Load and Season Adapted Solar Collectors

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Abstract

In Sweden solar irradiation and space heating loads are unevenly distributed over the year. Domestic hot water loads may be nearly constant. Test results on solar collector performance are often reported as yearly output of a certain collector at fixed temperatures, e g 25, 50 and 75 C. These data are not suitable for dimensioning of solar systems, because the actual performance of the collector depends heavily on solar fraction and load distribution over the year.

At higher latitudes it is difficult to attain high solar fractions for buildings, due to overheating in summer and small marginal output for added collector area. Solar collectors with internal reflectors offer possibilities to evade overheating problems and deliver more energy at seasons when the load is higher. There are methods for estimating the yearly angular irradiation distribution, but there is a lack of methods for describing the load and the storage in such a way as to enable optical design of season and load adapted collectors.

This report describes two methods for estimation of solar system performance with relevance for season and load adaption. Results regarding attainable solar fractions as a function of collector features, load profiles, load levels and storage characteristics are reported.

The first method uses monthly collector output data at fixed temperatures from the simulation program MINSUN for estimating solar fractions for different load profiles and load levels. The load level is defined as estimated yearly collector output at constant collector temperature divided be yearly load. This table may examplify the results:

Collector type	Load profile	Load level	Solar fraction	Improvement over flat plate
Flat plate	DHW	75 %	59 %	
Load adapted	DHW	75 %	66 %	12 %
Flat plate	Space heating	50 %	22 %	
Load adapted	Space heating	50 %	28 %	29 %

The second method utilises simulations with one-hour timesteps for collectors connected to a simplified storage and a variable load. Collector output, optical and thermal losses, heat overproduction, load level and storage temperature are presented as functions of solar incidence angles. These data are suitable for optical design of load adapted solar collectors. Results for a Stockholm location indicate that a solar combisystem with a solar fraction around 30 % should have collectors that reduce heat production at solar heights above 30 degrees and have optimum efficiency for solar heights between 8 and 30 degrees.

1. INTRODUCTION

One measure of the performance of a solar thermal system is the solar fraction (SF), defined as the annual useful produced heat by the solar collectors divided by the total annual need of energy. Generally, it is desirable to have a high SF for installations in single family houses since the investment done in the installation (piping, storage tank and equipment) then is utilised better and the need for auxiliary energy is reduced. Many auxiliary energy systems based on combustion, e g oil of wood fuel systems, also work better if the SF is high. Since these systems often are optimised for periods with rather high load, the running time of the combustion unit during summer time with low load is reduced if the SF is high, with an overall better system performance as a consequence.

In the south of Europe installations with solar fractions of 50% or more can be found. In north of Europe, almost all installations have a considerable lower SF, and a typical well working combisystem for DHW and heating for a modern Swedish single family house have a SF of 17 – 23% (Lorenz *et. al.,* 1998). The reason for this low SF at high latitudes can be understood from figure 1 which show the annual irradiation on a 45° tilted surface and the DHW and heating load for a typical Swedish house. As climatic data, a thermal reference year for Stockholm, latitude 59.4°N, was used, and the heating load was calculated out from the degree-day method (Bourges, 1992). A proportion between DHW and heating load of 1:2 was assumed, which is common in new-built single family houses.

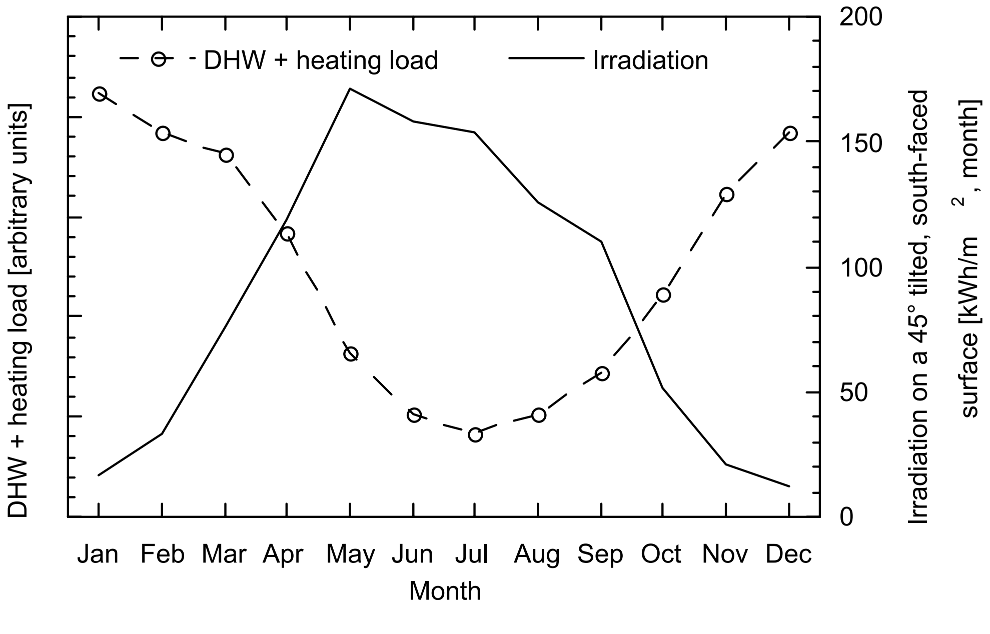

Figure 1. Total irradiation on a south-faced, 45° inclined surface and heat demand (DHW and heating) for a modern Swedish single family house. Climatic data for Stockholm, latitude 59.4°N.

Since the solar system is designed to produce 100 % of the hot water need during the summer month's, today's solar thermal systems have an embedded limit in the possible contribution to the annual load. There are, however, several ways to increase the solar fraction:

- The solar collector area may be increased, , but this will also increase the number of stagnation hours during summertime with subsequent overheating problems of the thermal system. Another problem is that the system may be too expensive if standard collectors are used since the the output/m^2 is reduced due to the useless production of heat during periods with overheating.

- Most roofs have an inclination of 25-45°, which is rather good for solar thermal systems optimised for the load during the summer half of the year. If the collector inclination is increased to 60-90° there will automatically be a more even annual heat production. However, for a specified collector area, the solar fraction can only marginally increase if the tilt is increased to 90° (Dalenbäck, 1999). In practice, these collectors should be mounted (or integrated into) the façade which increase the risk for shading from nearby buildings or vegetation. It can also be hard to find sufficient large free façade surface on small houses which is needed to get a large solar fraction.

- In theory, the storage capacity can be increased, either by an increased storage volume or innovative storage materials with a large volymetric heat capacity. However, this will only slightly affect the SF, unless the storage is very large in order to store the heat on a monthly time scale. Increasing the storage capacity to substantially increase the SF is therefore not a viable alternative for single family houses.

In this paper, we propose the use of modified CPC-collectors (i e collectors with internal relectors) as a mean to reach large solar fractions in future installations at high latitudes. Such collectors have several advantages compared to flat plate collectors in these applications:

- The efficiency of the collector depends on the sun position in the sky. Therefore this type of collector can be designed to work optimal during autumn, winter and spring, while the optical efficiency is decreased during summer. This type of collector can therefore be optimised for large SF rather than a large annual production. Problems with overheating of the solar system can therefore be more or less eliminated.
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- Solar collectors based on internal reflectors can be made cheap since the absorber area is reduced and replaced by reflector material which are cheap. The absorber area will be reduced, reducing the collector heat losses and the need for collector insulation can be reduced or eliminated. This type of collector can therefore be manufactured to a lower cost since the amount of absorbers, piping and insulation is reduced. One examle of this type of collector, which show promising results, is the mareco-collector (Karlsson and Wilson, 1998).

SOLAR FRACTIONS WITH DIFFERENT COLLECTOR GEOMETRIES

The possible solar fractions for DHW and heating for Stockholm (latitude 59.4°N) was investigated. Five different collectors, specified in table 1, was investigated by use of the MINSUN simulation programme. Of these collectors, one is a standard flat plate collector, while the others are reflector-based collectors with restricted angular acceptance regions.

The principal difference between these collectors are that they accept radiation from different regions of the sky, which is described as the upper acceptance angle. These angles are described in effective solar height, which is defined as the solar height of the component of the solar vector parallel to the north-south vertical plane. Since all collectors are assumed to be tilted towards south and all reflector geometry's are east-west aligned, the solar acceptance of these collectors is conveniently expressed in terms of a thus defined effective solar height. The two principal types of collectors is illustrated in figure 2.

Collector type	**Figure**	**Coll. slope**	**Upper accept. angle for refl.**	**$F'\eta_{o,beam}$ inside accept. region**	**$F'\eta_{o,beam}$ outside accept. region**	**$F'U_L$ [W/m^2,K]**
1. Flat plate	a	30°	-	0.77	-	3.9
2. Mareco	b	30°	60°	0.72	0.27	2.5
3. Mareco	b	30°	47°	0.71	0.22	2.1
4. Mareco	b	30°	37°	0.71	0.19	1.75
5. Mareco	b	30°	25°	0.70	0.14	1.32

Table 1. Specification of collectors investigated

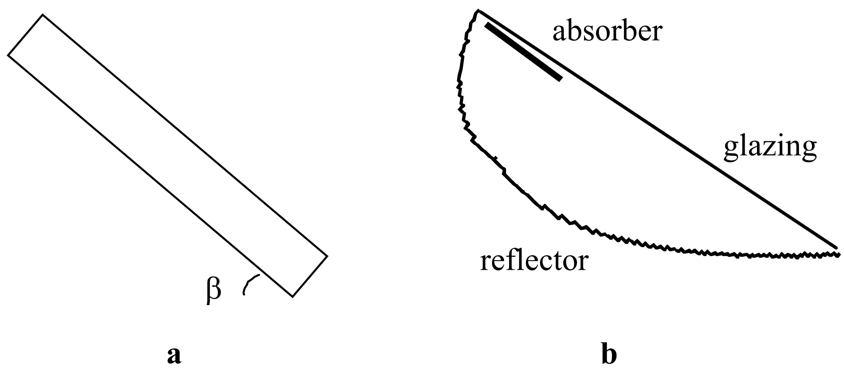
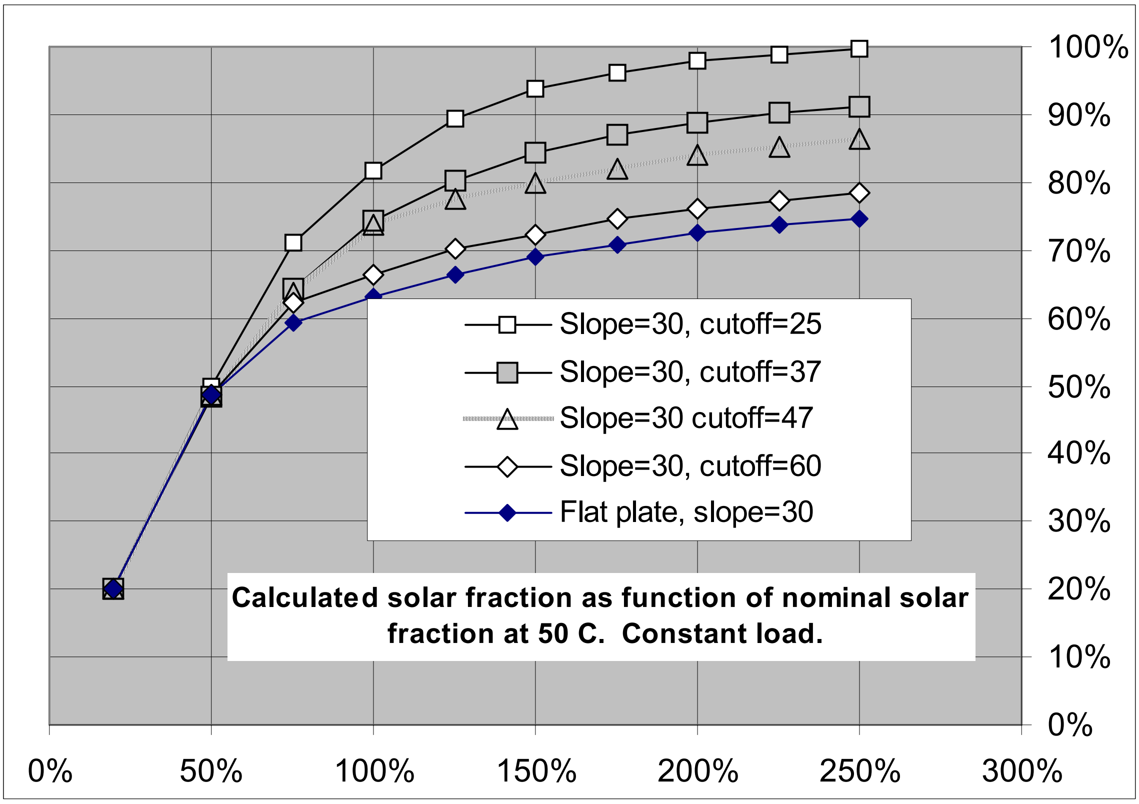


Figure 2. Principal collector geometries investigated. a) Flat plate collector b) mareco type collector. Collector tilt is β.

• Description on the calculation algorithm´s. (Calculated out from monthly radiation sum. No storage effects included: monthly storage capacity).
• Define nominal solar fraction etc
• Test results from Solar collectors: 25, 50, 75°C. Give wrong result


Slope=30, cutoff=25
Slope=30, cutoff=37
Slope=30 cutoff=47
Slope=30, cutoff=60
Flat plate, slope=30
Calculated solar fraction as function of nominal solar fraction at 50 C. Constant load.
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
50%
100%
150%
200%
250%
300%

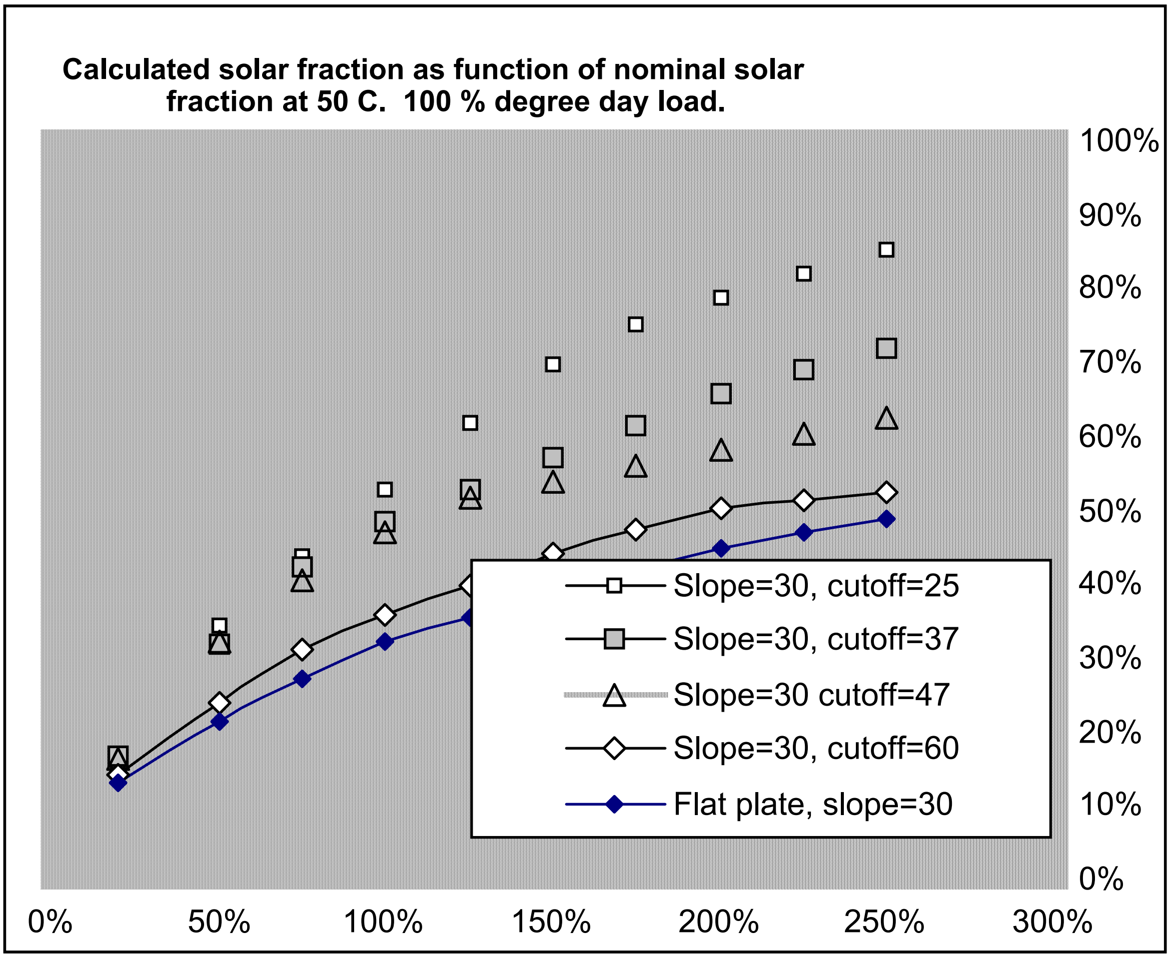

Calculated solar fraction as function of nominal solar fraction at 50 C. 100 % degree day load.
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Slope=30, cutoff=25
Slope=30, cutoff=37
Slope=30 cutoff=47
Slope=30, cutoff=60
Flat plate, slope=30
0%
50%
100%
150%
200%
250%
300%

Figure 3. Solar fraction vs. nominal solar fraction for a) DHW and b) heating load

DHW: Rather easy to get 50% SF without production of access heat production. Higher SF not so easy, the collector area has to be overdimensioned.

Heating load: Less SF possible since heating load dominates during winter. Even at 20 % useful SF, 20 - 60% of the produced energy is eccess heat.

Lowest SF for collector 3, designed for a high annual output. Upper cut-off angle 65° allow a large heat production during summer, Lower cut-off angle 20° restricts the heat production during winter. Best SF for collector 2. Cut-off angle 45° restricts the heat produced during summer, Lower cut-off angle 0° allow heat production during winter.

3. INCREASE OF SOLAR COLLECTOR AREA FOR INCREASING THE SOLAR FRACTION

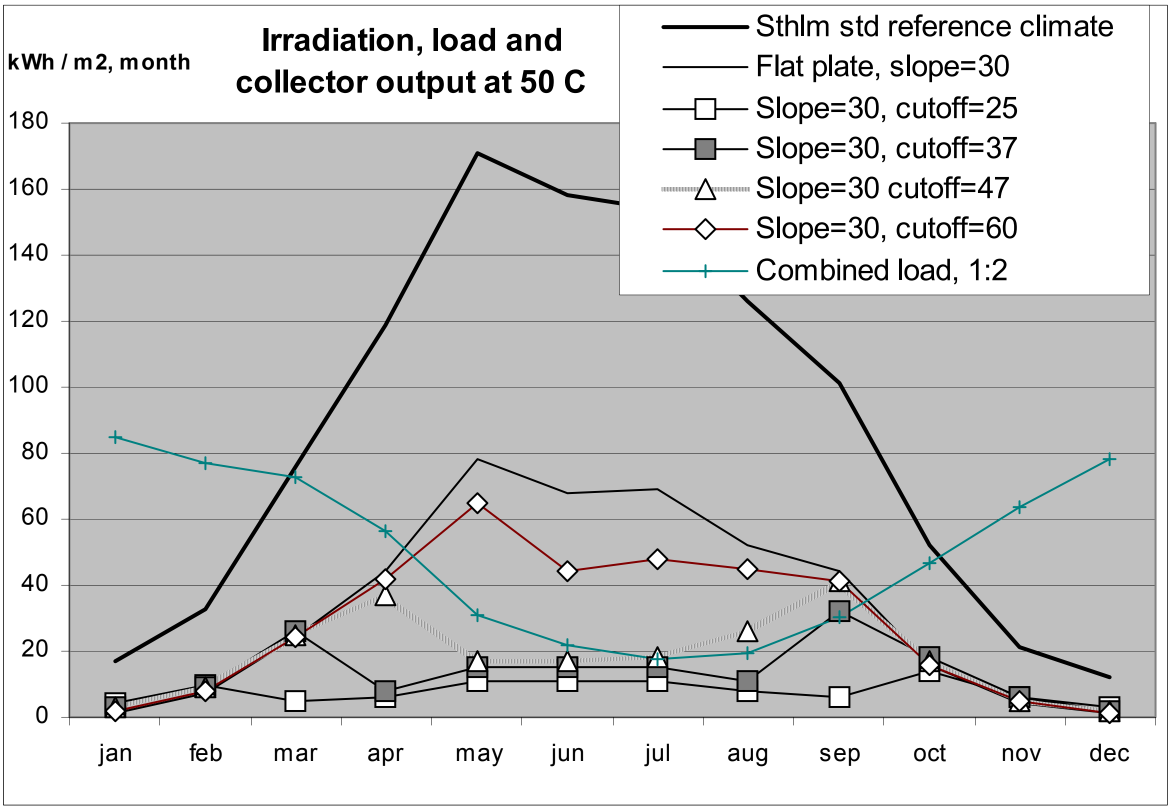


Figure 4. Monthly sum of produced heat and load
(at 50°, infinite storage!)

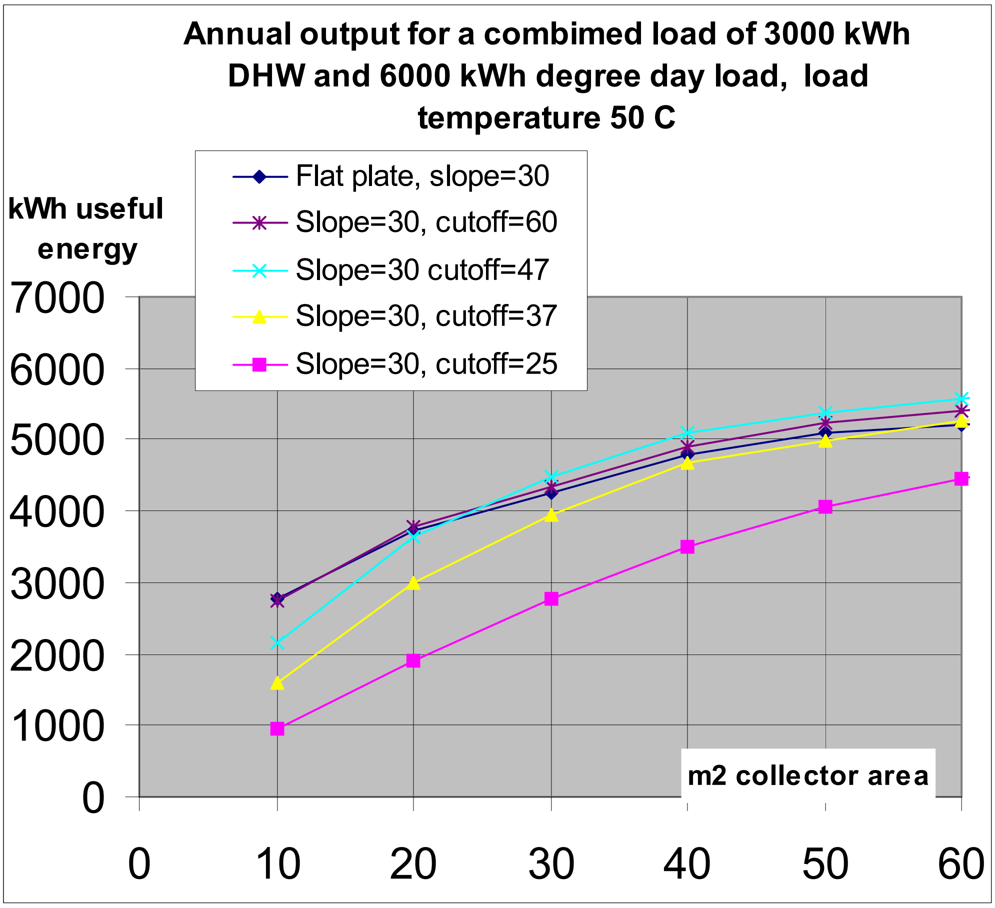
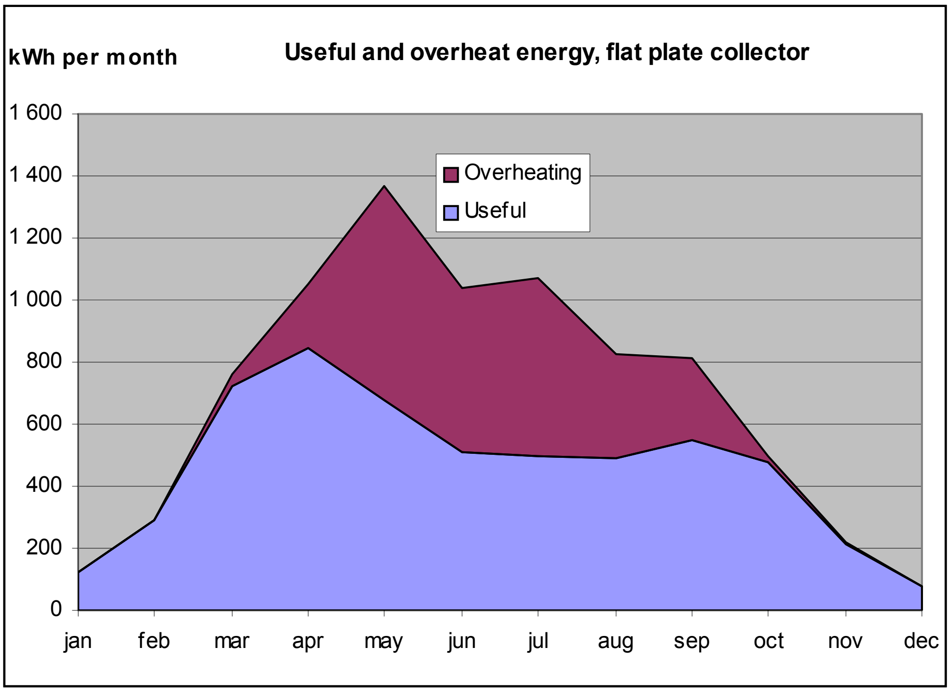


Figure 5. Solar fraction reahed with different collector area.



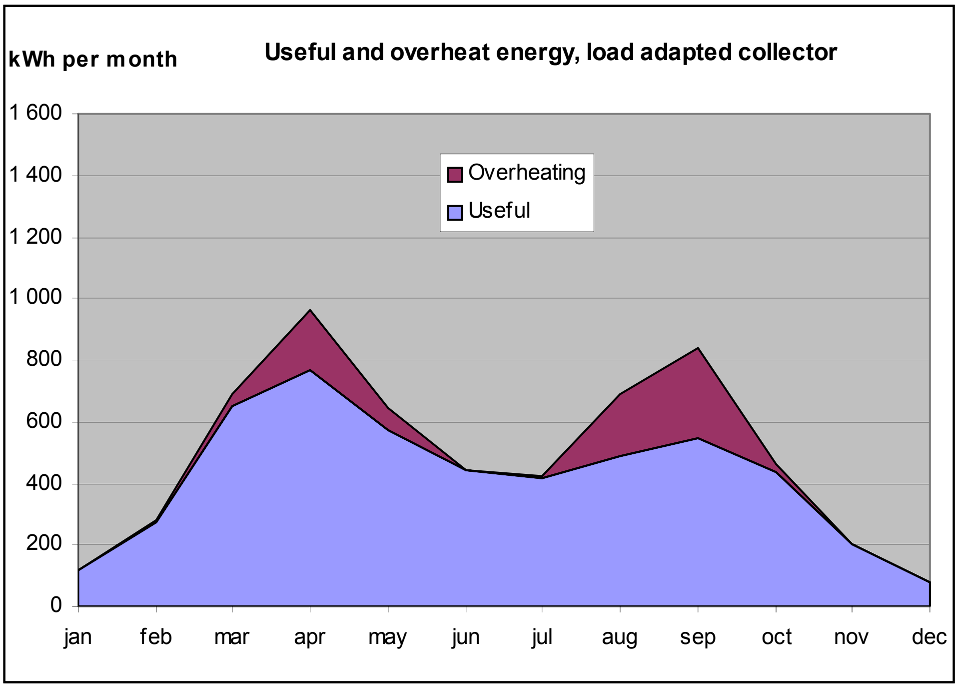


Figure 6. a) b)

4. DISCUSSION

In principle impossible to create solar heating systems for heating application at high latitudes without production of eccess heat during summer if not solar collectors has a lower efficiency during summer than the rest of the year. (e.g. higher working temperature, lower irradiation due to larger collector tilt or lower optical performance due to collector design).

Preferable collector performance possible to derive from a load-profile diagram coupling the available irradiation and load together.

Possible solar fractions for future solar collector systems.

Future work: Build and test such systems. Create reliable siulation model. Tank losses

ACKNOWLEDGEMENTS

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