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Using Adsorption Chiller in Solar Cooling: Economic Benefits for Jordan

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ABSTRACT

Jordan has been facing a rigorous economic problem related to the high cost of energy. One of the main reasons is the cost of subsiding imported fuels to produce electricity for its domestic uses. The importation of energy represents more than 10% of its gross domestic product (GDP) despite it has plentiful resources of renewable energy that can cover all its needs from electrical energy, while the national resources of energy in Jordan cover only 3-4% of the country's energy needs. This study investigates the potential of using the technology of cooling air by solar energy (CASE) for air-conditioning applications to minimize the consumption of energy in Jordan. The main objectives of this work are to provide an overview of different commercially available CASE technologies and analyze the economic feasibility of selected CASE technology. The study of the economic feasibility has been done on the CASE technologies used for four scenarios. Analysis of data collection and assessment of economic viability in comparison to conventional VCC was also investigated. The results showed the relevance of the economic feasibility with the cost of electricity tariff, it also showed that the use of this device is feasible at a high electricity tariff; while there is a high risk on feasibility at a low electricity tariff.

Keywords: Adsorption Chillers, Vapor Compression Chillers, Economic Feasibility
JEL Classifications: C54, Q20, Q43, Q55

1. INTRODUCTION

The increase in the temperature of climate change will increase the cooling load, and thus consume higher energy in the air-conditioning. All previous indications show that the CASE technology has the potential to remarkably reduce the consumption of electricity that contributes to economic development. There are two systems of air-conditioning of building in Jordan which are for aqaba residency (AR) and dead sea hotel and spa (DSHS) with a cooling capacity of 10 kW and 17.5 kW respectively. This is due to the high initial cost, as well as, the higher technical hurdle accompanied by these systems, which are designed for different weather conditions than those for Jordan, and lastly, the lack of experience in these technologies.

The main objectives of this study are to provide an overview of various commercially available CASE technologies and analyze

the economic feasibility of selected CASE technology in Jordan. These objectives will be attained by answering the following:

- Are the CASE systems save energy compared with conventional systems in Jordan?
- Is the use of CASE being economically feasible in Jordan?

Analysis of data collection and valuation of economic viability in comparison to classical VCC was also studied. Three SCS are commercially used, which are "Absorption Chillers, Adsorption Chillers, and Desiccant Systems" (Solem, 2008). The adsorption chiller is divided into single effect cycle (SEC) and double effect cycle (DEC). The most widespread chillers are absorption chillers. About 60% of the existing solar cooling system is operating with absorption chillers and about 11% with adsorption chillers, (Jakob, 2009). Vapor Compression Cooling (VCC) Cycle is the most commonly used in cooling systems (Moran and Shapiro, 2006). These types of VCC is generally used, which are reciprocating

compressors, screw compressors and centrifugal compressors. The main idea of thermal CASE technology is to use different STC as heat sources for thermal driven chillers, Figure 1.

It is important to understand the thermodynamic principles of thermal drive chiller, Figure 2 describes these thermodynamic principles:

The cycle of the thermal drive chiller represents the thermodynamic cycle where the heat is absorbed at a specific level of temperature and raised to a higher temperature level where it is rejected. The process scheme can be represented by:

Q_C is the heat reject
Q_H is the heat drive
Q_{Rej} which equal the sum of Q_C and Q_H

The coefficient of performance (CP) of the thermal drive chiller or CASE system is split up into 2 types, as shown in equations 1 and 2 respectively.

Electrical CASE CP ($CP_{E,CASE}$)

Thermal CASE CP ($CP_{T,CASE}$)

$$YSLC = \frac{NCV}{R^{-1}(1 - (1+R)^{-P} lt)} \quad (1)$$

Where $P_{E,CASE}$ is the CASE electric consumption

$$CP_{T,CASE} = \frac{Q_C}{Q_H} \quad (2)$$

A Jordanian company, millennium energy industries (MEI), has developed two stages of adsorption chiller (ADC-2) suitable for the Middle East climate. Table 1 shows the Adsorption chiller versus Absorption chillers (ECO-MAX, 2011).

2. REVIEW OF LITERATURE

Recent inventions in solar energy use were a breakthrough in terms of economic benefits and CO_2 emissions reduction that were the primary focus of scientific research studies on solar air cooling's energy and economic impact. Nonetheless, several themes emerge from these studies. For example, Fu et al. (2021) investigated an advanced adiabatic compressed air energy storage system with a variable pressure ratio based on the organic Rankine cycle to improve compressed air energy storage's cycle efficiency. The thermodynamic model of the system is established and used to calculate the thermodynamic characteristics of the system. When compared to advanced adiabatic compressed air energy storage, the results indicate that the system with a variable pressure ratio reduces compression process power consumption by 12.45% and increases expander output power by 37.29%, thereby increasing the system's cycle efficiency from 40.16% to 63.00%.

Ma et al. (2019), on the other hand, used a cost-benefit analysis to determine the optimal integration of the recompression CO_2 Brayton cycle with primary compression inter-cooling. Sensitivity

Figure 1: Basic principle of thermal drive systems
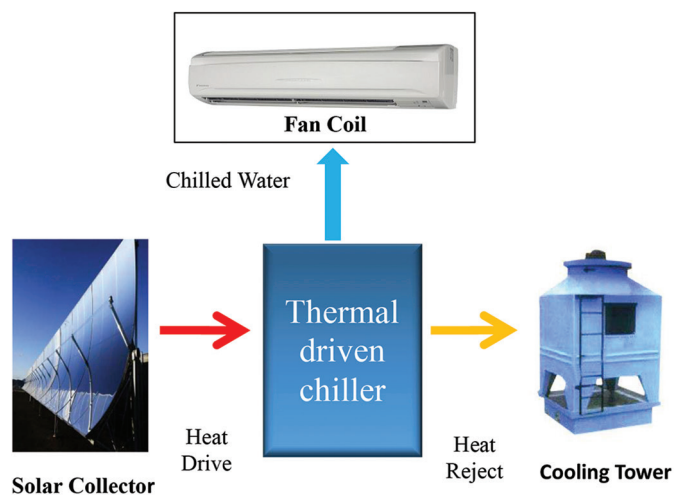
Figure 2: Basic process scheme of a thermal drive chiller (Fraunhofer 2009)
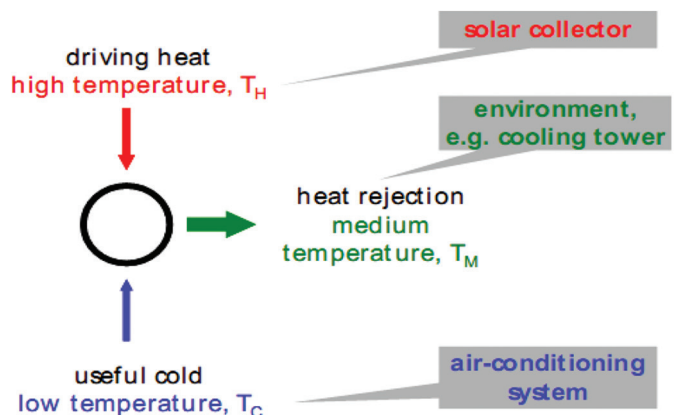
analysis demonstrates the effect of solar component cost and design on the optimal $CO_{2\ cycle}$ integration, indicating that under certain solar component cost and design conditions, the optimal cycle layout may degrade from recompression to a simple recuperating cycle. Additionally, Zhang et al. (2019) developed a model based on the characteristics of a real-world wind farm in China with a capacity of 49.5 MW. Medel results indicate that it was possible to increase the compressor and expander operational ranges of the proposed system by 70.85 and 27.27%, respectively. Additionally, the results indicate that after integration with the specified system, wind power (average: 21.05 MW) with fluctuations up to 49.5 MW can be stabilized to 18.64 MW of steady electric power, increasing the wind power utilization coefficient from 26.29 to 71.02%. Ratlamwala and Abid (2018) compared the performance of multiple-effect absorption refrigeration systems. Solar energy is used to power the absorption cooling cycles, maximizing the efficiency of high-temperature heat sources used in absorption systems. The absorption refrigeration cycles with multiple effects are modelled and designed for identical refrigeration capacity and operating conditions. The coefficient of performance (CP) and energy efficiency of absorption cooling cycles are determined using the engineering equation solver. The performance of solar parabolic trough collectors was simulated

Table 1: Absorption versus adsorption chillers

Attribute	Absorption chiller	Adsorption chiller
Continuous operation	Daily dilution of LiBr solution for shutdown maintenance	Possibility of continuous operation for 8000 h/years. and more
Time for startup and shutdown	Dilution cycle required	No requirement for a specific procedure. Reach to full capacity in a maximum of 8 min without any –ve impact from losing power.
Maintenance	Continuous monitoring and maintenance are required including: 1. Controls; 2. Pumps; 3. Liquid analysis; 4. Exchange Li-Br; 5. Air leak; 6. Backup boiler. Replacement of heat exchanger; 8. Approximately $20K-$30K/year. for full maintenance	1. Replace vacuum pump oil when needed (advised to replace every 5 years.) 2. Condenser tubes annual cleaning 3. Approx. $5000/year. or less, depends on the cost of labor
Chemistry	Distilled water and LiBr	Municipal water and silica gel

under a variety of operating conditions, including the effect of heat transfer fluids (nanofluids). The coefficient of performance of the triple effect absorption refrigeration cycle is 1.752. The double effect absorption refrigeration cycle is perceived to have a higher coefficient of performance (51.9%) than the single effect absorption refrigeration cycle (0.852).

Another study also used experimental and numerical methods to investigate the use of an advanced metal-organic framework adsorbent material in a one-bed adsorption system for water desalination and cooling applications. It investigated the effect of operating parameters on cycle water production and cooling. They presented an analytical simulation model for forecasting cycle outputs under a range of operating conditions. Cycle outputs increased as the temperature of the evaporator increased and the temperature of a condenser decreased. Additionally, open-loop adsorption desalination cycles were demonstrated to operate with a condenser pressure less than the evaporator pressure, Youssef et al.(2017). Kojok et al. (2016) researched one of the hybrid cooling systems, which are an energy-efficient method of cooling buildings. The study concluded that a properly chosen hybrid cooling system can significantly reduce energy consumption and improve performance, with the coefficient of improvement differing according to climate and system design. They utilize various hybrid cooling systems and their associated individual cooling machines in detail. To begin, a brief overview of the state of the art is provided for the most commonly used individual cooling systems in hybrid cooling for building use. Then, hybrid cooling systems are classified into five broad categories based on the combination of cooling processes or machines: vapor compression-based cooling, absorption-based cooling, adsorption-based cooling, desiccant-evaporative cooling, and multi-evaporator cooling. Each category contains the investigated

configurations and the advantages of each hybridization method. Each hybrid system is designed to maximize the benefits of the various cooling methods used. However, if the hybrid system is not appropriate for the climatic zone in which it will be used, it may have negative consequences. Giwa et al. (2016) examined recent advances in humidification dehumidification (HDH) desalination processes to demonstrate the enormous economic benefits of HDH technology. This article discusses the fundamental components of HDH systems, the latest research on HDH systems powered by renewable energy, and recent advancements in HDH design for sustainable water production. It is worth noting that the key characteristics and sustainability aspects of HDH desalination technology are still being developed, and additional improvements are required to optimize process performance parameters such as the amount of water produced, the amount of renewable energy required, and the cost of water produced. However, it has been demonstrated that HDH technology is cost-effective. Grossman (2002) discussed the current state of solar-powered air conditioning. The study confirms that the majority of closed-cycle heat-powered cooling devices are absorption chillers, a long-established technology that utilizes the working fluid pair LiBr–water. However, these systems require the use of high-temperature solar collectors. We discuss the fundamentals of multiple-stage absorption systems. Economic analysis of the system reveals that the solar component accounts for the lion's share of the total system cost. Additionally, it demonstrates that the alternative at high temperatures is still more expensive than the alternative at low temperatures.

To conclude, an examination of these fields in the literature reveals that their application was either limited to developed countries or was theoretical. While emphasizing the theoretical methodology, this study focuses on the application of solar air cooling with a two-stage adsorption chiller in a developing country: Jordan, thereby contributing to knowledge in this field.

3. METHODOLOGY

RETSCREEN software was used to conduct the economic analyses for different scenarios based on the following assumptions:
1. The cost of a VCC is around 1000 JD (approximately 1,41 USD) per kW of cooling
2. There has been a 4% increase in the price of gasoline
3. Inflation is 4%
4. There is a 4% discount rate
5. The value of salvage is 15% of the purchase price
6. Cost of maintenance costs for both proposed and base cases was omitted
7. The price of tCO_2 is 26.6 JD
8. T & D losses account for 13.16 per cent of total revenue (Jakob, 2009).

The installed prototype was assessed for AR weather conditions, where the maximum temperature reaches 40°C. The annual average temperatures for the Aqaba region in °C are shown in Table 2. The BLUE cells show the coldest months and the PINK ones show the hottest months.

Table 2: Average annual temperatures in Aqaba region, °C

Months	J	F	M	A	M	J	J	A	S	O	N	D
Ave. Temperature (°C)	14.7	16.15	19.3	23.85	27.9	31	32.25	32.2	29.85	26.3	20.95	16.05
Max Temperature (°C)	20.5	22.2	25.7	30.7	35.1	38.4	39.4	39.1	36.4	32.7	27	21.8
Min Temperature (°C)	8.9	10.1	12.9	17	20.7	23.6	25.1	25.3	23.3	19.9	14.9	10.3

Source: World Metrological Organization, 2020

The main equipment that makes up the project under study consist of:

- MEI ADC-2
- The heat loop consists of solar water collector storage tank circulation pump piping and fitting
- The heat rejection loop consists of a dry-cooler circulation pump piping and fitting
- The cooling loop consists of a buffer tank and fans coil circulation pump piping and fitting
- Appliances and monitoring units.

In our case study, evacuated tube solar collector (ESC) with compound parabolic concentrator (CPC) is used, as recommended by the chiller manufacture. Solar radiation is commonly depending on azimuth and tilt angles. The SWC was oriented geographically and inclined (tilted) to receive the utmost amount of solar energy radiation on a daily and seasonal basis. The best tilt angle in the summer season for AR was taken from the RETSCREEN software, and it was 20° and 0° for tilt and azimuth angle, at tilted daily solar radiation in summer (February to November) of 6.73 kW-day/m², and 4.18 kW-day/m² in winter (December and January).

4. ECONOMIC ANALYSIS

Evaluation of installed prototype at Aqaba weather condition has been done to determine and analyze the economic feasibility for the operating of ADC-2 cooling systems The primary reason for using CASE technology is to decrease the operating costs, as well as, emissions of greenhouse gases (GHG). As a result, economic analysis is used in this part of a study to determine if the use of ADC-2 systems is feasible economically. To determine the CASE system feasibility, operating cost (OC), capital cost (CC), and maintenance cost (MC) are added together, taking into consideration time-money value to calculate the total project "lifecycle cost. Note that, the different expenses associated with CASE systems are un-steady and it is varies depending on the project. Solar cooling capital cost including a chiller, medium, cold, and hot water pumps, heat reject solar thermal system, safety, and control features, as well as installation and support. Typically, the cost of the solar collector field is the largest component of the total system cost breakdown. The term "running cost" refers to the electrical consumption costs associated with the use of medium, cold, and hot water pumps and a chiller used in this work. The following equation represents the electrical energy consumption for the case study:

$$P_{E,CASE}=P_{rej}+P_{ch}+P_{chr}+P_{h} \quad (3)$$

where $P_{E,CASE}$ is the **CASE** system electric consumption, P_{Rej} is the heat reject electric consumption, P_{h} is the heat drive electric consumption, P_{ch} is the chilled water electric consumption, and

P_{chr} is the chiller electric consumption. The VCC consumption of electrical energy can be measured using below equation (4):

$$P_{E,VCC} = \frac{Q_c}{CP_{VCC}} \quad (4)$$

where
$P_{E,VCC}$ is the VCC system electric consumption.
Q_{C} is chiller cooling capacity.
CP_{VCC} is the coefficient of performance of VCC.

The save in the consumption of electric energy can be measured using the below equation (5):

$$\Delta PE=P_{E,VCC}-P_{E,CASE} \quad (5)$$

The saving of cost in electricity can be calculated by multiplying equation 5 with the annual operating hour (H) and price of electricity EC as follows:

$$SC_{elec}=H \times EC \times \Delta PE \quad (6)$$

Where SC_{elec} is the save of cost in electricity, thus the consumption of real electric

energy can be measured from the below equations (7 and 8).

$$P_{R,E,VCC} = \frac{P_{E,VCC}}{\eta g} \quad (7)$$

$$P_{R,E,CASE} = \frac{P_{E,CASE}}{\eta g} \quad (8)$$

where η_g is the efficiency of the electrical grid with T & D. The real save in the consumption of electric energy ΔPE_R can be measured from the below equation (9):

$$\Delta PE_{R}=P_{R,E,VCC}-P_{R,E,CASE} \quad (9)$$

Where $P_{R,E,VCC}$ is the real VCC system electric consumption, and $P_{R,E,CASE}$ is the real CASE system electric consumption. The fossil fuel save can also be measured if the heat rejects from CASE are used to involve a load of heating, such as hot water for homes and industries, or other purposes, and when using the SWC for heating uses in winter. The saving in the consumption of diesel can also be measured if the diesel boiler is used to cover a load of heating, based on the below equation (10):

$$V_{D} = \frac{Q_{Rej} \times \eta_{Rej}}{H_{VD} \times \eta_{Boiler} \times \rho_D} \quad (10)$$

Where Q_{Rej} is the heat reject, η_{Rej} is the electric efficiency of the heat reject, V_{D} is the consumption of diesel, H_{VD} is the value

of diesel heating, η_{Boiler} is the efficiency of the boiler, and ρ_D is the density of diesel, which is equal to 0.950 kgL^{-1}. By the use of heating of solar, the save in the consumption of diesel is also be measured. This can be achieved when using the diesel boiler to include a load of heating, based on the below equation (11):

$$V_D = \frac{Q_{SWH} \times \eta_{SWH}}{H_{VD} \times \eta_{Boiler} \times \rho_D} \quad (11)$$

where Q_{SWH} is the capacity of SWH, and η_{SWH} is the electric efficiency of SWH. Equation (11) above is used to find the saving cost of diesel as follows:

$$SC_D = V_D \times PD \times H \quad (12)$$

Where SC_D is the diesel's saving cost, and PD is the price of diesel. The lower maintenance costs associated with adsorption technology are a result of the integration component acting as a solar collector, and not because of the use of a chiller, which has smaller highly stressed movable parts than for VCC. The calculations in this work have been made without regard for maintenance costs, as such costs do not exist in Jordan. The cost of maintenance varies significantly depending on the site conditions. The payback period (PP) can be defined as "the number of years required for the project cash flow equivalent to the total investment." This period does not represent a measurement of how a project is lucrative comparing with other ones, but it is a sense of time that denotes the number of years needed to recover the investment of one project versus other. The payback period should not be taking into account as the main metric for a project evaluation; The payback period should not be taking into account as the main metric for a project evaluation. The method of payback period neglects the money of the time value and the impact of inflation, and this represents another criticism of this method. The project' net current value (NCV) is the value of all future cash flow, deducted at the current value of the currency. It is measured by deducting all cash flow as shown below (equation 13). The net current value (NCV)

$$NCV = \sum_x^{P_{lt}} C_x (1+R)^{x-1} \quad (13)$$

Where C is the cash flow of money, P_{lt} is a project's lifetime (years.), and R is the rate of discount.

The yearly saving of life cycle (YSLC) is the nominal level of every year saving and it can be measured from the below equation (14):

$$YSLC = \frac{NCV}{R^{-1}(1-(1+R)^{-P_{lt}})} \quad (14)$$

Different scenarios were assumed to check the economic feasibility of ADC-2 based on weather and markets in Jordan. This has been done using RETSCREEN software package. Table 3 shows the different scenarios investigated in this study.

The design and components for various scenarios are based on:
- A load of daily cooling is larger than the capacity of MEI ADC-2
- The rest of the load will be covered by VCC. Based on this assumption and scenario, the VCC's size will be lesser than a load of the day cooling through the ADC-2 capacity. The decrease in the cost of VCC will be reduced from the price of ADC-2
- The cooling month in this work is presumed based on 10 months (February-November), while January and December are assumed for heating
- The calculations of temperature were assumed based on 32°C of surrounding temperature, and 18 °C for the temperature of chilled water.

4.1. First Scenario
The first scenario is assumed as follows: ADC-2, Heat Drive System, Heat Reject System, and Monitoring Units. In this study, a "Wilo Stratus" model is used because it is highly efficient to permits a saving in a power up to 90% compared to another un-controlled pump. The electric consumption for this pump is 296 Watt. To regulate and check the effectiveness of the system, a monitor with flow meters for HW, MW, and CW is required to be utilized with temperature sensors for the inlet and outlet of all circuits. Table 4 shows the first scenario acquisition cost.

Where the total consumption of electricity is 695 Watt, $CP_{E, CASE}$ is 14.2 Watt and η_{SWH} is 9912 %.

Table 3: Scenarios of the study

Type of scenario	Heat rejection sink/ technology	Heat driven source/ technology
Scenario 1	Ambient/dry cooler	CPC collector/Solar energy
Scenario 2	Heat recovery sys.	CPC collector/Solar energy
Scenario 3	Ambient/dry cooler	Waste heat
Scenario 4	Heat recovery sys.	Waste heat

CP is the compound parabolic concentrator

Table 4: First scenario acquisition cost

Component	Cost (JD)*	Total Cost (JD)*
Chiller		
MEI ADC-2 + Installation and Piping		12,200
Heat driven		
21 Compound parabolic concentrator solar water collectors + hot water storage tank and installation	860	18060
Water pump for hot water stratos Model 25/1 10 CANPN10	490	490
Heat reject		
Dry Cooler Model GEADXC 132H EC2 15 with Shipping	7660	7,660
Water Pump (Medium) Stratos Model 40/1 12 CANPN6/10	970	970
Monitoring units		
3 × convertors and flow meters with shipping	710	2,130
8 × Temp. Sensor	160	1,280
Laptop computer	520	520
Total		43,310

* 1JD = 1.41 USD

4.2. Second Scenario

The difference between this scenario and the first one is in the method of heat rejection. The second scenario was accomplished using a SWEP B12MT ×60 heat exchanger (a Sweden company specialized in the plate heat exchanger). The cost of acquisition for the second scenario is the same as in Table 4 above, except for the process of heat reject that is done by the use of a heat exchanger. The cost of Plate "heat exchanger B12 MT ×60" including shipping is 397JD (Approx. 560USD) which leads to a total cost of 35,671 (Approx. 50,000USD) JD rather than 43,310 (Approx. 61,000USD) for the first case. The consumption of electricity for this scenario is similar to the first scenario, except for the process of heat reject which is done "Stratos Pump 40/1-12 CAN PN6/10 with the total consumption of electricity of 548 Watt rather than 695 Watt for the first scenario.

4.3. Third Scenario

The difference between this scenario and the first one is the heat drive source. In this work, the heat waste is presumed to arrive as hot water at a temperature value of 95°C. A 30 Kw energy heat exchanger will assist to use the heat waste to operate the chiller. A "SWEP B10T × 54" plate heat exchanger is chosen in this scenario, and the feasibility of its economy is calculated related to its cost. The cost of acquisition for this scenario is similar to those in Table 4 above, except for the process of heat that has taken place by the heat exchanger. The cost of "B10T × 54" plate heat exchanger including shipping is 332JD (Approx. 468USD), which leads to a total cost of 25,417JD (Approx. 36,000USD) rather than 43,310 (Approx. 61,000USD) for the first scenario and 35,671JD (Approx. 50,000USD) for the second scenario. The consumption of electricity for the third scenario is similar to that for the first scenario, except for the process of heat drive that is done by the use of the "B10T ×54" heat exchanger rather than SWC of 116 Watt used in driving the chiller. This leads to a total consumption of electricity equal to 582 Watt comparing with 698 for the first scenario and with $CP_{E,CASE}$ of 17.2 Watt and η_{SWH} of 6873%.

4.4. Fourth Scenario

The difference between this scenario and the first one is the process of reject and drive the heat source. Table 5 shows the fourth scenario acquisition cost.

Where the total consumption of electricity is 433 Watt, $CP_{E,\,CASE}$ is 23.3 Watt and η_{SWH} is 9259 %.

5. RESULTS AND DISCUSSION

Figure 3 presents the net current value for different scenarios for the fourth residential building block electricity tariff.

For all scenarios investigated, Figure 3 shows that all net current values are higher than zero according to residential building fourth block electricity price. This gives a clear indication that all assumed scenarios are feasible from the economic viewpoint at this electric cost, while the third and fourth scenarios are more appealing than the first and second scenarios. Thus, one should concentrate on the third and fourth scenarios.

The credit effect of carbon on the feasibility will form useful investments' incentives and has a large influence specifically when the NCV is quite low as in the first and third scenarios. For the price of fuel, the base case fuel cost and initial cost are highly sensitive resolved to the feasibility of the economy of the first and third scenarios due to the very low value of the NCV value comparing with other scenarios. Tables 6 and 7 show the sensitivity analysis results.

The result above confirms that the NCV stays larger than zero if the base case fuel cost is decreased by 20% or the initial cost increased by 20%, and there is a little potential for the NCV to become lower than zero as in Table 7. Figure 4 shows the yearly cycle saving for different scenarios.

5.1. Commercial Buildings and Hotels

The NCV of different scenarios is shown in Figure 5 for the commercial buildings and hotels' electric tariffs. The results indicated that the NCV is kept larger than zero according to the electric tariffs of the commercial buildings and hotels. The decrease

Figure 3: The net current value for different scenarios for the fourth residential building block electricity tariff

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
with GHG credit	13,370	194,203	7,489	198,486
without GHG credit	9,572	175,410	5,458	180,577
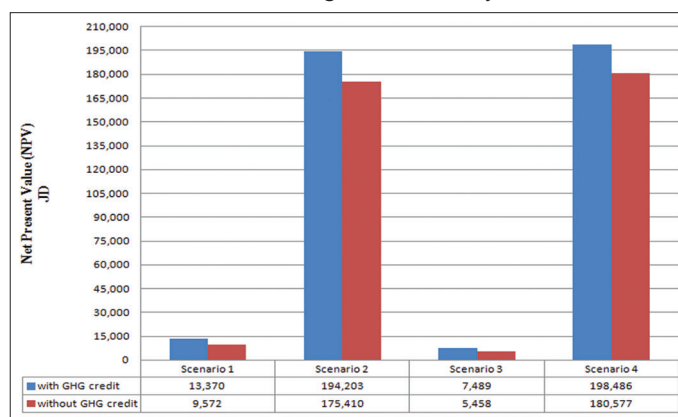
Table 5: Fourth scenario acquisition cost

Component	Cost (JD)*	Total Cost (JD)*
Chiller		
MEI ADC-2 + Installation and Piping		12,200
Heat Driven		
Plate heat exchanger	232 +100	332
Model B 10T × 54 with shipping		
Water pump for hot water	490	490
Stratos Model 25/1-10 CANPN 10		
Heat reject		
Plate heat exchanger	297 +100	397
Model B 12MT × 60 with Shipping		
Water Pump (Medium)	970	970
Stratos Model 40/1 12 CANPN6/10		
Monitoring units		
3 × Convertors and Flow Meters with Shipping	710	2,130
8 × Temp. Sensor	160	1,280
Laptop computer	520	520
Total		18,319

* 1JD = 1.41 USD

in the price of electricity is in the range of 23% comparing with the residential buildings. This leads to a conclusion that all the four case study scenarios are feasible from the point of economic view at this tariff.

The credit effect of greenhouse gases (GHG) on the feasibility will form useful investment incentives and has a large influence specifically when the NCV is quite low as in the first and third scenarios. For the price of fuel, the base case fuel cost and initial cost are highly sensitive resolved to the feasibility of the economy of the first and third scenarios due to the very low value of the NCV value comparing with other scenarios. Tables 8 and 9 show the sensitivity analysis results.

The above results indicate that the NCV of the first scenario remains greater than zero even for the increase of 10% in the initial costs or a decrease of 10 % in base case fuel costs. There is a possibility that the NCV will be lower than zero if there is a decrease of 10% in the cost of fuel or a 10% increase in the initial cost, Table 9. the net current value of the third scenario remains greater than zero even if there is a 10% increase in the initial cost or a 20% decrease in the base case fuel. According to Table 10, the probability of NCV being <0 is very small when the initial cost of fuel is increased by 10%. The annual cycle savings are depicted in Figure 6.

Figure 4: Annual cycle saving for different scenarios for the fourth residential building block electricity tariff (third scenario)
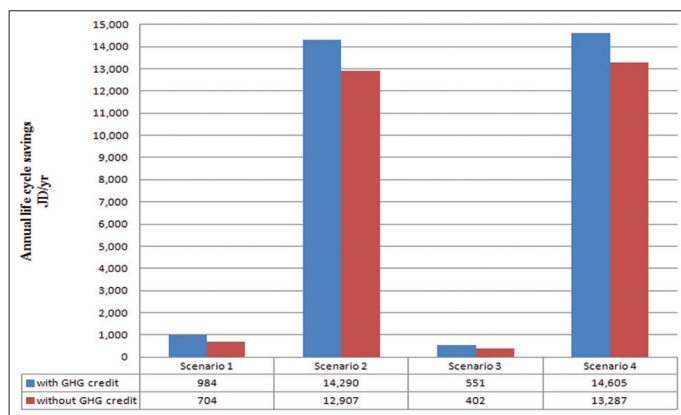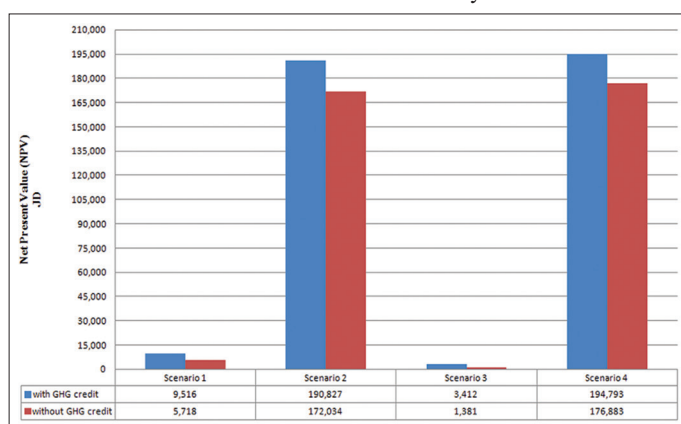

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
with GHG credit	984	14,290	551	14,605
without GHG credit	704	12,907	402	13,287

Figure 5: The net current value for different scenarios for the commercial and hotels electricity tariff

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
with GHG credit	9,516	190,827	3,412	194,793
without GHG credit	5,718	172,034	1,381	176,883

5.2. Minor's Industries

Figure 7 shows the net current value for different scenarios for minor's industries electricity tariffs.

According to the price of electricity for the minor industries, the NCV for the second and fourth scenarios >0. It is close to zero in the first scenario and lower than zero in the third scenario.

Table 6: Analysis of net current value for both cases of fuel costs (initial and base) for the fourth residential building block electricity tariff (first scenario)

Sens. analysis					
Sensitivity range analysis	Net current value 20.1%				
		Base case fuel cost			*JD
Initial Cost (JD)	1,618	1,811	2,017	2,216	2,417
%	−20%	−10%	0%	10%	20%
26,344 −20	8,112	12,132	16,159	20,188	24,217
29,652 −10	4,814	8,835	12,866	16,895	20,924
32,947 0	1,520	5,541	9,572	13,601	17,630
36,232 10	−1,781	2,251	6,279	10,308	14,337
39,538 20	−5,069	−1,044	2,985	7,014	11,043

*1JD=1.41 USD

Table 7: Analysis of net current value for both cases of fuel costs (initial and base) for the fourth residential building block electricity tariff (third scenario)

Sens. analysis					
Sensitivity range analysis	Net current value 20.1%				
		Base case fuel cost			*JD
Initial cost (JD)	814	916	1,018	1,119	1,221
%	−20%	−10%	0%	10%	20%
12,328 −20	4,471	6,506	8,542	10,577	12,612
13,881 −10	2,929	4,965	7,000	9,035	11,070
15,422 0	1,388	3,423	5,458	7,493	9,529
16,963 10	−154	1,881	3,916	5,952	7,987
18,503 20	−1,696	340	2,375	4,410	6,445

*1JD=1.41 USD

Table 8: Analysis of net present value for both cases of fuel costs (initial and base) for the commercial and hotels electricity tariff (first scenario)

Sens. Analysis					
Sensitivity range analysis	Net current value 20.1%				
		Base case fuel cost			*JD
Initial cost (JD)	1,418	1,593	1,769	1,951	2,129
%	−20%	−10%	0%	10%	20%
26,344 −20	5,217	8,759	12,307	15,850	19,389
29,639 −10	1,929	5,471	9,014	12,557	16,099
32,941 0	−1,364	2,178	5,721	9,259	12,806
36,232 10	−4,659	−1,120	2,427	5,971	9,509
39,519 20	−7,952	−4,409	−871	2,676	6,220

*1JD=1.41 USD

Table 9: Analysis of net current value for both cases of fuel costs (initial and base) for the commercial and hotels electricity tariff (third scenario)

| Sens. Analysis					
Sensitivity range analysis	Net current value 20.1%				
			Base case fuel cost		*JD
Initial cost (JD)	101	114	126	140	151
	%	−20%	−10%	0%	10%	20%
12,328	−20	4,968	4,719	4,468	4,213	3,966
13,881	−10	3,426	3,178	2,919	2,676	2,419
15,422	0	1,878	1,629	1,379	1,129	879
16,963	10	339	91	−161	−413	−659
18,503	20	−1,204	−1,449	−1,704	−1,949	−2,201

*1JD=1.41 USD

Table 10: Analysis of net current value for both cases of fuel costs (initial and base) for the small industries electricity tariff (third scenario)

Sens. Analysis					
Sensitivity range analysis	Net current value 20.1%				
			Base case fuel cost		*JD
Initial cost (JD)	1,151	1,294	1,440	1,582	1,726
	%	−20%	−10%	0%	10%	20%
12,328	−20	1,272	4,148	7,026	9,901	12,777
13,881	−10	−2,022	855	3,734	6,607	9,484
15,422	0	−5,315	−2,439	437	3,314	6,190
16,963	10	−8,609	−5,732	−2,856	20	2,897
18,503	20	−11,902	−9,026	−6,150	−3,273	−397

*1JD=1.41 USD

Figure 6: Annual cycle saving for different scenarios for the commercial and hotels electricity tariff
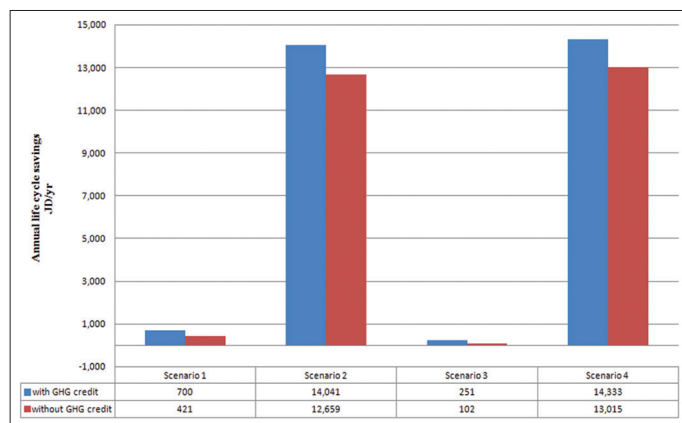
This gives a clear indication that the investment in the first and third scenarios is not feasible for the electricity prices of minor's industry. Additionally, the effect of GHG credits (carbon credits) is very strong when electricity prices are low, creating an extremely encouraging incentive for investment in CASE technology. To confirm the economic feasibility of the first scenario, the price sensitivity for both cases of fuel costs (initial and base) were used. Table 10 shows the sensitivity analysis results.

Figure 7: The net current value for different scenarios for the minor's industries electricity tariff
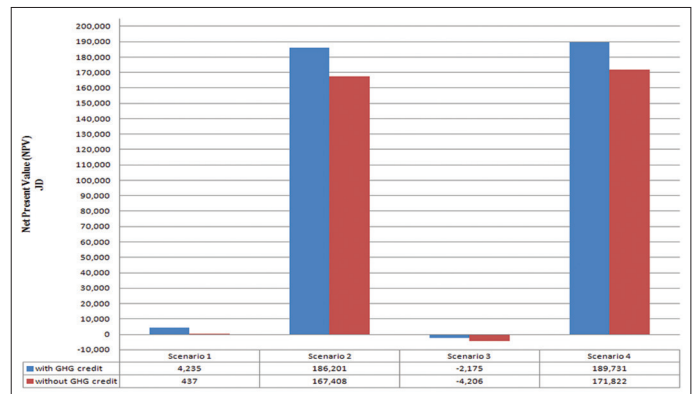
Figure 8: Annual cycle saving for different scenarios for the small industries electricity tariff
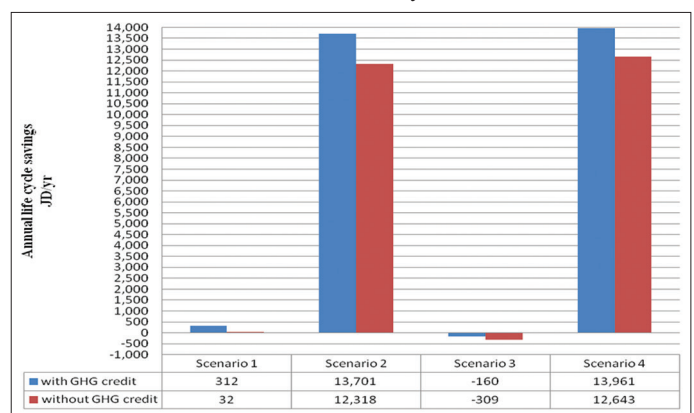
The above results indicate that there is a large risk to invest in the first scenario at the electric price of smaller industries, at which NCV will be lower than zero if there is a decrease of 10 % in the cost of fuel or a 10% increase in the initial cost. The annual cycle savings are depicted in Figure 8.

6. CONCLUSION

This work shows that the use of two stages adsorption chiller is feasible from the economic point of view, especially for Jordan's weather. The analysis of the study on the technology of cooling air by solar energy using two stages adsorption chiller shows that this technology is more economically viable than those for vapor compression chillers, owing to the lower greenhouse gasses emissions and higher electricity tariffs associated with vapor compression chillers. This is in addition to the find out the economic risk at low prices, such as the risk accompanied by small industries that do not reuse the heat reject. The greenhouse gasses credits have been specified as a remarkable spur for using cooling of air by solar energy, specifically for the case of electricity of low tariff.

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