Solar absorption cooling systems versus traditional air-conditioning in hot climate

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Abstract

Building sector globally accounts more than 40 % of the energy use, consuming more than industrial or transport sector. Especially in hot climates cooling – air conditioning represents the highest share of the energy used in buildings. Decreasing the cooling load and utilization of solar energy are key factors in minimizing the dependency on the power systems and maximizing the environmental effects having the suitable indoor comfort for the occupants.

A comparison of traditional and modern technology has been conducted for hot climate and presented by a case study for Iraq. According to the calculations building retrofitting contributed by 14 % of reducing the need for cooling. As a result, it can be concluded too that solar AC systems contribute to a low electric power consumption (165 kWh) compared to the traditional one (around 1440 kWh) and results a CO_2 emission decrease by more than 88 %.

Keywords

Absorption solar cooling, cooling load, HVAC systems, Building retrofitting

1. Introduction

The building sector in Iraq is one of the most important sectors responsible for energy consumption due to population growth and increasing of various other economic activities year after year. The share of energy consumption within the total supplied energy by residential buildings is high, in the capital- Baghdad alone was about 48% [1]. The buildings use high proportion (92 %) of total energy processed to operate air-conditioning and cooling systems [2]. The long summer season in Iraq is characterized by high-temperature and long day hours, and during the hot period in order to overcome the high temperature and reach the thermal comfort of the occupants there is a need for using efficient cooling system. The use of renewable energy becomes more relevant because of the electric power instability and because of the environmental impacts of the traditional air-conditioning systems and their refrigerants. In this paper energy efficiency measures and solar absorption air-conditioning system is introduced and discussed compared to the traditional air conditioning system in a given building.

2. Cooling load calculations Methodology

The calculations have been made according to two methods: Cooling Load Temperature Difference/ Solar Cooling Load/ Cooling Load Factor (CLTD/SCL/CLF) method of ASHRAE and then, by using Hourly Analysis Program (HAP 4.8).

CLTD/ SCL/ CLF method

This method is one of the most important traditional methods used to calculate the external and internal loads of the buildings based on set of parameters available by ASHRAE. It is an accurate method and addresse the aspects that are related to the building one by one, as following [3]:

Roofs load:

$$Q_{Roof} = A_r U_r CLTD_c \quad (1)$$

Q_{Roof}: heat gain of the roof (kW)
A_r: roof's area (m^2)
U_r: overall heat transfer coefficient of the roof (W/m^2K).
$CLTD_c$: correction of cooling load temperature difference of the roofs.

$$U_r = 1/R,\ R = L/k \quad (2)$$

R: thermal resistance of roof layers (m^2K/W),
L: layer thickness (m),
k: layer thermal conductivity (W/mK)

$$CLTD_c = CLTD + (25.5 - T_r) + (T_o - 29.4) \quad (3)$$

T_r: inside temperature (comfort temp.) (°C).
T_o: mean outdoor temperature (°C).

$$T_o = t_o - DR/2 \quad (4)$$

$t_{o:}$ outdoor design temperature (°C).
DR: daily range during the day (°C).

Walls load:

- External walls

$$Q_{Ext.\ wall} = A_w U_w CLTD_c \quad (5)$$

A_w: net wall's area (excluding the windows and doors) (m^2).
A_w = Width x height, height= 3 m

U_w: overall heat transfer coefficient of the external wall (W/m^2K)
$CLTD_c$: correction of cooling load temperature difference of external walls.

- Internal walls

$$Q_{Int.\ wall} = A_w U_w \Delta T \tag{6}$$

A_w: net wall's area (m^2). A_w = Width (m) × height (m).
U_w: overall heat transfer coefficient of the internal wall (W/m^2K)
ΔT: temperature difference between the adjacent space and the conditioned room.

Windows load:

- Conductive load

$$Q_{Cond.\ window} = A_w U_w CLTD_c \tag{7}$$

A_w: window's area (m^2), A= length (m) × width (m).
U_w: overall heat transfer coefficient of the windows (W/m^2K).
$CLTD_c$: correction of cooling load temperature difference of windows.

- Solar load through glass

$$Q_{Solar\ window} = A_w (SC)(SCL) \tag{8}$$

A_w: widow's area (m^2).
SC = shading coefficient.
SCL = solar cooling load factor with no interior shade or with shade.

Occupants load:

$$Q_{sensible} = N \times q_s \times \tag{9}$$

N: number of occupants in space.
q_s: Sensible heat gain for each person (kW).
CLF: cooling load factor. CLF= 1.0 (cooling off at night and during weekends).

$$Q_{latent} = N \times q_L \tag{10}$$

q_L: latent heat gain for each person (kW).

Lighting load:

$$Q_{lighting} = (watt / m^2) \times \text{Space area} \tag{11}$$

Infiltration load:

$$Q_{sensible} = 1.23 \times V_{inf} \times \Delta T \tag{12}$$

V_{inf} = ACH × Room volume / 3600, ACH = 1 (the room has window in one side)
ΔT: outside & inside air temperature (°C) = 50- 24 = 26 ˚C.

$$Q_{Latent} = 3010 \times V_{inf} \times \Delta w \quad (13)$$

Δw: outside & inside air humidity ratio, kg (water)/kg (dry air).

Equipment load: Selected directly from the tables for all equipment in space.

Floor load: Neglected (the calculated space above conditioned area).

Total Load = $Q_{Roof} + Q_{Wall\ (Ext.\ +\ Int.)} + Q_{Window\ (Cond.\ +\ Solar)} + Q_{Occupants} + Q_{Lighting} + Q_{Infiltration} + Q_{Equipment}$

Hourly Analysis Program (HAP4.8)

HAP program is one of the widely used software programs in the design of air-conditioning systems in Iraq. The program was developed by Carrier Company where it is uses to design HVAC systems of various buildings and makes selection of the appropriate system with all components on one hand, and uses to make an analysis of energy consumption and fuel on the other hand. The program has been used for estimating the cooling load of case study building according to the same data that have been applied with CLTD method in order to support the results.

3. Case study calculation and results

Iraq is located in the south-west region of the continent of Asia. It is part of the north-east of the Arab world and lies between latitudes 29 – 37 degrees north. The summer season is hot, longer daytime and the mean temperature is more than 45°C most of the year.

The building is located in Maysan province to the north of Amarah city (center of Maysan province) on the main line linking the city to the capital Baghdad (Amarah city located south-east of Iraq, on a low ridge next to the Tigris River waterway south of Baghdad about 50 km from the border with Iran). The building shown in Figure 1. is used for educational purposes at Maysan University– Faculty of Engineering.

The calculations have done according to the conditions of Table 1:

The total load of the building calculated by CLTD/ SCL/ CLF method is 167.2 kW. While, it was 165.6 kW using HAP software.

Table 1. The boundary design conditions of the building.

Location	Al- Amarah city/ Maysan province	
Outdoor conditions	t_d = 50℃	t_w = 26℃
Indoor conditions	t_d = 24℃	RH = 50 %
Daily range	13.5*	

* Daily range of Al- Amarah city during July 2016. [4]

Figure 1. Building case study

Selection of solar absorption A/C system

The selection of appropriate solar cooling system can be done based on the total cooling load of the building. The solar cooling system consists of one chiller having cooling capacity covering the total cooling load required, or consists of a number of chillers having less cooling capacity can cover building total load combine with all other necessary accessories. Table 2 consists of the specifications of solar absorption chiller of (35 kW) cooling capacity. [5]

Table 2. The main technical data of a) solar absorption chiller and b) solar thermal system

a) Solar Absorption Chiller (LiBr - Water)		
Model		GRS-35
Cooling Capacity		35 kW
Hot Water	Inlet/ outlet temperature (°C)	90/85
	Flow Rate (m^3/hr)	9.2
	Connection Diameter	DN4o
Chilled Water	Inlet/ outlet temperature (°C)	15/10
	Flow Rate (m^3/hr)	6
	Connection Diameter	DN32
Power Consumption (kW)		3
Total Cost ($)		18,800

b) Solar Thermal System	
Solar Collector Type	Evacuated Tubes
Solar Collector Area (m^2)	45
Hot Water Buffer Storage Tank Volume (m^3)	2

The building needs to use 5 chillers of 35 kW to cover the total load.

Minimizing cooling loads of the building

Cooling loads of existing building can be minimized by several methods. Generally, these methods are applied for the building envelope (roofs, walls and windows) where costs should be taken under consideration. As following:

– **Roofs load:** Adding a compressed glass fiber layer of (30 mm).

Insulating material	Thickness (mm)	Thermal conductivity (W/m.K)
Compressed glass fiber	30	0.038

– **Walls load:** Covering the inner walls of each room with wood insulation of (14 mm) away from the wall by air gab of (~25 mm).

Insulating material	Thickness (mm)	Thermal conductivity (W/m.K)
Softwood- southern cypress	14	0.131

– **Windows load:** Replacing the existed single glazing windows by double glazing ones of (6.4 mm) thickness and (12.7 mm) air gab.

Glazing type	Thickness (mm)	Air gab (mm)	U (W/m2.K)	SC
Clear double glazing	6.4	12.7	3.26	0.81

The total building cooling load after applying those techniques has became 143.76 kW.

4. Evaluating of traditional A/C and solar absorption cooling systems

Electrical energy consumption and CO_2 emissions

Traditional air-conditioning systems consume a large electric power volume to work, unlike the solar absorption systems that rely on thermal energy produced from the solar system primarily, as well as using less electrical energy to operate some parts of the system such like solution pump and other measurement and control devices.

The amount of CO_2 emissions are linked with the electrical energy consumed by air-conditioning systems. In fact, the power plants in Iraq are still dependent on oil products and natural gas by a large margin. According to the International Energy Agency IEA [6], the value of CO_2 emissions that generated from each kWh in Iraq is 1002.8376 depending on the type of sources used to generate electrical power. Table 3 below shows the amounts of CO_2 emissions generated from the traditional and solar absorption systems for each single working day (11 hours).

Table 3. CO_2 emissions/ kWh consumption of the systems

A/C systems type	Energy kWh/ day	CO_2 grammes/ kWh	CO_2 kg emissions
Electricity driven A/C	1438.8	1002.8367	1442.88
Solar absorption chillers	165	1002.8367	165.47

Initial cost and operational lifetime

The traditional air-conditioning systems are very economic because they are widely available and there are many companies producing such systems. Unlike solar absorption systems, those are modern technologies that need a long time to be common and competitive.

In general, the cost of traditional systems is much lesser than the solar driven systems. The average cost of a conventional system/s of split unite type of 35 kW cooling capacity is around $ 3000, while the cost of solar-powered absorption chiller which gives the same cooling capacity is about $ 18,800 (excluding the cost of solar thermal system).

On the other hand, the expected mean operating lifetime of the traditional A/C systems ranging from 5 to 8 years depending mainly on the stability of the electrical power. While the average operating lifetime of the solar absorption chiller is about 23 years (according to the manufacturer company) because that the moving parts of the latter system is much lesser than the traditional one, which prolongs its operational lifetime.

Conclusions and recommendation

One of the most important goals of this paper is finding a way to take advantages of the available solar energy on one hand, and solve the problem of power shortage that affects negatively on people's comfort on the other hand.

The study has been studied for building in Iraq in order to assess the current situation of its air-conditioning systems and recommend the possibility of using other modern technology that has many advantages. Several conclusions have been derived and can be summarized as follow:

- The possibility of using environmentally friendly air-conditioning systems has been studied by conducting detailed calculations of overall cooling loads of the building. These calculations are very important to choose the number and size of A/C systems that have to be used as a substitute for traditional systems. The calculations of cooling loads have been made by two methods and the results were approximately equal.
- The calculations were carried out as a kind of building retrofitting are very important and reflect positively in reducing the need for cooling by 14%. That reduction is led to reduce the number of solar absorption chillers that need to cool the building from 5 to approximately 4 chillers. Although it was simple and a bit expensive but it is more economic if compared with the rationalization in the air-conditioning systems usage.
- It was found that the use of traditional A/C systems of the building consumed about 1,438.8 kWh of electric power for each day work. While the proposed solar absorption chillers are consume only 165 kWh. And from an environmental perspective, CO_2 emissions that linked to the amount of electricity consumed by the traditional systems were about 1442.88 kg, but the generated CO_2 emissions from solar ones were 165.47 kg only.

– The initial cost of traditional systems constitutes about 10% of the initial cost of solar A/C systems also, the fact that traditional systems are more efficient than those driven by solar and they are easy to install and maintain. On the other hand, the operating lifetime of the solar A/C systems represents approximately 3 times more than the operational lifetime of the traditional ones as they contain moving parts much lower than those found in conventional systems as well as other electrical problems associated with the traditional systems.

As a result, it can be concluded that the main problem facing the solar A/C systems in general is the cost. Also, they still need more improvements to increase the total system efficiency. But, it could be a rival to traditional systems when taking into consideration the electric power consumption, long operating lifetime and positive environmental impact. Likewise, the type of application is essential to examine the feasibility of their use, as applying such systems in buildings that have more daily working hours, like hospitals or airports; they are definitely going to be highly interesting.

References

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