8. CASE STUDIES AND SENSITIVITY ANALYSIS

In these case studies I have changed some of the input variables, e g the efficiency of the new boiler, which have been changed to 0.8 instead of 0.7. This because it could be interesting to see if it is profitable to change the old boilers to a new one with a higher efficiency. In Table XIII I have shown the LCC for the building with different heating systems and under those figures the amount of money saved if an envelope retrofit is introduced. In those cases, where the retrofit is unprofitable a hyphen is shown. In other cases the money saved using the optimal retrofit strategy is shown and finally the resulting LCC. I will start with the base case:

Table XIII Optimal envelope retrofit strategies with different heating systems. LCC in 10^6 SEK. Base case.

	Heating system					
	Existing oilboil.	New oil-boil.	Electric boil.	District heat.	Heat pump	T-O-U Distr heating
LCC with no envelope retrofits	2.43	2.43	2.80	2.13	2.41	2.14
Savings						
Attic floor	0.11	0.11	0.16	0.06	0.11	0.06
Floor ins	-	-	-	-	-	-
Ext wall	0.03	0.02	0.07	-	0.03	-
Three glass	-	-	-	-	-	-
Four glass	-	-	-	-	-	-
Five glass	-	-	-	-	-	-
Caulking	0.17	0.16	0.21	0.13	0.17	0.13
Exhaust air heat pump	0.05	0.04	0.14	-	-	-
Resulting LCC	2.07	2.10	2.22	1.95	2.11	1.95

The cheapest heating system possible to choose is the district heating. This is also logical because of the rather low variable energy cost and the very low cost for the power in the heating system. The most expensive system is the electrical boiler. It is so because of the high variable energy cost. The heat pump with a low energy cost and a high "power cost" comes in the middle of the ranking.

The LCC for "ordinary" and time-of-use rates for district heating shall be identical with the existent building, but differs slightly because of truncation errors.

The retrofit strategy for each type of heating equipment also differs, which is logical. The most extensive strategy is chosen for the electric boiler system, which has the highest energy cost. The heat pump system makes the insulation profitable because of the decrease in the power demand. The exhaust air heat pumps make the energy recirculate. This retrofit is, thus, chosen where the energy is rather expensive, i e oil and electricity. The systems, with both low energy and low power costs, i e the district heating, make most of the retrofits unprofitable.It shall here be noted that the rates used in this thesis for district heating reflects the costs for producing the energy in the plant or the short range marginal cost (SMRC). Such rates cannot be used when the plant is new, because in that case the plant investment cost never will be covered. In Sweden it is thus common to use a so called alternative rate. This means that the energy cost in the rate shall be of the same magnitude as other suitable heating equipment alternatives for the landlords to use. For most cases this means that the price for light oil shall be used. However, using such a rate makes an extensive retrofit strategy profitable. This also means that the district heating plant will not be used in an optimal way, because this provides the use of SMRC and almost no retrofits to the building. It shall also be noted that the window and floor retrofits are never chosen by the computer. Looking at the resulting LCC it is obvious that they get closer to each other using optimal envelope retrofits. The maximum difference in LCC is 0.66 x 10^6 SEK before the envelope retrofits and 0.35 x 10^6 SEK after those are selected.

8.1 CHANGING THE OPTIMIZATION TIME

Choosing another time of optimization, in the base case 50 years, makes the LCC change. This is depicted in Table XIV.

Table XIV Optimal envelope strategies with different heating systems. LCC in 10^6 SEK. Base case with optimization time 10 years.

	Heating system					
	Existing oil	New oil	Electricity	District heat	Heat pump	T-O-U District heating
LCC with no envelope retrofits	0.86	0.85	1.01	0.76	0.84	0.76
Savings PV						
Caulking	0.07	0.07	0.09	0.06	0.07	0.06
Exhaust air heat pump	0.02	0.01	0.05	-	-	-
Resulting LCC	0.77	0.78	0.88	0.70	0.77	0.70

Choosing a short optimization time makes almost all retrofits unprofitable. The district heating system is still the cheapest both with and without envelope retrofits. Choosing a longer optimization time in the basic alternative makes almost no differences to the strategy compared to the base case because of the small influences from the present values calculated for "time distant happenings". This is also obvious from (67 Figure 5).

8.2 CHANGING THE DISCOUNT RATE

As mentioned in the introduction it is not possible to find an accurate discount rate that is valid during all conditions. Unfortunately, this boundary condition is very important to the result. Choosing a low rate makes the expensive equipment better, and high rates makes them loose in rank. This can be seen in Tables XV and XVI.

Table XV Optimal envelope strategies with different heating systems. LCC in 10^6 SEK. Base case with discount rate 3 %

	Heating system					
	Existing oil	New oil	Electricity	District heat	Heat pump	T-O-U District heating
LCC with no envelope retrofit	3.38	3.36	3.90	2.93	3.21	2.94
Savings PV						
Attic floor	0.23	0.22	0.31	0.15	0.21	0.16
External wall insul	0.15	0.15	0.22	0.08	0.13	0.09
Caulking	0.24	0.24	0.30	0.18	0.22	0.19
Exhaust air heat pump	0.12	0.10	0.24	-	-	-
Resulting LCC	2.63	2.65	2.83	2.51	2.64	2.50

Table XVI Optimal envelope strategies with different heating systems. LCC in 10^6 SEK. Base case with a discount rate of 15 %.

	Heating system					
	Existing oil	New oil	Electricity	District heat	Heat pump	T-O-U District heating
LCC with no envelope retrofit	0.89	0.91	1.03	0.83	1.10	0.83
Caulking	0.05	0.05	0.07	0.04	0.08	0.04
Resulting LCC	0.83	0.85	0.96	0.79	1.02	0.79

Using a high discount rate also makes almost all of the retrofits unprofitable. Only caulking is chosen by the computer. The district heating system, however, is the best choice both with a discount rate of 3 and 15 %.

8.3 UNIFORM RAISINGS OF THE ENERGY PRICES

After the oilcrises in the 1970-ies the energy prices raised a lot. Now the oil price is lower again, but it can be interesting to see what happens to the retrofit strategy when the energy prices raise. This can be calculated using another discount rate for the energy costs (8 p 9). This justified discount rate can be calculated as:

$$r_j = \frac{r-q}{1+q}$$

where r = the earlier discount rate and
q = the escalation price rate

Using r = 5 % and q = 3 % the new rate to be used will be 1.94 %.

Using this the retrofit strategy becomes:

Table XVII Optimal envelope retrofit strategies with different heating systems. LCC in 10^6 SEK. Base case with 3 % annual energy price escalation.

	Heating system					
	Existing oil	New oil	Electricity	District heat	Heat pump	T-O-U District heating
LCC with no envelope retrofit	3.80	3.79	4.49	3.27	2.97	3.29
Savings PV						
Attic floor insulation	0.32	0.32	0.43	0.23	0.20	0.24
External wall insulation	0.22	0.21	0.32	0.14	0.10	0.15
Three pane windows	0.01	0.01	0.05	-	-	-
Caulking	0.32	0.32	0.40	0.25	0.23	0.26
Exhaust air heat pump	0.37	0.35	0.53	0.23	-	0.14
Resulting LCC	2.55	2.58	2.77	2.42	2.44	2.49

From Table XVII it is obvious that uniform energy cost raisings makes the heat pump heating system more competetive. At least the heat pump is the best alternative before the envelope retrofits and has almost the same LCC as the district heating system after the optimal retrofit strategy. One more interesting thing is shown in Table XVII. The time-of-use rate has earlier given almost the same amount of savings for the envelope retrofits. Now the time-of-use rate gives advantages to the insulation retrofits, which lowers the need for power in the house and disadvantages the exhaust air heat pump, which becomes less profitable. This is a very important result because for the energy producer it is the power in the winter that is most the expensive. In (79) this is treated more elaborate. However, the figures for the district heating with and without time-of-use rates cannot be compared with each other without consideration. This is so because the rates are not normalized, i e the income to the producer is not the same in the two cases for the more expensive energy alternatives. The effects, however, are the same for such cases, which also is shown in (79). In (80) other energy prices are used and this discussion is treated in a somewhat different way. Note also what is mentioned above about the so called alternative rate for district heating.

8.4 CHANGES IN THE CLIMATE

It is natural that the retrofit strategies will not be the same in a mild climate compared to a cold one.

I will thus show this in two new tables.

Table XVIII Optimal envelope retrofit strategies with different heating systems. LCC in 10^6 SEK. Base case with 50 000 degree hours.

	Heating system					
	Existing oil	New oil	Electricity	District heat	Heat pump	T-O-U District heating
LCC without any envelope retrofits	1.62	1.64	1.82	1.47	2.09	1.48
Savings PV						
Attic floor insulation	-	-	-	-	0.05	-
External wall insulation	-	-	-	-	-	-
Caulking	-	-	-	0.04	0.12	0.04
Exhaust air heat pump	0.16	0.14	0.29	-	-	-
Resulting LCC	1.47	1.51	1.53	1.44	1.91	1.44

Table XIX Optimal envelope retrofit strategies with different heating systems. LCC in 10^6 SEK. Base case with 150 000 degree hours.

	Heating system					
	Existing oil	New oil	Electricity	District heat	Heat pump	T-O-U District heat
LCC with no envelope retrofits	3.09	3.07	3.60	2.67	2.68	2.68
Savings PV						
Attic floor insulation	0.24	0.23	0.32	0.15	0.16	0.16
External wall insulation	0.14	0.13	0.21	0.07	0.07	0.08
Three pane windows	-	-	0.01	-	-	-
Caulking	0.26	0.25	0.31	0.20	0.20	0.21
Exhaust air heat pump	0.05	0.04	0.14	-	-	-
Resulting LCC	2.41	2.42	2.61	2.25	2.24	2.24

The mild climate only generates a few retrofits. Interesting is also that in some cases it was not an adequate retrofit to caulk the building. Using an exhaust air heat pump and caulking is worse than using only the heat pump, because of the lower ventilation flow.

8.5 CHANGES OF THE TIME CONSTANT

Described above, in Chapter 7, the retrofit on the envelope changes the building as a heat capacity. The time constant gets much longer than without the retrofit and, thus, the climate variations will not influence so much in the retrofitted building. However, it is very hard to describe how much the building time constant changes and I have thus assumed that the LUT is changed from -6 °C to -6 °C or with 10 °C. In the next table this is shown.

Table XX Optimal envelope retrofit strategies with different heating systems. LCC in 10^6 SEK. Base case with LUT = -6 °C.

	Heating system					
	Existing oil	New oil	Electricity	District heat	Heat pump	T-O-U District heating
LCC without any envelope retrofit	2.42	2.40	2.80	2.12	2.11	2.13
Savings PV						
Attic floor insulation	0.11	0.10	0.16	0.05	0.06	0.06
External wall	0.03	0.02	0.07	-	-	-
Caulking	0.17	0.16	0.21	0.12	0.13	0.13
Exhaust air heat pump	0.05	0.04	0.14	-	-	-
Resulting LCC	2.06	2.08	2.22	1.94	1.92	1.94

Comparing Table XX with Table XIII (the base case) it is obvious that it is the high "power cost" system that benefits on this lower dimensioning outside temperature. The best solution is the heat pump system with some retrofits. However, having chosen a heating system, the retrofit strategy for the envelope will almost not change at all.