FEASIBILITY STUDY ON ABSORPTION COOLING BASED THERMAL ENERGY STORAGE

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Abstract

Human needs are unlimited, but resources that fulfil human needs are limited. Because of this reason, consideration of sustainability in utilization of energy is of immense importance. In this view, use of renewable energy, reduction of energy usage, and reduction/ elimination of use of fossil fuels are encouraged. Space cooling has the highest share (40% to 60%) from total energy consumption and there is an increasing demand of this share in the building sector. Hot and humid climate prominently prevails in the city Colombo, Sri Lanka. On the other hand Sri Lanka experiences a considerable increase of energy demand and electricity tariff rates annually, and these increases have significant impact on the economy. Therefore the need for finding energy efficient, renewable and cost effective solutions is inevitable. Accordingly, a study was carried out to conduct a techno-economic feasibility on thermal energy storage integrated heat driven cooling. Thermal energy storages and absorption chillers are commercially available and have the measure towards sustainability. It was found that most common air conditioning applications among several others are in office buildings, and therefore the main focus of this study is on a typical office building in Colombo city. The result of the study can generalized and applied to other office buildings in the city.Trace700 software tool was used to model and to simulate different system alternatives and to investigate techno-economic performances. Results shows that cool thermal storage integrated thermally driven absorption chiller has a significant energy and cost saving potential, furthermore biogas is proven to be a sound energy source thermal energy supply for the chiller, all aiming for sustainable future. The model developed may be extended to the different climatic conditions and cost structures.

Keywords: Sustainable energy, Absorption chillers, Thermal energy storage, Space cooling

1. Introduction

1.1 Background

In Sri Lanka, majority of commercial and state sector buildings are located in Colombo city limits, which has the hottest and the most humid climate. Therefore, air conditioning is one of the main requirements to maintain comfortable indoor climate. In building sector, Heating Ventilation and Air Conditioning (HVAC) systems have the highest share of total electricity bill. It is in the range of 40% to 60% [1]. Almost all high-rise building in the area have installed air conditioning systems of various types. On the other hand, Sri Lanka experiences a considerable rise in electricity tariff rates annually and the national demand for electricity for air conditioning has been increasing over the years. Furthermore Sri Lanka, which is a signatory to Kyoto protocol, is required to follow strict regulations that it sets binding targets for reducing Green-House Gas (GHG) emissions.

Accordingly, this study is focused on investigating ways and means to minimize energy consumption in a typical office building in Colombo area by using an effective air conditioning system. The use of Thermal Energy Storage (TES) and absorption chillers is investigated here. Reasons in selecting these technologies are as follows.

- To increase utilization of renewable energy or waste energy.
- To minimize electricity demand.
- To provide environmentally friendly and clean technology solutions.
- To perform feasibility study for commercial availability.
- To be on the cutting edge technology with the rest of the world.

Yet, these technologies are new to Sri Lanka. Even the “Code of Practice for energy efficient building in Sri Lanka” published by the county’s Sustainable Energy Authority of Sri Lanka in 2009 does not mentioned about these technologies or equipment. However, clause on “Absorption Chiller” can be found in the revised edition 2000 of “Specification for Electrical and Mechanical Works Associated with Building and Civil Engineering” published by Institution for Construction Training and Development. There are several on-going projects implemented by private sector apparel companies in Sri Lanka on absorption cooling for air conditioning of factory buildings. Although there are some applications of absorption systems, only one application of TES system was found to have been introduced, at the Blood Bank, Ministry of Health, Narahenpita, Colombo in Sri Lanka.

1.2 Literature review and previous studies

1.2.1 Absorption chillers

The most important feature of the absorption chiller is that, it provides opportunity to use renewable energy sources, such as solar and bio-gas, to drive the chiller (or absorption system). The basic refrigeration or cooling cycle of absorption chiller and of conventional mechanical chiller is fundamentally same. Absorption chillers are thermally driven; whereas mechanical chillers are electrically driven. The mechanical compressor in a mechanical chiller is replaced by a thermally driven absorption cycle (thermal compressor). Common working media used in the absorption cycle can be mixture of either LiBr/Water or Water/Ammonia. The applicability of these fluids in specific cases may vary, based on the properties of them. Depending on the means of thermal-energy-supply to the above cyclic process, the systems can be divided mainly in to two types of systems: direct fired system and indirect fired system. The required thermal energy in direct fired system is supplied directly through gas burners. Indirect fired system uses heat from hot water or steam produced by boilers. Furthermore, utilization of heat from hot gas such as by-product of a turbine or an engine generator can also be possible in indirect fired system. The absorption cycle can be single effect cycle, double effect or multiple effect. The thermal coefficient of performance (COP_h) of single effect LiBr/water cycle is usually 0.75 to 0.7[2]. This value can be increased by increasing the number of stages in the absorption cycle, known as multiple effect cycles. Other than the improving of efficiency, these cycles can be utilized to increase the temperature lift of the cycle, or to maintain the desired temperature lift by using low temperature (waste) heat input [2]. Double effect cycles are commercially available.

1.2.2 Thermal Energy Storage system

Storage provides mean of shifting a peak load in the day time from the off peak period typically at night [3]. This study focuses on cool thermal storage. Usually, cool thermal storage consists of a vessel or a tank filled with storage medium. This energy storage medium can be water, ice or other phase change material (PCM) (eutectic salt and organic material such as paraffin). The cool thermal storage system can be either full storage or partial storage. This means the system may provide all the cooling demand, or part of the demand during on-peak hours. The partial storage systems can work either as load levelling or demand limiting. Chillers in e load levelling mode are operated at full capacity on peak (cooling) demand day [4], minimizing thus the space and cost required by the TES system. The demand limiting strategy provides middle ground between full storage and load levelling strategies [4]. Furthermore, operating system can be distinguished to storage priority and chiller priority. As the name implies in chiller priority system, the load is mainly provided by the chiller, whereas in the storage priority system, load is preferably provided by the thermal storage.

1.2.3 Economic analysis

Economic feasibility is carried out by conducting cost benefit analysis. Benefits, in general can be monetary, tangible or intangible. For example, benefits such as additional income or reduction of cost can be assessed in rupee value. Some benefits however cannot be measured in monetary terms. The main cost categories of this type of plant are installation cost (i.e. initial cost), operating and maintenance cost. In current literature three approaches are identified regarding economic analysis. They are: 1. Pay Back Analysis which estimates the number of years that the benefits of a particular alternative take to cover the total cost related to it, compared to another alternative. Two types of payback as “Simple Payback” and “Life Cycle Payback” were considered in this regard. 2. Net present value (NPV) Analysis which is the most common method that used to determine the most economical alternative. It determines the profitability of one alternative compared to another alternative in terms of current rupee (or dollar) value [5]. 3. Internal rate of return (IRR) Analysis that compares the life time profitability of alternative solutions. In fact this is the discount rate where NPV is zero. Higher the IRR better the alternative.

1.2.4 Previous Studies

With increasing requirement of saving the energy as much as possible and in order to meet the set environmental goals, such as achieving targeted amount of reduction of CO_2 emission and eliminating use of ozone depleting refrigerant, many studies have been conducted on cool thermal storage and absorption cooling in the recent past. For example Rydstrand et.al.[6] revealed an ongoing experimental investigation on thermal energy storage technology integrated with an absorption chiller. Further, a good practical application of thermal energy storage coupled with water-ammonia absorption chiller can be found at Gamboro Dasco S.P.A., Medolla in Italy [7]. R.K. Suri et.al. reveals the cooling system with TES had 87% less power demand than conventional cooling system during utility peak period [8]. In this assessment cooling requirement of an office building in Kuwait was considered. Tawatchai et.al. found that solar powered absorption chiller in Thailand can save electricity up to 7880kWh per year per ton of refrigerant, and this accounted 98% of total electricity consumption of vapour compression system [9]. These studies confirm that the two technologies have both energy saving potential and cost saving potential.

2. Methodology

The main objective of this study is to establish a techno economic feasibility of thermal energy storage integrated with an absorption chiller, which is the method employed to minimise energy consumption in a typical office space in Colombo. This is compared with traditional mechanical chillers and conventional thermal energy storage systems. The system parameters are compared to evaluate performance. The concept which used to conduct this study is indicated by figure 1.

The seven storied building, is 26m high, has a total floor area 2250 m^2 with the space on 1775 m^2 being air conditioned. The building mainly consists of office spaces, an auditorium located on top-most floor and the library on a mezzanine floor. Except the lobby, toilet and service areas (i.e. plant rooms, pump room, etc.) all others are air conditioned. The air conditioning system utilises water cooled chiller having capacity of 100 ton (350 kW).The orientation of the building is 45° from North to the anti-clockwise direction.

In this study existing water cooled chiller is replaced by an absorption chiller and cool thermal storage. The air conditioning system is modelled with the building, the system lay outs and technical data of existing cooling tower, condenser water piping system, chilled water piping system, duct system, and air handling units.

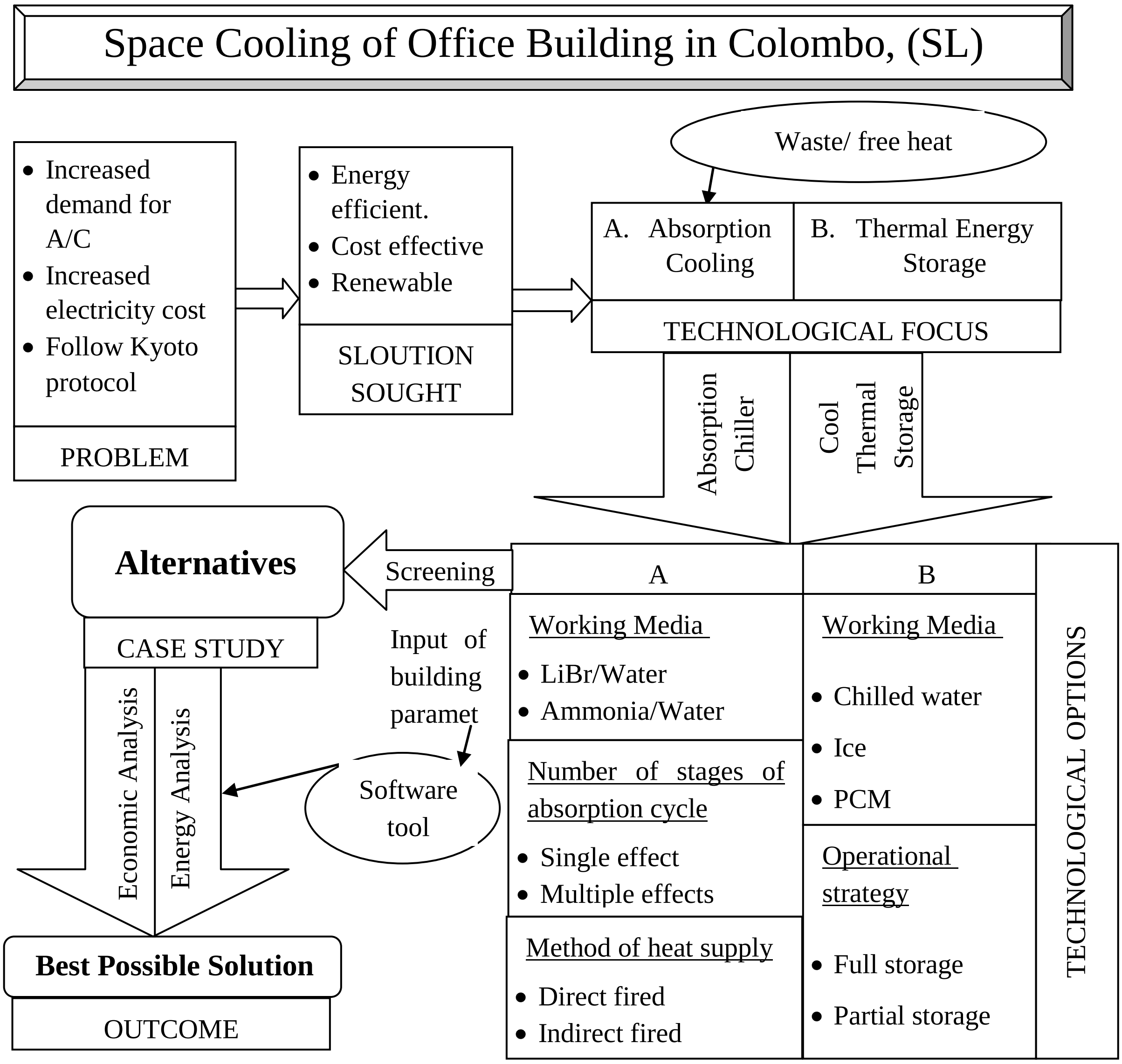


Figure 1: Conceptual frame work

Further this study encourages the use of sustainable energy sources and eliminating the use of fossil fuels. Therefore in order to supply the thermal energy required to drive the absorption chiller it was intended to use free or waste energy. Solar, waste incineration and bio gas were observed as possible alternatives in this regard.

Preliminary screening for selection of appropriate design was carried out considering the criteria indicated below.

- Capacity range of the cooling application is 50-300 ton (175 – 1050 kW).
- Possible thermal energy sources for absorption chiller. – Solar system, Bio gas plant, and waste incineration plant

- Avoid use of fossil fuel fired boilers.
- Maximum charging period of TES per day of 6 hours from 22:30 hr to 5:30 hr
- Storage system with as small space requirement cost per square meter of land costs from Rs.60,000.00 ($545) to Rs.100,000.00 ($ 910)
- Availability of equipment.
- Convenience and safety of handling and maintenance.

After preliminary screening following alternatives were considered for further analysis.

- Conventional electrically driven chiller without PCM TES
- Conventional electrically driven chiller with PCM TES.
- Direct fired single stage LiBr/water absorption chiller with PCM TES.
- Indirect fired single stage LiBr/water absorption chiller with PCM TES
- System with storage priority control.
- System with chiller priority control
- System where chiller in parallel to TES
- System where chiller in Series with TES

Bio-gas was considered as the most suitable renewable source of energy in this study. Solar heat and the waste incineration are not favourable because of the following reasons. In case of Solar, to achieve the expected energy saving and the cost saving from TES, it must be charged during the off peak period of electricity demand, which is from 22:30hr to 5:30hr. But during this period solar is not available. If waste incineration solution is considered, the method cannot be used to drive direct fired absorption chillers. Another drawback of this is production of flue gas with hazardous substances. Furthermore, due to high moisture content and low calorific value of the waste generated within Colombo waste incineration is not economically viable either [10].

For the analysis of different energy alternatives and to validate the proposed energy concept developed through this study simulation software, called Trace700, is used.

For the calculation of building load inputs data in Table 1 are used. The Chiller and the thermal storage were sized considering the load profile of the building and the sizes are 60 ton (210kW)

Chiller and 600 ton-hr (2110 kW-hr) cool thermal storage. When defining the chiller priority system, it is assumed that storage is in the "charging" modes from 00:00 hr to 08:00 hr and 22:00 hr to 24:00 hr of the day. Rest of the time of the day it is in the "normal" mode.

Table 1: Input data to define building load

Parameter	Value		
	Office	**Auditorium**	**Library**
People density, m^2/person.	6	2	45
Lighting density, W/m^2	0.05	0.05	0.05
Miscellaneous loads, Density of 350W computer workstation per person	0.75	0.25	1.00
Air flow			
Ventilation, cfm/person	20		
Infiltration, air changes/hr	0.6		
U factors, W/m2. ◦C			
Ground	0.52		
Slab	1.2		
Walls	0.52		
Partition	2.2		
Window	5.68		

Estimate for chillers includes cost of all the duct work, piping work, associate equipment and accessories such as cooling tower, pumps, valves, and control panels. The estimation is carried out based on the prevailing economic conditions and tariffs of the country in the middle of the year 2011 considering the exchange rate as Rs. 110.00 per USD. The rates used for the cost estimation are given bellow.

- Water cool chiller system:
  Supply and installation cost = $ 635 per ton [11].
  Yearly maintenance cost = $ 1136 (average cost for chillers range from 50 ton to 150 ton) [11].
- Absorption chiller system : Initial cost = $ 1,000 to $ 1,400 per ton[12]
- Gas fired boiler:
  Supply and installation cost = $ 56800 (boiler capacity of 355kW) §
  Yearly maintenance cost = $ 545 §
- Total installation cost of simple unheated Bio-gas plant = $ 50-$ 75 per m^3 (35%-40% of this is for digester) [5]
- PCM storage system:
  Installed tank cost = $100 - $150 per ton-hour [13]
  Material cost = $95 per ton-hour [13]
  Inflation on capital cost = 10%

§These values were obtained after a market survey conducted among the boiler suppliers in Sri Lanka

County's electricity tariff structure is of immense important in designing the best system configuration. Office buildings falls in to the customer category of General Purpose (GP). The category GP2 is the applicable structure for the application selected for this study. According to the revised tariff structure for the year 2011 this category is not charged for "Time of Use" (TOU) tariffs. As an alternative, it is investigated whether the application can have any economic advantage by introducing TOU stricture instead of flat structure, using the TOU structure of customer category I2. Table 2 [14] indicates the rates.

The factor that is used to compare the traditional chiller is the value of COP. But in theory the definition of COP for conventional chiller and for absorption chiller is not the same.

For conventional chiller:
COP = heat transfer to the cycle (or cooling energy output)/network input

For absorption chiller:
COP_h = cooling energy output / necessary heating energy for operation of the cycle

To compare the performance of plant with thermally driven chiller, thermal coefficient of performance (COP_h) is used and for electrically driven chiller COP is used.

In addition, total electrical and thermal (gas) energy input to the whole system, and reduction or increase of electric energy demand with respect to the existing system are calculated in technical analysis.

In the cost benefit analysis, Payback Period, Net Present Value, and Internal Rate of Return are calculated using the software tool.

3. Results and Discussion

The results obtained out of the technical feasibility study were indicated by Table 3. Out of the four alternatives considered in the study, two have thermally driven absorption chillers and other two have electrically driven vapour compression water chillers. The result indicates that direct fired system has high COP_h, while existing water chiller system that has no thermal storage is shown to have better COP.

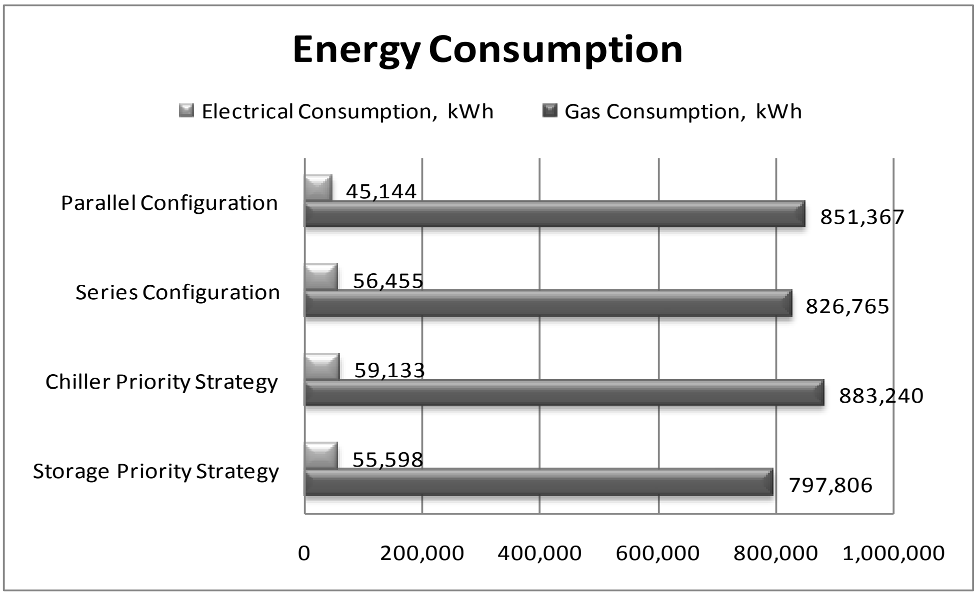
The total energy consumption of the system having water cooled chiller with cool thermal storage (alternative 4) is the smallest of all the proposed alternatives. As the heat driven chiller consumes large amount of thermal energy, their total energy utilization is high. However in terms of electrical energy used, in the thermally driven chiller shows the best solution. Direct fired absorption chiller with cool-thermal storage gives highest electrical energy saving compared to the exiting water cooled chiller system.

The system of direct fired absorption chiller with TES is further analysed for different control strategies and flow configurations. The system with storage priority strategy has less annual electrical and gas energy consumption than chiller priority systems as shown in Figure 2. The study further indicates that system with storage priority strategy has less annual electrical and gas energy consumption than chiller priority systems.

Table 2: Performance of different alternatives

		Alternatives				
		1	2	3		4
		Direct fired absorption chiller with TES	Water cooled chiller without TES	Indirect fired absorption chiller with TES†		Water cooled chiller with TES
				Chiller only	Total with Boiler	
Peak cooling energy demand met by chiller,(kW)		211.0	480.9	211.0	-	211.0
Electricity consumption at perk demand, (kW)		2.0	104.0	1.6	3.2	51.8
Gas energy consumption at peak demand,(kW)		230.9	-	-	392.2	-
Steam energy consumption at peak demand,(kW)		-	-	334.5	-	-
COP or COP_h		0.91	4.62	0.63	0.54	4.07
Annual energy consumption by the whole plant.(including chilled water pumps, condenser water pimps and cooling tower), (kWh)	Electrical	56,500	356,500	65,300		321,100
	Gas	826,800	0	1,411,000		0
	Total	883,200	356,500	1,476,300		321,100
Deference in electricity demand with respect to existing plant (i.e. Alt2), (kW)		300,100	0	291,200		35,500

† COP_h(Chiller) is calculated considering only the thermal energy input by steam. In calculating



COP_h(Total) thermal energy from the source (i.e. bio-gas plant) is considered.

Figure 2: Energy consumption of different control strategies

The results from economic analysis indicate that although the initial cost and maintenance cost of existing system (Alternative 2) are less, it has the largest total operating cost. The life cycle payback period of direct fired absorption chiller system with TES, compared to the existing system is only 1.6 years as shown in Table 4

Table 3: Economic comparison of different alternatives-Flat structure

Couple of alternatives compared	**Simple payback period, yrs**	**Net Present Value, $**	**Life Cycle Pay Back, yrs**	**Internal Rate of Returns, %**	**Remarks**
Alt 1 vs Alt 2	1.5	1,002,100	1.6	77.2	Alt 1 better
Alt 3 vs Alt 1	No Pay Back	-156,700	No Pay Back	No Pay Back	Alt 1 better
Alt 1 vs Alt 4	0.5	896,700	0.6	193.9	Alt 1 better
Alt 3 vs Alt 2	3.0	845,400	3.3	43.1	Alt 3 better
Alt 4 vs Alt 2	6.7	105,400	7.4	23.4	Alt 4 better
Alt 3 vs Alt 4	2.3	740,000	2.5	54	Alt 3 better

Compared to the alternative 1 (direct fired absorption chiller system with TES) all alternatives show the negative cost savings. Furthermore, alternative 1 has the highest electrical energy saving. This result indicates that the "electrical energy consumption of a plant has considerable impact on operation cost." It is attributed to that the cost of gas fuel if generated from the city waste is negligible compared to the cost of electricity.

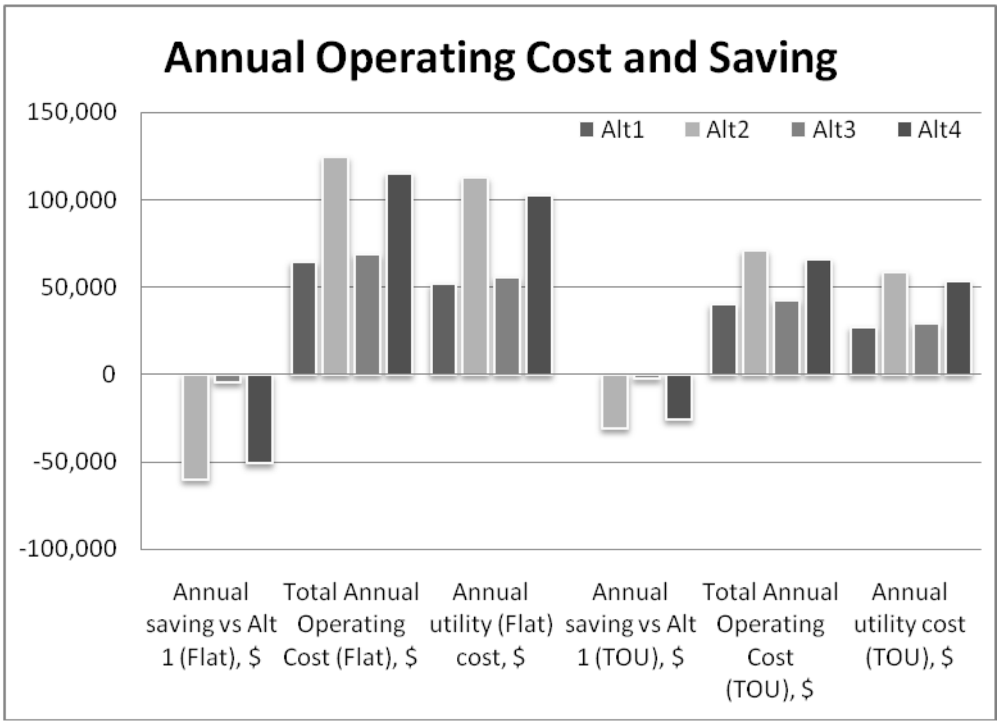


Figure 3: Operating cost and annual savings with respect to Alt1

As the energy charge with flat rate structure is higher than the charge of peak demand period in TOU structure (ref. Table 2), the operating cost is higher in flat rate scenario. However the results reveal that flat rate structure offers high cost saving with respect to existing system (alternative 1), and therefore the payback periods become less than that for TOU structure.

4. Conclusion

In this work, a techno-economic feasibility study for space cooling of the office building in Colombo with use of thermal energy storage integrated absorption cooling was performed. The results on energy and economic performance discussed above reveals that TES integrated direct fired absorption chiller provides the most economical and energy efficient renewable solution among the four alternatives. Accordingly it can be concluded that the proposed technology, which is absorption cooling based TES, provide feasible solution for space cooling of office buildings in Colombo.

The approach and methodology proposed in this work and the findings may be considered as the work and result of initial research conducted for an office premises in Colombo city. The applicability of this model to other countries with different environmental conditions, and where cost structures are different is left for future research on this theme. Based on the outcome of further research the proposed concept and the model can be generalised.

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References

1. Cassie Koelmeyer (2007), Lecture notes on Energy Efficiency in HVAC System, Awareness Programme on Practical Guidelines on Basic Air Conditioning System Design, The Institution of Engineers in Sri Lanka. 24 March 2007.

2. Eric Granryd, Ingvar Ekroth, Per Lundqvist, Ake Melinder,Bjorn Palm, Peter Rohlin (2005) *Refrigerating Engineering*, Department of Energy Technology, Royal Institute of Technology, KTH, Stockholm, Sweden

3. Sri Lanka Sustainable Energy Authority (2008), *Code of practice for energy efficient building in Sri Lanka-2008*, Design Systems (pvt)Ltd., Colombo, Sri Lanka. 30th June 2009.

4. Federal Technology Alert,(2000) *Thermal Energy Storage for Space Cooling*, federal energy management program (DOE/EE-0241), USA, 2000.

5. Biogas Digest-VolumeIII(2011)-*Biogas Cost and Benefit and Biogas Program Implementation*, Information and Advisory Service on Appropriate Technology.
6. M.Rydstrand and V. Martin,(2003) *Design of a PCM Cool Thermal in Comfort Cooling Application*, Advanced Thermal Energy Techniques – Feasibility Studies and Demonstration Projects, 4th workshop, 21-23 March 2003, Indore, India.
7. Robur S.p.A(2011) *Air Conditioning System with Gas Absorption heat pump, Gambro Dasco S.p.A*, advance heating and cooling technology, Italy
8. R.K. Suri, G. P. Maheshwari, K. Al- Madani and H. Aburshaid (1985), "Cool Storage for Air Conditioning System in Kuwait", International Journal of Refrigeration, Butterworth & Co.(Publishers) Ltd. And IIR 1985
9. Thawachi Jaruwongwittaya, Guangming Chen (2010), "A review: Renewable energy with absorption chiller in Thailand." Renewable and Sustainable Energy Reviews 14 (2010), pg 1437-1444
10. Environmental Foundation Ltd. (2007), *Climbing out of the Garaging Dumb: Managing Colombo's Solid Waste Problem*, EFL Policy Paper, January 2007.
11. Jeffrey J. Jayasinghe (2011), Personal Communication with C.Eng Jeffrey J. Jayasinghe at Central Engineering Consultancy Bureau and Project Manager(Building Services), Interview, 5th April 2011.
12. Energy innovators Initiative (2009), *Choosing a High-Efficiency Chiller System*, Natural Resources of Canada at www.nrcan.gc.ca, last modified 22.04.2009 as accessed 12.02.2011
13. Kirt Roth, Rober Zogg, and James Brodrick (2006), *Cool Thermal Energy Storage*, ASHRAE Journal volume 48, American Society of Heating Cooling and Ventilation, USA, September 2006
14. Public Utilities Commission of Sri Lanka (2011), *Decision on Electricity Tariffs (Effective from 1st January)*, at www.pucsl.gov.lk, as accessed 05.05.2011