OPTIMAL USE OF SOLAR COLLECTORS FOR RESIDENTIAL BUILDINGS

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Abstract

Solar radiation is an abundant free resource which may be utilized in the form of solar heated water. This is achieved in solar collectors, which unfortunately are expensive devices, and further the warm water must be stored in accumulators which items also cost money. This paper shows how we have optimised the situation for a block-of-flats in Sweden. In order to find this point we have used the minimum Life-Cycle Cost, LCC, concept as a criterion. The best solution is therefore found when that cost finds its lowest value. It is also examined under which conditions solar collectors are part of the optimal solution and further it is calculated what happens if this optimal point is abandoned, i. e. how much will the LCC increase if other than optimal solutions are chosen. LCC optimisation almost always results in a heating system with low operating costs such as district heating. The installation cost must, however, be kept on a reasonable level and expensive solar panel systems are therefore normally avoided if the lowest LCC shall be reached, at least for Swedish conditions. For buildings where the only alternative energy source is electricity, solar collectors seem to be on the rim of profitability, i. e. for an energy price of about 0.6 SEK/kWh.

INTRODUCTION

Solar collectors used for domestic hot water, and space, heating are not very common in Sweden but have found widespread use in other countries, see e. g. References [1] and [2] which describe some recent studies. This is to a part the result of our cold climate but also the fact that other energy sources with reasonable costs are available, e. g. in the form of district heating produced in Combined Heat and Power, CHP, plants. Solar applications will therefore be unprofitable compared to the alternative solutions. In this paper we have used the concept Life-Cycle Cost, LCC, as a criterion for optimisation, i. e. the best solution is achieved when the LCC for the studied building finds its lowest value. Hence, if solar collectors are found unprofitable the LCC, with solar collectors included, has been calculated to a higher value than was the case if they were abandoned. There are also other methods described in literature, see e. g. Reference [3] where the LCC-concept has been simplified in order to gain in popularity. The calculations are many times computerised in the form of programs and the program used here is called the OPERA model, see Reference [4] for a detailed description. The program was written in Fortran 77 and therefore it runs under almost all operative systems with only small modifications. (In this study an ordinary PC was used equipped with both DOS and LINUX.)

The OPERA-model is designed for finding optimal retrofit measures for existing buildings. Multi-family blocks of flats was emphasized but single-family houses or industrial buildings can be analysed as well. An existing building is presented to the computer model in the form of an input data file containing about 200 values describing energy tariffs, U-values of the climate shield, the costs for the building measures and so forth. It is not possible to describe the building in all detail in a paper of this length but a short presentation is necessary. More details are also presentad in due course.

THE STUDIED BUILDING

The building consists of 14 apartments and it is originally sited in Malmö, Sweden, about 600 km south of Stockholm. The thermal shape of the building is presented in Table 1.

Building asset	Area [m^2]	U-value [$W/m^2 \times K$]	U×A-value [W/K]
Attic floor	273	0.8	218.4
Floor	273	0.5	136.5
External wall	616	1.2	739.2
Windows east	75.6	3.5	264.6
Windows west	69.6	3.5	243.6
Total			1602.3

Table 1: Thermal conditions of the considered climate shield.

It must be noted here that Table 1 does not show the real conditions in the building. To a part it as an academic product and the thermal shape is therefore better in reality. This is so because no retrofits will "show up" if the real values were used for e. g. the external wall.

Heat is also used for ventilation and it is assumed that 0.6 renewals per hour of the building air volume is valid. (The Swedish building code sets a value of 0.5.) The area of the apartments are 814 m^2 and 2.8 m between floor and roof. The ventilation rate will therefore be 1,367.5 m^3/h. The density of air is 1.18 kg/m^3 while the heat capacity is 1.005 kJ/(kg×K), see Reference [5] p. 646. The heat amount ventilated to the outside each hour will therefore become 1621.7 kJ/(K×h) or 450.4 W/K. Adding the losses from the thermal shield results in 2,053 W/K. The model uses monthly mean average temperatures for the last 30 years as climate input data and the year is therefore split in 12 segments. Degree hours are generated whenever the desired indoor temperature is higher than the outdoor temperature. In Malmö the average outdoor temperature for January is 0.5 °C while it is assumed that 21 °C is used indoors. Hence 15,996 degree hours are generated in that month and the energy demand will become

32,839 kWh, see Table 2. (The values in Table 2 are fetched from the computer program and small differences therefore occur.)

MONTH NO	DEG.-HOURS	ENERGY-TRANSM	HOT-WATER	FREE ENERGY	SOLAR HEAT	UTILIZ FREE	FROM BOILER	SOLAR PANELS
1	15996.	32893.	3500.	4167.	1201.	5368.	31027.	0.
2	14713.	30254.	3500.	4167.	2609.	6776.	26980.	0.
3	14582.	29987.	3500.	4167.	6078.	10245.	23245.	0
4	10800.	22209.	3500.	4167.	8998.	13165.	12548.	0.
5	7440.	15299.	3500.	4167.	12717.	15299.	3500.	0.
6	4320.	8883.	3500.	4167.	13200.	8883.	3500.	0.
7	2827.	5814.	3500.	4167.	12933.	5814.	3500.	0.
8	3199.	6579.	3500.	4167.	10900.	6579.	3500.	0.
9	5400.	11104.	3500.	4167.	7712.	11104.	3500.	0.
10	9002.	18512.	3500.	4167.	4109.	8276.	13746.	0.
11	11592.	23837.	3500.	4167.	1561.	5728.	21620.	0.
12	14136.	29069.	3500.	4167.	778.	4945.	27635.	0.
TOTAL	114008.	234440.	42000.	50004.	82796.	102183.	174257.	0.

Table 2: Energy balance in kWh for the test building sited in Malmö, Sweden.

The demand for domestic hot water heating was assumed to be 3.5 MWh. Free energy from persons and appliances have been calculated to 4.2 MWh each month while solar radiation through the windows has been calculated to 1.2 MWh for the first month of the year. For January all the free heat can be used and it adds up to 5.4 MWh. Hence, the boiler must provide 31.2 MWh. In this first calculation no solar collectors are thought to be installed and, subsequently, all values in Table 2 are zero.

During summer there is no need for extra space heating by using the boiler. Free energy covers the demand. The boiler must, however, be used for domestic hot water heating which results in 3.5 MWh each month. The question is now if a solar heating system will result in a lower LCC compared to the original situation. Should such a system be designed for covering only the domestic hot water demand or is it optimal to add extra solar collectors for space heating purposes as well? In order to solve this problem it is necessary to find out how much heat a solar collector could collect. Sweden is a very long and narrow country where conditions differ a lot between the north and south. In the north of Sweden the sun is up 24 hours a day during some summer months. This might result in a lot of heat from a solar collector. The climate, however, is cold which results in a high demand, and further the sun will not show up at all during the winter. This paper therefore deals with two cases, one for the north of Sweden, Kiruna, and one for Malmö in the south.

SOLAR COLLECTOR CALCULATIONS

We have used a computer program written in C for Windows 95 in order to calculate how much heat it is possible to utilize from a solar collector. The position of the sun is calculated for each hour during one year. Further, data for clear, half clear and overcast days are used in order to find monthly mean values for the available heat. The locations on the earth surface is for Malmö, longitude 13.1°E, latitude 55.2 °N and for Kiruna, 20.3°E, 67.5 °N, i. e. even north of the polar circle. The tilt angle between the solar collector and the earth has been varied between 0 and 90°. When the angle is zero the collector is located flat on the ground while it is vertical when the angle is 90°. The collector was faced exactly to the south. For a detailed description of the solar calculations, see Reference [6]. The performance of the collector is strongly dependent of the temperature inside the collector, see Reference [7] page 251 or [8]. Here 60 °C is used which normally is used for domestic hot water in Sweden. The overall U-value of the collector has been set to 5.0 W/m^2×°C. A method found in Reference [7], page 281, is used for the solar collector output. The collector contributes only if the absorbed solar radiation exceeds the thermal losses from the warm collector. In Figures 1 and 2 it is shown how available energy from each square meter varies depending on the tilt angle and month of the year for the site Malmö.

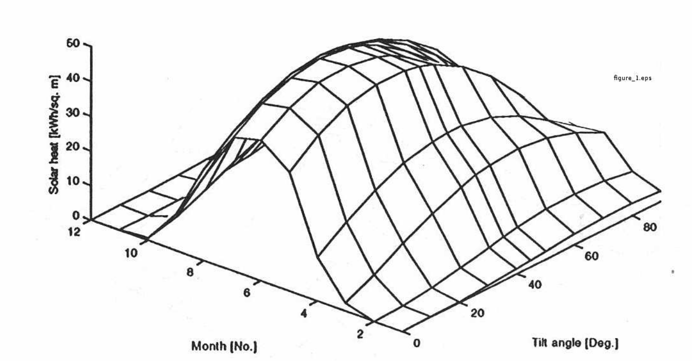

Figure 1: Solar collector output in Malmö where a tilt angle of 0° is shown in the front.

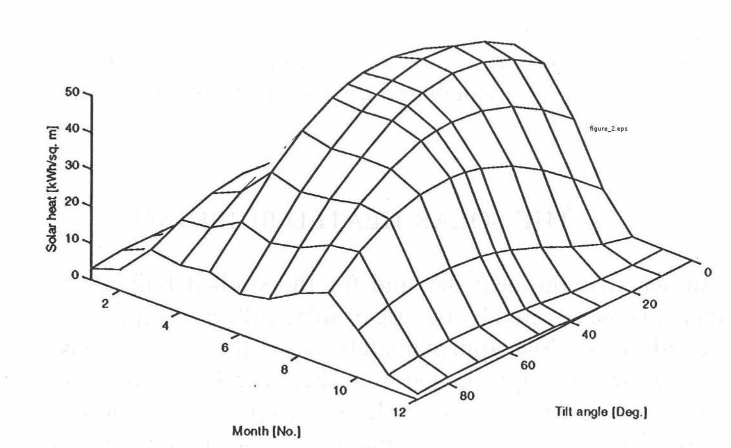

Figure 2: Solar collector output in Malmö where a tilt angle of 90° is shown in the front.

The maximum monthly value, 49.7 kWh/m^2 is present for July and a tilt angle of 30°°. Adding values also for the other months, however, show that an optimal solar collector should be tilted about 45° resulting in 292 kWh/m^2 for one year.

If the building was located in Kiruna, i. e. close to the arctic circle, the following would apply, see Figures 3 and 4.

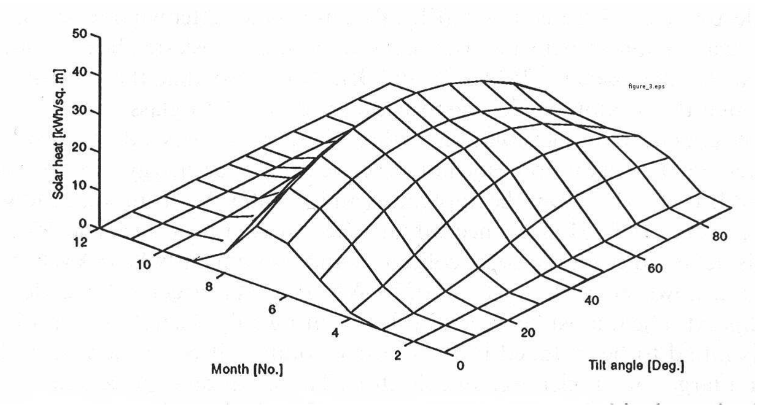

Figure 3: Solar collector output in Kiruna where a tilt angle of 90° is shown in the front.

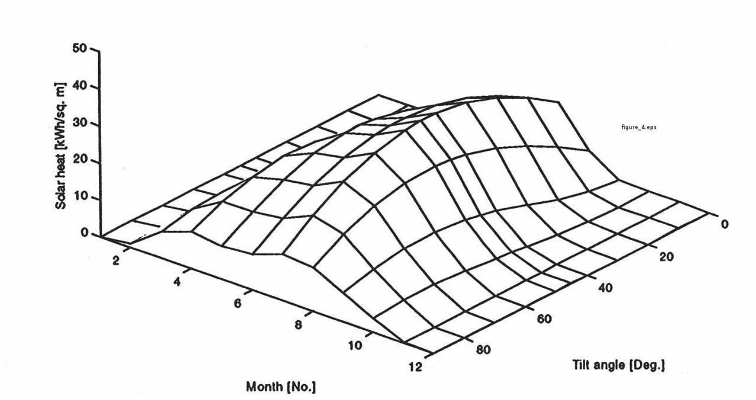

Figure 4: Solar collector output in Kiruna where a tilt angle of 90° is shown in the front.

The maximum value for one month, 29.7 kWh/m^2 is present for July and for a tilt angle of 45°. Optimum performance from the solar collector calculated for one year, 140 kWh/m^2, was found for a tilt angle of about 53°.

THE SOLAR HEATED BUILDING

In Table 2 it is shown that the heat demand for the studied building is about 3.5 MWh in the summer. If all of this must be covered by use of solar collectors, approximately 70 m^2 must be used for Malmö conditions while approximately twice this area is necessary in Kiruna. If, however, an even larger area is implemented more heat can be produced but some of this solar collector heat cannot be used during the summer. In Table 3 the conditions are shown for a solar collector area of 200 m^2 which is the approximate available area on the roof of the building.

MONTH NO	DEG.- HOURS	ENERGY- TRANSM	HOT- WATER	FREE ENERGY	SOLAR HEAT	UTILIZ. FREE	FROM BOILER	SOLAR PANELS
1	15996.	29410.	3500.	4167.	1081.	5650.	27260.	402.
2	14713.	27050.	3500.	4167.	2348.	7653.	22897.	1138.
3	14582.	26811.	3500.	4167.	5470.	13757.	16553.	4120.
4	10800.	19856.	3500.	4167.	8098.	18245.	5111.	5980.
5	7440.	13679.	3500.	4167.	11445.	17179.	0.	9220.
6	4320.	7943.	3500.	4167.	11880.	11443.	0.	9260.
7	2827.	5198.	3500.	4167.	11640.	8698.	0.	9220.
8	3199.	5882.	3500.	4167.	9810.	9382.	0.	8460.
9	5400.	9928.	3500.	4167.	6940.	13428.	0.	6800.
10	9002.	16551.	3500.	4167.	3698.	10865.	9186.	3000.
11	11592.	21313.	3500.	4167.	1405.	6132.	18681.	560.
12	14136.	25990.	3500.	4167.	700.	5039.	24450.	172.
TOTAL	114008.	209609.	42000.	50004.	74516.	127471.	124138.	58332.

Table 3: Energy balance for a case where triple glazed windows and solar collectors were implemented as retrofits.

The table is a result from the OPERA model. Triple glazed windows were optimal in the original case but solar collectors were too expensive to take part. Therefore, in order to ascertain that the collectors were included in the optimal solution, a very low collector price has been applied, about 1 SEK/m^2 collector area. (1 US $ equals 9 SEK.) Because of the better window status, triple-glazing is introduced instead of double paned windows, the amount of transferred heat through the climate shield is not exactly the same in Tables 2 and 3. Note also that the amount of solar heat transferred through the windows is decreased because of this extra glass pane.

An example might elucidate the situation. For July there is a demand of 5,198 kWh for space heating and 3,500 kWh for domestic hot water heating. Free energy which could be used for space heating adds up to 4,167 from the appliances and 11,640 kWh from solar radiation through the windows. However, only 5,198 are needed and the rest is of no value. The 3,500 kWh for hot water heating is achieved from the solar collectors and subsequently 8,698 kWh is utilized. The available amount, however, adds up to 25,027 kWh. If a still larger solar collector would be implemented this extra heat must be useless, at least during July. Therefore, if a solar collector of a certain size is found to be included in the optimal solution it is not necessary that the same will happen for a larger or smaller area of collectors. The situation is presented in more detail in Table 4 where the implemented area of solar collectors are changed while the rest of the input data are the same.

The available output from the collectors is doubled for a doubled square area but the demand from the boiler is not decreased to the same amount as the available heat is increased. This is also evident on the total LCC which becomes lower for an increased collector area but not to the same rate as available energy increases. This phenomenon is also present when other retrofits are considered. If one retrofit is supposed to save A kWh and the other B kWh, the combination of the retrofits will not save A + B kWh but slightly less. This is so because the heating season gets shorter.

Area [m^2]	LCC [MSEK]	From boiler [MWh]	From solar collectors [MWh]
10	1.19	154.0	2.9
50	1.14	142.4	14.6
100	1.10	131.9	29.1
200	1.07	124.1	58.3
300	1.04	116.4	87.5
400	1.02	109.6	116.6
500	1.00	104.9	145.8
1000	0.93	84.3	291.6

Table 4: LCC for the building and boiler demand when solar collector area is varied.

THE SOLAR COLLECTOR COST

The cost for implementing solar collectors in a building has been split in two parts. One part for the actual collectors and one part for the hot water accumulator. The reason for doing so is due to the present value calculations, which are numerous in LCC optimisation. The accumulator is supposed to have a long service life and it is not replaced during the studied number of years. The collectors on the other hand are replaced each 20 years and this cost emerges year 0, year 20 and year number 40. A salvage value is of course withdrawn when the period of 50 years is reached. The accumulator is always needed because the solar energy must be stored from sunny days, to nights and cloudy days. Hot water is, however, not the only medium for solar heat storage purposes. Concrete, ceramics and salt could also be used but mostly for larger applications, see Reference [9]. The thermal size of the accumulator is of vital importance for the overall performance of the solar energy system, see Reference [7] p. 382 but in this study we have modeled the cost for the accumulator as a value in SEK/m^2 collector area. In order to calculate the present value cost, used in Life-Cycle Costing, further data are needed. One example of the conditions is the assumed life in years for the collector but also the actual cost for the collector and costs for the installation must be considered. In the OPERA-model the costs and other solar collector input data are presented as found in Table 5.

Life of collectors	20 years
Life of accumulator	50 years
Collector installation cost, type C_1	0 SEK
Collector installation cost, type C_2	2,000 SEK/m^2
Accumulator installation cost, type C_1	0 SEK
Accumulator installation cost, type C_2	1,000 SEK/m^2

Table 5: Assumed costs and input data for solar equipment in the OPERA-model.

When equipment such as a boiler or a solar collector is installed there are a number of things that must be achieved first. For instance, the old boiler must be demolished and carried to the scrap yard. Such costs are not dependent of the thermal size of the new equipment but are nonetheless important because they might make the whole installation unprofitable. These costs are presented as C_1 in Table 5. The actual output dependent collector cost, however, is shown in C_2. Even if the C_1 cost is zero in this example it is important that the model are able to deal with such a cost structure.

Present value, PV, calculations are numerous in Life-cycle costing. First an interest rate must be set, here 5 % is used, and a project life assumed, here 50 years. For a 200 m^2 solar collector implementation the following costs apply, note that a salvation value is withdrawn from PV_{sc}.

$$PV_{sc} = 2000 \times 200 \times [1 + 1.05^{-20} + 1.05^{-40} - \frac{1}{2} \times 1.05^{-50}] + 1000 \times 200 = 790 \quad kSEK$$

When the values in Table 5 are used in the OPERA model, solar collectors no longer are parts of the optimal solution. If collectors are profitable or not depend on a number of input data, e. g. the interest rate and, of course of the price for the collectors. In order to examine this a so called sensitivity analysis is performed. For a start the cost is set to a level where solar collectors are optimal to install. Therefore, the accumulator cost has been set to zero and the collector cost to 500 SEK/m^2 which result in solar collectors at least for some combinations of data. The collector area has after this been varied from 10 - 300 m^2 while the interest rate has been varied between 2 to 10 %. The resulting LCC and collector status are shown in Figure 5.

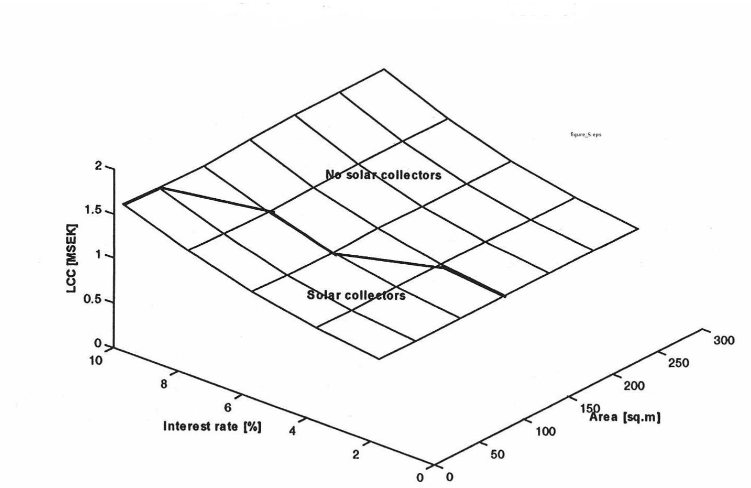

Figure 5: Sensitivity analysis of variations in solar collector area and interest rate.

If the interest rate is high, i.e. 10 %, about 50 m^2 is optimal. If a low rate is applicable, say 2 %, the area should be about three times larger. Similar graphs can be drawn for a number of cases where input data are varied. Important is, however, to notice that the optimal solar collector area depends on a number of other parameters than the actual cost. For a number of such cases solar collectors will not be parts in the best solution.

For northern Sweden the installation cost must be still lower if solar collectors are going to be optimal to install. In Table 6 an energy balance for the building, now academically located in Kiruna, is presented, compare with Table 2.

MONTH NO	DEG.-HOURS	ENERGY-TRANSM	HOT-WATER	FREE ENERGY	SOLAR HEAT	UTILIZ. FREE	FROM BOILER	SOLAR PANELS
1	24701.	50794.	3500.	4167.	1201.	5368.	48926.	0.
2	22645.	46567.	3500.	4167.	2609.	6776.	43290.	0.
3	22246.	45745.	3500.	4167.	6078.	10245.	39000.	0
4	17640.	36274.	3500.	4167.	8998.	13165.	26609.	0.
5	13615.	27998.	3500.	4167.	12717.	16884.	14614.	0.
6	8496.	17471.	3500.	4167.	13200.	17367.	3604.	0.
7	6026.	12392.	3500.	4167.	12933.	12392.	3500.	0.
8	7812.	16064.	3500.	4167.	10900.	15067.	4497.	0.
9	11448.	23541.	3500.	4167.	7712.	11879.	15163.	0.
10	16740.	34423.	3500.	4167.	4109.	8276.	29647.	0.
11	20016.	41160.	3500.	4167.	1561.	5728.	38932.	0.
12	23138.	47581.	3500.	4167.	778.	4945.	46135.	0.
TOTAL	194524.	400009.	42000.	50004.	82796.	128092.	313917.	0.

Table 6: Energy balance in kWh for the existing test building sited in Kiruna, Sweden.

No retrofits have yet been implemented. It is obvious that much more heat is used and space heating is needed for all months except for July. The boiler must provide 314 MWh each year while Table 2 shows 174 MWh for the same building sited in Malmö. In order to include solar collectors in the optimal solution the OPERA program has been run several times with different solar collector data. This resulted in a solar collector cost of about 250 SEK/m^2 and about 150 m^2 seems to be the optimal total area. An energy balance for this case is presented in Table 7.

MONTH NO	DEG.-HOURS	ENERGY-TRANSM	HOT-WATER	FREE ENERGY	SOLAR HEAT	UTILIZ. FREE	FROM BOILER	SOLAR PANELS
1	24701.	25904.	3500.	4167.	1081.	5248.	24156.	0.
2	22645.	23748.	3500.	4167.	2348.	6605.	20643.	90.
3	22246.	23329.	3500.	4167.	5470.	10834.	15995.	1197.
4	17640.	18499.	3500.	4167.	8098.	14875.	7124.	2610.
5	13615.	14278.	3500.	4167.	11445.	17683.	95.	3405.
6	8496.	8910.	3500.	4167.	11880.	12410.	0.	3735.
7	6026.	6320.	3500.	4167.	11640.	9820.	0.	4395.
8	7812.	8192.	3500.	4167.	9810.	11552.	140.	3360.
9	11448.	12005.	3500.	4167.	6940.	13625.	722.	1620.
10	16740.	17555.	3500.	4167.	3698.	8342.	12713.	477.
11	20016.	20991.	3500.	4167.	1405.	5573.	18917.	2.
12	23138.	24265.	3500.	4167.	700.	4867.	22898.	0.
TOTAL	194524.	203996.	42000.	50004.	74516.	121436.	123401.	20891.

Table 7: Energy balance in kWh for the retrofitted test building sited in Kiruna, Sweden.

Table 6 shows the situation where no energy saving measures are implemented while Table 7 shows the building where optimal retrofits are added. Note that the demand of heat from the boiler is more than halved in Table 7. This is so because extra insulation was found optimal on both the attic floor and the external walls. Weather-stripping as well as triple-glazed windows were other measures which were found optimal to implement.

ALTERNATIVE ENERGY SOURCES

In the cases above solar energy competed with heat from natural gas or district heating which have assumed running costs of about 0.25 SEK/kWh. Such heating systems are not always available. Multi-family buildings in Sweden are many times heated by firing oil in a boiler or sometimes even electricity is used. Such systems have considerable higher operating costs and, hence, solar collectors might be favorable. It is, however, difficult to examine the resulting LCC from such high running cost systems by using the OPERA-model. This is so because the program always chooses the cheapest way to achieve the desired indoor temperature. In order to examine the total LCC of the building if heating systems with high operating costs are installed, a small C-program has been designed where it is possible to change input data and see the resulting LCC. The situation is not optimised which makes it possible to implement for example an oil-fired boiler even if this results in a very high LCC. For a start we used the costs in Table 5 and an assumed high oil price of 2 SEK/kWh just in order to achieve that collectors were part of the optimal solution.

Solar collectors, about 100 m^2, were therefore found optimal and the resulting LCC was calculated to 7.79 MSEK, compare with the LCC in Table 4. If no solar collector was implemented a LCC of 8.54 MSEK was present, i.e. higher. For an oil price of 0.5 SEK/kWh it is cheaper to avoid solar panels, the LCC was 2.549 MSEK while a collector area of 10 m^2 did result in a LCC of 2.555 MSEK. About 50 m^2 yield the lowest LCC for an oil price of 0.6 SEK/kWh, see Figure 6.

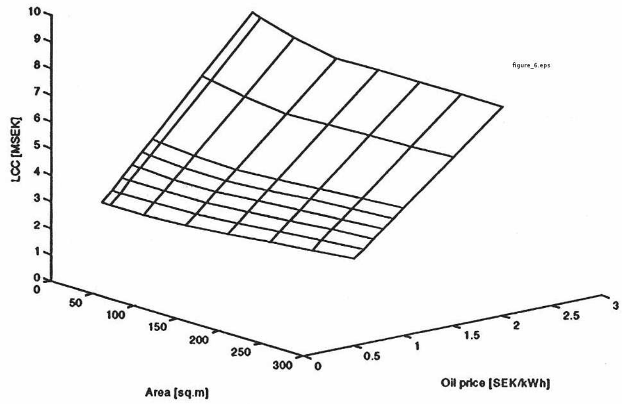

Figure 6: Life-Cycle Cost in MSEK for a varying energy price and solar panel area.

With the prices valid in Sweden today solar collectors seem to be profitable for an energy price of about 0.6 SEK/kWh. Note that the LCC only slowly increases if the solar collector area is increased. If the proprietor decides to implement solar heating it is therefore better to use a larger area if input data are uncertain. The question is now if such prices are applicable and, hence, solar collectors of interest.

The proprietors of multi-family buildings normally have several options when it comes to the design of the heating system and, therefore, such expensive heat sources as electricity is abandoned. OPERA therefore rejects solutions where electricity is used in resistance heating boilers. Heat pumps, run on electricity, might however be of interest. The running cost is by this decreased which in turn results in that solar collectors will no longer be part of an optimal retrofit strategy. In Sweden and Norway there is, however, a large building stock with single-family houses heated with electricity and many larger such buildings as well. Further, these buildings usually are not located in denser parts of the cities and district heating is because of this not available. Oil- or wood-fired boilers cannot be used because there are no chimney etc. Electricity is therefore the only option. With the nowadays deregulated electricity market it is not easy to predict the electricity price and because of this know if solar collectors apply in our block of flats. We have therefore used a real electricity tariff from yet another Swedish town, Norrköping 1999. For somewhat larger buildings where more than 10 MWh are used, the tariff in Table 8 applied.

Working days during November to March, 06-22,	0.77 SEK/kWh
Other time	0.52 SEK/kWh
Subscription fee for a fuse size of 100 A, 3-phase, 400 V	10,937 SEK/year

Table 8: Electricity tariff T17 for Norrköping 1999.

The prices include electricity taxes and V.A.T. If 100 A is not enough a demand tariff is used instead, see Table 9, which shows the fees for using the grid.

Subscription fee, fixed	3,750 SEK/Year
Demand fee	281.25 SEK/(kW×Year)
Energy fee, November - March, 06 - 22,	0.075 SEK/kWh
Other times	0.0625 SEK/kWh

Table 9: Electricity demand tariff for Norrköping 1999.

It is also necessary to buy the actual electricity and the costs were 0.616 and 0.416 SEK/kWh for winter working days and other times respectively. Because of such high running cost the OPERA program tries to decrease the use of electricity by e. g. adding extra insulation on the external walls. The tariff in Table 8 was applicable because the necessary current was as low as about 60 A due to several such retrofits. Solar panels were, however, not competitive. The normalised electricity price, i. e. the total cost for electricity divided by the amount of kWh was calculated to 0.65 SEK/kWh and solar collectors, with prices according to Table 5, emerged as optimal devices when this average price was 0.75 SEK/kWh. They are therefore not optimal to install but if energy tariffs increase or if solar collectors could be achieved to somewhat lower prices these devices will be of interest for many house owners in Sweden.

CONCLUSIONS

Solar collectors seems to be unprofitable for use in Swedish multi-family buildings, at least with the prices and conditions applicable today. This depends to a part on the cheap alternative heat sources which are available, e. g. district heating or sometimes even natural gas. For the south of Sweden the cost for solar collectors must be reduced by about 75 % if they are going to take part in an optimal retrofit strategy while still cheaper collectors must be used in the north of the country. There are, however, sites where neither district heating nor natural gas are available. If the alternative heat sources are oil-fired boilers or electricity heating, solar collectors might be profitable if they are reduced in price with about 25 %. Single-family, and smaller multi-family buildings in Sweden, on the other hand, are many times heated with electricity and they are very expensive to convert to other heating systems. With the tariffs used today solar collectors are therefore on the rim to become profitable energy conservation measures.

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