Journal of Fundamental and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

Research Article

NUMERICAL ANALYSIS OF AN INTEGRATED SOLAR COOLING AND HEATING SYSTEM IN INDIVIDUAL HOUSE IN DIFFERENT ALGERIAN CLIMATES

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Received: 25 September 2020 / Accepted: 21 February 2021 / Published online: 01 May 2021

ABSTRACT

There is a growing concern about energy use in Algeria. As fast as, building programs developed and living conditions improved, the building sector makes big focus as a major energy end-user. Main energy needs in buildings are due to heating and/or cooling, depending on local climatic conditions and type of building. In this paper, the primary aim is to analyze two aspects – heating load, and cooling load of an individual house energy consumption in the major climatic zones in Algeria. The individual house uses heating and cooling solar system. The system performance is simulated using TRNsys program. This solar heating and cooling system incorporates between 89 m^2 and 170 m^2 of flat plate double glazed solar collectors, which provide solar energy contribution during both the heating and cooling seasons; between 13.28 kW and 25.11 kW single effect, water– lithium bromide (H_2O/LiBr) absorption chiller. This system is the smallest solar heating and cooling system in the world.

Keywords: individual house; solar heating and cooling; solar energy; TRNsys; climatic.

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doi: http://dx.doi.org/10.43 14/jfas.v13i2.12

1. INTRODUCTION

It is well known that a cold house is less airproof in cold times incurring higher bills of heating and cooling. For instance, a number of integrated studies established by the national center building (CNERIB), shows that the costs bills of energy for one flat house in Algeria is very high and can reach 630 MJ/m^2. The energy consumed by buildings counts for 40% of the total energy used.

Actually, the major dilemma is how to come up with new solutions to solve the problem of energy exploitation in buildings with in mind energy mastering and environment protection. Today, solar energy is one ideal alternative to replace non-renewable energies so that buildings consume less and may even become energy producers.

There are four steps of solar thermal applications worldwide [1]:

(1) Hot water supply usually 2-4 m^2 with 150-300 L per family. For example, in China there were about 90,000,000 m^2 cumulative installed aperture solar collectors in use in 2008;

(2) Solar energy for hot water supply and heating in winter through one whole year. A family may need 20-50 m^2 solar collector floor radiation heating in winter. Such modules are more and more common in Germany and other European countries.

(3) Solar cooling in summer, which is based on the integrated solar collectors upon building roofs, in which a 5-10 kW cooling is welcome for residential applications. Such demonstrations have been well accepted in Europe [2,3] where many new start-up companies have joined the marketing process;

(4) Integrated solar energy systems for a building, to provide heating in winter, cooling in summer, hot water supply throughout the year and also solar enhanced natural ventilation in spring and autumn, have been well considered [4].

The basic concept of solar heating and cooling systems consists in exploiting solar radiation to provide space heating or cooling as required. Such systems form a very promising technology, especially in summer operation mode, when the cooling demand is associated to a long overheating solar period. The research in this direction attempts to match solar thermal technologies with thermally driven cooling equipment like absorption, adsorption and desiccant chillers. A comprehensive review of these technologies is given in several references [5-9]

The solar heating and cooling systems may significantly contribute to achieve the energy savings, emissions reductions and to increase the use of renewable energy sources. In fact, the energy consumption of buildings contributes significantly to the overall energy demand. Presently in Algeria, this consumption is mainly due to the cooling demand, so it is expected to grow significantly in the next years as a consequence of the dramatic increase of the air conditioning market.

The aim of this paper is to investigate, by the means a simulation method [**TRNsys]** [10], the energy demands (for heating/cooling loads) in an individual house using solar technologies under the seven major climatic regions [11]. This research has proved the feasibility of this technology and helped to promote its widespread use. It also allowed to answer the question of how solar energy can be used in supplying energy for the operation of a building.

2. RESULTS AND DISCUSSION

2.1. Weather Data

Algeria is a large country with an area of about 2.3 million km^2. The parametric study is done for different climatic zones of Algeria. In terms of the thermal design of buildings, there are seven major climatic regions fig. 1, namely; Mediterranean hot and humid summer/ mild winter, hot summer/ cold winter, hot summer/ mild winter, mild summer and cold winter, hot summer/ cold winter, and dry hot summer/ mild winter in Algeria [11].

The present study involves identifying major climatic zones and selecting the representative cities, developing the weather databases, individual house, and site measurements and building energy simulation using TRNsys (TMY). The typical meteorological year (TMY) method developed by the Sandia National Laboratories in the United States is among the most widely adopted methods for the determination of typical weather years [12].

This Selection is based on statistical analysis and evaluation of climatic variables, namely; temperature over 10 years period (2000-2009) and global solar radiation (Table 1) recorded over a period of 20 years (1991-2010).

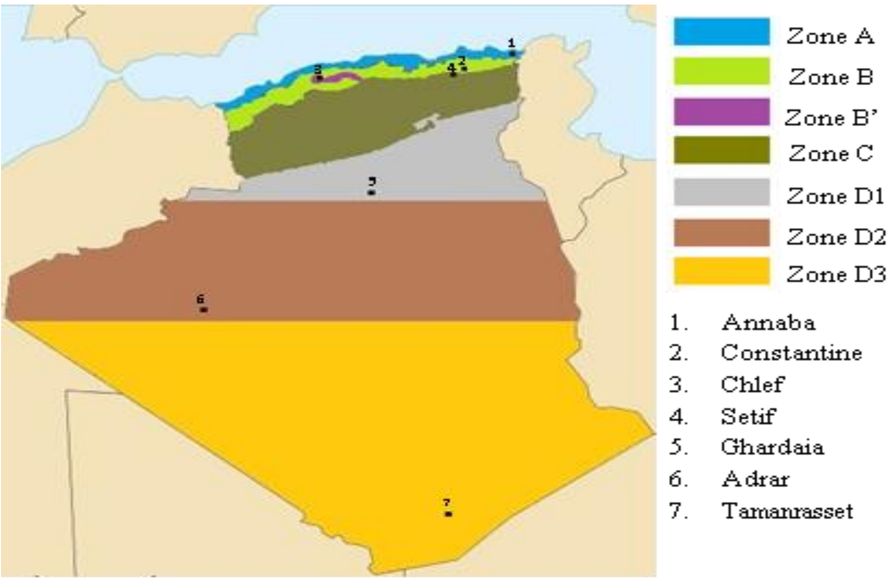


Fig. 1. Geographical distribution of the seven major climates and the seven cities.

Table 1. Climate data and latitudes for seven cities

Location	Latitude (N°)	Annual average Temperature (°C)	Yearly global solar radiation (kWh/m^2)
Annaba	36.8	17.5	1743
Constantine	36.3	15.9	1873
Chlef	36.2	18.8	1882
Setif	36.1	14.7	1909
Ghardaia	32.4	21.6	2209
Adrar	27.8	24.6	2296
Tamanrasset	22.8	22.9	2382

2.2. Weather Data

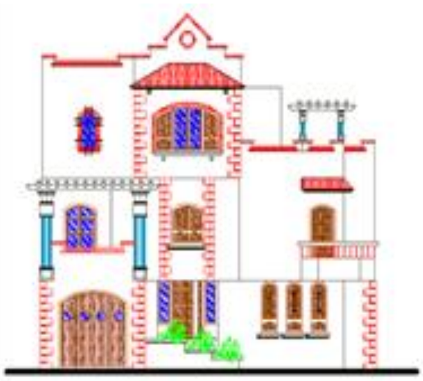
If a building is well adapted to the climate, it can protect its inhabitants against the extreme outdoors conditions, and create thermal indoor comfortable conditions. Unfortunately, today designs are not appropriate and energy is widely used for creating comfort. Since, two decades and due an authentic awareness of energy saving matters has become a major issue and generated various wordwide designs proposals and options [13].

The building was simulated in TRNSYS environment, using the TRNBUILD application, included in TRNSYS package. The transient thermal behavior both of the individual house components and the complete system was studied using the TRNSYS simulation software. The TRNSYS routines (Types) and the values of the various parameters used for the simulations are summarized in Table 2.

The individual house consisting of ground floor and two floors (Fig. 2, 3 and 4). The individual house study is a multi-zone structure, modeling in TRNSYS, led to define 14 thermal zones.

Table 2. Simulation characteristics of the building model

Individual house	
Dimension(for each floor)	15×12×2.86 m^3
Total window area	11.52 m^2
Heating set -point	20°C
Cooling set- point	26°C
Ventilation (incl. infiltration)	0.5 h^{-1}
Internal heat gain	24.45MWh/an
Components	**K (W/m.°C)**
External wall	0.616
Internal wall	2.23
Window	1.45
External door	2.5
Floor	3.056
Roof	0.665



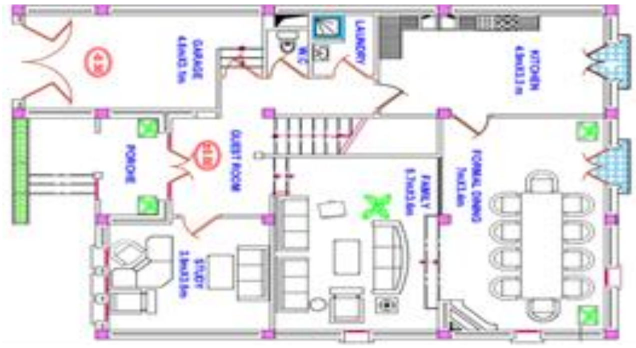


Fig. 2. Ground floor cuts

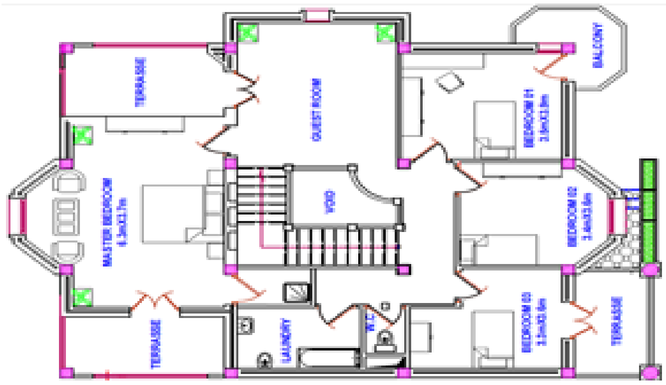


Fig. 3. 1st floor cuts

Fig. 4. 2nd floor cuts

2.3. Heating and Cooling Loads of Building

Climate is an important factor that can affect not only the physical aspects of human's beings but also their habits and living styles. Indoor conditions are greatly affected by the outdoor climate [14]. Hourly heating and cooling loads were calculated by TRNsys.

The heating season can be defined by the week with an average temperature below the temperature of not heating 15°C.The temperature of comfort inside the room is generally fixed at 20 °C. It is considered that the free solar contribution can compensate for the losses between the limit of heating (15°C) and the temperature of the buildings (20 °C).

Using weather files giving hourly outside temperature over the year in the cities of Annaba, Constantine, Chlef, Setif, Ghardaia, Adrar, and Tamanrasset, it is possible to determine the heating season corresponding to each of these regions (these seven climatic zones represent a panel of the Algerian climates).

The fig. 5 shows the average monthly temperatures of different regions mentioned. The heating seasons for different climate zones are estimated:

- For Annaba 3720 h from 26/11 to 30/04 (end of November to the end of April).
- For Constantine 4368 h from 31/10 to 30/04 (end of November to the end of April).
- For Chlef 3696 h from 01/11 to 04/04 (beginning of November to the beginning of April).
- For Setif 4608 h from 22/10 to 02/05 (mid-October to the beginning of Mai).
- For Ghardaia 2208 h from 26/11 to 26/02 (end of November to the end of February).
- For Adrar 1536 h from 26/11 To 29/01 (end of November to the end of January)
- For Tamanrasset: 1752 h from 05/12 to 16/02 (mid-December to mid-February).

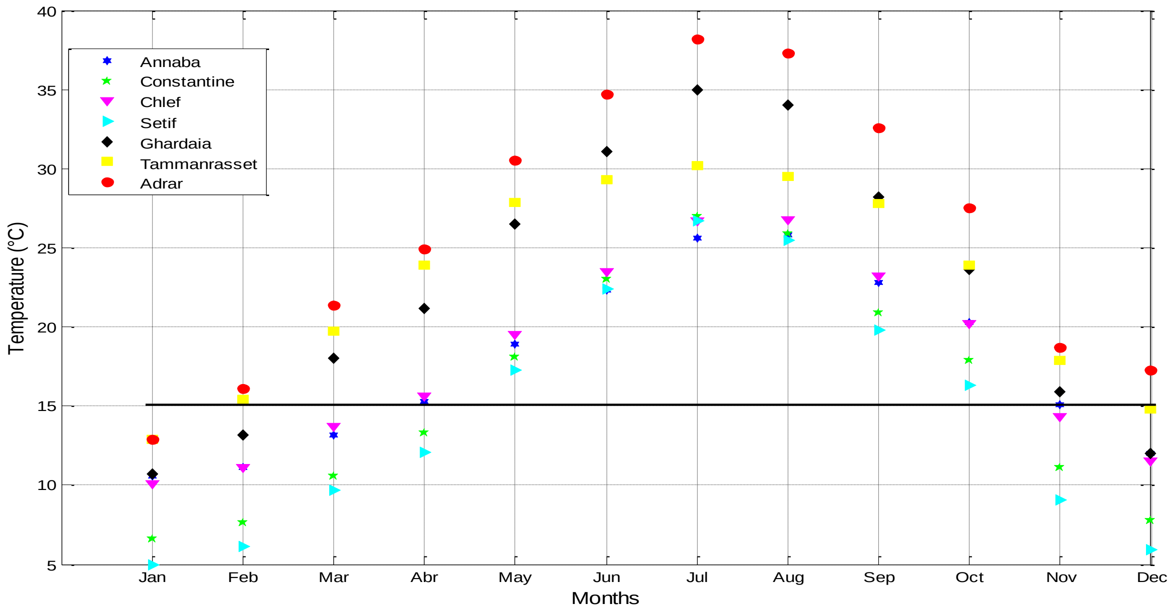


Fig. 5. Monthly average Temperature (°C)

The Fig.6 shows the need of energy in the individual house. We notice the influence of regional climate on the annual energy exploitation. For the city of Annaba (mild). The need of heating nearly in winter by (9590 kWh), compared to (14392 kWh) in summer. As for the city of Constantine (cold winter), The need of energy looks closer in heating and cooling (15971 kWh)/ (14156 kWh). The city of Chlef (hot summer/ warm winter, we notice that cooling is more than heating in need going almost to 51%. In Setif, heating is almost 31% compared to cooling. Concerning desert areas within climatological ranking, we notice that cooling counterbalances frequently compared to heating, that represents 18 %, 9%, and 10% successively in Ghardaia, Adrar and Tamanrasset (hot summer)

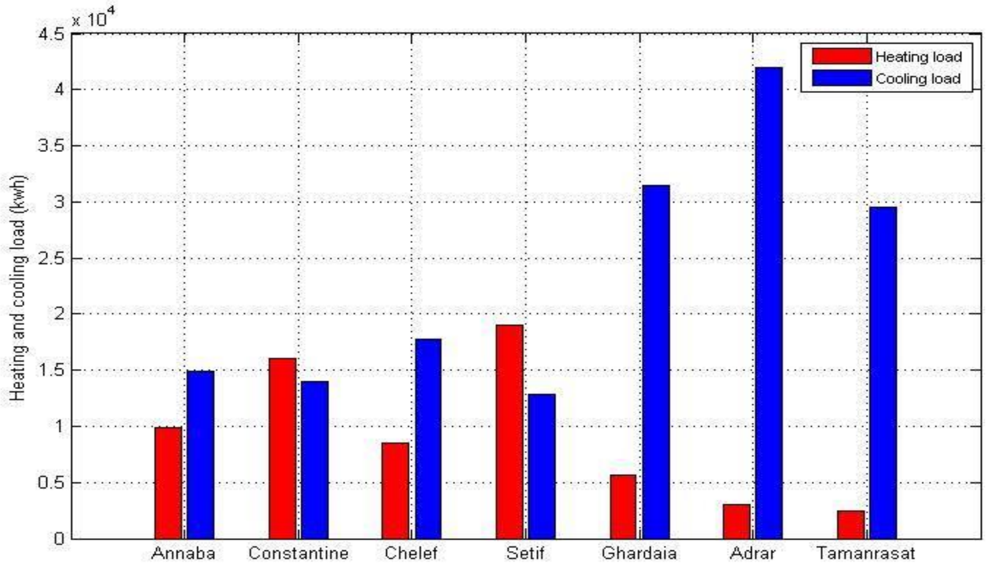


Fig. 6. Building's annually heating and cooling load in the seven cities

Fig. 7 shows the monthly heating and cooling needs. Where we can determine hottest and coldest months for each area we want to focus on in study, proving the diversity of climate in Algeria.

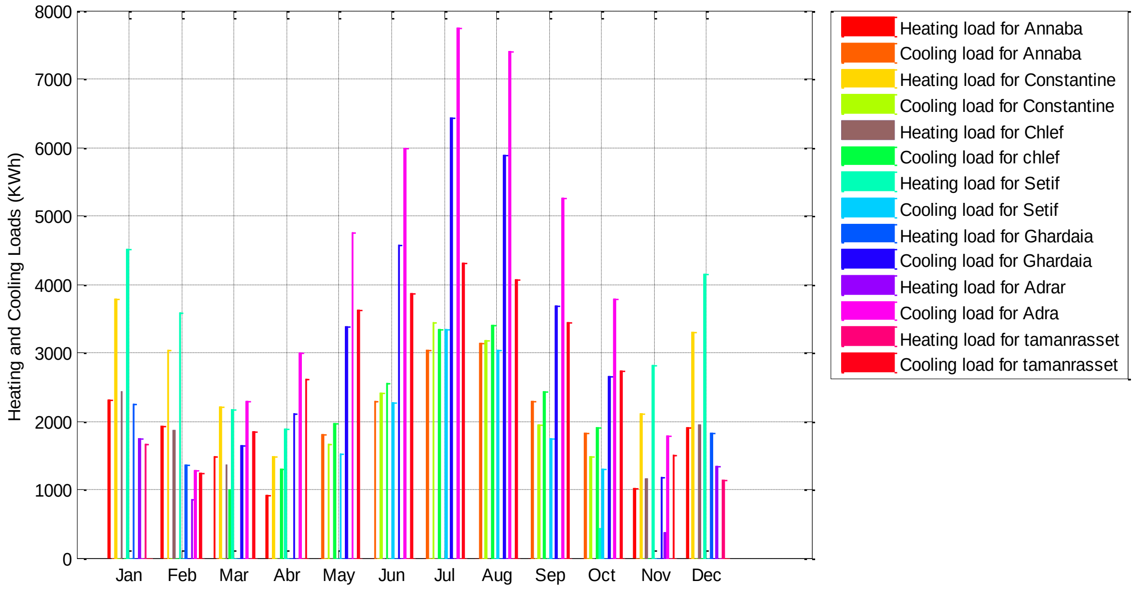


Fig. 7. Building monthly heating and cooling load in the seven cities

2.4. Description of the Solar System

For the integrated solar system configuration, both heating and cooling options were considered. The most common solutions were adopted with distribution of hot water or cold water to the load. The complete system includes the solar system (flat plate collectors and storage tank), an auxiliary heating system, the absorption chiller with the cooling tower, the control system, and building. The following sections present the main system components in detail Table 4.

Fig. 8 indicates the schematic diagram of a single-effect absorption chiller adopted by [15]. LiBr solution is used as the absorption media and water becomes the refrigerant. By applying the energy and mass balance in the generator. Firstly, the solar energy received by the solar collectors is converted into heat energy that heats up the water (heat-transfer fluid) circulates between the thermal storage tank and collectors. The high-temperature water in the tank is also circulating in the generator to increase the temperature of the lithium bromide (LiBr) solution and drive the water vapor out of the solution leaving a strong solution, containing more LiBr in the LiBr-H_2O solution. The superheated vapor produced in the generator is cooled and condensed in the condenser to a saturated liquid state. This liquid refrigerant (water) is then throttled across the valve into the evaporator, where upon evaporation at low pressure absorbs energy from the water chilled thereby producing the cooling effect required by the individual house. The water refrigerant leaves the evaporator as nearly saturated vapor and flows to the absorber, where it is absorbed in by the solution. At the same time, the strong solution in the generator is returned to the heat exchanger and flows back to the absorber through the expansion valve. The water vapor leaving the evaporator is absorbed in the strong LiBr solution producing an exothermic heat in the absorber, and this heat is then rejected to the cooling water supplied by the cooling tower. This maintains the low pressure and low temperature required in the evaporator. In other word, the required low pressure and temperature in the evaporator is made possible by the absorption process. Afterwards, the dilute LiBr solution at low pressure in the absorber is pumped through the heat exchanger to a higher pressure in the generator. Cooling water from the cooling tower is circulated through the condenser to condense the water vapor and through the absorber to remove the heat of absorption. The function of thermal storage tank is to store the thermal energy collected from solar energy. The hot water from the thermal storage tank is continuously circulating to the generator providing the thermal energy required (the high temperature level needed) by the generator.

Concerning winter period, just reverse the cycle. The condenser fits a role of evaporator and vice versa thanks to 4- way valve.

$$Q_{gen} = m_{hw} \cdot C_{w} \cdot \left(T_{hw,i} - T_{hw,o}\right) \tag{1}$$

The heat and mass transfer in the absorber is determined from

$$Q_{ab} = m_{abw} \cdot C_{w} \cdot \left(T_{abw,o} - T_{cw,i}\right) \tag{2}$$

The modelling methods adopted by Lee CK et al. [16] are used for the condenser and the evaporator. Each coil is divided into maximum three portions corresponding to the different states of the refrigerant (sub-cooled, saturated or superheated) and the complete coil performance is calculated using an iterative approach. In general,

$$Q_{cond} = m_{cw} \cdot C_{w} \cdot \left(T_{cw,o} - T_{cw,i}\right) \tag{3}$$

$$Q_{evp} = m_{ew} \cdot C_{w} \cdot \left(T_{ew,i} - T_{ew,o}\right) \tag{4}$$

$$COP = \frac{Q_{evap}}{Q_{gen}} \tag{5}$$

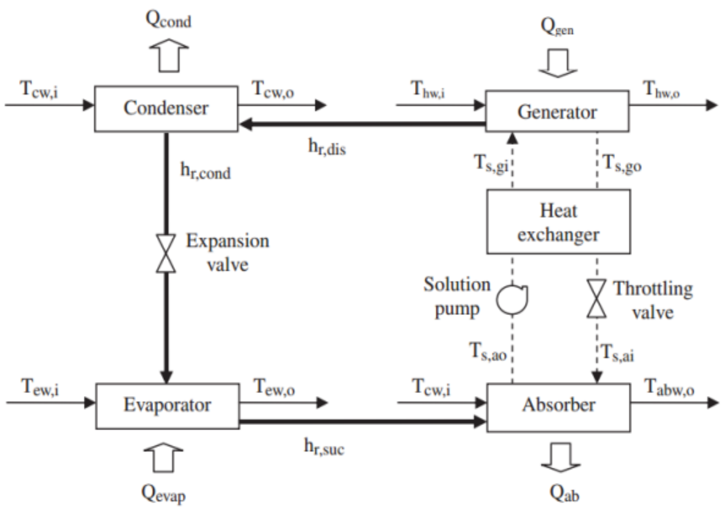


Fig. 8. Schematic diagram of a single-effect absorption chiller

Today almost all solar heating and cooling systems use solar thermal collectors as main solar energy source and employ a thermally driven cooling cycle to cover cooling loads. It is estimated that up to about 1000 systems are installed worldwide [17].

Table 3. Characteristics of building for simulations

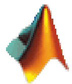
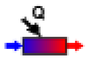
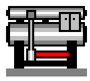
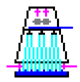
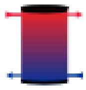
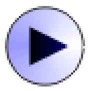
Parameter			
Climatic data TRNSYS Types:109-TMY2)	Weather data for seven Algeria locations	Annaba, Constantine, Chlef, Setif Ghardaia, Adrar and Tamanrasset	 Type109-TMY2
Building models (TRNSYS Types: 56)	Parameters are summarized in Table 2.		 Type56a
Solar collector Flat plate collector	Collector type	Double glazed collectors	
	Specific heat of collector fluid (kJ/kg C)	4.19	 Solar Collector
	Collector total area	between 5 and 10 m^2/kW	
	Collector azimuth	Due South	
	Collector tilt	Closer to the location latitude of each cities	
Auxiliary heating (TRNSYS Types: 6)	Set temperature for auxiliary between 75-87 °C	Natural Gas	 TYPE6
Absorption heat pump (TRNSYS Types: 107)	Water inlet temperature Water outlet temperature Absorber pump: Water flow rate in the absorber	Depending location and cooling/heating load.	 Type107
Cooling tower	Number of tower cells	One cell	 TYPE51a
Hot water storage tank (TRNSYS Types: 4b)	Volume (l)	Depending location and cooling/heating loads.1000 to 1800 l.	 Type4b
Pumps	Two pumps single speed, one for absorption and the other for cooling tower	Depending a flow rate	 Type3b

Fig. 9 shows the global solar radiation and temperature variation on the 21st of December in the seven cities. The cold (Constantine) and severe cold (Setif) zones illustrate much larger seasonal variation than the other cities. Except in the mild zone (Annaba) with the Mediterranean climate. The highest value is received during the day in Tamanrasset

Fig. 10 shows the global solar radiation and temperature variation on the 21st July in the seven cities. It can be found that Adrar and Tamanrasset (both with hot summer and hence significant cooling requirements) have a peak in global solar radiation and temperature at noon. The highest values are received during the day in Adrar, Ghardaia and Tamanrasset.

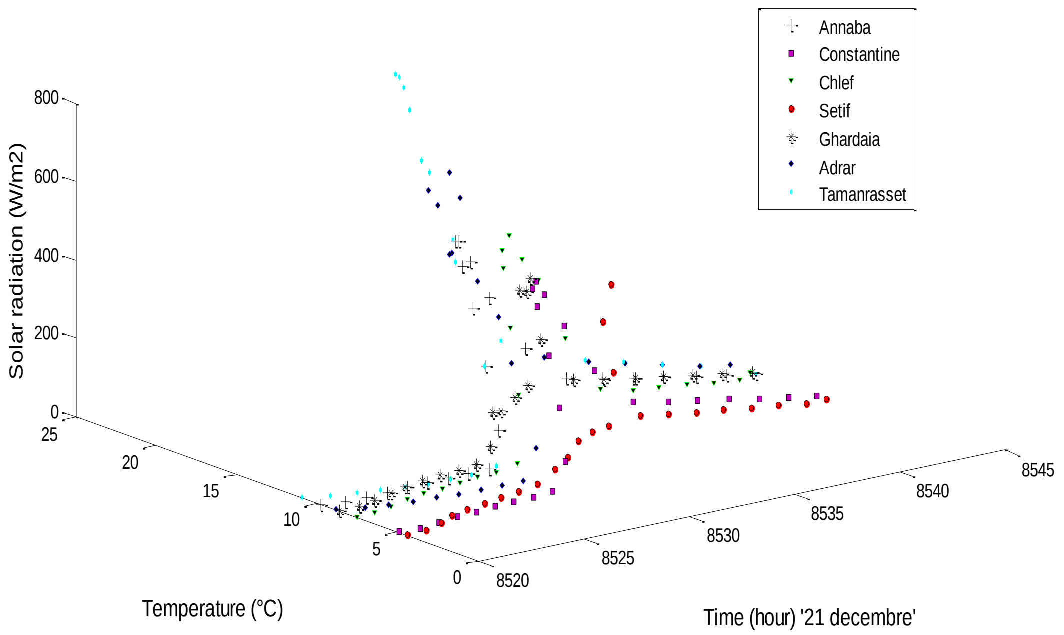


Fig. 9. Variation of total solar radiation and air temperature on 21st December for the seven cities

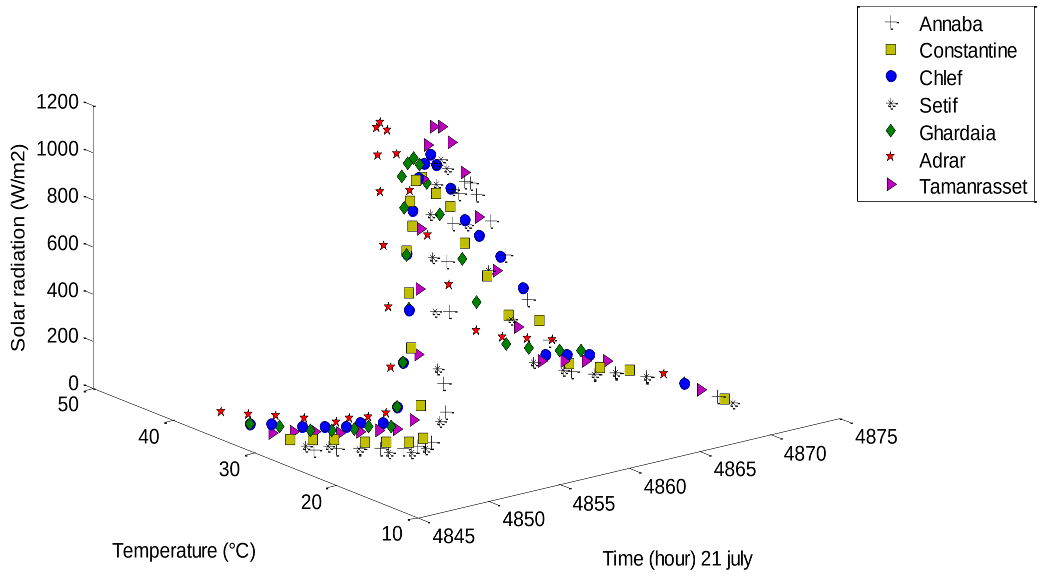


Fig. 10. Variation of total solar radiation and air temperature on 21st July for the seven cities

To determine the necessary area of the solar collector, an expression for the useful heat gain is given by [18]:

$$Q_{gen} = A_c \cdot F_r \cdot \left(S - U_L \left(T_{ci} - T_a\right)\right) \qquad (6)$$

Where Ac is the area of the solar collector, S is the solar radiation absorbed by the plate collector, T_{ci} is the inlet water temperature to the collector, T_a is the ambient air temperature, U_L is the overall heat transfer loss coefficient and FR is the heat removal factor.

The power of generator (Qgen) must be the recovery of heating and cooling loads (for the worst case). We have certain steps to follow; first, we mainly need to define the higher capacity of the generator in winter or summer regarding the geographic location of the individual house. Taking 21st of July in summer, and 21st of December in winter as both referential days for calculations. Second, we have fix COP=0.7 to determine the maximum power of generator Table 5. It is interesting to determine the solar system in the unfavorable case for maximum heating and cooling loads which are set now (15.94 kW, 170 m^2) for Annaba, (17.52 kW, 142 m^2) for Constantine, (16.85 kW, 136 m^2) for Chlef, (16.14 kW, 116 m^2) for Setif, (23.28 kW, 140 m^2) for Ghardaia, (25.5 kW, 147 m^2) for Adrar, and (17.57 kW, 89 m^2) for Tamanrasset.

Table 4. Max heating/cooling, generator power, and collector area with cop=0.7

Location	**Q_{evp} kW**	**Q_{gen} kW**	**Collector Area (m^2)**	**Ratio (m^2/kW)**
Annaba	11.16	15.94	170	10.6
Constantine	12.27	17.52	142	8.1
Chlef	11.80	16.85	136	8
Setif	11.30	16.14	116	7.1
Ghardaia	16.30	23.28	140	6
Adrar	17.85	25.5	147	5.7
Tamanrasset	12.30	17.57	89	5

Fig. 11 shows the effect of air temperature on the collector area, which makes us notice the temperature degrees' influence on big scale the necessary area of solar collector to assure the proper functioning of the solar absorption. So the more temperature increases the less area occurs for solar collector. For instance, in the city of Adrar the solar collector area is less inquired compared to the increasing temperature going 138 m^2 to 232 m^2 (with Q_{gen} = 25.5 kW). Same thing for the city of Annaba which goes between 94 m^2 to 140 m^2 (with Q_{gen}=15.94 kW). In addition, for better widening this study, we analyzed the effect of the generator power on the collector area Fig. 12, to notice that there is a slight coherence between the collector area and the generator power. Therefore, the small powers need no bigger area of solar collector that shift and differ from a site to another.

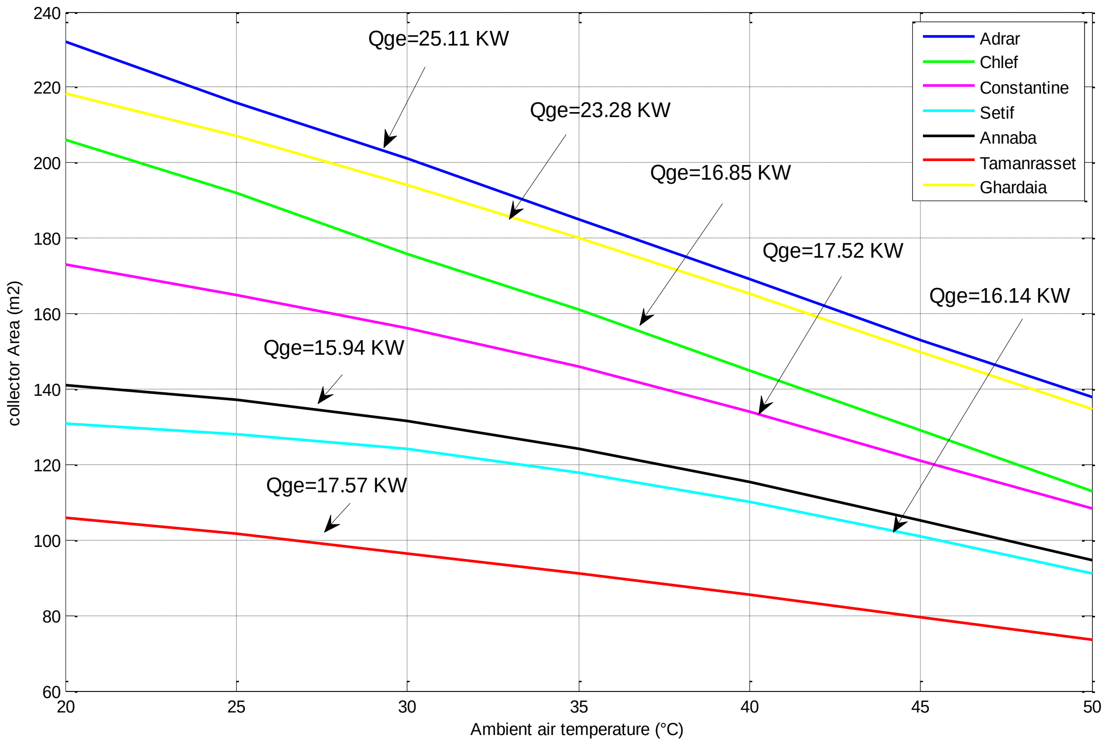


Fig. 11. Effect of ambient air temperature on the collector area on 21st July for the seven cities

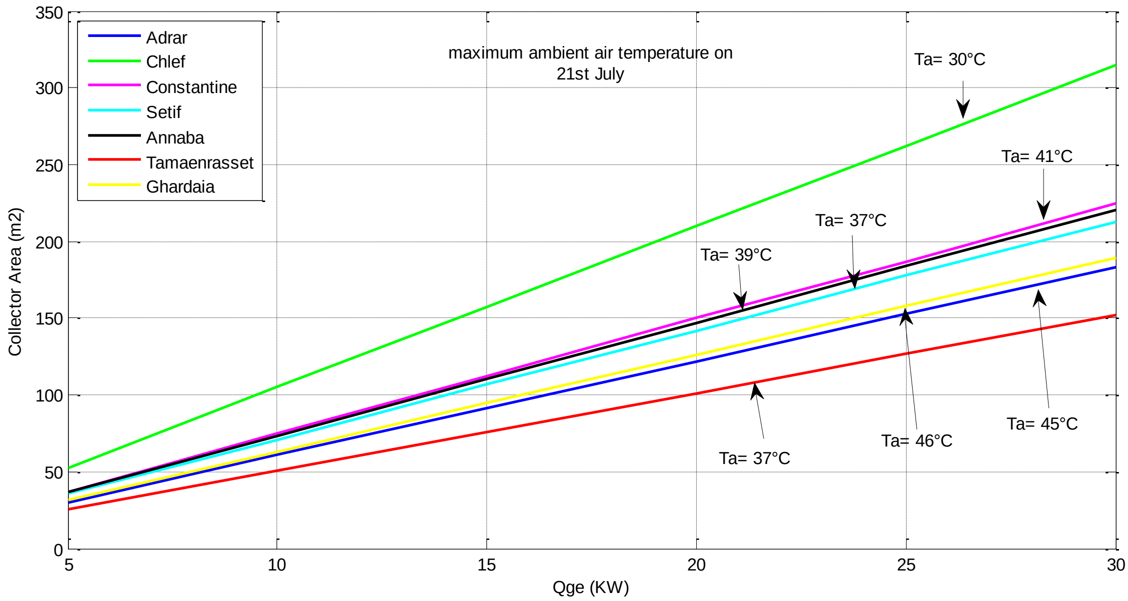


Fig. 12. Effect of the power generator on the collector area for the seven cities

3. CONCLUSION

In order to reduce the enormous energy consumption and change the fossil fuel dominant energy used in different sectors especially the housing sector in by other energies, as Algeria has enormous renewable energy potentials, mainly solar one, we ptesented this current work aiming to give a method of using solar energy for heating and cooling of an individual house in seven cities. The system is modelled with TRNSYS program and the weather conditions for Annaba, Constantine, Chlef, Setif, Ghardaia, Adrar, and Tamanrasset.

The computed results were analyzed and compared to heating and cooling loads for an individual house for different locations. We noticeably conclude that heating and cooling loads majorly differ from geographic location to another. Therefore, these needs are influenced directly by climate factors. So every location has its own specific conditions in matters of construction for buildings and the used materials according to such fact. But we used the same building for all location as referential item. Hence, using special construction materials certainly shrinks the heating and cooling loads wether in summer or winter. It is quite clear that we have more panels over in winter so we can exploit them for hot water. The design and operation of a solar absorption cooling and heating system should consider the building and its load profiles, the climate conditions and the incident solar radiation profiles. Solar collector area is reasonably determined by the solar energy collected and the generator capacity. The minimum required collector area per kW delivered is then 5 m2/kW for Tamanrasset, 5.7 m2/KW for Adrar, 6 m2/KW for Ghardaia, 7.1 m2/KW for Setif, 8 m2/KW for Chlef, 8.1 m2/KW for Constantine, and 10.6 m2/KW for Annaba.

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How to cite this article:
Halloufi O, Kaabi A, Chougui Md. Numerical analysis of an integrated solar cooling and heating system in individual house in different Algerian climates. J. Fundam. Appl. Sci., 2021, 13*(2), 845-863.*