do is to calculate the need for power in the building. In (5 p 237 -) one method is proposed, which is similar to the expression (F1). The outside temperature, however, can be chosen from two maps with isotherms in (5). In Malmö this temperature, called LUT 1, equals - 16 ^{o} C as mentioned above. LUT 1 is used for buildings of wood or other light-weighted material, while LUT 5 is proposed to be used for buildings of stone or heavy material. In Malmö LUT 5 = -12 ^{o}C. In subsequent chapters I will discuss the imply of thermal capacities in the building, but until then I am going to use the LUT concept in (5). Using the method in (5) makes the need for power in the existing building to:

$$P = (U_{af} \times A_{af} + U_{ew} \times A_{ew} + U_{fl} \times A_{fl} + U_{wd} \times$$
$$\times A_{w} + VF \times C_{pa} \times \rho_{a})(T_{i} - LUT\ 1) = (0.8 \times 1\ 000 +$$
$$+ 1.05 \times 700) + 0.56 \times 1\ 000 + 4.0(30 + 30 + 12) \times 1.7 +$$
$$+ (3\ 840 \times 1.18 \times 1.005 : 3\ 600)(20 - - 16) = (2\ 566 +$$
$$+ 1\ 265) \times 36 = 142\ kW$$

It shall be noted that the window U-value for darkness (= U_{wd}) is used in this calculations. In my case the existent oil boiler in the house has a power of 170 kW and because of this it can be considered a little too big. However, it could be nice to have some extra power to produce tapwater or for other reasons. The sizes of boilers are manufactured in discrete values and thus it might not be possible to find a boiler of exactly 142 kW.

In order to calculate the LCC for the building, there is now a need for the retrofit cost of heating equipment. I will start with calculations on the oil boiler and after that show how the heating system implies on the climate shield and the retrofit strategy of ventilatio. After that I will discuss what happens if other types of heating equipment are installed in the building. As before, the necessary addings and modifi-cations to the mathematical model will be made for each step in the procedure.

4.1.6.1.1 Retrofit cost for oil boilers

The cost for changing the existent oil boiler to a new one consists of demolishing cost, acquisation cost and installation cost. These costs can be calculated using pricelists from manufacturers and the contract for wages concerning installations. (56, 57, 58.)

The acquisition cost for oil boilers can be depicted as in Figure 22 (59 p 15:1 -).

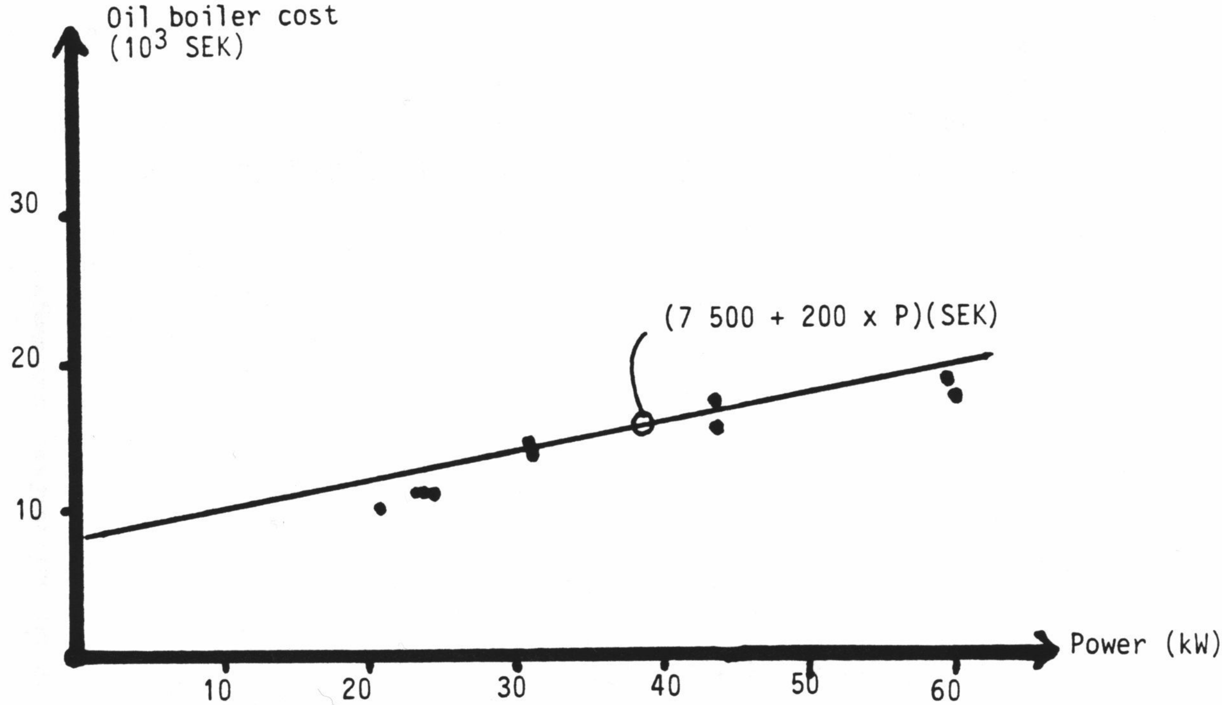

Figure 22. Oil boiler acquisition cost.

Before the new boiler can be installed the old one has to be demolished. In (57) there is no information about this cost. I will therefore assume that this is the same as the installation cost. The cost is in (57 p 107) measured in so called "partimmar" = two hours (pt). Installation cost for each apparatus is 3.20 p + 0.06 pt/kg weight. Note! When working in old houses it is recommended with a multiplying factor of 6.4 (57 p 7). Combination of the information of the weight for each apparatus in (58) and this expression gives us the installation cost 3 000 + 132 x P, where P is the power of the equipment. Adding the demolishing cost, the aparatus cost and the installation cost makes the total Heating Equipment Cost become:

$$HEC_{OB} = 13\ 500 + 464 \times P$$

where P = The power in (kW)

Of course, also this is a very rude method to find the retrofit cost. The function between the size of the boiler (the weight) the maximum output is much more complicated as can be seen in (59).

In (48 p 137 f) the following retrofit cost for oil boilers can be depicted, Figure 23.

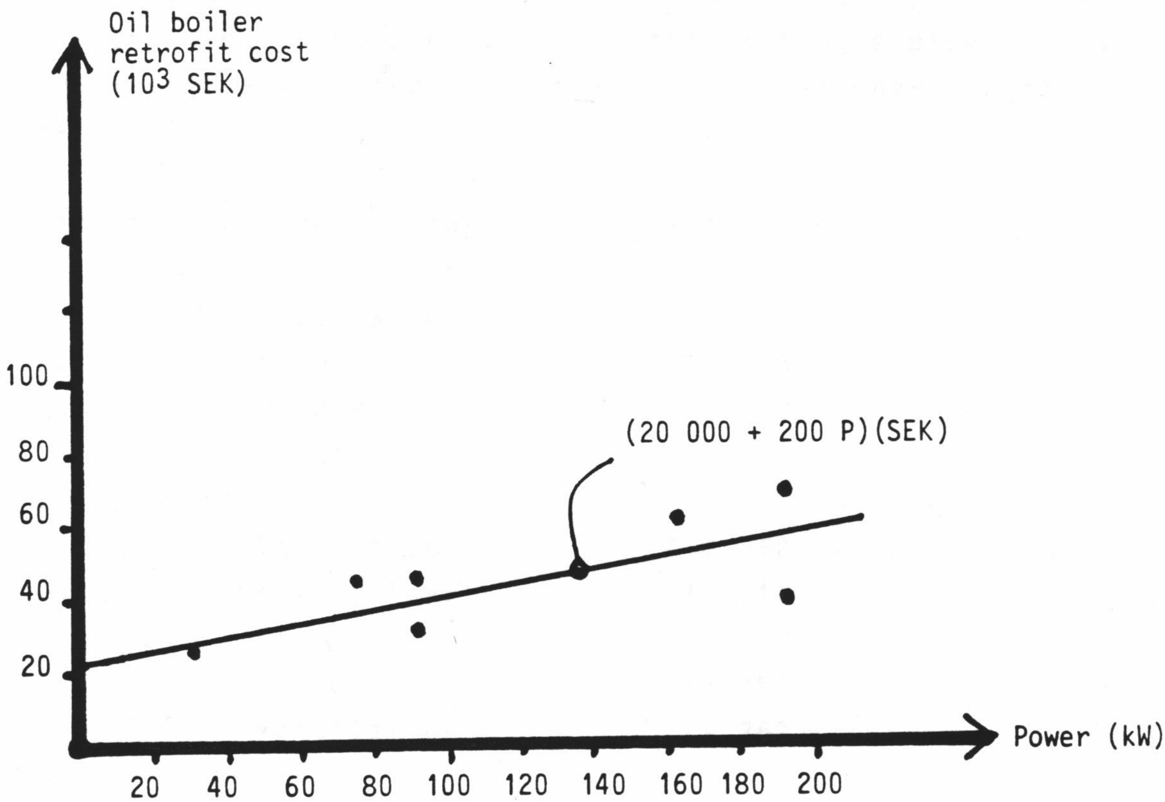

Figure 23. Oil boiler retrofit cost.

The costs depicted in Figure 22 are only valid for rather small boilers, up to approximately 60 kW. However, it is often common to install more than one boiler because of the efficiency problem with oil boilers running with only a little part of their total power. Because of the lack of exact information I have chosen to use the expression:

$$HEC_{OB} = 20\ 000 + 350 \times P \qquad (F39)$$

Then the high initial cost has been chosen and a mean value of the variable cost in the previous expressions.

4.1.6.1.2 Oil boiler - existent LCC for the building

It is obvious that adding the heating equipment to the model makes it convenient to calculate the total LCC for building. This because the need for power in the house depends on the different building parts. Adding the heating equipment cost, the ineviteable retrofit cost and the total energy cost result in the total LCC. The costs are:

Ineviteable retrofit cost		SEK x 10^6
	attic floor	-
	external wall	159 243
	floor	91 108
	windows	201 768
	ventilation	-
Energy cost		
	attic floor	460 962
	external wall	423 947
	floor	322 842
	windows	59 957
	ventilation	729 262

Heating equipment cost:

$$(20\ 000 + 350\ 142)(1.05)^{-5} + + 1.05^{-20} + 1.05^{-35} = 93\ 328$$

Sum 2 542 417

4.1.6.1.3 Oil boiler - retrofit on the climate shield

The reason for an energy retrofit is that the LCC shall be lower. In (F11) I have shown the LCC for the attic floor only concerning the energy cost.

A retrofit to the attic floor will change the U-value and thus not only the energy cost, but also the need for power at the heating equipment. In the formula at p 41 the need for power because of the attic floor can be calculated. Adding insulation to the attic floor will make the need for power in the house lower. The power calculation in Chapter 4.1.6 thus becomes:

$$P = \frac{32}{0.04+0.8 x t_{af}} + 3\ 131 \ x\ 36 = 112.7 + \frac{1.152}{0.04+0.8 x t_{af}} \text{ kw}$$

The cost for this power is $2\ 000 + 350(112.7 + \frac{1.152}{0.04+0.8 x t_{af}} =$

$$= 20\ 000 + 39\ 445 + \frac{403.2}{0.04+0.8 x t_{af}} = 59\ 445 + \frac{403.2}{0.04+0.8 x t_{af}}$$

Multiplying this with the present value factor 1.808 makes the cost to:

$$107\ 476 + \frac{729}{0.04+0.8 x t_{af}}$$

However, it is not possible just to add this expression to the model, because this consists of the different energy consuming parts in the building.

In Chapter 4.1.1.5 the first part of the model is shown. Using the power expression (p 38) it is easy to calculate the

Heating Equipment Cost for the existing attic floor to:

$$1.808\ (20\ 000 + 350(1.152 : 0.04) = 54\ 384\ \text{SEK}$$

Adding extra insulation to the attic floor makes the cost become:

$$1.808(20\ 000 + 350\ \frac{1.152}{0.04+0.8t_{af}} = 36\ 160 + \frac{729}{0.04+0.8\times t_{af}}$$

These expressions can be added to the first model in Chapter 4.1.5.5:

$$\text{Minimize: } Y_1(36\ 160 + \frac{729}{0.04+0.8\times t_{af}} + 125\ 000 + 300\ 000\ \times$$

$$\times\ t_{af} + \frac{18\ 438.5}{0.04+0.8\times t_{af}} + Y_2(460\ 962 + 54\ 384)$$

The rest of the model is identical, and minimizing this makes $Y_1 = Y_2 = 0$

$$\text{and } t_{af} = -\frac{0.04}{0.8} \pm \sqrt{\frac{19\ 158}{300\ 000\times 0.8}} = 0.23\ \text{m}$$

The fact is that calculating with the "power equipment cost" only changes the value on t_{af} with 0.0054 m. The influence of the heating equipment thus in many caces almost can be neglected. The value of the objective function = 315 731 SEK.

However, adding the retrofit of the external wall in exactly the same way makes the initial heating equipment cost (1.808 x 20 000), perform twice in the model. This cost does not imply on the minimization point for the variables because it is a constant, but, of course, it will change the total

LCC. The evaluation of the variables Y_1 and Y_2 will be the same if the initial cost is transferred outside of those expressions. This means that the objective function for optimizing the attic floor retrofit will become:

$$\text{Minimize: } Y_1\left(125\ 000 + 300\ 000 \times t_{af} + \frac{19\ 168}{0.04+0.8 \times t_{af}}\right) +$$

$$+ Y_2 \times 479\ 186 + 36\ 160$$

In exactly the same way it is possible to calculate the other retrofit "Power cost" contributions. In Table XI these are shown.

Table XI Heating equipment costs (oil boiler) for different retrofit parts

Retrofit part	Mathematical expression	
	existent part	retrofitted part
Attic floor	18 224	$729:(0.04+$ $+0.8 \times t_{af})$
External wall	16 751	$796:(0.0475+$ $+1.05 \times t_{ew})$
floor	12 757	$605:(0.0475+$ $+0.56 \times t_{fl})$
windows 2 panes (for each)	155	93
3 panes	-	58
4 panes	-	46
5 panes	-	39
Caulking windows, doors	28 817	18 010
Exhaust air heat pump	28 817	16 812
Exhaust air hp + caulking	28 817	21 307
Heat exchanger	28 817	12 388

Maybe the ventilation retrofits need to have an explanation. In the existent building the ventilation flow is 3 840 m^3/h. The power demand to heat this up from - 16 ^oC is 3 840 x x 1.005 x 1.18 x 36 : 3 600 = 45.5 kW. The variable heating equipment cost for this is 350 x 45.5 = 15 938 and the present value 1.808 x 15 938 = 28 817 SEK.

Caulking the windows deminutes the flow to 2 400 m^3/h, which makes the cost to 18 010 SEK. For the exhaust air heat pump the power transferred back to the house is 18.97 kW. The remaining power demand for the ventilation system is then 45.5 - 18.97 = 26.5 kW, which makes the cost to 350 x 26.6 x x 1.808 = 16 812 SEK. For the heat exchanger the efficiency is 0.57, which means that 57 % of the heat in the exhaust air is transferred back into the building. 43 % then has to be covered by the heating equipment or 0.43 x 45.53 = 19.6 kW, which costs 1.808 x 350 x 19.6 = 12 388 SEK during the 50 years. However, I also have to use the proper oil price when calculating the energy cost. 1986-08-08 the oil price was approximately 1 800 SEK/m^3 (Shell in Linköping). 1 m^3 has a heat content of 35.9 GJ (9 960 kWh), which makes the cost to 50.14 SEK/GJ or 0.18 SEK/kWh. Not all of the energy in the fuel comes out from the boiler. The efficiency is assumed to 0.7, which means that the price will become 71.6 SEK/GJ, (0.26 SEK/kWh). This is a little lower than our earlier estimated 0.30 SEK/kWh, so it is obvious that a change has to be done in the model using the new price for energy. Also adding the power cost to the model makes this become:

$$Y_1(125\ 000 + 300\ 000 \times t_{af} + \frac{16\ 709}{0.04+0.8 \times t_{af}}) + Y_2 \times$$

$$\times\ 417\ 724 + 36\ 160 + Y_3(333\ 867 + 387\ 100 \times t_{ew} +$$

$$+ \frac{18\ 248}{0.0475+1.05 \times t_{ew}}) + Y_4 \times 543\ 414 + Y_5(X_1(477\ 865 +$$

$$+ 250\ 000 \times t_{fl}) + X_2(620\ 000 + 553\ 000 \times t_{fl}) +$$

$$+ \frac{13\ 895}{0.0475+0.56 \times t_{fl}})) + Y_6 \times 383\ 661 + Y_7(125\ 760 +$$

$$+ 20\ 410 + 2\ 790) + Y_8(100\ 608 - 16\ 328 + 2\ 232) +$$
$$+ Y_9(125\ 760 - 65\ 754 + 2\ 790) + Y_{10}(163\ 410 + 2\ 252 +$$
$$+ 1\ 740) + Y_{11}(130\ 728 - 27\ 206 + 1\ 392) +$$
$$+ Y_{12}(163\ 410 - 72\ 566 + 1\ 740) + Y_{13}(190\ 920 -234 +$$
$$+ 1\ 380) + Y_{14}(152\ 736 - 25\ 396 + 1\ 104) +$$
$$+ Y_{15}(190\ 920 - 65\ 754 + 1\ 380) + Y_{16}(222\ 840 - 910 +$$
$$+ 1\ 170) + Y_{17}(178\ 272 - 21\ 756 + 936) + Y_{18}(222\ 840 -$$
$$- 56\ 680 + 1\ 170) + Y_{19}(72\ 060 + 36\ 348 + 4\ 650) +$$
$$+ Y_{20}(57\ 648 - 3\ 245 + 3\ 720) + Y_{21}(72\ 060 - 48\ 932 +$$
$$+ 4\ 650) + Y_{22}(395\ 016 + 52\ 012 + 18\ 010) +$$
$$+ Y_{23}(632\ 027 + 28\ 817) + Y_{24}(632\ 027 + 562\ 065 -$$
$$- 789\ 114 + 16\ 812) + Y_{25}(632\ 027 + 406\ 148 - 493\ 195 +$$
$$+ 21\ 307) + Y_{26}(632\ 027 + 649\ 242 - 449\ 734 + 12\ 388)$$

Subject to:

$t_{af}, t_{ew}, t_{fl} > 0$

$Y_{1-26}, X_{1,2} = 0$ or 1 integers

$Y_1 + Y_2, Y_3 + Y_4, Y_5 + Y_6, X_1 + X_2 = 1$

$$Y_7 + Y_8 + \ldots\ldots + Y_{21} = 3$$
$$Y_7 + Y_{10} + Y_{13} + Y_{16} + Y_{19} = 1$$
$$Y_8 + Y_{11} + Y_{14} + Y_{17} + Y_{20} = 1$$
$$Y_9 + Y_{12} + Y_{15} + Y_{18} + Y_{21} = 1 \qquad (F40)$$
$$Y_{22} + Y_{23} + Y_{24} + Y_{25} + Y_{26} = 1$$

If $Y_2 = 1$ then $t_{af} = 0$

If $Y_4 = 1$ then $t_{ew} = 0$

If $Y_6 = 1$ then $t_{fl} = 0$

4.1.6.2 Retrofit costs. Changing to other types of heating equipment

In many cases, one of the best things to do in order to make the LCC lower is to change the existing heating equipment to one with another energy supply. Choosing electric boilers, heat pumps or district heated systems might be very profitable. However, it is very hard to predict the future energy prices and because of this to decide an optimal retrofit strategy. Not long ago the oil price in Linköping, Sweden, was 3 000 SEK/m^3 making the energy price in oil boilers to 0.42 SEK per kWh. Today, as mentioned before, it is 0.26 SEK/kWh. Of course, such fluctuations makes any calculated retrofit strategy very hazardous. Nevertheless, it is possible to find very interesting results from the LCC calculations and optimization process.

4.1.6.2.1 Electric boiler. Retrofit cost

Changing the heating system before the existent heating equipment is worn out makes it necessary to calculate the value of the existent boiler. In my case the boiler had a power of 170 kW and the cost is thus 20 000 + 350 x 170 = = 79 500 SEK. It was 5 years left of its life-cycle of 15 years. The remaining value of the boiler is therefore 26 500 SEK.

Noted before in Chapter 4.1.6.1.1 the demolishing cost for an oil boiler is 3 000 + 132 P, where P is the power of the boiler.

The aquisition cost for some new electrical boilers can be found in (58) and in (62). Using the same technique as in Figures 22 or 23 the cost for the boilers is approximately 12 000 + 85 x P.

Electrical boilers do not have the same power-to-weight dependence. Instead, often the weight is rather constant what ever the power is. From 45 kW to 150 kW the weight is the same or 115 kg (62). The cost for demolishing and installation can thus be calculated to approximately 7 000 SEK. An approximate mathematical expression for the Heating Equipment Cost for Electrical Boilers thus is:

$$HEC_{EB} = 20\ 000 + 100 \times P \qquad \text{(F41)}$$

The first time the boiler is installed is a little more expensive than the latter ones, because there might be a need for bigger cables into the house etc. Such effects does not imply very much on the total LCC and is thus included in the little higher equipment cost.

4.1.6.2.2 Electrical boilers, energy and power costs. LCC for the building

The energy cost for electricity depends on the rates used by the electric power company. In our case, Malmö, the power company uses a new time-of-use rate. The use of this shall be considered later in this thesis. In this chapter I will use the old type of rate with one firm part paid each year and one variable part constant over the year. In our case, with a rather high energy demand, the variable cost will be 0.183 SEK/kWh + 0.072 SEK/kWh for taxes = 0.255 SEK/kWh. The annual energy cost from the variable part is thus approximately 106 000 SEK (55). The firm part in this region is 11 700 SEK, so the total cost is approximately 118 000 SEK/kWh.

The boiler retrofit cost for the existent house can be calculated, assuming the life-cycle for an electrical boiler to 20 years:

The remaining value of the existent boiler = 26 500 SEK

Present value of the electric boiler cost including installation = 34 200(1 + + 1.05-20 + 1.05-40 - 1/2 x 1.05-50 = 50 456 SEK

Sum 76 956 SEK

The life-cycle energy cost for the electric heated building differs from the oil heated, because of the difference in the variable cost, but also because of the difference in efficiency, which for the electricity can be assumed as 1.0.

The total LCC for the existent building with a new electricity boiler thus can be calculated as: (see Chapter 4.1.6.1.2).

Inviteable retrofit cost as earlier		452 119 SEK
Energy cost	attic floor	430 231 SEK
	external wall	395 683 SEK
	floor	301 319 SEK
	windows	55 959 SEK
	ventilation	680 644 SEK
Heating equipment cost		76 955 SEK
	Sum	2 392 912 SEK

The corresponding values for the oil heated building are: (variable energy cost = 0.26 SEK/kWh)

Ineviteable retrofit cost		452 119 SEK
Energy cost	attic floor	399 500 SEK
	external wall	367 420 SEK
	floor	279 796 SEK
	windows	51 962 SEK
	ventilation	632 027 SEK
Heating equipment cost		93 328 SEK
	Sum	2 276 152 SEK

Because of the LCC it is cheaper to leave the heating equipment as it is and continue to heat the building with oil. However, the difference is very small and because of the uncertainties the fact is that it is impossible to tell which is the best solution with any accuracy.

4.1.6.2.3 Electric boiler - retrofit on the climate envelope. Augmenting the model

Using the same example, i e the attic floor in Chapter 4.1.6.1.3, it is possible to calculate the retrofit cost for the heating equipment and the retrofitted attic floor to:

$$26\ 500 + 1.4753(20\ 000 + 100(112.7 + \frac{1.152}{0.04+0.8xt})) =$$

$$= 26\ 500 + 29\ 506 + 16\ 627 + \frac{170}{0.04+0.8xt_{af}}$$

The part that is independent of the attic floor retrofit, i e 26 500 + 29 506 = 56 000 SEK, can be added separately to the model.

However, I will get a change also in the energy cost terms. For the attic floor this is 15 980 : (0.04 + 0.8 x t_{af}) and thus the expression for retrofitting the attic floor, if the boiler is changed to an electrical system is:

$$56\ 006 + 16\ 627 + \frac{170}{0.04+0.8xt_{af}} + \frac{15\ 980}{0.04+0.8xt_{af}} +$$

$$+ 125\ 000 + 300\ 000\ t_{af}$$

However, I have to add all the different retrofit possibilities for the climate envelope and ventilation system expressions to find out if the electrically heated building with the optimal retrofit strategy makes a lower total LCC than the oilheated one. Thus, I have to expand my model rather drastically because of the new heating equipment alternative.

The model can be expressed as:

Minimize: $H_1(Y_1(125\ 000 + 300\ 000 x t_{af}$ ..... etc as in expression (F41) ..... $+ Y_{26} \times 843\ 923 + H_2 \times Y_{27}(125\ 000 +$

$$+ 300\ 000 \times t_{af} + 16\ 627 + \frac{16\ 150}{0.04+0.8 x t_{af}}) + Y_{28} \times 420\ 377 +$$

$+ 56\ 006 +$ (the expressions for the other possibilities

multiplied with their 0/1 variables Y_{29-53}) +
$+ Y_{54}(649\ 242 + 680\ 644 - 484\ 339 + 2\ 892)$

$H_1 + H_2 = 1$

$H_{1,2} = 0$ or 1 integers (F41)

These two last lines in the model make sure that there is a heating system, but not more than one. From this discussion I claim that it is possible to find a mathematical model for choosing the optimal retrofit strategy with both envelope retrofits and heating equipment retrofits. Before showing calculations for different heating systems etc I will show how the other heating equipment retrofit costs have been evaluated.

4.1.6.3.1 Retrofit cost for district heating equipment

In many towns in Sweden there is a possibility to connect the building to a district heating system. The energy is then transported in hot water. In the winter time the temperature of the water can be up to 120 °C, but in the summer it is much lower or about 70 °C. In the district heating power plant there is a possibility to burn fuels etc in the most efficient way and thus it is often possible to manufacture the energy cheaper than it is in smaller plants. In the beginning of the district heating era the fuel in the plant almost always was heavy oil (64 p 87), which was much cheaper than the light oil, possible to burn in small oil boilers. It is common today that the heat is transferred to the building using a heat exchanger. This is so because the heat is transported in hot water, which is treated to be less corrosive to the steel pipes. In (26 Chapter 10) the theories for these types of equipment are shown.

The equipment that is needed is often one heat exchanger for the "climate heating" in the building and one or two for tap-water production. Sometimes there is also one heat exchanger for drying purposes, e g laundry. These facilities are, however, neglected in this thesis.

Mostly the consumer installation in the building is factory made and is delivered in one or two pieces.

I have examined the aquisition cost for the heat exchangers in (58 p 17:1 -) and found the following approximate costs:

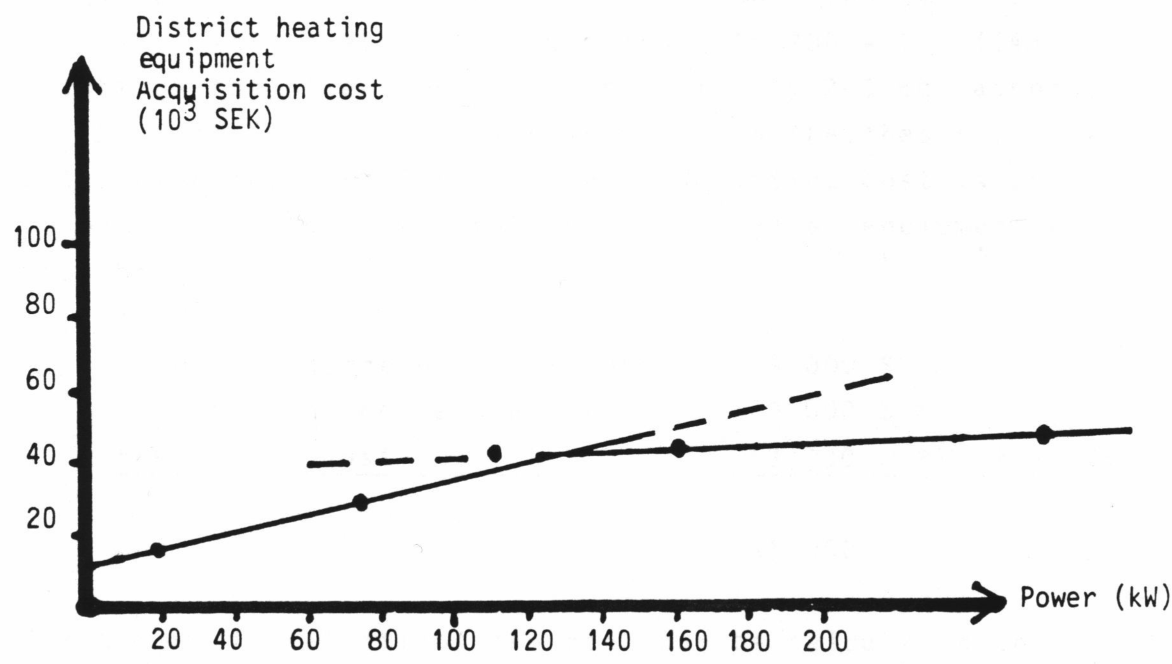

Figure 24. Acquisition cost for district heating equipment.

To find the costs in Figure 24 the following table has been made:

Table XII Consumer equipment cost for district heating

Power	Equipment	Cost	Tap-water device	Automation	Assembling	Sum
20	CTC-201	18 000	-	-	-	18 000
75	CTC-203	30 000	-	-	-	30 000
110	SKR-28-1.5	8 000	12 500	13 000	9 000	42 500
160	SKR-42-1.5	10 300	12 500	13 000	9 000	44 800
260	SKR-63-1.5	13 100	12 500	13 000	9 000	47 500

It shall also be noted that the power of the equipment depends on the difference between the incoming and outgoing water temperature in the primary pipes (connected to the plant). In the summer-time the exchangers have a lower power than during the winter.

The cost for installing the equipment in the building depends, as mentioned before, on the weight. The smaller equipment weighs about 165 kg (Parca KAP 200 - 16) (64). The weight on the other parts is approximately 200 kg, according to (56) and (57). As earlier is shown in the thesis it can be calculated that the installation/dismounting cost is approximately 9 000 SEK. The total cost for smaller equipment will thus be:

Dismounting the old equipment	9 000 SEK
Mounting the new equipment	9 000 SEK
Aquisition cost	13 000 + 250 x P SEK
Sum	31 000 + 250 x P SEK

For bigger installations the cost can be calculated to approximately 58 000 + 50 x P.

The difference point between smaller and bigger installations is set to 120 kW.

The Heating Equipment Cost for District Heating thus is:

$$HEC_{DH} = \begin{cases} 31\ 000 + 250 \times P & 0 < P < 120 \text{ kW} \\ 58\ 000 + 50 \times P & P > 120 \text{ kW} \end{cases} \qquad \text{(F42)}$$

In (49 p 56) the installation cost for up to 1 000 kW consumer installations is shown. Equipment of 200 kW cost approximately 500 SEK/kW, which means 100 000 SEK. A mathematical expression can be calculated as 75 000 + 75 x P SEK. Using (42) the cost is calculated to 68 000 SEK. In (48 p 29) 800 SEK/kWh i mentioned, but nothing is said how this figure is calculated. The values in (48) and (49) are valid for new installations and, thus, more expensive than retrofitted ones. Because of this and the lack of better information, the expression (42) is used in this thesis.

4.1.6.3.2 District heating. Energy and power costs LCC for the building

In Malmö the power company uses as time-of-use rate for the energy cost. The rate is described in (65). However, it is a little complicated to use this rate and, thus, I will describe this later. I will instead use a constant price for each kWh during the year. This price can be calculated as a mean value considering the degree hours in Malmö. During November - March the price is 0.19 SEK per kWh and the rest of the year 0.10 SEK/kWh. From Table II the number of degree hours is 67 389 during November - March and 37 852 the other period.

The mean variable energy price thus is:

$$\frac{67\ 389 \times 0.19 + 37\ 852 \times 0.10}{105\ 241} = 0.158 \text{ SEK/kWh}$$

There is also a power fee to be paid, which is calculated using:

$$700 + 600 \times \frac{3.944(15\ 242+14\ 035)}{744+672} \times 0.25 = 12\ 931 \text{ SEK}$$

The total cost will thus be during a year:

$$12\ 931 + 0.158 \times 415\ 000 = 78\ 512 \text{ SEK or } 0.189 \text{ SEK/kWh}$$

The first time connecting the building to the district heating pipes a fee of 300 x P = 42 600 SEK has to be paid.

The district heating equipment is very simple in its construction and will thus have a rather long life-cycle. I have assumed 30 years. One of the problems with heat exchangers is the fouling. In (26 p 443) this is treated. In (65) this is compensated using a different U-value, which is common for other manafacturers as well.

Now the total LCC for the existing house with a district heating retrofit can be calculated:

Inevitable retrofit cost		452 119 SEK
Energy cost	attic floor	290 406 SEK
	external wall	267 087 SEK
	floor	203 390 SEK
	windows	37 783 SEK
	ventilation	459 435 SEK
Heating equipment		
	old boiler	26 500 SEK
	connection fee	42 600 SEK
	installation fee $(58\ 000 + 50 \times 142)(1 + 1.05^{-30} - 1/3 \times 1.05^{-50}) =$	78 270 SEK
	Sum	1 857 580 SEK

Comparing this to the LCC in Chapter 4.1.6.2.2 it is obvious that it is a good idea to install district heating at least if nothing is done to the building envelope.

4.1.6.3.3 District heating - retrofit on the climate envelope. Expanding the model

Using the same technique and the same example, i e the attic floor, the expression to be minimized is:

$$26\ 500 + 42\ 600 + 1.2023(58\ 000 + 50(112.7 + $$

$$+ \frac{1.152}{0.04+0.8 \times t_{af}})) + \frac{11\ 616}{0.04+0.8 \times t_{af}} + 125\ 000 + 300\ 000 \times$$

$$\times\ t_{af} = 270\ 608 + \frac{11\ 685}{0.04+0.8 \times t_{af}} + 300\ 000 \times t_{af}$$

The miminum value of this function emerges when (F12):

$$t_{af} = -\frac{0.04}{0.8} \pm \sqrt{\frac{11\ 685}{300\ 000 \times 0.8}} = 0.1707 \text{ m}$$

and the "LCC" for the attic floor is:

$$270\ 608 + \frac{11\ 685}{0.04+0.8 \times 0.17} + 300\ 000 \times 0.17 = 388\ 000 \text{ SEK}$$

Using no attic floor retrofit the cost is:

$$26\ 500 + 42\ 600 + 1.2023(58\ 000 + 50 \times 142) + \frac{11\ 616}{0.04} =$$

$$= 437\ 769 \text{ SEK}$$

The difference between attic floor retrofit and no retrofit is now approximately 50 000 SEK to compare with 184 000 SEK calculated in Chapter 4.1.1.5. It is obvious that choosing a special type of heating system will have a great influence in the retrofit strategy. However, in this case the strategy was the same, it is profitable to insulate, but a little less than earlier. A little lower energy cost will make the extra insulation unprofitable. In (67) I have shown how the optimal insulation thickness changes when calculating with different input boundary conditions.

To expand the model with the district heating alternative, I have to add one more variable H_3 to the model, which only values can be 0 or 1. New calculations have to be made to find all the values following the Y variables, which number also has to be expanded. The procedure is exactly the same as for adding the electric boiler equipment.

4.1.6.4.1 Retrofit cost for heatpump heating systems

In (48 p 157 -) the installation costs for some different types of heat pumps are given. The values are depicted in Figure 25.

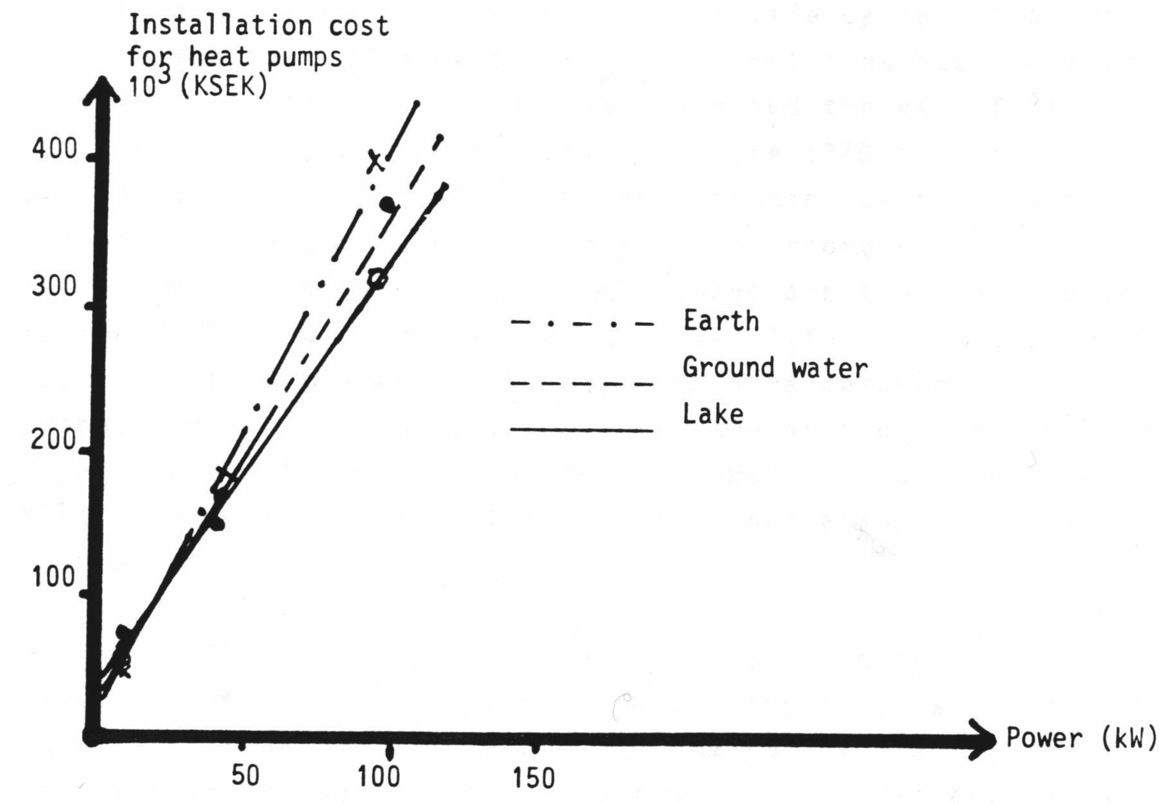

Figure 25. Installation cost for heat pumps.

From Figure 25 it is clear that the different heat pump systems only differs a little from each other, which could be expected. It is only the heat source that differs. A mathematical expression that gives the approximate cost is:

$$HEC_{HP} = 30\ 000 + 3\ 300 \times P \text{ SEK} \qquad (F43)$$

As mentioned in a previous chapter it is common to use ordinary oil boilers as a peak load heater in those cases, when the heat pump cannot deliver a sufficient amount of power. In this thesis, however, these bivalent systems are not treated at all because of the complicated process of optimizing a system like that. Further research in this field will be done in the future. I have therefore assumed that the heat pump can deliver the demand of power to the building and no peak load alternatives are considered.

4.1.6.4.2 Energy and power costs LCC for the building

One of the difficulties calculating on life-cycles of a heat pump is the lack of experience. It was not long ago the first systems were started. No one has discussed the use of heat pumps at all before the oil crises in the 1970-ies. In the litterature, e g (69), it is shown that many of the installations have big problems and the costs according to this reference for the systems in (F43) above are too low. However, in the following I am assuming that the life-cycle is only 10 years and that the whole equipment then is changed. This probably will make the total LCC for the heat pump system too high. Because there is no better information about the long time costs, I will use (F43) and the other assumings mentioned above.

One more assumption has been made, the efficiency for the system is 3.0 during the year, i e putting in 1 kW electricity in the heat pump, 3 kW heat is coming out. This is really a very rude suggestion, but will be sufficient for my purposes in this thesis.

The energy cost for the electricity is assumed to 0.28 SEK/kWh and for the heat thus 0.093 SEK/kWh. Because of this the LCC for the building can be calculated to:

Inevitable retrofit cost:		452 119 SEK
Energy cost:	attic floor	143 359 SEK
	external wall	131 423 SEK
	floor	100 404 SEK
	windows	18 587 SEK
	ventilation	226 071 SEK

Heating equipment cost:

$$26\ 500 + (30\ 000 + 3\ 300 \times 142)(1 + 1.05^{-10} + 1.05^{-20} + 1.05^{-30} + 1.05^{-40}) = $$
$$= 1\ 205\ 303 \text{ SEK}$$

Sum 2 277 266 SEK

Choosing district heating makes the LCC approximately 400 000 SEK lower.

4.1.6.4.3 Heat pump - retrofit on the climate envelope. The model

I shall use the same example as earlier, the attic floor, to show how the model can be further augmented.

The objective function changes in this part to:

minimize:

$$26\ 500 + 2.3642(30\ 000 + 3\ 300(112.7 + \frac{1.152}{0.04+0.8 \times t_{af}} + \frac{5\ 734}{0.04+0.8 \times t_{af}}) + 125\ 000 + 300\ 000\ t_{af} = 1\ 101\ 695 +$$

$$+ \frac{14\ 721}{0.04+0.8 \times t_{af}} + 300\ 000 \times t_{af}$$

This expression has its minimum for:

$$t_{af} = -\frac{0.04}{0.8} + \sqrt{\frac{14\ 721}{300\ 000 \times 0.8}} = -\ 0.051 + 0.248 = 0.2\ \text{m}$$

The LCC will be 1 235 300 SEK.

Without the insulation the LCC would become 25 500 + + 1 205 303 + 143 359 = 1 344 726. Once again the heating equipment with an attic floor retrofit is cheaper and the difference is bigger than in the last case. This is so, because of the very expensive heating equipment called the "power cost" in this thesis.

Expanding the model with the new heating equipment retrofit forces me to add one more H-variable to the model and also one more bunch of Y variables. The procedure is the same as before and I will not repeat it here. However, with the end of this chapter I will consider the model as developed and I also have shown that it is possible to build a mathematical model of the building and the retrofit of it in order to calculate an optimal retrofit strategy. The next chapter will deal with the optimization techniques available today and the way I have chosen to calculate the different LCC.