Effective Cost Management of Building Services in Hong Kong - Managing Sustainability and Costing in Air-Conditioning

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Keywords Sustainability, Environmental protection, Air-conditioning system, Energy consumption, Life cycle costing.

ABSTRACT

Energy consumption in air-conditioning has been the greatest among all major building services systems, especially for commercial properties in Hong Kong. There was trend of increasing energy consumption which in turn affects the sustainability, environmental protection and our well being. Through proper design of relevant air-conditioning system such as adopting portable water or seawater as cooling media, would help minimizing energy usage and environmental problems, and reducing overall life cycle costs. However, such system may bring forth potential problems like llegionnaire disease, sick building syndrome, poor indoor air quality etc. if not appropriately controlled and maintained. In this research, we'll investigate for sustainable design and life cycle costing considerations in adopting relevant air-conditioning system to cater for long range planning in facility/maintenance management; with reference to government policies, professional concerns and local practices. Both qualitative and quantitative methodologies would be engaged to help explore the issue.

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1. INTRODUCTION

Energy Consumption in Hong Kong

In the last decade, large numbers of commercial buildings and shopping arcades cladded with curtain walls were built in Hong Kong. Central air-conditioning systems (A/C) are thus heavily involved for occupiers to tackle Hong Kong's tropical climate (temperature at above 33℃, and relative humidity at above 80% in summer). There are mainly two types of A/C chiller systems i.e. air-cooled air-conditioning system (ACAS) and water-cooled air-conditioning system (WCAS) adopted in Hong Kong. Though ACAS may be claimed as less efficient, it has been widely adopted in the past as the local government has once not encouraged the use of city water for WCAS. Refrigeration compression cycle is a major component of central air-conditioning system that consumes the most electric energy. By studying this cycle, we may achieve more energy saving.

The "Energy End-user Data, 1992-2002" was published by EMSD in 2004, which covers all kinds of fuel used by internal civilian energy end-users in Hong Kong. It did not include energy exported, energy uses for transportation between Hong Kong and foreign countries. The energy end-user data are classified into four sections namely residential, commercial, industrial and transportation. This report will concentrate on the energy use in A/C system in the commercial section. Table 01 shows the changes of Electricity End Uses since 1992.

Electricity End Uses													
Year	**Space Conditioning**		**Lighting & Refrigeration**		**Cooking**		**Hot Water**		**Industrial Process Equip.**		**Others**		**Total**
1992	30097	32%	21569	23%	4094	4%	2965	3%	15103	16%	20325	22%	94154
1993	32444	33%	22648	23%	4368	4%	3093	3%	14666	15%	22591	23%	99811
1994	35125	33%	23324	22%	4519	4%	3201	3%	13813	13%	25072	24%	105055
1995	35990	33%	23919	22%	4356	4%	3235	3%	13099	12%	26878	25%	107478
1996	37571	33%	24729	22%	4298	4%	3264	3%	12825	11%	31192	27%	113880
1997	38163	33%	25799	22%	4334	4%	3312	3%	12409	11%	32044	28%	116062
1998	41409	33%	26719	21%	4703	4%	3425	3%	12422	10%	36767	29%	125446
1999	40509	32%	27705	22%	4571	4%	3451	3%	11678	9%	37374	30%	125289
2000	42225	32%	28895	22%	4674	4%	3540	3%	11825	9%	39516	30%	130676
2001	43093	32%	29776	22%	4533	3%	3607	3%	11220	8%	41909	31%	134139
2002	43581	32%	30446	22%	4615	3%	3748	3%	10851	8%	43871	32%	137113

The energy unit used is "Terajoule" which is equal to "$1x10^{12}$

Table 1 Electricity End Uses

Table 2 shows the changes in Energy Use in All Fuels since 1992.

Energy Use in All Fuels							
Year	**Town Gas & LPG**		**Oil & Coal**		**Electricity**		**Total**
1992	25871	10%	126539	51%	94152	38%	246562
1993	25906	10%	123899	50%	99810	40%	249615
1994	26918	10%	124812	49%	105054	41%	256784
1995	27931	11%	116641	46%	107476	43%	252048
1996	27705	11%	114365	45%	113879	44%	255949
1997	27841	11%	118402	45%	116061	44%	262304
1998	27562	10%	115426	43%	125446	47%	268434
1999	29256	11%	117578	43%	125288	46%	272122
2000	30848	11%	122534	43%	130675	46%	284057
2001	35255	13%	110947	40%	134138	48%	280340
2002	39194	14%	107615	38%	137112	48%	283921

Table 2 Energy Use in All Fuel

The total energy consumption was increased by 15% from 246562 (TJ) in 1992 to 283921 (TJ) in 2002 (Table 02). The electric energy consumption grew by 45% from 94152 (TJ) to 137112 (TJ), which is the highest increase amongst all energy sources. The electric energy spent on air-conditioning was about 32% of the total consumption as in 2002 (Table 01). The growth was 45% from 30097 Terajoule (TJ) in 1992 to 43581 (TJ) in 2002. Air-conditioning energy would be further consumed due to the increasing construction of commercial properties and economic activities. Reducing the potential energy demand would help improve sustainability and environmental protection such as mitigation of global warming, greenhouse effects. According to the HKSAR Census & Statistic Dept. report (2006) (Table 02a), the power consumption figures from 1999 revealed that the commercial building power consumption was 76028 Terajoule (TJ), and it has increased by 25.44% to 95370 (TJ) in 2006. About 65.86% electricity consumed in HK was used in commercial buildings in 2006. (versus 60.84% in 1999).

Calendar Year	Commercial Building	Residential Building.	Industrial Building	Total Consumption
1999	76028	31400	17547	124975
2000	80347	32234	17769	130350
2001	84214	32799	16759	133772
2002	87241	33394	16112	136747
2003	88834	34365	14851	138050
2004	91255	34134	15430	140819
2005	93341	35811	14636	143788
2006	95370	35428	14015	144813

Table 2a Power Consumption (Terajoule) of HKSAR Census & Statistics Dept.

2. FRESH WATER CONSUMPTION IN HONG KONG

According to the annual water consumption report by HKSAR Water Supply Department (WSD), there is a surplus of fresh water (from Dongjiong Guangdong province) on average in the past decade (Table 03). Sine 1990, substantial light industries were moved to Mainland China. The industrial water consumption for the first time registered a 1.7% decrease. The water usage was reduced from 1989’s 182 mcm to 1998’s 66 mcm, a reduction of 63.7%, even the Hong Kong population rose by 1.5 million during that period.

Water Resources of Hong Kong

Calendar Year	Local Yield (Mm3)	Dongjiang Water Supply from Guangdong (Mm3)	Total Fresh Water Gain	Fresh Water Annual Consumption (Mm3)	Fresh Water Balancing
1999	106.37	737.95	844.32	910.72	-66.4
2000	260.76	706.36	967.12	924.13	42.99
2001	301.46	728.63	1030.09	939.55	90.54
2002	252.40	743.84	996.24	948.65	47.59
2003	252.67	760.58	1013.25	973.75	39.5
2004	111.00	808.43	919.43	955.33	-35.9
2005	298.16	770.60	1068.76	967.71	101.05

Table 3

3. GOVERNMENT'S PRELIMINARY STUDY ON FRESH WATER COOLING TOWER

The Electrical and Mechanical Services Department (EMSD) of HKSAR completed a Preliminary Phase Consultancy Study (PPCS) regarding "Wider Use of Water-cooled air-conditioning system in Hong Kong" was completed in April 1999. The PPCS established the technical viability of the wider application of WACS and its economic/environmental benefits. The implementation study for WACS in Hong Kong was commissioned in 2000 to examine in greater details on technical viability, financial viability, infrastructure works, land use, traffic impact, environmental/health issues, and regulatory control; especially for non-domestic buildings. Three types of WACS schemes were studied i.e. cooling tower scheme, central seawater scheme, and district cooling scheme.

The study reported that Central Seawater Scheme and District Cooling Scheme requires substantial capital investment, new piping network, road excavation; which seemed quite not cost effective when compared with the cooling tower scheme. Fresh water, instead of seawater, would better be adopted for cooling towers because of the high corrosion effect from employing seawater and the high make-up water demand/constraints of city main seawater supply.

4. GOVERNMENT'S PILOT SCHEME ON FRESH WATER AS COOLING MEDIA

In May 2000, the HKSAR Government launched a pilot scheme on the wider use of fresh water for WCAS in non-domestic buildings in six designated areas. In May 2002, the scheme was extended for two years to cover twenty eight designated areas. With the positive feedbacks/results on energy saving, the scheme was extended to May 2006 to cover fifty seven designated areas. The pilot scheme provides applicants with guidelines in associated water works, building works, sewage services, noise control, water pollution control, and air pollution control.

Air-conditioning Systems

In large scale commercial building, the central A/C system can mainly be divided into two parts, i.e. **air-side** and **water side**. The components in the air-side include AHU, PAU and FCU. The heat and moisture of conditioned space will be absorbed and taken away to obtain the designed temperature by the air-side equipment. The heat absorbed through the air-side components will be transferred to the water-side; and rejected to atmospheric air or water. The heat rejection component of the water-side (condenser unit) is classified as water type and air type. Higher condensing temperature would lead the compressor doing more work to produce the same cooling effect, giving a lower performance and a higher running cost.

System Description for Water-Side

The term refrigeration, as part of a building energy system, generally refers to a vapour-compression system wherein a chemical substance alternately changes from liquid to gas and from gas to liquid. The "cycle" actually consists of four steps; namely (1) Vapour Compression Cycle - Low-pressure refrigerant gas is compressed, thus raising its pressure, by expending mechanical energy. Thermodynamically, there is a corresponding increase in temperature along with the pressure; (2) Condensation - The high-pressure gas is cooled by outdoor air or water, and condenses into a liquid at high pressure; (3) Expansion - The high-pressure liquid flows through an orifice in the expansion valve, thus reducing the pressure. (A small portion of the liquid "flashes" to gas, due to the pressure reduction); and (4) Evaporation - The low-pressure liquid absorbs heat from the indoor air or water (subject to the purpose), and evaporates into gas. The low-pressure gas returns to the compressor and the process repeats. Thus, for any refrigerant whose properties are known, a pressure-enthalpy chart can be constructed and the performance of a vapour-compression cycle analysed by establishing the high and low pressures for the system.

Central Air-conditioning Systems

The vapour compression refrigeration cycle stated at above can be applied to all A/C units including the unitary window type and split type unit in which the air directly pass through the cool containing evaporated refrigerant to absorb heat from the air passing through. The refrigerant that absorbs heat through expansion or vaporization is termed primary refrigerant.

However the travelling distance of the primary refrigerant is not enough to pass through a building even though a large room. In central A/C system, water is used as heat exchange media between refrigerant and space condition. The refrigerant absorb heat from water makes the water temperature lower, in normal design for central A/C system the temperature range of chilled water is 8 to 13 with 5 degree C difference. The water in the system is a secondary refrigerant as it absorbs heat but does not undergo a phase change in the process.

Condenser Unit of A/C systems

In the refrigeration cycle the condensing stage affects the overall performance of the cooling effect of the refrigeration cycle. If the condenser were arranged to 'sub-cool' the liquid, each unit mass of refrigerant in circulation would produce a greater cooling effect and the cycle would be more efficient. The ratio of the cooling effect to the energy input, in terms of enthalpy, is known as the coefficient of performance. The smaller the range of pressure over which the cycle operates, the less will be the energy expended for a given cooling effect. Hence, for economy in running, evaporator temperature would be high whilst condenser temperature would be as low as possible. When cooling is to be atmospheric, weather records will decide the safe minimum level to be assumed. Maximum cooling is generally required in the hottest summer weather when the condensing arrangements are least efficient and caution in selection is thus necessary.

Air-Cooled Condenser

Air-cooled condensers use outside air to cool the hot refrigerant gas that is pumped by the compressor to the heat exchange coil (condenser). The outside air reduces the refrigerant temperature, which condenses the gas and sub-cools the refrigerant. There are two types of air-cooled methods to reject heat to ambient in order to liquefy the refrigerant vapour. They are *"Direct Air Cool" and "Indirect Air Cool"*. There is no air resource problem in air-cooled condenser as water-cooled needs water resources however the contact surface area and the ambient temperature limits the performance. The two common types of air-cooled condenser are V and W shaped coil surface which governs the air velocity passing through the coil.

Water-Cooled condenser

Water-cooled condensers adopt water from outside to cool the hot refrigerant gas that pressurized by the compressor to the heat exchange coil (condenser). The water used can be sea water or fresh water. The water reduces the refrigerant temperature, which condenses the gas refrigerant to liquid state. There are three types of water-cooled methods to reject heat to water, to liquefy the refrigerant vapour; namely *"Direct Water Cool", "Indirect Water Cool"* and *"Water Cooling Tower"*.

5. ENVIRONMENTAL IMPACTS

The cooling tower for A/C system is more energy efficient than the conventional air-cooled A/C. The saving in electricity will reduce the demand for power and hence the carbon dioxide emissions from the power generation process. A research reports that assuming a 50% penetration rate of cooling tower in non-domestic buildings in the whole territory by the year 2020, the annual energy savings over the conventional air-cooled A/C would be 1,170,000,000 kWh (about 3.1% of total electricity consumption of HK in 2020). Annual electricity bill is saved by HK$1.05 billion. The carbon dioxide would be reduced annually by 830,000 tonnes (about 2.34% of total carbon dioxide emission of Hong Kong in 2002).

Water pollution

For air-cooled type there is no water pollution problem but in high temperature season the performance of the air-conditioning would drop. The operator would use cold water to flush the cooling coil of the condenser unit. This uncontrolled activity would bring forth dirty water into the harbour through the storm water drainage system, and thus may pollute the harbour water quality. For fresh water cooling tower there is a continuous concentration of scale-forming solids which may build up to such a degree as to foul the condenser tubes. Similarly, the evaporative surfaces of the cooler suffer a build-up of deposit. A constant bleed-off of the water is required. The bleed-off water (containing some chemical) will be discharged to the drainage system.

Air pollution

The ACAS cools the refrigerant by enforcing air to pass through the condenser coil. The enforced air will blow up dust that may become suspended respiratory particle which is harmful to health. The water cooling tower does not have air pollution problems. However, the misty substances generated by the cooling tower produce another nuisance to neighbourhood residents, and may also spread out legionnaire disease if not controlled properly.

Noise pollution

Most ACAS is direct expansion type, all components are constructed in one package and should be located in open space, such as podium or roof, for massive heat emission. In this configuration the noise created would be greater than that of WCAS. In addition, the total number of fans used in ACAS is much more than that of WCAS (about five to one).

6. RESEARCH METHODOLOGY

Both quantitative and qualitative research methods are adopted. A case study on Modern Plaza will be conducted to investigate the conversion approach, life cycle cost implications, environmental impacts and optimal protection measures. Furthermore, a questionnaire is sent to professionals working in property developers, building services consultants, contractors and suppliers to examine the benefits and implications of converting air-cooled systems to water-cooled systems.

Case Study on Chung Plaza

Please find below details, findings and analysis of the case study on Modern Plaza; which is a composite building completed in 1990, with three levels of shopping centre and residential towers above. The air-conditioning for the shopping centre was supplied through a total of 1810 RT air-cooled air-conditioning system (4nos. 340RT; 3nos. 100RT & 2nos. 75RT) installed on podium. The existing air-cooled chillers were adjacent to the residence. Substantial noise/hot emission/nuisance were created. Silencer was later on installed to reduce the noise, but it also deterred the hot air emission from the system and subsequently reduce the A/C's overall efficiency.

In Modern Plaza, due to space constrain, it was required to demolish the existing chiller to provide space for the new WCAS. Replacement was done in two phases, to be completed in winter. The pipe work running on top of the cooling tower contains hot condenser water as it absorbs heat from refrigerant (for discharge to the container). The condenser water becomes droplet by passing through the container holes. A motorized fan fixed on top to extract air from the side of tower, to take away the sensible/latent heat of the condenser.

Technically, there is no driveway directly from ground floor to podium for transportation of the new cooling tower components. The headroom of podium floor is about 3m - another constraint for transportation. Equipments were lifted from existing road from ground floor. The captioned site location affects also the transportation of materials, mobilization of manpower and associated cost/time for travelling of workers and inspectors. Most ACAS are constructed in package type, i.e. all components including compressor, condenser, evaporator and expansor are packed together within a large steel framework. Mobile crane (at higher preliminary cost) would be required, subject to site constraints. Sometimes, hoisting within a confined area would become remote or even impractical.

The WCAS possesses individual component (condenser, cooling tower, pumps etc.) which can be transported separately to the spot, and thus gives more flexibility. Bearing the complicated subcontracting system of the building industry in Hong Kong, the above factors may help estimate the costs more accurately:

Life Cycle Cost Analysis

Life cycle costing technique is applied to compare the conversion cost from ACAS to WCAS. Net Present Value (NPV) is adopted to evaluate the projected maintenance, operation, and replacement costs, with the following example of a 900RT cooling capacity chiller. The NPV for equal payment series is used to convert the value of operational costs, with the following formula:

NPV for equal payment series is $\{1-1 \div (1+j)^n\} \div j$

Assume the investment rate is 6% and the life cycle of ACAS and WCAS are 17 years and 25 years respectively. Present value for equal payment are shown below.

PV for equal payment	Investment rate (j)	Year (n)
1.345	6%	17
1.558	6%	25

Table 3 Present value for equal payment

The future cost considers the inflation effect for the cost of a part or parts that should be replaced within a period recommended by the manufacturer, as follows:

The Future Value (FV) for replacement is $(1+s)^n$

Assume the inflation rate is 3% and the life cycle of parts is within 10 to 25 years.

FV for replacement	Inflation rate (s)	Year (n)
1.345	3%	10
1.558	3%	15
1.653	3%	17
1.806	3%	20
2.094	3%	25

Table 4 Future Value

It is necessary to convert this cost back to PV to represent the true value at date of evaluation, with the following formula:

The Present Value (PV) for single payment is $1 \div (1+j)^n$

Assume the investment rate is 6% and the life cycle of ACAS and WCAS are 17 and 25 years respectively.

PV for single payment	Investment rate (j)	Year (n)
0.558	6%	10
0.417	6%	15
0.371	6%	17
0.312	6%	20
0.233	6%	25

Table 5 Present Value for Single Payment

Relevant costs were obtained from reliable sources for comparing ACAS and WCAS.

		Water-cooled ACS Life cycle = 25 Yrs		**Air-cooled ACS Life Cycle = 17 Yrs**	
		Cost	**Interval**	**Cost**	**Interval**
Initial Cost					
	Chiller	$3,465,000		$4,285,000	
	Cooling tower	$45,000		------------------	-------
	Condenser Pump	$250,000		------------------	-------
	Chiller water pump	$200,000		$260,000	
	Electrical System	$250,000		$180,000	
	Total initial cost:-	$4,210,000		$4,725,000	
Operation Cost					
	Preventive Maintenance	$54,000	Yearly	$36,000	Yearly
	Annual Maintenance	$30,000	Yearly	$42,000	Yearly
	Repairing	$50,000	Yearly	$60,000	Yearly
	Pump overhaul	$30,000	Yearly	$40,000	Yearly
	Running cost (electricity & Water)	$2,641,534	Yearly	$3,547,800	Yearly
	Demolition	$80,000		$100,000	
Parts Replacement					
	Condenser Unit	$150,000	20 Yrs	$72,000	10 Yrs
	Cooler	$500,000	15 Yrs	$585,000	15 Yrs
	Compressor	$650,000	15 Yrs	$1,080,000	10 Yrs
	Cooling Tower	$45,000	10 Yrs	--------------	--------

Table 6 Estimated Cost Summary

Detailed LCC calculations were shown below, with figures in blue representing the PV of equipments, operation, maintenance and components to be replaced.

Item	Description	Water-cooled ACS Life cycle = 25 Yrs Present Value (PV)	Air-cooled ACS Life Cycle = 17 Yrs Present Value (PV)
1	Chiller	**$3,465,000**	**$4,285,000**
2	Cooling tower	**$45,000**	-------------------
3	Condenser Pump	**$250,000**	-------------------
4	Chiller water pump	**$200,000**	**$260,000**
5	Electrical System	**$250,000**	**$180,000**
6	Preventive Maintenance	$54,000x1.558=**$84,132**	$36,000x1.345=**$48,420**
7	Annual Maintenance	$30,000x1.558=**$46,740**	$42,000x1.345=**$56,490**
8	Repairing	$50,000x1.558=**$77,900**	$60,000x1.345=**$80,700**
9	Pump overhaul	$30,000x1.558=**$46,740**	$40,000x1.345=**$53,800**
10	Running cost (E&W)	$2,641,534x1.558=**$4,115,510**	$3,547,800x1.345=**$4,771,791**
11	Demolition	$80,000x2.094x0.233=**$39,032**	$100,000x1.653x0.371=**$61,263**
12	Condenser Unit	$150,000x1.806x0.312=**$84,521**	$72,000x1.345x0.558=**$54,037**
13	Cooler	$500,000x1.558x0417=**$324,843**	$585,000x1.558x0.417=**$380,066**
14	Compressor	$650,000x1.558x0.417=**$422,296**	$1,080,000x1.345x0.558=**$810,551**
15	Cooling Tower 1st Repl.	$45,000x1.345x0.558=**$33,773**	-------------------
16	Cooling Tower 2nd Repl.	$45,000x1.806x0.312=**$25,356**	-------------------
	Total Present Value	**$9,150,843**	**$11,042,118**

Table 7 Life Cycle Cost Summary

It reveals that the LCC for WCAS is about $9.15 million and the ACAS is $11.04 million; with saving of 1.89 million (11.7%) even WCAS would last longer (25 years) than ACAS (17 years).

Pay Back Period Calculation

The pay back period could be derived from dividing the initial cost of WCAS by the annual energy saving:

$$\$4,210,000 \div (\$3,547,800 - \$2,641,534) = 4.64 \text{ years}$$

and after considering the Real Rate of Interest:

$$1 + \text{real rate} = \frac{1 + \text{nominal rate}}{1 + \text{inflation rate}} = 1.029126$$

the pay back period would be about 5.07 years*.

*Detail calculations of energy saving:

1st year energy saving = \$906266 ÷ 1.029126 = \$880617
2nd year energy saving = \$906266 ÷ 1.0591 = \$855695 (Acc. total 1736312)
3rd year energy saving = \$906266 ÷ 1.090 = \$831437 (Acc. total 2567749)
4th year energy saving = \$906266 ÷ 1.1217 = \$807940 (Acc. total 3375689)
5th year energy saving = \$906266 ÷ 1.15436 = \$785081 (Acc. total 4160770)
At 5.07 year energy saving = \$4210000 (which equals initial capital outlay)

6th year energy saving = \$906266 ÷ 1.18799 = \$762859 (Acc. total 4923629)

Alternatively, we may adopt the *Constant Chain of Replacement Assumption*, namely with 3 approaches: (1) Lowest common multiple method, (2) Constant chain of replacement in perpetuity, and (3) Equivalent annual value method, to compare projects/machineries of different life expectancy. It's common to adopt the constant chain of replacement in perpetuity approach, with the following formulas:

Net Present Value in Perpetuity: $$NPV\infty = NPV\left[\frac{(1+k)^n}{(1+k)^n - 1}\right]$$

The NPV in perpetuity for WCAS is \$9.15 million x 1.95255 = \$17.87 million

The NPV in perpetuity for ACAS is \$11.04 million x 2.5894 = \$28.59 million

Therefore the net total saving for using WCAS is \$28.59 – \$17.87 million = 10.72 million (about 60%) in perpetuity terms.

The energy saving in perpetuity by WCAS would be:

The NPV in perpetuity for WCAS is \$4.12 million x 1.95255 = \$8.05 million

The NPV in perpetuity for ACAS is \$4.77 million x 2.5894 = \$12.35 million

Therefore the net energy saving for using WCAS is \$12.35 – \$8.05 million = 4.30 million (about 35%) in perpetuity terms.

Questionnaires – Findings and Analysis

A total of 220 questionnaires were sent out to engineers, operators, suppliers and property developers. 100 responses were received, with a response rate of 45% as shown below.

Type of Company	Questionnaire sent out	Questionnaire received
Building Services Consultants	45	26 (26%)
Air-conditioning Contractors	50	16 (16%)
Property Maintenance Co.	65	36 (36%)
Property Developers	50	19 (19%)
Suppliers	10	3 (3%)
Total	220	100 (100%)

The survey is mainly divided into two parts. Part I questions focus on the background of respondents. Part II questions no. 1 to 7 focus on the economic benefits. Part II questions 8 to 11 focus on operation and maintenance. Part II questions 12 to 14 focus on the environmental impacts.

Part I - Background of respondents

Nature of respondent's company				
Consultant	Contractor	Maintenance	Developer	Supplier
26% (26)	16% (16)	36% (36)	19% (19)	3% (3)
Nature of respondent's work				
Installation	Design	Maintenance	Other	
15% (15)	7% (7)	56% (56)	22% (22)	
Working experience of the respondents				
1~3 yrs	4~6 yrs	7~9 yrs	10~12 yrs	Above 12 yrs
28% (28)	40% (40)	18% (18)	7% (7)	7% (7)

Property maintenance companies and developers have highest return rate, and opine that conversion from ACAS to WCAS generates more benefits.

Part II - Economic Benefit

Question	Strongly Agree	Agree	Fair	Disagree	Strongly Disagree
Q1. Fresh water cooling tower chiller has greater environmental, economic and financial benefits than air-cooled chiller.	20% (20)	44% (44)	24% (24)	12% (12)	0% (0)
Q2. Compare with energy saving and water resources, it is still worth to use fresh water cooling tower chiller in air-conditioning system.	13% (13)	51% (51)	24% (24)	12% (12)	0% (0)
Q3.The life cycle of fresh water cooling tower chiller is much longer than air cooled chiller.	15% (15)	50% (50)	26% (26)	9% (9)	0% (0)
Q4. The performance of air cooled chiller is mainly affected by ambient temperature so it has lower efficiency at higher ambient temperature.	28% (28)	49% (49)	16% (16)	7% (7)	0% (0)
Q5. As an engineer, you will recommend the client to replace the air cool with fresh water cooling tower	12% (12)	42% (42)	34% (34)	12% (12)	0% (0)
Q6. Energy saving is the main concern for selecting fresh water cooling tower chiller.	16% (16)	47% (47)	18% (18)	19% (19)	0% (0)
Q7. With the same cooling capacity, energy saving of fresh water cooling tower chiller (comparing with air-cooled chiller) is around………	1%~5% Saving	6%~10 % Saving	11%~16% Saving	17%~20% Saving	Over 20% Saving
	9% (9)	28% (28)	25% (25)	18% (18)	20% (20)

All respondents opine that the fresh water cooling is more energy saving (bearing the constraints), yet with diversifying views on degree of energy saving.

Part II - Operation and Maintenance

Question	Strongly Agree	Agree	Fair	Disagree	Strongly Disagree
Q8. In respect of maintenance, you prefer to use fresh water cooling tower chiller.	15% (15)	44% (44)	35% (35)	6% (6)	0% (0)
Q9. Fresh water cooling tower chiller has higher reliability.	15% (15)	56% (56)	20% (20)	9% (9)	0% (0)
Q10. In conversion of air cooled chiller, the space and plant room location is not the main concern.	10% (10)	32% (32)	22% (22)	26% (26)	10% (10)
Q11. From the operation point of view, fresh water cooling tower chiller is much better than air cool chiller.	13% (13)	49% (49)	28% (28)	10% (10)	0% (0)

In respect of operation and maintenance, more than 60% of the respondents agree that fresh water cooling tower is better than air-cool cooling tower.

Part II - Environmental Impacts

Question	Strongly Agree	Agree	Fair	Disagree	Strongly Disagree
Q12. In fresh water cooling tower chiller, all biological pollution can be controlled through proper water treatment.	21% (21)	50% (50)	19% (19)	10% (10)	0% (0)
Q13. The misty discharge from fresh water cooling tower create more nuisance to occupiers than that of noise from air cooled chiller.	15% (15)	44% (44)	29% (29)	12% (12)	0% (0)
Q14. Using fresh water in water cooling tower will increase the water demand and consequently affect the normal water supply.	10% (10)	49% (49)	21% (21)	16% (16)	4% (4)

In environmental aspect, the respondents agree that fresh water cooling tower require better control in water treatment to mitigate possible water pollution and other problems.

Summary

In general, fresh water-cooling tower is widely accepted by professionals as a better A/C system in energy conservation and environment protection. Most property developers and maintenance companies intend to replace the existing air-cooled system (if so installed) with fresh water cooling tower system.

7. CONCLUSION AND LIMITATION

There has long been shortage of energy resources. Before new sources of energy could be developed, saving would be the only means to safeguard human beings on earth. To improve the air-conditioning plant efficiency is one achievable way to go ahead. Form the above research and analysis, conversion from ACAS to WCAS would save around 35% running costs. This research is limited by some factors e.g. variance of annual maintenance cost, environmental effects, energy cost fluctuation, changes in interest rates, daily operation time of A/C plants, mode of maintenance etc. which could not be accurately predicted and applied in the life cycle cost calculations. Due to limited resources, questionnaires may only be despatched to minimal targets. If there may be more respondents, the representation of this research would certainly push up. Other potential issues and cost implications such as adequacy of proper water treatment for preventing legionnaire disease in WCAS could be further explored.

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