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Use of parabolic troughs in HVAC applications – Design calculations and analysis

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ABSTRACT

The present work is concerned with the combination of solar energy systems with HVAC systems. Namely, the objective is finding a way of applying green energy concepts to HVAC systems. Particularly, solar concepts are employed to supply electrical power to HVAC systems. Hence, an innovative concept that permits the use of electrical energy provided by parabolic troughs to drive electrical components of the HVAC system is suggested. Thermal modeling along with governing equations of electricity production from parabolic troughs are presented. Calculations of the electrical power needed for HVAC system, showed that an order of magnitude of energy saving is attainable. Finally, the aforementioned concept was applied on a genuine case in Beirut city. It was shown that four mirrors with a 0.5 efficiency of the storage system are capable to drive the pumps of a HVAC system of a 4-floor building all over the year.

1. Introduction

The alerting increase in population and the continuous sought of extravagance living that often become necessity; in addition to environmental pollutions have made lawmakers worldwide to increase the political pressure on scientists to not only seek new sources of energies but also to use them wisely and efficiently. Furthermore, recent studies have proved that the globe will suffer a lack of fuel within the next thirty years [1]. Therefore, Wind, River, Solar, Sea waves, even nuclear are different forms of renewable energy which scientists are trying to benefit from [2–4], in many sectors, by generating electricity and other forms of energy. These renewable energies as well as heat recovery concepts [5–14] are actually the main means towards the reduction of fuel consumption and carbon dioxide emissions.

Solar energy concepts are mainly implemented in water heating solar systems (flat collectors) and electricity production solar systems (concentrating solar energy systems) [15–17]. Water heating solar systems are flat collectors that gather the sun's energy, transform its radiation into heat and then transfer that heat to a fluid, most commonly water or air [15]; whereas electricity production solar systems are the common technologies for solar thermal power plants where concentrating solar energy systems such as parabolic dishes and parabolic troughs are used.

Additionally, a typical flat-plate collector is an insulated metal box with a glass or plastic cover (called the glazing) and a dark-

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Nomenclature

DNI	Direct normal insulation, W/m^2
DST	Daylight savings time adjustment
E	Function of B
$Endloss$	Loss performance factor
$E_{cold,mirror}$	Energy provided by the solar system during the cold months, J
$E_{components,cold}$	Electrical energy required to drive the prescribed HVAC components during cold months, J
$E_{components,hot}$	Electrical energy required to drive the prescribed HVAC components during hot months, J
f	Focal length of the collector, m
HCE	Heat collection elements
HVAC	Heating, ventilating and air conditioning
IAM	Incidence angle modifier
K	Function of θ
L_{loc}	Local meridian of the collector site, deg
L_{SCA}	Length of the single collector assembly, m
$L_{spacing}$	Spacing length between troughs, m
L_{st}	Standard meridian for the local time zone, deg
n	Number of the day in the year
N	Number of mirrors
P_{mirror}	Output electrical power recuperated from a mirror, W
$\dot{Q}_{absorbed}$	Solar radiation absorbed by the receiver tubes, W
$Rowshadow$	Shadow performance factor
SFa	Fraction of the solar field that is operable and tracking the sun
$t_{components,cold}$	Time of operation per day of the prescribed HVAC components during cold months, s
$t_{components,hot}$	Time of operation per day of the prescribed HVAC components during cold months, s
w	Hour angle, deg
W	Collector aperture width, m
δ	Declination angle, deg
ϕ	Latitude location of the solar plant
θ	Angle of incidence of the sun irradiation, deg
θ_z	Zenith angle, deg
$\eta_{electrical}$	Electrical efficiency
η_{field}	Field efficiency
η_{HCE}	HCE efficiency
$\eta_{storage}$	Efficiency of the solar energy storage system
$\eta_{thermal}$	Thermal efficiency

colored absorber plate carrying the pipes where the fluid circulates. However, the concentrating solar energy systems, such as Dish systems use parabolic reflectors in the shape of a dish to focus the sun's rays onto a dish-mounted receiver at its focal point [16]. In the receiver, a heat-transfer medium takes over the solar energy and transfers it to the power conversion system mounted in one unit together with the receiver (e.g. receiver/Stirling engine generator unit) or at the ground. On the other hand, the another solar energy systems, namely, Trough systems [17] use linear concentrators of parabolic shape with highly reflective surfaces, which can be turned in angular movements towards the sun position and concentrate the radiation onto a long-line receiving absorber tube. The absorbed solar energy is transferred by a working fluid piped to a conventional power conversion system. The used power conversion systems are based on the conventional Rankin-cycle/steam turbine generator or on the combined cycle (gas turbine with bottoming steam turbine).

Even though, Heating, Ventilating and Air Conditioning systems (HVAC) vary in their needs from one place to another, they are of extreme necessity in Middle East. Such systems involve many mechanical and electrical components that require a considerable and continuous supply of energy. In this context, the present work suggests an innovative design that permits to employ the

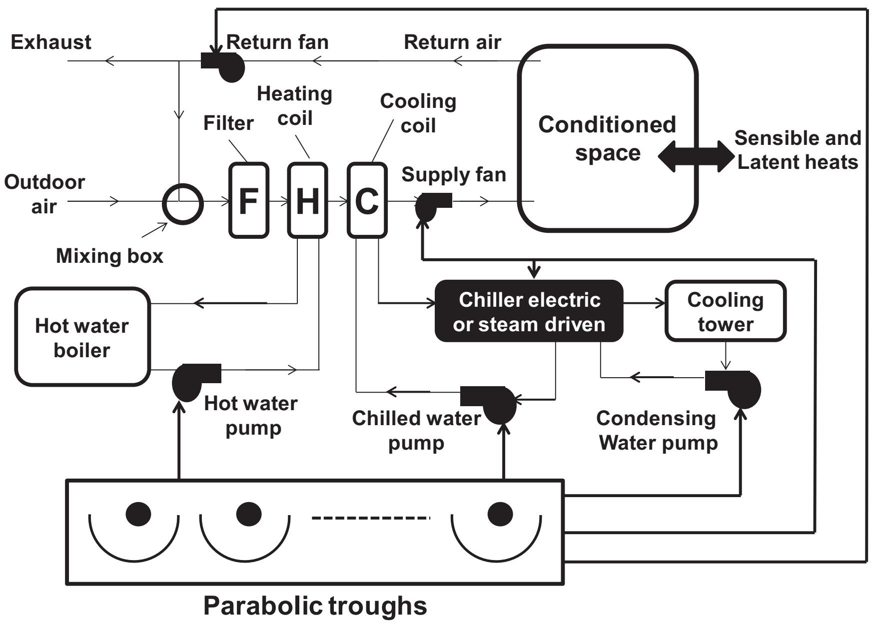

Fig. 1. Schematic of the complete air conditioning process of an All-air system.