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Triple storage concept for solar assisted heat pump heating systems

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Introduction

Photovoltaic and solarthermal systems combined with heat pumps are a promising solution for the decarbonization of domestic heat supply. The problems connected to the volatile availability of solar energy can be reduced by integrating a hot water storage as heat sink of the heat pump and the solarthermal collectors. The performance of the system can be increased by additional storage capacity on the heat source side of the heat pump. A concept combining solar energy generation, heat pump, two thermal water storages, and a battery is presented (Fig. 1).
The low temperature storage that serves as heat source for the heat pump improves the coefficient of performance. The tank can be loaded by solar energy or by reverse operation of the heat pump. Moreover the low temperature tank allows to model a heat pump system that is supplied by a low temperature heat net.
A system based on the described concept will be installed as a demonstration plant during 2022 at the University of Applied Sciences and Arts in Hannover. A process model has been developed using the software Ebsilon Professional. The model simulates the heat supply of an older family home by the system. Simulations of an entire year using a time interval of 1 h have been carried out for different process variations.

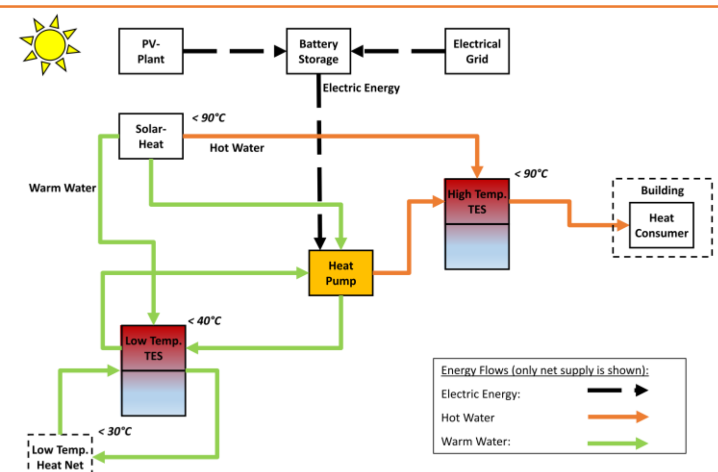

Figure 1: Block diagram of the concept

Technical description

The flow diagram (Fig. 2) shows the main equipment of the process. Heat storage and transfer media is water or a mixture of water and glycol. The heat pump (approx. thermal power of 10 kW) uses the low temperature tank (LTT) as heat source and the high temperature tank (HTT) as heat sink. Each tank has a volume of 1 m³. The solar thermal installations (flat plate collector and parabolic trough, approx. thermal power of 10 kW each) heat up the HTT or LTT depending on the solar irradiation and the status of the tanks.

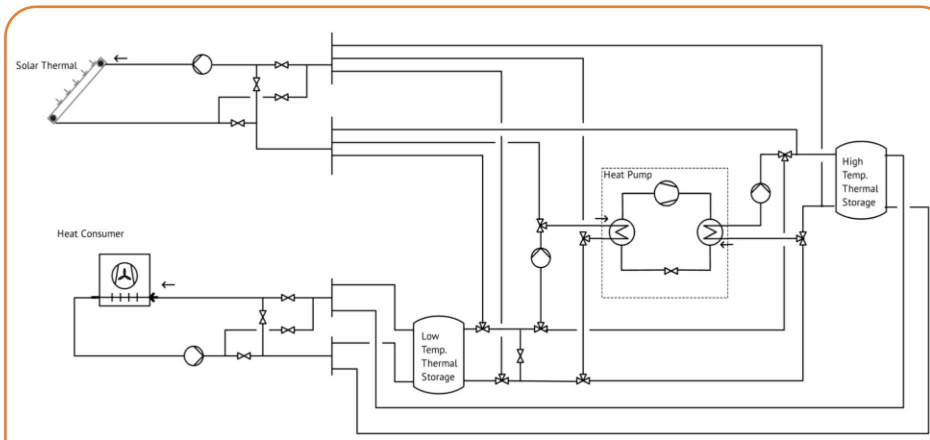

Figure 2: Process flow diagram

Modelling of the process

The model is approximated to the actual system described above and the main parameter are summarized in table 1 and the variations in table 2.
In case the heat source of the heat pump (LTT) is below or close to its minimum temperature, the heat pump is working as a direct electrical heater. The heat pump working additionally in reverse mode to heat up the cold tank (heat sink) and using ambient as heat source is simulated in variation V_3. Using a heat net with a constant temperature as heat source is simulated in variation V_4.

Table 1: Main parameter of the model

Heat consumption consumer (specific value based on living space)	$Q_{Cons} = 20{,}44 \frac{MWh}{a};\ q_{Cons} \approx \frac{160kWh}{m^2a}$
Solar thermal (ST): active collector area	$A_{ST} = 10\ m^2$
Heat pump (HP): thermal power, max. output temp.	$P_{th\_HP} = 6\ kW;\ t_{\max\_out\_HP} = 75°C$
HP: Assumption exergetic efficiency (Gütegrad)	$\eta_{ex\_HP} = 0.5 = COP_{HP}/COP_{Carnot\_HP}$
LTT: storage mass, max. and min temperature	$m_{LTT} = 1000\ kg;$ $t_{\max\_LTT} = 20°C;\ t_{\min\_LTT} = 3°C$
HTT: storage mass and max. temperature	$m_{HTT} = 1000\ kg;\ t_{\max\_HTT} = 75°C$
Location and source of hourly weatherdata	Hannover, meteonorm

Table 2: Modelled variations

Variation	A_{ST}	$T_{\max\_NTT}$	m_{NTT}	Further modification
V_0 (Reference)	10 m²	20°C	1000 kg	
V_1	20 m²	20°C	1000 kg	
V_2	20 m²	40°C	2000 kg	
V_3	10 m²	20°C	1000 kg	Reverse operation of HP at night
V_4	10 m²	12°C	1000 kg	LTT acts as heat net with a constant temperature

Results

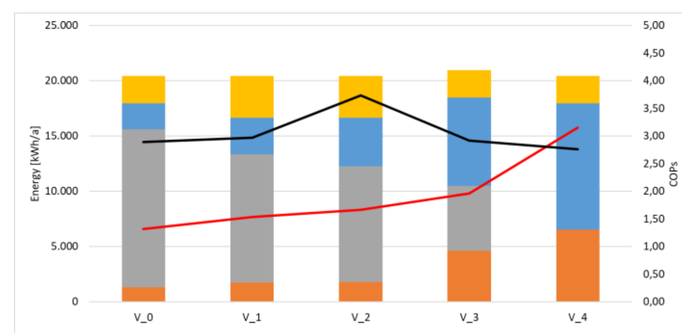

Figure 3: Yearly energy input and COPs for all variations

Values shown:

- Energy input: W_{el_HP} (electric energy to the HP working as HP), W_{el_HE} (electric energy to the HP working as direct electric heater), Q_{HP_LTT} (heat to the HP from the LTT), Q_{ST_dir} (solarthermal heat directly used to heat HTT)
- COPs: COP_{av} (average COP of the HP during HP-operation), $SCOP_{Syst}$ (seasonal COP of the system defined as: $SCOP_{Syst} = Q_{Cons}/(W_{el_{HP}} + W_{el_{HE}})$

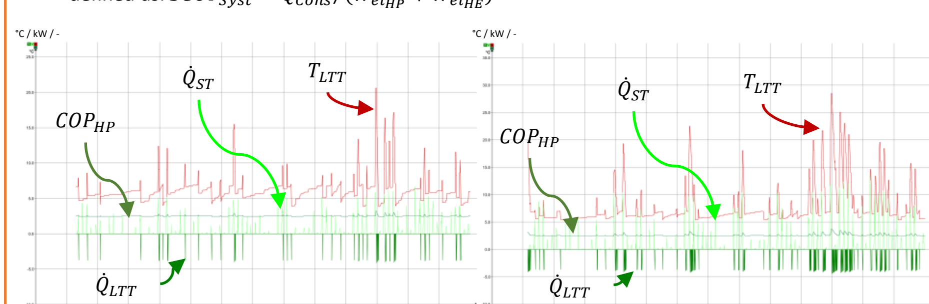

Figure 4 and 5: Selected hourly Results for January to March for V_0 and V_2

Values shown:
T_{LTT} (Temperature of LTT); COP_{HP} (COP of HP); $\dot{Q}_{ST}$(Heat from ST); $\dot{Q}_{LTT}$(Heat from LTT (negative))

Conclusions and summary

The results of the simulation (Fig. 3) show that relatively high COPs (COP_{av}) for the heat pump with high output temperature (75°C) are possible due to the LTT as heat source. As the system uses also solar energy for heating, the SCOP ($SCOP_{Syst}$) could be even higher. However, the results reveal that this is not the case because of extensive direct electric heater operation.
Figure 4 shows that from January to March the temperature of the LTT most of the time is too low and its operation as heat source of the HP is very limited (see number of vertical lines ($\dot{Q}_{LTT}$)). The heating by solar energy is not sufficient. The situation improves slightly for Variation V_2 (Fig. 5).
In summary, the availability of low temperature heat in the LTT is the bottleneck for the presented concept. For central European locations the increase of solar thermal capacity might not be the best solution. More promising seems to be the reverse operation of the heat pump or the connection of the LTT to a low temperature heat net, which could be supplied by waste heat from industry.