Sea Water Air Conditioning [SWAC]: A Cost Effective Alternative

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Abstract

The energy demand for air conditioning is quite extensive due to the hot and humid summer climate in Egypt. The rapid increase in non industrial electricity consumption is due to the rural electrification and the presence of many buildings air conditioned in summer using electricity.

Deep cold ocean and seawater is a valuable natural resource that can be used for energy production, cooling, desalination, aquaculture and agriculture. The most economically viable use of this deep water is to air-condition buildings through a Sea Water Air Conditioning (SWAC) system.

This study reports the results of a technical and economical assessment of the potential for using (SWAC) other than conventional vapor compression systems to air condition hotels at a new tourists resort called “Sahl-Hasheesh”,18km south of Hurghada, Egypt.

This study analyzed and sized the major components of the Sea Water Air Conditioning (SWAC) system, determined the operational performance, and estimated the probable costs. The economic analysis was based on two different methods, the simple pay back and the net present value (NPV) method.

The results showed that the SWAC system is the preferred option for its short payback period as well as the minimum net present value when being applied at Sahl-Hasheesh area. Large energy savings approaching 80% compared to conventional. This is in addition to the low greenhouse gas emissions.

Keywords: *Seawater, HVAC, Sahl-Hasheesh, Economical Study.*

Nomenclatures

Symbol	Description	S.I Units	Symbol	Description	S.I Units
CW	Chilled water	-	i	Interest rate	-
Dep C	Depreciation Coefficient	-	IC	Initial cost	-
Dep K	Depreciation at the year K	-	L	Pipe length	m
HDPE	High Density Polyethylene	-	m^o	Mass flow rate	kg/s
NPV	Net Present Value	-	NOx	Mono nitrogen oxides	-

PLC	Programmable logic controller	-	SOx	Sulphur oxides	-
QA/C	Air conditioning load	kW	SW	Seawater	-
RC	Running Cost	-	VAS	Vapor Absorption System	-
SDR	Standard Dimension Ratio	-	VCS	Vapor Compression System	-
TOR	Ton Of Refrigeration				

1. INTRODUCTION

All current air conditioning systems depend mainly on electricity or heat source to operate their various components, the two main known types of air conditioning are the vapor compression system (electric operated) and the absorption system (Heat operated).

A growing number of scientists and engineers have become concerned about global climate change. This phenomenon shows a strong correlation to human use of fossil fuels. Exponential growth in the build-up of combustion products trapped within Earth's atmosphere is implicated as the primary cause of the "Greenhouse Effect". [1]

The amount of greenhouse gas emissions is expressed in tons of "carbon dioxide equivalents". CO2 has the largest warming potential and as such is used as an index for other greenhouse gases. Egypt ranked the 27th over the world in producing CO_2 emissions year 2006 [2].

Furthermore, one of the main fossil fuels, petroleum, is a finite resource and has been a focus of international conflict. This may be considered as another main reason for searching for new and renewable energy sources or lowering the power consumption.

In order to make a reasonable assessment of the technical and economic feasibility of deep sea water air conditioning, three options were investigated in the economical study.

The first is the use of a conventional air conditioning system. This option provides a baseline for the other options being investigated. The second option is the use of deep seawater only and the third option involves the use of a hybrid system using both a sea water air conditioning and a conventional chiller in series where part of the AC demand will be held by the SWAC and the rest of the demand by the chiller.

Additionally, this study introduces a new air conditioning technique in the Middle East region known as Sea Water Air Conditioning (SWAC) system utilizing a renewable energy source to reduce the electricity consumption. The reduction of the greenhouse gases was estimated.

2. CASE STUDY

SITE (LOCATION)

SAHL HASHEESH [SH] (located 18km south of Hurghada - Upper Egypt) is to be a Resort Community project of a scale and scope that is unprecedented in the region. The project promises to become an Integrated Resort destination of world-class standards.

The typical meteorological year database for Sahl-Hasheesh was used to estimate the gross cooling load for the hotels. HVAC Load Explorer program [3] was used to calculate the air conditioning demands of the on duty hotels and the results were checked manually.

SH is planned to contain 24 hotels at the seaside. Survey has been taken for the site's hotels. Air conditioning load was calculated for "Pyramisa hotel" (on duty hotel) using the (HVAC Load Explorer program) [3] and based on the area of each hotel and the numbers of rooms, the air conditioning load for the other hotels was estimated according to ASHRAE [4,5].

It turns that the sum of all the loads was estimated to be 26,500 TOR. Figure 1 shows the AC load map for Sahl-Hasheesh.

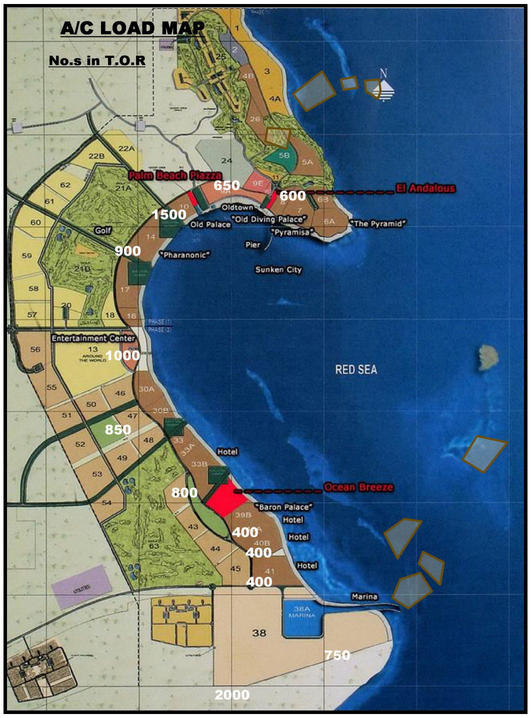

FIGURE 1: Sahl-Hasheesh Master Plan & Load Map

SWAC SYSTEM

A Sea Water Air Conditioning district cooling system consists of a cold seawater supply line, a heat exchanger (at the shoreline), and a closed cycle fresh water distribution system, all with appropriate pumps as shown in Figure 2.

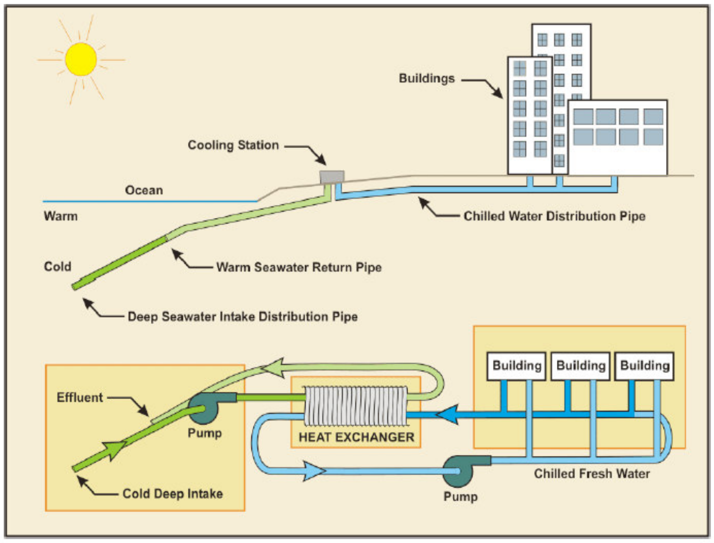

FIGURE 2: SWAC Schematic diagram

Cold seawater is drawn from 600 meters deep at a temperature of 7℃. It follows a long pipeline that lies along the seabed about 500 meters from shore. Pump station delivers the water into a cold water distribution pipe buried under the beach then after getting warmed from the heat exchange.
It is well known that the discharge of thermal heat into seawater imposes an environmental and biological impact on the marine life. This impact is called “Cold shock”. Hence, the seawater is then pumped back to the sea through an effluent pipe at 200 meters depth to avoid biological effect. On the other side the chilled distribution closed loop exchange heat with the air to be conditioned.

For air conditioning hotels in SH, 9-10℃ water is needed to circulate inside the buildings based on Pyramisa hotel request [6], taking into consideration the low relative humidity in SH resulting in low latent cooling load.

To obtain this low temperature for the fresh water, a lower temperature of 7℃ shall be drawn out of the sea circulating through the heat exchanger.

For this purpose an approximate temperature depth profile at SH shown in Figure 3 was obtained for the red sea from the navy forces [7].

Local Bathymetry

From Figure 3, a depth of about 600 m is determined to achieve the desired water temperature (7℃). The SWAC system technical evaluation method begins by outlining coastal regions where the 600 m bathymetric contour (7℃) lies within the minimum distance from shore. For this purpose, bathymetry map for Sahl-Hasheesh area was obtained from the (Egyptian naval forces). By the aid of this map and after the site visit, a pipeline schematic was designed starting from the point at depth 600 m up to the shore at the pump station.

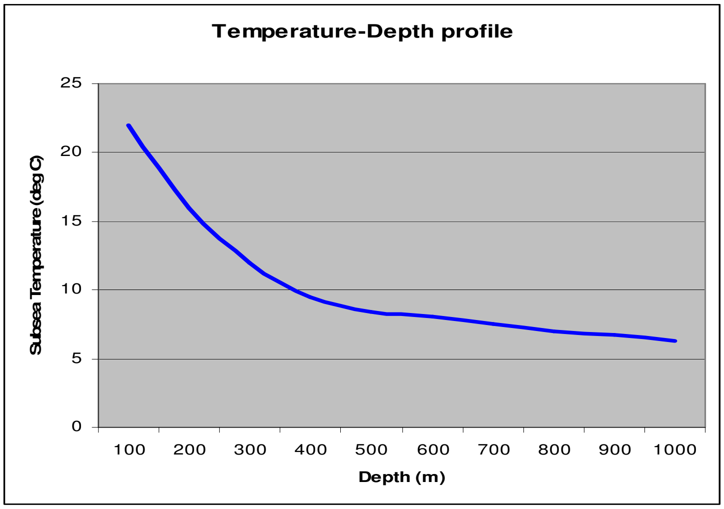

FIGURE 3: Sahl-Hasheesh Temperature-Depth profile

Seawater Pipe

A primary concern regarding pipeline placement is the impact upon SH marine preserve. Two possible pipeline paths have been investigated in this study. Both routes A and B are shown in Figure 4.

Route A is the most direct path between the distribution system onshore and the offshore source, requires the shorter tunneling, not far away from the marine preserve area, and has a landing at the north end of the distribution system. Route B provides cold water to the center of the SH distribution system, thus splitting the seawater flow onshore and allowing smaller pipelines in addition not supplying all the hotels from a single line. Route B provides an alternate pipe landing and an alternative pump station location based on the site visit.

HDPE 1000mm (40"), SDR 11 (Standard Dimension Ratio refers to the outside diameter divided by the wall thickness of the pipe with thickness above 76mm (3") is used to withstand the external pressure on the pipe.

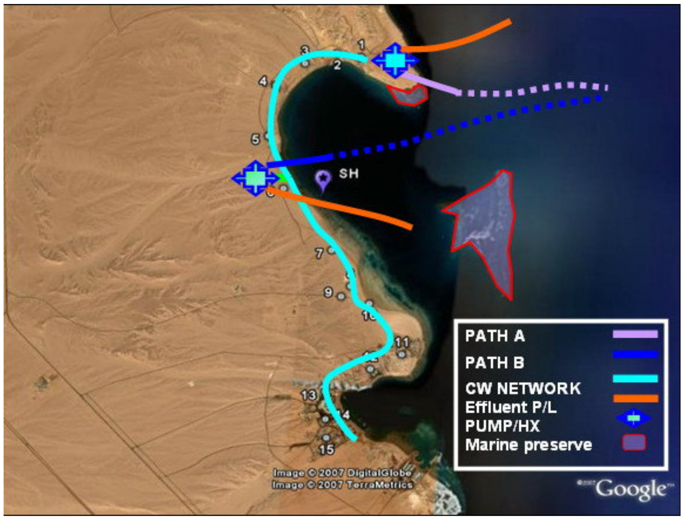

FIGURE 4: Seawater Pipe Route scenarios

Distribution Network

The pump station shall be located halfway of the distribution network in order to decrease the pipe diameters and to secure the availability of AC at least for half of the hotels.

The two lines shown in Figure 5 represent the distribution network feeding the customers where the (North pipeline) represents a pipeline feeding 12,250 TOR and the (South pipeline) represents a pipeline feeding 14,250 TOR of the total expected air conditioning demands in SH.

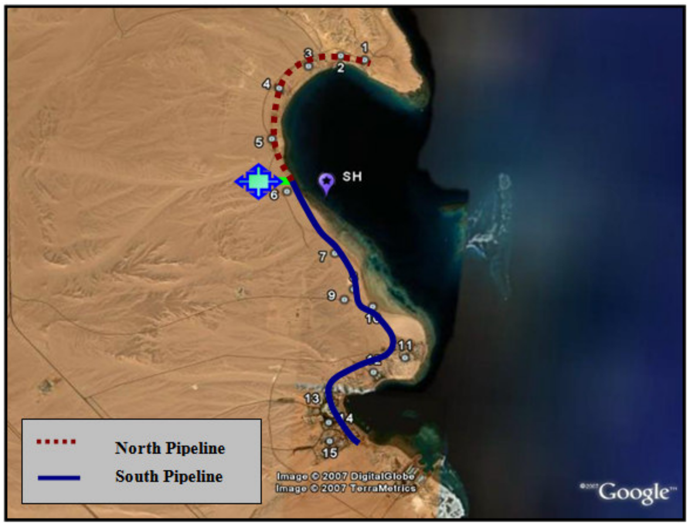

FIGURE 5: Distribution network pass

Each pipe of the above two pipes is divided into two sections with determined lengths and known flow rates feeding the hotels in order to design the network.

Based on the required flow rates and the recommended velocity in pipes, a set range of diameters was chosen from 400mm (16") up to 760mm (30") to be the interest in this study.

Head losses were calculated for each section after determining the flow type and Reynolds's number and the friction factor , hence the corresponding pumping power was estimated and the optimum network diameter was established to be 760 mm. [8].

3. RESULTS & DISCUSSIONS

Technical Analysis

A piping schematic is constructed connecting the district loads and the cold-water supply pipe via a heat exchanger.

Computer program is used to optimize the piping network for best ratios of capital expenditure versus displaced electricity, which is the driving variable.

The head losses in all distribution, deep seawater supply, and return pipelines are determined based on optimal pipe sizes that are staggered throughout the system. The required pressures are set for each user and total system pressure is computed to provide all customers the minimum desired pressure differential. The cold water intake pipe is sized based on flow and allowable suction pressure and pump station elevation limitations. The wall thickness of the intake pipe is set to prevent collapse and, if necessary, stiffeners are added to the pipelines. Finally, the pumps are sized based on total fresh water and seawater flows and the total heads for these systems.

Most of the deep seawater intake pipelines designed for by (Makai, 1994) use polyethylene as the pipeline material [9]. Polyethylene has significant advantages for these pipelines in that it is inert and will neither corrode nor contaminate the water. Polyethylene lengths are heat fused together to form a long, continuous pipeline with joints that are as strong as the pipeline itself. Polyethylene has excellent strength and flexibility and is buoyant in water. For the distribution network material, a comparison between the polyethylene, Steel and PVC pipes was done.

For the (SWAC) system, the best choice of heat exchanger is a modular titanium plate heat exchanger with gasket joints in a counter-flow configuration.

SWAC System Summary

Table 1 summarizes the contents of the SWAC system in Sahl-Hasheesh

Distance from shore to the point of the desired depth (m)	520
SW pipe diameter (mm/inches)	1000/40
SW pipe length (m)	10,000
SW velocity in pipe (m/sec)	5
SW pumping power (MW)	4.12
Distribution network (length in meter / diameter in mm (inches))	8900/760(30)
CW pumping power (MW)	5.32

TABLE 1: SWAC system summary.

Economical Analysis

The costs associated with the proposed SWAC system are primarily related to the initial capital expenditure. This, in turn, is related to the distance to the cold water, the temperature of that water, the extent and location of the onshore distribution loop, and the sizes of all pipelines.

Operating costs are related to amount of pumping power required. This is related to the amount of water to be pumped and the size and length of the pipelines.

Initial Costs

Item	Cost ($)
Seawater Pipe	29,200,347
Effluent Pipe	10,220,121
Distribution Network	4,458,900
SW Pump and Sump	27,176,074
Heat Exchanger	13,894,500
CW Pump	1,250,323
20% Contingency	17,240,053
Total	**103,440,318**

TABLE 2: SWAC system initial costs in US$

The costs of the conventional systems are estimated according to "An Introduction to Absorption Cooling" by Harwell, 1999.

The initial cost of the distribution network ($ 4,458,900) shall be added to the vapor compression system as added to the SWAC system.

INITIAL COST			
	Single-Effect VAS	**Double-Effect VAS**	**VCS**
Vapor Absorption System VAS &Vapor Compression System VCS			
Machine Capacity (TOR)	26500		
Cost $ / TOR	684	936	504
Total Cost ($)	18,126,000	24,804,000	13,356,000
Life Time (yr)	16	16	8
Heat Rejection Equipment			
Cost $ / TOR	227	205	151
Total cost ($)	6,015,500	5,432,500	4,001,500
Life Time (yr)	16	16	16

TABLE 3: Conventional Systems Initial Costs in US$

Running Costs

Tables 4 and 5 show the SWAC and conventional running costs respectively. For the vapor absorption system, knowing that it is a heat operated system and a large amount of fuel (Solar energy, Natural gas) has to be located continuously at SH which is hard to obtain because there is no source for such a fuel there in addition applying a solar system is beyond the scope of this study and would be inapplicable due to the very high initial costs required.

Economical comparison was based on two methods: Simple Pay Back and the Net Present Value.

Item	Cost ($)
Seawater Pump	975,785
Chilled water pump	1,258,622

Maintenance & Labor cost	400,000
Total	2,634,407

TABLE 4: SWAC System Running Costs in US$

RUNNING COSTS			
Price of kWh ($/kWh)	**0.045**		
VAS& VCS machines	**Single-Effect VAS**	**Double-Effect VAS**	**VCS**
kWh/TOR/yr	108	108	6224
Total Use (kWh/yr.)	2,862,000	2,862,000	164,954,550
Annual cost $	**128,790**	**128,790**	**7,422,955**
Cooling Water Pump			
Cooling Water Pump motor Efficiency	0.68		
kWh/TOR/yr	739	506	493
Total Use (kWh/yr.)	19,599,400	13,409,000	13,064,500
Annual Cost $	**881,973**	**603,405**	**587,903**
Cooling Tower Fans			
Fans Efficiency	0.6		
Fan partial use factor	0.4		
kWh/TOR/yr	588	480	392
Total Use (kWh/yr.)	15,582,000	12,720,000	10,388,000
Annual Cost $	**701,190**	**572,400**	**467,460**
Natural gas consumption			
NG m3/hr	8,480	8,480	0
m3 / year	44,570,880	44,570,880	0
Gas unit cost $/ m3	0.045454545	0.045454545	0
Annual Gas cost $	**2,025,949**	**2,025,949**	**0**
Total Annual Operating Cost $	**3,737,902**	**3,330,544**	**8,478,317**

TABLE 5: Conventional Systems Running Costs in US$

SIMPLE PAY BACK

An energy investment simple payback period is the amount of time it will take to recover the initial investment in energy savings, dividing initial installed cost by the annual energy cost savings and is calculated according to the following equation: [10]

Pay Back Period = Difference in initial cost / Saving in Running Cost (1)

Difference in initial cost = 81,623,918 $
Saving in Running Cost (1st year) = 5,843,910 $

Pay Back Period = 11 years

NET PRESENT VALUE TECHNIQUE [NPV] [11]

The NPV method determines the worth of a project over time, in today's dollars. Unlike the payback method, NPV also accounts for the savings that occur after the payback period. To calculate the NPV, The following factors were taken into consideration. [10,11]

It is also important to note that if the cold seawater pipeline were to fail, than cooling for the hotel would not be available until the pipeline could be restored. Of course no one would pay top dollar to stay in a hot and humid hotel room, so the loss of the pipeline can result in significant losses in revenue. Emergency portable vapor compression units could be rented while the pipelines are repaired; however, these costs were not included in this study.

$$\text{Dep C} = \frac{(1+i)^{n} \times i}{(1+i)^{n}-1} \quad \text{' Depreciation coefficient'} \qquad (2)$$

Where i is the interest rate and is taken as 0.1

$$\text{DEPRECIATION=INITIAL COST* Dep C} \qquad (3)$$

$$\text{Dep K=DEPRECIATION+RUNNING COST} \qquad (4)$$

But ;

$$\text{Net Present Value=Dep K*}((1+i)^{-k}) \qquad (5)$$

Where: n is the number of years [life period] and is taken as 15 years, k is the current year
Total Net Present Value is the accumulated NPV throughout the life period of the project or i.e., it is the sum of NPV of all 30 years.

The results show that although the SWAC system requires high initial costs nearly about seven times that for the CCS, its running cost is 15% of that for the CCS.

In Addition to the less maintenance needed for running this system either than the conventional systems and the thermal energy storage that can be utilized from the effluent cold seawater.

	SWAC	VCS
IC	103,440,318	21,365,500
RC (1st Year)	2,634,407	8,478,317
NPV (30 Years)	143,078,436	193,002,429

TABLE 6: NPV for SWAC and VCS systems

Environmental Analysis

Greenhouse gas emissions from power production will be reduced by the following quantities shown in Table 7. [1]

Pollutant Name	kg/kWh	kWh Savings	Reduction in Tons
CO2	0.714	138,753,559	99,070
CO	0.000365		51
CH4	0.00168		233
NOX	0.00125		173
N2O	0.0000169		2
SOx	0.00379		526
Solid Waste	0.0863		11,974

TABLE 7: Greenhouse Gases Emissions Reductions

Hybrid System

This study was based on the temperature-depth profile shown in Figure 3. There may be unfavorable temperature variations at the intake site; if the SWAC system fails to provide this 7°C seawater to the heat exchanger, the temperature of the chilled fresh water exiting the heat exchanger will rise up and further chilling through an auxiliary chiller should be needed. This may be solved by implementing a Hybrid system in which part of the air conditioning load should be provided by the SWAC system and the rest part by an auxiliary chiller which will be automatically operated by a programmable logic controller (PLC) taking a signal from a temperature sensor.
Figure 6 shows the result NPV for different scenarios of the Hybrid system where the percentages are changed among the system.

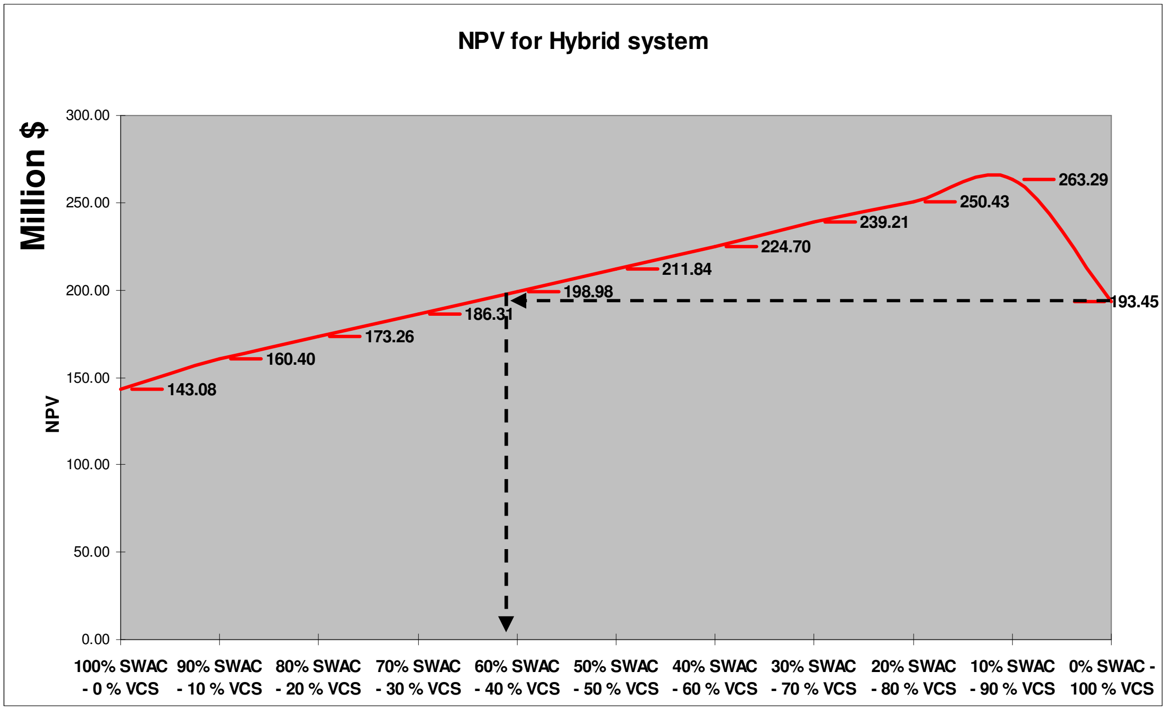

FIGURE 6: Hybrid system for Sahl-Hasheesh

At the end of the economic analysis the impact of the electricity unit rate and the life time of the project were studied.

Economic Sensitivity: Impact of electricity rate and project life time

Electricity rate is a major factor in determining the profitability of a SWAC system. For this study 0.25 Egyptian pounds (0.045$) was assumed as a cost for the kWh based on year 2007 costs. Any variation in the electricity unit cost will result in changes in the results.

Figure 7 illustrates the impact of the electricity rates on the net present values for the SWAC and VCS systems. Thirty years was chosen as a project life time for the air conditioning system at SH and which the author assumed that the life time shall exceeds this value since SH is a very huge project and shall always require air conditioning for the hotels.

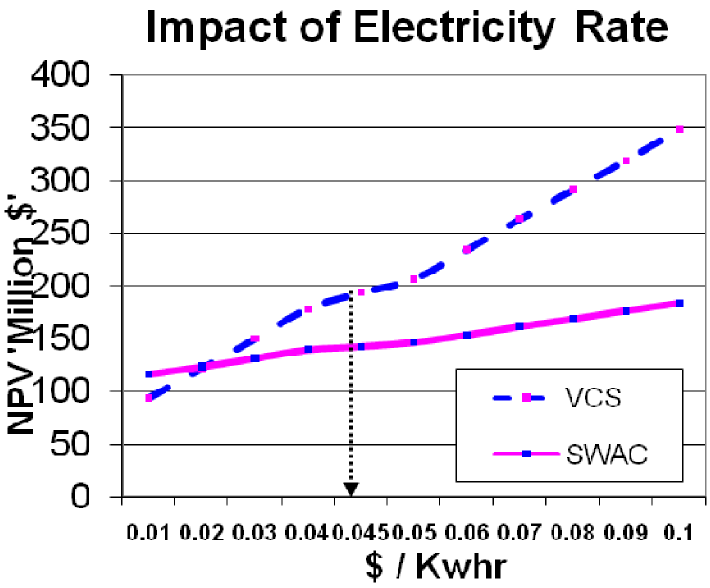

FIGURE 7: Impact of electricity rate on NPV

Increasing the project life time shall result in more economical SWAC system than VCS as illustrated in Figure 8.

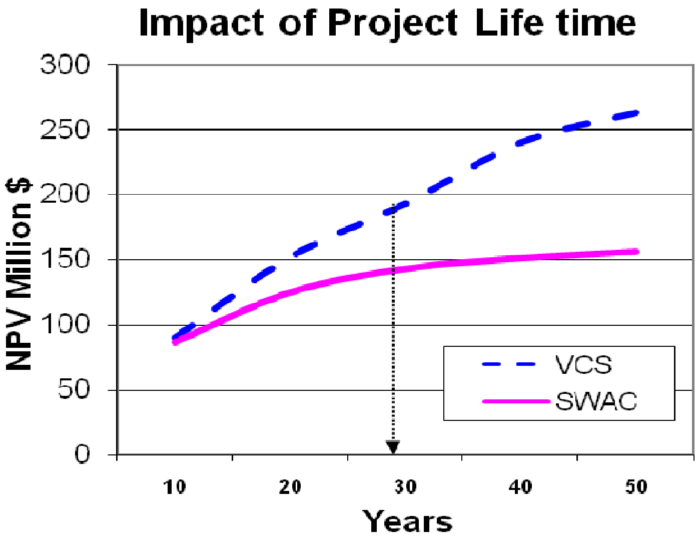

FIGURE 8: Impact of life time on NPV

4. CONSLUSIONS

Sea water air conditioning is an established technology being applied in an innovative way. The cold sea water air conditioning has merit over conventional vapor compression air conditioning systems. This merit is for hotels located in regions of the world where access to cold seawater is at a minimum and there is year-round high humidity.

This study dealt with the design and economical investigation for the Sea Water Air Conditioning (SWAC) System for a very high cooling load area [Sahl-Hashish, Egypt]. It is concluded that:

- SWAC is technically feasible in Sahl-Hasheesh. On the other hand, cold sea water air conditioning is not considered economically feasible for tropical cooling loads less than 5000 TOR.
- The major challenge is crossing the Marine Preserve.
- If water below 8°C is required, the flattening bathymetry suggests that auxiliary chillers would be more cost-effective.
- Bathymetry and site specific temperatures need to be collected; differences from the values assumed could introduce unexpected challenges.
- Greater Independence from Energy Price Escalation - In a world of rapidly increasing energy prices, SWAC costs (which are capital dominated) are relatively flat compared to that of energy intensive conventional AC systems. Users will have a known and relatively flat future AC cost.
- Short economic payback period.
- Reduction of electricity use. The SWAC system reduces the annual electric energy usage with 75% compared to on-site chillers. At a peak demand of 26,500 tons of refrigeration (TOR) in SH and 60% as a utilization factor the SWAC system will reduce the electric energy usage by 138,745 MWh per year.
- Reduction of air pollution due to greenhouse gases emissions reduction.

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