Volume 25, No. 11
September 2001

International Journal of Energy Research

Editor **J. T. McMullan**

WILEY
IJERDN 25(11) 939–1032 (2001)
ISSN 0363-907X

INTERNATIONAL JOURNAL OF ENERGY RESEARCH
Int. J. Energy Res. 2001; **25**:993–1004 (DOI: 10.1002/er.736)

Optimal use of solar collectors for residential buildings

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SUMMARY

Solar radiation is an abundant free resource which may be used 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—items which also cost money. This paper shows how we have optimized 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 optimization for multi-family buildings almost always results in a heating system with low operating costs such as district heating or dual-fuel systems where a heat pump takes care of the base load and an oil boiler the peak. The installation cost must, however, be kept to a reasonable level. Expensive solar panel systems are therefore normally avoided if the lowest LCC shall be reached, at least for Swedish conditions. This is so even if the solar system has a very low operating cost. 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^{-1}. Copyright © 2001 John Wiley & Sons, Ltd.

KEY WORDS: solar collectors; optimization; space heating; domestic hot water heating; accumulators

1. 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. Abdul-Jabbar (1999) and Dincer (1999) for some recent studies. This is partly 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 have a high installation cost compared to the output in useful kWh and will normally be unprofitable compared to the alternative solutions. In this paper we have used the concept life-cycle cost (LCC) as a criterion for optimization, 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. Lunde (1982) where the LCC concept has

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Received 22 May 2000
Accepted 1 August 2000

been simplified in order to gain popularity. The calculations are many times computerized in the form of programs and the program used here is called the OPERA model, see Gustafsson and Karlsson (1989) 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 were 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 presented in due course.

2. 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 I.

It must be noted here that Table I does not show the real conditions in the building. It is partly 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. This academic building has been studied in a number of papers, see e.g. Gustafsson (1998), and hence it is practical to use it for scientific evaluation of LCC optimization.

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 1367.5 $m^3 h^{-1}$. The density of air is 1.18 $kg m^{-3}$ while the heat capacity is 1.005 $kJ kg^{-1} K^{-1}$, see Holman (1997, p. 646). The heat amount ventilated to the outside each hour will, therefore, become 1621.7 $kJ K^{-1} h^{-1}$ or 450.4 $W K^{-1}$. Adding the losses from the thermal shield results in 2053 $W K^{-1}$. The model uses monthly mean average temperatures for the last 30 years as climate input data and the year is, therefore, split into 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,

Table I. Thermal conditions of the considered climate shield.

Building asset	Area (m^2)	U-value ($W m^{-2} K^{-1}$)	$U \times A$-value ($W K^{-1}$)
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

see Table II. (The values in Table II are fetched from the computer program and small differences therefore occur.)

The demand for domestic hot water heating was assumed to be 3.5 MWh for each month. 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 this 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 31.02 MWh. In this first calculation no solar collectors are thought to be installed and, subsequently, all values in Table II 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 the south. In the north of Sweden the sun is up 24 h 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.

3. SOLAR COLLECTOR CALCULATIONS

We have used a computer program written in C for Windows 95 in order to calculate how much heat is possible to be utilized 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 Gustafsson (1990). The performance of the collector is strongly dependent on the temperature inside the collector, see Duffie and Beckman (1991, p. 251) or Perers (1993). Here 60°C is used which is normally used for domestic hot water in Sweden. The overall U-value of the collector has been set to 5.0 $\mathrm{W\,m^{-2}\,°C^{-1}}$. A method found in Duffie and Beckman (1991, p. 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.

The maximum monthly value, 49.7 $\mathrm{kWh\,m^{-2}}$ is 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 $\mathrm{kWh\,m^{-2}}$ for 1 yr.

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

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

Month no.	Degree hours	Energy transm	Hot water	Free energy	Solar heat	Utiliz free	From boiler	Solar panels
1	15 996	32 893	3500	4167	1201	5368	31 027	0
2	14 713	30 254	3500	4167	2609	6776	26 980	0
3	14 582	29 987	3500	4167	6078	10 245	23 245	0
4	10 800	22 209	3500	4167	8998	13 165	12 548	0
5	7440	15 299	3500	4167	12 717	15 299	3500	0
6	4320	8883	3500	4167	13 200	8883	3500	0
7	2827	5814	3500	4167	12 933	5814	3500	0
8	3199	6579	3500	4167	10 900	6579	3500	0
9	5400	11 104	3500	4167	7712	11 104	3500	0
10	9002	18 512	3500	4167	4109	8276	13 746	0
11	11 592	23 837	3500	4167	1561	5728	21 620	0
12	14 136	29 069	3500	4167	778	4945	27 635	0
Total	114 008	234 440	42 000	50 004	82 796	102 183	174 257	0

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

Month no.	Degree hours	Energy transm	Hot water	Free energy	Solar heat	Utiliz free	From boiler	Solar panels
1	15 996	29 410	3500	4167	1081	5650	27 260	402
2	14 713	27 050	3500	4167	2348	7653	22 897	1138
3	14 582	26 811	3500	4167	5470	13 757	16 553	4120
4	10 800	19 856	3500	4167	8098	18 245	5111	5980
5	7440	13679	3500	4167	11 445	17 179	0	9220
6	4320	7943	3500	4167	11 880	11 443	0	9260
7	2827	5198	3500	4167	11 640	8698	0	9220
8	3199	5882	3500	4167	9810	9382	0	8460
9	5400	9928	3500	4167	6940	13 428	0	6800
10	9002	16551	3500	4167	3698	10 865	9186	3000
11	11 592	21 313	3500	4167	1405	6132	18 681	560
12	14 136	25 990	3500	4167	700	5039	24 450	172
Total	114 008	209 609	42 000	50 004	74 516	127 471	124 138	58 332

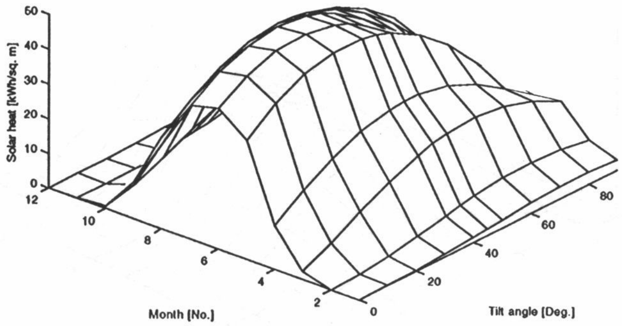

Figure 1. Solar collector output in Malmö where a tilt angle of 0° is shown in the front.

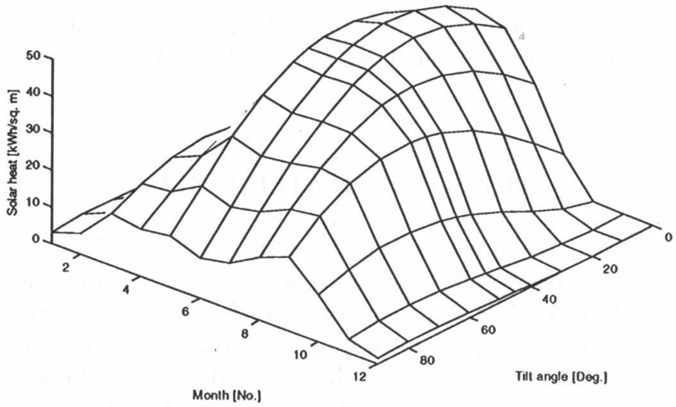

Figure 2. Solar collector output in Malmö where a tilt angle of 90° is shown in the front.

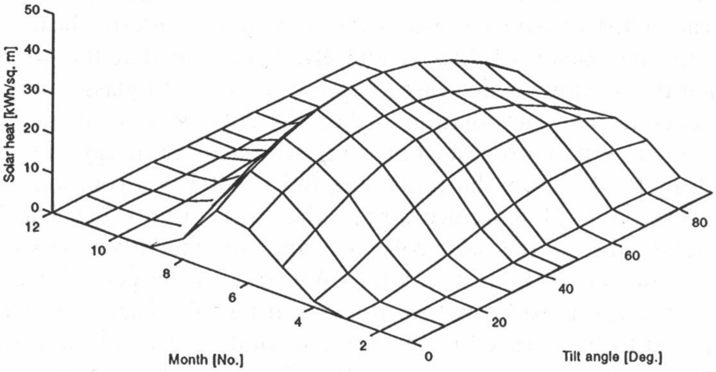

Figure 3. Solar collector output for Kiruna where a tilt angle of 0° is shown in the front.

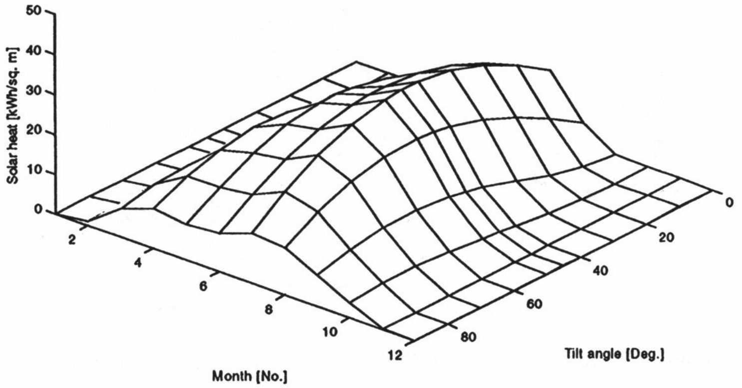

Figure 4. Solar collector output for Kiruna where a tilt angle of 90° is shown in the front.

The maximum value for 1 month, 29.7 kWh m^{-2} is for July and for a tilt angle of 45°. Optimum performance from the solar collector calculated for 1 yr, 140 kWh m^{-2}, was found for a tilt angle of about 53°.

4. THE SOLAR HEATED BUILDING

In Table II, it is shown that the heat demand for the studied building is about 3.5 MWh in summer. If all of this must be covered by the 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 summer. In Table III, 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.

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 II and III. 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 further. For July there is a demand of 5198 kWh for space heating and 3500 kWh for domestic hot water heating. Free energy which could be used for space heating adds up to 4167 from the appliances and 11 640 kWh from solar radiation through the windows. However, only 5198 are needed and the rest is of no value. The 3500 kWh for hot water heating is achieved from the solar collectors and subsequently 8698 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 more in detail in Table IV, where the implemented area of solar collectors are changed while the rest of the input data are the same.

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

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

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.

5. THE SOLAR COLLECTOR COST

The cost for implementing solar collectors in a building has been split into 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 optimization. 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 thought to be replaced every 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, *vide infra.* 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 Tamme *et al.* (1991). The thermal size of the accumulator is of vital importance for the overall performance of the solar energy system, see Duffie and Beckman (1991, p. 382) but in this study we have modelled the cost for the accumulator as a value in SEK m^{-2} collector area. In order to calculate the present value cost, used in LCC, 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 V.

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 on 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 V. The actual output dependent collector cost, however, is shown

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

Life of collectors	20 yr
Life of accumulator	50 yr
Collector installation cost, type C_1	0 SEK
Collector installation cost, type C_2	2000 SEK m^{-2}
Accumulator installation cost, type C_1	0 SEK
Accumulator installation cost, type C_2	1000 SEK m^{-2}

in C_2. Even if the C_1 cost is zero in this example, because of lack of input data for solar collector installation costs, it is important that the model are able to deal with such a cost structure.

Present value, PV, calculations are common elements in life-cycle costing. First, an interest rate must be set, here 5 per cent 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}.

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

When the values in Table V are used in the OPERA model, solar collectors are no longer a part 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 to 300 m^2 while the interest rate has been varied between 2 and 10 per cent. The resulting LCC and collector status are shown in Figure 5.

If the interest rate is high, i.e. 10 per cent, about 50 m^2 is optimal. If a low rate is applicable, say 2 per cent, the area should be about three times larger. Similar graphs can be drawn for a number of cases where input data are varied. However, it is important 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 a part of 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 VI an energy balance for the building, now academically located in Kiruna, is presented (compare with Table II). 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 II 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. If the cost is higher solar equipment is abandoned.

An energy balance for the former case is presented in Table VII. Table VI shows the situation, where no energy saving measures are implemented while Table VII shows the building where optimal retrofits are added. Note that the demand of heat from the boiler is more than halved in Table VII. 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.

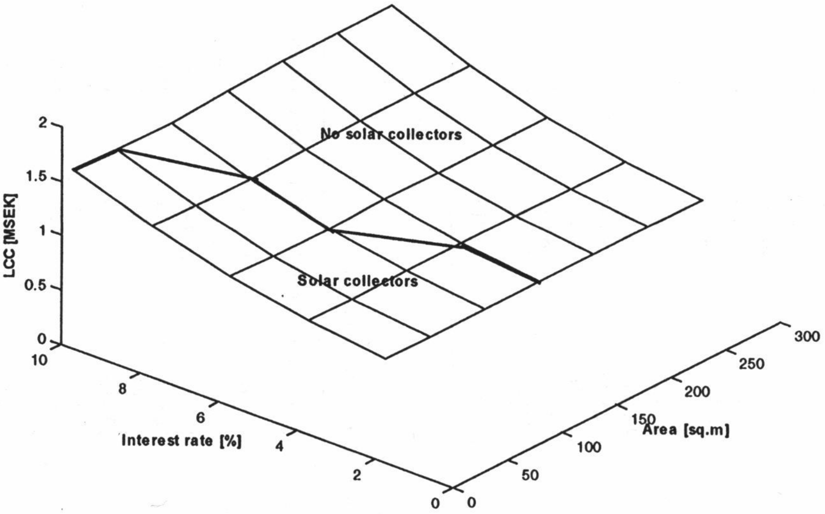

Figure 5. Sensitivity analysis of variations in solar collector area and interest rate.

6. PEAK HEATING 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^{-1}. Such heating systems are not always available. Multi-family buildings in Sweden are often 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 favourable. 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 optimized which makes it possible to implement for example an oil-fired boiler even if it results in a very high LCC. For a start we used the costs in Table V and an assumed high oil price of 2 SEK kWh^{-1} 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 IV. 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^{-1} 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^{-1}, see Figure 6. With the prices valid in Sweden today solar collectors seem to be profitable for an energy price of about 0.6 SEK kWh^{-1}. 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

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

Month no.	Degree hours	Energy transm	Hot water	Free energy	Solar heat	Utiliz free	From boiler	Solar panels
1	24 701	50 794	3500	4167	1201	5368	48 926	0
2	22 645	46 567	3500	4167	2609	6776	43 290	0
3	22 246	45 745	3500	4167	6078	10 245	39 000	0
4	17 640	36 274	3500	4167	8998	13 165	26 609	0
5	13 615	27 998	3500	4167	12 717	16 884	14 614	0
6	8496	17 471	3500	4167	13 200	17 367	3604	0
7	6026	12 392	3500	4167	12 933	12 392	3500	0
8	7812	16 064	3500	4167	10 900	15 067	4497	0
9	11 448	23 541	3500	4167	7712	11 879	15 163	0
10	16 740	34 423	3500	4167	4109	8276	29 647	0
11	20 016	41 160	3500	4167	1561	5728	38 932	0
12	23 138	47 581	3500	4167	778	4945	46 135	0
Total	194 524	400 009	42 000	50 004	82 796	128 092	313 917	0

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

Month no.	Degree hours	Energy transm	Hot water	Free energy	Solar heat	Utiliz free	From boiler	Solar panels
1	24 701	25 904	3500	4167	1081	5248	24 156	0
2	22 645	23 748	3500	4167	2348	6605	20 643	90
3	22 246	23 329	3500	4167	5470	10 834	15 995	1197
4	17 640	18 499	3500	4167	8098	14 875	7124	2610
5	13 615	14 278	3500	4167	11 445	17 683	95	3405
6	8496	8910	3500	4167	11 880	12 410	0	3735
7	6026	6320	3500	4167	11 640	9820	0	4395
8	7812	8192	3500	4167	9810	11 552	140	3360
9	11 448	12 005	3500	4167	6940	13 625	722	1620
10	16 740	17 555	3500	4167	3698	8342	12 713	477
11	20 016	20 991	3500	4167	1405	5573	18 917	2
12	23 138	24 265	3500	4167	700	4867	22 898	0
Total	194 524	203 996	42 000	50 004	74 516	121 436	123 401	20 891

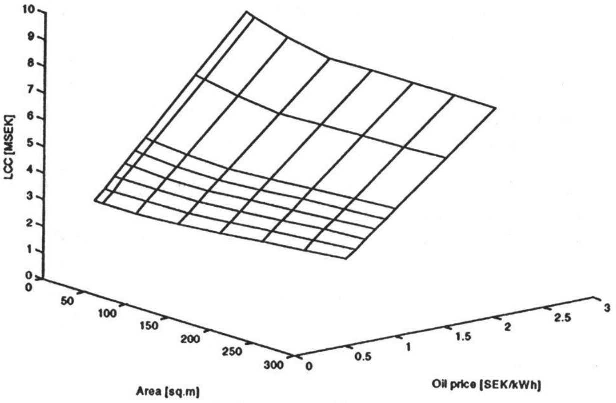

Figure 6. Life-cycle cost in MSEK for a varying energy price and solar panel area.

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 decreased by this type of heating system 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 electricity heated 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 deregulated electricity market nowadays, it is not easy to predict the electricity price and because of this to 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 VIII is applied.

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

It is also necessary to buy the actual electricity from the market and the costs were 0.616 and 0.416 SEK kWh^{-1} for winter working days and other times, respectively. That is if the prices applied by the municipality owned market company are used. 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. For the original building where no retrofits were implemented Table IX must be used, but when OPERA had optimized the situation this changed. The tariff in Table VIII was now applicable because the necessary current was as low as about 60 A due to several such retrofits which significantly decreased the demand. Solar panels were, however, not competitive even for this high-energy cost. The normalized electricity price, i.e. the total cost for electricity divided by the amount of kWh was calculated to be 0.65 SEK kWh^{-1} and solar collectors, with prices according to Table V, emerged as optimal devices when this average price was 0.75 SEK kWh^{-1}. They are, therefore, not optimal to install today 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.

Table VIII. Electricity tariff T17 for Norrköping 1999.

Working days during November–March, 06–22,	0.77 SEK kWh^{-1}
Other time	0.52 SEK kWh^{-1}
Subscription fee for a fuse size of 100 A, 3-phase, 400 V	10 937 SEK yr^{-1}

Table IX. Electricity demand tariff for Norrköping 1999.

Subscription fee, fixed	3750 SEK yr^{-1}
Demand fee	281.25 SEK kW^{-1} yr^{-1}
Energy fee, November–March, 06–22,	0.075 SEK kWh^{-1}
Other times	0.0625 SEK kWh^{-1}

7. CONCLUSIONS

Solar collectors seem to be unprofitable for use in Swedish multi-family buildings, at least with the prices and conditions applicable today. This depends partly 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 per cent 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 per cent. 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.

ACKNOWLEDGEMENT

The work behind this paper has been financed by the Programme Energy Systems, a graduate research school funded by the Swedish Foundation for Strategic Research.

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VOLUME 25, ISSUE No. 11 September 2001

0363-907X(200109)25:11;1-M

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