Effective Cost Management of Building Services in Hong Kong –

Managing Sustainability and Costing in Air-Conditioning

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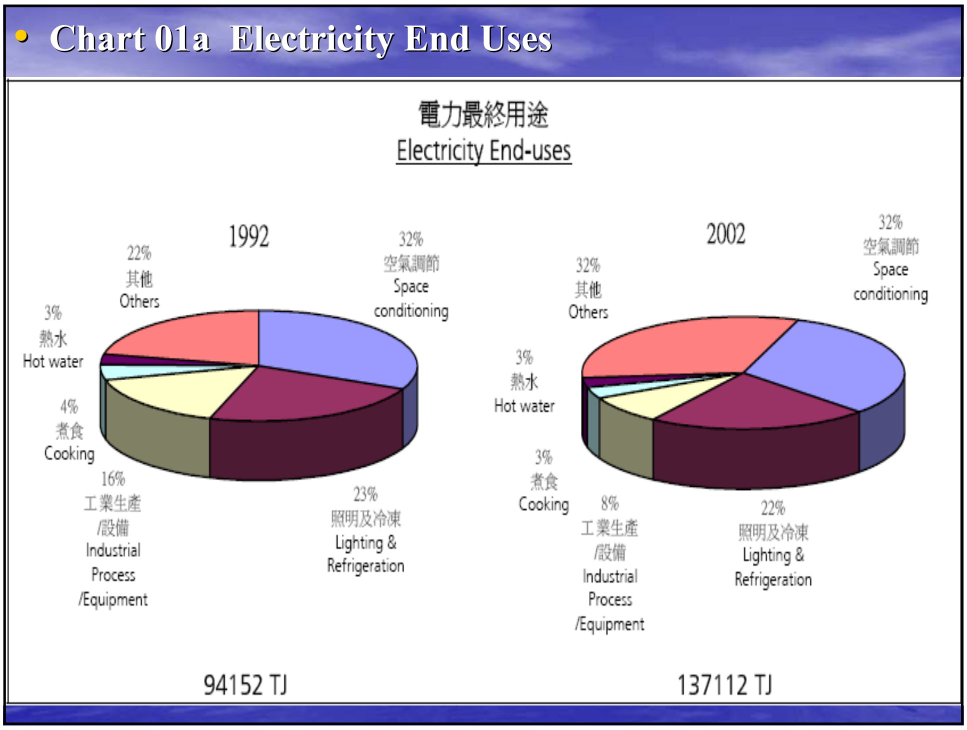
- **Introduction**
- **Energy consumption in HK**
- Many curtain walls + central A/C
- HK's tropical climate (temp. 33℃+, RH 80%+, esp. in summer)
- Principal 2 types A/C chiller systems-ACAS,WCAS
- ACAS - less efficient, widely adopted in past
- Local govt. not encouraged city water for WCAS
- Refrigeration compression cycle consumes most electric energy
- Energy End-user Data published by EMSD in 2004
- Covers all fuels used by energy end-users in HK

Electricity End Uses													
Yeay	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 01 Electricity End Uses



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 02 Energy Use in All Fuel

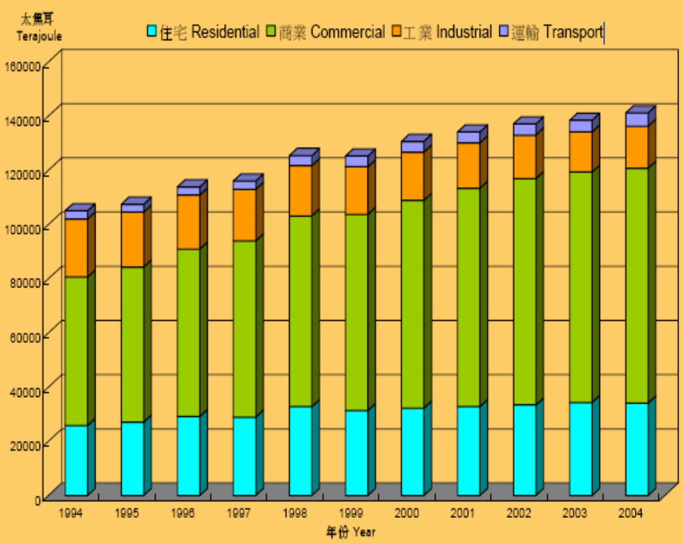
- Total energy consumption increased by 15% from 246562 Terajoule (TJ) in 1992 to 283921 (TJ) in 2002
- Electric energy grew by 45% from 94152 (TJ) to 137112 (TJ)
- 32 % electric energy spent on A/C in 2002
- 45% growth from 30097 (TJ) in 1992 to 43581 (TJ) in 2002
- More commercial properties & economic activities
- To improve sustainability & environmental protection
- Census & Statistic Dept. report (2006)
- Commercial bldg. power consumption, increased by 26% from 76028 (TJ) in 1999 to 95370 (TJ) in 2006
- About 66% electricity consumed in HK used in commercial bldgs. in 2006 (versus 61% in 1999)

Table 02a Power Consumption (TJ) from HKSAR Census & Statistics Dept.

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

Chart 02b

Figure 1: By All Sectors (Electricity)



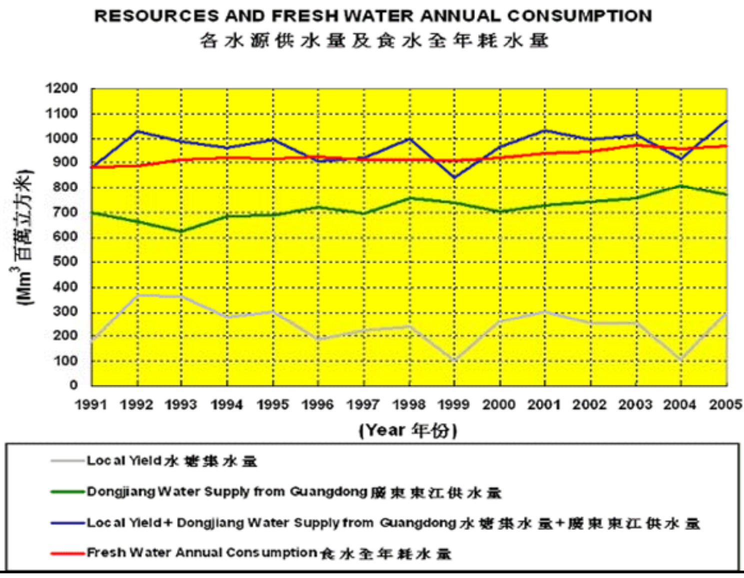
香港能源最終用途數據（2006年初版）Hong Kong Energy End-use Data 2006 (1st Edition) P.2

- **Fresh Water consumption in Hong Kong**
- Water Supply Dept. (WSD) - surplus fresh water from Dongjiang Guangdong China
- Light industries moved to Mainland China
- Water usage reduced by 63.7% from 1989's 182 mcm to 1998's 66 mcm, even population rose by 1.5 million

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

Water consumption chart

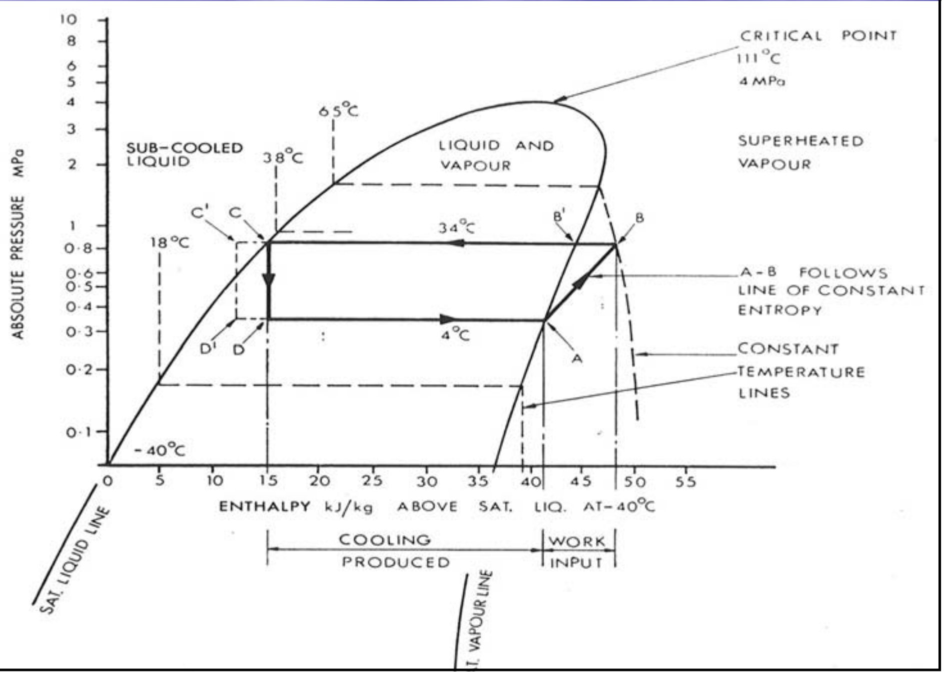


- **Govt.'s Preliminary Study - Fresh Water Cooling Tower**
- Electrical & Mechanical Services Dept. (EMSD)
- Complete study of "Wider Use of Water-cooled A/C system in HK" in 1999
- Implementation study for WCAS in HK in 2000
- Examine technical/financial viability, infrastructure works, land use, traffic impact, environmental/health issues, regulatory control
- 3 WCAS schemes studied i.e. Cooling Tower Scheme, Central Seawater Scheme, District Cooling Scheme
- Central Seawater Scheme & District Cooling Scheme not quite cost effective
- Fresh water, not seawater, be adopted

- **Govt.'s Pilot Scheme on Fresh Water as Cooling Media**
- In 2000, launched a pilot scheme on wider use of fresh water for WCAS in non-domestic buildings in 28 designated areas
- In 2006, covered 57 designated areas
- Provide guidelines in associated water/building works, sewage services, control of noise/water pollution/air pollution

- **<u>Air-conditioning Systems</u>**
- Central A/C system - mainly divided into 2 parts, i.e. **air-side, water side**
- Air-side includes AHU, PAU, FCU
- The "cycle" of water side consists of 4 steps - vapour compression, condensation, expansion, evaporation

Refrigeration Cycle



- **Air-Cooled Condenser**
- Direct Air-Cooled Condenser: Natural Draft, Forced Draft
- Indirect Air-Cooled Condenser
- Water-Cooled Condenser: Direct Water Cool, Indirect Water Cool, Water Cooling Tower
- Water Cooling Tower:Natural Draught, Fan Draught
- Natural Draught: Spray pond, Natural Draught Cooling Tower, Condenser Coil Type
- Fan Draught: Crossflow Type, Induced Draught Cooling Tower, Forced Draught Cooling Tower, Film Cooling Tower, Closed Circuit Water Coolers

Figure 02 Low Silhouette Cross-flow Cooling Tower

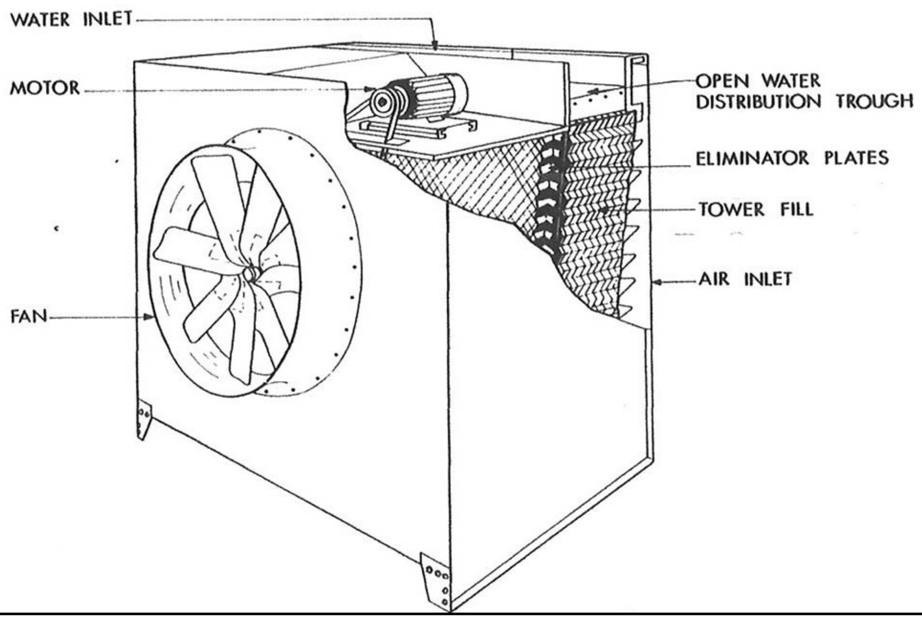


Figure 03 Induced Draught Cooling Tower

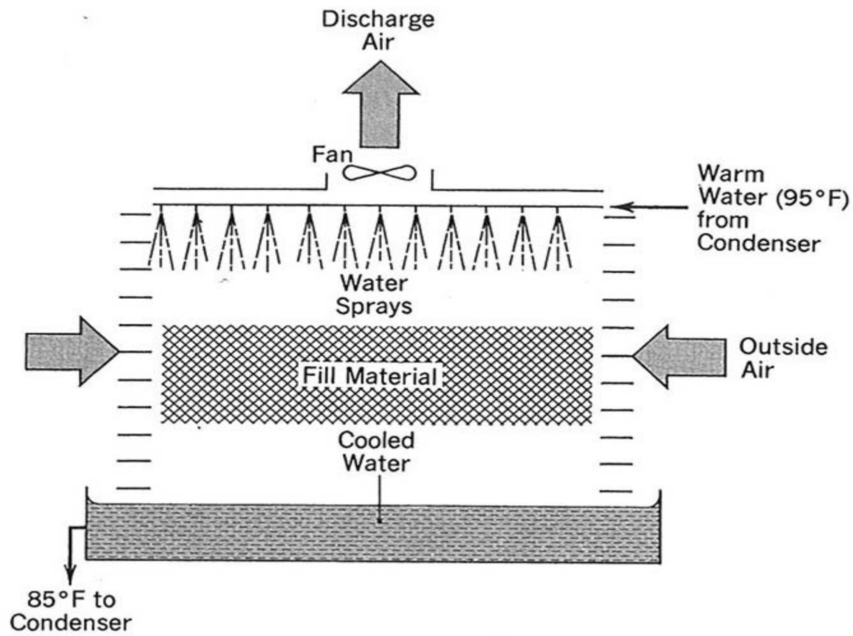


Figure 04 Forced Draught Cooling Tower

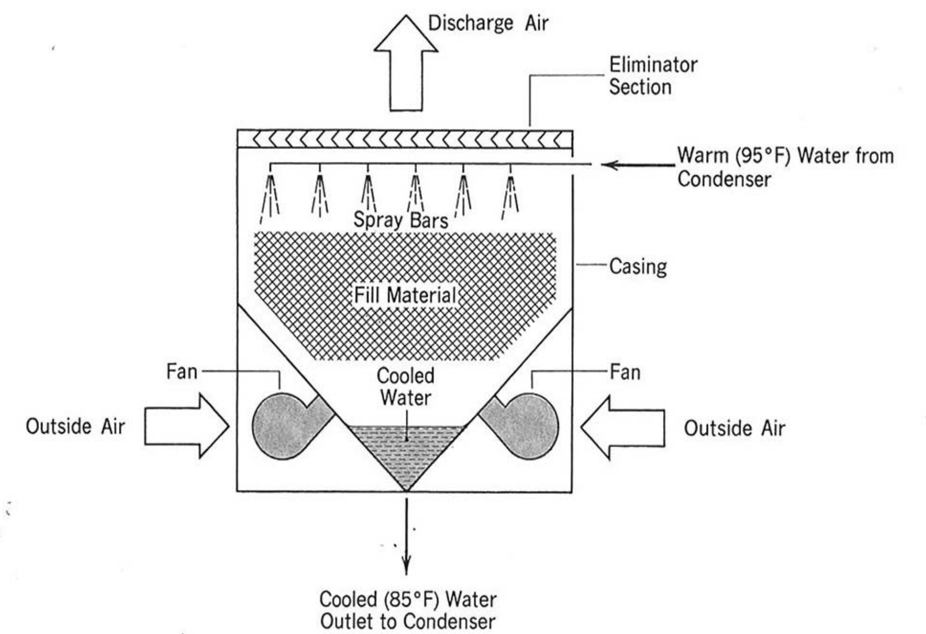
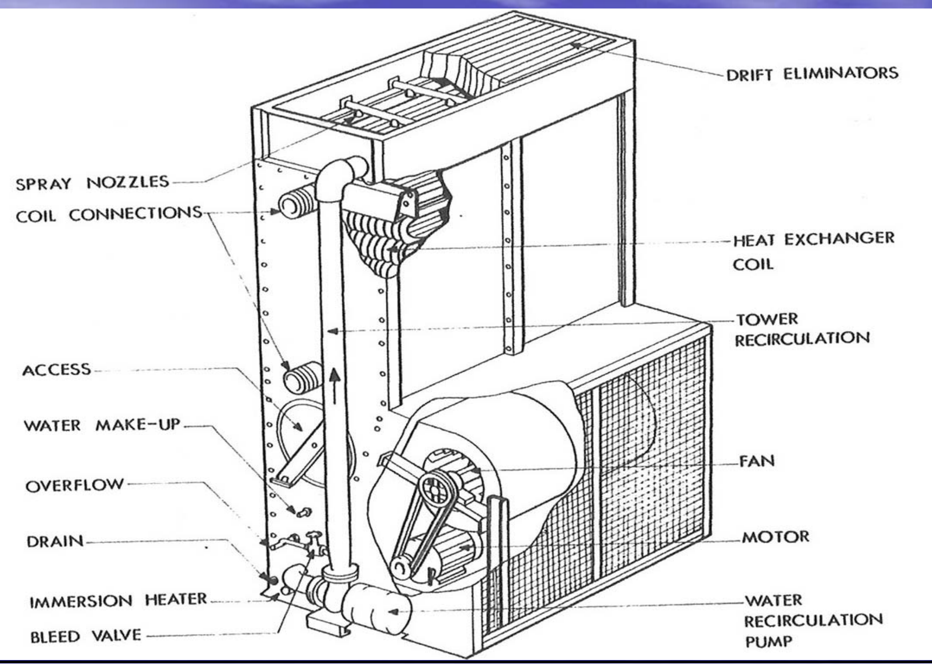


Figure 05 Closed Circuit Water Coolers



- **<u>Environmental Impacts</u>**
- Cooling tower is more energy efficient than conventional air-cooled A/C
- Reduce demand for power, CO_2 emissions
- In 2020, annual energy savings would be 1,170 million kWh (3.1% total electricity consumption)
- Annual electricity bill saved by HK$1.05 billion
- CO_2 would be reduced annually by 830,000 tonnes (2.34% total CO_2 emission of HK in 2002)

- **Water Pollution**
- Operator would use cold water to flush cooling coil of condenser unit in ACAS
- Bring forth more dirty water into harbour through surface water drainage system
- For WCAS - concentration of scale-forming solids, foul condenser tubes
- Bleed-off water + chemical, discharge to drainage system.
- **Air Pollution**
- ACAS cools refrigerant by enforcing air to pass through condenser coil
- Enforced air blow up dust - harmful to health
- For WCAS, misty substances produce nuisance to nearby, may spread out legionnaire disease

- **Noise Pollution**
- Most ACAS is direct expansion type
- All components are constructed in one package
- Located at open space/podium/roof
- Noise created greater than that of WCAS
- Fans used in ACAS - much more than that of WCAS (about 5 to 1).

- **<u>Research Methodology</u>**
- Quantitative & qualitative research methods adopted
- Case study on Modern Plaza
- Questionnaire sent to professionals working in property developers, building services consultants, contractors, suppliers

- **Case Study on Modern Plaza**
- Existing 1810 RT ACAS (4 no. 340RT; 3 no. 100RT & 2 no. 75RT) installed on podium roof
- Substantial noise/hot emission/nuisance created
- Silencer later on installed to help reduce noise
- But it deterred hot air emission
- Subsequently reduce the A/C's overall efficiency
- Due to space constraint, demolish extg. chiller first in sequence

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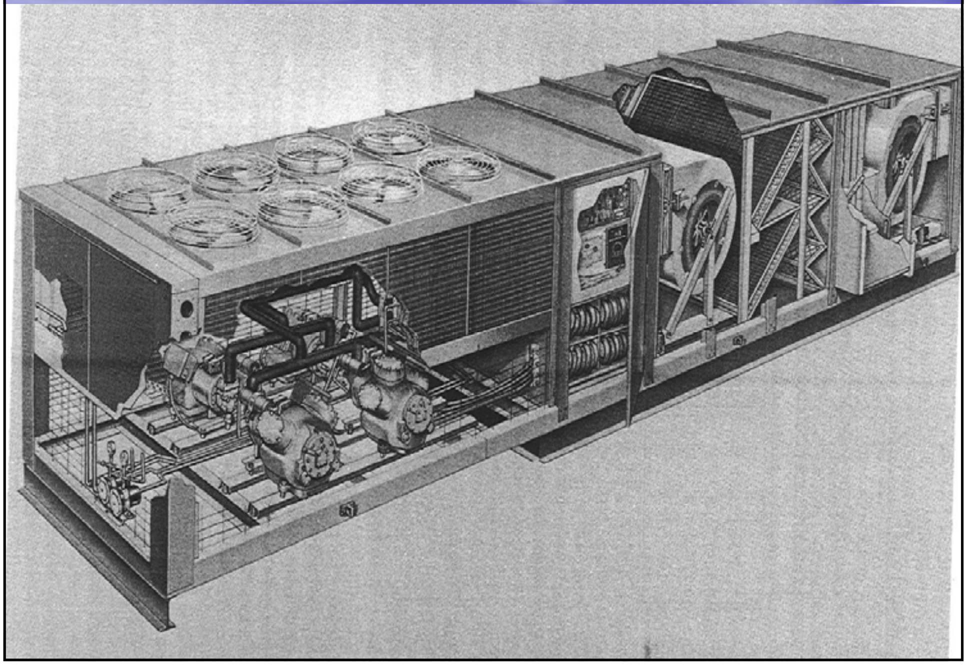
- Site location affects materials transportation, manpower mobilization, travelling cost/time
- ACAS components constructed in a package type (compressor, condenser, evaporator, expansor within a large steel framework)
- Mobile crane (at higher preliminary cost) required
- Hoisting within a confined area - difficult, remote or even impractical
- WCAS compose of individual components - more flexibility in construction
- Installation method dictates/affects end cost

Figure 06 Packaged Air-cooled air-conditioning



- **Life Cycle Cost Analysis**
- LCC technique applied to compare ACAS with WCAS
- Net Present Value (NPV) adopted

- NPV for equal payment series is $\{1-1 \div (1+j)^n\} \div j$
- Assume investment rate is 6%, life cycle of ACAS (17 years) WCAS (25 years)

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

Table 03 Present value for equal payment

- The Future Value (FV) for replacement is $(1+s)^n$
- Assume the inflation rate is 3% , 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 04 Future Value

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

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 05 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 06 Estimated Cost Summary

Detailed LCC calculations shown below

em	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	$54,000.00x1.558=**$84,132**	$36,000.00x1.345=**$48,420**
7	Annual Maintenance	$30,000.00x1.558=**$46,740**	$42,000.00x1.345=**$56,490**
8	Repairing	$50,000.00x1.558=**$77,900**	$60,000.00x1.345=**$80,700**
9	Pump overhaul	$30,000.00x1.558=**$46,740**	$40,000.00x1.345=**$53,800**
0	Running cost (E & W)	$2,641,534.00x1.558=**$4,115,510**	$3,547,800.00x1.345=**$4,771,791**
1	Demolition	$80,000.00x2.094x0.233=**$39,032**	$100,000.00x1.653x0.371=**$61,263**
2	Condenser Unit	$150,000.00x1.806x0.312=**$84,521**	$72,000.00x1.345x0.558=**$54,037**
3	Cooler	$500,000.00x1.558x0417=**$324,843**	$585,000.00x1.558x0.417=**$380,066**
4	Compressor	$650,000.00x1.558x0.417=**$422,296**	$1,080,000.00x1.345x0.558=**$810,551**
5	Cooling Tower 1st Repl.	$45,000.00x1.345x0.558=**$33,773**	-------------------
6	Cooling Tower 2nd Repl.	$45,000.00x1.806x0.312=**$25,356**	-------------------
	Total Present Value	**$9,150,843**	**$11,042,118**

Table 07 Life Cycle Cost Summary

- LCC for WCAS - about $9.15 million
- LCC for ACAS - about $11.04 million
- Saving of 1.89 million (11.7%)

Pay Back Period Calculation

- derived from dividing initial cost of WCAS by annual energy saving:
  $4,210,000 ÷ ($3,547,800 - $2,641,534) = 4.64 years

- after considering the Real Rate of Interest:

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

- pay back period would be 5.07 years*

*Detail calculations of energy saving:

- 1st year = $906266 ÷ 1.029126 = $880617
- 2nd year = $906266 ÷ 1.0591 = $855695
  (Acc. total 1736312)
- 3rd year = $906266 ÷ 1.090 = $831437
  (Acc. total 2567749)
- 4th year = $906266 ÷ 1.1217 = $807940
  (Acc. total 3375689)
- 5th year = $906266 ÷ 1.15436 = $785081
  (Acc. total 4160770)
- At 5.07 year energy saving = $4210000
  (equals initial capital outlay, break even)
- 6th year = $906266 ÷ 1.18799 = $762859
  (Acc. total 4923629)

- Alternatively, adopt the *Constant Chain of Replacement Assumption*
- 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
- Common to adopt the constant chain of replacement in perpetuity approach
- Net Present Value in Perpetuity: $NPV\infty = NPV\left[\frac{(1+k)^n}{(1+k)^n - 1}\right]$

- NPV in perpetuity for WCAS is \$9.15 million x 1.95255 = \$17.87 million
- NPV in perpetuity for ACAS is \$11.04 million x 2.5894 = \$28.59 million
- Net total saving for using WCAS is \$28.59 – \$17.87 million = 10.72 million (60%) in perpetuity terms
- Energy saving in perpetuity by WCAS would be:
- NPV in perpetuity for WCAS is \$4.12 million x 1.95255 = \$8.05 million
- NPV in perpetuity for ACAS is \$4.77 million x 2.5894 = \$12.35 million
- Net energy saving using WCAS is \$12.35 – \$8.05 million = \$4.30 million (35%) in perpetuity terms

- **Questionnaires - Findings & Analysis**
- 220 questionnaires sent out to engineers, operators, suppliers, property developers
- 100 responses (45%) received
- Part I Q. 1 to 3 focus on background of respondents
- Part II Q. 1 to 7 focus on economic benefits
- Part II Q. 8 to 11 focus on operation & maintenance
- Part II Q. 12 to 14 focus on environmental impacts

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%)

- **Part I (Background of respondents)**
- Q1. What is the nature of your co. that you are working in?
- Q2. How long have you worked in A/C firm. (years)
- Q3. What is your major work in company?

- **Part II (Economic benefit, operation, maintenance, environmental impacts)**
- Q1. Fresh water cooling tower chiller has greater environmental, economic & financial benefits than air-cooled chiller.
- Q2. Compare with energy saving/water resources, it is still worth to use fresh water cooling tower chiller in A/C system.
- Q3.The life cycle of fresh water cooling tower chiller is much longer than air cooled chiller.

- Q4. The performance of air cooled chiller is mainly affected by ambient temperature so it has lower efficiency at higher ambient temperature.
- Q5. As an engineer, you will recommend the client to replace air cool with fresh water cooling tower.
- Q6. Energy saving is the main concern for selecting fresh water cooling tower chiller.
- Q7. With the same cooling capacity, energy saving of fresh water cooling tower chiller (compare with air-cooled chiller) is around………
- Q8. In respect of maintenance, you prefer to use fresh water cooling tower chiller.
- Q9. Fresh water cooling tower chiller has higher reliability.

- Q10. In conversion of air cooled chiller, the space & plant room location is not the main concern.
- Q11. From operation point of view, fresh water cooling tower chiller is much better than air cool chiller.
- Q12. In fresh water cooling tower chiller, all biological pollution can be controlled through proper water treatment.
- Q13. The misty discharge from fresh water cooling tower creates more nuisance to occupiers than that of noise from air cooled chiller.
- Q14. Using fresh water in water cooling tower will increase water demand and consequently affect the normal water supply.

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
- 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 on Questionnaire Result**
- Fresh water cooling tower widely accepted by professionals
- A better A/C system in energy conservation/environment protection
- Most property developers/maintenance co. intend to adopt
- **Conclusion & Limitation**
- Save energy to safeguard human beings on earth
- Improve A/C plant efficiency is one achievable way
- Conversion from ACAS to WCAS save around 35% running costs
- Research limited by: 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.
- Questionnaires not wide spread enough
- Adequacy of proper water treatment for preventing legionnaire disease in WCAS could be further explored.

- **Reference**

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Thank you

Q & A

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