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Performance and Economic Study of Large-Scale Air-Conditioning System Using Renewable Energy Sources

A. Khalil[a], S. A. El-Agouz[1], M. O. A. El-Samadony[1] and Sh. M. El-Hetamy[2]

[1]Mechanical Power Eng. Department, Faculty of Eng., Tanta Univ., Egypt
[2]Higher Institutes for Engineering &Technology, El-Obour, Egypt.

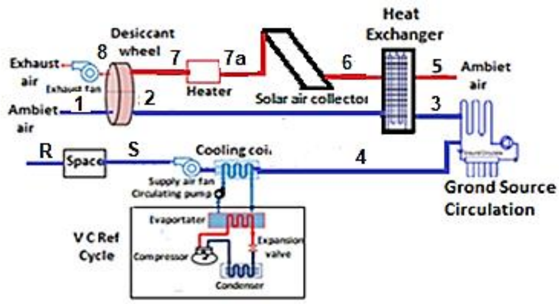
Abstract
As a result of the effects of climate change and global warming, air conditioning demand is increasing quickly. Continuous usage of conventional electric air-conditioning with electricity produced by the combustion of fossil fuels would constantly increase of greenhouse gases and significantly worsen global warming. Additionally, demand for air conditioning would keep increasing. Hybrid air conditioning systems provide the potential to save a lot of energy and reduce emissions when compared to traditional air conditioning systems. The thermal analysis of the desiccant wheel, heat exchanger, ground source circulation system, and solar collector for a hybrid air conditioning system is therefore performed in this study, and the system's economic effectiveness is evaluated. The hybrid system is more effective than the vapor compression technique, according to the results. The dynamic investment payback period is about 6 years, based on the results of the economic study, and t the vapor compression system life cycle cost is increasing at a rate that is faster than that of the hybrid air conditioning system. The hybrid system lowers the cooling coil load by 48% as compared to the vapor compression system.
Key words: Hybrid air conditional, Ground source circulation, Desiccant wheel, COP_{th}, life cycle cost.

Introduction

Hybrid air conditioning systems consume less electrical energy than vapor compression systems, which consumes more fossil fuels and pollutes the environment. A significant amount of electrical energy can be saved and a significant amount of carbon credit can be earned by replacing 50 percent of the current market of small AC systems with solar powered adsorption systems. The adsorption system's natural refrigerants have no potential for depletion of ozone and no potential for global heating. Adsorption systems are efficient and noise-free, and less sensitive to shocks and installation location. They do not necessitate regular adsorbent replacement. Since they have few rotating parts and no refrigerant/adsorbent pump, they only need minor maintenance and operation. Corrosion and crystallization issues are not present, as they are in absorbent systems. The degree of flexibility in regeneration temperature for part-load operation is far greater than in absorption systems. A Khalil. [1] studied a small-capacity hybrid desiccant integrated vapor-compression air-conditioning system. They discovered that the payback time was approximately 10 months without any significant additional capital cost when compared to the known split air-conditioning system. The results highlight the HDAC system's potential benefits. Elzahaby et al. [2] compared a hybrid desiccant air conditioning system in pre- and post-cooling configurations to a traditional vapor compression system. They found that the post-cooling hybrid system saved energy, saving nearly 23% of capacity of the cooling coil when compared to vapor compression cycle. The COP of the post-cooling configuration is over two times higher than that of the vapor compression system with reheat. Precooling ensures a low dew point temperature with a COP increase about 70% as compared to VCS with reheat. A rotary honeycomb wheel-based solar-powered desiccant air conditioning system's performance was studied by Kabeel et al. [3] under a variety of input air and radiation intensity conditions. They found that solar radiation and air flow rate have an effect on the wheel's effectiveness. At a flow rate of 90 kg/h, it reaches 0.92 for regeneration and 0.65 for absorption. For a humid and hot climate in North India, D.B. JANI et al. [4] studied experiments on a hybrid solid desiccant vapor compression air conditioning system. They observed that the hybrid system performed better in hot and humid environments due to the addition of a desiccant dehumidifier significantly reduced the humidity ratio. E. Hurdogana et al. [5] studied a novel desiccant-based air-conditioning system. This system includes a desiccant wheel, heat exchangers, fans, an evaporative cooler, an electric heating unit that simulates solar energy, and a refrigeration unit. It was determined that including solar energy into the system increases the coefficient of performance (COP) by 50 to 120%. J. Y. Dai et al. [6] developed a hybrid air conditioning system which includes a desiccant dehumidifier, evaporative cooling, and vapor compression air conditioning. S.A. El-Agouz et al. [7] conducted a thermal analysis of an air conditioning system and its many parts, which included a heat exchanger, a water spray evaporative cooler, a desiccant wheel, a solar collector, and a ground heat exchanger. Three distinct air conditioning cycles are simulated in the study for a variety of zones, including hot-dry, warm-dry, hot-humid, and warm-humid. The findings a better thermal comfort condition in a variety of climes is successfully provided by the desiccant air conditioning system. By using a hybrid system, the supplied air temperature can be reduced from 12.7 to 21.7 ºC across a variety of climate zones. S. Sabek et. al. [8] Solar potential energy can be utilized in Tunisia as a key component in the functioning of new air conditioning technology. Studies using simulation, experimental, or both units, as well as an analytical solution of heat and mass transfer processes in regenerator and air conditioning system (ACS) cores of a heat recovery / desiccant cooling system (HRDCS), could be conducted under Tunisian weather circumstances. The results show that when we use renewable energy for heating and cooling, the system's coefficient of performance improves. In order to provide the necessary human comfort conditions at a low cost, Chauhan [9] presented a combined evaporative-vapor compression-based air conditioning system. Sultan et al [10], investigate five types of adsorbents for desiccant air-conditioning applications. Each adsorbent generates a distinctive type-I, type-II, type-III, type-V, or type-linear water vapor adsorption isotherm, according to the International Union of Pure and Applied Chemistry. Niaz, et al [11], presented desiccant-based air-conditioning solutions for livestock's thermal comfort. For the purpose of storing agricultural products, Mahmood et al. [12] presented experimental research on indirect evaporative cooling and desiccant dehumidification. Compared to vapor compression systems, the suggested system has thermodynamic advantages. Sultan [13] designed a solid-silica-gel-based DAC system to evaluate the system's performance. This research aims to decrease energy consumption for large scale central air conditioning systems.

1. Systems Description

A desiccant wheel, a heat exchanger, a ground source circulation, a vapor compression cycle, a solar air collector, and an auxiliary heater are all part of the hybrid air conditioning system. As illustrated in figure. 1(a), two air streams, process (points 1-R) and regeneration (points 5-8), are employed to prepare the process and regeneration air streams. On the psychometric chart, figure. 1(b) depicts a schematic of the process and regeneration air. After drying the process air in the desiccant wheel (2) is precooled by passing it through the heat exchanger (3), and bypassing ground source circulation (4) in the first air stream. The precooled air (4) is then cooled by going through a cooling coil. At the second air stream, the regenerated air stream (5) is warmed by passing it through heat exchanger (6) and solar air collector (7a), and the preheated air (7a) is heated by passing it through heater (7). At the second air stream, the regenerated air stream (5) is warmed by passing it through heat exchanger (6) and solar air collector (7a), and the preheated air (7a) is heated by passing it through heater (7).



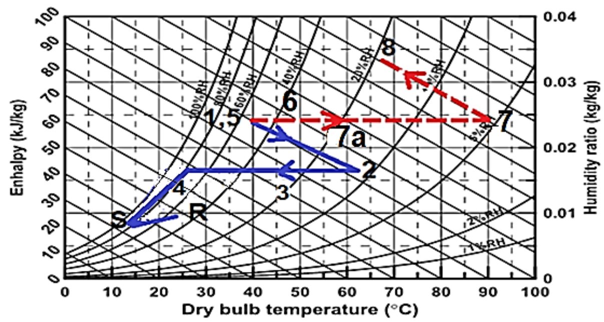


Fig. 1(a) Schematic of process and regeneration air streams through the hybrid system.

Fig. 1(b) Schematic of process and regeneration air on the psychometric chart

2. Cycle performance

The cooling system's thermal Coefficient of Performance (COP_{th}) was calculated by dividing the cooling load system by the sum of regenerated heat and electrical power input to the vapor compression cycle.

$$COP_{th} = \frac{Q_l}{Q_{Reg}+P_{in}} \quad (1)$$

The air's regeneration energy gain was calculated using:

$$Q_{Reg} = m_{Reg}(h_7 - h_6)$$

(2)

P_{in} is the power input for the vapor compression cycle compressor. The energy used by a circulator pump and a ventilation fan is not taken into account in the current study.

3. Case Study

Kafr El Sheikh University's Central Library's air conditioning system performance was investigated through a case study. Data for operational circumstances were collected using the system's file sheet for system analysis. 'HAP' (Hourly Analysis Program), which calculates design cooling and heating loads for this structure to determine required sizes for HVAC system components, is used to estimate the cooling load for the building.

4. Life Cycle Cost Analysis

In this study a typical operating data will be introduced for the theoretical analysis for the present study. The system requires 100% fresh air. This makes the total cooling load of 1600 kW. The system operates 9 hours daily and 150 days a year. Table 5.1 shows the operating data hybrid system. The economic efficiency of the system is evaluated in terms of the relevant economic parameters such as initial cost, running cost and payback period. Initial cost means the money required for construction of different systems. Running costs are made up of maintenance costs and energy costs. The cost of energy is determined by how much power is consumed and how much it costs. The electricity price 1.60 LE/kWh. It is assumed that the operating time is 160 full load day per year.

Present Worth Factor (PWF) can be calculated from the following equation:

$$PWF = \frac{1}{d-i}\left[1 - \left(\frac{1+i}{1+d}\right)^N\right] \quad (3)$$

Assuming that the system has no release value (i.e. its salvage value is zero); life cycle cost (LCC) may be calculated as follows by Riggs et al. [14]:

$LCC = C_{IC} + (PWF * C_{RC})$ (4)

The unacost value (UA), which is defined as the annual worth of the LCC may be calculated as follows by Riggs et al. [14]:

$$\mathbf{UA = CRF * LCC} \quad (5)$$

The CRF may be calculated as follows:

$$\boldsymbol{CRF = \frac{i(i+1)^N}{(i+1)^N - 1}} \quad (6)$$

The life cycle saving is the difference between the present value of the energy saving over the life cycle resulting from used hybrid air conditioning system (HACS) and extra initial investment

According to Riggs et al. [14], life cycle savings (LCS) can be calculated as follows:

$LCS = - \Delta CIC + (PWF * \Delta CRC)$ (7)

Where: $\Delta CIC = CIC\ (HACS) - CIC\ (VCS)$ (8)

$\Delta CRC = CRC\ (VCS) - CRC\ (HACS)$ (9)

A simple crude method for getting a quick evaluation of the alternatives is to calculate how long it takes to recover the initial investment. The time required for any system to recover initial investment is called payback period (PP).

The PP time may be calculated as follows by Riggs et al. [14]:

$$\boldsymbol{pp = \frac{ln[^{\Delta CIC * i}/_{\Delta CRC}]}{ln(i+1)}} \quad (10)$$

5. Numerical Procedures

Desiccant wheel simulation software was used to analyze desiccant cooling cycles. The desiccant wheel simulation is performed. by knowing the input conditions in points 1 and 7, and moreover the wheel parameters. The airstream simulation proceeds by calculating points 3 and 4 with regard to the equations in "Desiccant Wheel," "Heat Exchanger," "Ground Source Circulation," and "Solar Air Collector." The outdoor design condition at point 5 is known in the regeneration air stream, and air regeneration can be estimated at point 6. The effects of the solar air collector can then be calculated using the equations in "Solar Air Collector."

6. Results and Discussion

Fig. 2 and 3 show that the cooling coil load varies with the air temperature inlet and air humidity ratio inlet for a hybrid and vapor compression system, respectively. As indicated in the figures, the cooling coil load in a vapor compression system more than hybrid system. the hybrid system's cooling coil load is about 49% lower than that of the vapor compression system when the air temperature inlet increases from 30 to 50°C. When the air humidity ratio inlet increases from 0.01 to 0.024 kgw/kgda, the hybrid system's cooling coil load is about 47% lower than that of the vapor compression system. As a result, the hybrid system obviously more efficient the vapor compression system.

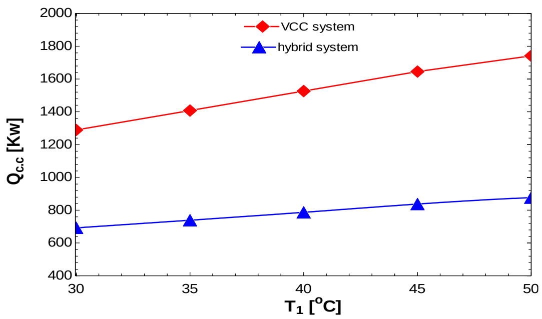


Fig. 2 Variation of cooling coil load for a hybrid system and vapor compression system with inlet air temperature.

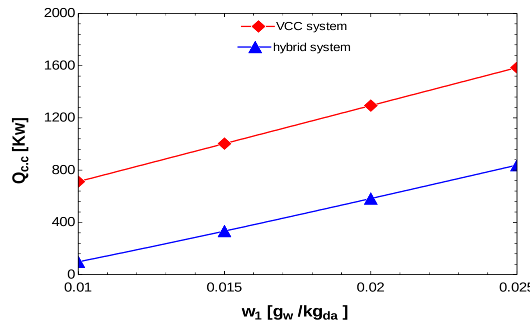


Fig. 3 Variation of cooling coil load for a hybrid system and vapor compression system with inlet air humidity ratio.

Fig. 4 shows the effect of life cycle on life cycle savings (LCS). The LCS increases linearly with the increase of the life cycle with energy cost 1.6 LE/kWh. Fig. 5 shows the effect of life cycle on life cycle cost (LCC). The LCC in the vapor compression system (VCS) is increasing at a faster rate than the hybrid air conditioning system (HACS). The maximum value of LCC is 3.469 x 10^9 LE for VCS, but maximum value of LCC is 1.912 x 10^9 LE for HACS at the end of cycle life with energy cost 1.65 LE/kWh. Fig. 6 shows the effect of life cycle on the unacost value. The unacost value decreases with increasing the life cycle for the hybrid air conditioning system (HACS). On other hand, the unacost value decreases with increasing the life cycle to 3 years as well as, the unacost value increases with increase the life cycle from 3 to 20 year for the vapor compression system (VCS) and hybrid air conditioning system (HACS). Fig. 7 shows the effect of energy cost on LCS and PP, with the LCS reaching 1.044x108 LE at a cost of 1.5 LE/kWh and 1.205 x108LE at a cost of 1.7 LE/kWh. The payback period (PP) decreases with increasing energy cost, reaching 2.216 at 1.5 LE/kWh and 1.956 at 1.7 LE/kWh. Fig. 8 shows the effect of energy cost on LCC. By increasing the energy cost, the rate of increases in LCC for the VCS is greater than that of the HACS, and it reaches to 2.542x10^8 LE for HACS and 2.007x10^8 LE for VCS at the end of life cycle for the energy cost 1.65 LE/kWh. Fig. 9 shows the effect of energy cost on UA. By increasing the energy cost, the rate of increases in UA for the VCS is greater than that of the HACS, and it reaches to 1.865 x10^8 LE for HACS and 2.688 x10^8 LE for VCS at the energy cost 1.65 LE/kWh. Fig. 10 shows the effect of energy inflation rate (i) on LCC and UA. The LCC and UA are almost increasing directly with the energy inflation rate. The LCC for (HACS) increases with 284 % by increasing i from 4% to 16%, as well as The LCC for (VCS) increases by 299 % for increasing i from 4% to 16%.

Fig. 11 shows the effect of energy inflation rate (i) on LCS and PP. The LCC increases directly with increasing the energy inflation rate. The LCS increases with 316.6 % by increasing i from 4% to 16%. On the other hand, the PP decreases with 75 by increasing i from 4% to 16%. Fig. 12 shows the effect of market discount rate (d) on LCC and UA. The LCC and UA are almost decreasing directly with increasing the market discount rate. The LCC decreases with 74.6 % in (HACS) by increasing d from 4% to 18%, as well as, the LCC decreases with 75.7 % in (VCS) by increasing d from 4% to 18%. On the other hand, the UA decrease with increases the market discount rate (d).

Fig. 13 shows the effect of market discount rate (d) on LCS. The LCS is almost decreases directly with increasing the market discount rate. The LCS decreases with 77 % by increasing d from 4% to 18%.

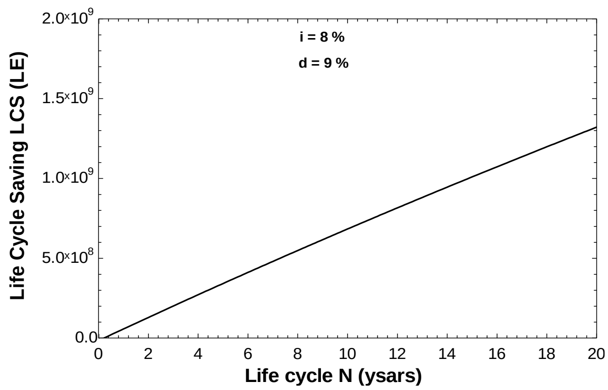


Fig. 4 The effect of life cycle on life cycle savings (LCS).

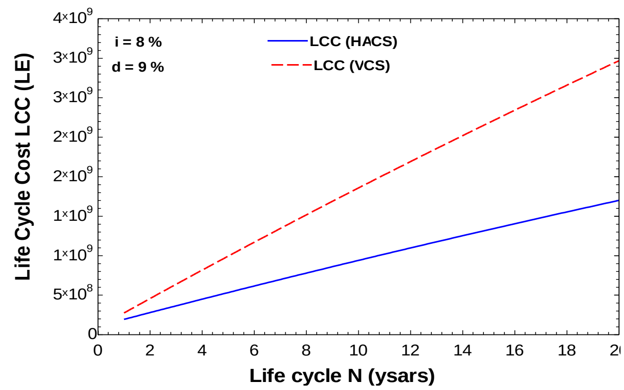


Fig. 5 The effect of life cycle on life cycle cost (LCC).

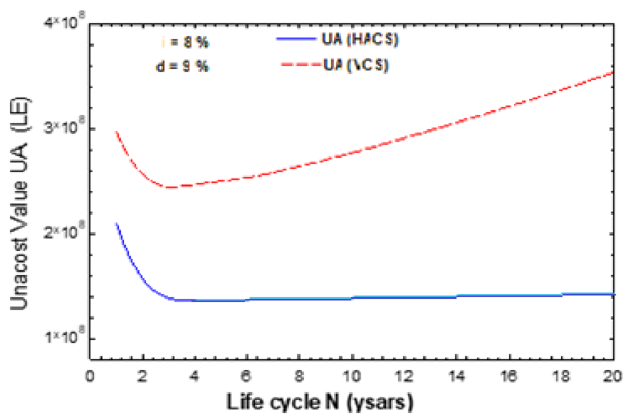


Fig. 6 The effect of life cycle on the unacost value (UA).

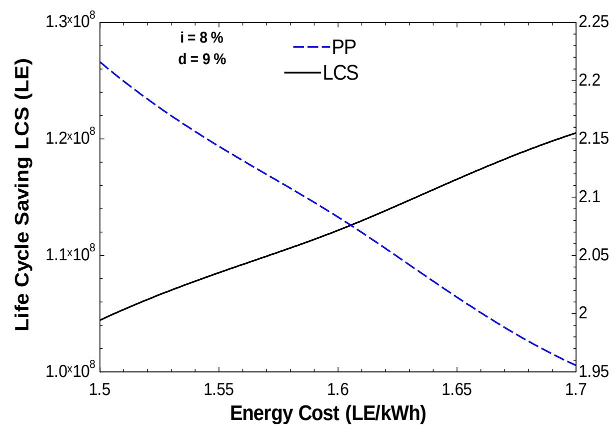


Fig. 7 The effect of energy cost on LCS and PP.

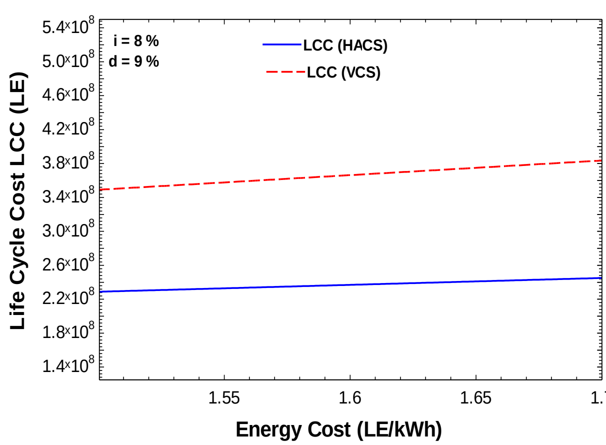


Fig. 8 The effect of energy cost on LCC.

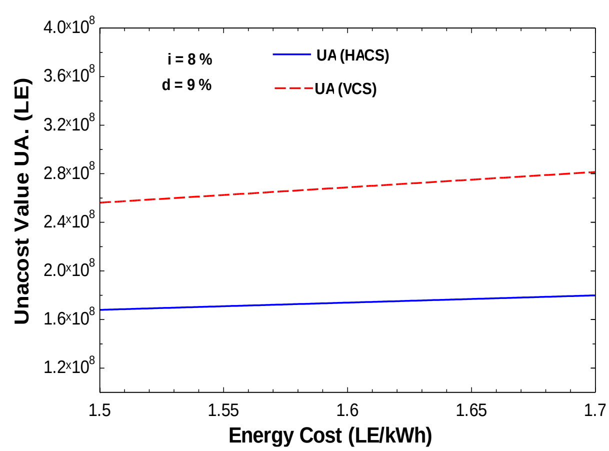


Fig. 9 The effect of energy cost on UA.

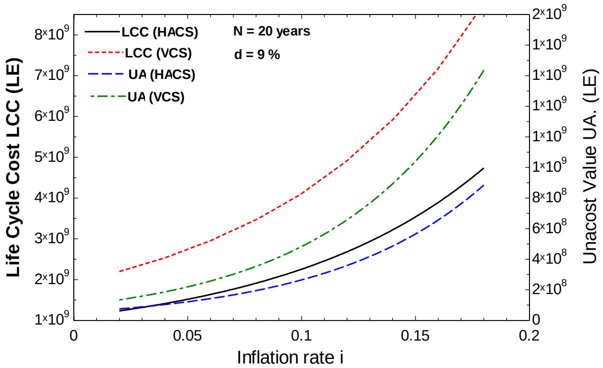


Fig. 10 The effect of energy inflation rate (i) on LCC and UA.

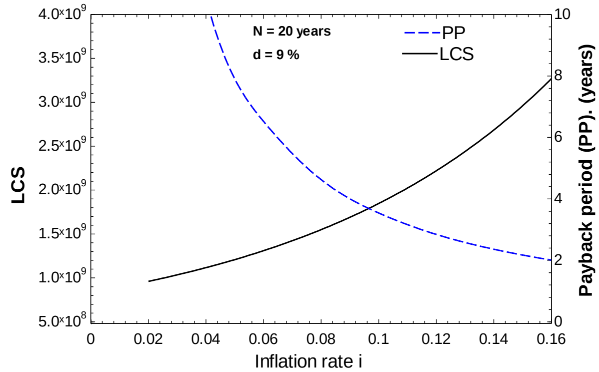


Fig. 11 The effect of energy inflation rate (i) on LCS and PP.

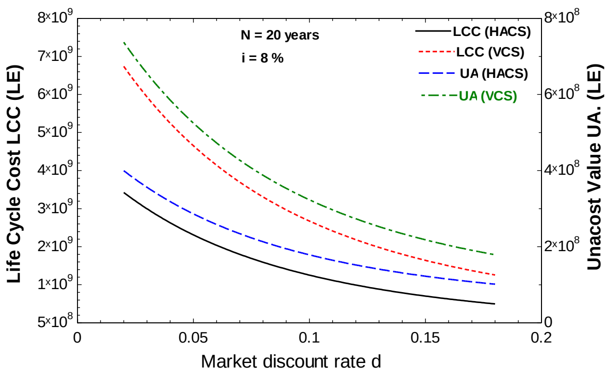


Fig. 12 The effect of market discount rate (d) on LCC and UA.

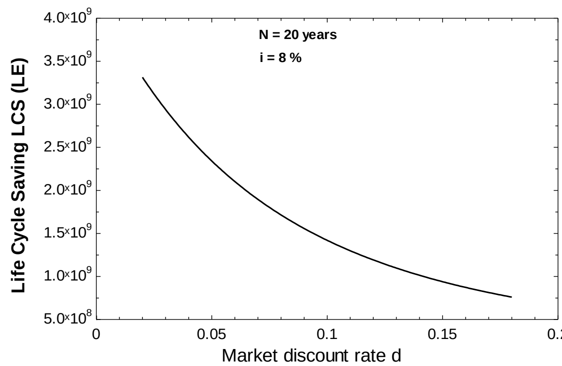


Fig. 13 The effect of market discount rate (d) on LCS and PP.

7. Conclusion

- Hybrid air conditioning system has a low cooling coil load and a high coefficient of performance.
- The initial cost of a solar energy aided hybrid air conditioning system had been found to be around 16231300 LE higher than that of a vapor compression system.
- On the hand, the annual running cost for the conventional vapor compression system is found to be greater than that of a solar energy assisted hybrid air conditioning system by about 93502998.7 LE.
- The results of the economic analysis demonstrate that the dynamic investment payback period is about 3 years in Egypt at an energy cost of 1.65 LE/kWh.

Nomenclature

The following symbols are used in this paper:

COP_{th}: coefficient of performance;
$\dot{m}_{Reg}$: Air mass flow rate
i: energy inflation rate interest rate);
d: market discount rate;
N: life cycle length (years);
CIC: total capital cost of the system (LE);
CRC: annual running cost of the system (LE);
PWF: present worth factor;
LCC: life cycle cost (LE);
UA: unacost value (LE);
CRF: capital recovery factor;
LCS: life cycle savings (LE);
ΔCIC: initial extra expenditure (LE) ; and
ΔCRC: annual running cost savings (LE).

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