Optimized System for Your Bottom Line

Trane Training Class
1 Dec, 2017

Total Cost of Ownership

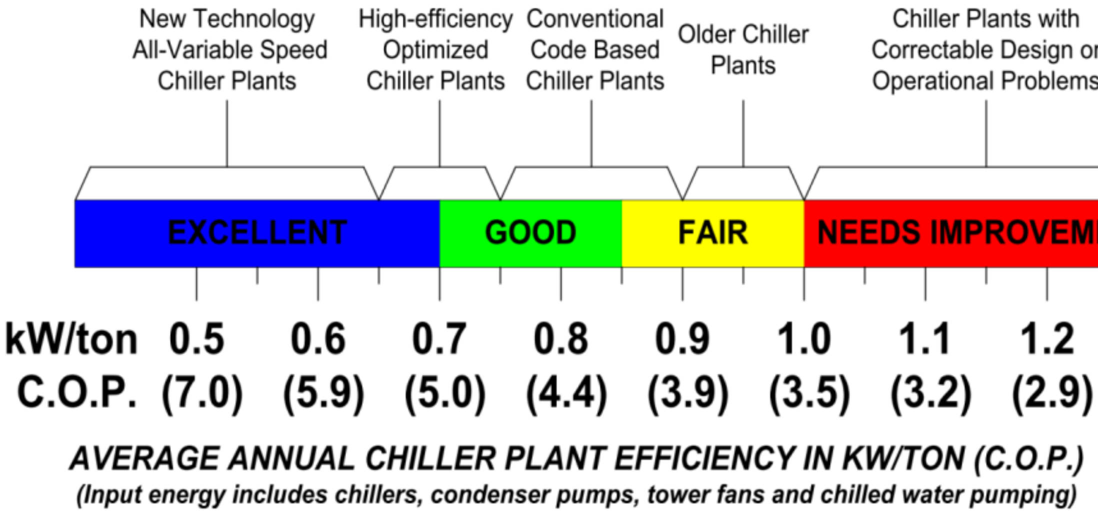
Setting your system for great payback

Where is money spent over a 30 year lifetime?

First Cost	4.9%
Service	6.6%
Power	88.5%

A Balanced Approach, with a Focus on Efficiency

Chiller Plant Efficiency



Note: Based on electrically driven centrifugal chiller plants in comfort conditioning application with 5.6C nominal chilled water supply temperature and open cooling towers sized for 29.4C maximum entering condenser water temperature and 20% excess capacity

Chiller Plant Efficiency

=

+

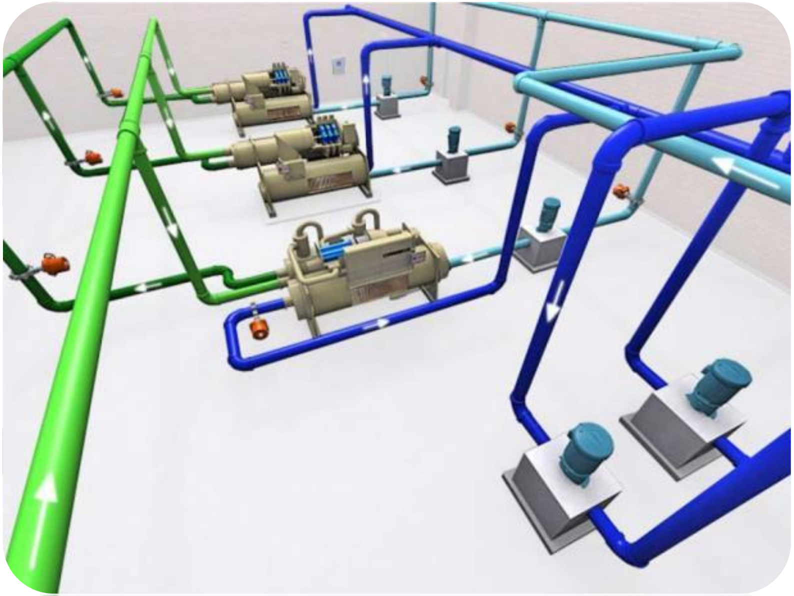
Optimal Plant Efficiency

Guaranteed chiller performance

System application & control strategy

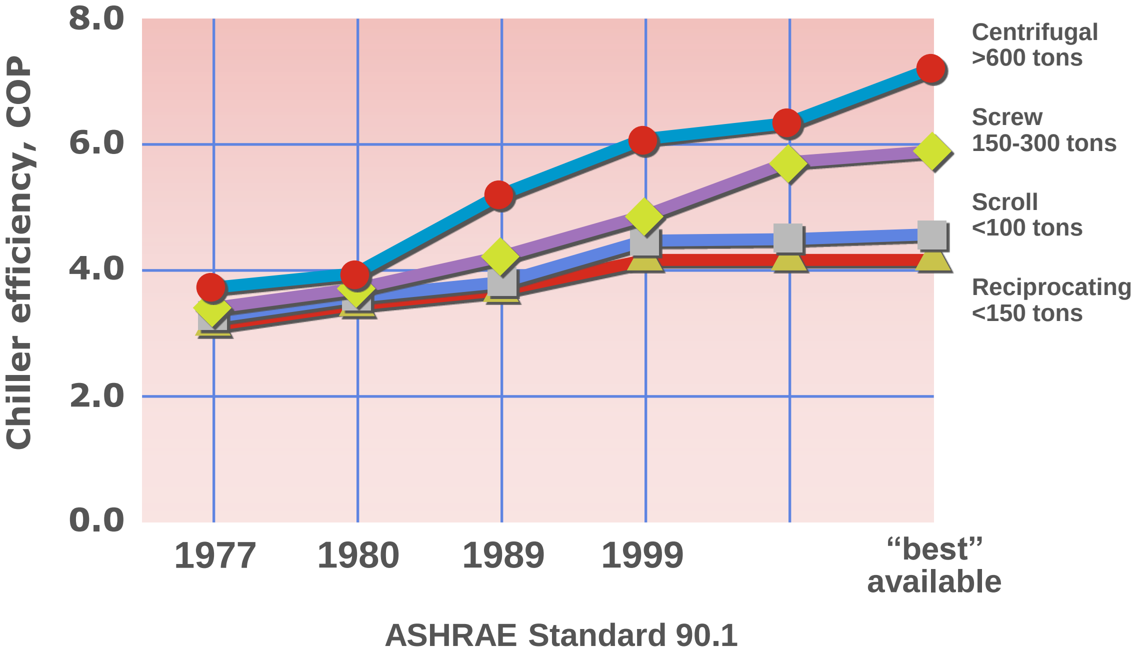
Chiller Plant Efficiency

- Major Equipment for water-cooled chiller plant
  - Chiller
  - Pump
  - Cooling Tower



Chiller Performance

History of Chiller Efficiency



Chiller Performance

BEEO Requirement (2015)

Table 6.12b : Minimum Coefficient of Performance for Chiller[@2] at Full Load

Air-cooled

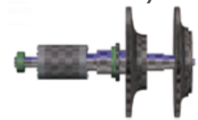
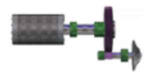
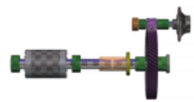
Type of compressor	Reciprocating		Scroll		Screw		VSD Screw		Centrifugal	VSD Centrifugal
Capacity Range (kW)	Below 400 kW	400 kW & above	Below 400 kW	400 kW & above	Below 500 kW	500 kW & above	Below 500 kW	500 kW & above	All Ratings	All Ratings
Minimum COP at cooling (free air flow[@1])	2.8	2.9	2.8	2.9	2.9	3.0	2.8 (3.6)[@5]	2.9 (3.7)[@5]	3.2	3.1 (4.0)[@5]

Water-cooled

Type of compressor	Reciprocating / Scroll			Screw			VSD Screw			Centrifugal			VSD Centrifugal		
Capacity Range (kW)	Below 500 kW	500 to 1000 kW	Above 1000 kW	Below 500 kW	500 to 1000 kW	Above 1000 kW	Below 500 kW	500 to 1000 kW	Above 1000 kW	Below 1000 kW	1000 kW to 3000 kW	Above 3000 kW	Below 1000 kW	1000 kW to 3000 kW	Above 3000 kW
Minimum COP (Cooling)	4.2	4.7	5.3	4.8	5.0	5.5	4.7 (6.1)[@5]	4.9 (6.3)[@5]	5.2 (6.7)[@5]	5.4[@3] / 5.6[@4]	5.7	5.8	5.1 (6.6)[@5]	5.5 (7.1)[@5]	5.6 (7.2)[@5]

Comprehensive review to be conducted in 2018, 2021 and 2024 respectively.

Chiller Performance
Centrifugal Chiller

	Direct Drive (Hermetic Mech)	Gear Drive (Hermetic Mech)	Gear Drive (Open Mech)	Direct Drive (Hermetic Mag Lev)
				
	Multi Stage	Single Stage	Single Stage	Multi Stage
Type of Refrigerant	R-123	R-134a	R-134a	R-134a
Theoretical Refrigerant Efficiency	0.433 kW/ton (8.1 COP)	0.460 kW/ton (7.6 COP)	0.460 kW/ton (7.6 COP)	0.460 kW/ton (7.6 COP)
Centrifugal Chiller Cycle Efficiency	0.388 kW/ton (9.1 COP)	0.415 kW/ton (8.5 COP)	0.415 kW/ton (8.5 COP)	0.415 kW/ton (8.5 COP)
Drive Train Efficiency	100%	98.1%	97.9%	100%
Compressor Efficiency	83.3%	80.4%	81.8%	78.8%
Motor Efficiency	95.5%	95.0%	95.0%	97.0%
Chiller Efficiency	0.487 kW/ton (7.2 COP)	0.554 kW/ton (6.3 COP)	0.545 kW/ton (6.4 COP)	0.543 kW/ton (6.5 COP)

Chiller Performance

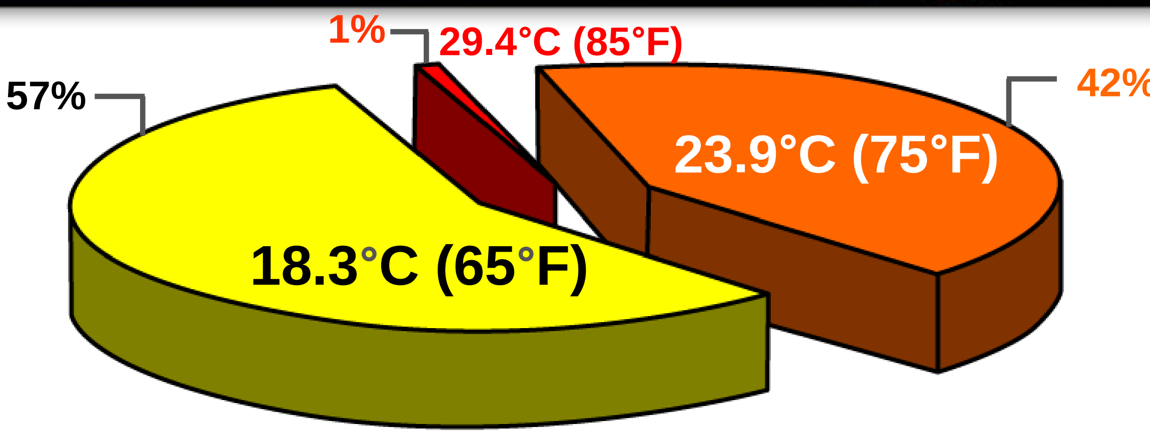
Efficiency Comparison – Index Rating

AHRI Definition of Integrated Part Load Value (IPLV/NPLV)

$$IPLV = \frac{1}{\frac{1\%}{A} + \frac{42\%}{B} + \frac{45\%}{C} + \frac{12\%}{D}}$$

A = kW/Ton @ 29.4°C (85°F) @100% Load
B = kW/Ton @ 23.9°C (75°F) @ 75% Load
C = kW/Ton @ 18.3°C (65°F) @ 50% Load
D = kW/Ton @ 18.3°C (65°F) @ 25% Load

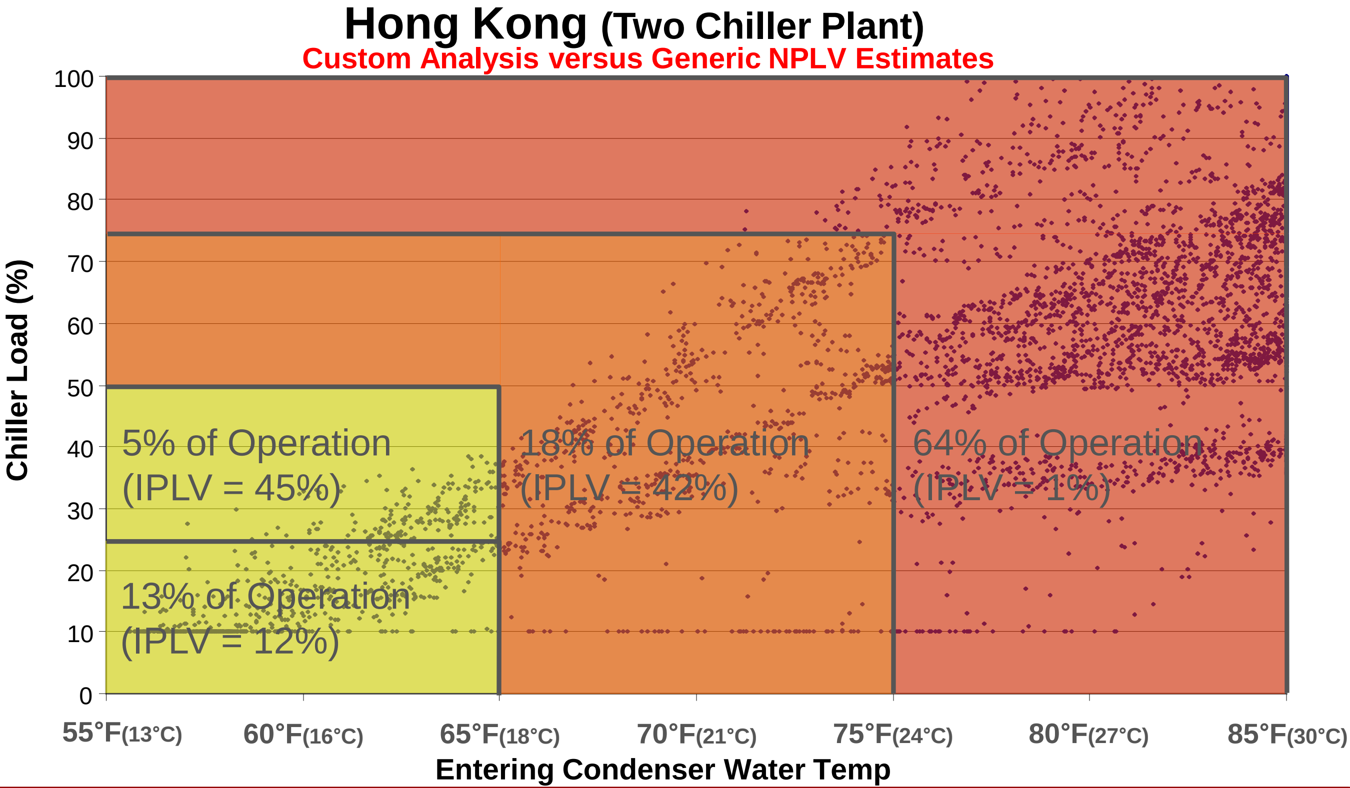
Temperatures: Expected Entering Tower Water
AHRI Conditions: Chilled Water: 54° /44° F (12.2° /6.6° C)
Condenser Water: 3 GPM/Ton (0.054 L/S/kW)



Real World Chillers Operate at Real World Conditions

Chiller Performance

Efficiency Comparison – Index Rating vs. Real-World



Where Do The Chillers in Your Plant Run?

Chiller Performance
Real Payback Require Real Analysis

Always, Always Remember …
The Meter is On The BUILDING

Chiller Performance

Real Payback Require Real Analysis

TRANE

TRACE™ 700

HVAC load design and analysis software

Trane Air Conditioning Economics, or TRACE™, is a design-and-analysis tool that helps HVAC professionals optimize the design of a building's heating, ventilating and air-conditioning system based on energy utilization and life-cycle cost.

A TRACE model can help establish the peak cooling and heating loads during the planning stage of a building project. At the design development stage, it aids evaluation of energy-saving concepts, such as the effects of daylighting, HVAC optimization strategies and high-performance glazing. And near the end of the construction, when the design is finalized, the TRACE model can help document compliance with ASHRAE Standard 90.1-2007/2010 or validate the building's eligibility for LEED® certification.

Powerful modeling capabilities

- Choose from eight load-simulation methodologies, including Heat Balance-based RTS, using algorithms provided in the latest ASHRAE Loads Toolkit. Specify either hour-by-hour (8760) or reduced-year energy/economic analysis.
- Choose from more than 500 predefined weather locations from around the globe.
- Describe building envelope and site orientation, as well as room construction, airflows, thermostat settings, heat sources and utilization schedules.
- Model various HVAC systems including single-zone, VAV-reheat, parallel fan-powered VAV, underfloor air distribution and dedicated outdoor-air systems.
- Model chillers, unitary equipment, water-source and geothermal heat pumps, boilers, electric resistance heating, gas-fired heat exchangers and air terminals.
- Include thermal storage, energy recovery, free cooling, cogeneration and district heating or cooling.
- Simulate control strategies, such as optimum start/stop, temperature or static pressure setpoint reset, humidification, night purge, fan cycling, demand-limiting and equipment sequencing.

Compliant calculation methodologies

TRACE 700 calculations apply techniques recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). The program is tested in compliance with ASHRAE Standard 140-2007/2011, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs*, and it meets the requirements for simulation software set by ASHRAE Standard 90.1-2007/2010 and the LEED® Green Building Rating System.

Compliant calculation methodologies

TRACE 700 calculations apply techniques recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). The program is tested in compliance with ASHRAE Standard 140-2007/2011, Standard Method of Test for the Evaluation of Building Energy Analysis

Computer Programs, and it meets the requirements for simulation software set by ASHRAE Standard 90.1-2007/2010 and the LEED® Green Building Rating System.

TRACE 700

Chiller Plant Analyzer

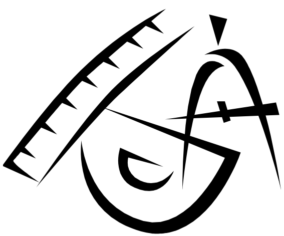
Chiller Plant Efficiency
Pump Performance

- Hydraulic Power $P_{h(kW)} = q\ \rho\ g\ h\ /\ (3.6\ x10^{6})$
  - q = flow capacity (m^3/h)
  - ρ = density of fluid (kg/m^3)
  - g = gravity (9.81 m/s^2)
  - h = pump head (m)

- Pump Head is the total resistance that a pump must overcome
  - Static Head
  - Friction Head
  - Pressure Head
  - Velocity Head

Pump Performance
Pump Head Calculation

- Never oversize pump
- Select pump duty point for best efficiency



Trane Hong Kong

Project: Air-to-Fresh Water Cooled Chiller Plant Conversion in Peninsula Centre
Pump Designation: CDWP 1 to 4
Location: R/F
Flowrate: 118.00 L/s
Design Pump Head: 26M (252 kPa)
Date: 07/19/10
Rev. 2

Pipe Section	Location / Designation	Description	Flow Rate V, (L/s)	Nominal Pipe Size D, (mm)	Flow Velocity v, (m/s)	Pressure Loss per Unit Length pl, (Pa/m)	Pipe Length l, (m)	Equivalent length Multiplier l_e	Velocity Pressure Loss Factor for Fitting ξ	No. of pipe fitting	Velocity Pressure Loss (kPa)	Pressure Loss p, (kPa)	Total Accumulative Pressure Loss (kPa)
1-2	R/F CDWP	**Pump Discharge**	–	–	–	–	–	–	–	–	–	–	–
		Pipe	118	250	2.41	160	3	–	–	–	0.48	0.48	0.48
		Butterfly Valve	118	250	2.41	160	–	–	–	1	0.58	0.58	1.06
		Check Valve	118	250	2.41	160	–	–	–	1	2.90	2.90	3.96
		90 deg Elbow	118	250	2.41	160	–	17	0.3	1	0.82	0.82	4.78
		Flexible Joint	118	250	2.41	160	–	17	0.1	1	0.27	0.27	5.05
2-3	R/F	Pipe	354	400	2.82	160	12.5	–	–	–	2.00	2.00	7.05
		45 deg elbow	354	400	2.82	160	–	29	0.21	2	1.95	1.95	9.00
		90 deg elbow	354	400	2.82	160	–	29	0.3	1	1.39	1.39	10.39
		Tee in	354	400	2.82	160	–	29	0.3	3	4.18	4.18	14.56
		Tee out	354	400	2.82	160	–	29	0.51	1	2.37	2.37	16.93
		Reduce	354	400	2.82	160	–	29	0.3	1	1.39	1.39	18.32
3-4	R/F	Pipe	236	300	3.34	240	12.1	–	–	–	2.90	2.90	21.23
		45 deg elbow	236	300	3.34	240	–	22	0.2	2	2.11	2.11	23.34
		90 deg elbow	236	300	3.34	240	–	22	0.3	1	1.58	1.58	24.92
		Tee out	236	300	3.34	240	–	22	0.51	1	2.69	2.69	27.62
4-5	R/F	Pipe	118	250	2.41	160	6	–	–	–	0.96	0.96	28.58
		Butterfly Valve	118	250	2.41	160	–	–	–	3	1.74	1.74	30.32
		Flexible Joint	118	250	2.41	160	–	17	0.1	2	0.54	0.54	30.86
		90 deg Elbow	118	250	2.41	160	–	17	0.3	4	3.26	3.26	34.12
5-6	R/F	Pipe	236	300	3.34	240	11	–	–	–	2.64	2.64	36.76
		45 deg elbow	236	300	3.34	240	–	22	0.2	2	2.11	2.11	38.88
		90 deg Elbow	236	300	3.34	240	–	22	0.3	1	1.58	1.58	40.46
		Tee in	236	300	3.34	240	–	22	0.85	1	4.49	4.49	44.95
6-7	R/F	Pipe	354	400	2.82	160	12	–	–	–	1.92	1.92	46.87
		Reduce	354	400	2.82	160	–	29	0.2	1	0.93	0.93	47.80
		45 deg elbow	354	400	2.82	160	–	29	0.21	2	1.95	1.95	49.74
		Tee in	354	400	2.82	160	–	29	0.3	2	2.78	2.78	52.53
7-8	Cooling Tower	Pipe	118	250	2.41	160	7	–	–	–	1.12	1.12	53.65
		90 deg elbow	118	250	2.41	160	–	17	0.3	3	2.45	2.45	56.10
		Tee	118	250	2.41	160	–	17	1.11	1	3.02	3.02	59.12
		Butterfly Valve	118	250	2.41	160	–	17	–	1	0.58	0.58	59.70
		Pipe	59	150	3.34	240	9	–	–	–	2.16	2.16	61.86
		90 deg Elbow	59	150	3.34	240	–	11	0.35	2	1.85	1.85	63.70
8-9	R/F	Pipe	118	250	2.41	160	3.5	–	–	–	0.56	0.56	64.26
		Butterfly Valve	118	250	2.41	160	–	–	–	2	1.16	1.16	65.42
		90 deg elbow	118	250	2.41	160	–	17	0.3	3	2.45	2.45	67.87
9-10	R/F	Pipe	354	400	2.82	160	7	–	–	–	1.12	1.12	68.99
		90 deg Elbow	354	400	2.82	160	–	29	0.3	1	1.39	1.39	70.38
		Tee in	354	400	2.82	160	–	29	0.6	3	8.35	8.35	78.74
		Tee out	354	400	2.82	160	–	29	0.6	4	11.14	11.14	89.87
10-1	R/F	Pipe	118	250	2.41	160	1.5	–	–	–	0.24	0.24	90.11
		Strainer	118	250	2.41	160	–	–	–	–	12.30	12.30	102.41
		Butterfly Valve	118	250	2.41	160	–	17	0.3	1	0.58	0.58	102.99
		90 deg Elbow	118	250	2.41	160	–	17	0.3	1	0.82	0.82	103.81
		Flexible Joint	118	250	2.41	160	–	17	0.1	1	0.27	0.27	104.08
		Pump Suction	–	–	–	–	–	–	–	–	–	–	–

Sub-total (+20% Safety Factor)	124.90
Chiller Pressure Drop	80.40
Static Pressure	46.31
Total (kPa)	251.61

Equation:
1. Velocity : v (m/s) = (V / 1000) / (3.1416 * (D / 2000)^2)
2. Veocity Pressure Loss : P (kPa) = pl (Pa/m) * le (m) * ξ / 1000

Notes:
1. The pump head calculation is according to "CIBSE Guide C" Section 4: Flow of Fluid in Pipes and Ducts.
2. Values of Equivalent length of pipe l_e and Pressure loss per unit length p_l are extracted from "CIBSE Guide C" Table 4.17
3. Value of Velocity pressure loss factor of fitting ξ is extracted from "CIBSE Guide C" Section 4.9

Pump Performance
Reduce Friction Loss

Pump Performance

Pump Head Calculation – BEC 2015

BEC 2015 Chapter 6 Energy Efficiency Requirements for Air-conditioning Installation

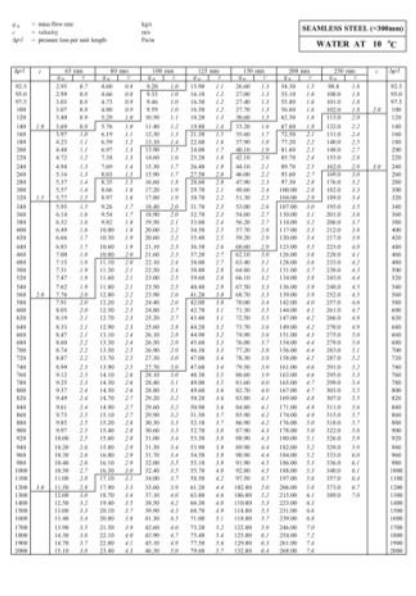
6.9 Frictional Loss of Water Piping System

6.9.1 Water piping with diameter 50 mm or below should be sized for water flow velocity not exceeding 1.2 m/s.

6.9.2 Water piping with diameter larger than 50 mm should be sized for frictional loss not exceeding 400 Pa/m and –

(a) water flow velocity not exceeding 2.5 m/s for system that operates under non-variable flow condition; or

(b) water flow velocity not exceeding 3.0 m/s for system that operates under variable flow condition.



CIBSE Guide C4
Flow of Fluids in Pipes and Ducts

- Pressure drop per unit length
  - 2.5m/s @ 200mm pipe
  - 240 Pa/m with 89.7kg/s

Pump Performance
Pump Head Calculation

- Friction Losses in Elbow (equv. length)
  - 18 Feet (90˚ Elbow)
- Pressure drop

  18 / 3.3 x 240 Pa/m

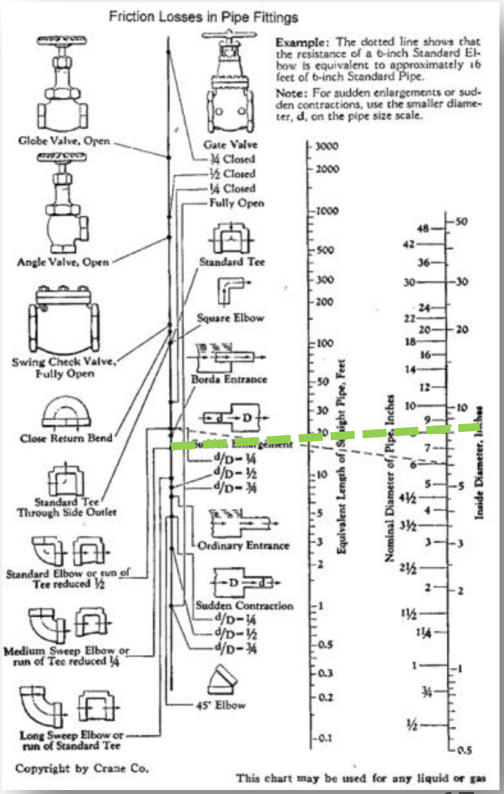
  = 1.309kPa
- Pump Power Consumption

  1.309 x 89.7 / 0.7 / 0.93 / 1,000

  = 0.18 kW
- Annual Operation Cost

  0.18 x 12 x 365 x 1.2

  = HKD946



Pump Performance
Pump Head Calculation

- Friction Losses in Elbow (equv. length)
  - 10 Feet (45° Elbow)
  - 18 Feet (90° Elbow)
- Pressure drop difference

  (18-10) / 3.3 x 240 Pa/m x 2

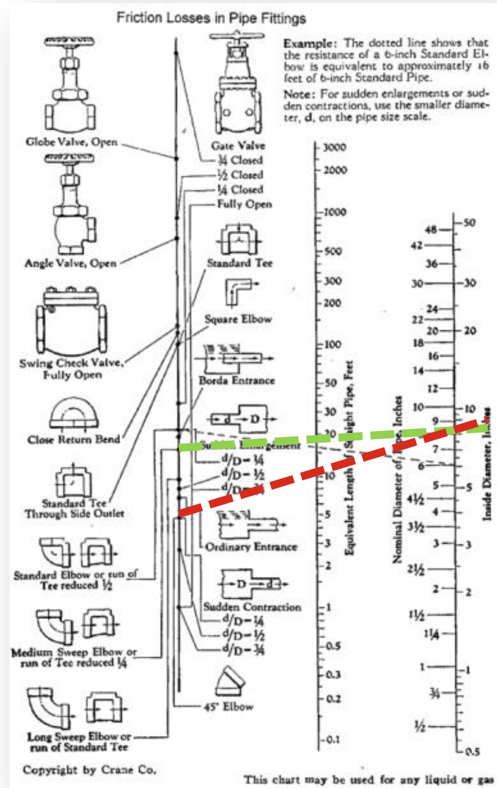
  = 1,164Pa = 1.164kPa
- Pump Power Consumption

  1.164 x 89.7 / 0.7 / 0.93 / 1,000

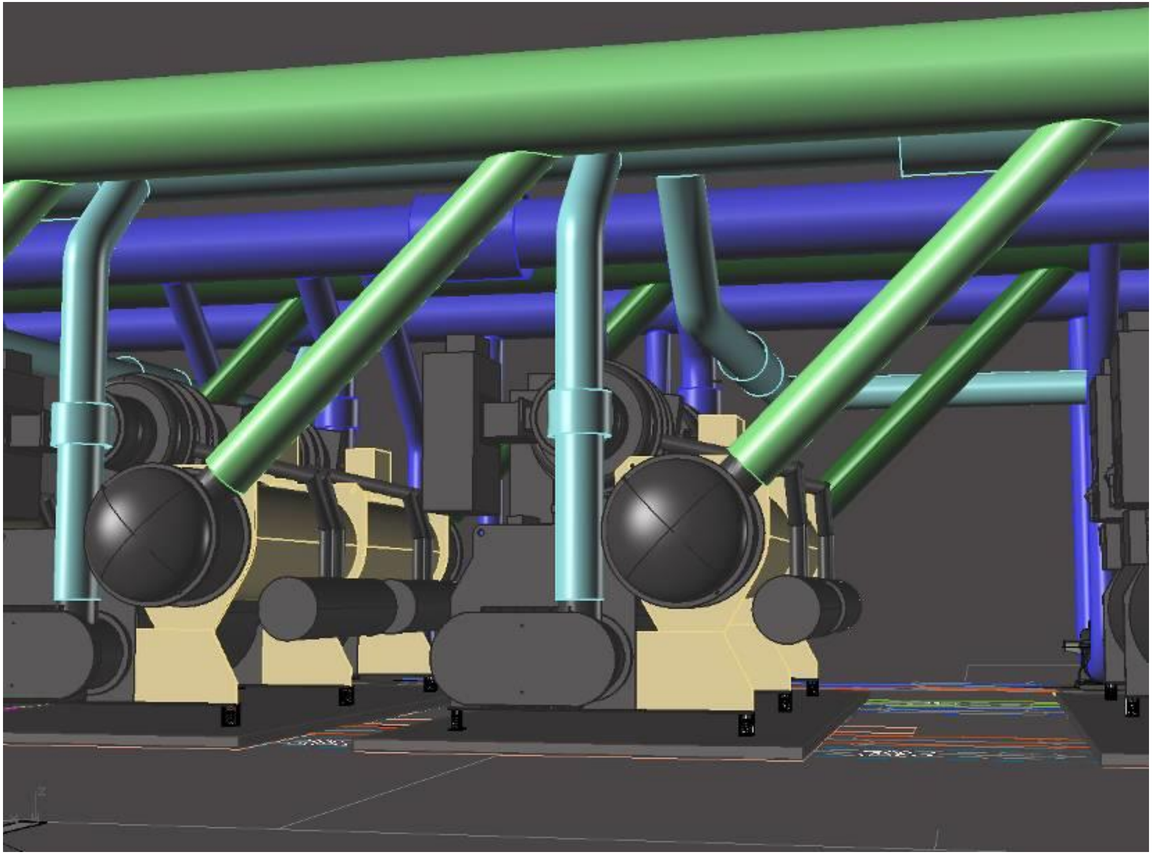
  = 0.16 kW
- Annual Operation Cost

  0.16 x 12 x 365 x 1.2

  = HKD841



Pump Performance
Reduce Friction Loss



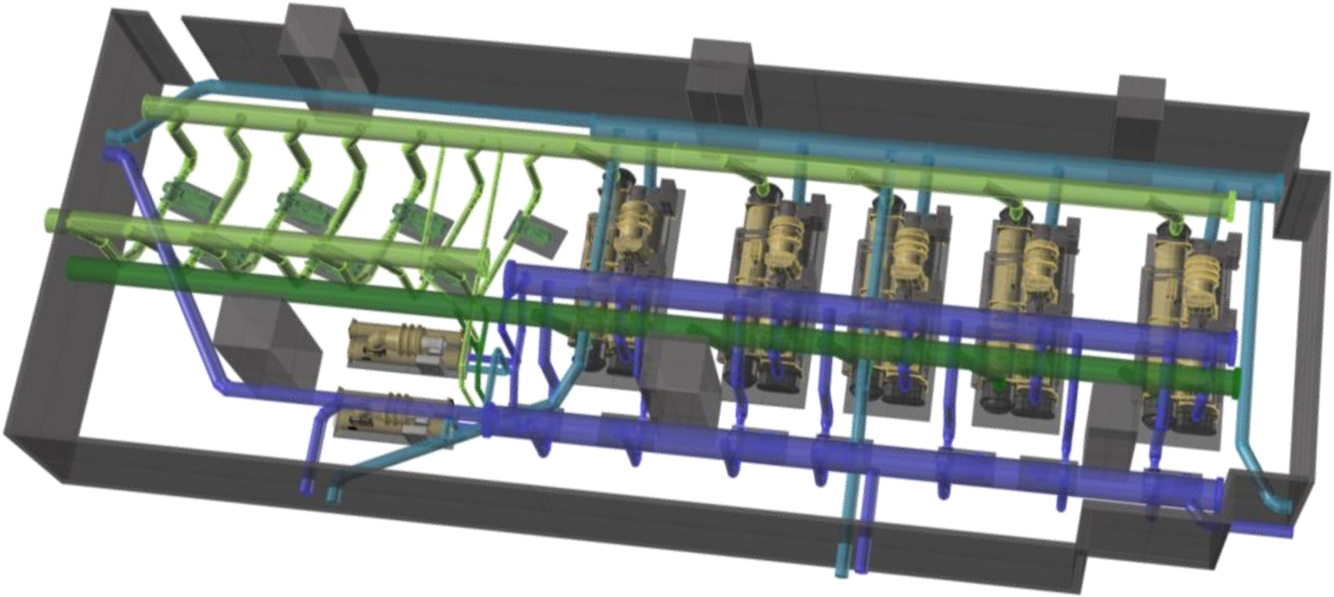
Pump Performance
Reduce Friction Loss

Pump Performance
Reduce Friction Loss

Pump Performance
Reduce Friction Loss

Pump Performance

Reduce Friction Loss



Optimal chiller plant layout and careful selection of low pressure drop devices reduces pressure losses

Pump Performance

Simplify Piping Layout

- Friction Loss in 100% open balancing valve
  - Nominal Size: 200mm
  - Flow Rate: 89.7l/s
  - Pressure drop = 17.8kPa
- Pump Power Consumption

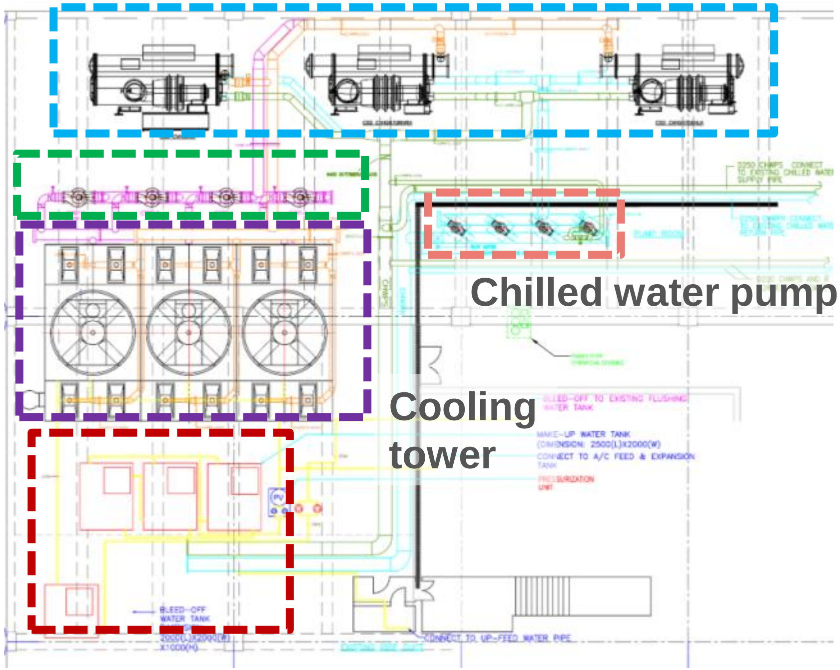
  17.8 x 89.7 / 0.7 / 0.93 / 1,000

  = 2.45 kW
- Annual Operation Cost

  2.45 x 12 x 365 x 1.2

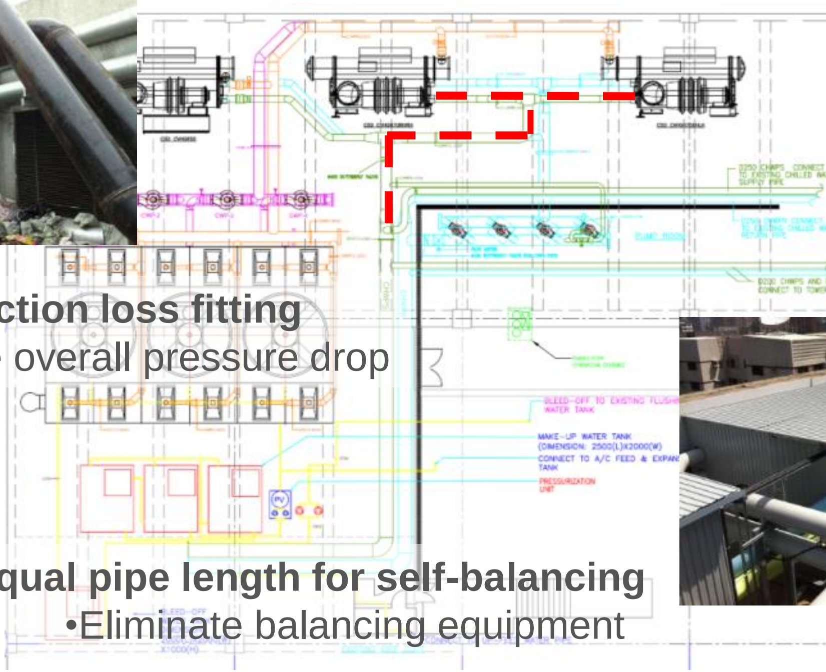
  = HKD12,877

Pump Performance
Simplify Piping Layout



Pump Performance

Simplify Piping Layout



Apply low friction loss fitting

- Reduce overall pressure drop

Equal pipe length for self-balancing

- Eliminate balancing equipment

Pump Performance
Reduce Friction Loss

- Increase the pipe diameter of the system
- Minimize the length of the piping in the system
- Simplifying the layout as much as possible
- Minimize the number of elbows, tees, valves, fittings and other obstructions in the piping system
- Reduce the flow rate

Cool More or Pump More?

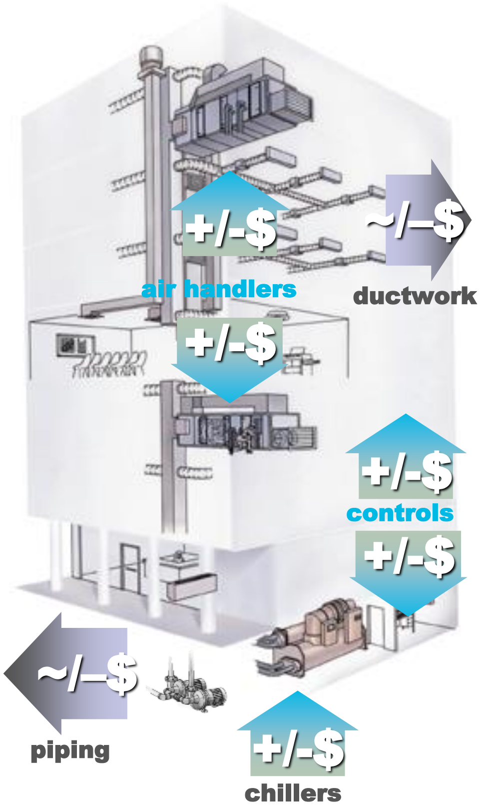
- Pump efficiency ≈ 70%

  COP ≈ 0.7
- Chiller COP ≈ 7.0
- Chiller COP ≈ 10x the pump COP

Conclusion:
work your most efficient equipment harder

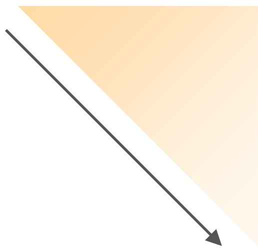
System Enhancement
Earthwise Application

- Low Flow
- Low Temperature
- High Efficiency Systems

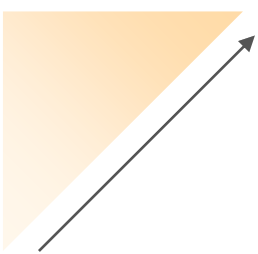


System Enhancement
Earthwise Application

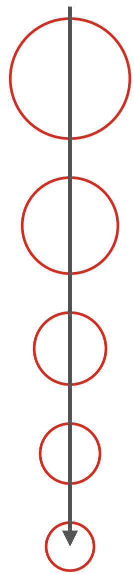
Supply temperature



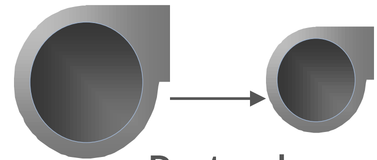
Temperature differential



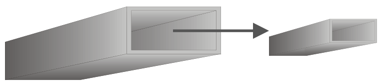
Flow rates



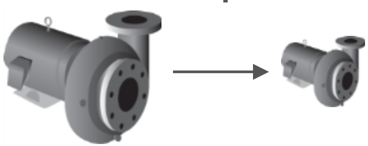
Fans



Ductwork



Pump

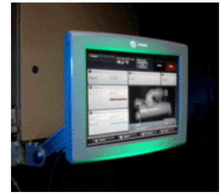


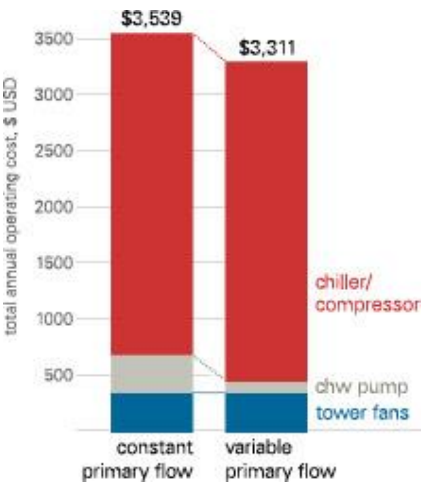
Piping

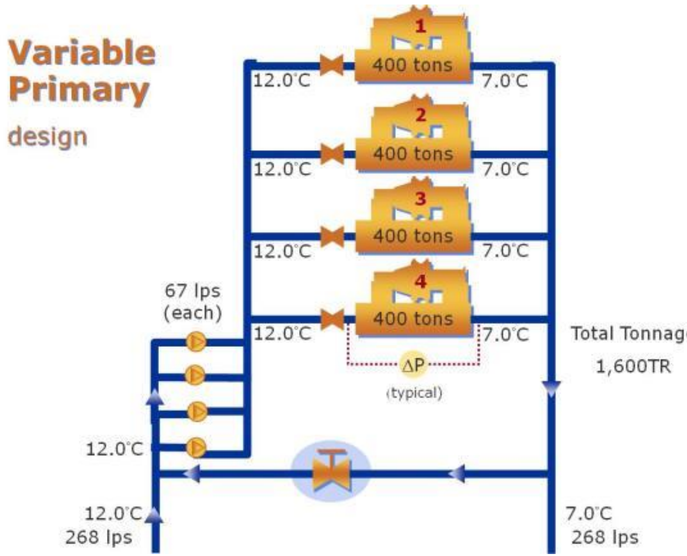
System Enhancement

Why Consider Variable Primary Flow (VPF) Now?

- Chiller control sophistication
- Operating cost savings
  - Pump energy
  - Response to low ΔT Syndrome



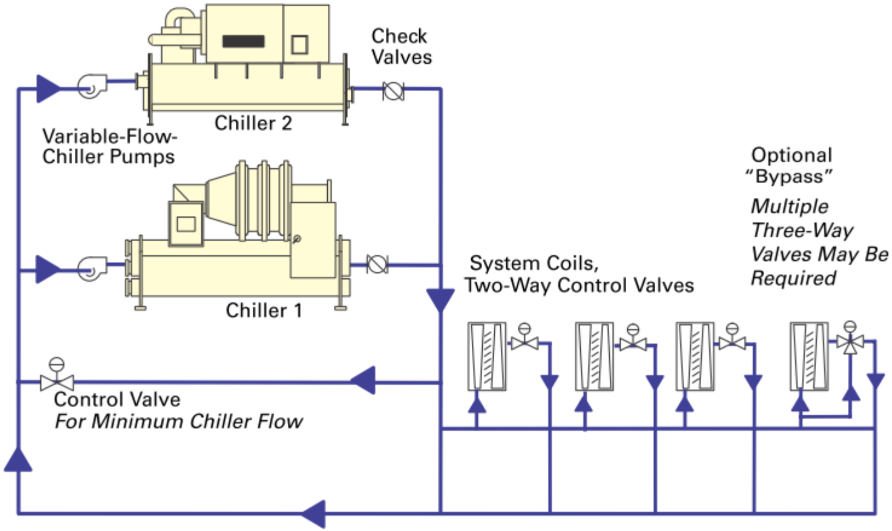




Variable Primary Flow (VPF)

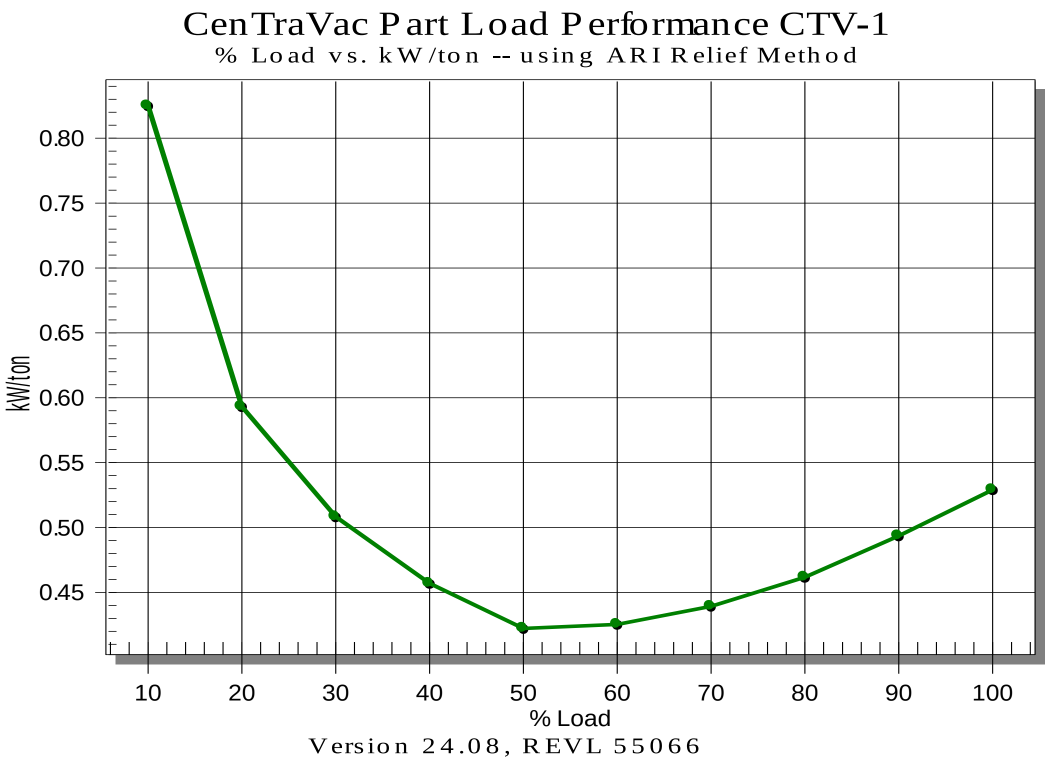
Advantages

- Reduces capital investment
- Saves mechanical-room space
- Simplifies control
- Improves system reliability
- Improved chiller performance

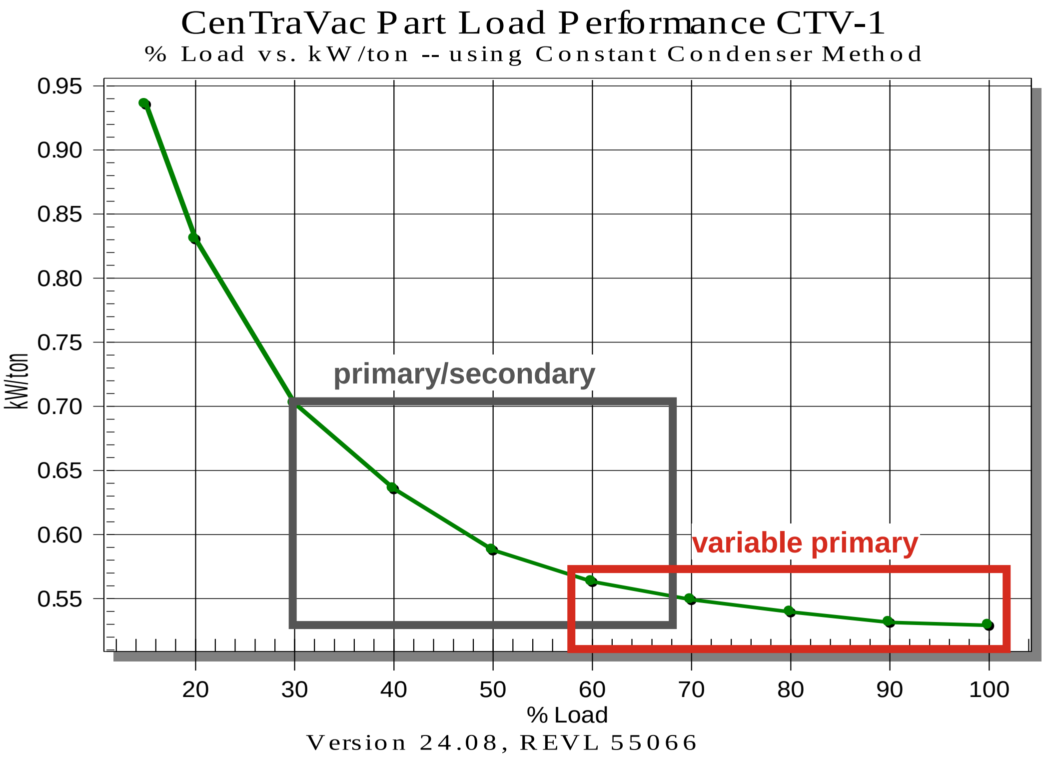


Variable Primary Flow (VPF)

Improve chiller performance



Variable Primary Flow (VPF)
Improve chiller performance



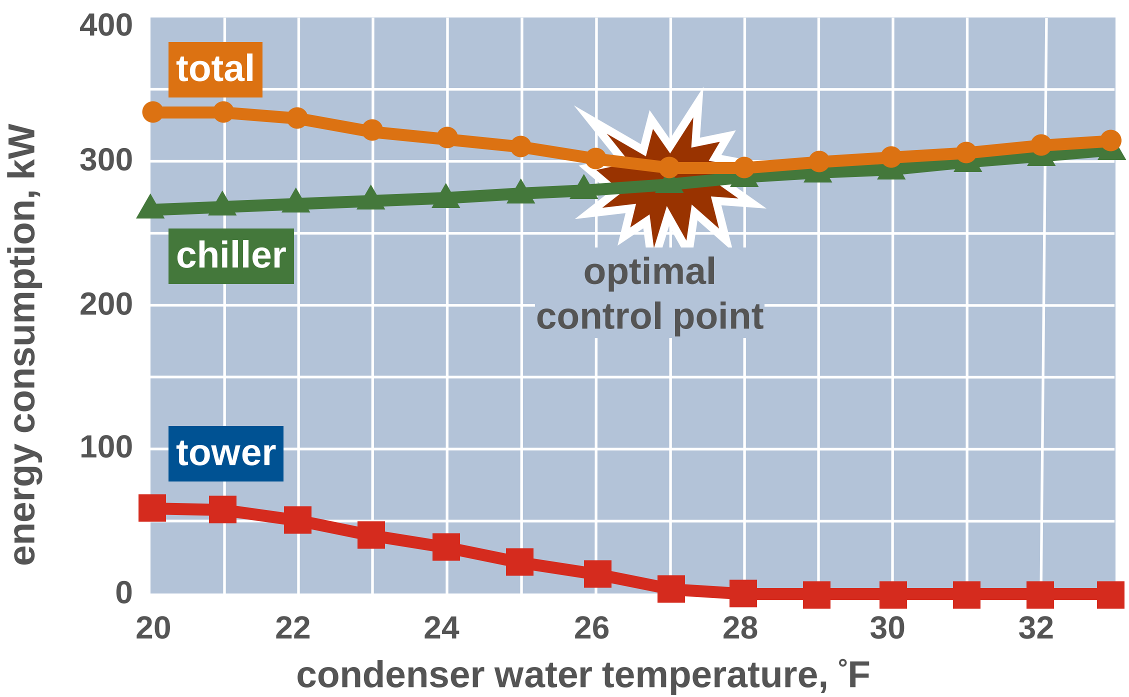
Variable Primary Flow (VPF)

Three Key Application Requirements

- Chillers must be able to accommodate a change of flow of at least 10% per minute; 30% or even 50% is even better
- Minimum and maximum flows must not be violated
- A bypass is required to maintain minimum flow

Chiller-Tower Optimization (CTO)

Optimal condenser water control



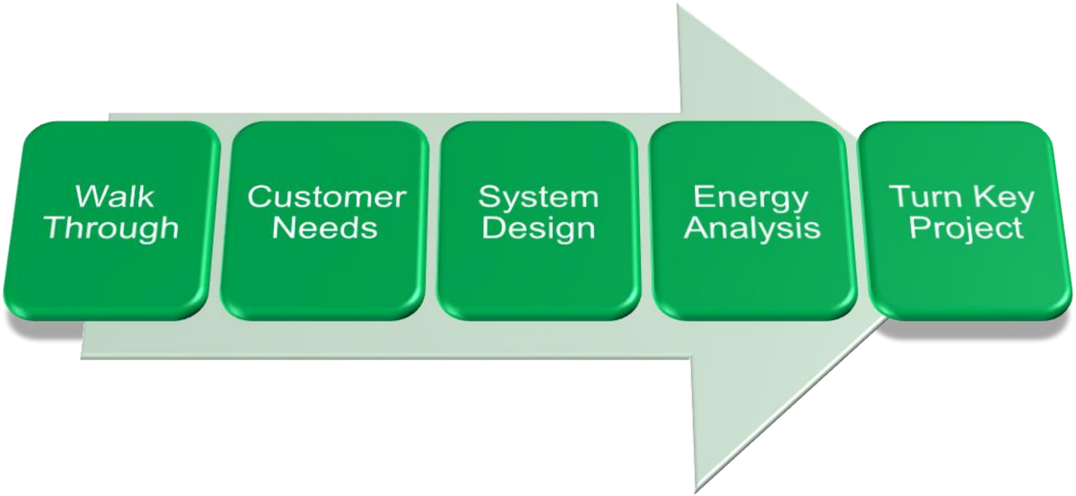
Chiller-Tower Optimization (CTO)
Dependent On?

- Chilled water plant
  - Tower design
  - Chiller design
    - Centrifugal
    - Helical rotary
    - Variable speed drive
    - Absorption
  - Changing conditions
    - Chiller load
    - Ambient wet bulb

System Enhancement

- EarthWise Application
  - Low flow, low temperature and large ΔT system
- Variable Primary Flow
- Chiller-tower Optimization

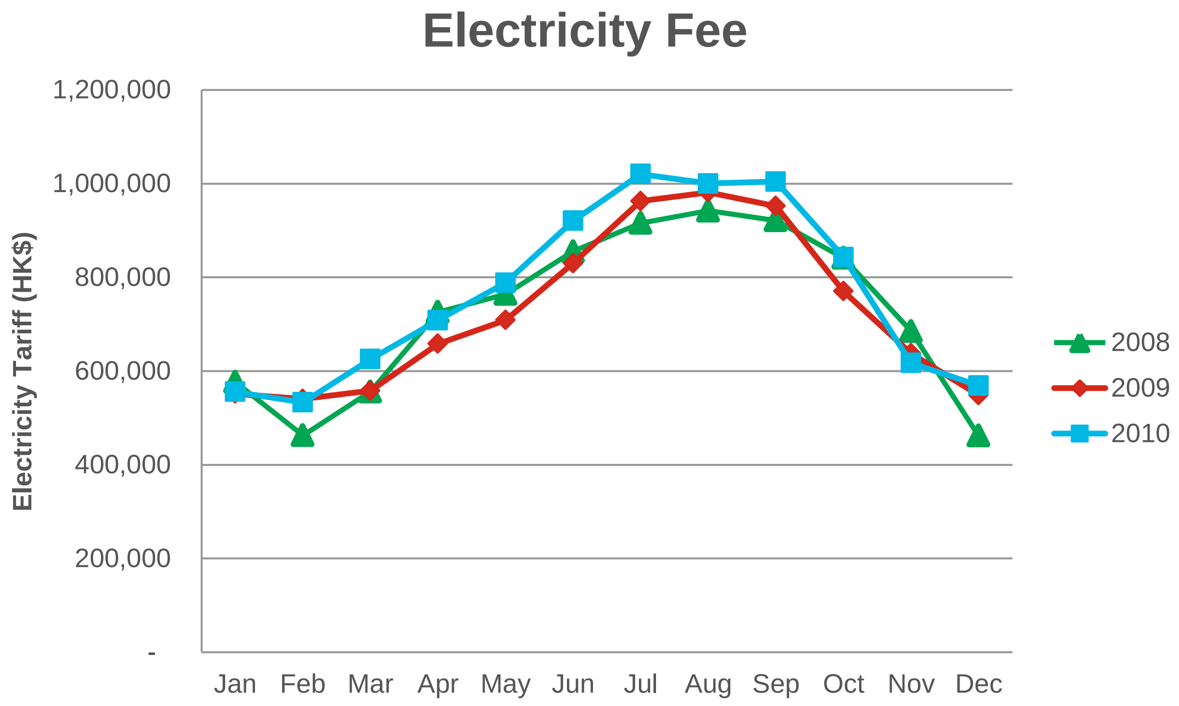
Energy Approach



PERFORMANCE MANAGEMENT

Energy Approach

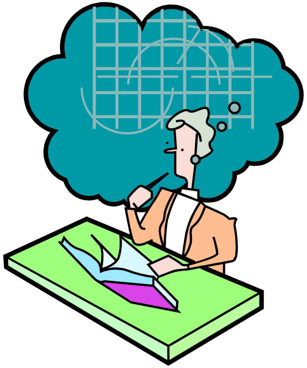
Baseline Energy Consumption



Energy Approach

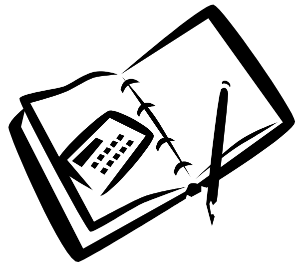
Strategies for chiller upgrades & optimization

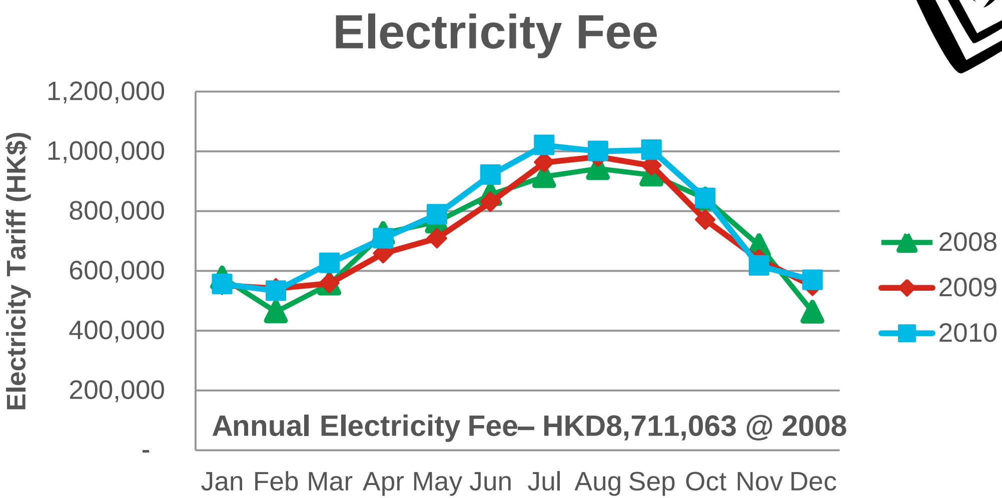
- Correctly Size the New Equipment
- Proper Chiller plant design
  - System Schematic
  - Layout
- Implement of Chiller Plant Control



Energy Approach
Correctly Size the New Equipment

- Determine actual building load
  - From BMS/operation log
  - Estimated from electric bill



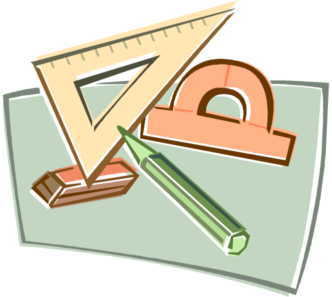


Electricity Fee for Chiller Plant = HKD5,662,191 (65% of overall)

Energy Approach

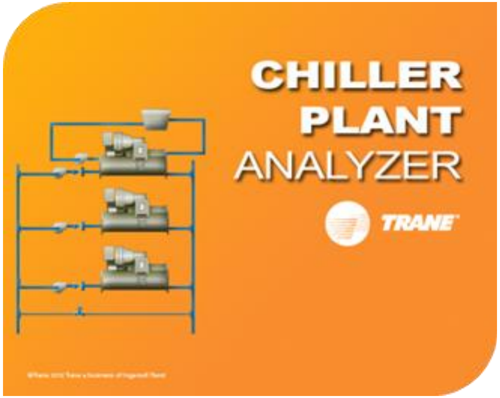
Correctly Size the New Equipment

- Determine actual building load
  - From BMS/operation log
  - Estimated from electric bill
- Downsize Chiller if possible
  - Match with cooling load profile
  - Reduce initial cost and payback period
- Replace with higher efficiency chiller
  - Improve overall savings



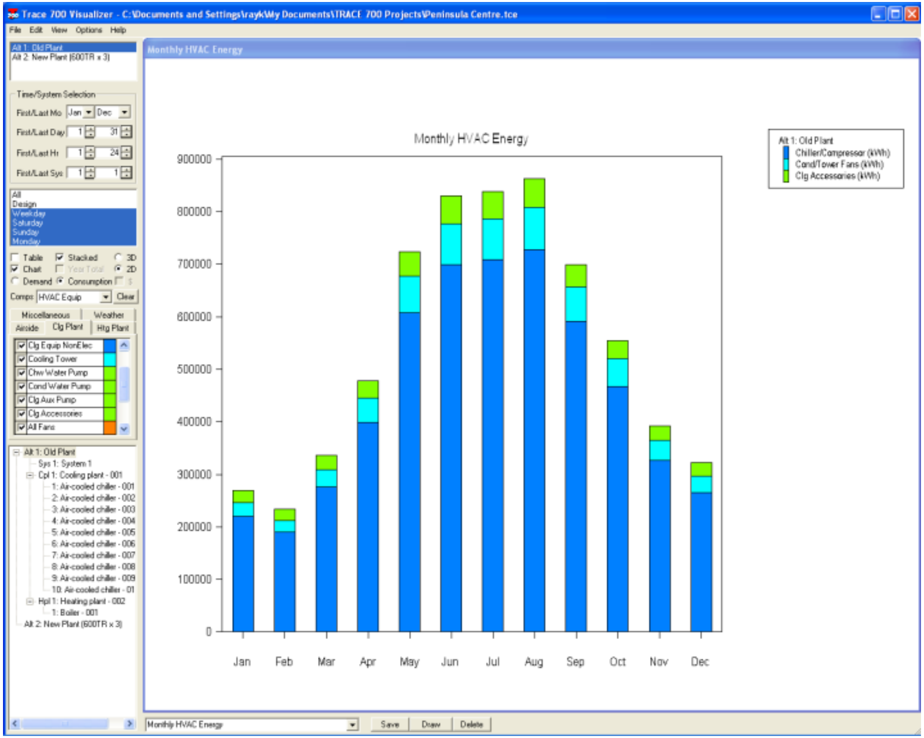
Energy Approach
Correctly Size the New Equipment

- Energy Analysis
  - Employ TRACE 700 Chiller Plant Analyzer for plant configuration comparisons
  - Input existing energy profile for analysis
  - Calculate the energy and economic effects on different configuration



Energy Approach

Correctly Size the New Equipment



Energy Approach
Correctly Size the New Equipment

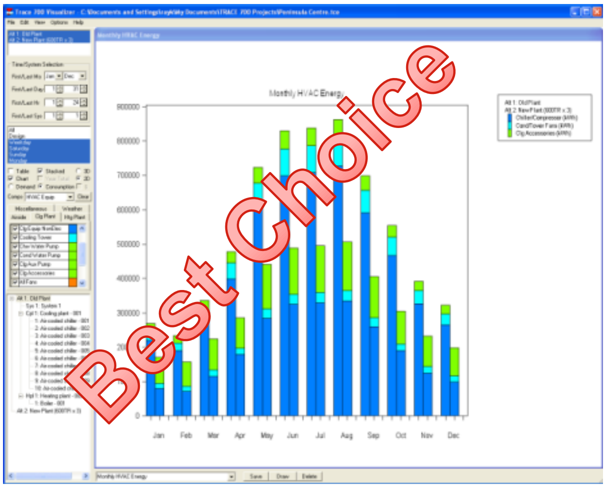
- Alternative 1
  - 2 no 600 TR water-cooled centrifugal chiller
  - 1 no 600 TR water-cooled centrifugal chiller c/w AFD
- Alternative 2
  - 2 no 750 TR water-cooled centrifugal chiller
  - 1 no 300 TR water-cooled screw chiller

Total 1,800TR cooling capacity will be provided

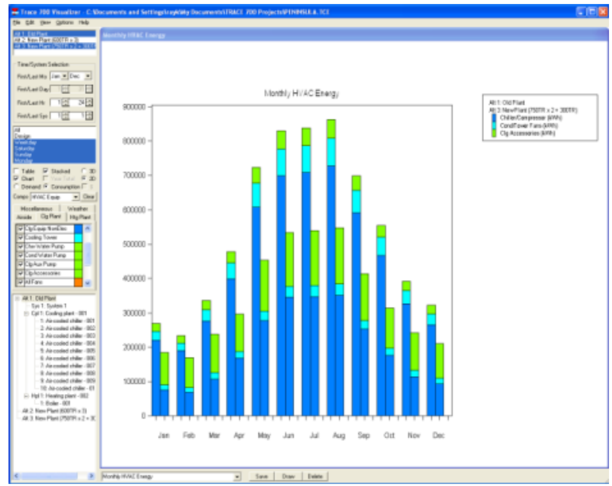
Energy Approach

Correctly Size the New Equipment

Alternative 1



Alternative 2



Annual Saving:

HKD 2,287,377 (40%) — **HKD 2,084,079 (36.6%)**

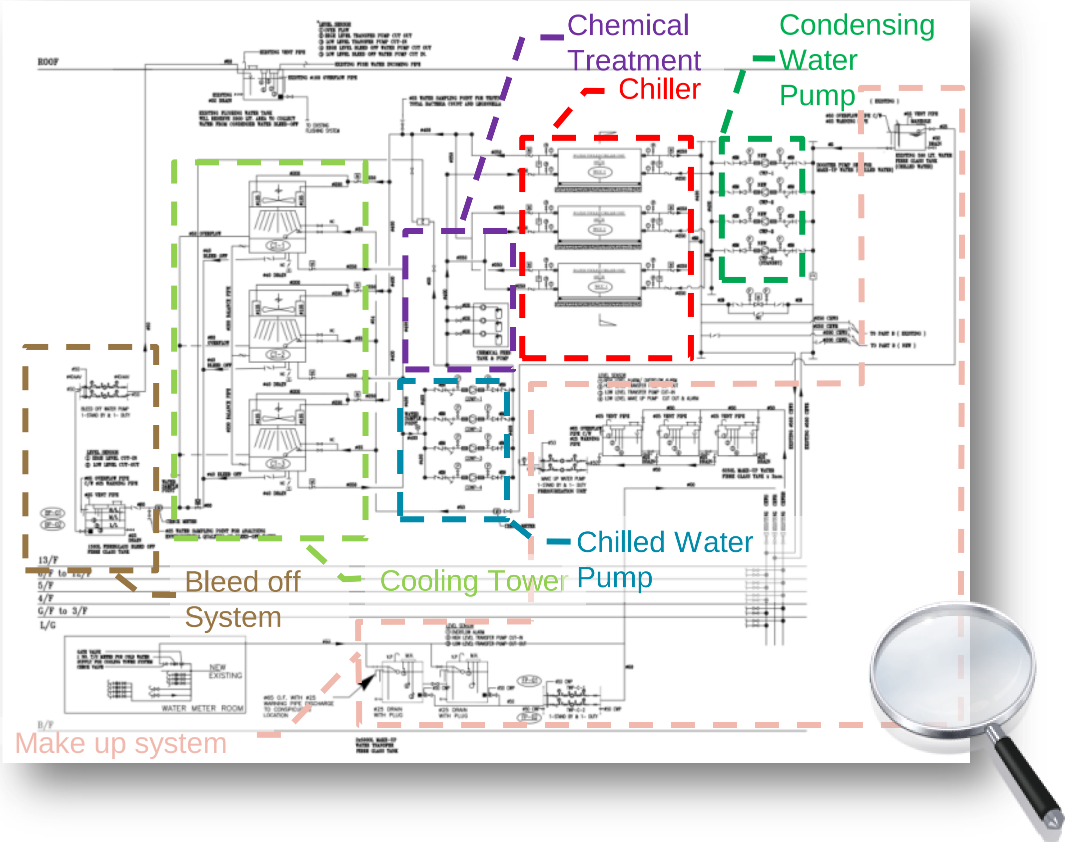
Energy Approach

Chiller Plant Design (Schematic)

- Review of Existing System Arrangement
- Consideration of System Change-over / Migration
- Select chilled / condensing water distribution system
- Decide equipment design condition
  (e.g. Chilled Water Temp, Cooling Tower Approach)
- Properly size pipe sizes
- Associated system design
  (e.g. Make-up / bleed off system, chemical treatment system)

Energy Approach

Chiller Plant Design (Schematic)

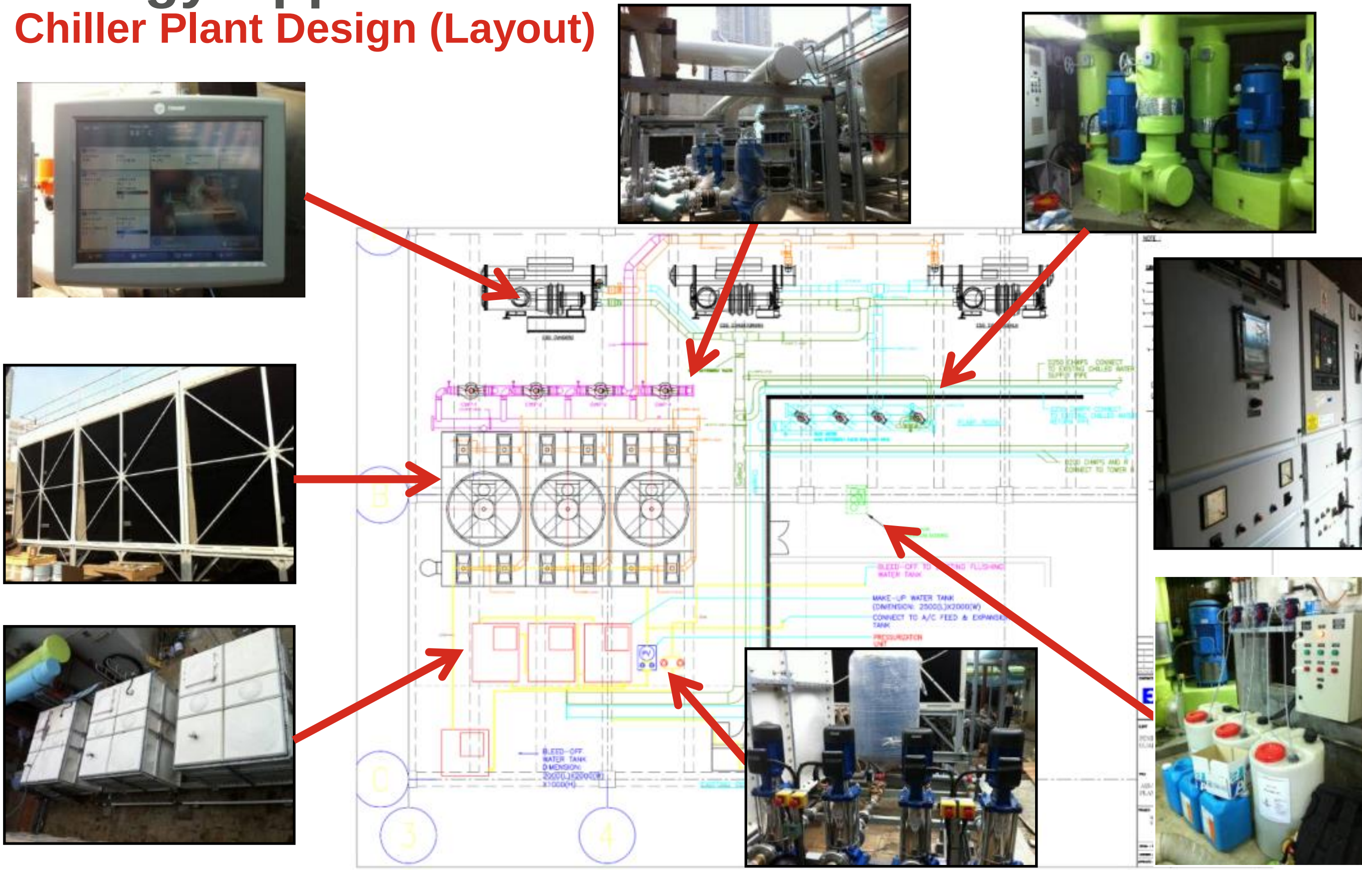


Energy Approach
Chiller Plant Design (Layout)

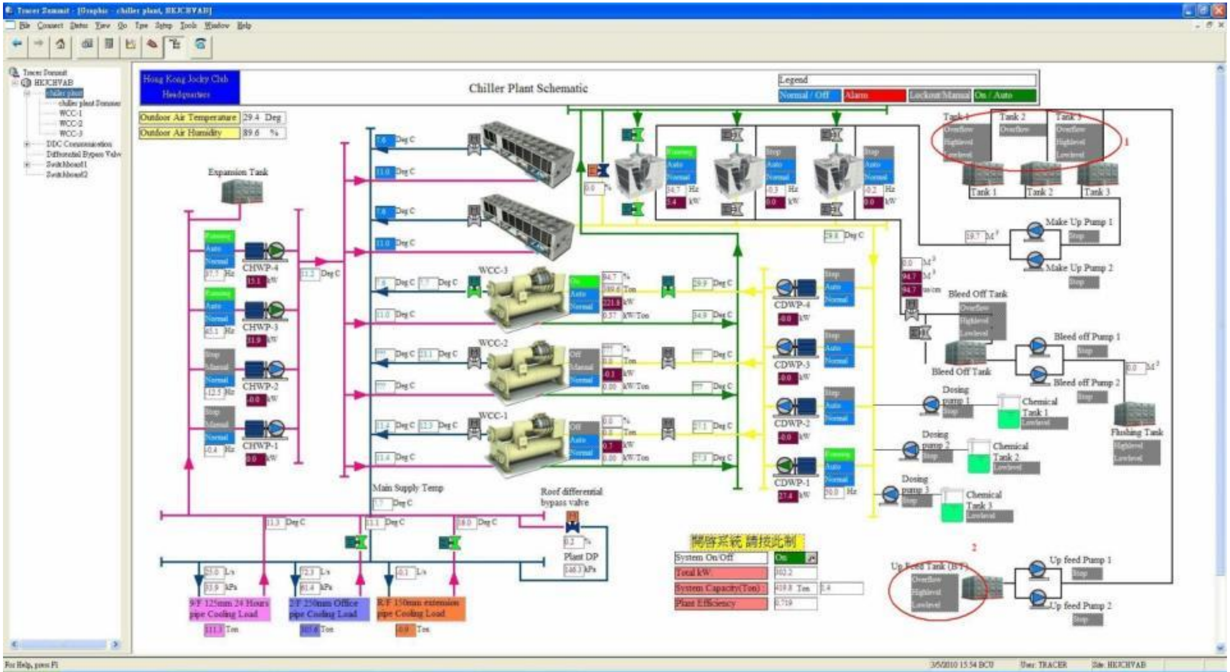
- Satisfy statutory requirement
- Sufficient space for maintenance and service
- Minimize water pressure drop

Energy Approach

Chiller Plant Design (Layout)



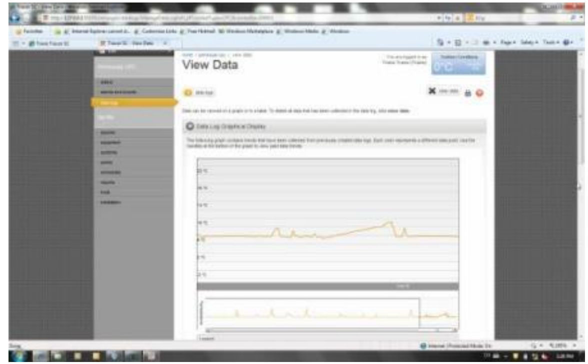
Energy Approach
Chiller Plant Control

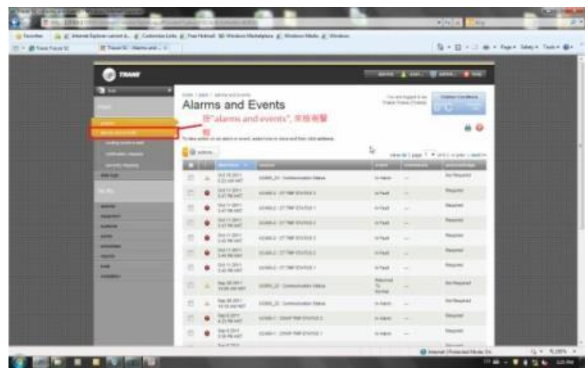


<u>Comprehensive control system with Cooling Tower Optimization</u>

Energy Approach
Chiller Plant Control

- Fully Automation
- Trend log for major equipment
- Alarm Management





Energy Approach

Summary

- System analysis for plant configuration design
- Select high efficiency for better energy saving
- Consider pressure drop and future maintenance during pipework and layout design
- Reliable Chiller Plant Control System
- Monitor the system performance after installation

TRANE®

Ingersoll Rand®