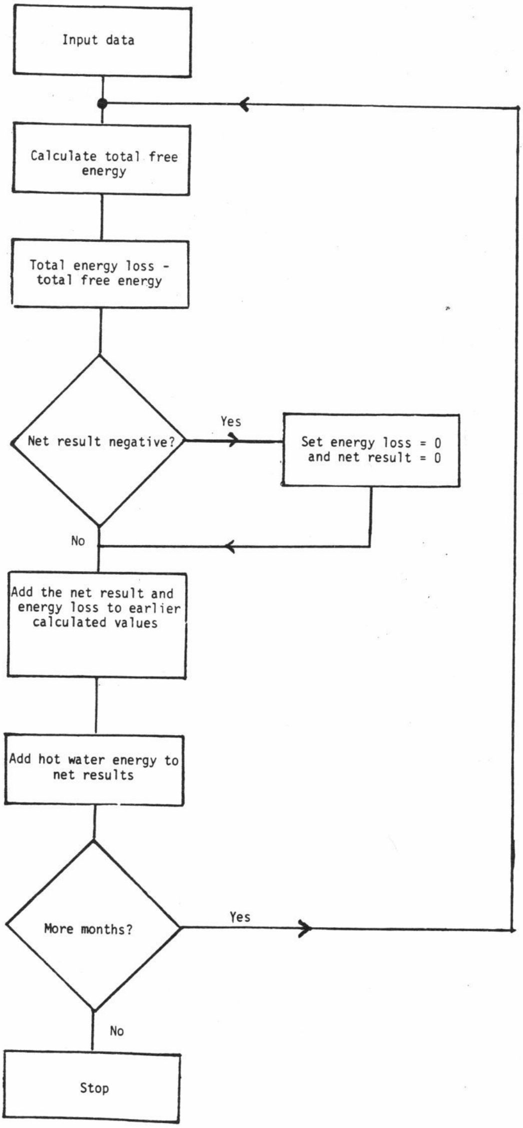

Figure AIII 2. Energy balance subroutine, flow chart.

The envelope retrofits, however, shall not be optimized for the same amount of energy. During most of the year the free energy is valuable. If there is no free energy the heating system must produce the heat. Only during the months when the heating system is not working with space heating, the free energy is of no value. It will only raise the temperature inside the building to an uncomfortable level. In those cases the free gains of course are useless.

Because of this it is necessary to calculate the energy balance for the existing building, and every time a new retrofit is implemented in the model. See table V at page 59 for an example.

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