Multi-objective design optimization of a hybrid renewable energy system

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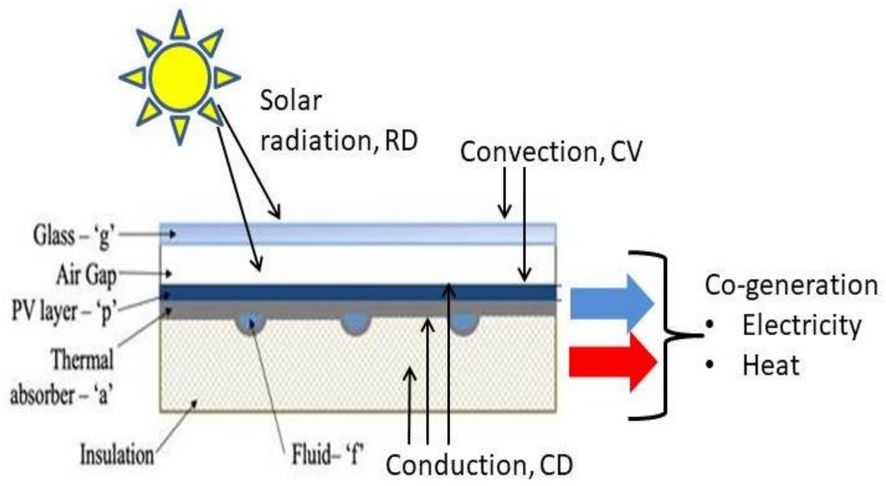
Context

In the context of smart energy grids, the share of renewable energy sources in the buildings is continuously increasing. To support fluctuating renewable energy production, energy storages are required to ensure the reliability of the carefully designed hybrid renewable energy systems. Smart energy buildings are characteristic by high energy efficiency and they play an important role in the smart grids.

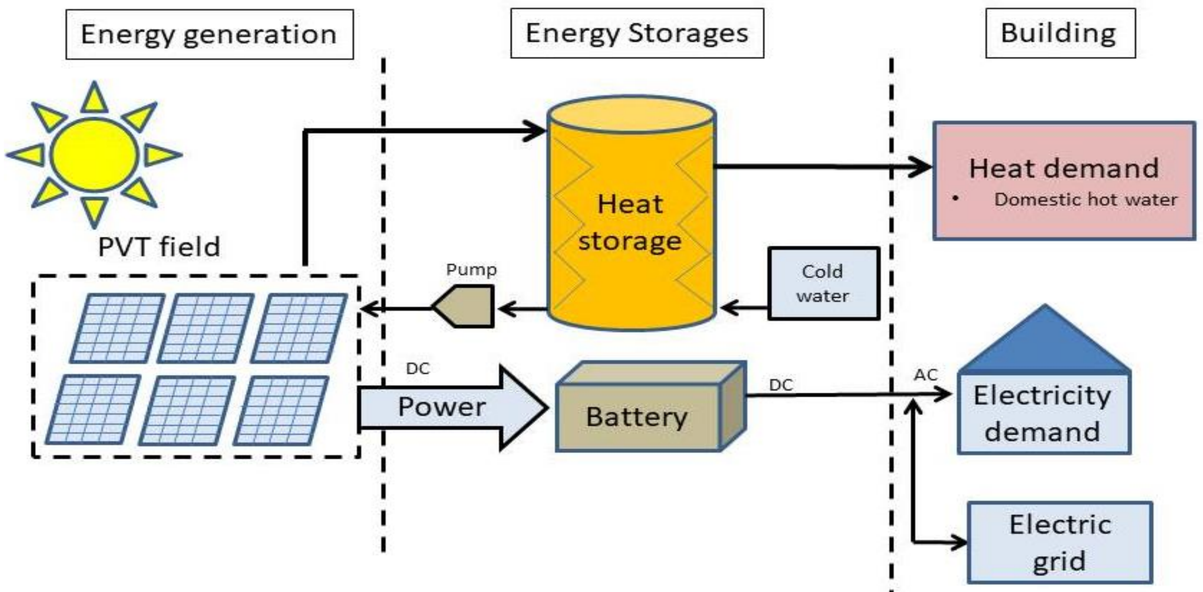
A photovoltaic-thermal (PVT) collector is a solar-based micro-cogeneration system which generates simultaneously heat and power for buildings. The energy efficiency is higher than separated solar production. Thermal and electrical energy storages are coupled with the PVT collectors to support fluctuating energy production in order to meet a certain energy demand of domestic hot water (DHW) production and electricity use. To maximize the self-consumption of renewable energy sources, the optimal size of the hybrid energy system components has to be determined. In this research, a solar energy system is modelled and a genetic algorithm (NSGA-II) is used to obtain a Pareto front of optimal design solutions for decision makers. The genetic algorithm is selected due to the conflicting nature of the objective functions in the optimization problem.



Methodology

Hybrid renewable energy system

Photovoltaic-thermal (PVT) collectors provide low-grade heat for domestic hot water (DHW) production and electricity for building appliances. The energy storages are used to support fluctuation of solar energy production.



Multi-objective optimization

Objective: to find a Pareto optimal set of system designs to minimize the initial investment costs and maximize thermal and electrical reliability of the system, simultaneously.

Optimization algorithm: The elitist Non-Dominated Sorting Genetic algorithm (NSGA-II) applied by the Matlab function called gamultiobj of the Global Optimization Toolbox.

The formulation of the 3-dimensional optimization problem:

$$f_1(x) = 1 - \frac{\sum_1^{8760} Q_{aux}(t)}{\sum_1^{8760} Q_{DHW}(t)} = 1 - \frac{\sum_1^{8760} m_L(t) c_p (T_{set}(t) - T_{TS}(t))}{\sum_1^{8760} Q_{DHW}(t)} = -R_{th}$$

$$f_2(x) = 1 - \frac{\sum_1^{8760} P_{grid}(t)}{\sum_1^{8760} P_L(t)} = 1 - \frac{\sum_1^{8760} [P_L(t) - (P_{PVT}(t) + SOC_B(t) C_B)]}{\sum_1^{8760} P_L(t)} = -R_{el}$$

$$f_3(x) = I_{PVT} A + I_B C_B + I_{HS} V_{TS} = I_{total}$$

Results

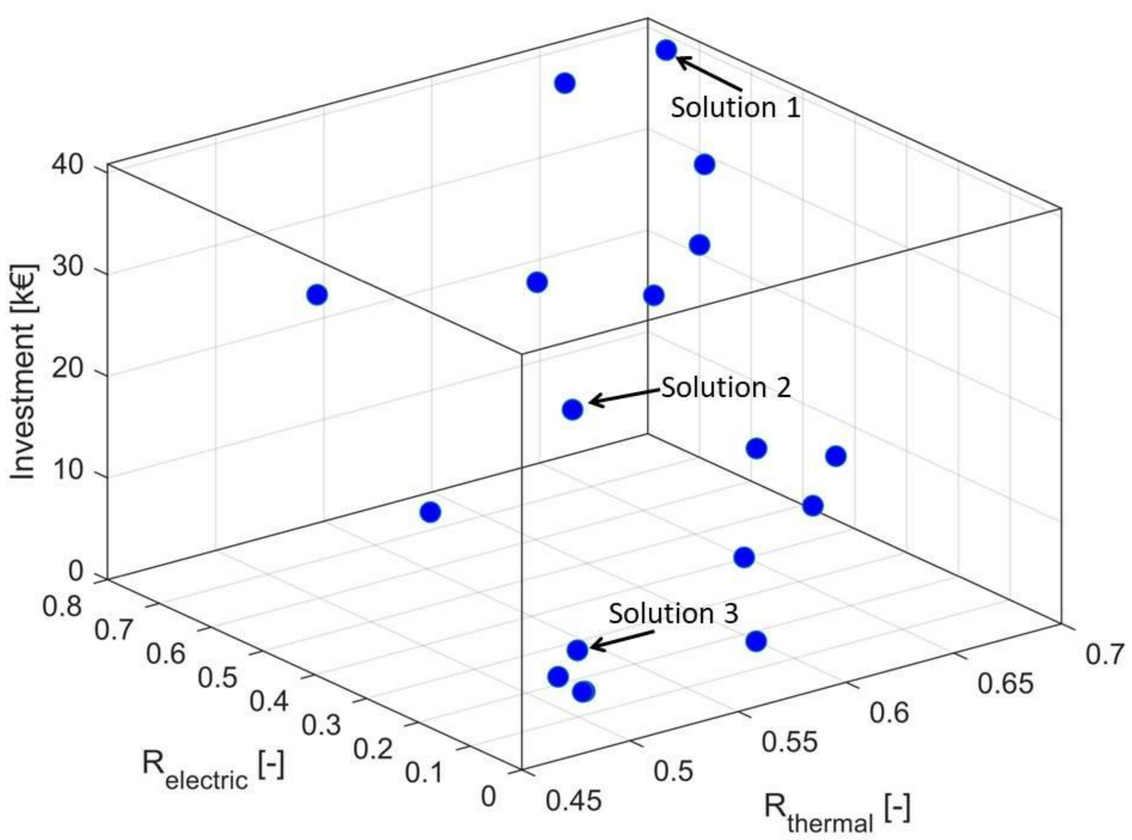
Case:
- residential building
- yearly DHW consumption at 60°C: 128 l/day, 7.5 kWh/day
- yearly electricity demand 24.6 kWh/day, 8970 kWh/year
- hourly yearly meteorological data of Strasbourg

Objectives:
- To find the optimal set of decision variables that minimize the investment costs and maximize the reliability of the system
- Non-dominated solution in the Pareto front for decision makers

	Decision variable	Bounds	Unit
$\dot{m}$	Coolant mass flow	60 ≤ x(1) ≤ 130	kg/h
N	No. of PVT in series	1 ≤ x(2) ≤ 6	-
M	No. of PVT in rows	1 ≤ x(3) ≤ 6	-
C_B	Battery capacity	4 ≤ x(4) ≤ 14	kWh
V_{TS}	Thermal storage volume	0.1 ≤ x(5) ≤ 0.5	m^3

Component	Price
PVT collector	325 €/m^2
Thermal storage	2.95 €/dm^3
Electrical storage	1143 €/kWh

	$\dot{m}$ (kg/h)	PVT in series	PVT rows	C_B (kWh)	V_{TS} (m^3)	R_{th}	R_{el}	Inv. (€)
Sol. 1	108	6	6	14	0.5	0.68	0.7	40877
Sol. 2	64	6	2	9	0.2	0.57	0.41	18677
Sol. 3	111	1	3	4	0.1	0.5	0.09	6817



Conclusion and perspectives

- Studied energy system cannot cover all energy demand under defined constraints
- The highest reliabilities: 68% for thermal and 70% for electrical with the investment costs of 40.9 k€.
- The mass flow rate around 110 kg/h dominated the results in the Pareto front
- Increasing the no. of collectors had high influence on the electrical reliability
- Increasing battery capacity increased electrical reliability relatively more than increasing thermal storage influenced on the thermal reliability
- The multi-objective optimization with the genetic algorithm is suitable for the system design optimization

Perspectives

The results revealed that the studied energy system cannot cover all energy demand under defined constraints but an additional energy source is required and the considered energy system should be extended to be a hybrid micro cogeneration system that integrates solar and fuel-based micro-CHP and storage technologies in order to form a sustainable and energy efficient set-up to satisfy a certain energy demand.

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