Energy Simulation Tool for Active Solar Collector Greenhouses

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Introduction & Methods

The standard tools for energetic evaluation of greenhouses are not able to evaluate completely and satisfactorily the components of a semi-closed installation, which includes the greenhouse, a solar thermal collector, a heat pump and a thermal energy storage. Thus, an energy simulation tool was developed using MS-Excel®. The underlying submodels (empirically determined) make use of iterative algorithms for the energy simulation of the mentioned greenhouses and allow to define input variables e.g. weather data, dimensions, efficiency factors and setpoints (Tab. 1). Energy modeling allows to conduct a scenario analysis to compare different assumptions about the technical system. As an example, a Venlo-type tomato greenhouse using as a solar collector (collector area 33%, 66%, 100%) with an electrically-driven heat pump system for cooling as well as heating, and thermal energy storage was simulated. Different thermal storage media, like water and phase-change material (PCM) were used, too. The results include the temperature of the thermal energy storage (TES), the efficiency ratios of the heat pump for cooling (SEER) as well as heating (HSPF) and the savings of fossil fuels for heating the greenhouse.

Tab. 1: Major setpoints and submodels for energy simulation of a solar collector greenhouse system

Parameters	Value / Model	Unit
Location	52° 28′ 2.28″N, 13° 17′ 57.88″E	-
Heating setpoint (Day/Night)	$20/18_{(Jan-Mar)}$; $19/17_{(Apr-Nov)}$; $10/10_{(Dec)}$	°C
Cooling setpoint (Day)	$24_{(Jan-Dec)}$	°C
Thermal energy storage U-value	0,9	W/m²K
Greenhouse U-value ($Day_{Jan-Dec}$)	$0{,}3216x_{(Wind\ speed)} + 3{,}5849$	W/m²K
Greenhouse U-value ($Night_{Jan-Apr;\ Oct-Dec}$)	$0{,}0605x_{(Wind\ speed)} + 1{,}7117$	W/m²K
Greenhouse U-value ($Night_{May-Sep}$)	$-0{,}0028x_{(Wind\ speed)} + 2{,}7956$	W/m²K
Greenhouse sensible heat flux	$0{,}0015x_{(Month\ number)}^6 - 0{,}0465x^5 + 0{,}5131x^4 - 2{,}5269x^3 + 5{,}9664x^2 - 14{,}19x + 93{,}583$	%
Solar collector efficiency	$8E\text{-}05x_{(Month\ number)}^6 - 0{,}003x^5 + 0{,}045x^4 - 0{,}325x^3 + 1{,}1426x^2 - 1{,}6345x + 0{,}7739$	-
COP heat pump heating	$0{,}0973x_{(Storage\ temperature)} + 2{,}0779$	-
COP heat pump cooling	$-0{,}1468x_{(Storage\ temperature)} + 7{,}9644$	-

	Greenhouse	Solar collector	TES	H_2O	PCM 250 kJ/kg
Scenario 1	1 ha	33%	20.000 m³	100%	0%
Scenario 2	1 ha	66%	40.000 m³	90%	10%
Scenario 3	1 ha	100%	60.000 m³	80%	20%

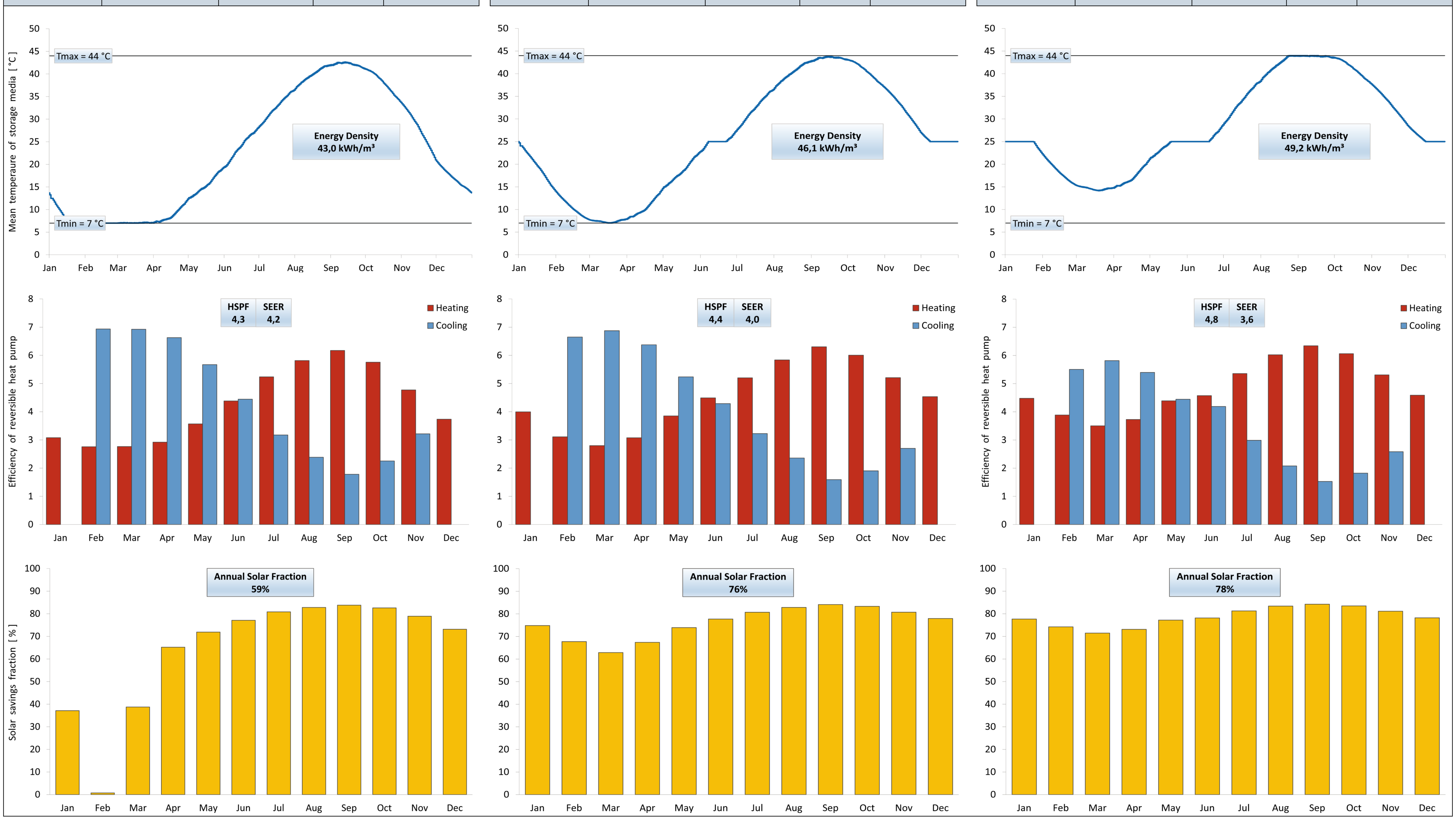

Fig. 1: Effect of the solar collector fraction, the TES-volume and PCM-fraction on the TES-temperature, heat pump efficiency and solar savings fraction

Results & Conclusions

Due to the fact that greenhouses need big amounts of energy, there is a growing interest on new technical systems to save fossil resources. In this context, the inclusion of solar thermal systems in greenhouses for energy harvesting represents an interesting solution. However, decision-support tools are needed to calculate and choose between different options of plant dimensioning. In the tested simulation scenarios (Fig. 1), it was determined that an annual solar fraction of 59-78% can be expected for greenhouse heating when using 6 m³ TES-volume to 1 m² collector area. The determined range of solar fraction originates from the increasing energy density of the storage media by using a PCM and the decreasing heat loss of the TES by rising storage size. The effect on the heat pump efficiency is relatively low. In conclusion, scenario 2 by using a solar collector area of 66% and heat storage concept with 6 m³/m² as well as 10% PCM seems to be a good solution for reaching a year-round solar thermal heating support (76%) of a greenhouse. In further investigations, the economic feasibility should be investigated (esp. large-scaled TES with different ratios of H_2O to PCM).

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