Achieving Net Zero Energy Building in a Hot Climate Using Integrated Photovoltaic and Parabolic trough Collectors

Adel A. Ghoneim

Abstract**—**In most existing buildings in hot climate, cooling loads lead to high primary energy consumption and consequently high CO2 emissions. These can be substantially decreased with integrated renewable energy systems. Kuwait is characterized by its dry hot long summer and short warm winter. Kuwait receives annual total radiation more than 5280 MJ/m2 with approximately 3347 h of sunshine. Solar energy systems consist of PV modules and parabolic trough collectors are considered to satisfy electricity consumption, domestic water heating, and cooling loads of an existing building. This paper presents the results of an extensive program of energy conservation and energy generation using integrated photovoltaic (PV) modules and Parabolic Trough Collectors (PTC). The program conducted on an existing institutional building intending to convert it into a Net-Zero Energy Building (NZEB) or near net Zero Energy Building (nNZEB). The program consists of two phases; the first phase is concerned with energy auditing and energy conservation measures at minimum cost and the second phase considers the installation of photovoltaic modules and parabolic trough collectors. The 2-storey building under consideration is the Applied Sciences Department at the College of Technological Studies, Kuwait. Single effect lithium bromide water absorption chillers are implemented to provide air conditioning load to the building. A numerical model is developed to evaluate the performance of parabolic trough collectors in Kuwait climate. Transient simulation program (TRNSYS) is adapted to simulate the performance of different solar system components. In addition, a numerical model is developed to assess the environmental impacts of building integrated renewable energy systems. Results indicate that efficient energy conservation can play an important role in converting the existing buildings into NZEBs as it saves a significant portion of annual energy consumption of the building. The first phase results in an energy conservation of about 28% of the building consumption. In the second phase, the integrated PV completely covers the lighting and equipment loads of the building. On the other hand, parabolic trough collectors of optimum area of 765 m2 can satisfy a significant portion of the cooling load, i.e about73% of the total building cooling load. The annual avoided CO2 emission is evaluated at the optimum conditions to assess the environmental impacts of renewable energy systems. The total annual avoided CO2 emission is about 680 metric ton/year which confirms the environmental impacts of these systems in Kuwait.

Keywords**—**Building integrated renewable systems, Net-Zero Energy Building, solar fraction, avoided CO2 emission.

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I. Introduction

ENERGY use in buildings represents a significant part of final energy end-use, making building energy efficiency a top priority. Buildings are typically responsible for a significant part of the total primary energy consumption. Net-Zero Energy Building (NZEB) is the building which, on an annual basis, produces energy from renewable sources that equals the amount of consumed energy from the building. If the produced energy from the building is slightly less than consumed; such building is called nearly net zero energy building (nNZEB). Buildings are typically responsible for 40% of the total primary energy consumption in the US, the European Union and also in developing countries like Brazil [1], [2]. So, it is the aim goal of researcher and building designers to develop efficient buildings that can use the energy produced from renewable energy sources. Net-Zero Energy Building (NZEB) is the building which, on an annual basis, produces energy from renewable sources that equals the amount of consumed energy by the building. If the produced energy from the building is slightly less than consumed; such building is called nearly net zero energy building (nNZEB). A grid connected nNZEB does not require on site electrical energy storage as any surplus in electricity production is provided to the grid. On the other hand, when the energy produced from the building is insufficient, the building satisfies the remaining part of the grid. In the future nNZEB concept may be extended to a life cycle zero energy approach, as proposed by [3]. The NZEBs concept is increasingly recognized worldwide. An early example of a solar based zero energy home is presented by [4]. A number of zero energy homes and buildings have been built and tested throughout the world [5]-[7].

The management on the supply side involves optimization techniques of the energy produced, e.g. use of maximum power point tracking system for photovoltaic and wind generators [8], energy storage management or feeding the extra energy produced to the grid. Some application examples around the world are summarized by [9]. NZEB performance is usually measured and evaluated using various indicators, i.e. net primary energy consumption, net energy costs, carbon emissions [10]. Another indicator found in the literature is the Net Energy Ratio (NER) introduced by [3] used to aid the decision making mechanisms during the building design process towards Lifecycle NZEBs or zero-carbon dioxide emissions. In order to achieve NZEB or nNZEB existed and newly designed buildings must be energy efficient before any integration of renewable energy is to be considered. Energy efficient buildings efficiently use energy, water and other resources. In these buildings, designers reduce, for example air leakage through the building envelope as well as using extra insulation in walls, ceilings and floors. Many guidance, standards have been published to lead designer on this task, such as Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environment Assessment Method (BREEAM). These standards audit the building process from design to construction to ensure the compliance of building to a certain standard of performance. Many research works have implemented such or similar audit standard and the results showed substantial energy reductions [11]-[14].

Recently, many new and existing buildings incorporate solar energy technologies to attain environmental benefits in comparison to the conventional energy in terms of reducing global warming and greenhouse gases emissions, mainly CO_2, and preventing toxic gas emissions. Building-integrated photovoltaic systems (BIPV) is considered as one of the most cost effective application of PV systems in terms of energy payback time and avoided CO_2 emissions and it is expected that they can reach widespread commercialization in the near future as claimed by [15]. Solar energy therefore has an important role to play in the building energy system.

The potential impact in energy demand reduction at the Florianopolis International Airport in Brazil with the use of building-integrated photovoltaic (BIPV) systems is analyzed by [16]. Their results showed that the integration of PV systems in airport buildings in warm climates can supply the entire electrical power consumption of an airport complex, in line with the general concept of a zero-energy building. A life cycle inventory model is presented by [17] to characterize the energy and environmental performance of BIPV systems relative to the conventional grid and displaced building materials. They concluded that the displacement of utility generated electricity and conventional building materials can conserve fossil fuels and have environmental benefits. The model is applied to an amorphous silicon PV roofing in different regions across the US. They determined the electricity production efficiency which is defined as the electricity output/total primary energy input, excluding insulation) for a reference BIPV system (2kWp PV system with a 6% conversion efficiency and 20 year life). The value of the electricity production efficiency is found to be ranged from 3.6 in Portland OR to 5.9 in Phoenix, AZ indicating a significant return on energy investment.

Da Graca et al. [18] explored the feasibility of NZEB systems for a typical single family home in the mild southern European climate zone. Solar thermal and photovoltaic collector systems were sized in order to meet all annual energy needs. Their results showed that, for the southern European climate, NZEB implementation is feasible, with a moderate increase in initial cost. Using current energy costs, their analysis predicts a payback time of 13–18 years. Zhai et al. [19] concluded that under the weather condition of Shanghai, 150 m2 vacuum tube solar collector arrays can be used to satisfy heating and air-conditioning for covered area of 460 m2. In addition, they are capable of inducing natural ventilation by stacking pressure and supplying hot water for the office building. Yin et al. [20] designed a building integrated multifunctional roofing system to harvest solar energy through photovoltaics and heat utilization while minimizing PV efficiency loss and eliminating the material and labor redundancies of conventional PV systems. Solar energy is collected by the PV modules in the form of PV electricity and heat energy. A thermal resistive structural substrate is integrated into the composite system to provide structural support for PV elements. The performance analysis indicates that the proposed solar roofing system provides significant advantages over the traditional asphalt shingle roof and PV systems without cooling.

In the present work, a mid-size existing institutional building is considered as a model for existing public buildings that can be moved toward NZEB in Kuwait. This study has two purposes; the first is to carry out an energy audit to reduce the energy consumption in the building to its lowest possible value by implementing the appropriate energy conservation measures. The second objective is to design building integrated PV modules and parabolic trough collectors in Kuwait to achieve Net Zero/near Net Zero Energy Building (NZEB or nNZEB). In addition, the performance and environmental impact of the building integrated photovoltaic and parabolic trough collectors are evaluated.

II. Building Load

The 2-storey building under consideration is the Applied Sciences Department at the College of Technological Studies, Kuwait the main building in the College of Technological Studies, Kuwait. The building load is the total energy consumption in the building and it is assumed to be time dependent. On average, 800 people use the building with irregular occupancy from 8 am to 7 pm, 5 days per week during the academic semesters. The building wall construction can be considered heavy mass, with an overall heat transfer coefficient of 0.514 W/m^2K, which is a common practice in very hot climates (such as those in the State of Kuwait). The roof of the building is constructed from light mass construction that is well insulated with an overall heat transfer coefficient of 0.188 W/m^2K. The windows and entrance doors are aluminum-framed constructed from 6 mm double-tinted glazing with an overall heat transfer coefficient of 3.49 W/m^2K. The heating, ventilation and air-conditioning (HVAC) system of the building consists of 6 air-cooled reciprocating chillers using R407c refrigerant and each has a capacity of 223.52 kW. The integrated distribution system consists of a number of air-handling units (AHUs) of constant air volume that serves the staff offices, classrooms, and laboratories. In dry and harsh hot weather such as the case in the State of Kuwait, the HVAC system is the most energy consuming equipment in buildings.

For building simulation, type 56 included in TRNSYS [21] is employed. This component models the thermal behavior of building having multiple thermal zones. This component model is adapted to describe the building construction from a set of external files. The files can be generated based on user supplied information by running the preprocessor program called TRNBuild. From the simulation done with the TRNbuild (Type 56) of TRNSYS to determine the demand for air conditioning in the house under study, we obtained results that indicate that this demand starts from April to October, with critical periods in the months of June, July and August in which occurs the maximum load. In this study, the HVAC system and its distribution system consume about 84% of the total building energy consumption. The remaining energy consumption is distributed between lighting system, 11%, and equipments, 5%.

III. Results and Discussions

A. Energy Auditing and Energy Conservation

A preliminary energy audit assessment is carried out, which revealed an inefficient practice upon the building and by the occupants. The building roof was partially damaged which left the steel structure of the roof bare of insulation, increasing the thermal loading on the building. In addition, the main entrance and emergency doors were deliberately left open for a long time while the HVAC system was running. This increases the amount of air infiltrated into the building and consequently the HVAC energy consumption dramatically. Moreover, visits at night and weekend to the building revealed that the lights and plug-in equipment of some offices were left on after working hours and during the weekends. In addition, the light intensity measured in offices, laboratories, workshops, classrooms, and corridors was found not to comply with the recommended intensity levels. In general, to reduce energy consumption, it is important to increase the awareness of the users to switch off the room lights and equipment before leaving. This could also be checked by the security officer. Also, the chillers operate at low performance when working at partial load outside the working hours. The coefficient of performance of the chillers during off-working hours dropped to 1/5 of the value during the working hours. For this reason, it is recommended to use the chillers when working efficiently and to avoid using them when working inefficiently as this will considerably contribute to energy saving. Therefore, a new schedule is proposed to switch off the chillers at the start of the non-occupied period and to start them again in the early morning to cover the heat stored in the building at night.

It is concluded that there is a potential opportunity of energy conservation that could be achieved by applying the above mentioned energy conservation measures. It is estimated that as a result of applying the preliminary auditing of the building an annual saving of about 91 MWh can be achieved which represents about 5% of the building consumption. An additional energy saving of 6% can be achieved if the temperature is set to 28 ºC after working hours. Additionally, 15% of the building's energy consumption can be saved if the HVAC system is switched off during weekends and holidays and at the same time ensuring that proper operation and maintenance are exercised. As the lighting is considered the second largest item that consumes energy in the building, more efficient lighting and better operation yields a saving of about 2% of the total energy consumption. Implementation of the above mentioned procedures can yield considerable energy savings as this procedure can reduce the annual energy consumption of the building from 1.94 GWh to about 1.4 GWh.

B. Phase-II: Building Integrated Solar Energy

The second phase is concerned with integrating the building with photovoltaic modules and parabolic trough collectors to provide the energy consumption of the building in an attempt to convert it into NZEB or if the generated amount of energy is less than the energy consumption, the building will be nNZEB. An integrated solar energy system is designed to provide lighting, equipment as well as air conditioning load of the building. Building integrated photovoltaic (BIPV) system is adapted to provide the lighting and equipment load of the building. For the power to drive adsorption chillers, the parabolic trough solar collectors are considered for the building under study. For the purpose of efficient utilization of solar energy, the collector units in each row were connected in a series arrangement, for the purpose of obtaining hot water with relatively high temperature, which plays an important part in improving performance of the solar energy system. Such an arrangement of solar collectors not only guarantees high system performance, but also improves the beauty of the building facade. Besides, it provides a feasible idea for integration of solar collectors in civil buildings especially for public buildings. The weather data used in this study have been measured and collected for over three years in the College of Technological Studies, Kuwait. The weather data used are hourly values of daily radiation on horizontal surfaces and ambient temperature.

C. Building Integrated Photovoltaic (BIPV)

Grid connected PV system is proposed for the present work because the PV array does not have to be sized large enough for the worst weather conditions. The PV array charges the battery during daylight hours and the battery supplies power to the loads as needed. A hybrid photovoltaic system is proposed for the present work as shown in Fig. 1. This may be an economical alternative to a large standalone PV system, because the PV array does not have to be sized large enough for the worst weather conditions. The PV array charges the battery during daylight hours and the battery supplies power to the loads as needed. The battery charging process is terminated by the charger regulator when the battery is full. The electricity is started during extended overcast situations or at periods of increased load. When the batteries are low, the electricity will power the AC loads in the building as well as the battery charger. The system includes a DC to AC inverter to convert the direct current (DC) produced by the PV array to alternating current (AC) which is required by most household appliances. Inverters are specified in terms of their capacity (in watts or kilowatts), their output voltage and their power quality. Inverter cost per peak watt influences the choice of inverter size for a given system; PV output profile and the efficiency curve of the inverter. In addition to DC to AC conversion, most stand-alone inverters incorporate some level of system control. A quality stand-alone inverter will include a low-voltage disconnect and other system controls and will often serve as a battery charger. Disconnect switches are needed for system servicing and personnel safety. They are typically installed on the inverter's input and output, at the array output, and on the battery bank's output. Most disconnect switches also include over-current protection, either as fuses or circuit breakers. The system usually requires a maximum power point tracker that monitors PV outputs such that the PV always operates near its point of maximum power along the IV curve.

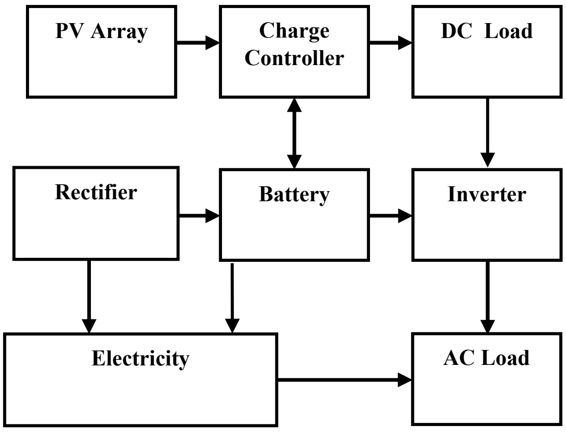

Fig. 1 Diagram of building integrated hybrid photovoltaic system

In the present work, the five parameter model [22] is used to simulate the characteristic of mono-crystalline solar cells at different weather conditions. This model adds the shunt resistance to the four-parameter model. At a fixed temperature and solar radiation, the I-V characteristic for the five parameter model is:

$$I = I_L - I_D - I_{sh} = I_L - I_o[exp(\frac{V + IR_s}{a}) - 1] - \frac{V + IR_s}{R_{sh}} \quad (1)$$

where, I current at the load, ID diode current, Ish shunt resistance current, IL photocurrent, Io diode reverse saturation current, V voltage at the load, Rs series resistance, and Rsh, shunt resistance.

Assumptions of the angle of orientation, local temperature and radiation levels, inverter efficiency and module efficiency are the most important factors that determine the output of the PV system. Each simulation has a length of one year period and employing mono-crystalline solar cell rated at 120 W. The five parameter model is implemented into TRNSYS to determine the PV output. The data used are weather data, building load, utility rate schedules and total utility demand. The weather data used are hourly global solar radiation on a horizontal surface, and hourly ambient temperature.

The variation of the annual energy production for various PV orientations is studied. The slope of the PV array is changed from 0° to 60° (i.e. latitude ± 30°). In addition, different azimuth angles are examined ranging from 0° (due south) to 40° west of south. It is found that the maximum energy generation from the PV arrays corresponds to array slope equal to 40° (i.e. latitude+10°) and for arrays facing south (azimuth angle=0°). So, annual energy production can be maximized by using an array sloped at an angle 10° greater than the latitude. The annual PV generation from 1200 mono-crystalline cells in this case is about 224 MWh, i.e. about 16% of the total building energy consumption after energy auditing. This means that the lighting and equipment loads of the building can be completely satisfied with the integrated PV modules.

D.Environmental Impact of BIPV

The overall benefit of BIPV systems over conventional electricity sources can be demonstrated also by calculating energy payback times. The Energy Payback Time (EPT) of a PV system is the time in which the energy input during the module life cycle is compensated by the electricity generated with the PV module and it depends on several factors including cell technology, PV system applications. The variation of EPT for the proposed BIPV system with a tilt angle of fixed azimuth angle (azimuth=0°) is presented in Fig. 2. This figure suggests that employing tilt angle of 40° (i.e. array with a slope of 10° greater than latitude) gives the minimum EPT which is approximately 8.4 years i.e. less than 9 years. These results indicate that the BIPV system can produce net or free power after 9 years of its operation.

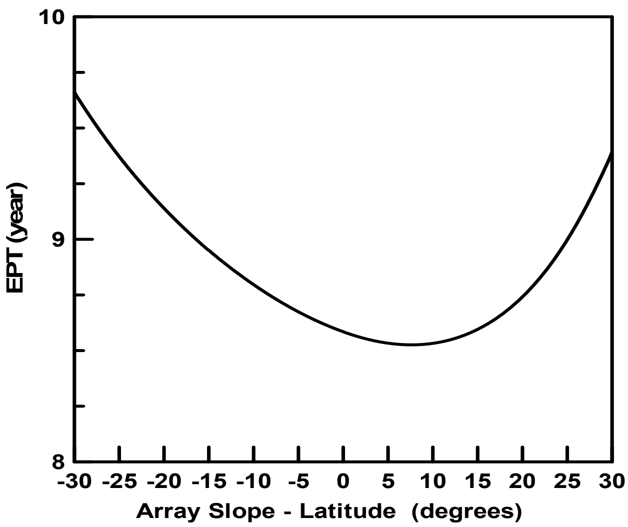

Fig. 2 Variation of EPT with tilt angle at fixed azimuth angle (azimuth=0°)

IV. Building Integrated Parabolic trough Collectors

Parabolic trough systems with a high-temperature heat transfer fluid (HTF) are currently the most-proven concentrating solar power (CSP) technology. Collector thermal efficiency (ηc) is defined as the ratio of energy collected by the working fluid to the direct normal solar radiation incident upon the collector aperture. It is typically determined by testing a collector over a range of high temperatures. Traditionally, the efficiency is plotted vs. the difference between operating temperature and ambient temperature.

Parabolic trough collector is assumed to be integrated with the building to satisfy the cooling load which represents about 84% of the total building load. A performance model is developed for solar thermal collector based on a linear, tracking parabolic trough reflector focused on a surface-treated metallic pipe receiver enclosed in an evacuated transparent tube: a Parabolic Trough Solar Collector (PTSC). This steady state, single dimensional model comprises the fundamental radiative and convective heat transfer and mass and energy balance relations. It considers the effects of solar intensity and incident angle, collector dimensions, material properties, fluid properties, ambient conditions, and operating conditions on the performance of the collector. The PTSC includes a parabolic reflective mirror, receiver pipe, steel support structure and a single-axis drive mechanism. It tracks the sun about a single axis during the day. Once the sun light strikes on the PTSC's reflective mirror, it is reflected to the PTSC's receiver tube. The heat transfer fluid flows from one end of the receiver tube to another end to convert solar energy into thermal energy, which can be used to drive any solar energy system to provide space heating and cooling.

The primary function of the model is to predict solar collector efficiency that is the thermal energy output of PTSC. The model created predicts PTSC performance by evaluating thermal losses involved in PTSC's receiver tube.

The efficiency of PTSC can be expressed as:

$$\eta_c = F_R\,(\tau\alpha) - \frac{A_r}{A_a} F_R U_L \frac{(T_i - T_a)}{G} \tag{2}$$

where A_r is the receiver area, A_a is collector aperture area, G is the incident radiation on a horizontal surface, F_R is the heat removal factor, $(\tau\alpha)$ is the transmittance-absorptance product, U_L is the collector overall heat transfer loss coefficient, T_i is the inlet collector temperature, and T_a is the ambient temperature.

The storage tank is modeled as a stratified tank. The energy balance of the water in the storage tank accounts for energy gain from the collector, energy removed by the load, and energy lost to the surroundings. The model created predicts PTSC performance by evaluating thermal losses involved in PTSC's receiver tube. The developed PTSC model is a steady-state model and based on the energy balance and heat transfer mechanism within PTSC's receiver tube. It could calculate the fraction of the incident solar energy recovered in the fluid circulating through the pipe receiver, the detailed thermal losses from the collector, the pressure drop of that flowed over the receiver, and the temperatures of various collector components and of the fluid throughout the receiver under different conditions like including direct normal solar irradiation, incidence angle, and wind speed. In addition, the model could be used for optimizing PTSC design by varying the size of receiver tube, the size of the glass envelope, receiver tube material, coating material and so forth. Single effect lithium bromide-water cooling absorption system is proposed to supply cooling demand for sunshine hours from April to October. Fig. 3 shows a schematic diagram of solar absorption cooling using PTC and the single-effect lithium bromide water absorption chiller. The main components of the absorption unit are; generator, condenser, evaporator, absorber, and low temperature heat exchanger.

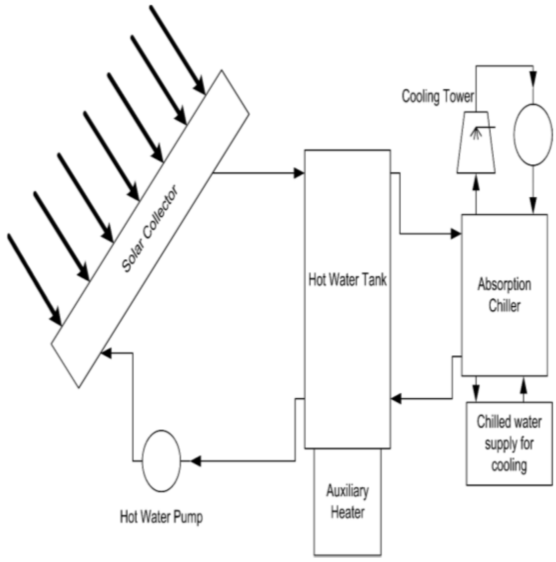

Fig. 3 Schematic diagram of solar absorption cooling

The lithium bromide solution is pumped from the absorber to the generator where the water is boiled off. The heat source is passed in a counter-flow arrangement through the generator to boil off water vapor from the LiBr-H2O solution. A cooling water loop is needed to condense the water vapor boiled off from the generator and to aid in the absorption of water vapor back into the LiBr-H2O solution. This cooling water is passed first through the absorber and then the condenser. The evaporator takes in low-pressure cold water and produces a cooling effect by evaporating the water and passing it to the absorber.

The chiller model is based on a commercially available LiBr-H2O absorption chiller system, Arkla model WF-36. The Arkla chiller has a nominal cooling capacity of three tons (37980 kJ/h). Units of different capacity are approximated by scaling the Arkla performance. Hot water is supplied to the air conditioner at a temperature of 87°C (minimum), 93°C (maximum) and leaves this unit 10°C cooler than the supply and returns to the storage (or to the auxiliary heater if storage is below 77°C). Whenever hot water from the storage is cooler than 87°C, the auxiliary heat is supplied to raise its temperature to 87°C. When storage is cooler than 77°C, it is not used, and the auxiliary heater carries the full cooling load.

The performance of air conditioning systems is expressed by their coefficient of performance (COP). COP determines how many units of cooling/heating one gets for every unit of energy he puts. The lithium bromide-water absorption systems have a good performance at generator temperatures between 70 and 95°C [23] which can be provided by a parabolic trough collector with direct water. A computer program is written to simulate and design a solar single effect lithium bromide-water cooling absorption system to supply building demand of cooling for sunshine hours from April to October. Transient simulation program (TRNSYS) is employed to simulate the different components of the solar cooling system. For hot thermal storage, a stratified liquid storage tank, with two inlets and two outlets flows (Type 60), for cold thermal storage Type 60f is used. Several data files of absorption chillers of single-effect employing Li Br – H2O solution as working fluid are used. Other types used were Types to simulate pumps and weather data.

Fig. 4 shows the variation of solar fraction (F), overall system efficiency (η) and life cycle savings (LCS) with collector area. The cost of the conventional fuel energy is the most important factor affecting the economic feasibility of the solar system. The economic calculations for this study are based on life cycle savings (LCS) method [23]. The life cycle savings of a solar system (LCS) over a conventional system can be defined as the difference between the reduction in fuel costs and the increase in expenses resulting from the additional investment in the solar system. The present results revealed that for each ton of refrigeration, it is required to have a minimum collector area of about 25 m2 with an optimal water storage tank capacity ranging from 1000 to 1500 liters for a system to operate solely on solar energy for about seven hours a day.

As seen from Fig. 4, the optimum area which corresponding to maximum solar savings is approximately equal to 765 m^2. It should be noted that the optimum area neither corresponds to maximum system efficiency nor to the maximum solar fraction. Also, the total solar fraction (F) for parabolic trough solar collector satisfies a significant portion of the cooling load about 0.73. The collector efficiency (η) which is defined as the ratio of solar energy provided to the total incident radiation behaves the same as the system efficiency with slightly higher numerical values.

The coefficient of performance (COP) of the absorption chiller is approximately 0.65 which is within the accepted practical values of the conventional lithium bromide system. The value of life cycle savings (LCS) is found to be $2300 per year for the optimum conditions. In the present study, the cost of unit energy provided by solar heating and cooling system, i.e. the cost of 1 kW.hr provided by the proposed solar system is about 0.017 $/kWh which represents 68% of the value provided by the conventional fuel system (0.025 $/kWh). These results prove the feasibility of the solar cooling systems in Kuwait climate.

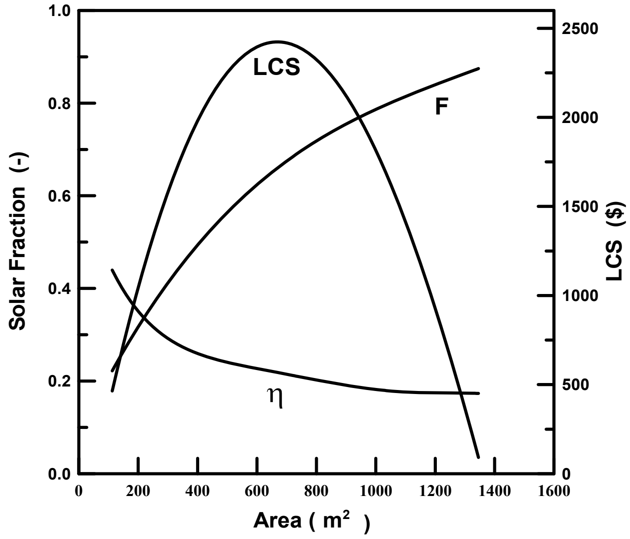

Fig. 4 Variation of system parameters with collector area

A. Environmental Impact of PTC

The variation of annual avoided CO_2 emission with collector tilt angle is shown in Fig. 5. The figure again illustrates that the optimum tilt angle which maximizes the avoided CO_2 emission is 40° which is the same angle which attains the minimum energy payback time (EPT).

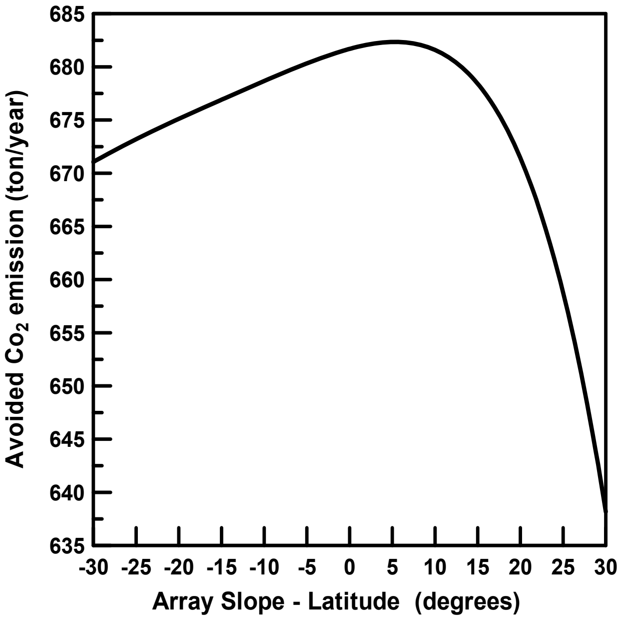

Fig. 5 Avoided CO_2 emission variation with collector tilt angle

At this optimum area, the avoided CO_2 emission has been found to be approximately equals to 680 metric ton/year. In addition, the costs of PV modules and solar collectors have decreased significantly in the last years and continue to decrease more which will enhance the economic and environmental aspects of solar heating and cooling systems much more making solar energy systems more feasible in

Kuwait climate.

V. Conclusions

This work evaluates the outcomes of energy auditing, energy conservation and energy generation, using photovoltaic modules and parabolic trough collectors on an existing institutional building in a trial to convert it into NZEB or nNZEB. Based on the present results, the following conclusions can be drawn:

- Preliminary energy audit, energy conservation and efficient operation strategies of the building result in an annual energy saving of about 543 MWh which is equivalent to about 28% of the building consumption without the need to any retrofitting or investments.
- Efficient energy conservation can play an important role in converting the existing buildings into NZEBs as it saves a significant portion of annual energy consumption of the building.
- The integration of PV modules into the building produces about 16% of the building energy consumption (224 MWh) and can completely cover the lighting and equipment load of the building.
- Parabolic trough collectors of optimum area of 765 m2 can satisfy significant portion of the cooling load which is about73% of the total building cooling load.
- Total avoided CO2 emission of about 680 metric ton/year can be achieved.
- Nearly NZEB can be achieved in existing buildings by re-commissioning the building, installing better performance HVAC systems and other equipment and integrating efficient PV modules and parabolic trough collectors.
- The results of the present work should encourage governments for wide installation of solar energy systems to keep our environment healthy and clean.

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