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Economic efficiency calculation and Scenarios for the installation and direction of solar thermal systems at the example of a reference

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Abstract: *The article examines different possibilities of the installation and the azimuth of solar thermal systems on a rooftop at the example of a reference building. The outcome of a different azimuth and installation are different costs of solar energy, savings of wood pellets and different degrees of system efficiency. In this way the economic efficiency of a solar thermal installation can be influenced strongly.*

Keywords: *Solar Thermal Installation, installation and direction of the solar thermal installation, economic efficiency of the solar thermal installation, costs of solar energy, savings of wood pellets and degrees of system efficiency*

I. Introduction

Environment-friendly solar thermal energy which is gained from the solar irradiation onto the own roof becomes increasingly more attractive. The sun is an inexhaustible source of energy. Thermally gained energy can be produced increasingly more favorably by most modern technique through a solar thermal system. The quality of the systems is safeguarded and controlled by norms of the European Union. In this way the independence on fossil fuel and of their prices increases. CO_2-emissions resulting from the combustion of fossil energy carriers are reduced. The installation of solar thermal systems can partly be supported by state measures. The living comfort increases and last but not least new jobs can be created in the domestic economy.

The figure shows a model of a complete pellet boiler plant with solar support for the hot water generation and for the heating support (Company August Brötje GmbH) [2].

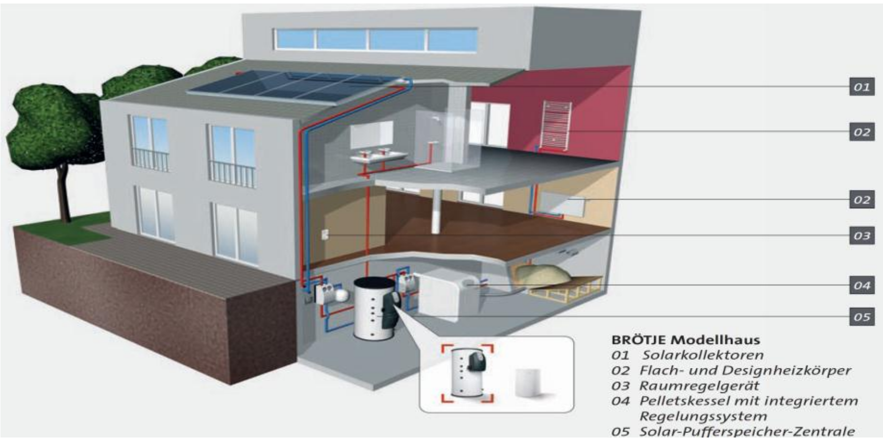

Figure 1: Pellet boiler with solar support to hot water generation and heating support [2]

Basics of the simulation of the system

With the help of Dr. Valentin energy software a simulation of the system is carried out [12].

By increasing improvement of the thermal insulation at buildings a reduced energy demand for the heating can be achieved. In this way the energy demand for the hot water generation gets more importance. This demand in part can be produced by thermal solar systems which convert the solar irradiation with the help of collectors into heat. At present these systems can produce an annual energy yield of 350-500 kilowatt-hours per m^2 collector surface area. This leads to a decrease of the CO_2-emissions of up to 150 kg [12].

Thermal solar systems convert solar energy with the help of collectors into heat. Then the produced heat is transported over pipelines into a so-called buffer storage. The energy losses occurring from the production up to the storage should be held as small as possible. The losses, resulting from the relation between the usable energy and the irradiated energy can be assessed with the help of degree of efficiency of the system. A solar system is established according to its mode of operation:

With a collector the solar irradiation is absorbed and converted into heat. The so won energy is transported over a net of pipelines and heat exchangers to a storage tank. The storage tank has the task of balancing the temporal variations of energy offer and energy demand. For a maximum utilization of the solar irradiation a control system is useful, that turns on a circulating pump as soon as a temperature difference arises between collector and storage tank. Thus the heat transportation to the storage tank is guaranteed.

Description of the reference building

The single-family house completely with basement is constructed in massive design on strip foundation. The walls consist of burned stones (Cellar: Lime sandstone). The floors consist of reinforced concrete, the grounds are made of floating floor and tiled (Attic: fitted carpeting). The stairs consist of reinforced concrete with timber sheeting. The attic is fully developed and is to be reached over the staircase. The cellar can also be reached over the staircase. Additionally there are stairs outside the house which lead to the cellar. The external walls have got brick facing. The building has a gable roof with clay bricks. The chimneys consist of burned stones.

Degree of efficiency and solar fraction

The degree of efficiency results from the relation between energy put out to the irradiated energy.

The degree of efficiency of the collector circuit results from the relation between the energy output of the collector circuit over the heat exchanger to the irradiated energy (irradiated onto the collector surface).

The degree of efficiency of the system results from the relation between the energy output of the solar system to the rradiated energy (irradiated onto the collector surface).

The energy output gained from the solar system is that energy which is passed on from the solar storage tank to the standby storage tank.

The solar fraction results from the relation between the energy provided by the stand by storage tank of the solar system to the sum of all energies provided to the standby system (Solar system and upstream with conventional systems).

The energy delivery for the heating of the drinking water is the energy which is necessary to get the temperature of the cold water to the temperature of the tapped drinking water. Losses are not considered here.

The used combustible is the combustible which is necessary to heat the standby storage tank to the nominal temperature. The heat losses of the storage tank and the degree of efficiency of the kettle are considered here.

Calculation of Economic Efficiency according to the cash value method (with T*SOL) [12]

- Investment Costs = Installation Costs – Subsidy
- yearly Operating Costs = Pump Performance*Operating Time*Electricity Costs

The cash value (CV) of a price-dynamic payment sequence Z, Z · r, Z · r^2... over T years (Lifespan) is calculated as follows (according to VDI 2067 [14]):

Cash value CV = Z · b(T,q,r)

Cash value factor $b(T, q, r) = \begin{cases} \frac{1-(r/q)^{T}}{q-r} & for\ r <> q \\ \frac{T}{q} & for\ r = q \end{cases}$

q: Simple interest factor on capital (e.g. 1,08 at 8 % of simple interest on capital)

r: Price change factor (e.g. 1,1 at 10 % of price change)

Capital value of the total investment (C):

C = sum of the cashl value of the price-dynamic payment sequence over the lifespan
+ promotions
- Investments

The pay-back time is the period the system must operate for the investment in order to yield a cash value of zero. Pay-back times of more than 40 years are not included here [12].

In order to calculate the heating price, the cash value of the costs must be calculated:

CV of the costs = Investments + Cash value of the Operating and Maintenance Costs.

If the Cash value of the costs is converted into a constant payment sequence (r=1) over the lifespan, then Z turns out for this consequence:

Z = CV of the costs / b(T, q, r).

According to VDI 2067 is valid:

For r =1 be comes 1/b(T, q, r) for the annuity factor a(q, T) = q^T · (q-1) / (q^T-1).

The heating price then represents itself as follows:

$$\text{Heating price} = \frac{\text{yearly Costs Z}}{\text{yearly Energy Yield}}$$

In the following the components of the system - as indicated in the figure - are described:

-Collector: Manufacturer August Brötje, Type: Solar Plus HP 20, denomination: Tube collector Parameter: Gross face 2,84 m^2, reference area 2,16 m^2, specific heat capacity 4300 Ws/(m^2K), collector field volume flow: 40 (l/h)/m^2, medium: Water Glycol, resulting specific heat capacity: 3588 Ws/(kg K) [2]

-tank: Pellets-Central heating boiler, Manufacturer Vaillant [13], Type: renerVIT VKP 202, capacity: 20 kilowatts

-Hot water tank: Standard, volume: 300 l

-Buffer storage: Standard, volume: 800 l
-Hot Water need: average day consumption: 200 l, nominal temperature hot water: 50 °C, interpretation for single-family home (morning top).

Simulation results of the reference building [12]:

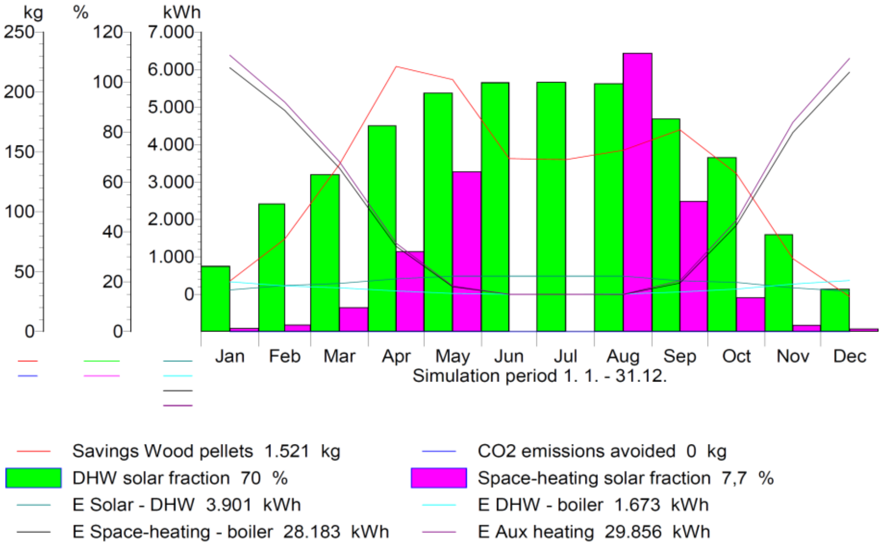

Figure 2: Fraction heating, hot water, total & saving natural gas [12]

Solar energy consumption as percentage of total consumption

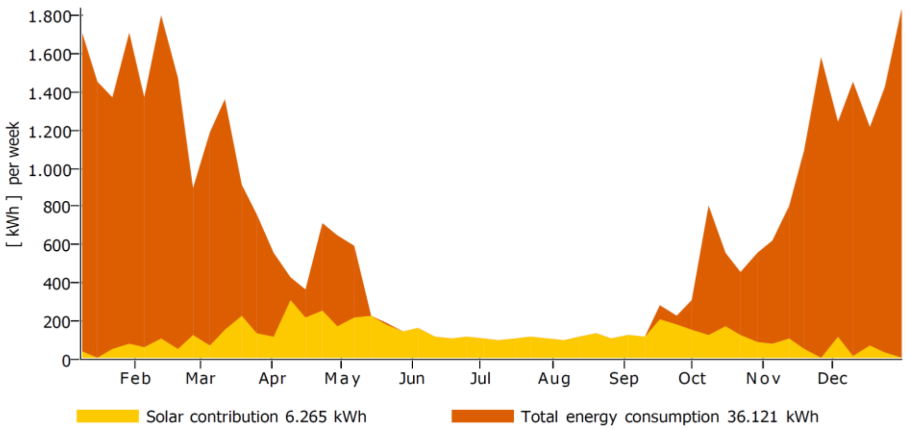

Figure 3: Solar energy consumption as percentage of total consumption [12]

Energy balance schematic

Legend

1	Irradiation on to collector surface (active)	20 MWh
1.1	Optical collector losses	5 MWh
1.2	Thermal collector losses	6 MWh
2	Energy from collector array	9 MWh
2.1	Solar energy to storage tank	4 MWh
2.3	Solar energy to buffer tank	3 MWh
2.5	Internal piping losses	1.396 kWh
2.6	External piping losses	228 kWh
3.1	Tank losses	851 kWh
3.2	Circulation losses	1.264 kWh
5.1	Buffer tank losses	1.005 kWh
5.2	Buffer tank to heating	2.364 kWh
6	Final energy	33 MWh
6.1	Supplementary energy to tank	1.673 kWh
6.4	Supplementary energy to space-heating	28 MWh
6.5	Electric element	0 kWh
9	DHW energy from tank	3 MWh
10.1	Heat to HT heating	6 MWh
10.2	Heat to LT heating	24 MWh

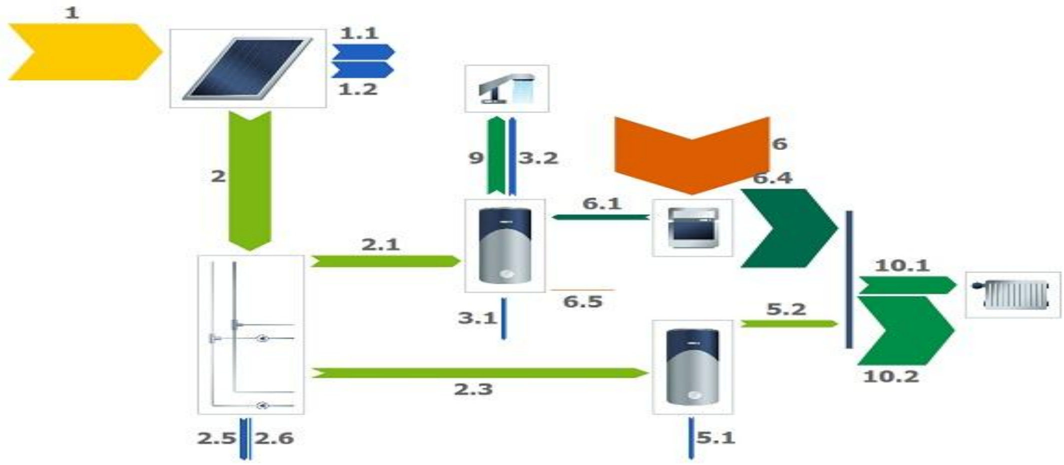

Figure 4: Energy balance schematic [12]

Financial analysis:

System

System yield	6, 26	MWh
Active surface area	22, 74	m2
Yearly electricity consumption for additional energy	610, 40	kWh/a
Annual fuel savings	1.520,40	kg
Financial analysis parameters		
Lifespan	20	Years
Interest on capital	2, 5	%
Energy cost escalation rate	3, 0	%
Running cost escalation rate	1, 5	%
Costs (Cash value)		
Investments	-52.000, 00	€
Subsidy	3.750,00	€
Savings	3.108,00	€
Running costs	-15.410, 00	€
Net present value	**-60.552, 00€**	
Amortization period	**No amortization**	
Cost of solar energy	**0, 65 €/kWh**	

Provisional Result

The variant does not show any amortization for a period of 20 years so that this variant is uneconomical.

II. Scenario „ A", Tilt Angle 35° (Degree) = Const., Azimuth = Variable

The tilt angle of the solar thermal collectors on the roof (roof parallel system) is 35 °. That is the existence of the reference building. The Scenario A shows the dependence of the costs of solar energy, the saving of wood pellets and the system efficiency of the solar thermal system on the azimuth of the reference building into the respective cardinal point.

Table 1: Dependence of the costs of solar energy, the saving of wood pellets and the system efficiency of the solar thermal system on the azimuth of the reference building

Azimuth ° (Degree)	Cost of solar energy 0,01 x €/kWh	Wood pellets savings 0,1 x t (Ton)	System efficiency %
135 °	71	14,064	30,3
175 °	65	15,226	31,2
180 °	65	15,277	31,3
225 °	70	14,398	30,7

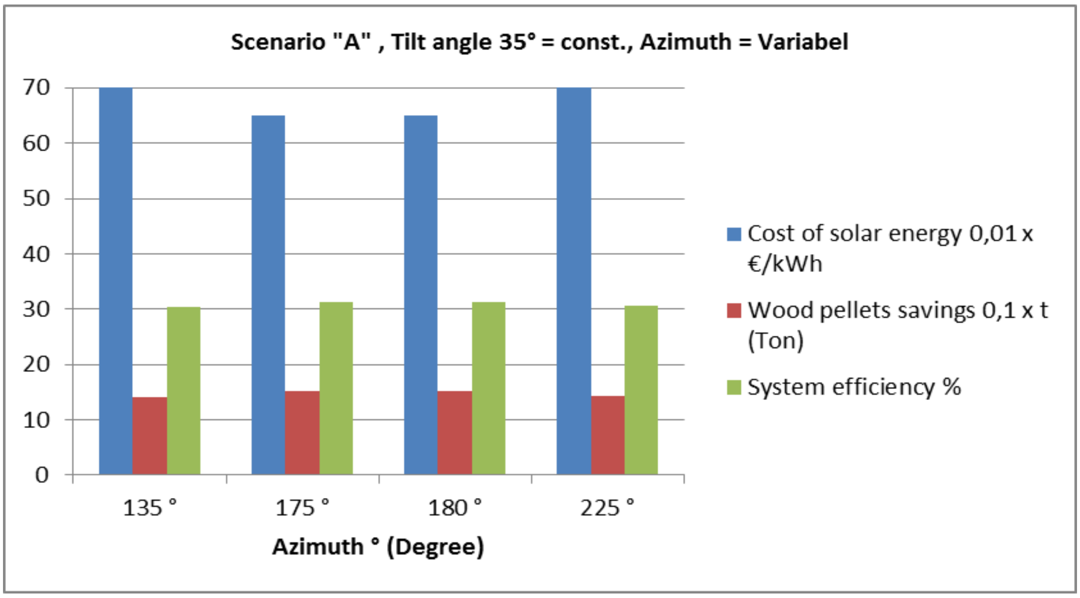

Diagram 1: Dependence of the costs of solar energy, the saving of wood pellets and the system efficiency of the solar thermal system on the azimuth of the reference building

Provisional Result

The optimal results for the costs of solar energy, the saving of wood pellets and the system efficiency are achieved at an azimuth of 180° of the reference building (to south).

III. Scenario „B", Tilt Angle = Variable, Azimuth 175° (Degree) = Const.

The azimuth of the solar thermal collectors on the roof (roof parallel system) is 175 °. That is the existence of the reference building. The Scenario B shows the dependence of the costs of solar energy, the saving of wood pellets and the system efficiency of the solar thermal system on the tilt angle of the solar thermal system on the roof.

Table 2: Dependence of the costs of solar energy, the saving of wood pellets and the system efficiency of the solar thermal system on the tilt angle

Azimuth ° (Degree)	Cost of solar energy 0,01 x €/kWh	Wood pellets savings 0,1 x t (Ton)	System efficiency %
25 °	69	14,579	30,1
30 °	67	14,921	30,6
35 °	65	15,209	31,2
40 °	64	15,421	31,8
45 °	65	15,209	31,2
50 °	63	15,636	32,9

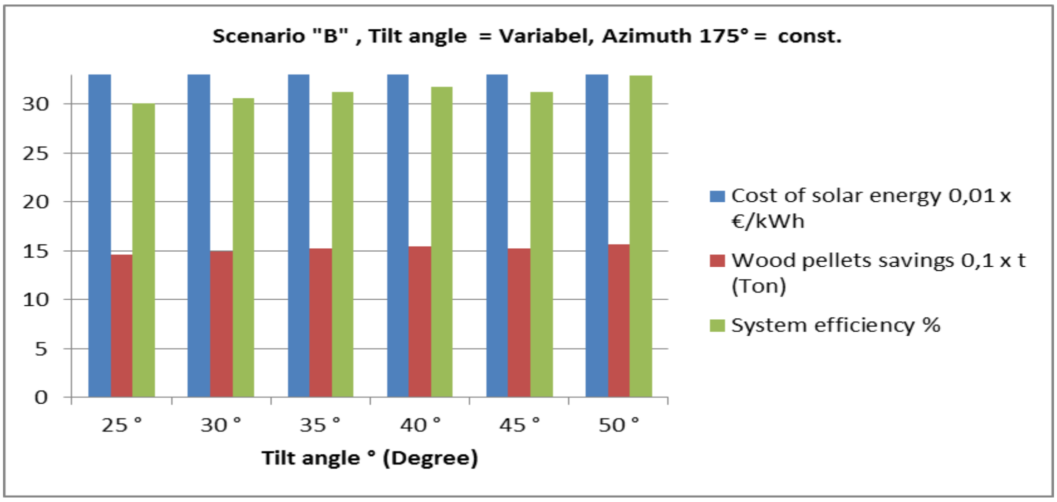

Diagram 2: Dependence of the costs of solar energy, the saving of wood pellets and the system efficiency of the solar thermal system on the tilt angle

Provisional Result

The optimal results for costs of solar energy, the saving of wood pellets and the system efficiency are achieved with a tilt angle of the solar thermal system on the roof of approx. 50 °.

IV. Conclusion

Solar power is good for the human being and for the environment. With a solar thermal system on the own roof a secure and clean kind of heat supply is guaranteed for water heating and heating support. With the correct azimuth of the house to south and the correct tilt angle of the solar thermal system on the roof the costs of solar energy, saving of wood pellets and the system efficiency can be optimized.

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