solar thermal home system - modelling and cost

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Intro:

Frequently, solar thermal systems are implemented in residential structures with the aim of attaining specified energy efficiency benchmarks like e.g. kfw-70, kfw-55 etc.
These systems commonly function as a black box for occupants, wherein residents are generally aware that the system utilizes some form of light energy. However, they lack comprehensive understanding regarding performance outcomes, potential cost savings, and the optimal configuration of the installed system. In order to address these challenges and gain insights into the primary parameters and potential cost savings, we conducted a modelling and assessment under certain conditions of an extant solar thermal system.

System description:

Original configuration:

- 3 x solar collectors in parallel connection
- type: flat plate
- SolarLine collector SCM3-H Bosch (https://rensa.nl/Product/0243296)
    - aperture_area = 2.43 m²
    - gross_area = 2.55 m²
    - $\eta 0 = 0.762$ (1)
    - a1 = 3.962 W/(m²K)(1)
    - a2 = 0.0137 W/(m²K)(1)
    - fluid = water/glycole
    - cp_{fluid} = 3.5 kJ/kg*K (2)
- mass flow: 2.5 - 3 l/min
  0.042 – 0.05/ kg/s(3)
- storage size 400l → 78,4l/m²
  0.042 – 0.05/ kg/s(3)

Alternative configuration:

- 3 x solar collectors in serial connection
- type: evacuated
- EUROTHERM SOLAR PRO 15R
    - aperture_area = 1.4 m²
    - gross_area = 2.35 m²
    - $\eta 0 = 0.433$ (1)
    - A1 = 0.994 W/(m²K)(1)
    - a2 = 0.01 W/(m²K)(1)
    - fluid = water
    - cp_{fluid} = 4.19 kJ/kg*K (2)
- mass flow: 2.5 - 3 l/min
  0.042 – 0.05/ kg/s(3)

Methods:

In the following procedure one can find the methods were used to derive the results with the F-Chart method to calculate the solar fraction and supply for different scenarios.

1. Collect system information

Since the system we assessed is already in use the system parameters are fixed to certain values (see “System description”). Also the tilt of collectors is already aligned at its optimum: 42.8°

(1)related to gross area, (2)as an average : https://tyfo.de/downloads/TYFOCOR-L_de_TI.pdf, (3)given with data sheet: https://www.heizungsdiscount24.de/heizung24/ebay/Junkers-Heizungen/PDF/Junkers-Systempufferspeicher-SP-400-SHU-Installation.pdf

2. Determine supply and demand

Demand

For this system the total demand is given for several years. Here the demand fluctuates between 8,5 – 11,5 MWh/year regarding different DHW ratios. To determine the demand profile with respect to seasonal variations and different ratios for DHW we used an online-toll (https://app.npro.energy/en) with the following parameters:

- type of building: single family house
- energy standard: kfw 70
- usage type: residential
- area: 120 m²
- 5 people
- min. temperature start heating: 15°C
- DHW ratios: 15% - 20% - 25% - 30% - 35

Supply

The supply represents the total amount of energy which is provided through irradiation and temperature at certain places. This values are provided through several databases e.g. https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html.

- database: sahra2
- year: 2020
- type: monthly data
- location: Oldenburg

3. Scenarios

For each of the following scenarios the solar fraction and the supply were calculated to compare them to the original configuration. Even if most of the parameters for this system are fixed, it was asked to "what if…" changes would be applied?

Different flow rates:

The original configuration was used but with mass flows between 0.001 - 0.05 kg/s and steps of 0.002 kg/s.

Different collector type and connection:

Here the original configuration with flat plate collectors in serial and parallel and evacuated tube collectors also in serial and parallel connection was calculated.

Number of collectors:

In this scenario the number of collectors from the original configuration was variated between 1 – 5.

Ratio of DHW:

Since the ratio between demand for DHW and the total demand (DHW + SH) is directly related to the energy the original configurations was used with different DHW demands for the total load.

Different storage capacities:

The storage capacity is also a part of hole system. So the original configuration was used with storage capacities between 37,5 – 300 l/m².

Limitations:

During this modelling certain limitations have to be considered. First the F-Chart method itself is a kind of estimation for static systems. Therefore dynamic behaviour is disregarded. Further for the F-Chart method some simplifications were assumed:

Fixed and disregarded parameters:

Heat exchanger and load heat exchanger correction factor set to 1. This factors depends usually on mass flow and in- & outlet fluid temperatures on both sides, which are not considered here. Also the alignment regarding the azimuth is assumed to be optimal: 0° - facing south

Estimated parameters:

Further the specific heat capacity of the fluid mixture with water/glycole was estimated, because the heat capacity depends in general the ratio and temperature. Here it was simplified to an average value of 3.5 kJ/(kg*k).

Also all considerations with respect to weight, installations, costs etc. were disregarded.

Conclusion:

The initial configuration with flat plate collectors in parallel represents already the best possible conditions. This setup is sufficient to cover the demand during summer term because the energy demand is significantly lower and almost only DHW is needed. All other configurations are less effective.

The least impact with respect to solar fraction and supply has the storage capacity. Here the entire scope from the F-Chart method was used without effective deviations.
Also the change from parallel to serial connect for flat plate and evacuated tubes resulted in low deviation whereas the difference between the deployment of flat plate and evacuated tube collectors lead to higher deviations.

Regarding the scope for different flow rates the best option is the upper limit of the original manufacturer specification. Lower rates would result in lower solar fraction and supply.

One of the highest influences is represented by the change of number of collectors. Here more collectors would expend the range of supply and yield higher seasonal solar fraction but still not cover the whole demand.

The second and most influence is given by the ratio of DHW. The higher the ratio of DHW the less becomes the solar fraction and the more the possible cost savings.