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Comparison of swimming pools alternative passive and active heating systems based on renewable energy sources in Southern Europe

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A B S T R A C T

This article examines different passive and active heating systems for swimming pools. The passive systems introduced in this article are:

* The swimming pools' enclosure.
* The placement of floating insulating covers on the pools' surfaces whenever they are not used.

The examined active systems in this article are:

* A biomass heater.
* A biomass heater and solar collectors combi-system.
* Vertical geothermal heat exchangers (GHE) co-operating with geothermal heat pumps (GHP).

The methodology employed for the introduced systems' evaluation is the arithmetic computational simulation of the swimming pools' annual heating, using annual time series of averaged hourly values for the available solar radiation and the calculated pools' thermal power demand (heating loads). The dimensioning of the active systems aims at the maximisation of the heating production from R.E.S. (renewable energy sources). and the optimisation of the corresponding investments' economic indexes.

The examined systems are evaluated technically and economically versus fundamental criteria. It is proved that significant reduction of the heating loads is achieved with the introduced passive systems. The reduced swimming pools' heating loads can be successfully covered by the proposed R.E.S. active systems. The fossil fuels consumption is eliminated. The corresponding investments' payback periods can be lower than 5 years.

1. Introduction

1.1. Setting the problem

Heating of swimming pools constitutes an energy consumable procedure. So far, most swimming pools are heated using liquid fossil fuels, mainly diesel oil, burnt in conventional diesel oil burners. As long as diesel oil was relatively cheap (until the late ′90s), the cost of swimming pools heating was affordable by most Municipalities or National Sports Secretaries in charge. However, the continuously rising fossil fuel prices during the last decade led to considerable increase of the swimming pools' heating cost. This fact, combined with the economic crisis held in Southern Europe since 2008, caused the closing of several Municipal or National swimming pools in Southern Europe. Drastic measures for the reduction of the swimming pools' heating cost are required to enable their opening again. Such measures can be the substitution of the conventional heating technologies with passive and active heating systems, based on Renewable Energy Sources (R.E.S.).

The perspective of the swimming pools' heating using R.E.S. systems, emerged above by pure economic parameters, is further strengthened by the generally admitted necessity for the reduction of the fossil fuels' global consumption, imposed by the available reserves exhaustion and environmental protection reasons.

Gathering the above economic, energy saving and environment conservation terms, it is justified that, maybe more than ever, the introduction of alternative swimming pools' heating technologies, based on cheap and abundant R.E.S., emerges as an imperative necessity, on the one hand, and, on the other, as a redemptive solution.

1.2. Previous research

The heating of swimming pools using alternative passive or active heating technologies has been widely studied in previous

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Notation

η_G	the current overall efficiency of the solar collectors
η_{G0}	the overall efficiency of the solar collectors for $t_m - t_a = 0$
t_{in}	the incoming water temperature in solar collectors
t_{out}	the outcoming water temperature in solar collectors
t_m	the averaged water temperature is solar collectors: $t_m = (t_{in} + t_{out})/2$
$\overline{U}_G$	the averaged U-value regarding the heat transfer from solar collectors to the ambient environment
G	the incident solar radiation
Q_L	the swimming pools' current total heating load (power)
Q_s	the currently available thermal power produced by the solar collectors
Q_b	the biomass heater produced thermal power
C_{tot}	the heating system's total annual production cost
E_{th}	the total annual thermal energy production (thermal load)
c_{th}	the heating system's total annual production specific cost ($c_{th} = C_{tot}/E_{th}$)
$C_{O\&M}$	the heating system's annual operation and maintenance cost
$C_{S\text{-}U}$	the heating system's total set-up cost
T_{LP}	life period
C_{fuel}	the fuels consumption cost for the swimming pools' heating
C_{maint}	the heating system's annual maintenance cost

articles. The research of the existing bibliography revealed that mainly two different approaches have been examined:

i. The exploitation of incident solar radiation for the swimming pools' heating. Several ideas on this topic have been proposed since the early ′60s. The most favourable one, met in the first studies, is a transparent or black plastic floating cover, put on the water surface whenever the swimming pool is not used [1–3]. Similar ideas are found in relevant articles until the early ′80s [4–6]. With the invention of solar collectors, the investigation focuses on thermal energy active production. In the middle ′70s fundamental issues on flat-plate solar collectors' installation are examined, such as the optimum installation tilt [7] or the effect of off-south orientation on the collector's performance [8]. In the middle eighties high-efficiency solar collectors are firstly proposed for swimming pools heating, mainly in warm climates, such as the Mediterranean basin [9] or India [10]. The introduction of high-efficiency flat-plate solar collectors enabled the heating of indoor swimming pools exclusively [11,12]. As the solar collectors' efficiency is improved, they are gradually proposed for swimming pools' heating in colder climates, such as in Western Europe [13]. In the early and middle ′90s the scientists use specialized software (the most popular seems to be TRNSYS) to study in detail the performance of solar passive or active systems, employed for swimming pools' heating [14–17]. From 2000 and on, the research on the swimming pools' heating is focused on the optimization of the performance of the examined solar systems. Advanced software tools and validated models are developed [18–21] and sophisticated techniques from informatics, such as neural networks, are employed for the prediction of the availability of solar radiation and the performance of the examined solar systems [22].
ii. The introduction of heat recovery systems from air compressors used in cooling production devices (air conditioners, refrigerators etc) [23–27]. This simple and ingenious technique can be applied in cases where significant amounts of thermal energy are produced as a by-product mainly by cooling production devices, close to swimming pools (e.g. hotels). In these cases, the available thermal energy can be provided through common heat exchangers for the swimming pools heating, instead of disposing it in the ambient environment. In this way, except the direct benefit of the swimming pools' heating, the cooling devices' Energy Efficiency Ratio (E.E.R.) is considerably increased, leading to primary energy further saving.

It is worthy of mentioning that during the last five decades the scientific community has focused on the above two technologies for swimming pools' heating, namely the exploitation of solar radiation and the introduction of heat recovery techniques. There is only one article, published in 2013, that examines the co-operation of a heat pump with a Geothermal Heat Exchanger (GHE) for swimming pools' heating [28], although this technology may be proved the most promising one in geographical regions with low available solar radiation.

1.3. *The scope of the present article*

The ultimate scope of this article is to indicate the technical and economic feasibility for the introduction of R.E.S. based passive and active systems for swimming pools' heating in the basin of Mediterranean and, generally, in other geographical regions with similar climatic conditions. The introduction of the examined systems for swimming pools' heating will enable the substitution of the currently employed liquid exhaustible fossil fuels, contributing, thus, significantly, to the global effort for conventional energy reserves' saving and for the green house gases emissions' reduction.

For this purpose, two passive systems are introduced in the existing pools:

- The swimming pools' enclosure.
- The placement of floating insulating covers on the pools' surfaces whenever the pools are not used.

The introduced passive systems aim at the minimisation of the swimming pools' heating loads and the maximisation of the solar radiation thermal gains.

Additionally, three alternative active systems for swimming pools' heating are investigated:

i. A common biomass heater.
ii. A combi-system of a biomass heater and selective coating solar collectors.
iii. A geothermal heat pump (GHP) co-operating with vertical GHE.

1.4. *Methodology employed*

For the comparison and the evaluation of the proposed passive and active systems, two existing outdoor swimming pools, currently heated with a conventional diesel oil burner and located in a small town (Arkalochori) in central Crete in Greece, are used as a case study. The first swimming pool is an olympic size one (50 × 20 m), while the second one is a small training swimming pool (25 × 6 m).

The methodology employed for the above mentioned passive and active systems' evaluation is the arithmetic computational