3.3 SCRUTINIZING THE OPERA CALCULATIONS

Emphasized above are the great options in OPERA to evaluate all the calculations resulting in the most profitable retrofit strategy. This is also very important in order to elaborate a sensitivity analysis, i e how will the final result change if some of the input variables are changed. In this chapter the calculations of an OPERA running are shown in order to depict the principal situation. Only one retrofit and one heating system are dealt with at the same time, total system changings are dealt with at page 75. This is because it is easier to understand what happens if the heating system cannot change. The oil-boiler system has been chosen for the calculations due to the more difficult situation with differential district heating. Thus it is not the optimal solution for the total model but instead a subsystem that is scrutinized here. All information can easily be provided by OPERA by setting strategic output parameters in the input data file.

In table III the first value in table I, 1.62, showing the existing LCC, is broken up into pieces.

Type of cost	Cost
Inevitable retrofit cost	0.882
Heating equipment cost	0.063
Energy cost	0.677
Total cost	1.622

TABLE III. The existing LCC in MSEK.

However even these values can be split into parts, showing e g the inevitable retrofit cost in detail. See the following table.

Building part	Cost
Attic floor	0.0
Floor	0.146
External wall, outside	0.345
External wall, inside	0.106
Windows, north	0.135
east	0.012
south	0.124
west	0.012
Total inevitable cost	0.882

TABLE IV. The inevitable retrofit cost in MSEK.

Also interesting is to analyze the energy demand during one year. OPERA shows the energy balance for the building in monthly mean values. First the number of degree hours is presented using the equation (AIII 1), at page 142, then the energy loss is calculated using also the expressions (AIII 4) and (AIII 5), at page 148 in appendix III. Equation (8) shows the situation.

$$E_{loss} = DH \cdot (TRANS + VENT) \qquad (8)$$

However, also the solar gains and free energy from appliances are presented. The energy delivered from the heating system as well as the energy demand used for insulation optimization, see page 18, is calculated. The two values are called Energy 1 and Energy 2 in table V. (OPERA calculates the values in kWh instead of GJ and thus some truncation errors might occur in the table.)

The table shows that for five months during the summer the building does not need any space heating from the heating system. During that time no contributions are made to the insulation energy demand, Energy 2.

Month	Degree hours	Energy loss	Hot water consumption	Solar gains	Free energy	Resulting demand Energy 1	Energy 2
Jan	15 252	125.8	21.0	6.8	42.5	97.6	125.8
Feb	14 035	115.8	21.0	10.8	42.5	83.5	115.8
Mar	13 838	114.1	21.0	19.5	42.5	73.2	114.1
Apr	10 080	83.1	21.0	22.9	42.5	38.7	83.1
May	6 696	55.2	21.0	29.0	42.5	21.0	---
Jun	3 600	29.7	21.0	30.1	42.5	21.0	---
Jul	2 083	17.2	21.0	29.8	42.5	21.0	---
Aug	2 455	20.3	21.0	26.1	42.5	21.0	---
Sep	4 680	38.8	21.0	22.0	42.5	21.0	---
Oct	8 258	68.1	21.0	15.5	42.5	31.1	68.1
Nov	10 872	89.7	21.0	7.8	42.5	60.4	89.7
Dec	13 392	110.5	21.0	4.8	42.5	84.2	110.5
Sum	105 241	868.1	252.0	225.0	509.8	573.7	707.1

TABLE V. Energy balance. Monthly mean values in GJ.

From table III, at page 57, it is obvious that it is the energy cost that has to be reduced if the LCC will be considerably lower. The heating equipment cost is too small and the inevitable cost cannot be decreased.

OPERA starts trying to achieve this by examining attic floor insulation. The total inevitable retrofit cost in this case is identical to the first one, shown in table III, because of the zero attic floor inevitable cost. However, the remaining life is zero years and this will also mean that the inevitable cost will not change.

The next step is to calculate the optimal thickness of insulation. As mentioned above the Energy 2 value from table V is used for this purpose and OPERA calculates the minimum LCC using the formulas (1) and (2), at page 18 and 19. In this case the optimal extra thickness of insulation is calculated to 0.18 meter, see table II at page 54. The new LCC is then calculated as presented in table VI.

Type of cost	Cost
Inevitable retrofit cost	0.882
Heating equipment cost	0.059
Energy cost	0.587
Retrofit cost	0.070
Total new LCC	1.599

Table VI. LCC with attic floor insulation. Costs in MSEK.

The new LCC is lower than the existing LCC and thus the retrofit is profitable.

This is not the case for floor insulation. The optimal amount is also in this case calculated to 0.18 meter. The constant C_3 in equation (5), see page 38, is identical for the two measures which would imply an identical insulation thickness, but this is not the case because the existing U-values differ. Further, the other insulation costs, C_1 and C_2 are higher, and the profitability will vanish. Table VII shows the situation.

Type of cost	Cost
Inevitable retrofit cost	0.882
Heating equipment cost	0.061
Energy cost	0.614
Retrofit cost	0.095
Total new LCC	1.651

Table VII. New LCC with floor insulation. Costs in MSEK.

The same information is available for all the retrofits tested by OPERA and furthermore, the final result can be examined in the same way.

In the following, the four parts of the LCC, i e

- the inevitable retrofit cost
- the heating equipment cost
- the energy cost
- the retrofit cost

are studied in detail and a number of OPERA runnings are elaborated in order to enlighten important parts dealing with LCC and the retrofitting of buildings.

3.3.1 Inevitable retrofit cost

In order to show the influence of changes in the input data on this cost, the external wall retrofit will be used. It is assumed that the remaining life of this building part is 20 years. The original situation, when the remaining life is 0 years, is not applicable. Neither the attic floor insulation can be used because the cost is 0 SEK due to the value of C_1 in equation (5), page 38. See also table IV at page 58. OPERA provides table VIII and IX as a starting situation.

The inevitable retrofit cost is calculated by the expression (AIII 2), page 144 in appendix III, and from equation (1) and (2) it is obvious that the optimal insulation thickness is independent of the remaining life of the considered building part. In table II this is presented to be 0.13 meter. However, it is very important to note that a longer remaining life span makes it more expensive to make a retrofit in advance, i e at the base year. The profit might vanish, and then it is better to leave the external wall as it is.

In table III the total existing LCC equals 1.622 MSEK. Setting the remaining life of the external wall to 20 years, instead of 0, makes the LCC 0.234 MSEK lower for the existing building, see table VIII.

The insulated building thus must have an energy- and heating equipment cost that is 0.234 + 0.111 MSEK lower then the not retrofitted building has, if the retrofit shall be profitable. This is not the case. This shows that the remaining life span for a retrofit can be very important.

Type of cost	Cost
Inevitable retrofit cost	0.647
Heating equipment cost	0.063
Energy cost	0.677
Total LCC	1.388

Table VIII. LCC existing building. Life span for external wall equals 20 years. Values in MSEK.

Type of cost	Cost
Inevitable retrofit cost	0.882
Heating equipment cost	0.055
Energy cost	0.488
Insulation cost	0.111
Total LCC	1.536

Table IX. LCC with external wall insulation. Remaining life span equals 20 years. Values in MSEK.

Unfortunately it is not very easy to make accurate estimations about the remaining life span. The importance however, is increased if the remaining span is short. An error in the estimation of 10 years is much more important close to the base year than far away from it. If the span above was 10 years the inevitable cost would be 0.735 MSEK, i e the difference between the first 10 years is 0.147 MSEK but the second 10 years will only increase the cost with 0.087 MSEK. It shall be noted here that if the wall really is retrofitted at the base year, the influence of the remaining life is none on the resulting LCC, table IX will not change no matter if the span is changed.

Increasing the cost C_1 in the building cost function, equation (5) at page 38, will of course be of importance. Assuming the life span is 20 years, as earlier, but changing the cost from 325 to 500 SEK/m^2 will result in a 0.360 MSEK more expensive inevitable retrofit, compared to 0.234 MSEK above, see table VIII and IX. The problem with wrong estimations of the remaining life span, thus is greater if the cost is high. A higher cost will of course increase the probability that the insulation is unprofitable.

The inevitable retrofit cost will also change if the discount rate is changed. A higher rate will almost always make the inevitable retrofit cost lower but the rate will also influence the other parts of the total LCC. In the tables below the building LCC is presented with a discount rate of 3, 5 and 7 %.

Type of cost	3%	5%	7%
Inevitable retrofit cost	1.044	0.882	0.782
Heating equipment cost	0.084	0.063	0.050
Energy cost	0.946	0.677	0.516
Total cost	2.074	1.622	1.348

Table X. Existing building LCC. Discount rate 3, 5 and 7 %. Costs in MSEK. Life span 0 years for the external wall.

From table X an XI it is obvious that the inevitable retrofit cost will change if the discount rate is changed. A higher rate will make the the cost lower, in the case discussed. However, all the other costs are also changed and the important thing is that the difference between the existing LCC and the insulated building LCC gets smaller when the rate is increased. Note that these differences decrease if the rates concerned are high, a change in the discount rate from 3 to 5 % will not change the LCC difference as much as a change from 5 to 7

%. A further increase will sooner or later make the difference change sign and the retrofit will in that case be unprofitable. The situation is also depicted in figure 7.

Type of cost	3%	5%	7%
Inevitable retrofit cost	1.044	0.882	0.782
Heating equipment cost	0.072	0.055	0.044
Energy cost	0.671	0.488	0.377
Insulation cost	0.123	0.111	0.103
(Insulation thickness in m.	0.155	0.125	0.105)
Total cost	1.910	1.536	1.306

Table XI. LCC with external wall insulation. Discount rate 3, 5 and 7 %. Costs in MSEK.

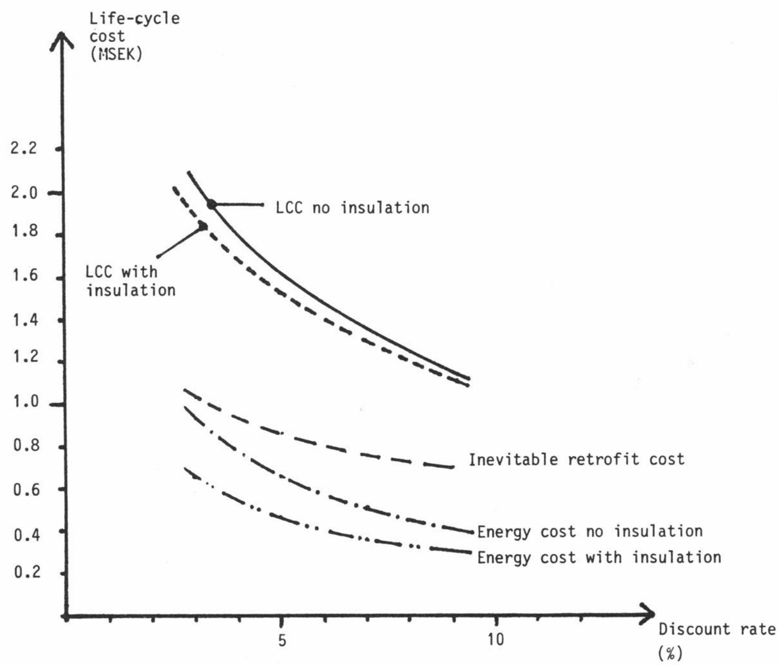

Figure 7. LCC changings due to discount rate.

It can be confusing to find that the LCC gets lower if the discount rate is increased. The answer to this situation can be found in equation (AIII 2) at page 144. This may lead to the presumption that a high discount rate is very profitable, because the LCC gets lower. This is of course wrong, in reality a high discount rate implies higher costs for the retrofit and will decrease profitability exactly as is shown in table X and XI and in figure 7.

Also important is the total optimization time. See the following tables.

Type of cost	10 years	20 years	30 years
Inevitable retrofit cost	0.414	0.597	0.754
Heating equipment cost	0.018	0.037	0.051
Energy cost	0.299	0.469	0.573
Total cost	0.731	1.103	1.378

Table XII. Existing building LCC. Optimization time 10, 20 and 30 years. Remaining life 0 years for the external wall. Costs in MSEK.

Type of cost	10 years	20 years	30 years
Inevitable retrofit cost	0.414	0.598	0.754
Heating equipment cost	0.016	0.032	0.044
Energy cost	0.277	0.345	0.417
Insulation cost	0.089	0.100	0.106
(Ins.thickness in meter	0.07	0.10	0.11)
Total cost	0.746	1.075	1.321

Table XIII. LCC with external wall insulation. Optimization time 10, 20 and 30 years. Costs in MSEK.

The inevitable retrofit cost will be lower with shorter time.

However, the decrease is much higher considering short optimization periods. Changing the period from 50 to 40 years will not influence as much as changing it from 20 to 10 years. From the tables it is obvious that the inevitable retrofit cost, as well as the other costs, will get lower if the optimization period is shortened. More important however, is the fact that for the short period, insulation is not profitable while the opposite is valid for longer periods. The situation is depicted in figure 8.

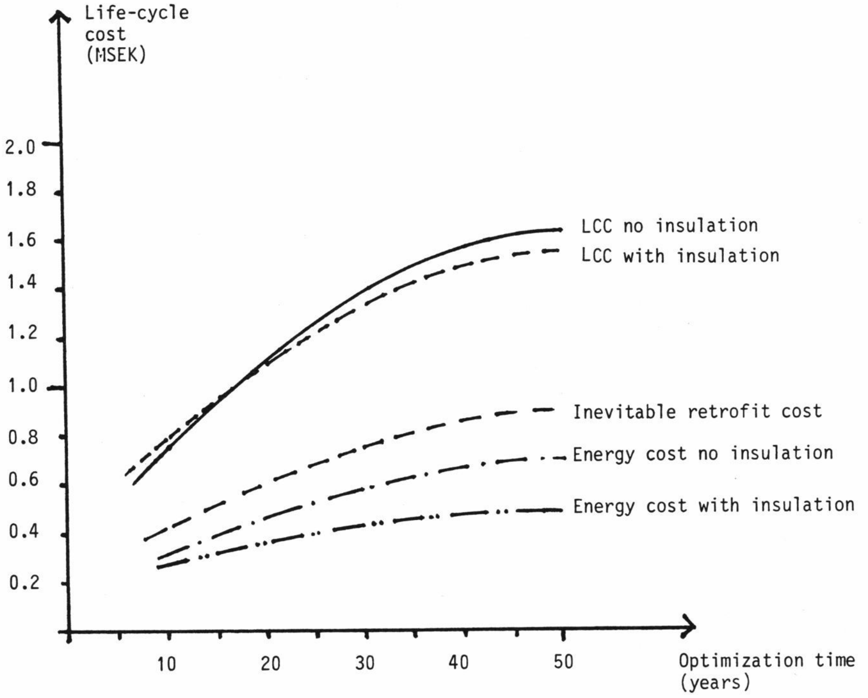

Figure 8. LCC changings due to different optimization time.

Above is mentioned that an increase in the discount rate will decrease the inevitable retrofit cost. However this is the situation only if the optimization period is longer than the remaining life of the building part. If the opposite is valid the inevitable retrofit cost will increase, and the fact is that if the optimization period is identical with the remaining life, the discount rate will not influence this cost at all.

3.3.2 Heating equipment cost

From the tables above it is obvious that the heating equipment cost in this case not considerably will influence the optimal total LCC. Note that only one heating system is dealt with here. The cost is calculated using equation (7), from page 39, and the total heating load for the building. This load however, is dependent of the total thermal loss in the existing or the retrofitted building.

Important is also the climate, which will influence on the size of the boiler. In OPERA this is dealt with using a lowest dimensioning outside temperature, provided by the Swedish building code. In Malmö this temperature is set to - 14 °C.

The retrofit cost for the boiler is dealt with in the same way as the retrofit cost for the building envelope, which is treated above. Thus the influence from a different rate, optimization time, retrofit cost etc will follow the same rules presented there. The exact procedure for the calculations are presented in [3].

The low influence on the total LCC in the case above, where the existing oil-boiler was dealt with, depends on the low cost for such boilers, which is of the magnitude 500 SEK/kW. The situation will be totally different for more expensive heating facilities such as heat pumps, which have costs of the magnitude 3000 SEK/kW or more. This more expensive heating equipment however, might be balanced by a much lower energy cost. (In [25] it is shown that boiler costs lower than 1000 SEK/kW will hardly influence the optimal retrofit strategy.)

In order to show this, the situation is stressed in some tables using the ground water coupled heat pump from table I at page 53 as a demonstration subject.

From the upper part of table XIV, it is obvious that the heating equipment cost gets lower if there is a low U-value on the existing external wall. However, more interesting is that if the wall is optimally insulated the existing U-value is of no importance at all, the heating equipment cost is not changed. The optimally insulated wall will have a total LCC that only slowly will increase if the existing wall is in a poor thermal shape. The total cost for the not insulated building has a steeper slope and for walls in a good thermal shape the insulation is unprofitable. This is also shown in figure 9.

		U-value in $W/m^2 \cdot K$			
	Type of cost	0.4	0.6	0.8	1.0
No extra insul-ation	Inevitable retrofit	0.882	0.882	0.882	0.882
	Heating equipment	0.607	0.646	0.686	0.725
	Energy	0.242	0.265	0.289	0.313
	Total cost	1.731	1.793	1.857	1.921
Optimal insul-ation	Inevitable retrofit	0.882	0.882	0.882	0.882
	Heating equipment	0.573	0.572	0.572	0.572
	Energy	0.225	0.224	0.224	0.224
	Insulation	0.091	0.106	0.113	0.117
	(Thickness in meter	0.075	0.112	0.129	0.139)
	Total cost	1.792	1.805	1.812	1.816

Table XIV. LCC for the building depending on thermal status for the external wall. Costs in MSEK.

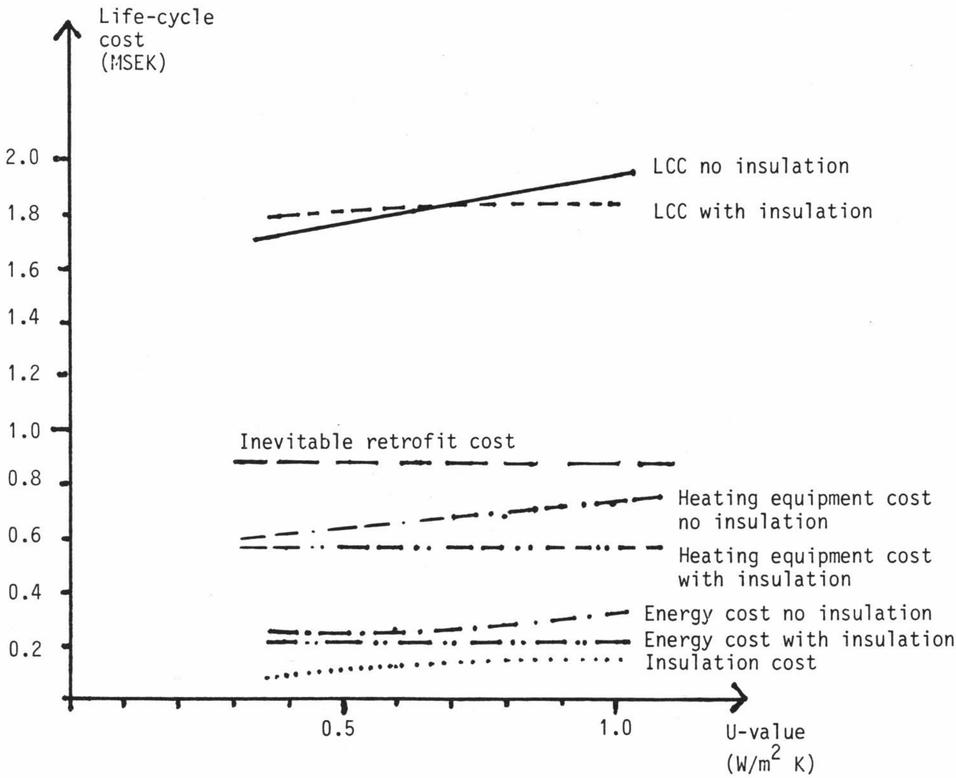

Figure 9. LCC changes due to thermal status, external wall.

The influence from the climate, under this heading i e the dimensioning outside temperature, can be analysed in the same way. In table XV the situation is presented. From the table it is obvious that the heating equipment cost is increased for lower outside temperatures, and so is the total LCC. If the wall is optimally insulated the slope is getting less steep and for high outside temperatures the insulation retrofit will be unprofitable. This however, will be the situation only in a very mild climate.

The dimensioning outside temperature can be found in the Swedish building code. If the building is retrofitted in order to decrease its thermal losses, it takes a longer period of time before it gets cold if e g the heating equipment is not working properly. A short period with cold weather, when the outside temperature is lower than the dimensioning one, will not influence as much as if the building had not been extra insulated at all. Insulation etc provides the building with a longer time constant. It is thus possible to use a higher dimensioning outside temperature in the retrofitted building. The problem is to find proper values for this influence. More details about this subject can be found in [3 and 77].

		Dim. outside temp. in °C			
	Type of cost	-6	-10	-14	-18
No insulation	Inevitable retrofit	0.882	0.882	0.882	0.882
	Heating equipment	0.578	0.652	0.725	0.799
	Energy	0.313	0.313	0.313	0.313
	Total cost	1.773	1.847	1.921	1.995
Optimal insulation	Inevitable retrofit	0.882	0.882	0.882	0.882
	Heating equipment	0.463	0.518	0.572	0.626
	Energy	0.226	0.225	0.224	0.223
	Insulation	0.111	0.114	0.117	0.119
	(Thickness in meter	0.125	0.132	0.139	0.145)
	Total cost	1.698	1.757	1.816	1.874

Table XV. LCC for the building depending on the dimensioning outside temperature. Costs in MSEK.

3.3.3 Energy cost

The energy cost part of the total LCC will almost always be most important to decrease in order to minimize the LCC. This part is of course influenced by the direct energy cost, i e the cost for each MJ delivered from the heating equipment. A low running cost is thus essential for the result. Also the climate will naturally affect the cost and so does the thermal status of the building. Other important factors are the discount rate and the optimization time. In table XVI the situation is shown for the oil-boiler equipment.

	Type of cost	Price in SEK/MJ 0.03	0.06	0.09	0.12
No insulation	Inevitable retrofit	0.882	0.882	0.882	0.882
	Heating equipment	0.063	0.063	0.063	0.063
	Energy cost	0.417	0.835	1.252	1.669
	Total cost	1.363	1.780	2.197	2.615
Optimal insulation	Inevitable retrofit	0.882	0.882	0.882	0.882
	Heating equipment	0.055	0.054	0.054	0.054
	Energy cost	0.309	0.596	0.879	1.159
	Insulation cost	0.098	0.118	0.134	0.148
	(Thickness in meter	0.092	0.143	0.183	0.217
	Total cost	1.344	1.650	1.949	2.243

Table XVI. LCC for the building depending on the energy price. Costs in MSEK. Existing heating system.

From the upper table it is obvious that the total energy cost is doubled if the direct cost for each MJ is doubled. The total LCC thus will increase with the same slope. If optimal insulation is implemented, more insulation is profitable if the direct energy price is increased, and thus the energy cost will not increase as much as could be expected, see figure 10.

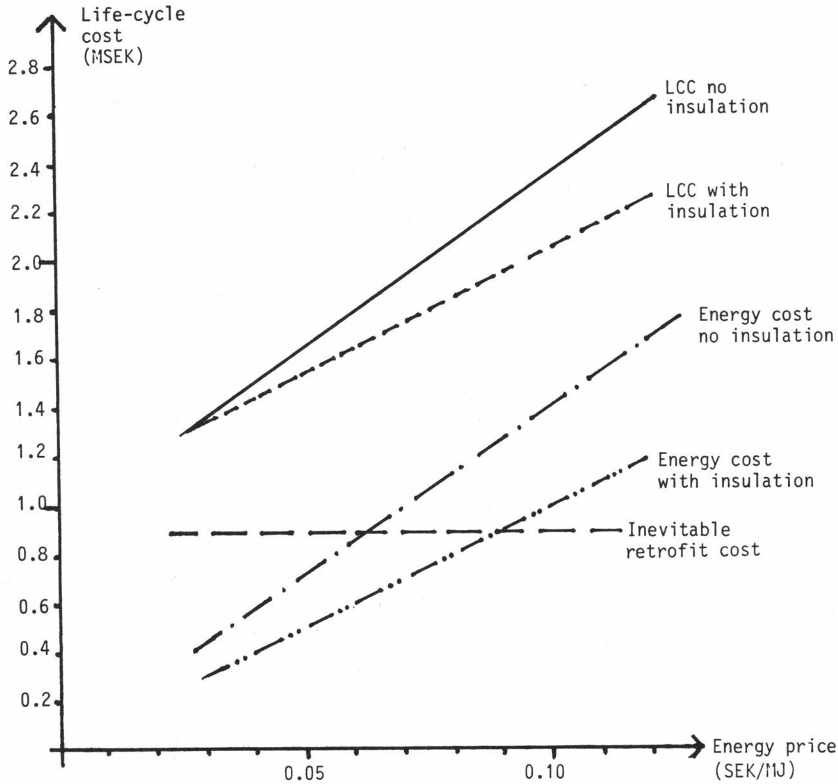

Figure 10. LCC changes due to energy prices.

Changing into a colder climate, will of course raise the total energy cost and thus the LCC. In Kiruna, in the north of Sweden, the number of degree hours is approximately twice the number in Malmö. The total energy cost for the existing building will thus be doubled. Retrofitting the wall with 0.19 meter insulation, which was found optimal, will however decrease the energy cost in the same way as was found in table XVI.

From tables X at page 63 and XI at page 64, the influence of a changed discount rate is presented. A low rate implies a high LCC and vice versa. The energy cost for the existing building will decrease faster than the energy cost for the retrofitted building, and for a high rate the gap between the two energy costs is less than the insulation cost. The retrofit will be unprofitable.

In tables XII and XIII at page 65, the situation for different optimization periods is shown. The energy cost will decrease faster for the existing building if the optimization period is shortened, and for some optimization time the gap is smaller than the insulation cost and the retrofit will be unprofitable.

The thermal losses in the building are naturally also important. This can be found in table XIV, page 68. The energy cost in the existing building will of course increase if the thermal shape is poor. The retrofitted building however will have a constant energy cost due to the optimal insulation, which is thicker for the poor envelopes. When the shape is good, the retrofit will be unprofitable.

3.3.4 Insulation cost

The direct insulation cost, C_2 and C_3 in equation (5), page 38, will of course influence on the total insulation cost. C_2 however, will only increase the level of the LCC and not the amount of insulation. It thus can be dealt with as an inevitable retrofit cost, only occurring once, i e at the base year. C_3 will influence the thickness of the insulation, and thus also the energy cost above.

From table XVII it can be found that the total insulation cost will increase if the direct insulation cost is higher. However, the optimal insulation thickness also decreases and the increase in cost is thus rather small. The LCC for the 200 SEK/m $\cdot$ m^2 case is only marginally lower than the 800 alternative. The total cost will nevertheless increase and for very expensive insulations the retrofit will be unprofitable.

This is also emphasized in figure 11.

Type of cost	Ins. cost in SEK/m · m² 200	400	600	800
Inevitable retrofit	0.882	0.882	0.882	0.882
Heating equipment	0.054	0.054	0.055	0.055
Energy cost	0.468	0.480	0.490	0.498
Insulation cost	0.095	0.106	0.113	0.118
(Thickness in meter	0.236	0.155	0.119	0.098)
Total cost	1.498	1.522	1.540	1.552

Table XVII. LCC due to different insulation costs, C_3. Costs in MSEK.

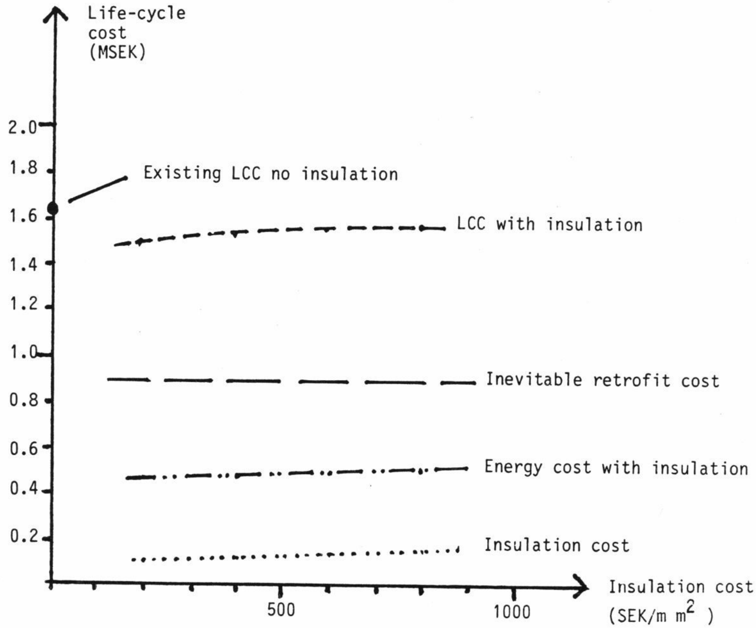

Figure 11. LCC changes due to insulation cost.