International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 5 Issue 3, March-2016

A Comparative Study of Solar Thermal Cooling and Photovoltaic Solar Cooling in Different Iraqi Regions

Dr. Kareem K. Jasim[1], Dr. Jaafar A. Kadhum[2]

[1,2]Energy and Renewable Energies Technology Center University of Technology, Baghdad, IRAQ

SUMMARY

In this work, a comparison and analyses of solar thermal and solar photovoltaic (PV) air-conditioning technologies for a Typical Single Family House in two different Iraqi climates are performed. This research can be extended to compare and analyze the methods in terms of primary energy, economic analysis and different buildings. Moreover, the future cost reduction by learning curves of both technologies can influence the economic feasibility. The PV air-conditioning method with storage behaves and compensates the cooling demand better than the solar thermal air-conditioning with storage method and needs less storage to cover the same amount of cooling load demand. However, the storage system in the PV air-conditioning method is minor and the direct compensation is major. That is vice versa in the thermal air-conditioning method.

1. INTRODUCTION:

Today, there are two main solar air-conditioning technology options: solar thermal air-conditioning, where the solar absorption cooling is the first type of this option and it is still practical for remote building in places where there is an excess of heat energy available. Another option is the solar photovoltaic air-conditioning, by using electricity from renewable sources to power the conventional cooling equipment. ‘‘On the other hand, the used photovoltaic systems is much more available than that of solar thermal power plants; cost reductions can be expected to be faster for photovoltaic systems. But even if there is a 50% cost reduction in photovoltaic systems and no cost reduction at all in solar thermal power plants, electricity production with solar thermal power plants in cold regions remains more cost-effective than with photovoltaic systems’’ [4].

A lot of papers have been published that describe the performance of thermal air-conditioning technology under different climate conditions in the world: [5], [7], [8] and [9]. In addition, there are also a number of publications available that cover the performance of solar photovoltaic air-conditioning technology or different performance between the two technologies such as [10]. However, there are very few research on the solar air-conditioning technology under the Iraqi region climate conditions, for its importance in this region. Therefore, there are areas in which one or the other of the two technologies should be preferred for technical reasons under the our regions’ climates.

2. DETERMINATION OF THE REFRENCE BUILDING IN IRAQI REGIONS:

To investigate the above objective two areas were selected regions. The reference building model in this study was selected for the two locations, namely typical single family house. The aim of this research is to determine the reference building, for various climate conditions of the selected locations in Iraqi regions. For the locations climate conditions, solar radiation, ambient air temperature and relative humidity. For the building, the construction (i.e. wall values, type of window glazing), internal heat gains air exchange rate etc... Were defined.

2.1 Reference Location Climates:

The building cooling and heating demands are strongly influenced by the outdoor ambient air temperature and global solar radiation around it. In this study, the house cooling demand calculations depends on the selected locations climates of the two areas. [11]

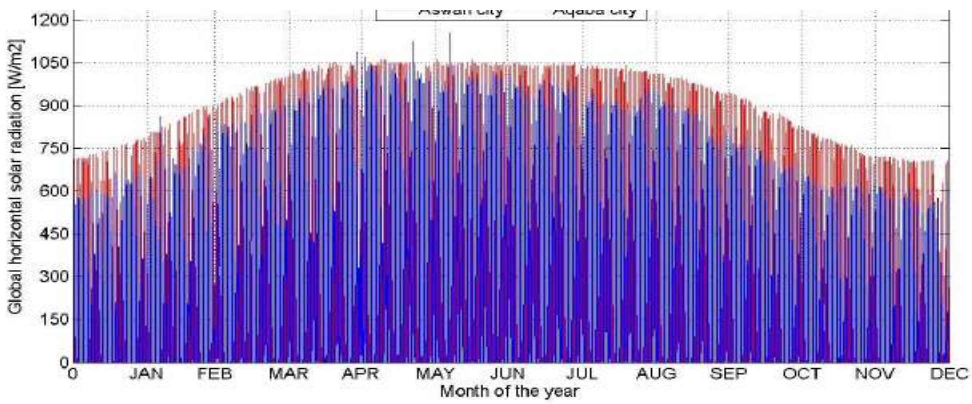

Fig. (1) Annual distribution of horizontal global radiation for the selected regions

Figure (1) shows, distribution of the global horizontal solar radiation for the two selected areas, in the first has higher peak daily of global horizontal solar radiation than the second area along the year; in summer season reaches near to 1000 W/m2 ,1050 W/m2 and in winter 600 W/m2 , 700 W/m2 for the first and the second area respectively. In addition the radiation difference between the two regions, in winter higher than in summer seasons. [11]

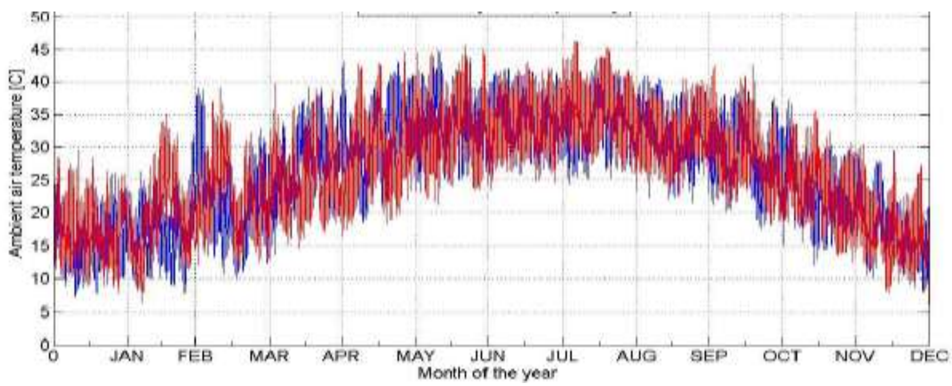

Fig. (2) Annual distribution of ambient air temperatures for the selected regions

Figure(2) illustrates, the annual distribution of ambient temperatures in both regions. Approximately in both regions; in summer season the daily maximum peak temperatures reaches to 40 C^o and in sometimes to 50 C^o, in winter changes between 25 C^o to 30 C^o. The first area daily temperatures are fluctuated along the year higher than the other, this means the second area night temperatures higher than first night temperatures. This leads to higher night cooling consumption by the buildings in first region than in second region. [12]

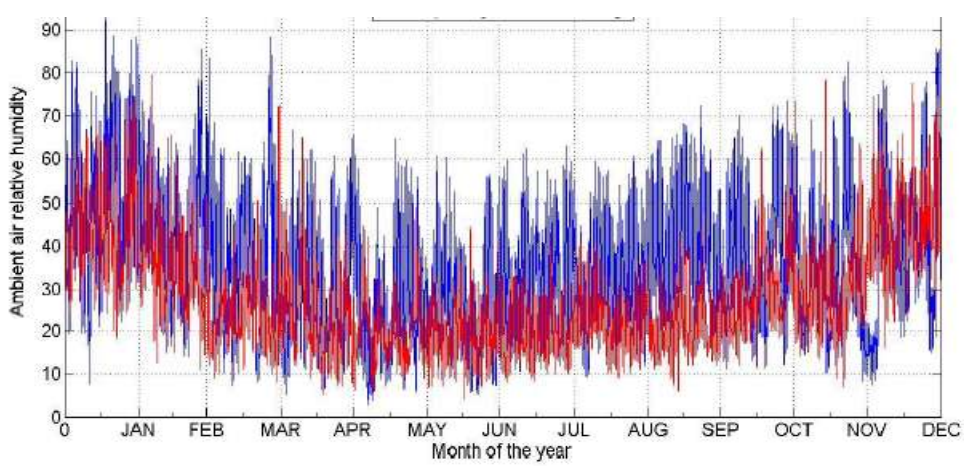

Fig. (3) Annual distribution of ambient relative humidity in both areas

As shown in Figure(3),the relative humidity distribute along the year for both areas. Generally first area has higher ambient air relative humidity along the year than second area, especially in July, August and September. Additionally, it is fluctuated in first more than in second. The high relative humidity of location, leads to increase building cooling consumption.

3. THERMAL COOLING RESULTS AND ANALYSIS

The major objective of the simulation is to determine the cooling load of a typical single family house in two different climate locations in the selected regions: The first and the second areas . The discussion and analysis on simulation results concentrate mainly on sensible cooling load demand (three bedrooms, living room, guest room and Kitchen). The simulation results and the analysis of the results are documented as follows. [13,14]

3.1 The Annual Energy Consumption:

The annual cooling load consumption for both cases, first and second area. Figure (4) and figure (5) below diagram the total annual and monthly cooling and heating energy consumptions for the selected cases respectively.

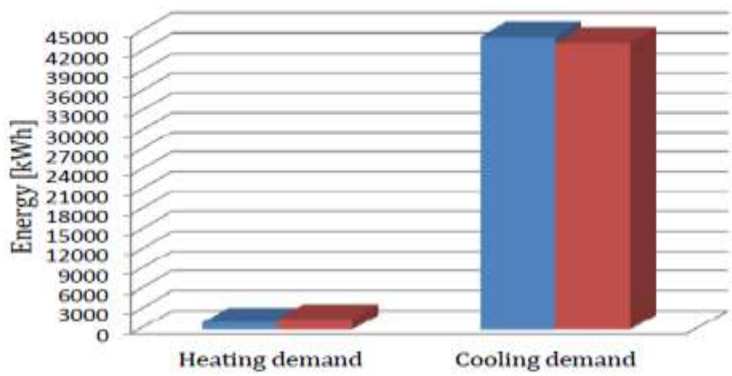

Fig. (4) Yearly cooling and heating energy demand for the selected areas

The simulation result in Figure (4) shows the annual energy consumption where the total cooling load energy are : 44,630 kWh/year and 43,260 kWh/year; the total heating load energy are: 1118 kWh/year and 1686 kWh/year for the first area and the second area respectively. On the other hand, 97 % and 95.6% of the annual energy consumption are cooling load for the two cases respectively. [15]

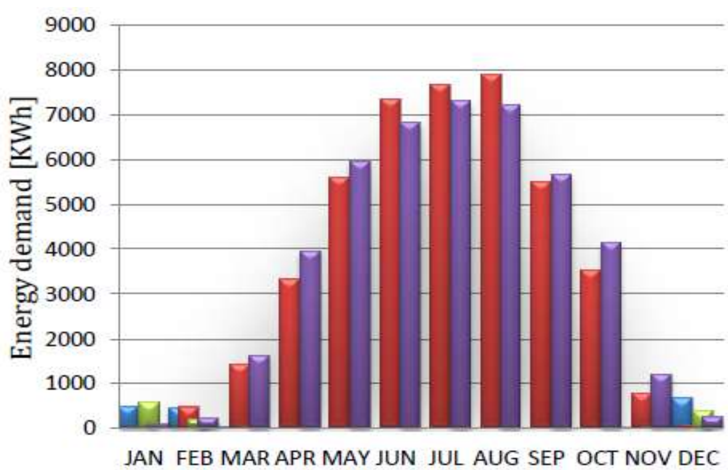

Fig. (5) Monthly cooling and heating energy demand in (kWh) for both regions

Figure (5) shows the cooling energy required during a long period throughout the year which is ten months, from February to the end of November, while the heating energy period is very short, three months (January, February and December) for both cases. The previous results and discussion show the extent of a need and importance of cooling compared to heating for both cases in the selected locations. [16]

3.2 The Performance of Cooling Load:

The maximum cooling load for the first area is 14.1kW as viewed in figure (6). As shown in the figure, the peak load takes place during the months of June and August. On the other hand, the smallest cooling load occurs during January, February and December.

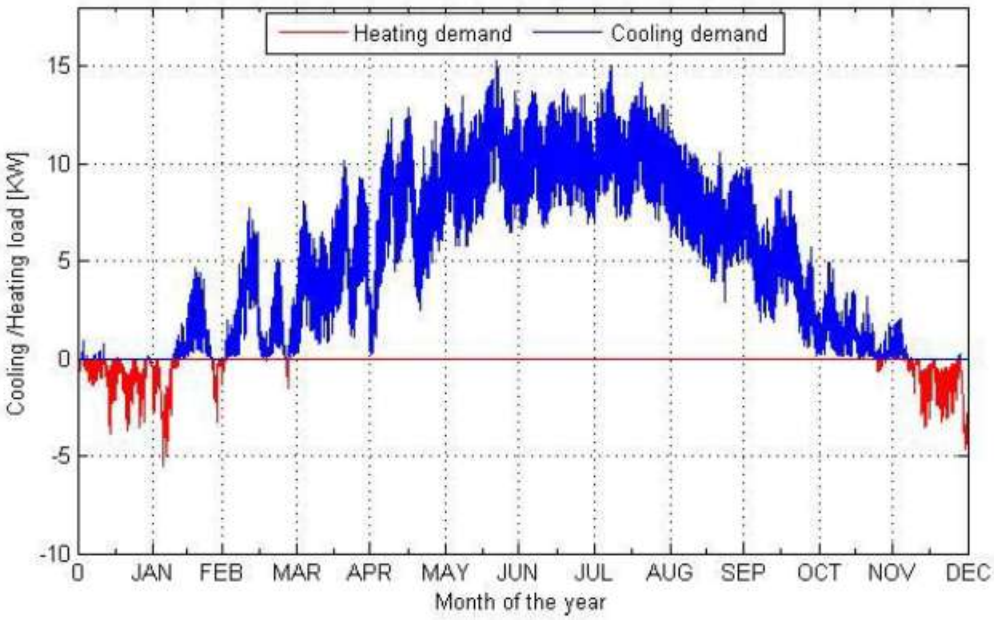

Fig. (6) Yearly cooling and heating demands distribution in(kW)for the first area

For first, Region the simulation result diagrammed in figure (7) shows that the maximum cooling load is in the range 14.5 - 15.2 kW and this load occurs during the periods of June and August. Besides, the smallest cooling load happens during January and December. [17]

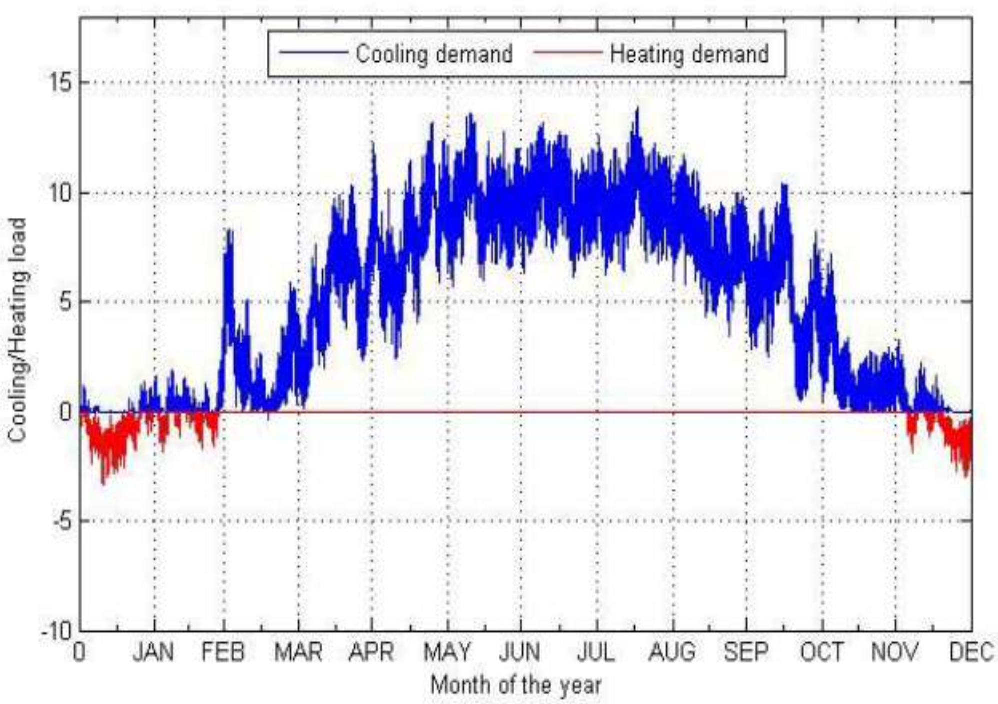

Fig. (7) Yearly cooling and heating demands distribution(kW)for the second area

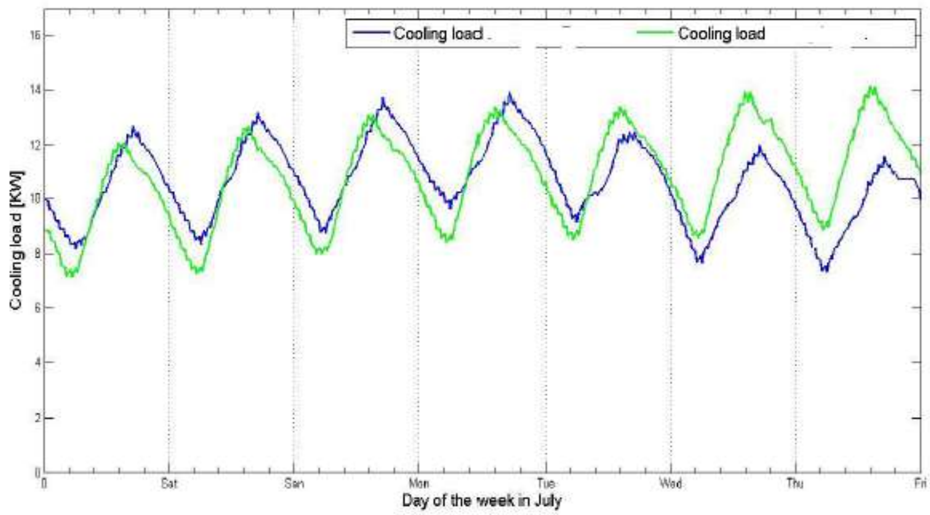

Fig. (8)Weekly cooling load demand distribution (kW)for the first and the second areas

The High cooling load demand shows a less daily fluctuation and is dominated by the external temperature conditions. The Performance of the cooling load during the day of the week in July for both cases (as in figure 8), the maximum daily cooling demand occurs at noon and the minimum occurs in the morning of the daytime. Additionally, this figure shows the extent needed for cooling in huge amounts (approximately 8 to10 kW) during the night as well as in the daytime in addition the night cooling load in second area higher than the first area. [19]

4. SOLAR AIR-CONDITIONING TECHNOLOGIES:

Solar air-conditioning systems can be divided into two groups of systems:‘‘ solar autonomous systems and solar-assisted systems. In a solar autonomous system “all” energy used by the air-conditioning system is solar energy. In a solar assisted system the solar energy covers a certain fraction of the energy used by the air-conditioning system and the rest of the energy is provided through an auxiliary or backup system’’. Only the solar-assisted systems are considered in this research. [18, 19]

4.1 Solar Photovoltaic Air-Conditioning Technology:

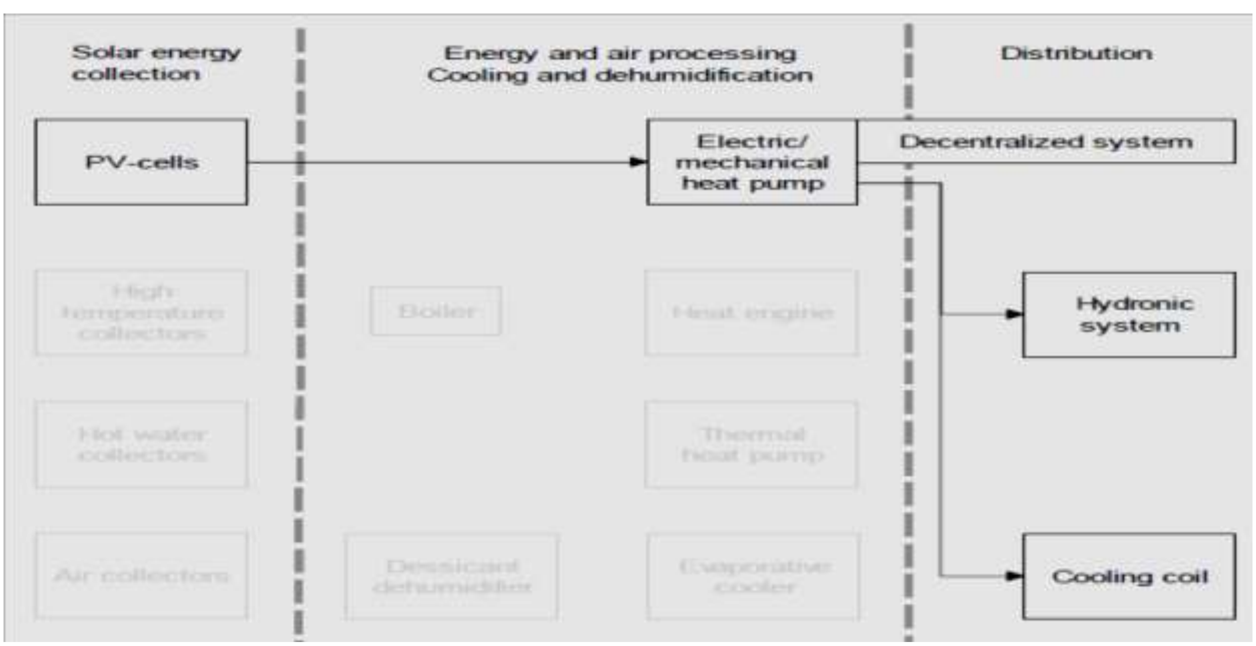

Fig. (9) Basic structure of PV air-conditioning systems,[2]

This system consists of three main parts: solar energy collection (includes PV cells) which converts solar radiation into electric power in order to drive the electric machine heat pump. This machine is any electric traditional air-conditioning system which converts the electric power to cooling power. [19]

4.2 Solar Thermal Air-conditioning Technology:

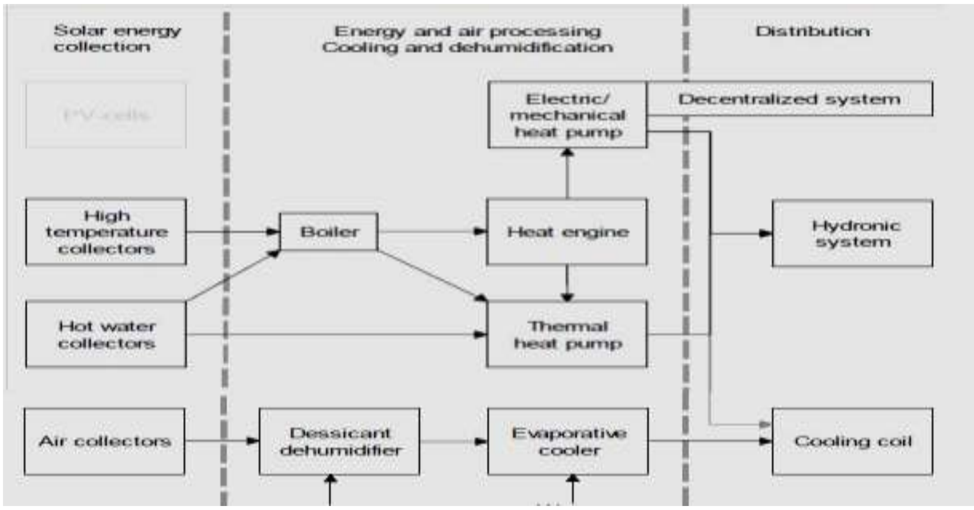

Fig. (10)Basic structure of heat driven and desiccant air-conditioning systems[2]

Figure (10) shows the basic components and structure of a thermal air-conditioning systems available. This technology can be divided in two groups [2]: a solar heat driven air-conditioning system which consists of a solar thermal collectors (high temperature or medium temperature hot water) where typically flat plate collectors, evacuated tube collectors or concentrated parabolic collectors are used. This converts the solar radiation to heat power. Then this power is provided to drive another system in order to produce cooling power for buildings. [21]

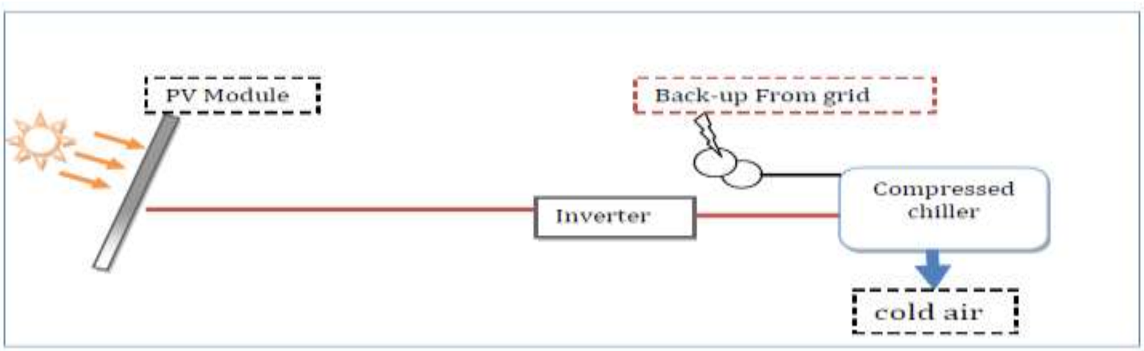

Fig. (11)Schematic flow diagram for PV air-conditioning without storage.

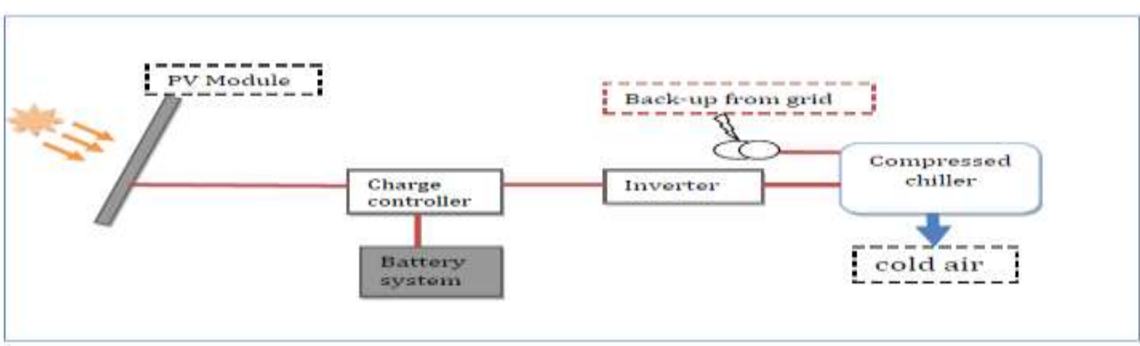

Fig. (12)Schematic flow diagram for solar PV air-conditioning with storage.

Compressed Chiller Design:

The vapour compression system is the dominant system today for cooling and refrigeration and is being used in almost all kind of applications [2]. It is available for a wide range of sizes from 50 W up to 50 MW. [2], [21].

PV array Sizing and Design:

The first step in designing a solar PV air-conditioning system is to find out the cooling power and energy consumption that need to be supplied by the PV-array. The maximum cooling power demands were 15 kW in the first area and 14 kW in the second area .In this study, the maximum cooling power demands were 15 kW assumed for both regions in order to simplify the comparison between the two cases . To compensate the power losses in the inverter and the battery system 20 % of power is added to this value. Thus, the required peak DC power equals:

Electric peak power needed = 5Kw x 1.2 = 6 Kw…………………………………………………………..(1)

Different sizes of PV modules produce different amounts of power. The air-conditioning system should be powered by at least 18 PV-modules with 100 Wp each:

Number of PV modules required=6 kW_P/0.1kW_P = 60 modules

The total PV array’s area required is calculated by using equation (1) where the PV module area equals 1.6 m2 .

PV array area = 1.6 x 60 = 96 m^2…………………………………………….(2)

The modules in a PV-array must be connected in combined connection, i.e 20 modules in parallel and three in series, in order to deliver an output voltage of 44 V-64 V which is the DC input voltage range for the inverter and battery system. [22]

Inverter Sizing and Design:

An inverter is used in the system where AC power output is needed. Stand-alone inverters are used to convert (DC)current from PV-array and battery to (AC) in order to run the compressed chiller. For the suggested PV system , in this study the required inverter should supply 230V AC, 50 Hz, 6 kW.

Storage (battery) System Design:

Energy produced by the PV array is accumulated and stored in batteries for use on demand. The battery system is designed for a PV air-conditioning with storage. In this system, when the electric DC power is higher than the electric power needed by the compression chiller. The battery accumulated and stored the excess DC power as electric energy. The battery system size is thus, the same for both cases. Given the compressed chiller, coefficient of performance(COP) of 3, the inverter efficiency of 96% and the daily excess cooling energy of 18.2 kWh, the resulting DC energy is 6.32 kWh (as in equation 3):

$E_{c,daily}$ = average daily of Excess cooling energy/COP x ζ_{Inv}..(3)
= 18200/3x96 = 6.32 kWh

The required output voltage (VBtt) is 48 V. In the case study, the battery safety requires that the discharge of batteries should not exceed 80 % of its capacity. The battery efficiency $\zeta_{Bat,Inv}$ is 85 %. The required output voltage (VBtt) is 48 V. The required autonomy factor (AF) for the selected locations is 2. Then:

Battery capacity(Ah) = 6.32 x 2/0.85x0.8x48 = 387 Ah

Thus 8 batteries of 12 V each are required and each 4 batteries are connected in series.

Controller:

The solar charge controller regulates the voltage and the current which comes from the PV module into battery. According to the previous calculations 20 PV modules are required; each module producing 17.9 V and 100 Wp (6.2 A). PV panels are connected in parallel to supply 120 A. A controller is needed to hold at least 125 A. A controller that carries a current of 125 A, 48 V DC has been chosen for the PV air-conditioning with storage system.

Back-up System

When there is no enough electric power coming from the PV-array and the battery system to cover the cooling power demands, the back-up system is designed to deliver the remaining needed AC power. The back-up system is assumed to have a direct connection to the electricity grid and to the compressed chillers.

5. SOLAR THERMAL AIR-CONDITIONING SYSTEM (ABSORPTION CHILLER):

The thermally driven air-conditioning process is the heart of every solar cooling system. Thermally driven air-conditioning systems are available which commonly utilize sorption processes. For air-conditioning applications, mainly absorption chillers using the sorption pair Lithium bromide-water (LiBr-H2O) are applied [9] since they require a comparatively low temperature as heat input. Most of the thermally driven cooling system and solar assisted air-conditioning systems installed today are based on absorption chillers [24], [25].

6. THE INFLUENCE OF A DIRECT COOLING PRODUCTIUON:

Yearly Analysis:

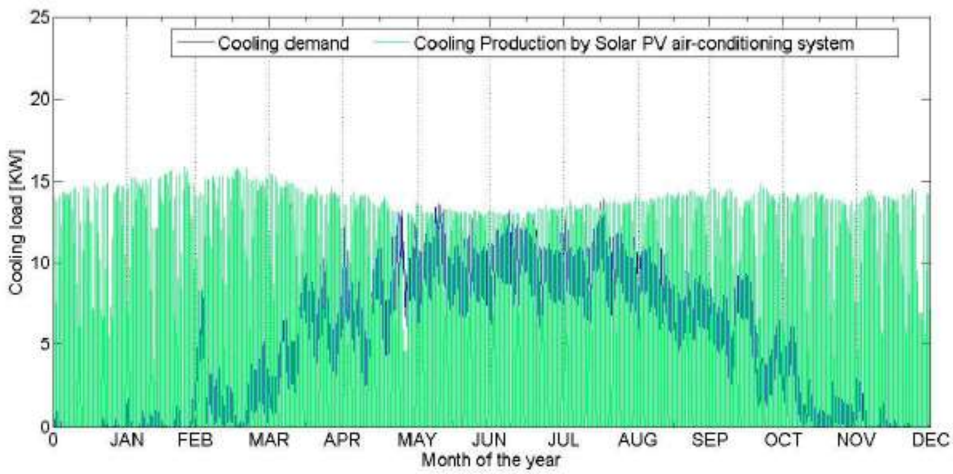

Fig. (13) PV air-conditioning cooling production along the year for first area

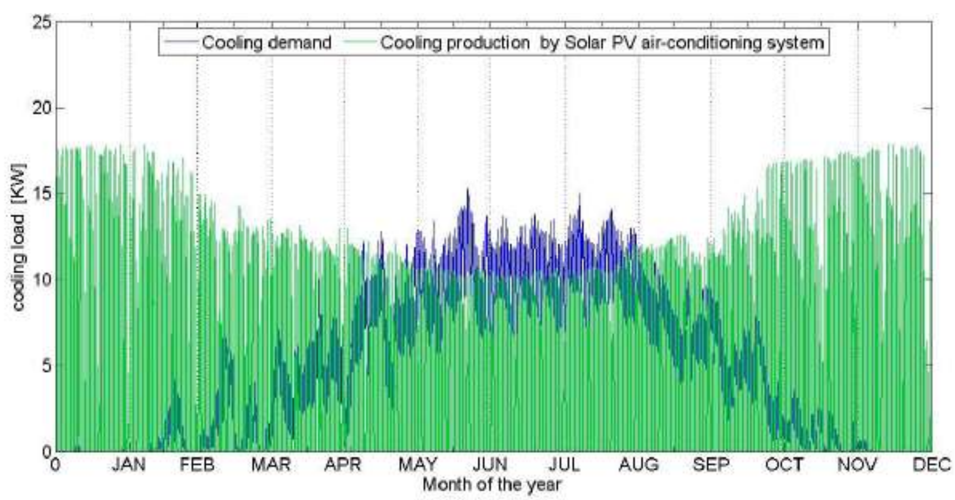

Fig. (14) PV air-conditioning cooling production along the year for second area

The cooling production covers almost entirely the maximum peak of the cooling load demand for first area especially in the summer. On the contrary, for the case of the second area, the cooling production is lower than the maximum peak of the cooling load consumption by 3 to 4 kW for the reason that there is a higher solar radiation in first region than in second region. Besides, the second region has higher peak load demand in summer than the first.

On the other hand, the ambient air temperature in winter is lower than in summer for both cases (as in fig.2). This reduces the thermal effect on the PV module by improving the heat transfer rate from the PV module to the ambient air with the help of the temperature difference between the module and the air which is higher in winter than in summer. This leads to increase the module efficiency and electric power output.

In winter, the cooling production reaches 20 kW and 15 kW in first and second areas respectively, due to a lower thermal effect on the module. In addition, there could be a higher diffused solar radiation and a higher reflected radiation by the ground in first area than in second area where the PV module is tilted at angle of 30 ^{o} in the first area and is higher than the second area 23 ^{o}. [25]

CONCLUSIONS

The traditional air-conditioning is one of the main consumers of electrical energy today in the selected regions. However, this region has a huge solar energy potential with an average of 2,34 kWh/m2/year and with average daily sunlight exceeding 10 hours [4]. Solar air-conditioning technology is definitely a solution to cover the cooling demand for this hot and sunny region. The present study analyzes and compares the solar thermal air-conditioning technology and the photovoltaic air-conditioning technology under two different locations in the selected region (area 1 and area 2). That is based on the cooling demand for the reference building in these regions. The yearly direct cooling compensation percentage of the PV air-conditioning scenarios is 40 % and 36 % for the second area and for the first respectively. The aforesaid percentages are higher than the direct cooling compensation percentages by the thermal air-conditioning system, 30 % and 31% for the second area and for the first area cases respectively. The performance of the daily direct cooling compensation by the PV air-conditioning systems is more efficient than in the thermal system although the flat plate collector efficiency is around 52 % and the PV module is around 16 %, due to three reasons.

The percentage of the cooling energy compensation by the storage in the thermal air-conditioning system is 24 % and 13 % for the second and for the first cases respectively. These are higher compared to those of PV air-conditioning with storage system, 11% and 8% for second and first respectively. That's because of the contribution of the excess power which is produced by the flat plate collector is higher than the excess output power of the PV module at noon. It can be concluded that the PV air-conditioning with storage system needs less storage to the storage system in PV air-conditioning scenario is minor and the direct compensation is major. That is vice versa in the thermal air-conditioning system. In winter season, the excess solar power gain is more useful in the PV air-conditioning systems than the thermal air-conditioning scenario due to, the electric power is more universal conversion compared with the thermal power conversion.

REFRENCES

[1] Nathan Rona, Solar Air-Conditioning Systems, Focus on components and their working principles, Building Services Engineering, Department of Building Technology, CHALMERS UNIVERSITY OF TECHNOLOGY, Göteborg, Sweden 5765/2004.

[2] Elsafty A , Al-Daini A.J, Economical comparison between a solar-powered vapour absorption air-conditioning system and a vapour compression system in the Middle East Renewable Energy, Vol. 25 No. 4 pp. 569-583 ISSN: 0960-1481, 2002, contents lists available at Science Direct Website, www.sciencedirect.com.

[3] Unlocking the Potential of Alternative Energy in MENA, Al Masah Capital Management Limite, Dubai International Financial Centre , Dubai-UA, 2011. http://www.almasahcapital.com/uploads/media/Alternative_Energy_in_MENA_Report18-Jan-11.

[4] Dr. Volker Quaschning, Dr. Manuel Blanco Murie, Photovoltaics or Solar Thermal Power Plants?, DLR, Plataforma Solar de Almería, Spain, CIEMAT, Plataforma Solar de Almería, Spain, VGB Congress Power Plants 2001 · Brussels · October 10 to 12, 2001, the contents available at : http://volker-quaschning.de/downloads/VGB2001.pdf.

[5] Ursula Eicker, Dirk Pietruschka, Design and performance of solar powered absorption cooling systems in office buildings, University of Applied Sciences Stuttgart, Schelling strasse, 28 July 2008, 24, D-70174 Stuttgart, Germany, contents lists available at Science Direct Website, www.sciencedirect.com.

[6] A. González-Gil, M. Izquierdo, J.D. Marcos, E. Palacios, Experimental evaluation of a direct air-cooled lithium bromide-water absorption prototype for solar air-conditioning,**[15]** Aswan, Egypt, Aswan overview, Aswan Weather, Asia rooms Website, last visit 05.02.2012,http://www.asiarooms.com/en/travel-guide/egypt/aswan/aswan-overview/aswan-weather. Applied Thermal Engineering, Volume 31, Pages 3358-3368, Issue 16, November 2011, contents lists available at Science Direct Website, www. sciencedirect.com.

[7] Francesco Calise 2011, High temperature solar heating and cooling systems for different Mediterranean climates: Dynamic simulation and economic assessment, DETEC, University of Naples Federico II, P.le Tecchio 80, 80125 Naples, Italy, contents lists available at Science Direct Website, www.sciencedirect.com.

[8] Hans-Martin Henning, Solar assisted air-conditioning of building-an Overview, Applied Thermal Engineering, 27 (2007)1734-1749, contents lists available at Science Direct Website, www.sciencedirect.com.

[9] N. Hartmann, C. Glueck b, F.P. Schmidt, Solar cooling for small office buildings: Comparison of solar thermal and photovoltaic options for two different European climates, a University of Stuttgart, Institute of Energy Economics and the Rational Use of

Energy (IER) , Renewable Energy 36 (2011) 1329e1338, 8 December 2010, contents lists available at Science Direct Website, www.sciencedirect.com.

[10] Jamal O. Jaber, Prospects of energy savings in residential space heating, Energy and Buildings 34 (2002) 311–319, Department of Mechanical Engineering, Hashemite University, Zarqa, Jordan, 13 August 2001, contents lists available at Science Direct Website, www.sciencedirect.com.

[11] Doppelintegral GmbH, in: INSEL Users Manual (2009), 8th ed., MS Windows, Stuttgart, Germany, 2009.

[12] Samar Jaber, Salman Ajib, Thermal and economic windows design for different climate zones, Energy and Buildings 43 (2011) 3208–3215, 16 August 2011, Technical University of Ilmenau, Department of Thermodynamics and Fluid Mechanics, Ilmenau, Germany, contents lists available at Science Direct Website, www.sciencedirect.com.

[13] Egypt, mission, Country-Profiles, This paper is available at this link, http://images.rca.or

[14] Weather data for Egypt, Africa, Building Technologies Program, Energy Plus Energy Simulation Software, Energy efficiency & renewable Energy, U.S. Department of Energy website, http://apps1.eere.energy.gov /buildings/energyplus /weatherdata_ about. cfm.

[15] Mr. Salah Azzam and Mr. Firas Alawneh, Meteorological measurement data for Aqaba city, The Higher Council for Science and Technology National Center (NERC), Amman , Jordan.

[16] Population and Housing Census, Department of Statistic DOS, Jordan, 2004.

[17] Samar Jaber, Salman Ajib, Optimum design of Trombe wall system in Mediterranean region, Ilmenau University of Technology, Department of Thermo and Fluid Dynamics, P.O Box 100565, 98648 Ilmenau, Germany,25 April 2011, contents lists available at Science Direct Website, www.sciencedirect.com.

[18] Samar Jaber, Salman Ajib, Optimum, technical and energy efficiency design of residential building in Mediterranean region, Ilmenau University of Technology, Department of Thermo and Fluid Dynamics, P.O Box 100565, 98648 Ilmenau, Germany, 22March 2011, contents lists available at Science Direct Website,www.sciencedirect.com.

[19] Thermal insulation code (2009), Ministry of Public Work and Housing , Amman, Jordan.

[20] MASDAR ENERGY DESIGN GUIDELINES (MEDG) VERSION 2.0 Office & Residential (2010), MASDAR (Abu Dhabi Future Energy Company) Page. 66. , 2010.g/docs/mission/country-profiles/Egypt.pdf

[21] Hining ,H.-M(Ed): Solar-Assisted Air – Conditioning in Building –A Handbook for planners.Springer-Verlag/wien, 2004.

[22] U.S. Department of Energy, Sitting Your Solar Water Heating System's Collector, U.S Energy efficiency & renewable, http://www.energysavers.gov , last visit 05.01.2012.

[23] Schüco Premium V Flat plate Solar collector, Solar flat plate technical data sheet ,Schüco Company USA L.P, www.schuco-usa.com**.**

[24] KWB Germany ,hot water storage tank, KWB Deutschland – Kraft und Wärme aus Biomasse GmbH, Branch office, South Königsberger Straße 46, D-86690 Mertingen, www.kwb.at.

[25] ASHRAE, in: Ventilation and Acceptable Air Quality in Low-rise Residen .