1. INTRODUCTION

The OPERA model, (OPERA = OPtimal Energy Retrofit Advisory), enables the user to find the optimal combination of building, installation and heating equipment retrofits which are possible to implement in a building. It is assumed that a multi-family building is of concern but the model will, of course, work also for single family houses.

This document emphasizes the design of the model, or the computer program, and the proper handling of it while the theories that led to the design, are described elsewhere, e.g. in [1]. References to literature, covering the theoretic background will be given when needed for the understanding of the context, but no closer explanations are given if they can be found in the specified reference. However, one of the references, [2] is very hard to find because it is out of print, and thus the necessary information is dealt with here.

It must also be noted that it is assumed that the operator is familiar with how to use and run programs in the IBM PC environment. Nothing, or very little, is mentioned here about how to use e.g. MS DOS or different editors, in order to change data in the input files.

The OPERA model is very easy to use when the input data file , see chapter 2, has been completed. When the program, and the input data file are copied to the hard disc of the system, type OPERA and press RETURN, and the program will start by asking for the name of the data file. See chapter 4 for closer details about how to use the program. There is an input file on the shipping disc, called HOUSE.DAT, which can be used for testing the program.

If the influence of the Swedish subsidy system is to be examined, this first input data file must be recalculated by using a program called SUB. The program will provide the operator with a new input data file called SUB.DAT. Use this file when OPERA asks for the input data file name. The program will then continue as if the original file was used. The subsidy system is often changed by the authorities why it was convenient to put these values necessary for calculations in an input data file too, called LOAN.DAT. The program SUB will read this file automatically and no typing is needed. See chapter 5 for more information.

Also included in this package is a program called SORAD. Together with the applicable input data file SUN.DAT, it provides values for the solar radiation through double-glazed windows in kW/m^2. The program is described in detail in chapter 6.

On certain conditions the optimization of bivalent systems may be miscalculated when the derivative method provided by OPERA is used. This prompted the design of a new program, called BIVAL, where these occational errors could be deleted. The input file to this program is created every time OPERA is run and the operator only has to start the program BIVAL. All details can be found in chapter 7.

The final program included in this package is used for a graphic presentation of the duration graph for the retrofitted building. The graphics in computers are closely related to the system used for the presentation. It has thus only been possible to design the program for VGA systems with a resolution of 640 x 480 pixels. If other graphic systems are to be used the programming code must be changed. All information is found in chapter 8.

It is recommended that the program is run, with a floating point co-processor, but it the program can be used with an emulating library as well. This library is present all the time but is not used if a co-processor is installed. Using a co-processor means that the process proceeds significantly faster.

A system with a hard disc is not compulsory, but recommended because of faster reading and writing operations.

Further it is recommended to use a printer to which OPERA can send its output. In the input data file, certain parameters can be set, in order to provide redirection of the chosen output. It is thus possible to reveal much of the calculations not normally printed out. DOS can of course also be used for the redirection and subsequently disc files can easily be used for the printing of the result.

In the following, the overall design of the model is shown and the input data files, with all the details about the elaboration, are presented. A more detailed presentation of how to run the program, and some possible problems are also shown in chapter 4. In that part of the document it is also shown how to interpret the output of the program.

The programming code is presented in the appendix in the end of this document.

2. THE OPERA MODEL IN BRIEF

When a building is to be renovated it is important to find the optimal way because, if the wrong strategy is used it might be hard to rechange the building with any profitability. The first thing to examine, is how to characterize the optimal solution. In the OPERA model it is assumed that this solution occurs when the remaining Life-Cycle Cost, LCC, is as at its lowest. The LCC for the building includes the cost for building, ventilation and heating equipment retrofits as well as maintenance and operating costs. It seems plausible that if the LCC is minimized, the best solution has been found.

The costs included in in the LCC, however, do not occur at the same time. The costs for heating the building exist as long as the building is used. Thus the different costs cannot be added without properly considering the aspect of time. In the OPERA model, this is done by use of the present worth, or present value, method, recommended by many economists today, [3]. An economic event, that will emerge in say, twenty years from now, can and must be transferred to a base year, which in the model is assumed to be at present. More

about the LCC and the present worth method can be found in e.g [4], and only the basic expressions will be shown here.
For a future non-recurring cost, B, the present value, PV, can be calculated as:

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

and for annually recurring costs, C, as:

$$PV = C \cdot \frac{1 - (1 + r)^{-b}}{r} \qquad (2)$$

where r is the real discount rate
a is the number of years until event B will occur and
b is the number of years event C ocurrs.

The values for a , b, and r cannot be chosen with absolute accuracy. The solution to this problem is to run the program several times and change the the values a little for each run. This is called a sensitivity analysis, and in fact, OPERA has a built in routine for this procedure.

One disadvantage with the LCC concept is that all the consequences from a retrofit must be described in monetary terms. The program will find the cheapest solution, but this one possibly has to be rejected for other than LCC reasons.

Two different optimization methods are involved in the procedure. One that uses the derivative of a continuous function and sets it equal to zero, and one that uses a trial and error method for finding the minimum point. The first method is used e.g. for insulation optimization and is described in Figure 1.

The cost for insulation is assumed to be reflected by a straight line showing how the cost for insulation increases with the insulation thickness.

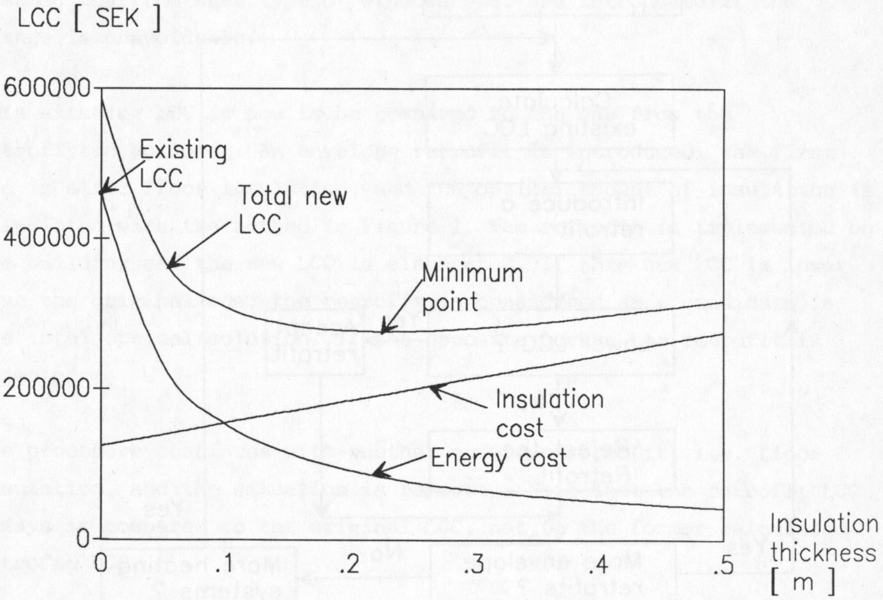

Figure 1. Insulation optimization in the OPERA model.

The energy cost, however, follows a curved line which will decrease if the insulation thickness increase. Note that both lines show the present values of the costs and thus the sum shows the total LCC for the asset. At some point on this total LCC line, the cost has its minimum value, which is calculated by the program.

The second method is to implement a measure, say a window retrofit, and then calculate if the LCC gets lower. The window itself is not optimized because of the difficulties in doing so, and thus the retrofit is introduced as a whole. Double-glazed windows are thus compared with e.g. triple-glazed ones.

The program starts by reading the input data, see Figure 2.

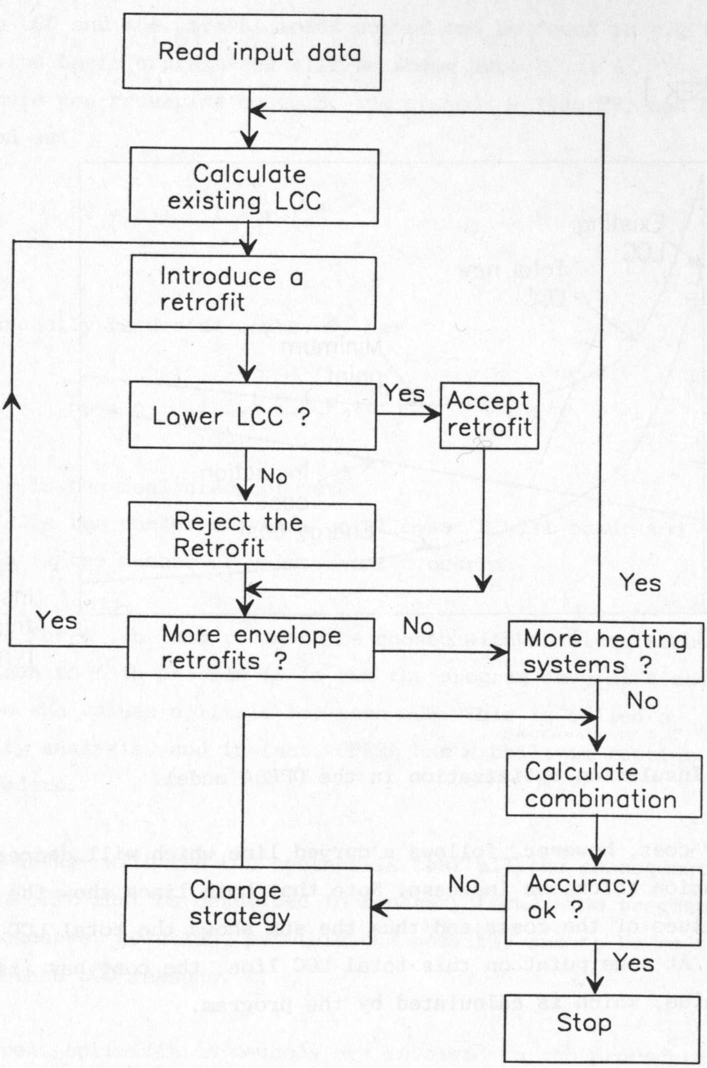

Figure 2. Schematic view of the OPERA model.

It calculates the existing LCC of the building if no, but the inevitable retrofits are introduced in the building. An inevitable retrofit, which also can be called an unavoidable retrofit, is one that has to be made from other than energy conservation reasons, like if the window frames are affected by rot and have to be exchanged for new ones. When the inevitable retrofit cost is calculated it is assumed that the same type of windows etc. are introduced if the change is unavoidable.

This existing LCC is now to be compared to the one from the retrofitted building. An envelope retrofit is introduced, the first one is attic floor insulation, and the optimal amount of insulation is calculated with the method in Figure 1. The retrofit is implemented on the building and the new LCC is elaborated. If this new LCC is lower than the original one, the retrofit is considered as a candidate in the total optimal solution. If the opposite occurs the retrofit is rejected.

The procedure continues with another envelope retrofit, i.e. floor insulation, and the situation is repeated. Note that the retrofit LCC always is compared to the original LCC, not to the former calculated retrofit LCC.

When the envelope and the ventilation retrofits have been examined a strategy has been found for the existing heating equipment. This equipment is is now changed to new one and the process starts almost from the beginning. When all the heating systems are tested, the program, mostly, has found the best solution, i.e. the one with the lowest LCC.

However, if two or more envelope or ventilation retrofits are selected in the solution, they might interact. It has been shown, [1], that this interaction almost always might be neglected but nonetheless, OPERA is provided with a routine for examining this interaction. It is also possible to choose one of the interacting retrofits and change it a little in order to examine if the LCC gets lower. Thus the optimal solution can be revealed with any wished accuracy.

The result from the OPERA running is presented in some tables, which show the strategies found best for all the heating systems under consideration, and the optimal LCC is presented in more detail. It is thus easy to find the resulting energy and power demand for the retrofitted building, the present values for inevitable retrofits, heating equipment costs and so forth. The strategy can be scrutinized in order to provide the operator with more details from the calculations. Parameters which affect the amount of output data from the program can also be changed.

Further, the program automatically provides the operator with tables suitable for a sensitivity analysis. The calculations are iterated for a number of discount rates, project lives and annual energy cost escalation rates. In the following chapter, the input data are examined in detail and references given to relevant literature.

3. THE INPUT DATA FILE

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 tedious, but very important for finding the "true" optimal solution. Fortunately, the experience from a number of earlier OPERA runnings can be used, and this means that less effort may be used on systems which rarely affect 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, at least for older multi-family buildings. Small changes in the installation cost of the electrical boiler will not change the total situation, and therefore it is not worthwhile to examine this installation cost in detail. Such a situation is described in [5].

Other equipment or retrofits are often selected by the model, and thus the efforts ought to be concentrated on those systems. Starting from scratch with a unique building, it can be hard to consider the plausible result from the OPERA running. Therefore, it is preferable to implement very approximate data in the first session, and after evaluation, continue with further examining of the more interesting parts.

In a following section of this manual all the input data that have to be implemented, are described. In that chapter most of the information is from [1] and [2], but new information is of course also treated.

In Figure 3, a print of the input data file is shown. The file consists of some 200 values which must be presented to OPERA. The program is written in FORTRAN 77 and thus there are certain rules for typing the values.

It is important to note that some of the values are floating point, i.e. they have a decimal point, some are integers, i.e. they cannot have decimal points and further some values consist of characters, i.e. they have to be enclosed between quotation marks, ' '. The program is very sensitive for these different types of values and if, for example an integer is presented, where the program wants a floating point, the session is terminated and an error message is written on the screen.

Each value must be separated by a comma, or start on a new line.

If an error is encountered when the program is started there is, however, some help for finding it. Figures, ranging from 1 to 7 are written on the screen when the input file is read. If the error emerges after the figure 1 has been written, but before figure 2 shows up, the error is in the beginning of the file. If everything works fine until number 6 is written, the error is located in the end of the file, and so forth. Exactely where the numbers are printed out, can be found in the beginning of the FORTRAN code in appendix A.

3.1 How to write it

When values are to be changed in the input data file some kind of editor or word processing program mus be used. Almost any editor will be suitable but it is important to save the file as an ASCII-file, i.e. only the text you want to change in the input file, shall be affected.

```
0
273.,273.,616.,819.
1.,0,2.8,27,1.,0,2.4,29
.8,.5,1.2
3.5
0.,50.,0.,0.,0.
.6
'OIL-BOILER',110.,.75,5.
42000.
.04,.05,.04,.05
2.
1.5
1.2
50.,50.,50.,50.,30.
50.,.05,.0,0.358
0.,260.,530.
0.,380.,500.
300.,200.,2000.
50.,390.,300.,2.8,450.
0.,1100.
0.,1300.
0.,1500.
100000.,100000.
55000.,60.,.75,15.,200.,50.
20000.,100.,.95,25.,1.,50.
40000.,60.,.95,25.,300.,50.
60000.,5000.,2.5,50.,1500.,10.
55000.,60.,.8,20.,200.,50.
40000.,6000.,66.43,20.54,15.,200.,40.,.1,7.
-.5,-.7,1.4,6.,11.,15.,17.2,16.7,13.5,8.9,4.9,2.
-2.9,-3.0,-.1,5.3,11.,15.4,17.7,16.4,12.2,7.1,2.7,.0
-12.2,-12.4,-8.9,-3.5,2.7,9.2,12.9,10.5,5.1,-1.5,-6.8,-10.1
56,250.,.1,10.
14,20.,21.,-14.
10000.,50.
10000.,4500.,10.,2.,10.
'UPPLAND 5'
1
1,0,0,0,0,0,0,0,1
4167.,4167.,4167.,4167.,4167.,4167.,4167.,4167.,4167.,4167.,4167.,4167.
4.3,8.94,18.57,28.82,44.5,53.48,50.54,36.63,23.12,13.54,5.82,3.08
8.27,17.97,41.86,61.97,87.58,90.91,89.07,75.07,53.11,28.3,10.75,5.36
29.66,43.69,73.68,75.29,82.59,76.28,78.5,79.81,79.37,61.57,32.7,21.22
8.27,17.97,41.86,61.97,87.58,90.91,89.07,75.07,53.11,28.3,10.75,5.36
.1,.6,.7
.233
.3658357,0.515,0.245
.175,120.
.2763422,300.,700.,2400.,600.,.64
.195,.195,.195,.145,.145,.145,.145,.145,.145,.145,.195,.195
830.,1030.,1230.,1640.,2060.,2380.,2900.,3520.,4300.,5420.,6760.,8400.
16.,20.,25.,35.,50.,63.,80.,100.,125.,160.,200.,250.
352,320,368,320,368,352,336,368,336,352,352,336
392,352,376,400,376,368,408,376,384,392,368,408
6000.,55.,245.
.405,.256,.218,.202,.179
```

Figure 3. The input data file to the OPERA model

Many word processing programs put other text or figures in the file in order to encounter format specifications etc. When an ordinary editor is used, the file almost always is saved as an ASCII-file and consequently it is simple to save input data files. Do not forget to save the original files or other accurate files before you change them.

3.2 How to present input data

The input data file describes the building under consideration. The geometry, the thermal conditions as well as building costs etc. are presented as certain values. As mentioned before, the model is the result of a research project and has lead to about fifteen publications in the field of building retrofits. During this work a major effort has been put on finding proper input data which reflect the building, its retrofits etc. as correct as possible. The design of the input file is a result of this research, and it is necessary to use the same method for other buildings.

It is recommended to put the geometry of the building into the original data file as a start but to leave the building costs etc. as they are. The program can then be run and the operator will be able to consider the output from the program. If the total input file is changed at the same time, reasons for errors or peculiarities that might occur will be harder to find .

The following pages show in detail how the input data are elaborated. Further details can be found in [1] or [2] but the facts presented here are supposed sufficient for an unexperienced OPERA operator. The input file presented in Figure 3 is used as a numerical example.

3.2.1 Type of file and building geometry

The first value in the input data file shows OPERA which type of file to be read. If a 0 is encountered, the file is an ordinary OPERA file while if a 1, or a 2, are found the file has been transferred to emulate the Swedish subsidy system, see chapter 5. The variable in OPERA, an integer, is called LAN. The value of LAN is checked at several places in the code, see appendix A and B.

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 values for 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 in ref. [1]. The basement is after this dealt with as an ordinary floor.

This because it is hard to calculate the proper U-values, or thermal resistance, for 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 made in the basement are seldom 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 [6]. In [2] this is also emphasized.

The situation is similar for a crawl space instead of a basement. The building part must also be simulated with a slightly different floor in the OPERA calculations. Crawl spaces are treated in [7], where the complexity of the problem is described in detail.

Of course also more complex situations can be implemented in the model but it is questionable whether it is worthwhile, due to the earlier experience.

In the following the input data is described. The parameter names, which can be found in the FORTRAN code in appendix A and B, are presented to make it easier for those of the readers who are heavy hackers and want to enhance the program code.

The four values, note the floating point, in the file show:

Area of the attic floor, = 273 m^2 AT
floor, = 273 m^2 AG
external walls,
windows excluded, = 616 m^2 AY
and the total apartment area, = 819 m^2 BA

There is also a variable named AI in the code, showing the area of the inside of the external walls. Setting a different value from the external wall area here, will lead to peculiar results. In the program code, the values thus are set equal.

The following line in the data file shows values for the window geometry. Four different orientations are dealt with. The real orientation is of no interest as long as the values are coupled to the solar gains, also shown in the input file. For simplicity, the orientations are said to be to the north, east, south and west. The values show:

Area of one north window = 1 m^2 AN
Number of north windows = 0 pcs ANN
Area of one east window = 2.8 m^2 AO
Number of east windows = 27 pcs ANO
Area of one south window = 1 m^2 AS
Number of south windows = 0 pcs ANS
Area of one west window = 2.4 m^2 AV
Number of west windows = 29 pcs ANV

The fact that an area value has been used although there is no window, is due to the fact that unpredictable results might occur when a number is devided with a very small value. It is possible, however, to use the integer 0 for the number of windows, because of facilities in the programming code. The area values are floating point and the number of windows are integers. The window area include the frames of the windows or otherwise the program expects that the frames are of the same material as the external walls.

3.2.2 Existing thermal status

The existing U-values of the building parts also have to be provided to the model. Usually these values can be calculated with traditional methods similar to those in [8] or [9].

The U-values in Figure 3 are:

Attic floor	0.8	$W/m^2 \cdot K$	BKT
Floor	0.5		BKG
External wall	1.2		BKY

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 the day. The situation is dealt with in [2].

However, it is not within the scope of OPERA to find an optimal window design and thus some different constructions are tested against each other. See [10] for information about the optimization of windows. Input to the model are the U-value during darkness. The solar gains are treated in an energy balance subroutine, see appendix III, in [1], and they are given as monthly mean values further down in the input file. In Figure 3 the existing U-value for the windows during darkness is 3.5 W/m·K. The value is supposed to reflect the situation for a double-glazed window and the variable is named MK2.

3.2.3 Remaining life of the envelope

In [1] or in [11] 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 needs renovation. The extra cost for insulation in such cases will nearly always be profitable, the energy savings only have to pay for the extra insulation.

However, it is very hard to predict the remaining life, with an absolute accuracy. The lack of information about the durability of building assets is considerable. 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. Recently there has been an increasing interest in predicting the remaining life of building envelope details and some authors could be found in [1].

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. In line 6 in the data file the values, used in this example, are shown:

Remaining life	attic floor	0 years	LT
	floor	50	LG
	external wall, out.	0	LY
	external wall, ins.	0	LI
	windows	0	LF

The abbreviations out. and ins. mean outside and inside respectively. It is important to note that these values are coupled to the present value calculations, see expression (1). They are used for calculating the so called inevitable retrofit cost, i.e. renovation for other than energy conservation reasons. Setting the remaining life to 0 for a building asset means that the retrofit has to be done immediately.

3.2.4 Ventilation system

The existing ventilation system is assumed to be of the natural ventilation type and it works only because warm air is lighter than cold air. 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. Also in this case the reality is much more complex. The number of renewals are not the same in different apartments and the situation will also change due to the outside temperature. Some references for finding this number are mentioned in [1]. In the example 0.6 renewals per hour is used and the variable name in the code is OMS.

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.

If some extra FORTRAN lines are added the use of air heat exchangers can be simulated by providing the program with a factor showing the efficiency of the equipment. This situation is described in [2].

Of course, in the same way, some small changes can be made in the programming code in order to evaluate mechanically ventilated systems, with exhaust air heat exchangers. However, such buildings are rarely subject for renovation, due to age and thermal envelopes.