2.4 INPUT DATA

The first thing to do in order to elaborate an OPERA runnning is to gather all the necessary input data about the building and the possible retrofit measures. This is a tedious work but very important for finding the true optimal solution. Fortunately, it is possible to use the experience from a number of earlier OPERA runnings, and this means that less effort can be used on such systems which almost never will be part of the optimal solution.

Such a system could be the electrically heated boiler. Due to the high energy price, this facility will seldom be the most profitable solution. On the contrary this system seems to have the highest LCC of all the examined heating systems. Small changes in the installation cost for the electrical boiler will not change the total situation and therefore it will not be worthwhile to examine this installation cost in detail. The situation is described in [25].

Other equipment or retrofits will be selected by the model very often and thus the efforts shall be concentrated on those systems. When starting from scratch with a unique building, it can be hard to consider the plausible result from the OPERA running. Thus it will be preferable to implement very approximate data in the first running and after this has been evaluated, continue with further examining of the interesting parts.

In the following section of this thesis the essential input data that have to be implemented, are described. The geometry is dealt with first and later the cost functions for different retrofit measures. In this chapter most of the information comes from [3], but new information found will of course also be treated.

In appendix II the total input file is presented, page 124.

2.4.1 Building geometry

The OPERA model is elaborated to find an optimal retrofit strategy for each unique building. It is thus important to describe the geometry of the building in the input data file.

The area of the attic floor, the external wall, the floor and the windows and their orientation have to be implemented as well as the number of apartments and the total apartment area. Some of these values are used for the thermal calculations while others are only used for the cost functions.

Today it is not possible to implement the basement directly in the input file. Instead the basement has to be simulated using other U-values or other geometry for the lowest floor in the building, see equation (9) and the discussion at page 82.

This is because it is hard to calculate the proper U-values or thermal resistance in the ground outside the basement wall. Furthermore, it is not common to use a fixed desired inside temperature in the basement. Experience from a number of OPERA runnings also implies that retrofits done in the basement seldom will be profitable due to the low inside temperature, the rather high outside temperature and the rather low equivalent U-values for the basement walls and the soil outside [14]. In [3] this is also emphasized.

The situation is similar for a crawl space instead of a basement. The building part has to be simulated using a slightly different floor in the OPERA calculations. Crawl spaces have been treated in [62], where the complexity of the problem is described in detail.

Of course it is possible to implement also those more complex situations in the model but it is questionable whether it is worthwhile, due to the above experience.

2.4.2 Existing thermal status

The existing U-values for the building parts also have to be provided to the model. Usually these values can be calculated with traditional methods similar to those in [3 p 32].

This is not the fact for the windows, which are very complex in their thermal performance and thus it is very hard to calculate proper U-values during darkness and the difficulties are still greater during day time. The situation is dealt with in [3 and 30 - 37].

However, it is not within the scope of OPERA to find an optimal window construction and thus some different constructions are tested against each other. Input to the model are the U-values during darkness. The solar gains are treated in the energy balance subroutine, see appendix III, page 148, where they are given as monthly mean values in the input file.

The existing ventilation system is expected to be of the type natural ventilation, and input is the number of renewals of air per hour.

Also in this case the reality is much more complex. The number of renewals are not the same in the different apartments and the situation will also change due to the outside temperature. In [38] the problem is examined.

Of course small changes can be made in the programming code in order to evaluate mechanically ventilated systems as well. However, those buildings are mostly not subject for renovation due to less age and better thermal envelopes.

2.4.3 Remaining life of the envelope

In [39] the importance of the remaining life of the existing building parts is shown. An external wall has a very high initial cost for extra insulation. Scaffolding and demolition of the outer part of the facade etc are expensive and thus it will probably never be profitable to put more insulation to an external wall if the facade is in a good shape. In such cases an inside insulation might be profitable and OPERA will examine this case too. However, the loss of apartment area can be a major drawback and the cost for this loss might make the insulation unprofitable.

The situation is different if the facade has to be renovated anyway. The extra cost for insulation in such cases will mostly always be profitable, the energy savings only have to pay for the extra insulation.

However, it is very hard to predict, with an absolute accuracy, how long the remaining life is. The lack of information about this subject is considerable, which is also emphasized in [3 p 26]. Nevertheless, the shape of the envelope has to be considered, and mostly it is possible to make qualified guesses about the remaining life of the envelope parts. In recent years there has been an increasing interest in predicting the remaining life of building envelope details [63 - 68].

The input values to the model must show the number of years from now to the year when the retrofit is inevitable. These values are used together with the retrofit cost functions in order to calculate the inevitable retrofit cost.

2.4.4 Ventilation system

The existing ventilation system is assumed to be of the natural ventilation type. The number of renewals of the air has to be implemented in the input file and the value is used for the thermal calculations of the building. This problem has been dealt with in [3], and in [60] some figures presented, show the situation in a multi-family house in Gävle, Sweden. The remaining life of the ventilation system is assumed to be very long and thus no inevitable retrofits are considered at present, in the OPERA model. It is also possible to simulate the use of air heat exchangers by providing the program with a factor showing the efficiency of the equipment. The situation is described in [3 p. 84].

2.4.5 Heating equipment

Input data concerning the existing heating system is the:

- Thermal power of the equipment
- The type of equipment
- The efficiency
- The remaining life

The first value is used for comparing the existing power installed, with the calculated need, provided by the OPERA model. OPERA tells the user if the system is too big or too small according to ordinary design routines, common in Sweden. The model also uses the calculated power in the continuing program.

Several types of equipment can be dealt with by the model. The alternatives are described in the chapter concerning the energy price subroutine, see appendix III, page 147.(The input text must be identical to the one stored in OPERA, otherwise the model cannot recognize the system.)

The efficiency of the heating system is given as being less, equal or higher then 1.0. The efficiency for ordinary oil-boilers are approximately 0.7 while heat pump systems can have "efficiencies", COP, of the magnitude 3. There are of course difficulties in choosing the values, because no absolute accuracy can be given. In [3 p. 95] some of the problems are discussed and references are made to mostly Swedish literature.

In [40] the performance of air-source heat pumps is discussed. However these pumps were installed in single-family houses and the COP was monitored for the total heating season. The values varied between 1.10 and 2.33.

Also here, in the heating equipment case, it is important to consider the remaining life of the existing equipment. There are difficulties if an accurate value is to be provided, but nevertheless a qualified guess must be made. References like [41] can be of importance if heat pumps are considered.

2.4.6 Domestic hot water production

OPERA also has to consider the hot water consumption in the building and the model requires information about the consumption in kWh. The calculations are made, assuming that no extra power is needed in the boiler for this. This is because of the short duration of the top peak load during the coldest winter days. However, this is not the fact for the bivalent system calculations. In [29] it is shown that it is optimal to provide all the heat for domestic hot water using the heat pump.

2.4.7 Thermal properties of new envelope measures

The model also has to be informed of the new thermal conductivities in the insulation material. Values have to be provided for the attic floor, the floor and the external wall insulation. The values must correspond to the cost functions dealt with below, see page 38.

The thermal performance of different types of windows must be presented as U-values during darkness. The values must correspond to the cost functions concerning the windows, see page 39.

2.4.8 New life-cycles for the envelope retrofits

The retrofits done to the envelope will change the periodicity when the retrofits are inevitable. It is thus necessary to inform the model of the new life span for the measures. The new life in years must thus be provided for the attic floor, the floor, the external wall and the windows. The situation is discussed in detail in [3 p. 53].

2.4.9 Economical factors

One of the most important values in the LCC calculations is the discount rate. The item is discussed in [3 p. 15], and in [7 and 51] more information can be found about it. The discussion can be summed up just by saying that there is no ultimate discount rate, but the references advise us to use a rate between 4 and 11 %. The rate used in OPERA is the real discount rate, i e inflation excluded.

Neither can an ultimate optimization time or project life be found. In Sweden there is an opportunity to get special subsidies if the building is older than 30 years or if more than 30 years have passed since it was last renovated with subsidies. Also in this case there must be a qualified guess to provide the model with a suitable value.

This is also the case for future escalating, or falling, energy prices. OPERA requires a value for the annual increase in % or zero. The problem is also dealt with in [3].

2.4.10 Building cost functions

OPERA has to be informed of the building cost for different retrofit measures. As mentioned earlier there is also a need for the inevitable retrofit cost if it is related to energy conservation measures. First OPERA must calculate the present value for e g an external wall, without any energy retrofits at all. Some time, the facade has to be renovated, maybe because it is rot. Earlier in the input data file, this instant is specified and the cost function will tell OPERA how much money that has to be spent.

However, the cost function must also provide the model with the specific insulation cost.

In [3 p. 52] or in [21] it is shown that an expression for the building cost can be written as:

$$C_1 + (C_2 + C_3 \cdot t) \qquad (5)$$

where C_1, C_2 and C_3 are different constants and t equals the extra insulation thickness. C_1 shows the value for the inevitable cost while C_2 and C_3 are connected to the direct insulation cost. OPERA deals with four different expression like (5) representing the attic floor, the floor and the external wall insulation measures. The author of [57] uses a similar concept however with no inevitable cost.

The retrofit cost for the windows is described with only two constants as can be found in the following expression:

$$C_1 + C_2 \cdot A_w \qquad (6)$$

C_1 and C_2 are constants and A_w is the area for one window. OPERA can handle four different types of windows, and expressions have to be presented for each type. Dummy values can be presented for OPERA if only a few alternatives shall be considered. The procedure is described in detail in [3 p. 77].

Expressions like (5) or (6) cannot show the building cost exactly but they will give an approximate view of the real cost good enough for the purpose of OPERA.

2.4.11 Heating equipment cost functions

The cost for acquisition and installation of new heating facilities must also be known to OPERA. This is provided by using expressions like:

$$C_1 + C_2 \cdot P \qquad (7)$$

Where C_1 and C_2 are constants and P equals the demand of the system. Of course one expression has to be presented for each system under consideration. However, the bivalent systems use the expressions given for the first heat pump or the outside air heat pump and the oil-boiler. In [3 p. 95] it is shown how to evaluate the expressions.

The efficiency and the new life span for the equipment must naturally be presented.

The program can deal with such installations as chimneys for oil-boilers or drilling holes for ground water coupled heat pumps as well. All of these items have a much longer life-cycle than the precise heating facility itself, and they have to be treated separately. A chimney can have a life span of 50 years while the oil-boiler itself has a life-cycle of 15 years.

2.4.12 Cost for ventilation measures

Weatherstripping is one measure that will be profitable in most of the OPERA runnings. The program assumes that the cost can be predicted by showing the cost for caulking one window or door and furthermore to present the number of doors etc to be dealt with. Important is also to present the decrease in the ventilation flow after the weatherstripping is completed. The caulking measures are also assumed to have a life span which must be known to the model.

Exhaust air heat pumps are dealt with by presenting the cost for the heat pump due to its thermal power. The expression is similar to (7).

The temperatures of the air flowing in and out of the equipment must be presented and OPERA will calculate the proper thermal power of the heat pump and proceed with the heat pump cost. Also necessary to present is the life-cycle of the pump and its COP. Similar to oil-boilers and chimneys the heat pump needs installations with another life-cycle then the pump itself. Those costs are presented due to the number of apartments in the building and the life span of the installations.

2.4.13 Energy prices and rates

In OPERA the energy prices are presented in a separate input file. For the oil-boiler or the electricity case the energy cost must be presented, while for district heating information also is needed about the connection fee. The heat pump cases use the electricity price.

Also implemented are real tariffs for energy used by the utilities in Malmö, i e the differential rates. The tariff elements are stored in the input file and new values can easily be implemented. The design of the tariffs is dealt with at page 86 - 90.

If a completely new tariff, with a different design will be used it is necessary to make small changings in the FORTRAN code.

2.4.14 Climate conditions

As mentioned above OPERA uses the monthly mean outside temperatures to calculate the energy balances for the building. Values can be stored for a number of sites in the input data file. At present, OPERA assumes that three sites are stored, but with small changements in the code, the number can be enlarged.

In Sweden it is common to design the power of the heating equipment due to a so called lowest outside temperature. This temperature can be found in the Swedish building code and in Malmö it is set to - 14 °C or -16 °C due to different types of buildings. A building made of heavy building material will be designed according to the higher of the temperatures. When using such a method it is possible to take into account the influence of the thermal mass in the building. The problem is discussed more in detail in [3 p. 124].

2.4.15 Solar gains and free heat from appliancies and persons

The values for solar gains and free heat must be given to OPERA as monthly mean values in the input data file. The solar gains are assumed to be presented as the heat in kWh/m^2, transferred through a double glazed window for the considered orientation. Four orientations can be dealt with without any extra programming work.

Also necessary to provide are the shading coefficients concerning the types of windows described above. The subject is dealt with in [3 p. 69].

2.4.16 Output information

In the input file it is also possible to assign values for the output presentation of OPERA. More or less of the calculations can be presented at the terminal or on the line printer etc. This means that it is possible to scrutinize each step of the calculations. By small changes in the code only parts of the calculations, e g one of the subroutines or the exhaust air heat pump can be considered in detail.

By assigning other values to the programming loops it is also possible to control how many cases of discount rates etc that shall be presented by the model. This provides the operator with a very good means for sensitivity analysis, i e how much the optimal solution changes if the input data are changed, see page 75 and appendix II at page 123.