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Technical assessment, economic viability and investment risk analysis of solar heating/cooling systems in residential buildings in Morocco

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ABSTRACT

This paper focuses on the potential of a solar installation combining air-conditioning, heating and Domestic Hot Water (DHW) production processes intended for mass use in building sector in Morocco. The objective is to measure the relevance of the investment in such systems through a technico-economic assessment and a risk analysis based on classic economic choice criteria. Then, a sensitivity study was conducted to analyze the impact of the major characteristics of a solar plant project (amount of investment, operation cost, solar sunshine, etc.) on the decision-making in various environments to conclude the technical feasibility and economic viability of these systems under Moroccan conditions. Parametric studies including the solar collectors' technology and field area in addition to the storage tank volume were carried out to design the solar plant and to ensure its optimization in dynamic mode operation. The major finding of this work is that incrementing the collector's field area to 30 m^2 optimizes the thermal efficiency of the solar plant, and the electric booster consumption is reduced. Furthermore, it would be advantageous to use a number of collectors of 14 (a total surface of 22 m^2 to satisfy) the cooling, heating and hot water needs over the year since the overall system solar fraction remain above 55% when the optimum parameters are considered. The results indicated also that solar cooling systems in hot climates are an attractive option to increase energy savings and to mitigate CO_2 emissions. In addition, the solar contribution has increased from 605 kW h to 705 kW h in winter and summer periods, respectively, while the auxiliary consumption has achieved 1450 kW h, 1875 kW h and 2300 kW h for Agadir, Tangier and Ben Guerir, respectively. However, according to the economic assessment, the high solar plant cost is a main barrier facing their implementation in Morocco. Several recommendations were drawn from the profitability study to identify the sensitive points and to consider avenues for improvement with a view to future industrialization of the combined solar thermal installation in Morocco.

1. Introduction

Nowadays, solar air conditioning and heating process represent a growing market in buildings worldwide, with a particularly significant growth rate observed in Moroccan commercial and residential buildings (Kalogirou, 2013; hcp). Heat driven cooling technologies are available because they can be used in combination with solar thermal collectors to alleviate the burden caused by air conditioning on the environment and the electric utility (Wang et al., 2009). Solar air conditioning has progressed considerably over the past years as a result of efforts toward environmental protection and new developments in components and systems, and significant experience has been gained from demonstration projects (Syed et al., 2005).

In the literature, several researchers have focused on the design and development of solar thermal systems in buildings worldwide. In central Queensland's subtropical climate like Australia that has a very sunny climate with a very high demand for air conditioning, Baniyounes et al. (2013) performed an assessment of solar assisted air conditioning system. They found that the proposed system indicated that an 80% of the primary energy savings can be achieved by installing 50 m^2 of solar collectors and 1.8 m^3 of hot water's storage tank under three selected climates.

For solar heating systems, Kumar and Kim (2017) analyzed a solar air-heating (SAH) system comprising single- and double-pass packed-

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Nomenclature

A_c	collector area [m^2]
A_i	surface area of the ith tank layer [m^2]
C_p	specific heat at constant pressure [J/K·kg]
C_{pf}	specific heat of the tank fluid [J/K·kg]
CF_t	Cash flow at time t
f	solar fraction [–]
I_{rad}	the total horizontal radiation [W/m^2]
$\dot{m}$	flow rate [kg/s]
$\dot{m}_L$	fluid mass flow rate to the load and/or of the makeup fluid [kg/s]
N	number of fully mixed (uniform temperature) tank layers (N 15)
k_1	first order heat loss coefficient [W/K.m^2]
k_2	first order heat loss coefficient [W/K^2.m^2]
$\dot{Q}_i$	rate of energy input by the heating element to the i_{th} segment
$\dot{Q}_s$	rate at which sensible energy is removed from the tank to supply the load
Q_{aux}	auxiliary energy of the booster system [W]
Q_{load}	Energy to load [W]
Q_u	useful energy [W/m^2]
T_a, T_{amb}	ambient temperature [K]
T_{env}	temperature of the environment surrounding the tank [K]
T_h	temperature of the fluid entering the storage tank from the heat [K]
T_i	temperature of the ith tank segment [K]
T_L	temperature of the fluid replacing that extracted to supply the load [K]
T_m	mean temperature [K]
T_{out}	outlet temperature [K]
T_{in}	inlet temperature [K]
U_i	loss coefficient between the tank and its environment (per unit area) [W/K.m^2]
V_t	tank volume [l]

Abbreviations

COP	Coefficient of Performance
ETC	Evacuated Tube Collector
FPC	Flat Plat Collector
IRR	Intern Rate of Return
NPV	Net Present Value [euro]

Greek symbols

α_l	control function defined by $\alpha_i = 1$ if $i = S_h$; 0 otherwise
β_i	control function defined by $\beta_i = 1$ if $i = S_L$; 0 otherwise
ΔE	internal energy change of the tank [J]
η	efficiency [–]
η_0	zero loss efficiency [–]
γ_f	control function that defines if the auxiliary heater is off or on. 1 is off, 0 is on
γ_i	control function defined by $\gamma_i = \dot{m}_h \sum_{j=1}^{i-1} \alpha_j - \dot{m}_L \sum_{j=i+1}^{N} \beta_j$
ρ_f	fluid density

bed energy-storage systems. The review shows that the double-pass packed-bed SAH has a higher thermal efficiency than the single-pass packed-bed SAH. Fertahi et al. (2017) studied the performance enhancement of a two-phase closed thermosyphon used in evacuated tube solar collectors through CFD numerical simulations. Moreover, Song et al. (2017) proposed an integrated approach for developing sustainable supplier selection criteria for solar air-conditioner manufacturer. They provided a case study in a solar air-conditioner manufacturer to show the feasibility and effectiveness of the proposed methodology.

Ma et al. (2017) predicted the energy consumption of air-conditioning systems in buildings by selecting similar days based on combined weights. A simulation case in an office building indicates that the proposed prediction method with high forecast accuracy can select similar days with a high degree of similarity under non-catastrophic weather conditions. Besides, Zhang et al. (2012) proposed an optimum selection of solar collectors for a solar-driven ejector air conditioning system by simulation and experimental study for Mediterranean climate. They found that the solar ejector cooling system when operated at the optimum generating temperature using the evacuated tube collector with selective surface and high performance heat pipe provide the most economic saving. Rosiek and Batlles (2013) performed a case study for reducing a solar-assisted air-conditioning system's energy consumption by applying real-time occupancy sensors and chilled water storage tanks throughout the summer. They found that during one cooling period, it is possible to conserve approximately 42% of the total electrical energy consumed by the system prior to the adoption of this operation strategy. In addition, Fong et al. (2011) investigated the application potential of solar air-conditioning systems for displacement ventilation. In another study, they conducted three integration strategies to advance the performance of solar air-conditioning through integrated system design for building. According to dynamic simulations, the year-round primary energy saving of the proposed integration strategies for solar NH_3–H_2O absorption air-conditioning systems could be up to 50.6% and 25.5%, as compared to the basic solar LiBr-H_2O absorption air- conditioning and the conventional compression air-conditioning respectively Fong and Lee (2014). Fong et al. (2010) also studied the solar hybrid air-conditioning system for high temperature cooling in subtropical city.

Park et al. (2017) performed an experimental evaluation and simulation of a variable refrigerant- flow (VRF) air-conditioning system with outdoor air processing unit. The results show that the yearly energy use of the VRF system without ventilation is found to be 213.6 kW h/m^2 and 93.9% of indoor air condition data provided by the VRF system with dedicated outside air system (DOAS) in the winter and 83.8% of the data in the summer. In addition, the thermal comfort percentage is improved during the winter and summer by 76.7% and 67.6%, respectively when the VRF system without ventilation is replaced with the VRF system with DOAS. Furthermore, Rosiek and Batlles (2009) conducted an analysis of the solar-assisted air-conditioning system installed in CIESOL building for the integration of the solar thermal energy in the construction to find the optimum conditions and operation parameters for the solar system through analyzing various systems' operation strategies. They found that the Coefficient of performance (COP) has values of about 0.6 at various generator, absorber, condenser and evaporator temperatures investigated.

A specific review on solar absorption systems and its integration with conventional absorption chillers was presented in the paper of Ibrahim et al. (2017). They considered the concept of absorption energy storage for air conditioning as an option to shift the solar thermal energy which is collected during the peak day-hours into the off peak night-hours. Besides, they highlighted in their paper the economic viability of the absorption energy storage, as well as a state of art regarding the improved designs of heat exchangers. The overall efficiency of solar adsorption cooling systems was performed by Allouhi et al. (2016) in the Sub-Saharan African countries for an application case study related to vaccine preservation. They found that the best solar coefficient of performance (SCOP) was achieved in Garoua (Cameroon) and Beitbridge (Zimbabwe). The maximum specific cooling power