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Simple calculation tool for central solar heating plants with seasonal storage

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Abstract

Central Solar Heating Plants with Seasonal Storage (CSHPSS) are able to produce thermal energy from solar radiation during all the year providing a significant part of the residential sector demands for Space Heating (SH) and Domestic Hot Water (DHW), using district heating systems. The yearly dynamic simulation is a complex process requiring local detailed climatic and demand data in order to properly design/sizing the plant components to reach the desired solar fraction. In this paper is proposed a simple method for the calculation of CSHPSS using demand data and easy to find available public climatic data. The proposed method is a useful tool to evaluate the CSHPSS system at early project stage as well as to perform parametric analysis in order to establish optimization and design criteria. The method is completely described and applied for a specific location in Spain to size the main components of the system which are the solar collector field area and the volume of the seasonal storage. It is also applied to perform a comparative analysis of CSHPSS located in different climatic areas of Spain. The obtained results reveal that the location of the plant and the different demands corresponding to different climatic areas affect very significantly the sizing and design criteria of CSHPSS.

Keywords: Solar thermal energy; Seasonal storage; Renewable energy; District heating; CSHPSS

1. Introduction

The World energy demand in the residential sector (2035 Mtoe) represents roughly 27% of the final energy consumption (IEA, 2014). The development of solar systems covering part of the thermal energy required in the residential sector is a viable option for reducing fossil fuel use and might solve an important part of the energy problems: shortage, dependency, high prices fluctuation, pollution and climate change, among others (IEA, 2012).

Central solar heating plants with seasonal storage can cover with a high solar fraction the space heating and domestic hot water demands of big communities at an affordable price. A very good example is Denmark, a country with a not high solar radiation, where a boomimg market for solar dictrict heating is occurring thanks to an appropriate legal and socioeconomic framework. In 2014 there were in Denmark more than 50 solar district heating plants in operation and the cost of heat produced in solar district heating systems without subsidies was lower than 0.05 €/kW h (Nielsen, 2014). The offer of thermal energy in periods of high solar radiation (summer) is coupled with high thermal energy demand for heating (winter), obtaining energy independence, non-renewable energy savings,

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Nomenclature

A	solar collector area (m^2)
A_{acu}	total surface area of the accumulator (seasonal storage) (m^2)
D	seasonal storage tank diameter (m)
DD	monthly degree-days (°C day)
EA	stored thermal energy (MW h)
EA_x	stored thermal energy without max. temperature limit (MW h)
E_{ff}	heat exchanger effectiveness
H	monthly average daily global radiation horizontal surface (MJ/(m^2 day))
h	solar hour
H_{acu}	seasonal storage tank height (m)
I_0	horizontal radiation (W/m^2)
m	month
m_s	solar field mass flow rate (kg/(h m^2))
N	number of month days
$N_{dwellings}$	number of dwellings
Q_b	solar contribution to immediate heat demand (MW h)
Q_c	solar thermal energy production at the solar field (MW h)
Q_d	heat demand (MW h)
Q_{DHW}	domestic hot water heat demand (MW h)
Q_e	accumulator (seasonal storage) inlet thermal energy (MW h)
Q_g	auxiliary thermal energy (MW h)
Q_l	accumulator (seasonal storage) heat loss (MW h)
Q_r	incident solar radiation on tilted surface (MW h)
Q_s	accumulator (seasonal storage) outlet thermal energy ((MW h)
Q_{SH}	space heating demand (MW h)
Q_{solar}	solar heat consumed (MW h)
Q_{sx}	maximum thermal energy available for discharge (MW h)
Q_x	solar thermal energy rejected (MW h)
T	temperature (°C)
Ta	hourly ambient temperature (°C)
Ta_{ave}	monthly average of daily medium ambient temperature (°C)
Ta_{max}	monthly average of daily maximum ambient temperature (°C)
Ta_{min}	monthly average of daily minimum ambient temperature (°C)
T_{acu}	water temperature in the accumulator (seasonal storage) (°C)
T_c	solar collector temperature (°C)
T_{DHW}	domestic hot water temperature (°C)
T_{in}	solar collector inlet water temperature (°C)
T_{max}	maximum temperature allowed in the storage tank (°C)
T_{min}	minimum temperature allowed in the storage tank (°C)
T_{net}	monthly average temperature of water from network (°C)
T_{out}	solar collector outlet water temperature (°C)
T_{ret}	temperature of return water from the district heating (°C)
T_{sup}	temperature of water supplied to the district heating (°C)
T_{ter}	ground temperature (°C)
U_{acu}	global heat transfer coefficient (seasonal storage) (W/(m^2 K))
V	volume of the accumulator (seasonal storage) (m^3)

Greek symbols

ρ_g	ground reflectance
β	solar collector tilt (0° is horizontal surface)
γ	solar collector orientation (0° is south oriented)
η_{acu}	seasonal storage efficiency
η_{coll}	solar field efficiency
η_{sys}	system efficiency
η_0	optical efficiency (solar collector)
κ_1	1st order heat loss coefficient (solar collector) (W/(m^2 K))
κ_2	2nd order heat loss coefficient (solar collector) (W/(m^2 K))

Abbreviations

CSHPSS	central solar heating plant with seasonal storage
RAD	ratio solar collector area/annual heating demand (m^2/(MW h/year))
RHD	seasonal storage tank shape ratio (height/diameter)
RVA	ratio accumulator volume/solar collector area (m^3/m^2)
SF	solar fraction
WCZ	winter climatic zone

and reduction of CO_2 and pollutant emissions. Despite the lower solar resource, CSHPSS are spreading in countries where district heating already provides a large proportion of the space heating demand, such as Denmark, Germany, Sweden and other central and northern european countries (SDH, 2014). Great potential exists for