Building Thermal Self-Sufficiency Functions of PV Driven Heat Pumps Charging Thermal and Battery Storages Compared to Solar Thermal-Heat Pump Systems

Summary

A PV driven compressor heat pump system for heating and DHW with different large thermal energy storages (NTES, PCM, ICE, WTES) for SFH application were defined. Simulation templates were setup, simulations were performed and the results show a smooth increase of the thermal self-sufficiency in function of the storage size i.e. volume. Even at large storages the thermal self-sufficiency does not reach 100 % except a battery is implemented. And results show a similar functional behavior to solar thermal(collector)-heat pump systems.

Keywords: Solar Heating & DHW, PV Driven Compressor, Solar Thermal, Storage Size, Thermal Self-Sufficiency

Field of application for the findings: Sustainable Heating and Cooling Systems for Buildings

Addressed audience: Solar PV & Solar Thermal Community

1. Introduction - Aim and Approach

A simple energy system was selected to supply energy for space heating (SH) and domestic hot water (DHW) preparation in buildings – single family house (SFH) applications. The energy demand profiles were selected and the renewable energy sources used are, the ambient air (environment), solar PV panels (design variable A – m^2) and the public electric grid. The location (weather conditions) of the building is Bern in Switzerland. And, to keep the energy supplying system simple, no solar thermal nor PVT collectors were applied. Figure 1 shows an iconographic system configuration with a phase-change material (PCM) storage as a Seasonal Thermal Energy Storage (STES) example system implementation. On the right of this figure 1, different types of STES are selected for energy supply to the SFH.

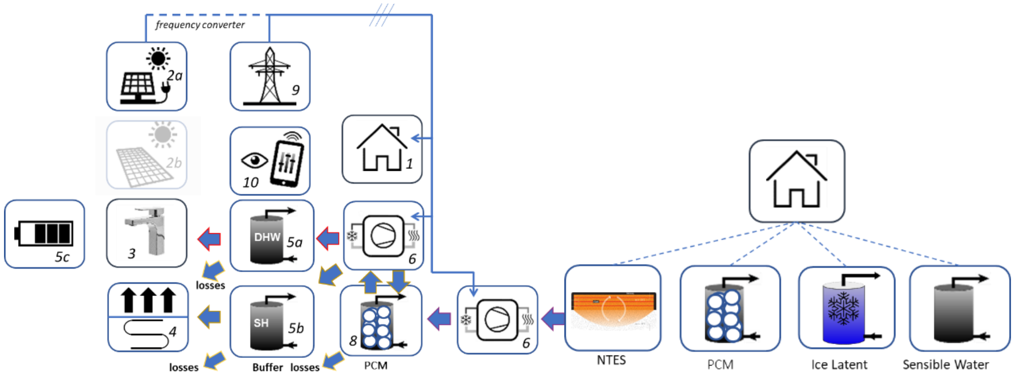

Figure 1 left) STES system configuration for space heating & cooling (4) and domestic hot water (3). The example shows the system for a single-family house (1) with a phase change storage PCM (8). Electric energy is supplied by PV panels (2a) and the public electric grid (9). Domestic hot water (DHW, 5a) is stored in a hot water tank and the heating fluid (water) is stored in a buffer tank (SH, 5b). Batteries (5c) are used for an increase of the self-sufficiency. Solar thermal collectors (2b) are not considered at this level of investigation. To prepare room heating and hot water a cascade of an air and water source heat pump (6a, 6b) is used. The energy supply system operates by a programmable controller (10). (right) Different STES types for SFH application – but for all the same system integration (NTES = Near Surface Energy Storage).

2. Boundary Conditions

To determine the self-sufficiency of a single-family house (SFH) a set of four templates [Berger et al. 2022] were used, modified and extended in the Polysun® simulation software. The location of the building is selected as Bern (Weather data), Switzerland. In table 1 the boundary conditions for the building energy demand and the design variables of the PV driven energy supplying system are summarized. Figure 1 shows an assembly of iconographic components comprising the system. In this study the main design variable is volume V (m3) of the STES, at constant PV panel area A (m2).

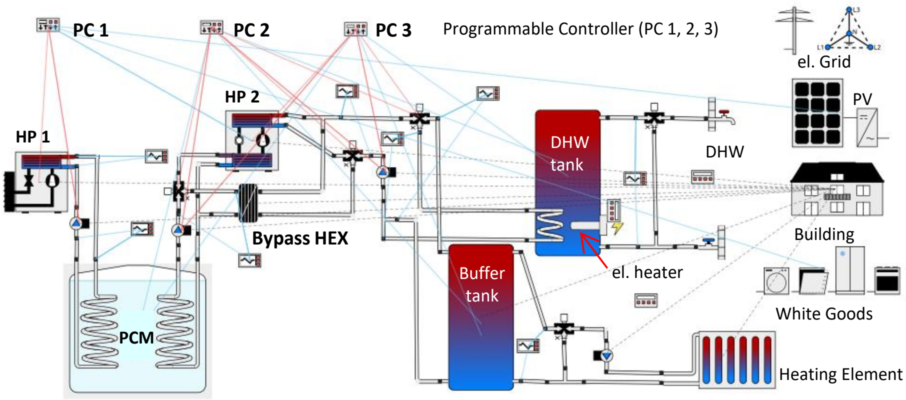

Figure 2 Single family house system configuration with a PCM STES implemented (battery not shown). Due to predominant operation in the liquid phase of the PCM storage a heat pump 2 (HP 2) bypassing heat exchanger "Bypass HEX" was added to the simulation template. PC 1, 2, 3 are programmable controllers. In this study, the electric heater (back-up el. heater) in the DHW tank is switched off.

And figure2 shows the GUI of the simulation template with PCM storage as an example. To reach a high PV-energy self-consumption the programmable controller is predominantly unlocked during daytime. The simulations were performed with the parameters listed in table 1. Due to the complexity of a reactor for the thermochemical storage (TCS) system no simulation model is set up at this level of investigation. Therefore, a good guess is made for the TCS case based on the absorption potential energy storage density data, but the findings are not presented here.

Table 1 List of system parameters in the simulations for SFH application.

Parameter / Variable	Range	Unit	Remark
SFH Heating Energy demand	45 .. 60	$kWh*m^{-2}*a^{-1}$	Location Bern (solar irradiation, Tamb etc., Meteotest AG), 2 floors
Living heating & cooling area	120 .. 160	m2	Swiss Federal Statistical Office
Room temperature	21 .. 23	°C	with DT +1 K→ ~7 % more energy
Buffer tank for heating	600	liter	floor heating (35 °C)
DHW consumption, 4 persons	35 .. 50	$l*person^{-1}*day^{-1}$	Domestic hot water (DHW) profile with daily peaks
DHW temperature	50	°C	hygienic aspects shot time 60 °C
DHW tank volume	300 .. 500	liter	short term storage (profile)
Air source / brine heat pump	8 .. 15	kW	"cheapest" installation
Electricity consumption	4500 .. 6341	$kWh*a^{-1}$	daily profile in 15 Min resolution
PV Cell Type mono crystalline	180	$Wp*m^{-2}$	Silicon (Si), south, tilt angle 35°
PV panel area A (20) 40 (XYZ) modules	(32.6); 65.2; (140)	m^2	design variable A, area available on the SFH roof 11.7 kWp
Public electric grid connection	400, 40, 27.7	V, A, kW	SFH el. connection to the grid

Due to parameter ranges (some) - the simulation results are presented in the diagrams with uncertainty bars on both axes.

3. Results and Discussion

In figure 3 and figure 4 the results for systems with Water, PCM, Water ICE and near surface NTES STES in a SFH are shown. A thermal self-sufficiency of 70 % and higher is reached at a volume lager than approx. 10 to 20 m3 for all STES types. This effect is intrinsic to the system design – a buffer tank for space heating and a domestic hot water (DHW) tank (Figure 2) – where short time thermal energy demand (covering peak demand) can be bridged.

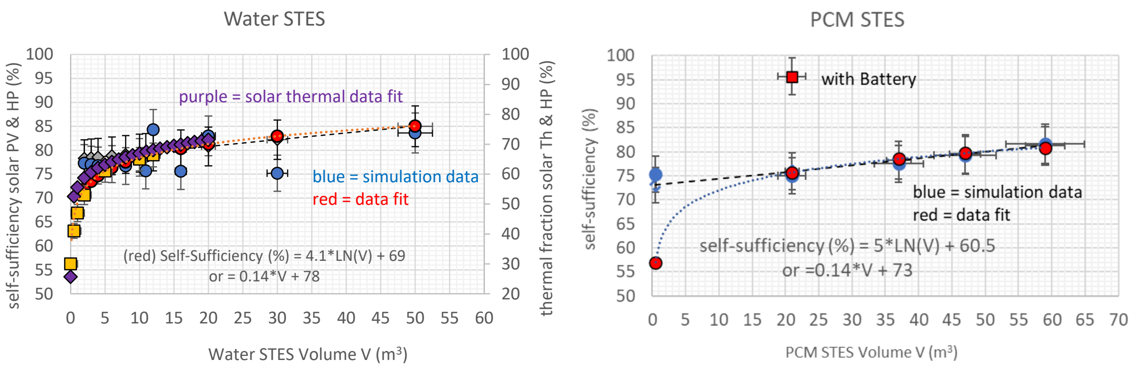

Figure 3 Thermal self-sufficiency (%) in function of storage size i.e. volume V (m3) of a sensible water STES for a SFH as the reference case (left). In the left graph, solar thermal data with heat pump from (Duffie Beckman [6]) are included. Thermal self-sufficiency (%) in function of STES size for PCM STES (right). A linear fit and a logarithm fit curve to the data show the functional behaviour. Due to the implementation of a battery (right, PCM STES) in the system, a nearly 100 % thermal self-sufficiency can be reached because the heat pump can be run with electric energy of the battery.

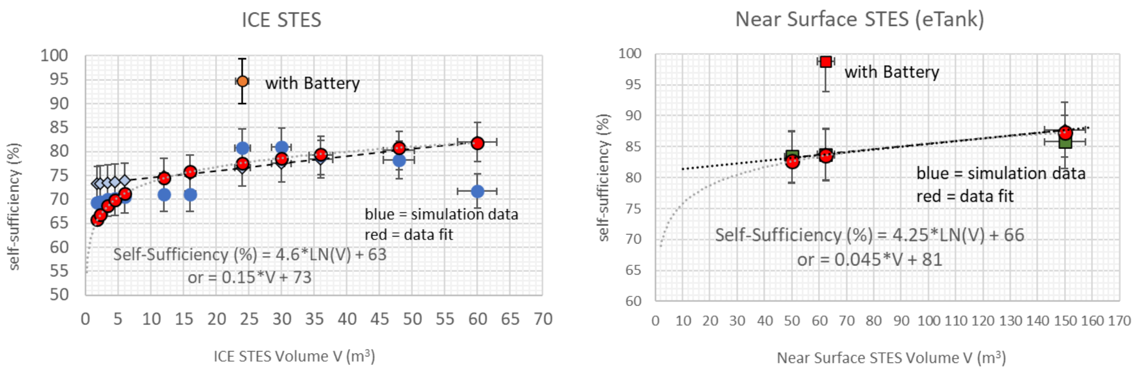

Figure 4 Thermal self-sufficiency (%) in function of STES size i.e. STES volume V (m^3) for ICE STES (left) and near surface STES (right). For comparison with an ICE STES results for a near surface STES (NTES called eTank) [Internet 2026-01-14]) are shown on the right. An eTank consists of humid soil/sand of (general) 10*10*1.5 m^3 size, has an immersed heat exchanger and the eTank position / location is under the building foundation (SFH). And as shown in these graphs, with a battery implemented in the system nearly 100 % thermal self-sufficiency can be reached.

The data show that after a certain size (volume V m^3) of the storage, the thermal self-sufficiency is relatively unsensitive of the size i.e. volume. And as soon as a battery of 25 kWh (approx. variable value C (kWh) of the battery capacity) electric energy is implemented in the system the thermal self-sufficiency increases up to nearly 100 %. In literature [Stefano Aneli et al. 2023; Michellod et al. 2026; Wang et al. 2025], such results are reported for similar systems implemented in SFH. A further simulation task would be needed to optimize the battery size C in combination with the electric consumers demand profiles. But this is shifted to later work. And due to the lack of a thermo-physical TCM model at this level, the simulation of the thermal self-sufficiency of a SFH with a TCM STES is post-boned as well.

$$self - sufficiency(V) = a_{ln} * LN(V) + b_{ln} \qquad (eq.1)$$

or

$$self - sufficiency(V) = a_l * V + b_l \qquad (eq.2)$$

Further simulations will be performed by changing the design variable C (kWh) of the battery, i.e. the electric energy capacity C (kWh) of the battery. And in regard of (thermal) self-sufficiency in function of area A, volume V and capacity C a comparison with solar thermal technology systems [Duffie Beckman 2013] is foreseen.

4. References

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