

Evaluation of the Potential of a Solar Louvre Collector System for Building Heating and Cooling by Means of Computer Simulation

Ana I. Palmero-Marrero, Armando C. Oliveira*

Faculty of Engineering, University of Porto (New Energy Tec. Unit)

Rua Dr. Roberto Frias, 4200-465 Porto, Portugal

*E-mail: acoliv@fe.up.pt

ABSTRACT: In this work, the application of a solar louvre collector system for building heating and cooling is studied. The system operates either in cooling mode, coupled to a water-fired absorption chiller, or in heating mode, when hot water is circulated through the slab (radiant heating). A mono-zone building, with an area of 100 m², was used as a case study, in order to assess the performance in both operating modes. The system was modelled with the TRNSYS simulation program, under the climatic conditions of Portugal.

Results show that the application of solar louvre collectors to building heating and cooling is viable and interesting, leading to energy and emissions savings when compared with conventional solutions. Interesting simple payback times were calculated for the system, both for heating alone and cooling/heating modes.

Keywords: building, cooling and heating, solar collector, louvre, TRNSYS.

NOMENCLATURE

A	area [m ²]
C	cost [€]
f	solar fraction [-]
F	collector heat removal factor [-] (based on collector average fluid temperature)
H	height [m]
l, L	length [m]
Q	monthly thermal energy [J, kWh]
T	temperature [°C]
U_L	collector heat loss coefficient [W/m ² /K]

Greek letters

η	efficiency [-]
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$(\tau\alpha)_n$	collector transmittance - absorptance product for normal incidence [-]
χ	louvre inclination angle [°]

Subscripts

air	air
aux	auxiliary
col	collector (louvre)
e	collector edge to façade
gas	natural gas
inc	incident
inv	investment
sol	solar
$usef$	useful
w	window

1. INTRODUCTION

Solar louvre collectors represent a new way of integrating solar energy into buildings. Different collectors have been developed, and applications to domestic water heating systems, [1], and cooling of buildings, [2], have been studied. Applications to domestic hot water systems are economically interesting, as they can be used throughout the year, [1].

However, for office or commercial buildings the requirements for hot water are usually small. For this type of buildings, space conditioning applications make more sense. For space conditioning applications to be economically viable, it is necessary to maximize the utilization period. Therefore, it is important to have a system operating both in cooling and heating modes, so that all year round operation is possible.

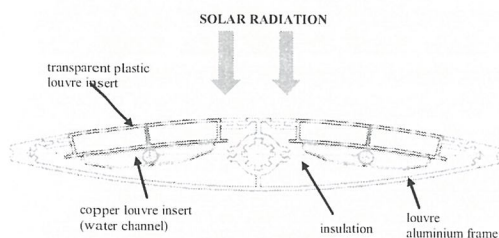


Figure 1: Section of solar louvre collector.

The solar louvre collector used in this study is shown schematically in Fig.1. It was integrated in an existing aluminium built louvre, with a width of 25 cm. The louvre solar collection (transparent) area is equal to 60% of the louvre area. The louvre collector efficiency has been assessed by modelling, [1], and experiment, [3]. Efficiency parameters considered are: $F(\tau\alpha)_n=0.47$ and $FU_L=3.1 \text{ W/m}^2/\text{K}$. The first parameter corresponds to the collector optical efficiency (maximum efficiency), and the second to the collector heat loss coefficient.

2. DESCRIPTION OF THE SOLAR HEATING/COOLING SYSTEM AND BUILDING

The system may operate under heating or cooling modes. During the cold season it operates in heating mode. For cooling (hot season), the collectors and storage are coupled to a water-fired absorption chiller, as already presented in [2].

2.1 Solar heating system

The solar heating system is illustrated in Fig.2. It includes the solar louvre collectors, a storage tank, an auxiliary boiler, the control system and hot water distribution to the building, which is done with floor heating (tubes under the floor).

The louvre collectors are placed as indicated in Fig.3. As discussed for the cooling season in [2], a total of 5 louvres were considered for optimum insolation in Winter and shading in Summer, for the climatic conditions of Lisbon (Portugal).

The same mono-zone building used in [2] was considered for system modelling, with a floor area of 100 m^2 . The external walls and slabs are made of brick (24 cm), with 10 cm outside insulation. All windows have double glazing (with clear glass). Hot water tubes are located in the concrete slab, with the characteristics indicated in Table I.

The louvre collector width along the south façade was varied, as well as the window width, which is equal. Like in [2], three different cases were considered, with collector and window widths of 50, 75 and 100% of the façade dimension (20 m). These correspond to louvre areas between 12.5 and 25 m^2 , and window areas between 15 and 30 m^2 .

2.2 Solar cooling system

The cooling system consists of solar louvre collectors, storage tank, an auxiliary boiler, an absorption chiller and a water-air heat exchanger - see [2]. The absorption chiller has a nominal cooling capacity of 10 kW and is driven by hot water coming from the storage tank.

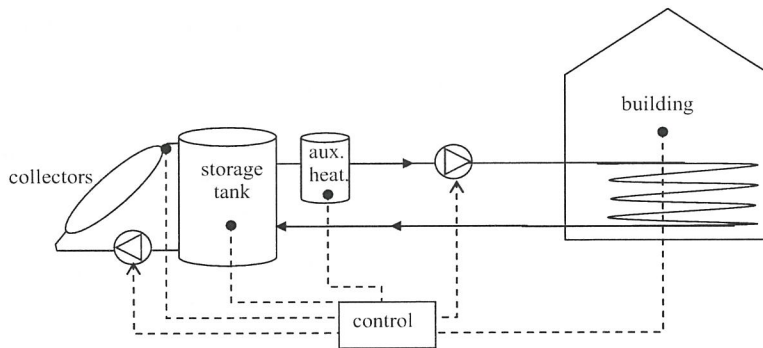


Figure 2: Schematic representation of the heating system.

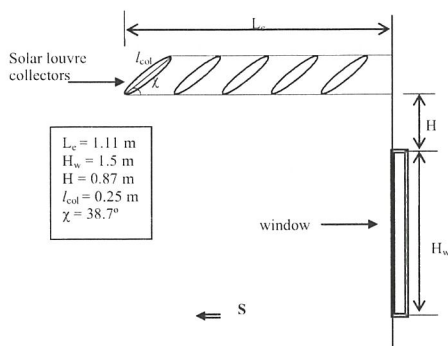


Figure 3: Louvre collector and window dimensions.

Table I: Dimensions and characteristics of the floor heating tubes.

Properties	Values
Tube spacing (centre to centre)	20 cm
External diameter	2 cm
Wall thickness	0.2 cm
Total length	100 m
Conductivity	$0.27 \text{ Wm}^{-1}\text{K}^{-1}$

3. MODELLING OF SYSTEM COMPONENTS FOR HEATING MODE

The system and its components were modelled with the TRNSYS simulation program version 16, [4]. The main characteristics of the components chosen to represent the heating system, are detailed in the following paragraphs.

For the solar (louvre) collectors, a TRNSYS type 1 component was used – flat-plate collector. The two efficiency parameters considered were: $F(\tau\alpha)_n=0.47$ and $FU_L=3.1 \text{ W/m}^2\text{K}$, with a water flow rate of 0.02 kg/s/m^2 .

The storage tank was modelled with a TRNSYS type 4 component, which does not include thermal stratification. A storage volume equal to $50A_{col}$ (in litres) was considered. A control system activates the circulation pump, so that water is circulated in the collectors only when the outlet temperature is higher than the storage temperature.

The auxiliary heater is activated when the storage temperature is lower than 30°C (set-point for floor inlet temperature) and has an input power of 2 kW. It is a TRNSYS type 6 component.

The control of the floor system aims to maintain the indoor space within the comfort zone. It activates the circulation pump for carrying hot water from the solar storage to the floor system, with a water flow rate of 0.14 kg/s . The pump works when the difference between supplied hot water temperature and indoor air temperature is greater than 5°C , stopping when the air temperature reaches 23°C .

A mono-zone building model (type 56) was used. Besides the definition of geometry and materials, other input data were: infiltration rate of 1 air change per hour, internal gains corresponding to 4

persons (between 6 pm and 8 am) and artificial lighting of 5 W/m² (between 6-8 am and 6-11 pm).

4. SIMULATION RESULTS

Simulation results were obtained using the climatic conditions of Lisbon - Portugal. The climatic data were obtained through Meteonorm, provided by TRNSYS.

The study was extended throughout a whole year: for the heating season, from November to April and for the cooling season, from May to October. For the cooling season results were already shown in [2]: comfortable conditions were assured all the time, with indoor temperature always below 26°C. Results for the heating season will be shown next.

Fig. 4 shows indoor air temperature results for two scenarios: with the floor heating system ($A_{col}=12.5 \text{ m}^2$) and without any heating system. The results for the larger area (25 m²) are shown in Fig. 5.

As can be seen, with floor heating, indoor temperature is between 21°C and 26°C for the lower area in the period studied (from November to April), while without heating it would be lower than 18°C in a large extent of the time. Fig. 5 shows similar results. For all cases, the average difference between indoor air temperature with and without heating system is approximately equal to 5°C.

Fig. 6 shows indoor air temperature, floor temperature and operative temperature during January, for the lower window and louvre areas. The operative temperature is a function of both air and surface temperatures in the building. This temperature is used most often in thermal comfort analyses. In this case, operative temperature varies between 21.5°C and 25.6°C. According to ISO thermal comfort standards, [5], the operative temperature for acceptable comfort levels should be between 22 and 26°C (with light clothes and light activity). The system under

analysis is therefore capable of providing comfortable conditions in the building. When no heating system is used, no comfortable conditions are achieved during most of the time.

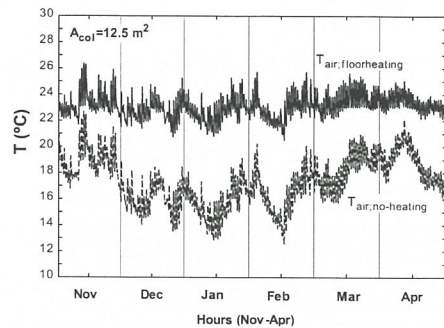


Figure 4: Indoor air temperatures with and without heating system – lower window and louvre areas.

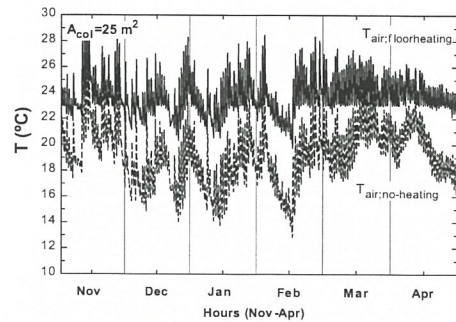


Figure 5: Indoor air temperatures with and without heating system – higher areas.

Different energy ratios were calculated to assess system thermal performance during the heating season: the monthly average solar fraction (f) and the monthly average solar energy efficiency (η_{sol}). They are defined by:

$$f = \frac{Q_{sol, usef}}{Q_{load}} = 1 - \frac{Q_{aux}}{Q_{load}} \quad (1)$$

$$\eta_{sol} = \frac{Q_{sol, usef}}{Q_{sol inc}} = \frac{Q_{load} - Q_{aux}}{Q_{sol inc}} \quad (2)$$

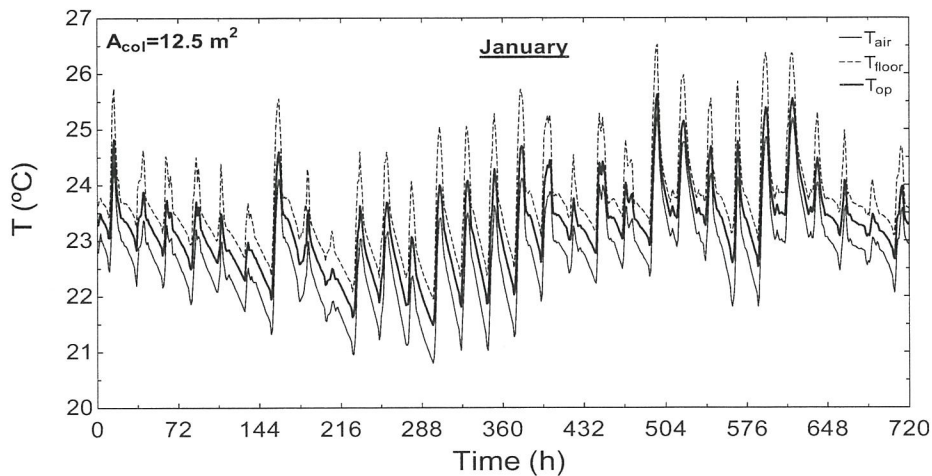


Figure 7: Indoor air temperature, floor temperature and operative temperature during January, for the lower window and louvre areas.

The building heating load during the simulation period was estimated by calculating energy requirements for conventional heating, with an indoor constant temperature equal to the same average value. For the lowest and highest window areas, average indoor air temperatures are equal to 22.8°C and 23.74°C, respectively. The corresponding heat loads are 15882 MJ and 16237 MJ.

Table II shows energy performance results for different months, for the lower area case ($A_{col}=12.5 \text{ m}^2$). Average seasonal solar fraction (f), which represents the percentage of heat load that is met by solar energy, is equal to 0.53. Average seasonal solar energy efficiency (η_{sol}), representing the fraction of incident solar radiation (on the louvre total area) that is converted to useful heating energy, is equal to 25%. For higher collector areas, f increases and η_{sol} decreases – see Table III. Note that good solar fraction values are obtained, although solar radiation levels are fairly low in Winter. This is due to the low water temperature needed for the floor heating system (30°C).

As Table III shows, energy savings for the heating season can reach 81%, for the higher collector area (25 m²).

Table II: Energy performance results for the heating season and $A_{col}=12.5 \text{ m}^2$.

Month	Q_{load} (MJ)	Q_{aux} (MJ)	f	η_{sol}
NOV	2214	1129	0.49	0.24
DEC	3130	2028	0.35	0.25
JAN	3229	1972	0.39	0.26
FEB	2659	1422	0.46	0.25
MAR	2443	396	0.44	0.25
APR	2207	477	0.78	0.23
SEASON	15882	7424	0.53	0.25

Table III: Energy savings for the heating season, with different louvre areas.

A_{col} (m ²)	Q_{aux} (MJ/year)	f (-)	savings (€/year)	savings (%)
12.5	7424	0.53	166	53
18.75	4542	0.71	225	71
25.0	3086	0.81	262	81

Energy savings were calculated by considering the reference energy costs for a floor heating system operating without solar energy input – natural gas heating only. Taking into account the cost of natural gas for domestic consumers (presently $C_{gas}=0.0717 \text{ €/kWh}$ in Portugal, including a burning efficiency of 85%), the annual savings were calculated with:

$$savings = Q_{load} \cdot f \cdot C_{gas} \quad (3)$$

A simple payback period economic analysis was carried out, although this type of analysis is frequently misleading regarding the interest of renewable energy systems: a more complete analysis should include emissions and risk costs, [6]. The payback period can be calculated by considering the initial cost (C_{inv}) for a given collector area, annual savings, interest rate and inflation rate. C_{inv} was calculated from the cost of existing louvres and the estimated cost for the solar louvre collector: an additional cost of 166.7 €/m², [1]. It is considered that normal louvres would be used for summer shading, and therefore only the additional collector cost is taken into account. If the reference heating system considered is a floor heating system with water heated by natural gas only, then the additional investment corresponds only to the additional louvre collectors' cost. The simple payback period for heating alone (no cooling system considered) would be 12.5 years for a 12.5 m² collector area, increasing for higher areas. This is an interesting value, as it is lower than system (collector) life expectancy.

If both heating and cooling modes are taken into account, the additional cost of a 10 kW absorption chiller must be considered in the initial cost (investment). The additional cost – compared to the conventional compression system – may be considered as around 5000 €. Note that this value is expected to drop in the future, as small capacity cooling chillers increase their market share. In this case, the payback periods would be higher than 30 years for all collector areas. Payback periods increase because of the chiller high initial cost and because energy savings for cooling are not as significant as those for heating. If the benefits regarding emissions and increasing costs for fossil fuels are taken into account, the system is definitely interesting, both for heating and cooling.

5. CONCLUSION

Results show that the application of solar louvre collectors to building heating and cooling is viable and interesting, leading to energy and emissions savings when compared with conventional solutions. The consideration of both heating and cooling modes leads to economically interesting simple payback periods for the system.

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