DESIGN OF THE LAY-OUT OF A PTC SOLAR FIELD FOR A SHC PLANT AT THE MISERICORDIA OF BADIA A RIPOLI: A METHOD FOR THE OPTIMIZATION OF THE ENERGY COLLECTION

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Abstract

Cooling demand is rapidly increasing in many parts of the world and the Solar cooling technologies, which use solar thermal energy provided by solar collectors to drive cooling machines can significantly contribute to a rising share of renewable heat sources in the building sector and a sustainable energy development in Europe. However, smaller systems have not yet entered the market due to various technical and economical reasons. Until today, there is a lack of small scale units, fully automated and autonomous package-solutions for residential and light commercial or industrial applications, low temperature cooling systems. Within the FP7-ALONE project, financed by the EU, the Department of Energy "S.Stecco" is responsible for the installation of a SHC plant that foresees the coupling of a 108 m^2 parabolic trough collectors (PTC) solar field with an ammonia-water (NH_3-H_2O) absorption chiller driven by direct steam.

The design of the lay-out of the solar field is a key-point for the optimization of the plant and it is necessary to take into consideration also the possibilities offered by the site for the installation of all components of the SHC System.

Generally the longitudinal optical losses are not considered in the evaluation of the energy collection of a PTC solar field: in this paper their influence on the solar field energy yield are implemented by the definition of the "Solar Field Efficiency" (η_{sf}).

A TRNSYS model has been developed in order to evaluate the thermal efficiency of collectors, the optical losses due to shading effects between rows, the "η_{sf}" and the seasonal energy yield. The main data from the solar field are latitude, tracking axis

orientation, number or rows, distance between rows, and total number of collectors.
The method have been tested using the available areas at the Misericordia Site: different lay-outs have been designed and their seasonal energy yield have been evaluated.

Nomenclature

a_1	1st Order Heat Loss Coefficient $[W/m^2K]$	SHC	Solar Heating and Cooling
a_2	2nd Order Heat Loss Coefficient $[W/m^2K^2]$	η_0	Optical Efficiency of Collector
DNI_{tilted}	Direct Normal Radiation on a Tilted Surface $[W/m^2]$	η_{SF}	Solar Field Efficiency
F_{coll}	Focal Length of the Collector $[m]$	η_{TOT}	Total Efficiency of the Solar Field
L_{coll}	Length of the Collector $[m]$	$\bar{\eta}_{TOT,year}$	Yearly Average Efficiency of the Solar Field
L^*	Length of the not-enlightened zone on the Absorber Tube $[m]$	η_{TH}	Thermal Efficiency of Collectors
N	Number of Collectors	$\phi_{Tube,Ext}$	External Diameter of the Absorber Tube $[m]$
N_{row}	Number of Collectors each row	θ	Incidence Angle of the Sun [*degrees]*
PTC	Parabolic Trough Collector		

Introduction

In the FP7-ALONE project the Department of Energy Engineering of Florence is responsible for the installation of a SHC plant based on PTCs (supplied by SOLITEM) and an ammonia-water absorption system (ROBUR) modified for steam produced by the solar field [1,2]. The optimization of the lay-out of the solar field relating the possibilities offered by the site is a key-point, in order to maximize the yearly energy savings and reduce the payback time [3].
In this paper, the method followed for the optimization of the PTC solar field will be shown: it evaluates the efficiency and the energy yield depending on thermal efficiency of collectors, on the orientation of the tracking axis and on shading effects between rows. The method also defines the "η_{sf}" which considers optical losses caused by the incidence angle of the sun along the longitudinal axis of the PTCs. A model has been developed with TRNSYS in order to estimate the energy production correlated with a 108 m^2 solar field. The available areas for the installation of the solar field have been analyzed: two main areas have been identified and 7 lay-outs have been designed. Results will show the most performing lay-out and will highlight the main disadvantages for each designed solution.

Misericordia Site

The Misericordia has a central building which is mainly used for outpatient assistance, and a "secondary" one, used for all administrative activities (Fig. 1). The main purpose of the SHC installation is to integrate cooling energy and heat from the plant to the existing air-conditioning system (vapor-compression and heat pump devices) for the central building.

Fig. 1 – Misericordia of Badia a Ripoli

Fig. 2 - Installation Areas

There are only few possibilities for the installation of the solar field, and all the other components of the SHC plant (Fig. 2): In the west side of the main building there an almost rectangular area (A1), tilted about 20° in respect of the NS direction (it is the area preferred by the Misericordia for the installation of the solar field). In the south-side there is a larger area (A2) oriented perpendicularly to A1, used as parking for ambulances and services vehicles (it will be necessary to design and construct an over-elevated steel structure, almost 4 meter high, in order to allow the parking).

The "MZ" is the area where all the other SHC plant components could be installed.

In this paper A1 and A2 will be considered the areas for the optimization of the lay-out of the solar field.

Modelling and Simulation

In order to estimate the PTC solar field energy yield a model has been developed with TRNSYS, with the following hypothesis: a) 12 SOLITEM PTC 1800 (η_0=0,75; a_1=0.1123 W/m^2K; a_2=0.00128 W/m^2K^2) [4]; b) operating Temperature: Summer Mode 180°C/Winter Mode 70°C; c) Minimum distance between rows, 5 meters; d) no distance between collectors in the same row; e) no transitory, no heat losses in the piping

The model implements all data relating the solar field (collectors' geometry, total number of collectors and rows, distance between rows, tracking-axis orientation) and the PTC characteristic curves as described in eq. 1.

$$\eta_{th} = \eta_0 - a_1 \frac{(\Delta T)}{DNI_{tilted}} - a_2 \frac{(\Delta T)^2}{DNI_{tilted}}; \quad (1)$$

The model implements also the evaluation of the "η_{sf}" which is defined as follows: the incident sun-rays are reflected onto the absorber with the same angle of incidence (θ): at the extremity of the collector there is a "not-enlightened zone" ($L*$) which depends on the solar angle of incidence and F_{coll} and $\phi_{Tube,Ext}$ (eq.5).

$$L^* = (F_{Coll} - \phi_{Tube,ext}) Tan\theta \quad (2)$$

$$L = N_{row} * L_{coll} \quad (3)$$

$$\eta_{SF} = \frac{L - L^*}{L} \quad (4)$$

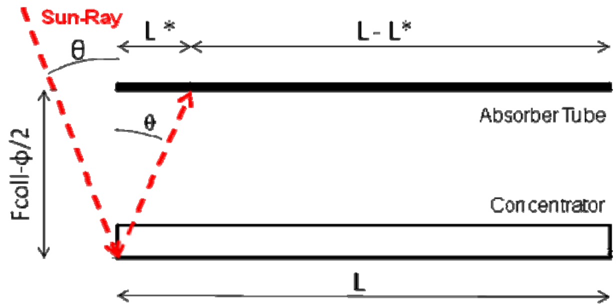

Fig. 3

Hypotesis "d" allows to extend the above-mentioned concept and to consider a row as a single collector (eq. 3). The ratio between the enlightened portion of the absorber tube ($L - L*$) with the total length (L) defines the "η_{sf}" (eq. 4).

MISERICORDIA – Lay-Outs Data					
Name	*Area*	*Orientation*	N	*Rows*	N_{row}
NS1	A1	21°	12	1	12
NS2	A1	0°	12	6	2
NS3	A1	0°	12	5	2x3 + 3x2
EW1	A2	108°	12	1	12
EW2	A2	90°	12	2	6
EW3	A2	90°	12	3	4
EW4	A2	108	12	2	6

$$\eta_{TOT} = \eta_{SF} \eta_{TH} \quad (5)$$

$$Q_{yield} = \eta_{TOT} DNI_{Tilted} \quad (6)$$

$$\bar{\eta}_{TOT,year} = \frac{\int Q_{yield}}{\int DNI_{Tilted}} \quad (7)$$

Table 1 – Lay-Outs Details and Equations for the Model

Seven solutions for the lay-out have been designed for a 108 m^2 solar field: 3 for the "A1" and 4 for the "A2" (Table 2). Simulations were run in order to evaluate seasonal and yearly energy yield and the yearly average efficiency of the solar field has been evaluated, as described in eq.7.

DESIGNED LAY-OUTS AT THE MISERICORDIA

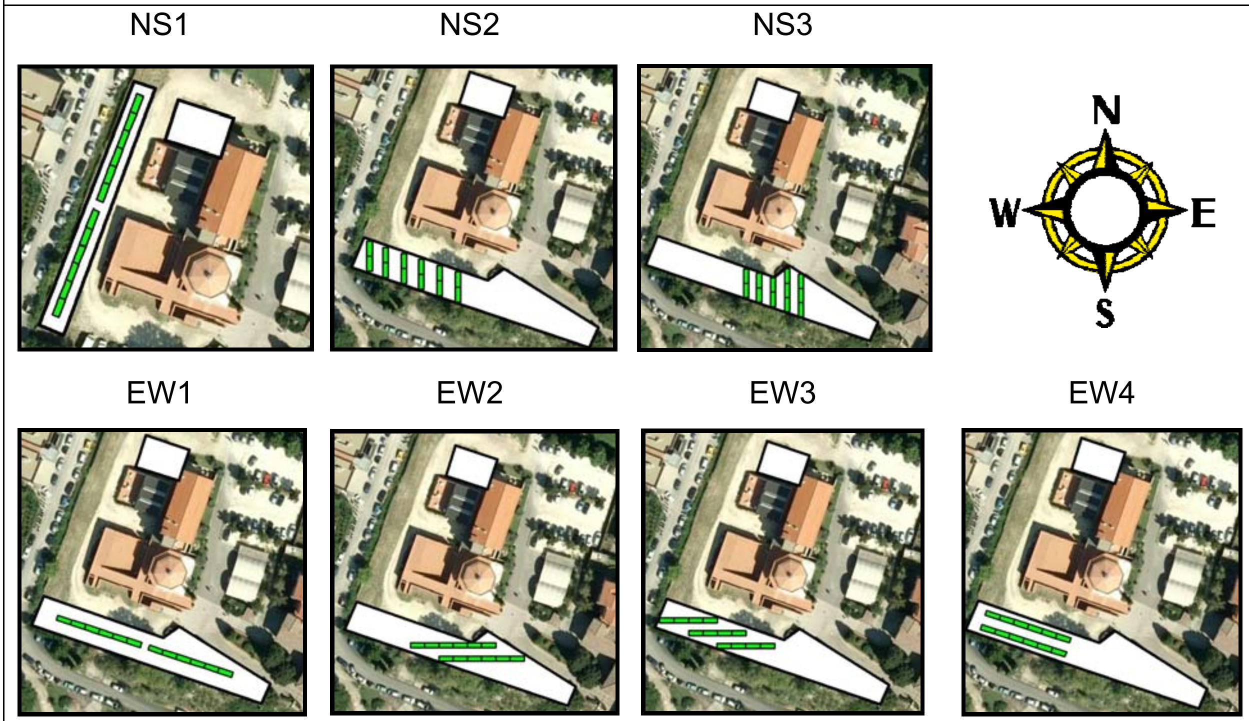

Table 2 - Designed Lay-Outs for the solar field

Results and Conclusions

The results of simulations can be summarized as in Fig. 4 : as expected, the most performing solutions in terms or yearly energy yield are “NS1” (Q_{yield}=65106 kWh) and “EW1” (Q_{yield}=60137 kWh). They maximize the “η_{sf}” and minimize optical losses due to shading effects between rows. These two lay-outs are quiet equivalent in terms of yearly energy yield since they differ of about the 9%, but they are significantly different in terms of seasonal energy distribution: during summer the NS1 (Q_{yield}=44121 kWh) provides 16% more energy than the EW1, while, during winter, EW1 provides an energy yield (Q_{yield}=22087 kWh) the 10% higher.

Even if it is not so clear in Fig. 4, it is important to highlight that the EW-oriented solutions are less affected by the optical losses due to the solar incidence angle: the yearly average efficiency is generally higher for EW-oriented lay-outs.

At Florence latitude, during summer, the available DNI_{tilted} is significantly higher for a NS-oriented lay-out, and, since in this conditions they are more efficient than the EW-oriented, the yearly amount of collected energy for NS1 solution is higher than the EW1 one.

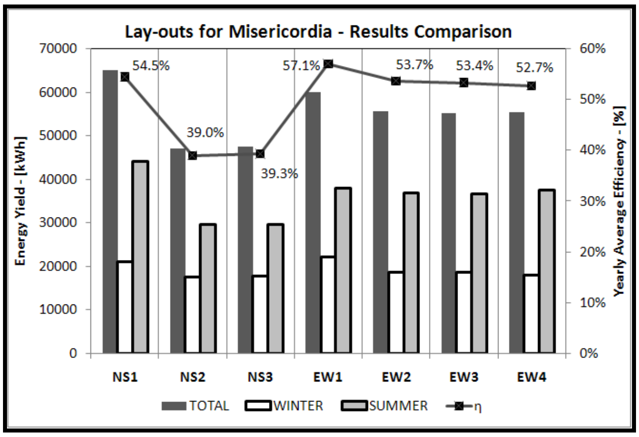

Fig. 4 - Results Comparison

In the end, for the optimization of the solar field arrangement it is necessary not only to analyze the energy efficiency of lay-outs, but also the economical effectiveness of the installation relating the user needs. In fact, if cooling energy is required, the NS1 arrangement may guarantee better performance during summer, otherwise, if heating is also economically important, it could be convenient to select EW1.

Since the aim of the FP7-ALONE project is to supply mainly cooling energy to the buildings, the selected lay-out for the SHC plant that is going to be installed at the Misericordia is the NS1.

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