77070

Certificate Course on "Measurement & Verification of Central Chilled-Water Plant Efficiency"

Background

In order to properly evaluate the efficiency of the chilled-water plant, it is first necessary to accurately measure the variables that will determine this efficiency. One of the pre-requisite requirements in Green Mark for New Non-Residential Buildings version 4.1, which came into effect on 15th January 2013, calls for the provision of permanent measuring instruments for measuring chilled-water plant thermal load and energy use and for calculating chilled-water plant efficiency. The installed instrumentation shall have the capability to calculate resultant plant efficiency i.e. (kW/RT) within 5% of its true value using heat balance substantiating test in accordance with ASHRAE Guide 22 and AHRI 550/590.

Course Objectives

The 3 ½ days course will equip participants with the knowledge and skills required to implement permanent instrumentation for common chilled-water plant layouts in conformance with Green Mark version 4.1, relevant international standards and industry best practices. Participants will have a better understanding of the recommended methods and devices used to measure electrical usage, fluid flow, and temperature, procedures for acquiring the necessary data, interpreting calibration reports of devices, and calculating heat balances for common plant layouts.

Delivery

This course will be conducted through a combination of lectures, hands-on practices using real data to compute measurement error and heat balance, and a visit to a 'model' plant with good practices to reinforce principles and concepts.

Target Audience

This workshop is aimed at

- mechanical PEs -responsible for the design, supervision and endorsement of the M&V works and calculations in accordance with GM version 4, and

- building professionals, project managers, developers, building owners, facilities and energy managers, ESCOs and other stakeholders involved in Green Mark projects and/or who wish to know how to improve the reporting of chilled plant efficiency.

To fully benefit from this course, it is recommended that candidates have prior knowledge of air-conditioning design and/or operations.

Assessment & Award of Certificate

Assessments will be administered to ascertain the competency acquired. Participants who have achieved a minimum of 75% class attendance and passed the two course assessment tests comprising a class individual project on heat balance computation and analysis (1 ½ hours), and a MCQ test (1 ½ hours), will be awarded the Certificate of Successful Completion (CSC). A minimum score of 50 out of 100 marks for each component of assessment tests is required to pass the course. For those who do not sit for the assessment tests, but have a minimum of 75% class attendance, will be issued with a Statement of Attendance (SOA).

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of the built environment

Certificate Course on Measurement & Verification of Central Chilled-Water Plant Efficiency (12th Run)

Day 1		Lecturers	Date	Duration
1.0	**Overview**			
	▪ Need for Measurement and Verification (M&V) ▪ GMv4 requirements on chiller plant performance M&V ▪ Scoring methodology ▪ Submission procedure and documentary evidences ▪ Case studies: GMv4 compliance projects	Yong Siew Hwa, BCA		**1 hour, 9.00am to 10.00am**
2.0	**M&V guidelines and standards**			
	▪ ASHRAE Guideline 22 ▪ AHRI 550	Steven Kang, Measurement & Verification		**1 hour, 10.30am to 11.30am**
3.0	**Fundamentals of Measurement Instruments**		**18 May 15**	
	Standards, types, calibration and calibration report interpretation: o Measurement Uncertainty o Temperature sensor o Reading Calibration report & laboratory	Victor Tan, National Metrology Centre, A*STAR		**4.5 hours, 11.30am to 5.00pm**
4.0	**Standards, types, calibration and calibration report interpretation:**			
	▪ Power meters ▪ Flow meters ▪ Pressure sensors	Dr Chua Sze Wey, Mr Wu Jian National Metrology Centre, A*STAR		
Day 2				
5.0	**Chiller Plant Measurement and Verification (M&V)**			
	▪ Impacts of measurement accuracy Instruments and sensors for: o Temperature measurement o Flow measurement o Power measurement ▪ Data acquisition o Recommended good practices o Data representation ▪ Case Studies	Lee Eng Lock, Measurement & Verification	**19 May 15**	**2.5 hours, 9.00am to 11.30am**

Day 2				
6.0	**Fundamentals of heat balance**			
	▪ Different system configuration (primary-secondary, variable primary flow and others) ▪ Effects of open drive and hermetic chillers ▪ Effects of pumps ▪ Effects on location of flow meters and temperature sensors ▪ Good practices to achieve heat balance	Steven Kang	**19 May 15**	**5 hours, 11.30am to 5.30pm**
7.0	**Mandatory periodic chiller plant audit requirements**	Steven Kang		
Day 3				
8.0	**Case study on "Practical practices to ensure accurate chiller plant performance M&V"**	Steven Kang	**20 May 15**	**1 hour, 9.00am to 10.00am**
9.0	**Practical session on preparing audit report using Excel**	Steven Kang		**3 hours, 10.30am to 1.30pm**
10.0	**Tour of high efficient chiller plant to gain insights on:**			
	▪ Examples of using the M&V system to continually improve performance ▪ Hands-on session in installation of ultrasonic flow meter ▪ Best practices in chiller plant design and installation ▪ Best practices in chiller plant M&V	Steven Kang		**3 hours, 2.30pm to 5.30pm**
Day 4				
	Assessments ▪ MCQ test (1.5 hours) ▪ Preparation of audit report (1.5 hours)	BCA Staff	**28 May 15**	**3 hours, 9.00am to 12.00pm BCAA, B1-9**

NEW

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BCA GREEN MARK

Standards for Permanent M&V Instrumentations for Central Chilled Water Plant Efficiency in New and Existing Buildings

Amendments to Building Control Act/Regulations for Existing Buildings

Yong Siew Hwa
Principal Manager
Green Mark Existing Building Dept, BCA



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Why Accurate Measurements of Chilled Water Plant Efficiency is IMPORTANT?

- Chiller plant system accounts for the highest electrical consumption in all commercial buildings
- Small temperature difference between supply and return chilled water temperature
- Making the most out of the Building Automation System
- Used as an accountability tool to gauge the performance of the installed equipment on site
- You can only improve what you can measure





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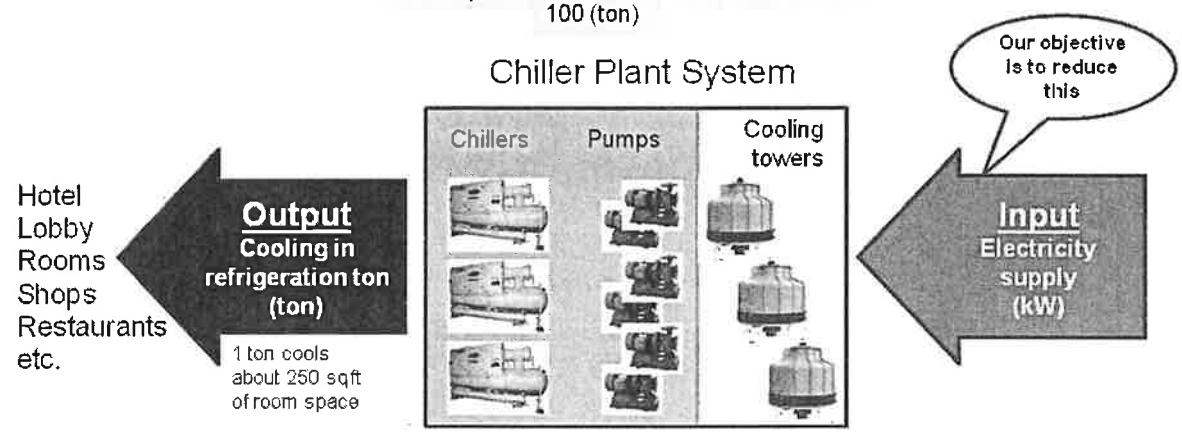
What is Chiller Plant Efficiency?

$$\text{Chiller Plant Efficiency} = \frac{\text{Input electricity (ikW)}}{\text{Output Cooling (ton)}} = \text{ikW/ton}$$

$$\text{Example}: \frac{120\ (\text{ikW})}{100\ (\text{ton})} = 1.20\ \text{ikW/ton}$$



Source: Carrier

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Minimum Standards for Permanent Instrumentations of Central Chilled Water Plant

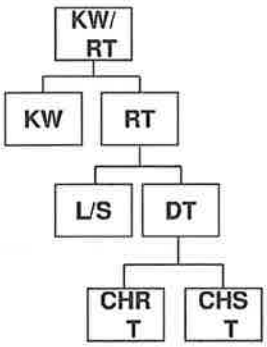
- Provision of permanent measuring instruments for monitoring water-cooled central chilled-water plant efficiency. The installed instrumentation shall have the capability to calculate **resultant plant efficiency (i.e. kW/RT) within 5%** of its true value and in accordance with ASHRAE Guide 22 and AHRI 550/590.
- The following instrumentation and installation are also required to be complied with:
  - Location and installation of the measuring devices to meet the manufacturer's recommendation.
  - Data acquisition system with a minimum resolution of 16 bit.
  - All data logging devices with capability to trend at 1 minute sampling time interval.
  - Flow meters to be provided for chilled water and condenser water loop and shall be of full bore magnetic/ ultrasonic type or equivalent.
  - Temperature sensors to be provided for chilled water and condenser water loop and the measurement system shall have an end-to-end uncertainty not exceeding ± 0.05 °C over the entire measurement or calibration range. Provisions shall be made for each temperature measurement location to have two spare thermo-wells located at both side of the temperature sensor for verification of measurement uncertainty.
  - Dedicated digital power meters, shall yield the true RMS power based on the measured current, voltage and power factor, to be provided for each group of equipment i.e. chillers, chilled water pumps, condenser water pumps and cooling towers. VSDs should not be used as the losses are not accounted for.



Worked Example

The overall measurement system consists of the temperature, flow and power measurement. To meet the overall 5% uncertainty in the resulting efficiency, the individual uncertainty of each measurement system - mass flow rate (by flow meter), electrical power input (by power meter) and the temperature difference (by temperature sensors) are as follows :

Item	Measurement System (includes sensor and data acquisition system)	Maximum allowable uncertainty (%) (Calibrated under laboratory condition)
01	Flow	1 % see note (1) + X %
02	Power	±1% see note (3)
03	Temperature sensors with uncertainty of ± 0.05°C	± 1.3% see note (2)
	Temperature difference (ΔT)	





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Worked Example (Cont')

Note:

(1) An additional 1% to be included in the computation of measurement errors for flow meter.

(2) The overall maximum uncertainty (%) for temperature sensors is calculated based on the Root Sum Square error for the 2 temperature sensors (supply and return of the chilled or condenser water) for the design or actual delta T (i.e. ΔT). In this case,

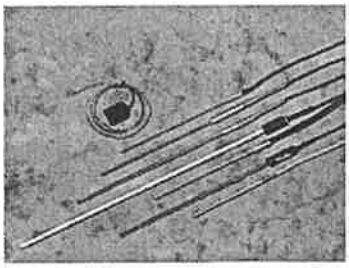
Temperature sensors calibrated = ± 0.05°C

Design/ Actual ΔT = 5.5 °C

Measurement errors for ΔT = $\sqrt{(0.05^2 + 0.05^2)}$/ 5.5 °C x 100%

= 1.3%

(3) Uncertainty of power measurement system shall include that of the digital power meter, voltage and current transformer, wiring etc.





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Worked Example (Cont')

Based on the above information, the overall uncertainty of the measurement is as shown in the following :

where U_N = individual uncertainty of variable N (%)

N = mass flow rate, electrical power input or delta T

$Error_{rms} = \sqrt{(\sum (U_N)^2)}$

$= \sqrt{(2^2 + 1^2 + 1.3^2)}$

$= \mathbf{2.6\%}$

Therefore, the total uncertainty for the calculated chilled-water plant efficiency (kW/RT) is 2.6% which falls within the 5% of the true value.



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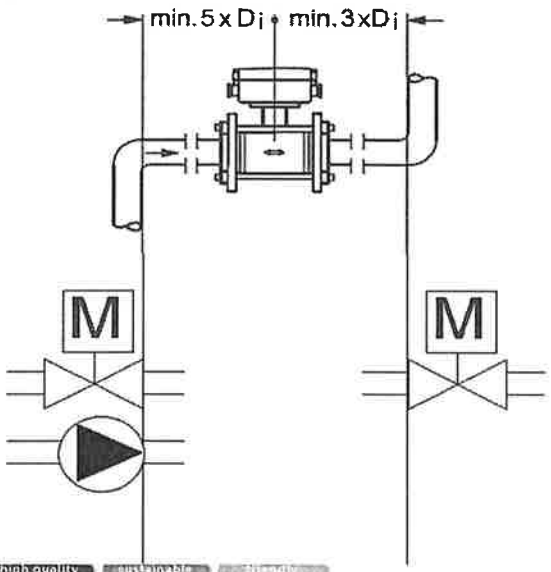
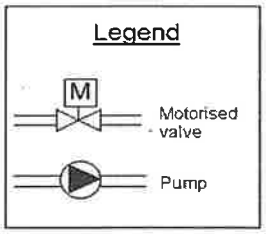
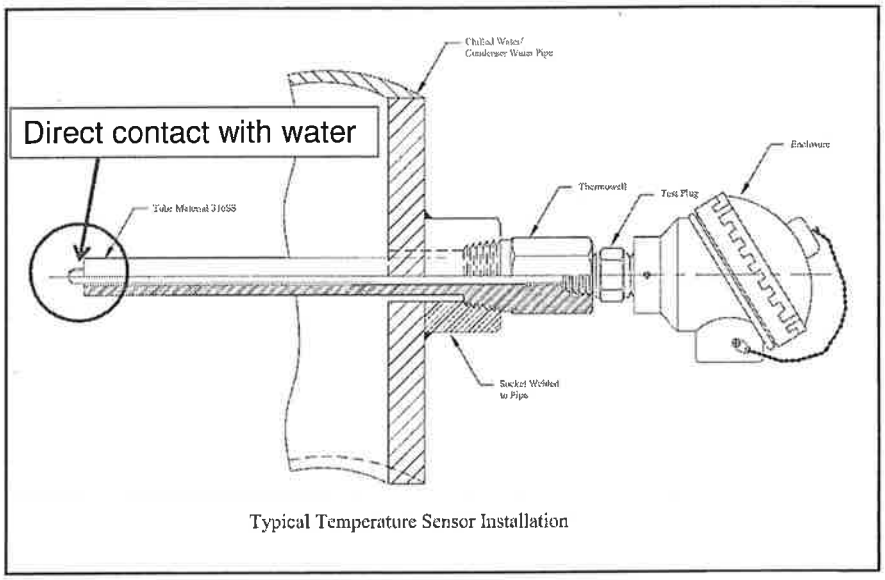
Example of flow sensor installation







Example of temperature sensor installation



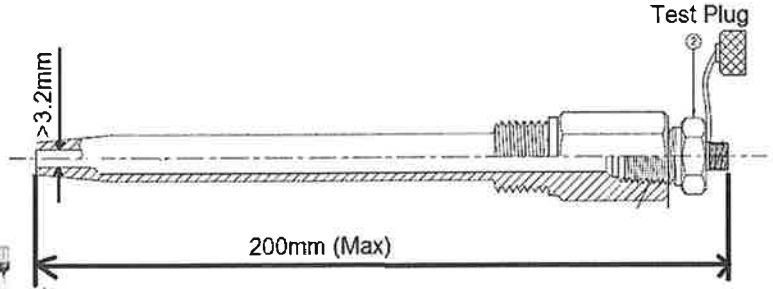
Typical Temperature Sensor Installation



What's the Specification for Spare Thermowell?

BCA's test probe(s) used for site verification are 228mm long and 3.2mm in diameter. For proper insertion, the thermowell should have an open tip larger than 3.2mm diameter, and the length of the assembly including isolation valve (if any) and the test plug should not exceed 200mm length. This would ensure that the test probe is in contact with the water.

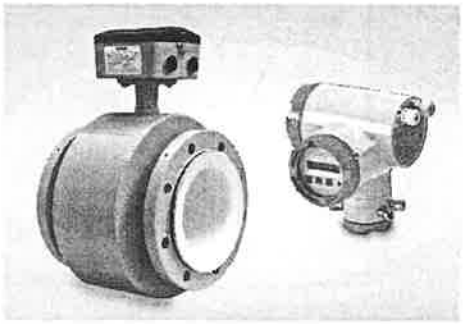
BCA also accepts spare test plugs without thermowell as long as the test probe is able to come in contact with the water especially for larger pipes.





Heat Balance Substantiating Test

- Verification of central chilled water plant efficiency: Heat balance – substantiating test for water-cooled central chilled water plant to be computed in accordance with AHRI-550/590





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Heat Balance Substantiating Test

The heat balance is represented by the following equation:

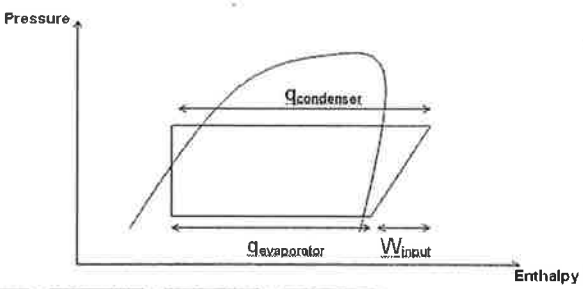
$q_{condenser} = q_{evaporator} + W_{input}$

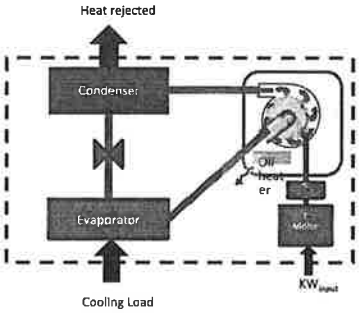
where,

$q_{condenser}$ = heat rejected

$q_{evaporator}$ = cooling load

W_{input} = measured electrical power input to compressor





Energy in = Energy out



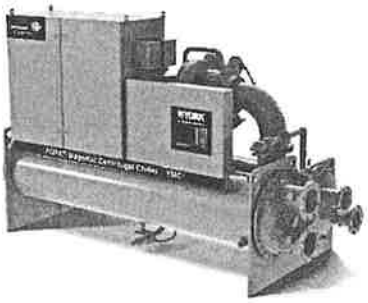
Adjusting for open drive chillers

The computation of the percent heat balance (see formula below) that is the total heat gain and total heat rejected must be **within ± 5% for 80% of the sampled points** over the normal building operation hours.

$$\text{Percent Heat Balance} = \left| \frac{(q_{evaporator} + W_{input}) - q_{condenser}}{q_{condenser}} \right| \times 100\% \quad \leq 5\%$$

Note: For **open drive chillers**, the W_{input} shall take into account the **vsd and motor efficiency** provided by the manufacturer. An example is provided as follows:

Input power (measured)	= 100kW
VSD rated efficiency (%)	= 98%
Motor rated efficiency (%)	= 90%
Adjusted W_{input}	= 100 x98% x 90% = 88.2 kW

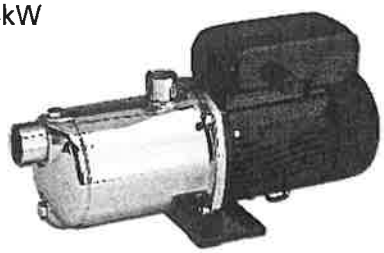




Heat Balance Substantiating Test

In the event where **hydraulic losses of pumps** constitute a substantial heat gain, these losses have to be properly accounted for. The value shall be determined from vsd and pump efficiency values provided by the manufacturer. An example is illustrated as follows:

Motor input power (measured)	= 30kW (A)
VSD rated efficiency (%)	= 98%
Motor rated efficiency (η)	= 90% (B)
Pump rated efficiency (η)	= 80% (C)
Hydraulic losses	= 30kW x 90% x (100% - 80%) = 5.4kW
Adjusted W_{input}	= kW_i (chillers) + 5.4kW





Worked Example (Variable Primary Flow)

A: $q_{evaporator}$ = FM1 x Cp x (CHWR - CHWS)

B: $q_{condenser}$ = FM2 x Cp x (CWR - CWS)

C: W_{input} = kW_{i-1} + kWi_{-2} + kWi_{-3}

where Cp = 4.19 kJ/kg.°C and density of chilled water is assumed to be 1kg/l

Percent heat balance = [(A + C) – B] / B x 100%

Note: In the event where heat balance exceeds ±5%, hydraulic losses of pumps constituting substantial heat gain can be included on the right hand side of the heat balance equation. The value of which shall be determined from certified gear losses and pump efficiency values provided by the manufacturer.

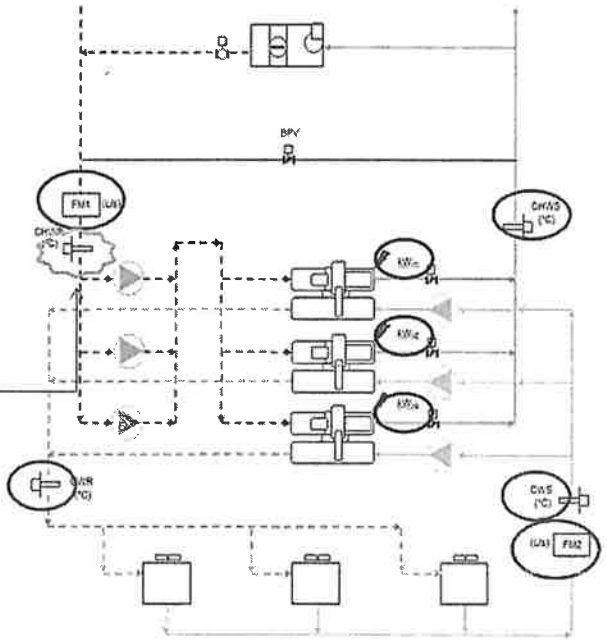
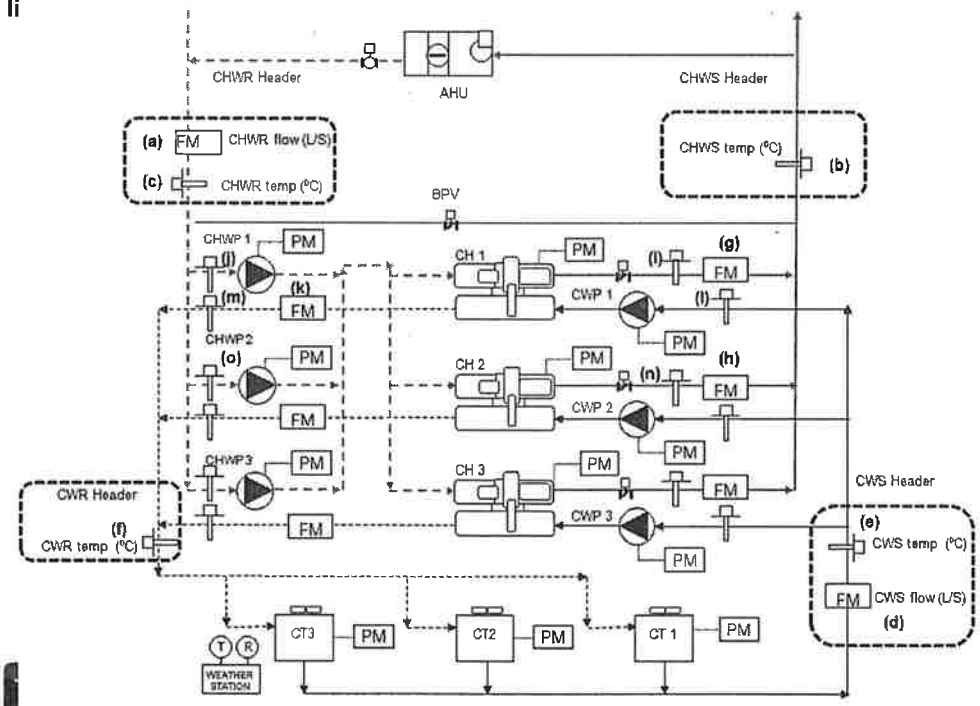




Figure provides the location of the minimum required instrumentation at the headers as well as the recommended instrumentation at each chiller. The minimum required instrumentation is circled in dotted li





Summary

	Temperature Sensor	Flow Meter	Power Meter	Data Acquisition
Installation	Location & installation of measuring devices to meet manufactures' recommendation			
	Direct contact with fluid flow			
Measurement Uncertainty	1.3%	2%	1%	16-Bit Resolution
Location	-Chilled water supply header(s) - Chilled water return header(s) - Condenser water supply header(s) - Condenser water return header(s)	-Chilled water supply/ return header(s) - Condenser water supply/ return header(s)	-Chiller(s) electrical panel(s) - Chilled water pump(s) electrical panel(s) - Condenser water pump(s) electrical panel(s) - Cooling tower(s) electrical panel	
Type	-Thermistors - RTDs	-Full bore magnetic - Ultrasonic	- Digital power meter	-DDC(s) - Heat meters
Others	2 spare thermo-wells at each measurement location			1 minute sampling interval



Environmental Sustainability Measures for Existing Buildings



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Green Mark legislation for new buildings

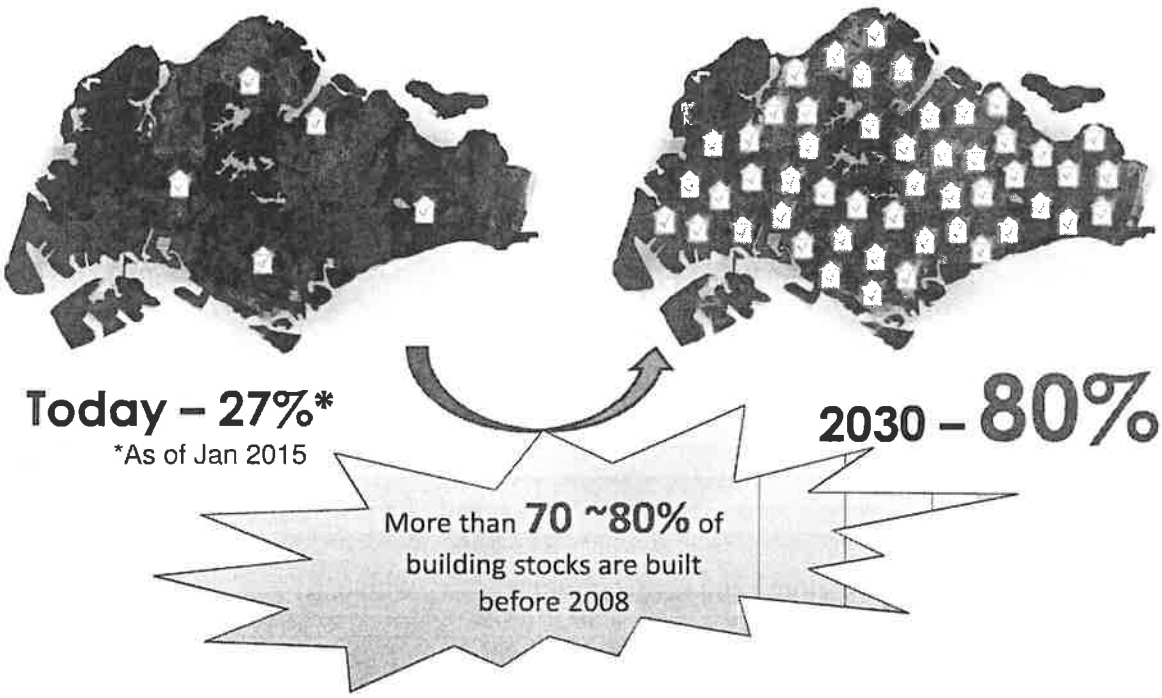
Building Control (Environmental Sustainability) Regulations 2008

Mandatory Standard

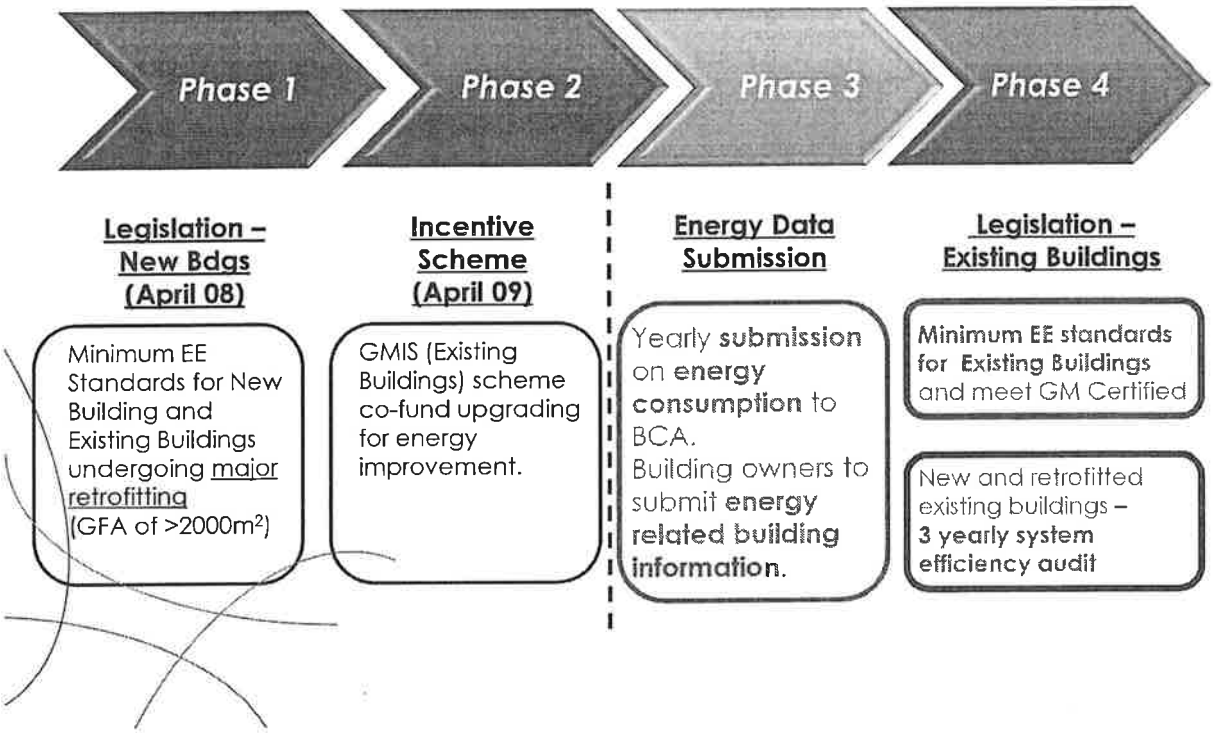


April 2008. All <u>New</u> Buildings *with* ***GFA ≥ 2000 m²*** to meet **at least GM-Certified Standard**

Sustainable Development Blueprint 2009



Four-Phased Approach to Green our Existing Building Stock



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3 new requirements for buildings to be energy-efficient

By Saifulbahri Ismail | Posted: 10 September 2012 2138 hrs



- **Min. GM standard for existing buildings**
- **Three-yearly energy audit on cooling system**
- **Annual submission of building info & energy consumption data**

Minimum GM Standard for Existing Buildings

changed

PHASE 1 → applies to hotels, retail and office buildings with gross floor area (GFA) of 15,000m² or more

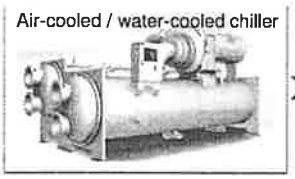
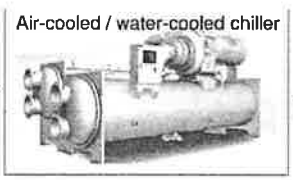
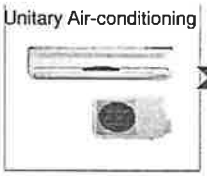
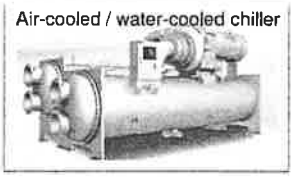
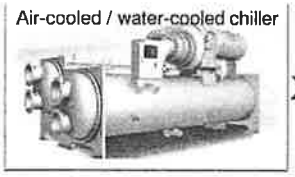
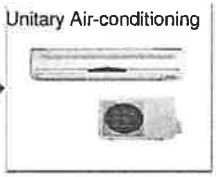
↓ when any chiller is installed or replaced

Building has to comply with minimum environmental sustainability standard for existing buildings.

Next phase: institutions, business parks, hospitals, convention centre, schools etc

Authority

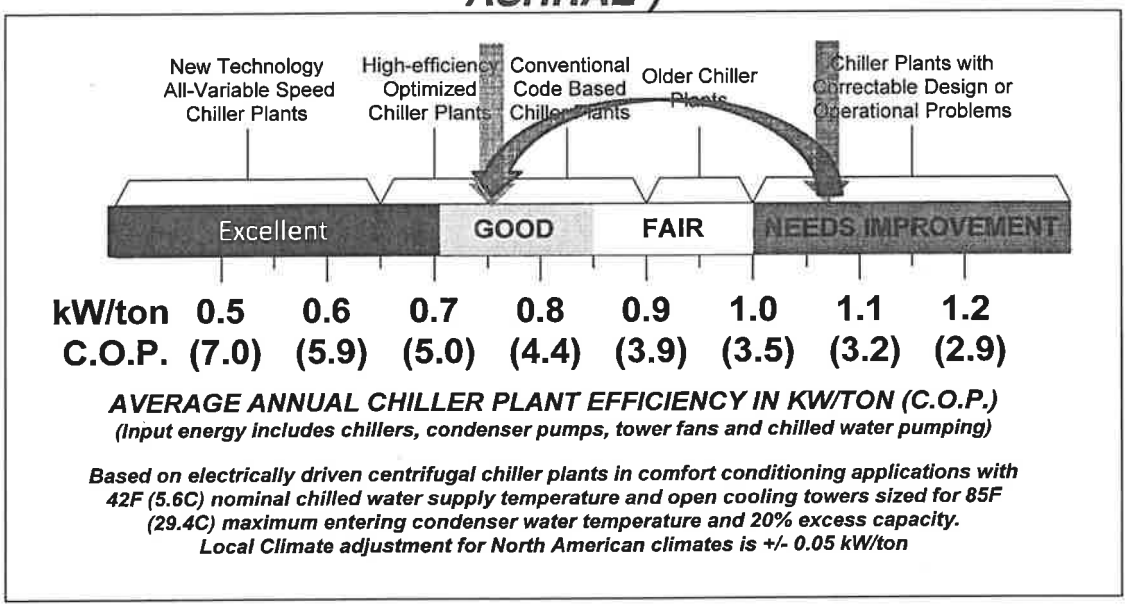
Prescribed Cooling Systems

1	Air-cooled / water-cooled chiller 	✓	Air-cooled / water-cooled chiller 	Regulated
2	Unitary Air-conditioning 	✓	Air-cooled / water-cooled chiller 	Regulated
3	Air-cooled / water-cooled chiller 	✓	Unitary Air-conditioning 	Regulated
4	Unitary Air-conditioning 	X	Unitary Air-conditioning 	Not Regulated

(see Building Control (Environmental Sustainability Measures for Existing Buildings) Regulations 2013, s4:Prescribed cooling systems)

Building and Construction Authority

Chiller Plant Efficiency Benchmarks *(Source: ASHRAE)*



AVERAGE ANNUAL CHILLER PLANT EFFICIENCY IN KW/TON (C.O.P.)
(Input energy includes chillers, condenser pumps, tower fans and chilled water pumping)

Based on electrically driven centrifugal chiller plants in comfort conditioning applications with 42F (5.6C) nominal chilled water supply temperature and open cooling towers sized for 85F (29.4C) maximum entering condenser water temperature and 20% excess capacity. Local Climate adjustment for North American climates is +/- 0.05 kW/ton



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Flow of Submission

Planning (Design Stage)

- Owner engages a **PE(Mech)**.
- PE (Mech) looks into the overall building design and ensures that the building can achieve **at least Green Mark 50 points (GMEB v3)**.
- Owner / PE(Mech) to submit the Green Mark design score, retrofitting design, drawings, computations **for approval before commencement of the energy improvement works**.

Electronic Submission for Professionals

Retrofitting

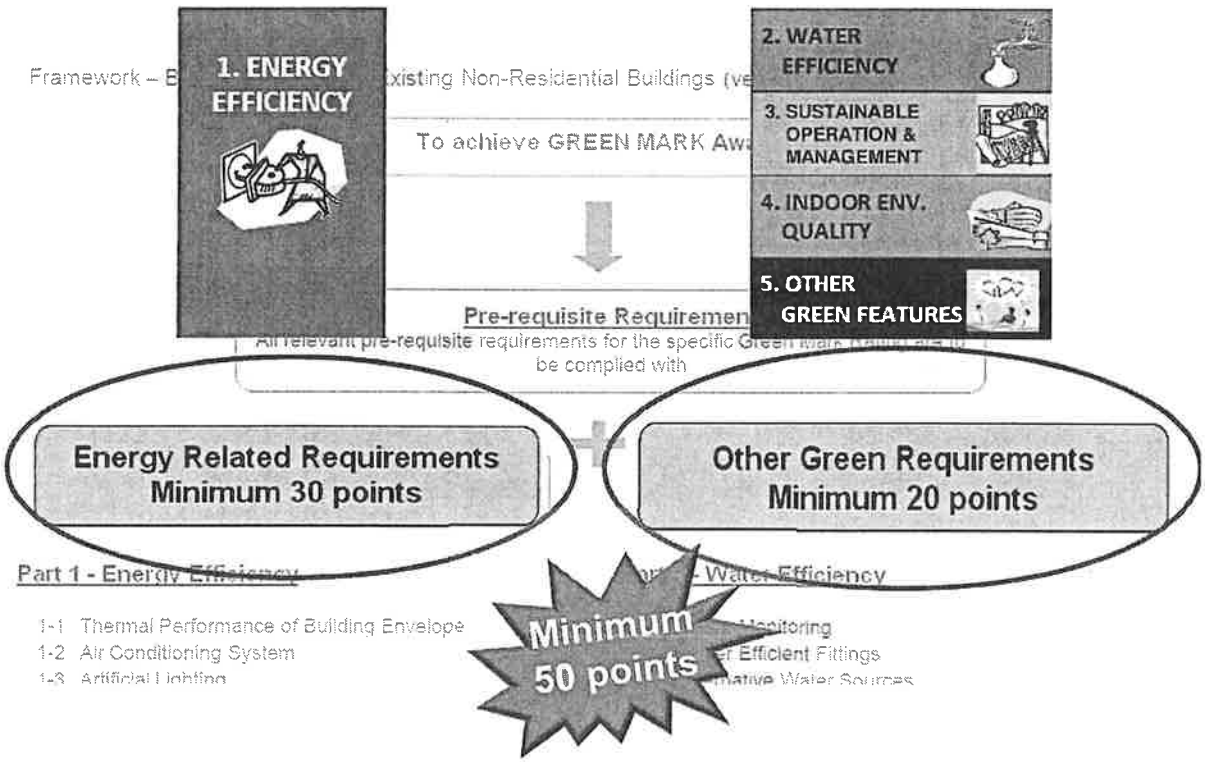
- Owner must complete the **energy improvement works within three years** from the date of approval of the design score by BCA.

Completion (As-Built Stage)

- Owner / PE(Mech) to submit the Green Mark as-built score **(at leas 50 points)** (including commissioning of the cooling system via submission of energy audit report).

Electronic Submission for Professionals

Pre-requisite Requirements



Pre-requisite Requirements

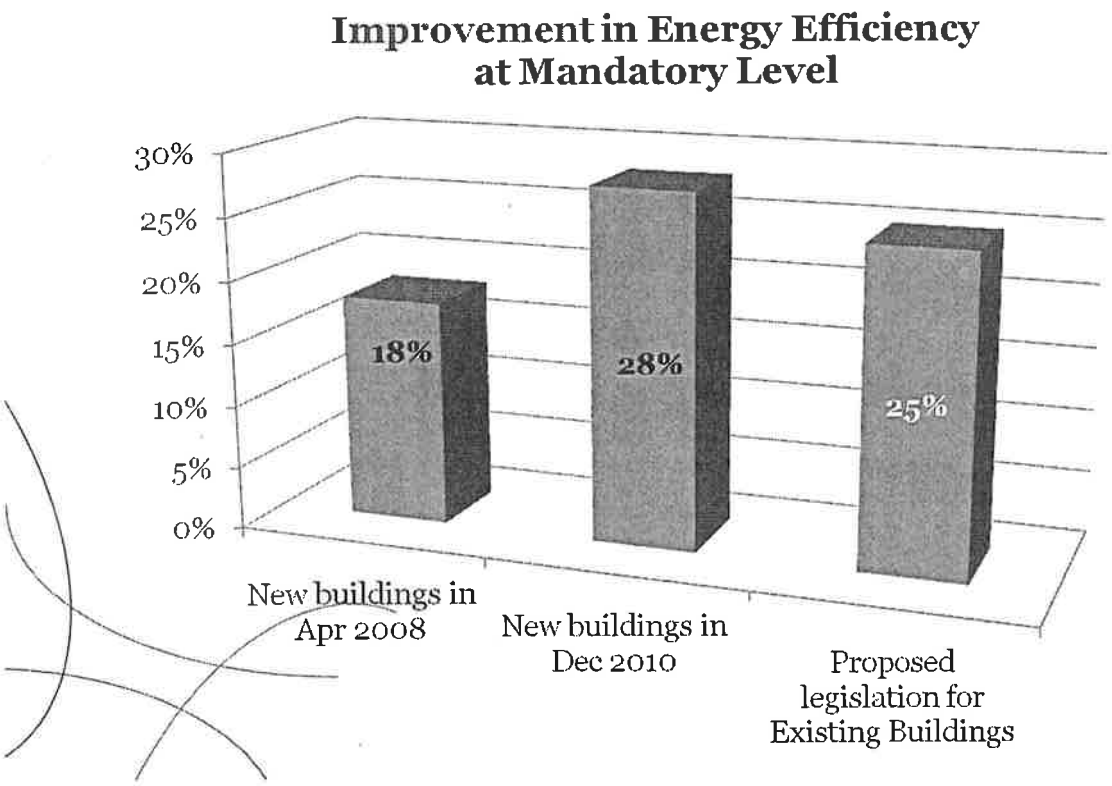
Air Conditioning System Efficiency

For buildings using **Water-Cooled Chilled-Water Plant**

Green Mark Rating	Building Cooling Load (RT)	
	< 500	≥ 500
	Efficiency (kW/RT)	
Certified	**0.85**	**0.75**
Gold	0.80	0.70
Gold^{Plus}	0.75	0.68
Platinum	0.70	0.65

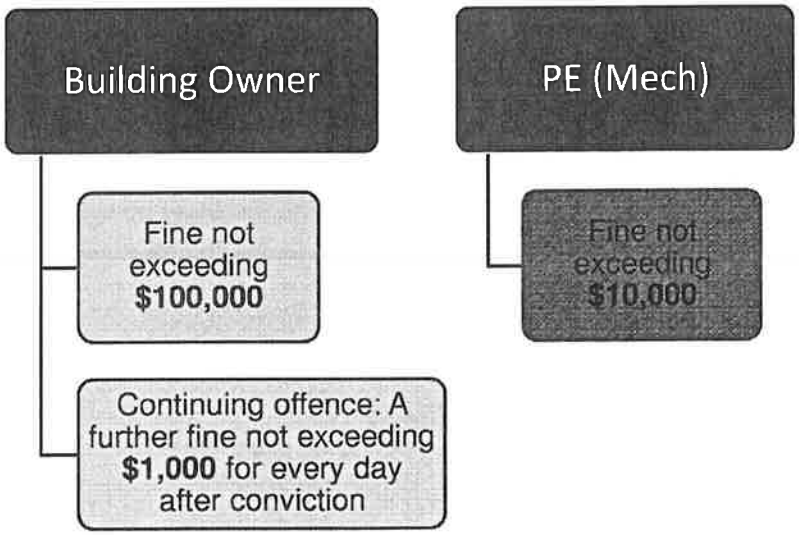
For buildings using **Air Cooled Chilled-water Plant or Unitary Air-Conditioner**

Green Mark Rating	Building Cooling Load (RT)	
	<500	≥ 500
	Efficiency (kW/RT)	
Certified	**1.1**	**1.0**
Gold	1.0	Not applicable
Gold^{Plus}	0.85	
Platinum	0.78	



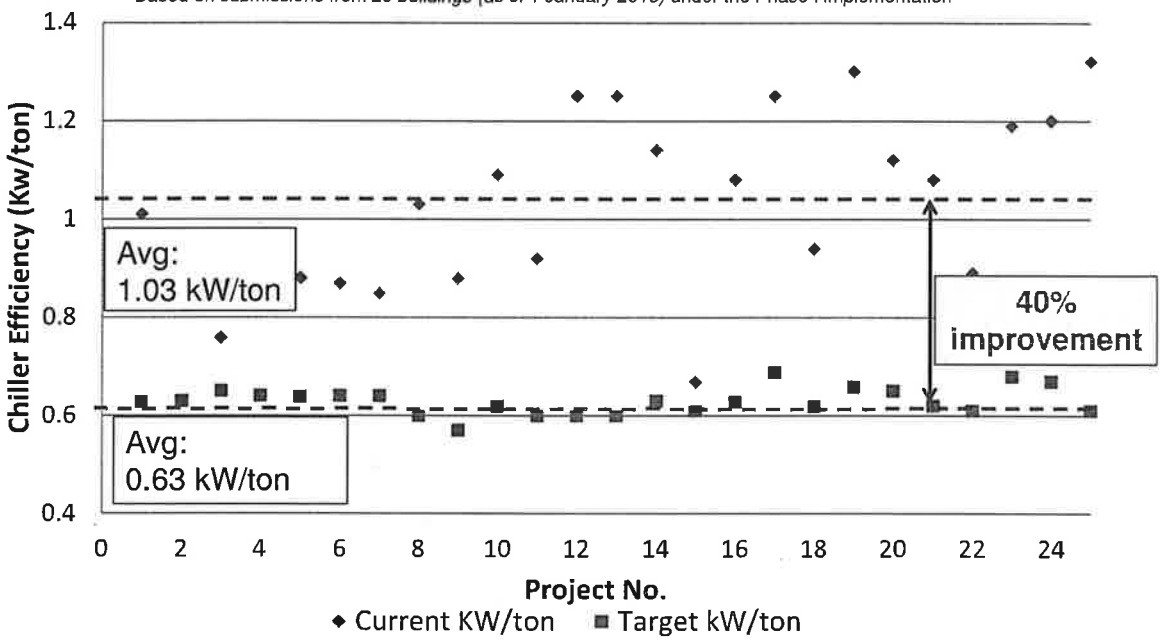
Min. GM Standard for Existing Buildings

Penalties for building owners / PE (Mech) who proceeds with the installation or replacements of the air-conditioning system without complying with the Regulations' requirements :



Legislated Projects' Building Cooling System Efficiency

**Based on submissions from 25 buildings (as of 1 January 2015) under the Phase I implementation*



2 3-Yearly System Efficiency Audit



Buildings involved

Existing buildings which have undergone retrofitting and are required to meet min. GM standard for existing buildings.

New buildings (except industrial and residential) with centralised chilled-water building cooling system which applied for planning permission on or after 1 December 2010 and required to comply with Building Control (Environmental Sustainability) Regulations

Periodic Energy Audit (Building Cooling System)

Act and Regulations

a. BC Act; and

b. Regulations.

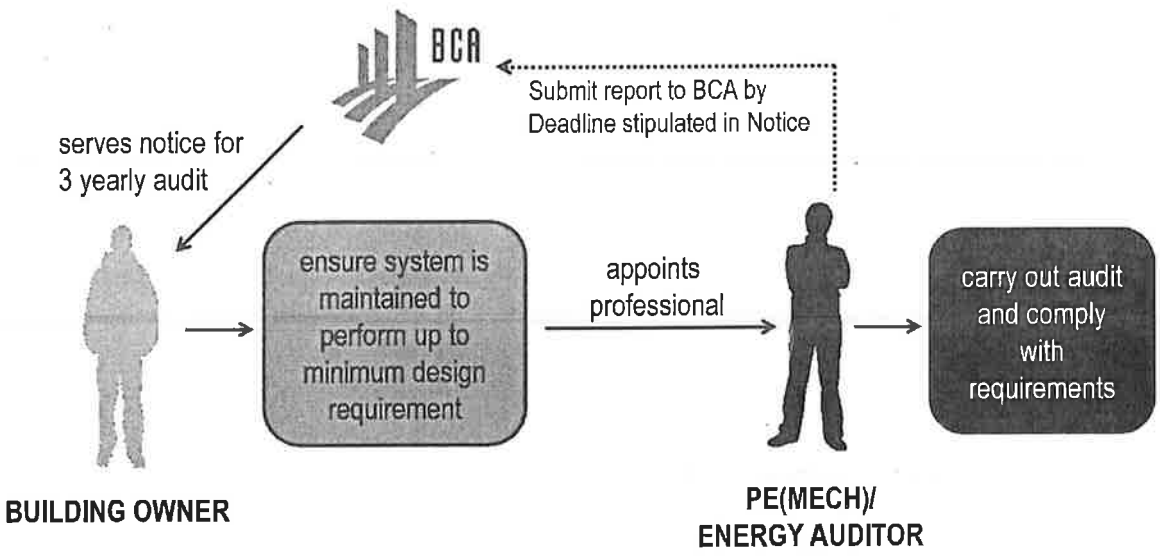
Referenced Codes and Standards

a. Code for Environmental Sustainability for Buildings (2nd Edition); and

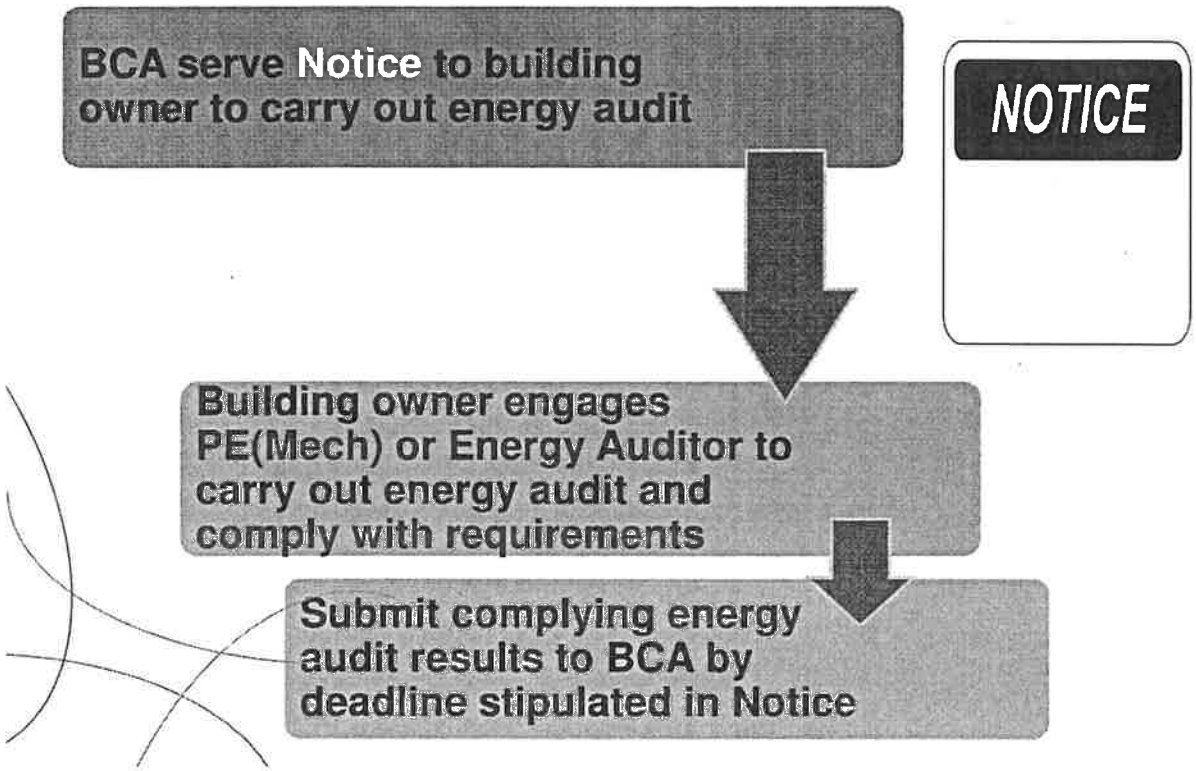
b. Code on Environmental Sustainability Measures for Existing Buildings (1st Edition)

c. Code on Periodic Energy Audit of Building Cooling System (1.01 Edition)

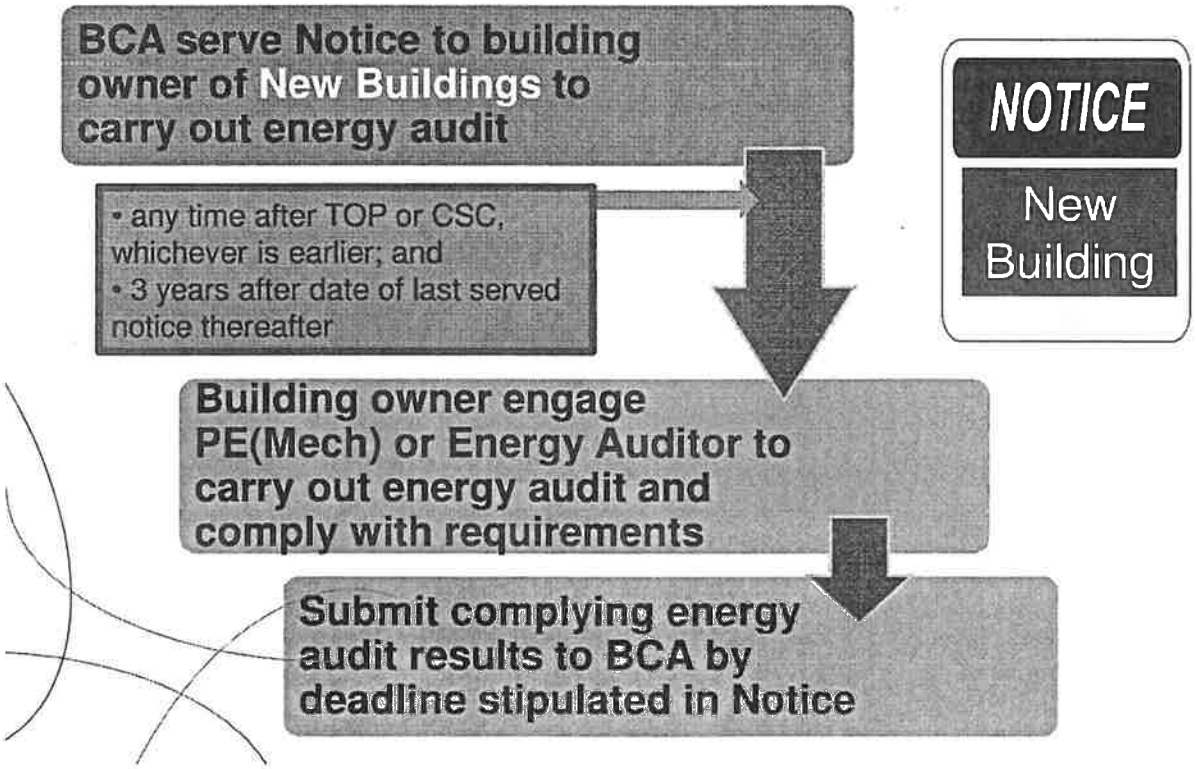
(2) Periodic Energy Audit of Building Cooling System



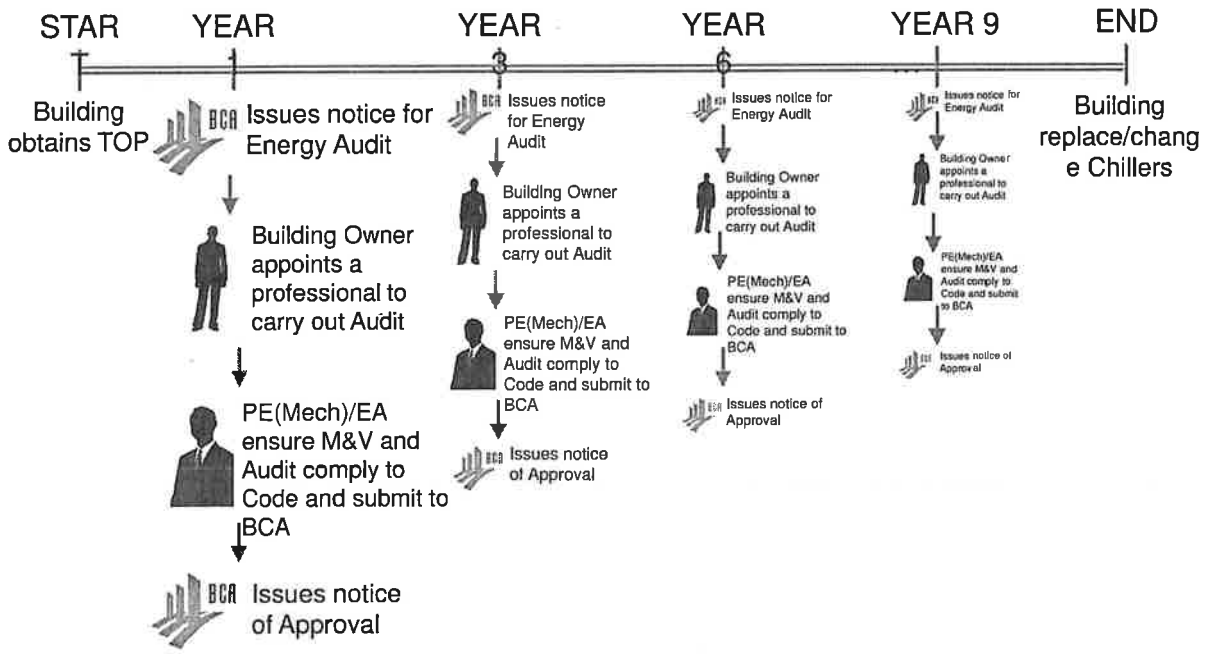
Periodic Energy Audit (Building Cooling System)



Periodic Energy Audit (Building Cooling System)



Three-Yearly Energy Audit on Building Cooling Systems (New Buildings)



Periodic Energy Audit (Building Cooling System)

BCA serve Notice to building owner of Existing Buildings to carry out energy audit

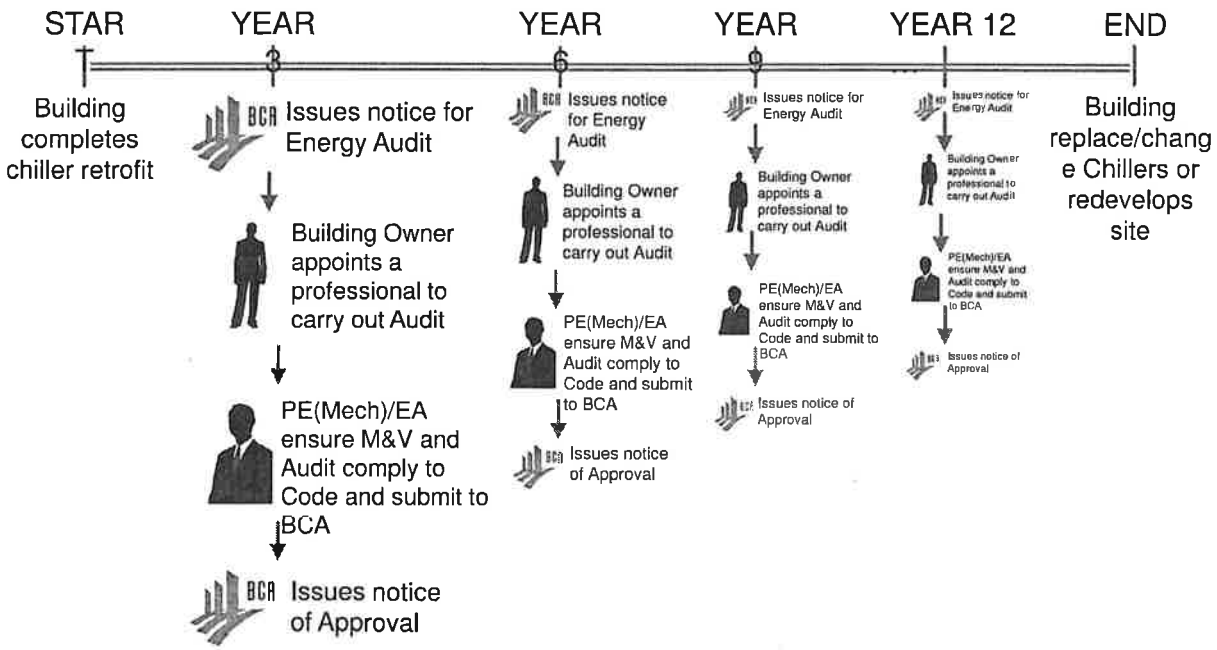
- 3 years after date of approved as-built score; and
- 3 years after date of last served notice thereafter

NOTICE
Existing Building

Building owner engage PE(Mech) or Energy Auditor to carry out energy audit and comply with requirements

Submit complying energy audit results to BCA by deadline stipulated in Notice

Three-Yearly Energy Audit on Building Cooling Systems (Existing Buildings)



Periodic Energy Audit (Building Cooling System)

Building Owner
(for failing to comply with Notice)

- Fine not exceeding **$20,000**
- For continuing offence, a further fine not exceeding **$500 for every day** after conviction

PE (Mech)
(for failing to conduct audit in accordance with Code)

- Fine not exceeding **$10,000**

Periodic Energy Audit (Building Cooling System)

Minimum Operating System Efficiency (OSE)

For Buildings using **Water-Cooled Chilled-Water Plant**				
	New Buildings		Existing Buildings	
	Building Cooling Load (RT)			
	< 500	≥ 500	< 500	≥ 500
Minimum OSE, (kWi/RT)	0.80	0.70	0.85	0.75

For Buildings using **Air-Cooled Chilled-Water Plant**				
	New Buildings		Existing Buildings	
	Building Cooling Load (RT)			
	< 500	≥ 500	< 500	≥ 500
Minimum OSE, (kWi/RT)	0.90	0.80	1.10	1.00

Minimum Operating System Efficiency (OSE)

Any building that is on land within areas stipulated under the First and Second Schedules to the BC (Environmental Sustainability) Regulations 2008

For Buildings using Water-Cooled Chilled-Water Plant		
Baseline	Building Cooling Load	
	< 500RT	≥500RT
Minimum OSE(kW/RT) -Gold^{plus} -Platinum	 0.7 0.7	 0.65 0.65

For Buildings using Air-Cooled Chilled Water Plants		
Baseline	Building Cooling Load	
	< 500RT	≥500RT
Minimum OSE(kW/RT) -Gold^{plus} -Platinum	0.85 0.78	Not applicable

Normal Building Operating Period for Energy Audit Report Submission	
Office Building	**Hotels**
Monday to Friday: 9am to 6pm	Monday to Sunday: 24 hours
	[Day time 7am – 11pm]
	[Night time 11pm – 7am]
Retail Malls	**Other building types**
Monday to Sunday: 10am to 9pm	To be determined based on the operating hours



Documents to be submitted (via CORENET)

1. BCA's notice for the submission
2. As-built drawings (to scale) & schematic drawings of chiller plant room indicating instrumentation location
3. 1 week raw data in excel format include all the chart plots (in accordance with Periodic Energy Audit Code – Annex B)
4. Energy Audit report (Periodic Energy Audit Code – Annex B)



Periodic Energy Audit Report (info to be provided)

	(a)	(b)	(c)	(d)	(e)	(f)	(g)
	Chilled water supply temperature	Chilled water return temperature	Chilled water flow rate	Condenser water supply temperature	Condenser water return temperature	Condenser water flow rate	Chiller kWe
dd/mm/yyyy hh:mm	°C	°C	L/s	°C	°C	L/s	kW
16/6/2012 15:00	6.70	12.60	84.10	29.4	35.5	97.65	308
16/6/2012 15:01	6.71	12.50	84.20	29.5	35.4	97.60	309
16/6/2012 15:02	6.72	12.30	84.30	29.6	35.3	97.55	310
16/6/2012 15:03	6.73	12.10	84.20	29.7	35.2	97.50	311
16/6/2012 15:04	6.74	12.20	84.10	29.8	35.1	97.55	312
16/6/2012 15:05	6.75	12.00	84.00	29.9	35	97.60	311
16/6/2012 15:06	6.74	12.10	84.10	29.8	35.1	97.65	310
16/6/2012 15:07	6.73	12.10	84.20	29.7	35.2	97.60	309
16/6/2012 15:08	6.72	12.10	84.30	29.6	35.3	97.55	308
16/6/2012 15:09	6.71	12.20	84.20	29.5	35.4	97.50	309
16/6/2012 15:10	6.70	12.40	84.10	29.4	35.2	97.55	310
16/6/2012 15:11	6.70	12.60	84.10	29.4	35.5	97.65	308
16/6/2012 15:12	6.71	12.50	84.20	29.5	35.4	97.60	309
16/6/2012 15:13	6.72	12.30	84.30	29.6	35.3	97.55	310
16/6/2012 15:14	6.73	12.10	84.20	29.7	35.2	97.50	311
16/6/2012 15:15	6.74	12.20	84.10	29.8	35.1	97.55	312
16/6/2012 15:16	6.75	12.00	84.00	29.9	35	97.60	311
16/6/2012 15:17	6.74	12.30	84.10	29.8	35.1	97.65	310

Date and time stamp

One Week raw data in excel format

Chilled water supply temperature	°C
Chilled water return temperature	°C
Chilled water flow rate	L/s
Condenser water supply temperature	°C
Condenser water return temperature	°C
Condenser water flow rate	L/s
Chiller power	kW
Chilled water pump power	kW
Condenser water pump power	kW
Cooling tower power	kW

Building and Construction Authority

Evidences to support complaince

- Instruments' calibration certificates from the accredited laboratories and their factory calibration certificates from manufacturers.
- Drawings showing the details of instruments installation
- All input parameters for the permanent instrumentations (e.g. flow meter settings for pipe material, diameter, circumference, thickness, roughness, type of lining etc.)
- Calculation of the overall uncertainty of measurement of the resultant chiller plant in kW/RT to be within ±5% of the true value based on instrumentation specifications and calibration certificates.



Chilled water plant information

ID	Description	Type	Name plate motor (kW)	Cooling Capacity (RT)	Chilled water LWT	Chilled water ΔT	Rated Efficiency kW/RT	Year Installed
CH01	Chiller 1	Centrifugal	150	1000	6.7 ° C	5.5° C	0.55	2012
CH02	Chiller 2	VSD Screw	90	500	6.7 ° C	5.5° C	0.52	2012

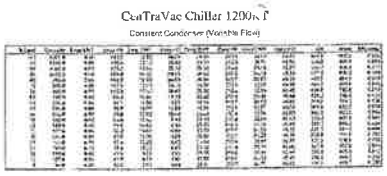
Table 1: Chiller Information (Example)

ID	Description	Name plate motor (kW)	Pump Head (m)	Flow rate (L/S)	Rated Pump/ Fan efficiency	Rated Motor Efficiency
CHWP01	Chilled water pump 1	55	30	151.2	85%	95%
CHWP02	Chilled water pump 2	30	30	75.6	85%	95%
CWP01	Condenser water pump 1	45	20	189	85%	95%
CWP02	Condenser water pump 2	22	20	94.5	85%	95%
CT01	Cooling tower 1	27	-	-	-	92%
CT02	Cooling tower 2	16.5	-	-	-	92%

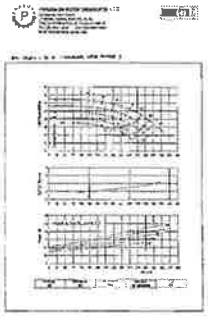
Table 2: Ancillary equipment Information (Example)



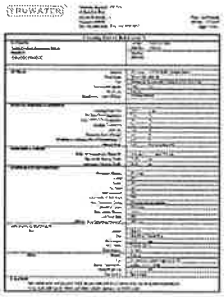
Energy Audit Report



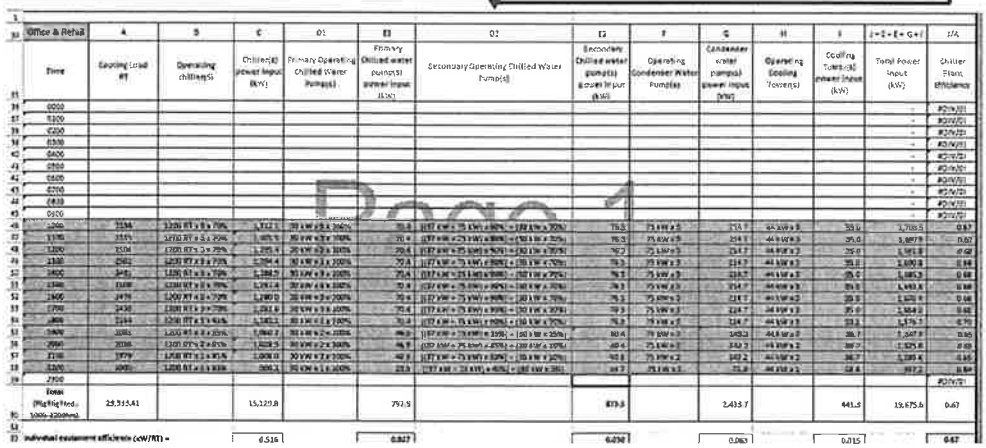
Chillers' Efficiency



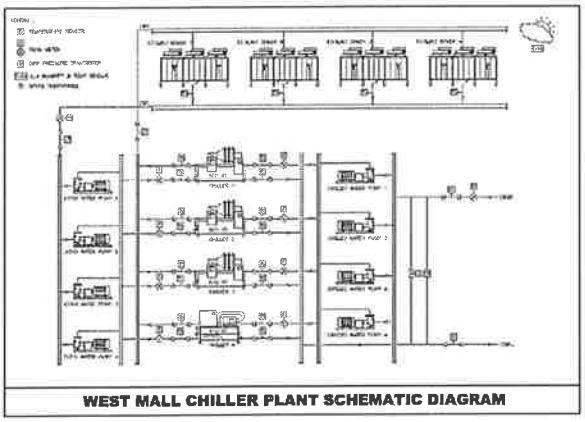
Pumps' Efficiency



Cooling Towers' Efficiency

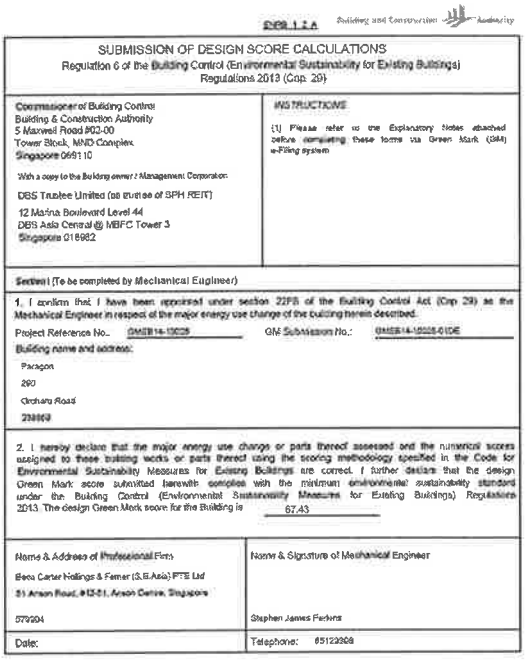


Page 1



WEST MALL CHILLER PLANT SCHEMATIC DIAGRAM

M & V Location



SUBMISSION OF DESIGN SCORE CALCULATIONS
Regulation 6 of the Building Control (Environmental Sustainability for Existing Buildings) Regulations 2013 (Cap. 29)

Commissioner of Building Control
Building & Construction Authority
5 Maxwell Road #02-00
Tower Block, MND Complex
Singapore 069110

With a copy to the Building owner / Management Corporation:

DBS Trustee Limited (as trustee of SPH REIT)
12 Marina Boulevard Level 44
DBS Asia Central @ MBFC Tower 3
Singapore 018982

INSTRUCTIONS

(1) Please refer to the Explanatory Notes attached before completing these forms via Green Mark (GM) e-Filing system

Section I (To be completed by Mechanical Engineer)

1. I confirm that I have been appointed under section 22F(3) of the Building Control Act (Cap 29) as the Mechanical Engineer in respect of the major energy use change of the building herein described.

Project Reference No.: GMEB14-15029 GM Submission No.: GMEB14-15029-S1DE

Building name and address:

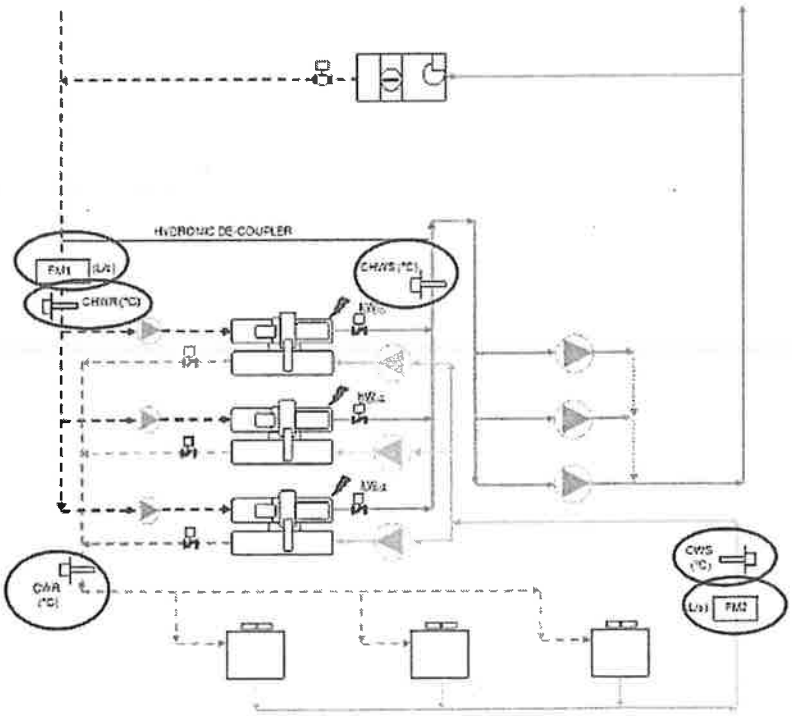
Paragon
290
Orchard Road
238859

2. I hereby declare that the major energy use change or parts thereof assessed and the numerical scores assigned to these building works or parts thereof using the scoring methodology specified in the Code for Environmental Sustainability Measures for Existing Buildings are correct. I further declare that the design Green Mark score submitted herewith complies with the minimum environmental sustainability standard under the Building Control (Environmental Sustainability Measures for Existing Buildings) Regulations 2013. The design Green Mark score for the Building is 67.43

Name & Address of Professional Firm	Name & Signature of Mechanical Engineer
Beca Carter Hollings & Ferner (S.E.Asia) PTE Ltd 51 Anson Road, #12-51, Anson Centre, Singapore 079904	Stephen James Perkins
Date:	Telephone: 65123909

Declared Green Mark Score

As-built schematic drawings of chiller plant



Building and Construction Authority

Details of Instrumentation

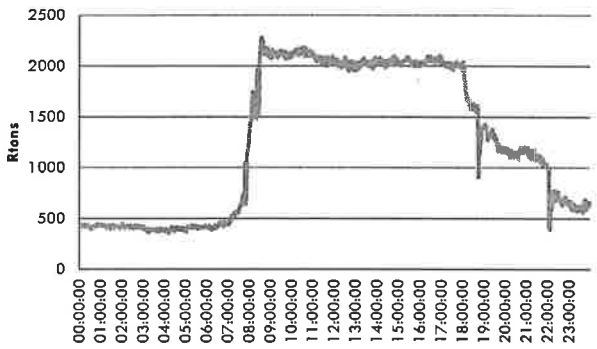
ID	Description	Sensor Type	Installation Location	Measurement/ Calibration range	Measurement Uncertainty (%)	Last Calibration Date
TT01	CHWS Temperature	10K Ω Thermistor	CHWS Header	0° C - 40° C	±0.03 ° C	15/10/2012
TT02	CHWR Temperature	10K Ω Thermistor	CHWR Header	0° C - 40° C	±0.03 ° C	15/10/2012
TT03	CWS Temperature	10K Ω Thermistor	CWS Header	0° C - 40° C	±0.03 ° C	15/10/2012
TT04	CWR Temperature	10K Ω Thermistor	CWR Header	0° C - 40° C	±0.03 ° C	15/10/2012
FM01	CHW Flow	Magnetic Full Bore	CHWR Header	30 l/s- 200 l/s	0.5%	20/10/2012
FM02	CW Flow	Magnetic Full Bore	CWR Header	30 l/s- 200 l/s	0.5%	20/10/2012
kW01	Chiller 1 Power	True RMS, 3 phase	ACMSB1	60 – 600 kW	0.5%	30/10/2012
kW02	Chiller 2 Power	True RMS, 3 phase	ACMSB2	60 – 600 kW	0.5%	30/10/2012
kW03	CHW Pump 1 & 2 Power	True RMS, 3 phase		20 – 200 kW	0.5%	30/10/2012
kW04	CW Pump 1 & 2 Power	True RMS, 3 phase	CHW SB	20 – 200 kW	0.5%	30/10/2012
kW05	CT 1 & 2 Power	True RMS, 3 phase	CT Panel	15 – 150 kW	0.5%	30/10/2012



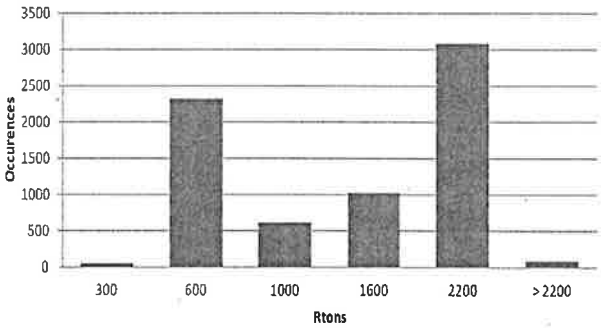
Complying with M&V Std in GM v3 Ext'g Bldg

We shape a safe, high quality, sustainable and friendly built environment.

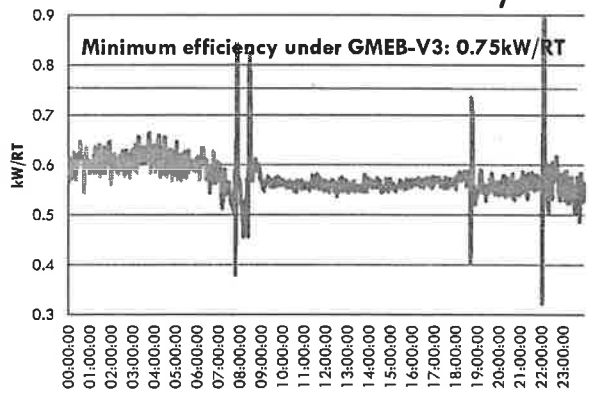
Cooling Load Profile



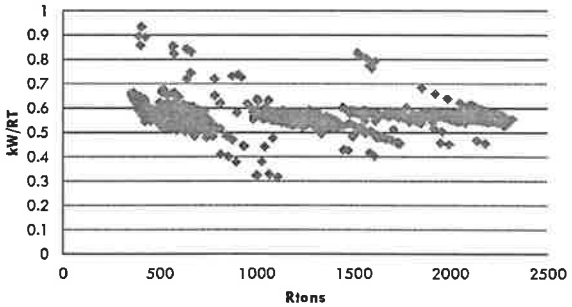
Frequency of Cooling Load Occurences



Chiller Plant Efficiency



Chiller Plant Efficiency VS Cooling Load Scatter Plot

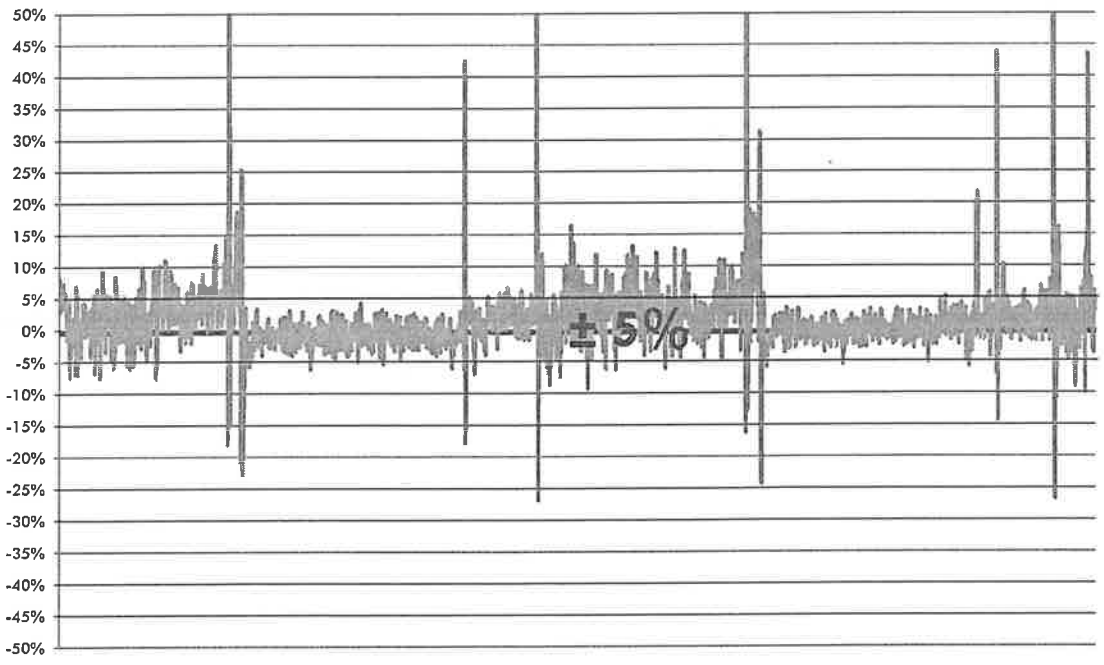


Summary of Chilled Water Plant Performance

	Efficiency		Unit
	Daytime^	Night-time~	
Chiller(s) efficiency	0.517	0.527	kW/RT
Chilled water pump(s) efficiency	0.025	0.028	kW/RT
Condenser water pump(s) efficiency	0.038	0.039	kW/RT
Cooling tower(s) efficiency	0.050	0.052	kW/RT
Overall chiller plant efficiency	0.630	0.646	kW/RT

^ Day time shall refer to 7am – 11pm (For hotels and other developments with 24-hr operations only); for all other developments, daytime shall refer to the normal building operating hours
~ Night time shall refer to 11pm – 7am (For hotels and other developments with 24-hr operations only)

Heat Balance Error Graph

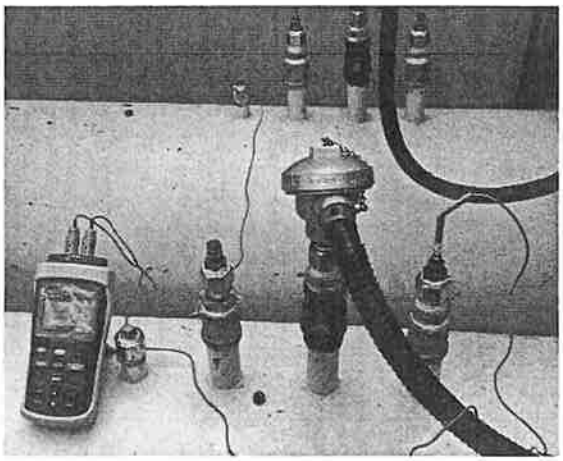


Heat Balance Result Summary

			Requirements	
Type of development	Hotel			
Period	01 June 2011 – 07 June 2011			
Operating hours coverage	24 hours			
Sum of total electrical energy used	60,000 kWh	(A)		
Sum of total cooling produced	84,000 RTh	(B)		
Sum of total heat rejected	110,000 RTh	(C)		
Chiller Plant Efficiency	0.714 kW/RT	(A) / (B)	< 500RT	≥ 500RT
			0.85kW/RT	0.75kW/RT
Total heat balance data count	10,080	(D)	No. of minutes over defined operating hours	
Data count > +5% error	500	(E)		
Data count < - 5% error	800	(F)		
Data count within ± 5% error	8,780	(G) = (D) – (E) – (F)		
% Heat balance within ± 5% error	87 %	(G) / (D) x 100%	≥ 80%	

Building and Construction Authority

On site verification of Air-Conditioning System – Water side



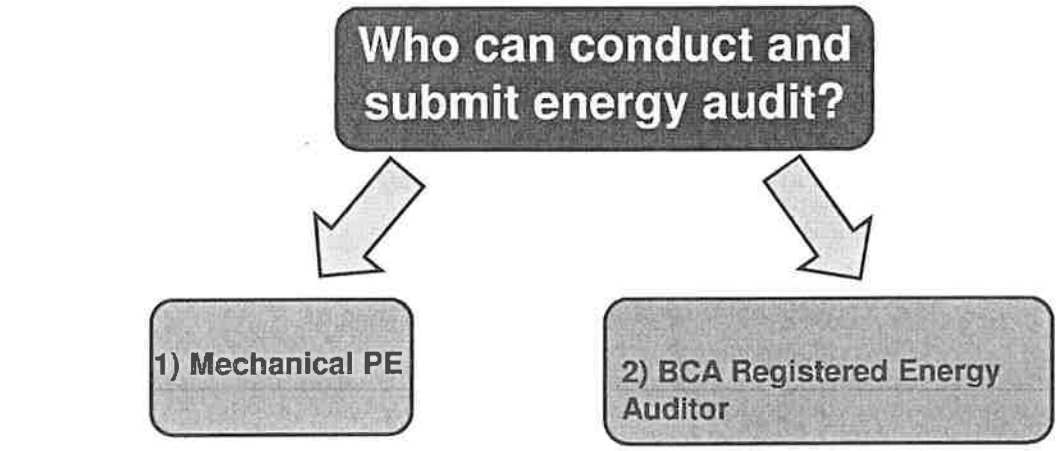
Verification of chilled-water & condenser water temperature with high accuracy thermistor





Building and Construction Authority

Periodic Energy Audit (Building Cooling System)





We shape a safe, high quality, sustainable and friendly built environment.

Registration Criteria for Energy Auditor

(as prescribed in Code on Periodic Energy Audit on Building Cooling System)

Requirements

- **An engineering or a building-related degree** in architecture, building science, facility management, and sustainable building design or equivalent;
- **3 years of relevant practical experience** in central air-conditioning design and installation, or operation;
- **2 ASHRAE Level III Energy Audits** or **3 Periodic Energy Audits** of Building Cooling Systems under the supervision of a PE(Mechanical) or an Energy Auditor registered with BCA; and
- **Passed interview** by the EA Registration Committee.

http://www.bca.gov.sg/EnvSusLegislation/Registered_Energy_Auditors.html

Building and Construction Authority

Duties of PE (Mech) / Energy Auditors

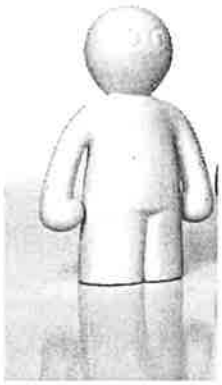
Under Section 22 FH of Building Control Act

- ✓ **Shall carry out the audit in accordance with the Code on Periodic Energy Audit;**
- ✓ **If the cooling system fails to attain the prescribed EE standard, may recommend such measures as may be necessary to attain the energy efficiency standard;**
- ✓ **Upon completion of the audit, shall prepare and sign energy report**



Building and Construction Authority

Registered Energy Auditors





Interested parties can apply using prescribed forms available at

http://www.bca.gov.sg/EnvSusLegislation/Registered_Energy_Auditors.html



Energy Auditors Registration Committee

BCA-Registered Energy Auditors - Renewal Requirements

in pipeline



1st Phase Implementation of EB Legislation

Implemented 2 Jan 2014

1. Minimum GM standard for existing buildings	**12** projects given approval for Design Score Submission, **3** under processing
2. Three-yearly **audit on building cooling system**	**5** projects have been served with Notices for Energy Audit Submission
3. Registration of BCA Energy Auditor (EA)	**40** registered EAs, **19** interviewed; **14** passed

List of Registered EAs

Registration No.	Energy Auditor	Company
EA 001	Lal Jayamaha	LJ Energy Pte Ltd
EA 002	Raisul Islam	LJ Energy Pte Ltd
EA 003	Patrick Goh	6-Sigma Pte Ltd
EA 004	Kolmakov Anatoli	6-Sigma Pte Ltd
EA 005	Teo Hwee Yean	CBM Solutions Pte Ltd
EA 006	Steve Seah Thiam Huat	DTZ Facilities & Engineering (S) Limited
EA 007	Steven Kang	Measurement and Verification Private Limited
EA 008	Lee Eng Lock	Trane Distribution Pte Ltd
EA 009	Andrew Chiang Siew Tung	Trane Distribution Pte Ltd
EA 010	Soong Sau Khong	Johnson Controls Singapore Pte Ltd
EA 011	Kaung Htat Nyunt	Johnson Controls Singapore Pte Ltd
EA 012	Leo Teo Siak Hian	Measurement and Verification Private Limited
EA 013	Vincent Low Loke Kiong	G-Energy Global Pte Ltd
EA 014	Joseph Loh Kum Hoong	G-Energy Global Pte Ltd
EA 015	Liu Xiaofeng	G-Energy Global Pte Ltd
EA 016	Choong Chow Neng	G-Energy Global Pte Ltd
EA 017	Challa Venu Kumar	Barghest Building Performance Pte Ltd
EA 018	Ahmad Sulaiman Bin Sumani	Kaer Pte Ltd
EA 019	Lai Choon Hoo (Benjamin)	Kaer Pte Ltd
EA 020	Patrick Foong Keng Yuen	e2green Pte Ltd
EA 021	Lu Lu	CNA Group Ltd
EA 022	Singarayar Wilson Lourdu Xavier	Honeywell Singapore Pte Ltd
EA 023	Maung Tin Tun	Honeywell Singapore Pte Ltd
EA 024	Derrick Hong	EMSI Singapore
EA 025	Anoop Sharma	Siemens Pte Ltd
EA 026	Alvin Woo Chee Wee	CPG Consultants Pte Ltd
EA 027	Beh Lean Hooi	CapitaMalls Asia
EA 028	Ero Rodjio	Ascendas Services Pte Ltd
EA 029	Leow Kok Chong	Siemens Pte Ltd
EA 030	Philip Chan Kok Leong	Jones Lang LaSalle Property Management Pte.Ltd
EA 031	Nagarajan Balamurugan	SMM Pte Ltd (Unit of Jurong International)
EA 032	Aye Minn	Equation Energy Pte Ltd
EA 033	Johny Salim	G-Energy Global Pte Ltd
EA 034	Numan Lim	6-Sigma Pte Ltd
EA 035	Yong Ping Quen	Building System and Diagnostic Pte Ltd
EA 036	Raveenthirakumar Prasantha	Comfort Management Pte Ltd
EA 037	Qiu Xuan	Comfort Management Pte Ltd
EA 038	Goo Chuen Cheng	CapitaMalls Asia Limited
EA 039	Justin Ng Yee Pong	Jones Lang LaSalle
EA 040	Chia Yeong Kuo	Johnson Controls Pte Ltd

Closing the loop

Ensure that a building that is designed and constructed as a green building would continue to operate efficiently through its life cycle

New Building Legislation

- Implemented in Apr 2008.
- Scope: New or existing building under major retrofitting with GFA > 2000m²
- Minimum Green Mark Standards for New buildings

1st in the World

Existing Building Legislation

- Scope: Existing building with A/C areas > 15,000m² (phase 1)
- Minimum Green Mark Standards for Existing buildings
- Periodic energy audit submission (3 yearly)
- Mandatory Energy submission (yearly)

Summary of Key Legislative Requirements

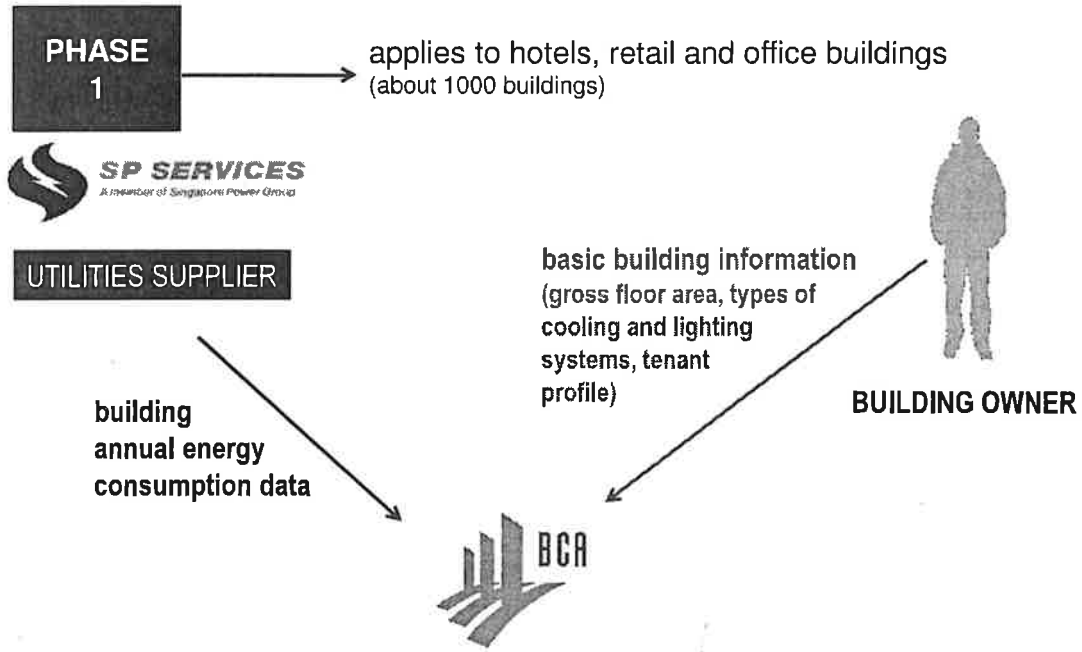
1) Minimum Green Mark Standards for Buildings installing/replacing Cooling Systems	2) Three-Yearly Audit on Cooling Systems	3) Annual Submission of Building Info & Energy Consumption Data
<u>Role of building owner</u> • Engage PE(Mech) to assess Green Mark scores. • Submit plans and Green Mark scores. • Ensure that **retrofitting works are completed within 3 years.**	<u>Role of building owner</u> • **Appoint PE(Mech)/energy auditor** to audit on the energy efficiency of the building cooling systems on receipt of Notice from BCA **at three-yearly interval.** • **Submit audit report** demonstrating that the energy efficiency of the cooling system **meets the minimum design efficiency standard.**	• Submission of **electricity consumption data** by utilities suppliers. • Submission of **building info** by building owners.
<u>Role of PE(Mech)</u> • Assess and prepare design score **(at least 50 points)** before retrofitting works. • Assess and prepare the as-built score **(at least 50 points)** after completion of retrofitting works.	<u>Role of Auditor</u> • Conduct audit on energy efficiency of building cooling system in accordance with Code. • Prepare audit report.	

3 Annual Submission of Energy Data

Purpose

Basis of the **national energy benchmarks**	**Sharing of data** with building owners for pro-active improvement to the energy performance of buildings	**Measure effectiveness** of energy efficiency initiatives

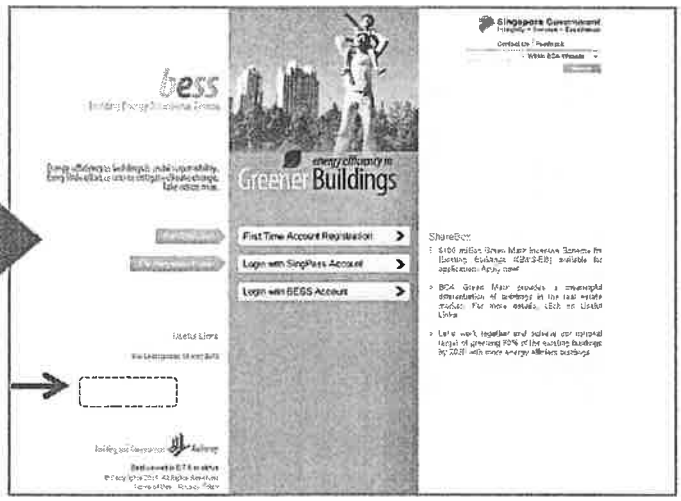
(3) Annual Submission of Building Info and Energy Consumption Data



(3) Annual Submission of Building Info and Energy Consumption Data

Building owners can enter their information through BCA's new Building Energy Submission System (BESS) using the BESS ID or SingPass.

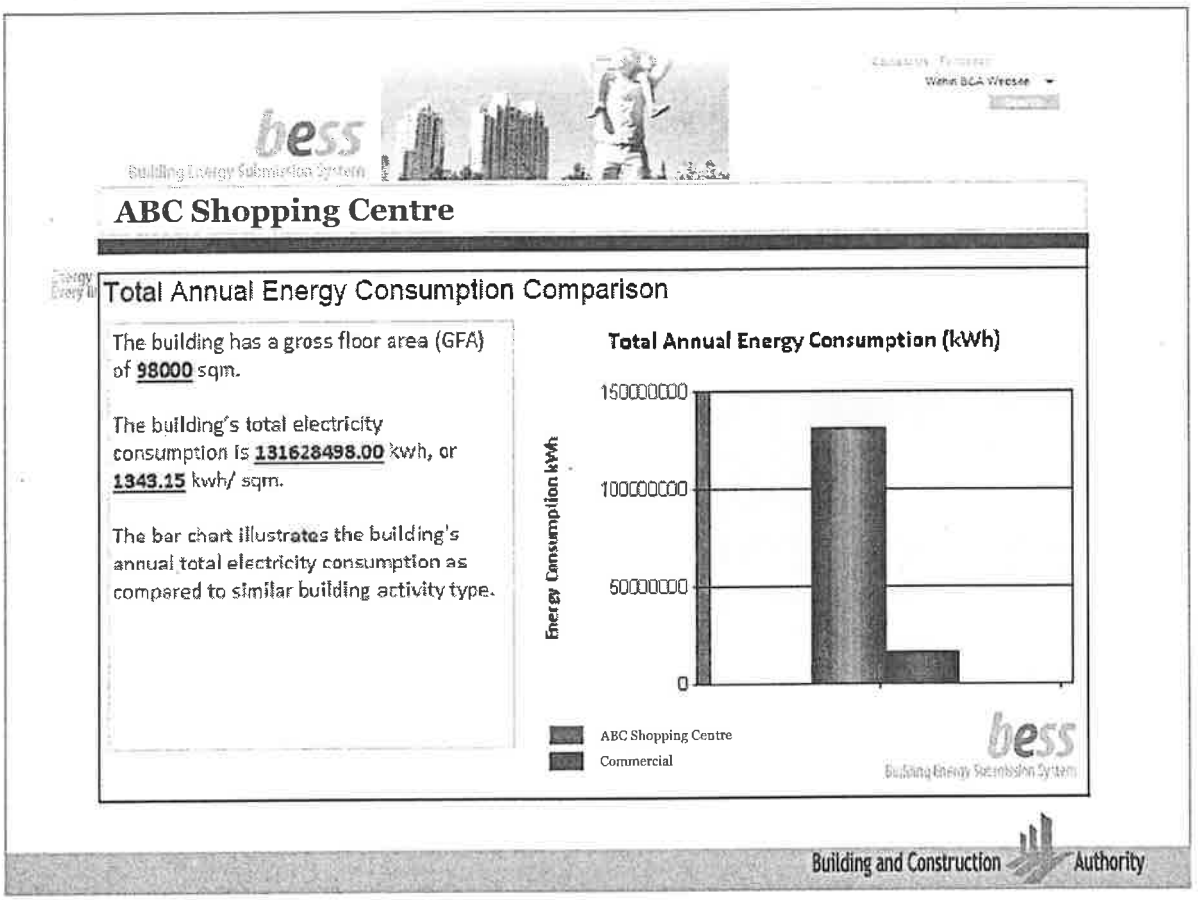
Submit to BCA through ***Building Energy Submission System*** (BESS)



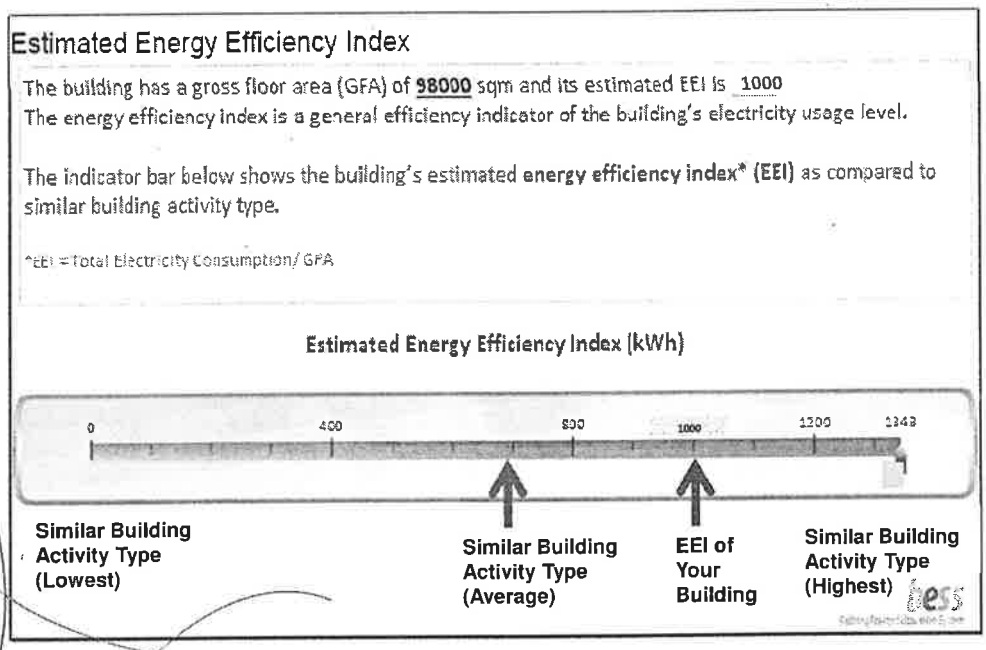
<u>Useful links</u>

- ✓ user submission manual
- ✓ technical guide
- ✓ demo-video

BESS URL: https://www.bca-bess.gov.sg



3 Annual Submission of Energy Data



3 Annual Submission of Energy Data

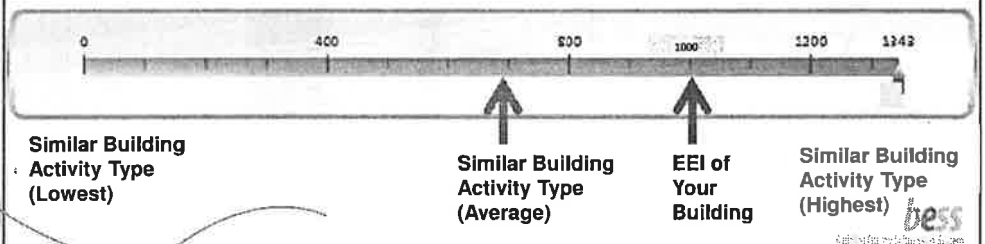
Estimated Energy Efficiency Index

The building has a gross floor area (GFA) of **98000** sqm and its estimated EEI is **1000**
The energy efficiency index is a general efficiency indicator of the building's electricity usage level.

The indicator bar below shows the building's estimated **energy efficiency index* (EEI)** as compared to similar building activity type.

*EEI = Total Electricity Consumption/ GFA

Estimated Energy Efficiency Index (kWh)





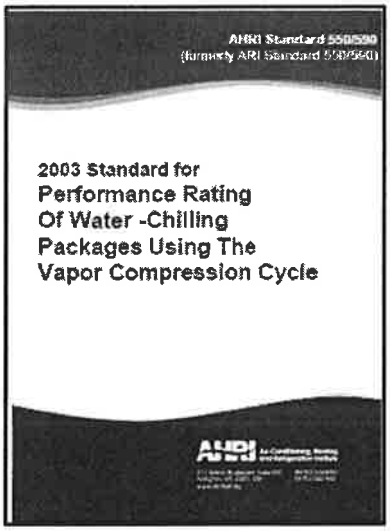


Building and Construction Authority

We shape a safe, high quality, sustainable and friendly built environment.

Overview of AHRI 550/590-2003

Standard for performance rating of water chilling packages using vapor compression cycle



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Agenda

1. Introduction of AHRI 550/590
2. Allowable tolerances
3. Heat balance substantiating test
4. Comparison of GMv4.1 to AHRI 550

Agenda

1. Introduction of AHRI 550/590

Purpose of standard

The purpose of this standard is to establish performance rating requirements for water chillers using the vapour compression cycle.

Covers:

- definitions;
- test requirements;
- rating requirements;
- minimum data requirements for published ratings; marking and nameplate data; and
- conformance conditions.

Scope of standard

Chiller performance verified by this standard includes:

1. Capacity, tons [kW]
2. Energy Efficiency, kW/ton [COP]
3. Water pressure drop, ft H2O [kPa]
4. Integrated Part-Load Value (IPLV)
5. Non-Standard Part-Load Value (NPLV)

Scope of standard

60 Hz Power	
Included in Certification Program	
Water-Cooled	**Air-Cooled**
All compressor types	All compressor types
Rated up to 2000 tons [7034 kW] at ARI Standard Rating Conditions	Rated up to 200 tons [703 kW] at ARI Standard Rating Conditions
Hermetic & open type, electric motor driven	Hermetic & open type, electric motor driven
Voltages up to 5000 volts	Voltages up to 600 volts
Excluded from Certification Program	
Water-Cooled	**Air-Cooled**
Condenserless chillers	Condenserless chillers
Evaporatively cooled chillers	Evaporatively cooled chillers
Chillers above 2000 tons [7034 kW]	Chillers above 200 tons [703 kW]
Chillers with voltages above 5000 volts	Chillers with voltages above 600 volts
Chillers powered by other than electric motor drives	Chillers powered by other than electric motor drives
Chillers with motors not supplied with the unit by The manufacturer	Secondary coolant ratings (other than water)
	Free cooling
Secondary coolant ratings (other than water)	Heat recovery & heat pump ratings
Free cooling	
Heat recovery & heat pump ratings	

Scope of standard

50 Hz Power	
Included in Certification Program	
Water-Cooled	**Air-Cooled**
Centrifugal & screw chillers with continuous unloading	Not applicable
Rated 200 - 1000 tons [703-3517 kW] at ARI Standard Rating Conditions	
Hermetic & open type, electric motor driven	
Voltages up to 5000 volts	
Excluded from Certification Program	
Water-Cooled	**Air-Cooled**
Scroll & reciprocating compressor chillers with step unloading	Not applicable
Condenserless chillers	
Evaporatively cooled chillers	
Chillers below 200 tons [703 kW]	
Chillers above 1000 tons [3517 kW]	
Chillers with voltages above 5000 volts	
Chillers powered by other than electric motor drives	
Chillers with motors not supplied with the unit by The manufacturer	
Secondary coolant ratings (other than water)	
Free cooling	
Heat recovery & heat pump ratings	

Full load rating conditions

Table 1. Standard Rating Conditions

	Water-Cooled		Evaporatively-Cooled		Air-Cooled	
Condenser Water						
Entering	85.0 °F	29.4 °C				
Flow Rate	3.0 gpm/ton	0.054 L/s per kW				
Condenser Fouling Factor Allowance						
Water-Side	0.00025 h · ft² · °F/Btu	0.000044 m² · °C/ W				
Air-Side			0.0 ft² · °F/Btu	0.0 m² · °C/W	0.0 h · ft² · °F/Btu	0.0 m² · °C/W
Entering Air						
Dry-Bulb					95.0 °F	35.0 °C
Wet-Bulb			75.0 °F	23.9 °C		
Evaporator Water						
Leaving	44.0 °F	6.7 °C	44.0 °F	6.7 °C	44.0 °F	6.7 °C
Flow Rate	2.4 gpm/ton	0.043 L/s per kW	2.4 gpm/ton	0.043 L/s per kW	2.4 gpm/ton	0.043 L/s per kW
Evaporator Fouling Factor Allowance						
Water-Side	0.0001 h · ft² °F/Btu	0.000018 m² · °C/W	0.0001 h · ft² °F/Btu	0.000018 m² · °C/W	0.0001 h · ft² °F/Btu	0.000018 m² · °C/W
Without Condenser						
Saturated Discharge	105.0 °F	40.6 °C	105.0 °F	40.6 °C	125.0 °F	51.7 °C
Liquid Refrigerant	98.0 °F	36.7 °C	98.0 °F	36.7 °C	105.0 °F	40.6 °C
Barometric Pressure	29.92 in Hg	101.3 kPa	29.92 in Hg	101.3 kPa	29.92 in Hg	101.3 kPa

Part load ratings: IPLV & NPLV

Integrated Part Load Value (IPLV)
Defines a chiller part load efficiency using 4 standard operating conditions and 4 standard weightage factors

Non-standard Part Load Value (NPLV)
Defines a chiller part load efficiency using 4 **non-standard** operating conditions and 4 standard weightage factors

$$\text{IPLV or NPLV} = 0.01A + 0.42B + 0.45C + 0.12D$$

Where: A = COP at 100% , B = COP at 75% , C = COP at 50% , D = COP at 25%

The weightage factors have been derived based on the weighted average of the most common building types and operations using average weather in 29 U.S. cities, with and without airside economizers.

Table 3. Part-Load Condition: for Rating

	IPLV		NPLV	
Evaporator (All Types)				
100% load LWT	[1]44.0 °F	6.7 °C	[1]Selected LWT	[1]Selected LWT
0% load LWT	44.0 °F	6.7 °C	Same as 100% load	Same as 100% load
Flow Rate (gpm)	[2]2.4 gpm/ton	0.043 L/s per kW	[3]Selected gpm/ton	[3](L/s per kW)
F F A	0.0001 h · ft² · °F/Btu	0.000018 m² · °C/W	As Specified	As Specified
Water-Cooled Condenser				
100% load EWT	[1]85.0°F	29.4 °C	[1]Selected EWT	[1]Selected EWT
75% load EWT	75.0 °F	23.9 °C	[4]	[4]
50% load EWT	65.0 °F	18.3 °C	[4]	[4]
25% load EWT	65.0 °F	18.3 °C	[4]	[4]
0% load EWT	65.0 °F	18.3 °C	65.0 °F	18.3 °C
Flow rate (gpm) [L/s]	[2]3.0 gpm/ton	0.054 L/s per kW	[3]Selected gpm/ton	[3]L/s per kW
F F A	0.00021 h · ft² · °F/Btu	0.000044 m² · °C/W	As Specified	As Specified
Air-Cooled Condenser (See Figure 5)				
100% load EDB	95.0 °F	35.0 °C		
75% load EDB	80.0 °F	26.7 °C		
50% load EDB	65.0 °F	18.3 °C	No Rating Requirement	
25% load EDB	55.0 °F	12.8 °C		
0% load EDB	55.0 °F	12.8 °C		
F F A	0.0 h·ft²·°F/Btu	0.0 m²·°C/W		
Evaporatively-Cooled Condenser				
100% load EWB	75.0 °F	23.9 °C	No Rating Requirement	
0% load EWB	50.0 °F	10.0 °C		
F F A	0.0 h·ft²·°F/Btu	0.0 m²·°C/W		
Air-Cooled Without Condenser				
100% load SDT	125.0 °F	51.7 °C	No Rating Requirement	
0% load SDT	35.0 °F	12.8 °C		
Water and Evaporatively-Cooled Without Condenser				
100% load SDT	105.0 °F	40.6 °C	No Rating Requirement	
0% load SDT	65.0 °F	18.3 °C		

1 If the unit Manufacturer's recommended minimum temperatures are greater than those specified in Table 3, then those may be used in lieu of the specified temperatures.
2 Corrected for Fouling Factor Allowance by using the calculation method described in G6.5
3 The flow rates are to be held constant at full load values for all part-load conditions.
4 For part-load entering condenser water temperatures, the temperature should vary linearly from the selected EWT at 100% load to 65.0 °F at 50% loads, and fixed at 65.0°F for 50% to 0% loads.

SDT - saturated discharge temperature
LWT - leaving water (liquid) temperature
EWT - entering water (liquid) temperature
EDB - entering air dry-bulb temperature
EWB - entering air wet-bulb temperature
F F A - Fouling Factor Allowance

Part load rating conditions

Agenda

2. Allowable tolerances for chiller performance

11

Allowable tolerances

The allowable test tolerance on

Tons [kW], kW/ton [COP], Heat balance error

shall be determined from the following equation:

$$\text{Tolerance \%} = 10.5 - (0.07 \times \%FL) + \frac{833.3}{DT_{FL} \times \%FL}$$

DT_{FL} = Chilled water delta temperature at full load, °C

%FL = % of full load capacity

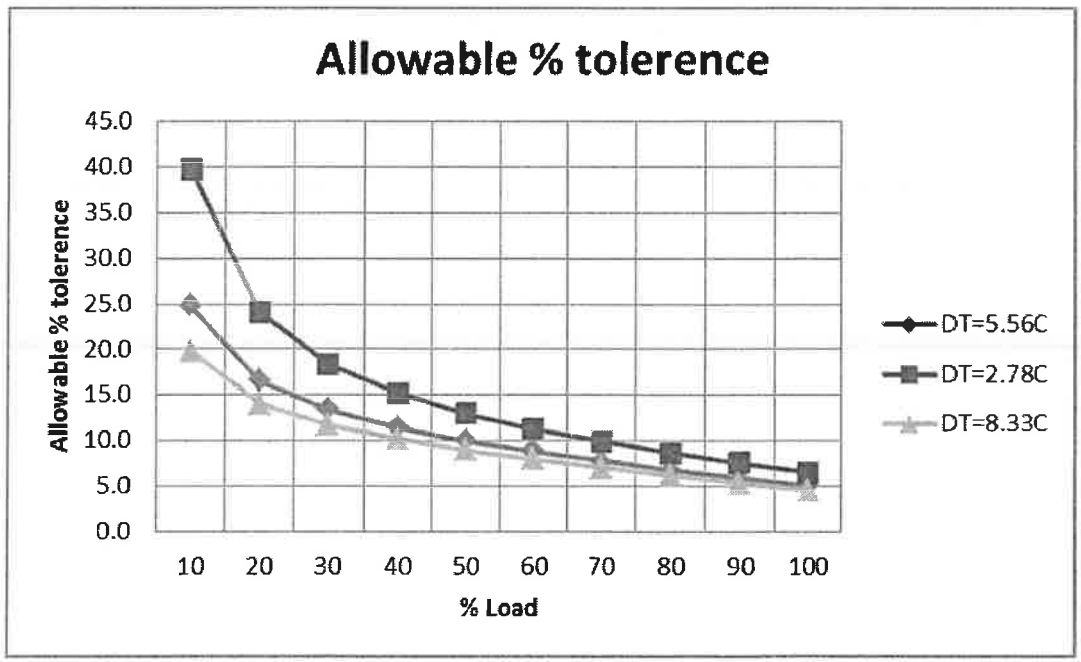
12

Allowable tolerances

	CHW DT at Full Load (C)		
% Full load	5.56	2.78	8.33
10	24.8	39.8	19.8
20	16.6	24.1	14.1
30	13.4	18.4	11.7
40	11.4	15.2	10.2
50	10.0	13.0	9.0
60	8.8	11.3	8.0
70	7.7	9.9	7.0
80	6.8	8.6	6.2
90	5.9	7.5	5.3
100	5.0	6.5	4.5


Allowable tolerences

Allowable tolerances



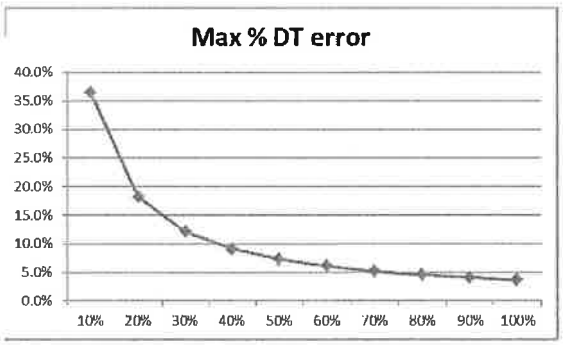
Instruments standards

- Accuracy of instruments selected shall be in accordance with ANSI/ASHRAE Standard 30.
- Temperature measurements shall be made in accordance with ANSI/ASHRAE Standard 41.1.
- Flow: +/- 1%
- Temperature: +/- 0.1C

Max % DT error at part load when using +/- 0.1C temperature sensor

Ashrae std 41.1 temp accuracy 0.1 C
Full load CHW DT 5.5 C

% load	DT	Max DT error	Max % DT error
10%	0.55	0.2	36.4%
20%	1.1	0.2	18.2%
30%	1.65	0.2	12.1%
40%	2.2	0.2	9.1%
50%	2.75	0.2	7.3%
60%	3.3	0.2	6.1%
70%	3.85	0.2	5.2%
80%	4.4	0.2	4.5%
90%	4.95	0.2	4.0%
100%	5.5	0.2	3.6%



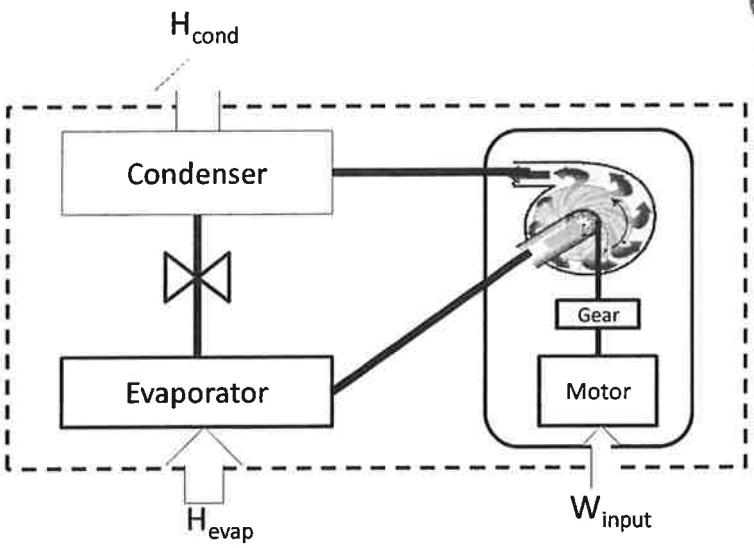
An temperature accuracy of ±0.1C will lead to very large error in DT at part load!

Agenda

3. Heat balance substantiating test

Heat balance substantiating test
Hermetic motor chiller

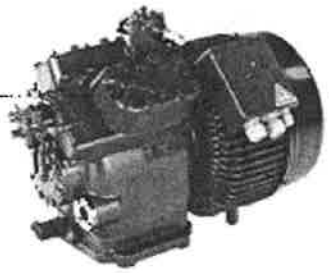


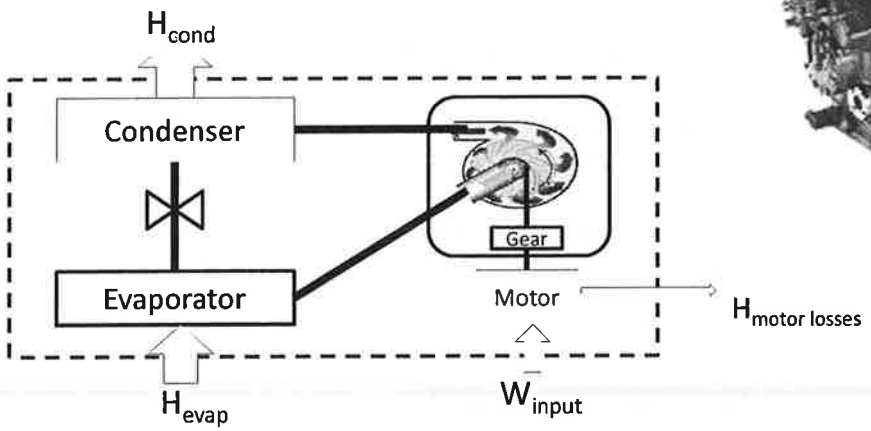


$$H_{evap} + W_{input} = H_{cond}$$

Where W_{input}: Electrical power input into compressor

Heat balance substantiating test
Open motor chiller





$$H_{evap} + W_{input} = H_{cond} + H_{motor\ losses}$$

$$H_{evap} + W_{input} = H_{cond} + W_{input} \times (1\text{-}Motor_{eff})$$

$$H_{evap} + (W_{input} \times Motor_{eff}) = H_{cond}$$

Where

W_{input}: Electrical power input into compressor

$Motor_{eff}$: Motor eff (obtain from manufacturer)

Agenda

4. Comparison of GMv4.0 to AHRI 550

GMv4 compared to AHRI 550

- Permanent on-site M&V system
- Performance verification for entire chiller plant instead of just for chiller.
- Measurement tolerance is +/-5% for all loads within designated operating hours.
- Heat balance is optional (1pt).
- Heat balance test for entire chiller plant
  - 80% of data point within +/-5% for 1 week
- Emphasis on accuracy of instruments
  (To be covered in Ashrae Guideline 22)

GMv4 compared to AHRI 550





AHRI 550





GM v4

- System perspective
- Whole load spectrum M&V (Full & part load) except for non standard op hours.
- Account actual operation & maintenance effect
- Long term M&V
- Singapore weather conditions

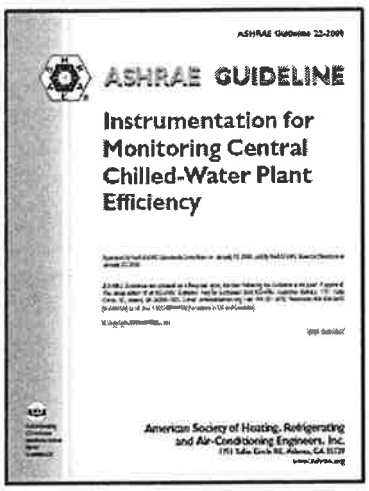
Thank You

for your attention

Q&A

Overview of Ashrae Guideline 22 - 2008

Instrumentation for monitoring central chilled-water plant efficiency



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Agenda

1. Introduction of Ashrae Guideline 22
2. Guidelines on power, temperature, flow, measurements and data acquisition
3. Measurement errors
4. Calibration
5. GMv4 compared to Ashrae Guide 22

Agenda

1. Introduction of Ashrae Guideline 22

Purpose and scope

Purpose

- This guideline defines recommended methods for measuring chilled-water plant thermal load and energy use and for calculating chilled-water plant efficiency.

Scope

- Recommendations for methods and devices used to measure electrical usage, fluid flow, and temperature, and procedures for acquiring the necessary data and calculating system efficiency.
- Cover only electrically driven chiller plant.
- Entirely focused on reporting the operational efficiency of existing plants.

Determination of Work Done

- $Wd = Mw \times Cp \times DT$

  Wd: Work done (KW)
  Mw: Fluid flow rate (kg/s)
  Cp: Specific heat of fluid (kj/kg.k)
  DT: Temperature difference (C)

- Properties of pure water

Chilled Water

Temp	Specific heat	Density
C	Kj/Kg.K	Kg/L
7.0	4.1977	0.99996
12.0	4.1893	0.99958
Average	**4.1935**	**0.99977**

Condenser Water

Temp	Specific heat	Density
C	Kj/Kg.K	Kg/L
30.0	4.1785	0.99571
35.0	4.1782	0.99408
Average	**4.17835**	**0.99489**

- Common to assume
  Cp = 4.19 kj/kg.k
  Density = 1.00 kg/L

- Wd for pure water

Wd (KW) = 4.19 x flow rate (L/S) x DT (C)

1 RT = 3.517 KW

Determination of COP

$$COP = \frac{\sum Wd}{\sum Wi}$$

COP: Coeff of perfromance (Dimensionless)
Wd: Work done (KW)
Wi: Electrical input (KW)

$\sum Wi$ = Sum of power input of
Chillers
+ Primary chilled water pumps + Secondary chilled water pumps
+ Condenser water pumps
+ Cooling towers.

$$COP = \frac{4.19 \times \text{flow rate (L/S)} \times DT (C)}{\sum Wi}$$

$$KW/RT = \frac{3.517}{COP}$$

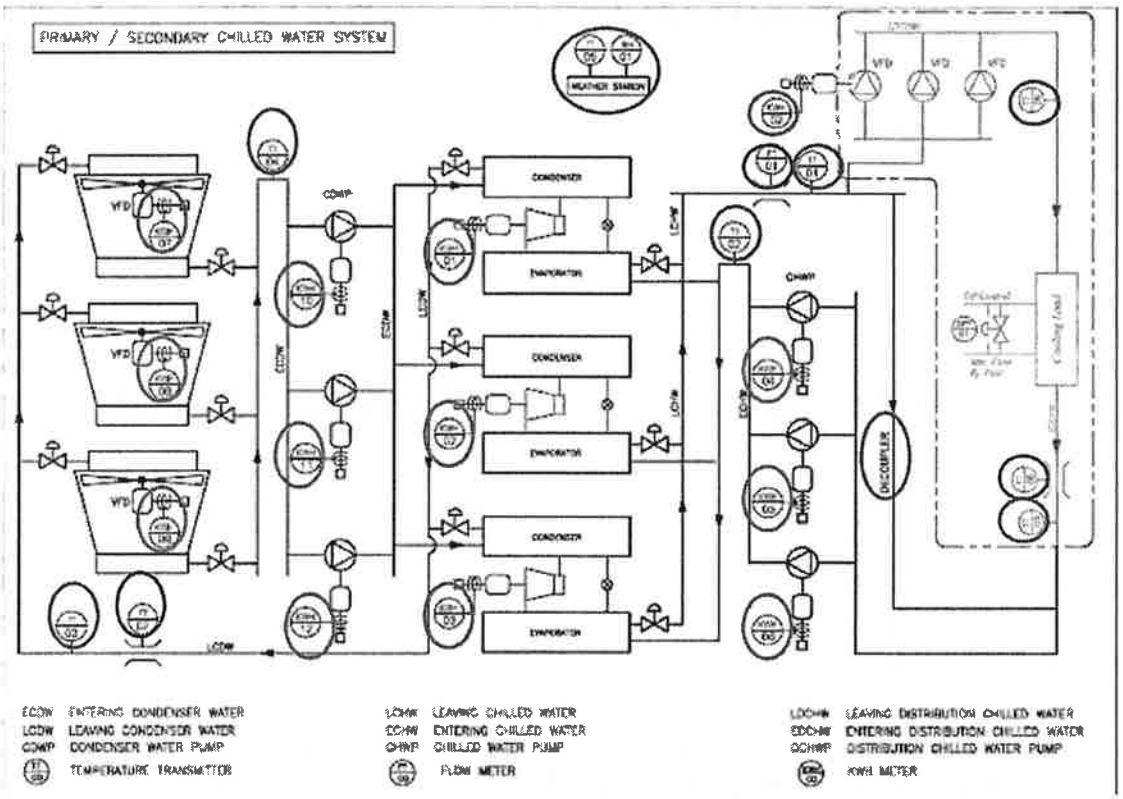


Figure 5-1 Example of primary/secondary chilled-water plant.

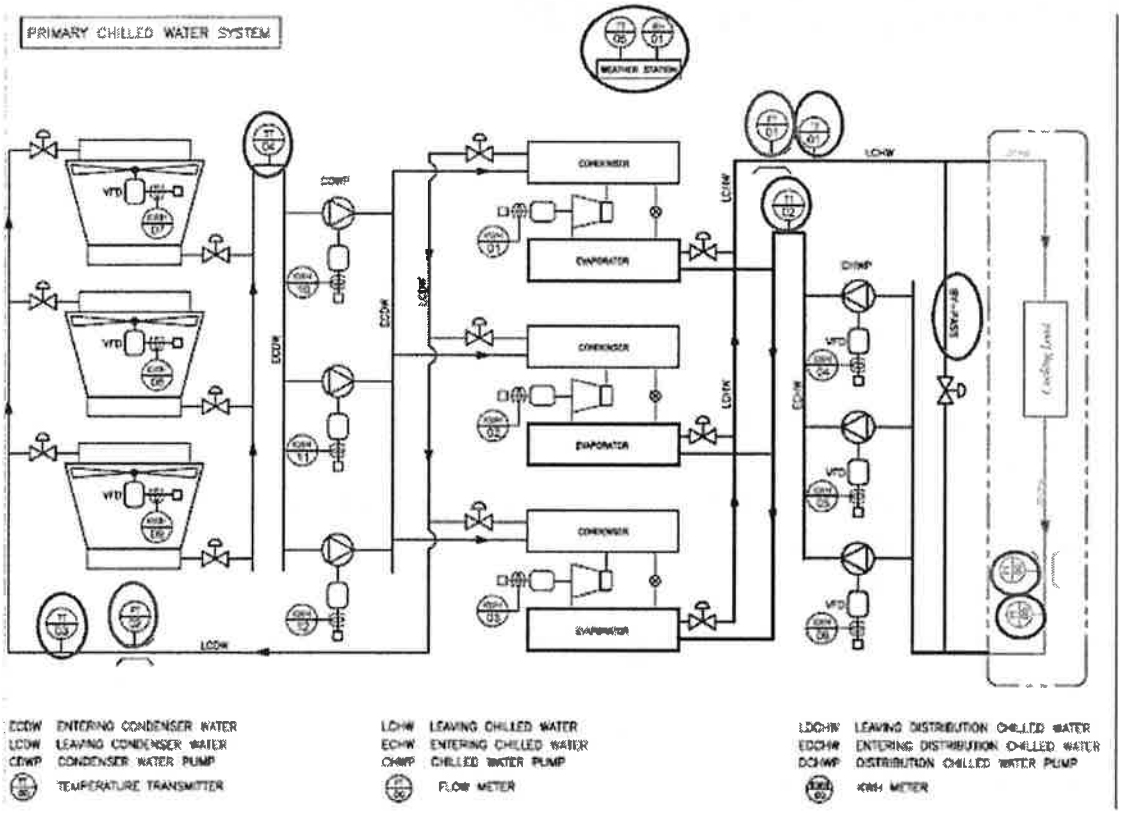


Figure 5-2 Example of primary-only chilled-water plant.

TABLE 5-1 Instrumentation Table

ID	Point Description	Measurement Range	Sensor Type or Calculation Method	Installation Location	Input Type	Instrument Range	End-to-end Accuracy (% of reading unless noted)	Data Resolution	Refresh Interval (min)	Trend Interval (min)
Power Measurements										
kW01	Chiller 1 Power									
kW02	Chiller 2 Power									
kW03	Primary ChW Pump 1 Power									
kW04	Primary ChW Pump 2 Power									
kW05	Secondary ChW Pump 3 Power									
kW06	Secondary ChW Pump 4 Power									
kW07	Chiller 1 CW Pump Power									
kW08	Chiller 2 CW Pump Power									
kW09	Cooling Tower Fan 1 Power									
kW10	Cooling Tower Fan 2 Power									
Flow Measurements										
FT01	Chilled Water Flow									
FT02	Condenser Water Flow									
TT01	Chilled Water Supply Temperature									
TT02	Chilled Water Return Temperature									
TT03	Condenser Entering Water Temperature									
TT04	Condenser Leaving Water Temperature									
TT05	Ambient Dry-Bulb Temperature									
TT06	Ambient Wet-Bulb Temperature									
Calculated Values										
CC01	ChWPlant Thermal Cooling Output									
CC02	chilled-water plant Efficiency									
CC03	Plant Heat of Rejection									

Agenda

2. Guidelines on power, temperature, flow, measurements and data acquisition

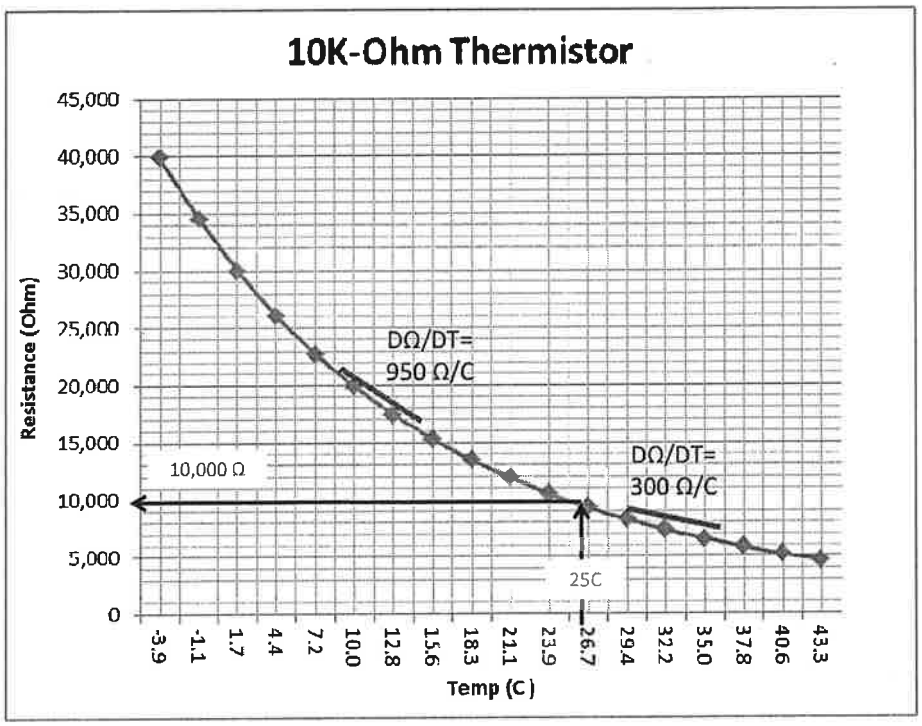
Power measurement

- The accurate measurement of electrical power usually presents the least challenge in terms of resolution, accuracy, and reliability.
- The power meter must provide the true RMS power including the effects of power factor.
- Accuracies of better than 1% are reasonably achievable with newer instrumentation. "Metering Grade" power meters of class 0.5% and 0.2% are available.
- The Guideline appears to allow the power measurement to be taken from VSDs. However, caution is needed to ensure that VSD power measurement are within the required accuracy.

Temperature measurements

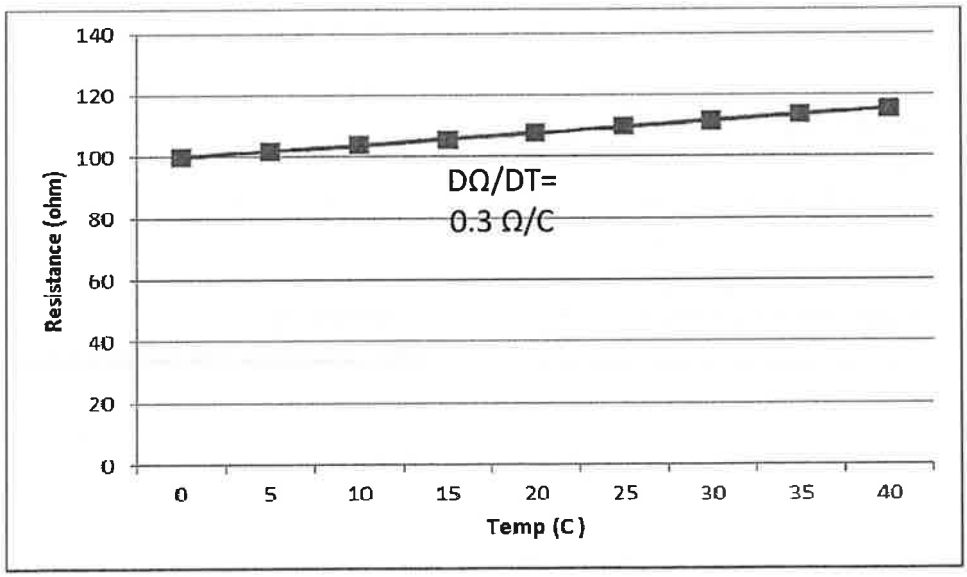
	Thermocouple	Resistant temperature detectors (RTD)	Thermistors
Principle of operation	It consists of two dissimilar metals, joined together at one end. When the junction of the two metals is heated or cooled a voltage is produced that can be correlated back to the temperature.	It exploits the predictable change in electrical resistance of some materials with changing temperature. Most commonly used material is Platinum and they are commonly called PRT. They have positive temperature coefficient.	Like RTD, it also exploits the predictable change in electrical resistance. Thermistors are made from certain metal oxides whose resistance decreases with increasing temperature. Therefore, they are known to have negative temperature coefficient.
Accuracy	A large uncertainty of approximately 0.6C. Greater accuracy in the measurement of temperature difference can be obtained through the use of a differential thermopile consisting of a series of thermocouple junctions. An uncertainty of 0.1°C (0.18°F) is possible.	It is very accurate and nearly linear over typical temperature ranges of interest for these applications. With proper calibration, uncertainties of better than 0.01°C can be achieved.	Thermistors provide greater sensitivity and accuracy. Temperature measurement accuracy is limited by the ability to measure the voltage drop across the thermistor and current flow. The thermistor itself can be calibrated to an uncertainty of 0.001°C. The calibration must be performed at a minimum of three temperatures to enable an adequate curve fit for the temperature/resistance characteristics. With this procedure, system measurement uncertainties of better than 0.1°C (0.18°F) are easily obtained.
Cost	Low	High	Medium

Thermistor R/T characteristic



Thermistor plot

PT 100 R/T characteristic



Due to small resistance and sensitivity

- Lead resistance become significant (4 wire required)
- Require very sensitive resistance measurement (High resolution and high accuracy)

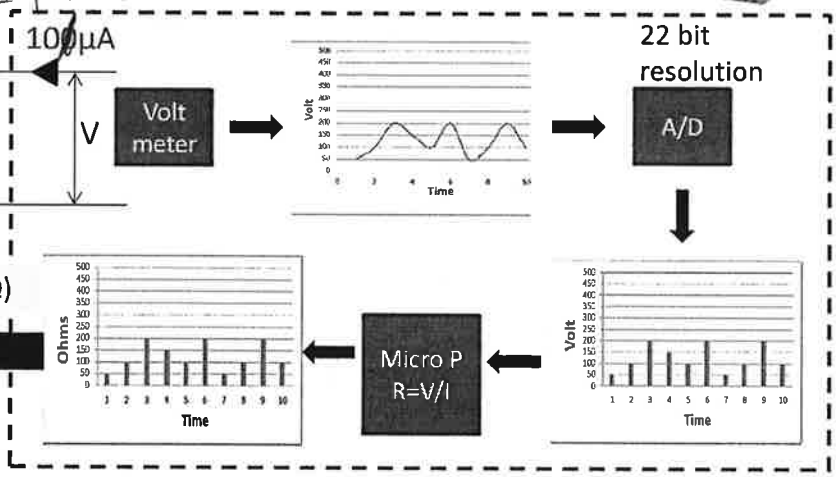
Temperature measurement chain

Calibrated thermistor with a/b/c



Agilent 34972A Data logger

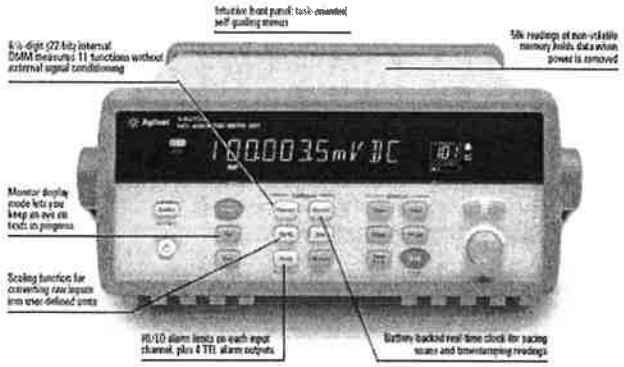




Customized program

$$T = \frac{1}{a + b(\ln R) + c(\ln R)^3}$$

Measurement of thermistor resistance



- Measurements include dc volts, ac volts, thermocouple, thermistor and RTD temperature measurements, 2- and 4-wire Ohms, dc current, ac current, frequency, and period
- 6½ digits (22 bits) of resolution with 0.004% basic 1-year dcV accuracy

Resistance measurement uncertainty
+/- (% reading + % range)

Range[3]	Frequency, etc.	24 Hour[2] 23°C±1°C	90 Day 23°C±5°C	1 Year 23°C±5°C
Resistance[6]				
100.0000	1 mA current source	0.0030 + 0.0035	0.008 + 0.004	0.010 + 0.004
1.000000 k	1 mA	0.0020 + 0.0006	0.008 + 0.001	0.010 + 0.001
10.00000 k	100 µA	0.0020 + 0.0005	0.008 + 0.001	0.010 + 0.001
100.0000 k	10 µA	0.0020 + 0.0005	0.008 + 0.001	0.010 + 0.001
1.000000 M	5.0 µA	0.002 + 0.001	0.008 + 0.001	0.010 + 0.001
10.00000 M	500 nA	0.015 + 0.001	0.020 + 0.001	0.040 + 0.001
100.0000 M	500 nA/10 M	0.300 + 0.010	0.800 + 0.010	0.800 + 0.010

10k thermistor error
=10kΩ x (0.01% +0.001%)
= +/- 1.1Ω

1.1Ω error at 950Ω/C
= +/- 0.001C

Flow measurements

- The measurement of chilled-water flow rate is the most difficult task in the process of determining chiller efficiency. That is because flow measurements are typically invasive and because flow rate is not uniform over most flow cross sections. The measurement of fluid flow generally requires consideration of adequate runs of straight pipe.
- While laboratory flow measurement uncertainties of 1% or better are possible, field measurement accuracy will likely be less, with uncertainties of 5% or greater commonly encountered.
- Since only a few flow sensors are required, cost may not be a major concern. Durability and reliability are important considerations, and, in this regard, ultrasonic and pressure drop meters may be of some advantage.

Data acquisition

- The selection of a data recording device is dependent upon the following factors:
  - Quality of the device (accuracy, precision, drift, rate of response).
  - Measurement range.
  - Signal conditioning.
  - Quantity and type of inputs required.
  - Installation restrictions.
  - Resources available to purchase and support the device.
- BAS hardware is typically not designed for the kind of data acquisition this guideline recommends, and its ability must be demonstrated before it can be used with confidence.

Agenda

3. Measurement errors

Measurement errors

- It is recommended that the installed instrumentation be capable of calculating a resultant COP within 5% of the true value.
- Resolution is the smallest change in the measured quantity that can be detected.
- Accuracy is the capability to indicate the true value of the measured quantity.
- Measurement accuracy is determined by the measurement uncertainty. Uncertainty includes both systematic offset (bias) and random errors (precision).
- Calibration can help reduce bias, while random errors can be treated using statistical methods.

Measurement errors

- The contribution of the individual uncertainties to the overall measurement error, in terms of probable errors, can be computed using the root-sum square formula, as follows:

$$Error_{rms} = \left(\sum\left(u_N \frac{\partial \eta}{\partial N}\right)^2\right)^{1/2} \qquad \text{(C-1)}$$

where

u_N = individual uncertainty of variable N

$\frac{\partial n}{\partial N}$ = partial derivative of efficiency with respect to variable N

N = mass flow rate, electrical power input, or temperature difference

Example 1

Chiller electrical power E = 2100 kW ± 2.1 kW (±0.1% of reading)

Chilled-water flow rate ω = 441 l/s ± 13.2 l/s (±3.0% of reading)

Temperature change of chilled water ΔT = 6.67°C ± 0.056°F (±0.8% of reading)

What is the chiller efficiency and error of measurement?

The chiller COP = (4.19*441*6.67) / 2100 = 5.87

Total error $= \sqrt{(2.1/2100)^2 + (13.2/441)^2 + (0.056/6.67)^2}$

$= \sqrt{(0.1\%)^2 + (3\%)^2 + (0.8\%)^2}$

= 3.1%

Example 2

Assume that the conditions produce a smaller ΔT. What is the chiller efficiency and how does this affect the uncertainty requirements for each measurement?

Chiller electrical power E = 1400 kW ± 1.4 kW (±0.1%of reading)
Chilled-water flow rate ω = 441 l/s ± 13.2 l/s (±3.0% of reading)
Temperature change of chilled water ΔT = 3.33°C ± 0.056°C (±1.7% of reading)

What is the chiller efficiency and error of measurement?

The chiller COP = (4.19*441*3.33) / 1400 = 4.40

Total error $= \sqrt{(0.1\%)^2 + (3\%)^2 + (1.7\%)^2}$

$= 3.5\%$

Measurement errors

TABLE 5-2 Impacts of Measurement Errors

Measurement Error (% of Reading)			Result Error (%)		
% Power (e.g., kW)	% Flow (e.g., gpm, L/s, lb/h)	% ΔT (e.g., °F, °C)	% Capacity (e.g., ton, kW, ton-h)	% COP (or kW/ton, kWh/ton-h)	
1	1	2	2.24	2.45	5% limit
1.5	2	2	2.83	3.20	
1.5	3	3	4.24	4.50	
1.5	3	4	5.00	5.22	
3	5	5	7.07	7.68	
3	7	7	9.90	10.34	
3	7	12	13.89	14.21	
3	10	10	14.14	14.46	
3	10	12	15.62	15.91	
3	10	15	18.03	18.28	
5	15	15	21.21	21.79	
5	10	20	22.36	22.91	
5	7	24	25.00	25.50	
5	10	25	26.93	27.39	
5	15	25	29.15	29.58	

Agenda

4. Calibration

Calibration

- It is highly recommended that instrumentation used in measuring the information required to evaluate chilled-water plant efficiency be calibrated with procedures developed by the National Institute of Standards and Technology (NIST).
- Primary standards and no less than third-order NIST traceable calibration equipment should be utilized wherever possible.
- Calibration by NIST is considered first order.
- An independent lab calibration against the NIST standard is second order,
- A user's calibration against the independent lab instrument (a transfer standard) is considered third order.

Calibration

- Manufacturers' calibration data should include documents of traceability to the calibration facility and, ultimately, traceability to national standards, typically NIST standards.
- Periodic calibration checks and recalibration may be required for measurement sensors. In addition, the entire measurement system must be maintained in proper calibration, including not only the sensing elements but also voltage and current measurement devices and analog to digital converters.

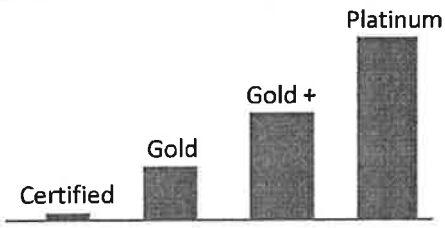
Agenda

5. GMv4 compared to Ashrae Guide 22

GMv4.0 compared to Ashrae guide 22

- Temperature sensor accuracy of +/- 0.05C is specified.
- Temperature sensor need to be in direct contact with the fluid ie wet thermal well.
- Only electromagnetic and Ultrasonic flow meter acceptable. Others types need validation of accuracy before acceptable.
- Additional 1% error to be added to the flow meter error to account for constraint of straight pipe within chiller plant room.
- A/D converter must have resolution of at least 16bit.
- Efficiency to be reported in 1 minute interval.
- Heat balance validation check is encouraged.

GMv4.0 M&V philosophy



Basic energy standards



Basic M&V standards

- No information drives no action 
- Inaccurate information drives wrong action 
- Accurate information drives right action 

(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX A—EXAMPLE INSTRUMENT SPECIFICATION TABLE

TABLE A-1 Example Instrument Specification Table

ID	Point Description	Measurement Range	Sensor Type or Calculation Method	Installation Location	Input Type*	Instrument Range	End-to-End Accuracy (% of reading unless noted)	Data Resolution	Refresh Interval (min)	Trend Interval (min)
Power Measurements										
5	Chiller 1 Power	30 to 288 kW	True root-mean-square (RMS), three-phase, integrated equipment, stand-alone analog output or networked power meter		AI	0 to 300 kW	±1.0%	0.1 kW	1	1
6	Chiller 2 Power	30 to 288 kW	True RMS, three-phase, integrated equipment, stand-alone analog output or networked power meter		AI	0 to 300 kW	±1.0%	0.1 kW	1	1
7	Primary Chilled-Water Pump 1 Power	12 to 15 kW	True RMS, three-phase, integrated equipment, stand-alone analog output or networked power meter		AI	0 to 25 kW	±1.0%	0.01 kW	1	1
8	Primary Chilled-Water Pump 2 Power	12 to 15kW	True RMS, three-phase, integrated equipment, stand-alone analog output or networked power meter		AI	0 to 25 kW	±1.0%	0.01 kW	1	1
9	Secondary Chilled-Water Pump 3 Power	2 to 10 kW	Variable-frequency-drive (VFD) bus output for kW		AI	0 to 25 kW	±3.0%	0.01 kW	1	1
10	Secondary Chilled-Water Pump 4 Power	2 to 10 kW	VFD bus output for kW		AI	0 to 25 kW	±3.0%	0.01 kW	1	1
11	Chiller 1 Chilled-Water Pump 5 Power	50 to 54 kW	True RMS, three-phase, integrated equipment, stand-alone analog output or networked power meter		AI	0 to 75 kW	±1.0%	0.01 kW	1	1
12	Chiller 2 Chilled-Water Pump 6 Power	50 to 54 kW	True RMS, three-phase, integrated equipment, stand-alone analog output or networked power meter		AI	0 to 75 kW	±1.0%	0.01 kW	1	1
24	Cooling Tower Fan 1 Power	5 to 22 kW	VFD bus output for kW		DI	0 to 25 kW	±3.0%	0.01 kW	1	1
25	Cooling Tower Fan 2 Power	5 to 22 kW	VFD bus output for kW		DI	0 to 25 kW	±3.0%	0.01 kW	1	1

*AI = analog input; DI = digital input; C = calculated value; #C4 = constant for converting chilled-water flow times ΔT to tons; #C5 = constant for converting condenser water flow times ΔT to tons.

TABLE A-1 Example Instrument Specification Table *(continued)*

ID	Point Description	Measurement Range	Sensor Type or Calculation Method	Installation Location	Input Type*	Instrument Range	End-to-End Accuracy (% of reading unless noted)	Data Resolution	Refresh Interval (min)	Trend Interval (min)
Flow Measurements										
26	Chilled-Water Flow	800 to 2400 gpm	Hot tapped insertion vortex shedding		AI	0 to 3000 gpm	±3.0% 1 to 15 ft/min	1 gpm	1	1
27	Condenser Water Flow	1000 to 3000 gpm	Hot tapped insertion vortex shedding		AI	0 to 4000 gpm	±3.0% 1 to 15 ft/min	1 gpm	1	1
Temperature Measurements										
32	Chilled-Water Supply Temperature	38 to 55°F	1000 ohm thermistor or resistance temperature detector (RTD)		AI	35 to 75°F	±0.2°F	±0.01°F	1	1
33	Chilled-Water Return Temperature	42 to 60°F	1000 ohm thermistor or resistance temperature detector (RTD)		AI	35 to 75°F	±0.2°F	±0.01°F	1	1
34	Condenser Entering Water Temperature	55 to 90°F	1000 ohm thermistor or resistance temperature detector (RTD)		AI	50 to 110°F	±0.2°F	±0.01°F	1	1
35	Condenser Leaving Water Temperature	55 to 100°F	1000 ohm thermistor or resistance temperature detector (RTD)		AI	50 to 110°F	±0.2°F	±0.01°F	1	1
42	Ambient Dry-Bulb Temperature	32 to 110°F	In weather station in fully shaded location or ventilated enclosure		AI	-20 to 140°F	±0.3°F	±0.01°F	1	5
43	Ambient Wet-Bulb Temperature	20 to 85°F	In weather station in fully shaded location or ventilated enclosure		AI	0 to 100°F	±0.3°F	±0.01°F	1	5
Calculated Values										
51	Chilled-Water Plant Thermal Cooling Output	50 to 1000 tons	(Difference of 2 measured values) [#33, #32] multiplied by measured valued [#26] multiplied by a constant #C4*		C	N/A	±3% tons	0.1 tons	1	5
54	Chilled-Water Plant Efficiency	0.3 to 0.8 kW/ton	(Sum of measured values) [#5, #6, #49a, #49b, #9, #10, #24, #25] divided by calculated value [#51]		C	N/A	±5% kW/tons	0.01 kW/ton	1	5
55	Chilled-Water Plant Heat of Rejection	0 to 1300 tons	(Difference of 2 measured values) [#35, #34] multiplied by measured valued [#27] multiplied by a constant #C5*		C	N/A	±3% tons	0.1 tons	1	5

*AI = analog input; DI = digital input; C = calculated value; #C4 = constant for converting chilled-water flow times ΔT to tons; #C5 = constant for converting condenser water flow times ΔT to tons.

TABLE 2 Example Descriptions and Data for Sensors, Meters, and Calculated Values

#	Point Name	Point Description and Location if Applicable	Input Type*	Sensor Type or Calculation Method	Required End-to-End Accuracy (Note 1)	Display Resolution	Refresh Interval (min)	Trend Interval (min)
5	Chlr1 kW	Chiller 1 Power	AI	True RMS, three-phase, integrated equipment, stand-alone analog output or networked power meter; use maximum resolution if pulse output	±1.5%	0.01 kW	1	1
6	Chlr2 kW	Chiller 2 Power	AI	True RMS, three-phase, integrated equipment, stand-alone analog output or networked power meter; use maximum resolution if pulse output	±1.5%	0.01 kW	1	1
9	SecChWP1 kW	Secondary Chilled-Water Pump 1 Power from VFD	AI	Reprogram existing VFD analog output for kW	±3.0%	0.01 kW	1	1
10	SecChWP2 kW	Secondary Chilled-Water Pump 2 Power from VFD	AI	Reprogramexisting VFD analog output for kW	±3.0%	0.01 kW	1	1
11	Chlr1CWP kW	Chiller 1 CW Pump Power	AI	True RMS, three-phase, integrated equipment, stand-alone analog output or networked power meter; use maximum resolution if pulse output	±1.5%	0.01 kW	1	1
12	Chlr2CWP kW	Chiller 2 CW Pump Power	AI	True RMS, three-phase, integrated equipment, stand-alone analog output or networked power meter; use maximum resolution if pulse output	±1.5%	0.01 kW	1	1
24	ClgTF1 kW	Cooling Tower Fan 1 Power	AI	Reprogram existing VFD analog output for kW	±3.0%	0.01 kW	1	1
25	ClgTF2 kW	Cooling Tower Fan 2 Power	AI	Reprogram existing VFD analog output for kW	± 3.0%	0.01 kW	1	1
26	Chlr1ChW Flow	Chiller 1 CHW Flow	AI	Hot tapped insertion vortex shedding	±2.0%	0.1 gpm	1	1
27	Chlr2ChW Flow	Chiller 2 CHW Flow	AI	Hot tapped insertion vortex shedding	±2.0%	0.1 gpm	1	1
32	Chlr1ChWS Temp	Chiller 1 CHWS Temperature	AI	1000 ohm thermistor or RTD	±0.1°F	±0.01°F	1	1
33	Chlr1ChWR Temp	Chiller 1 CHWR Temperature	AI	1000 ohm thermistor or RTD	±0.1°F	±0.01°F	1	1
34	Chlr1CWS Temp	Chiller 1 CWS Temperature	AI	1000 ohm thermistor or RTD	±0.1°F	±0.01°F	1	1
35	Chlr1CWR Temp	Chiller 1 CWR Temperature	AI	1000 ohm thermistor or RTD	±0.1°F	±0.01°F	1	1
36	Chlr2ChWS Temp	Chiller 2 CHWS Temperature	AI	1000 ohm thermistor or RTD	± 0.1°F	±0.01°F	1	1
37	Chlr2ChWR Temp	Chiller 2 CHWR Temperature	AI	1000 ohm thermistor or RTD	± 0.1°F	±0.01°F	1	1
38	Chlr2CWS Temp	Chiller 2 CWS Temperature	AI	1000 ohm thermistor or RTD	±0.1°F	±0.01°F	1	1
39	Chlr2CWR Temp	Chiller 2 CWR Temperature	AI	1000 ohm thermistor or RTD	±0.1°F	±0.01°F	1	1

* AI = analog input; C = calculated value

33

TABLE 2 Example Descriptions and Data for Sensors, Meters, and Calculated Values *(continued)*

#	Point Name	Point Description and Location if Applicable	Input Type*	Sensor Type or Calculation Method	Required End-to-End Accuracy (Note 1)	Display Resolution	Refresh Interval (min)	Trend Interval (min)
40	Chlr ChWInHdr Temp	Chiller CHW Inlet Header Temperature	AI	1000 ohm thermistor or RTD	±0.1°F	±0.01°F	1	1
41	Chlr CWInHdr Temp	Chiller CW Header Temperature	AI	1000 ohm thermistor or RTD	±0.1°F	±0.01°F	1	1
42	OA Temp	Ambient Dry-Bulb Temperature	AI	In weather station in fully shaded location or ventilated enclosure	±0.2°F	±0.01°F	1	10
43	OAWb Temp	Ambient Wet-Bulb Temperature	AI	In weather station in fully shaded location or ventilated enclosure	±0.2°F	±0.01°F	1	10
49	Chlr # ChWP kW	Chiller # Chilled-Water Pump Amps converted to kW	C	Measured value [#7; #8] multiplied by a constant #C2	N/A	0.1 kW	1	10
50	Chlr # CWP kW	Chiller # Chilled-Water Pump Amps converted to kW	C	Measured value [#11; #12] multiplied by a constant #C3	N/A	0.1 kW	1	10
51	Chlr # tons	Chiller # Thermal Cooling Output	C	(Difference of 2 measured values) [#34, #33; #37, #36] multiplied by measured valued [#26; #27] multiplied by a constant #C4	N/A	0.1 tons	1	10
52	Chlr # kW/ton	Chiller # Efficiency	C	Measured value [#5; #6] divided by measured value [#51a; #51b]	N/A	0.01 kW/ton	1	10
53	ChW Plant tons	Chilled-Water Plant Thermal Cooling Output	C	Sum of measured values [#51a, #51b]	N/A	0.1 tons	1	10
54	ChW Plant kW/ton	Chilled-Water Plant Efficiency	C	(Sum of measured values) [#5, #6, #40a, #40b, #9, #10, #50a, #51b, #24, #25] divided by calculated value [#53]	N/A	0.01 kW/ton	1	10
55	Avg ChW Plant tons	Average Chilled-Water Plant Thermal Cooling Output	C	30 minute running average of calculated value [#53]	N/A	0.1 tons	1	10
56	Max ChW Plant tons	Maximum Averaged Chilled-Water Plant Thermal Cooling Output	C	Maximum 30 minute running average of a calculated value [#55]	N/A	0.1 tons	1	10
57	Daily ChW Plant Tons-hrs	Daily Chilled-Water Plant Thermal Cooling Energy	C	Calculated value [#53] integrated over 24 h period	N/A	0.1 ton-hrs	1	10
58	Max Daily ChW Plant Tons-hrs	Maximum Daily Chilled-Water Plant Thermal Cooling Energy	C	Maximum 24 h total of a calculated value [#57]	N/A	0.1 ton-hrs	1	10
72	Avg ChW Plant Eff	Average Chilled-Water Plant Efficiency	C	30 minute running average of calculated value [#54]	N/A	0.01 kW/ton	1	10

34

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Save Chiller Plant Energy With Guideline 22-2008

Guideline for Instrumentation for Monitoring Central Chilled-Water Plant Efficiency

By James B. (Bart) Rishel, P.E., Fellow/Life Member ASHRAE

ASHRAE Guideline 22-2008, *Instrumentation for Monitoring Central Chilled-Water Plant Efficiency*, is the result of years of work to come up with a meaningful procedure for determining the overall energy rate for the total electric motor-driven, chilled water plant. The overall efficiency of central chiller plants is important, as they consume many megawatts; it is estimated that their energy use is around 30% of the entire HVAC industry.

This guideline was developed for conducting a test on a specific chiller plant to determine its coefficient of performance (COP). The data collected included energy values that would be needed for such a test. This article's goal is to assist designers and operators in using this guideline in the continuous measurement and recording of the energy rate of an operating chilled water plant. It is limited to electric motor-driven plants (as is the guideline), but includes chiller plants with heat recovery chillers and water-side economizers.

Measured kW/ton can be trended against plant load in tons of cooling, outdoor temperatures and condenser water temperature. The resultant information can be a useful tool in maintenance programming; an increase in kW/ton may signal a need for maintenance or an imminent equipment failure. For example, an increase in kW/ton may indicate dirty condenser tubes in the chillers, a partially clogged strainer for tower pumps, or a leaking coil valve as the ΔT for the chilled water drops below design.

Harvard University was an early proponent of using kW/ton as a means of measuring the improvements of chiller plant efficiency. For years, they displayed it in large numerals on the wall of one of its chiller plants. It proved to be an effective tool in the operation and maintenance of that plant. Today, they show it prominently on their chiller plant computer screens as shown in *Figure 1*.

Most of the central chiller plants in the United States use I-P instrumentation and measure the energy rate in kW/ton. Since this is a practical document rather than a theoretical one, COP and SI procedures will not be covered. Likewise, uncertainty of measurement will not be addressed. Anyone who wishes to determine this can use the guideline for assistance in making this evaluation. The instrument error expressed in this article should result in an uncertainty of around 2.2%. This is derived from Table 5-2 of the guideline.

Derivation of the Basic kW/ton Equation

The basic kW/ton equation is derived in Paragraph B1.3 of the guideline. It is Equation B-3 in the guideline; it is repeated here with a different designation for flow as *Equation 1*.

$$kW = \frac{\Sigma\, kW \times 24}{Q \times (T_2 - T)} \quad (1)$$

About the Author

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Thank You

for your attention

Q&A

Fundamental Principles of Temperature Measurements and Its Traceability

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Introduction

- Temperature is defined by thermodynamics which is the science of heat
- Thermodynamic scale is difficult and inconvenient to use
- Poor repeatability

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Introduction

- **Empirical temperature scale is sufficiently reproducible for use in industry, science and trade**
- **International Temperature Scale (ITS-90)**

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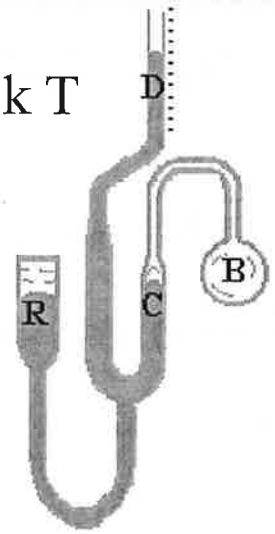
Constant Volume Gas Thermometer (Pimary Std)

- P is the pressure of the gas
- V is the volume of the gas
- N is the number of molecules of the gas
- k is the Boltzmann's constant, 1.3807×10^{-23} J/K,
- T is the thermodynamic temperature

$$P V = N k T$$



Constant volume gas thermometer

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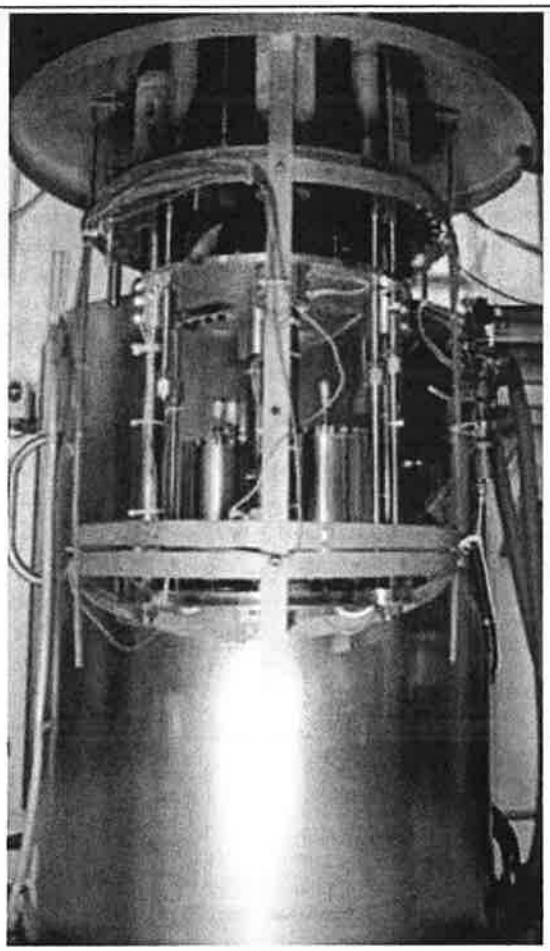

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International Temperature Scale

- **ITS is revised periodically**
  - **As closed as possible to the thermodynamic scale**
  - **The recent revision was in 1990 and is known as ITS-90**

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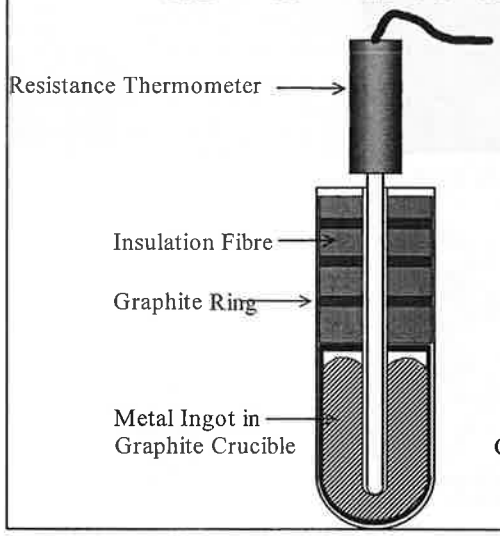
NMC A*STAR

ITS-90

- **Seventeen temperature fixed points are used to define the ITS-90**



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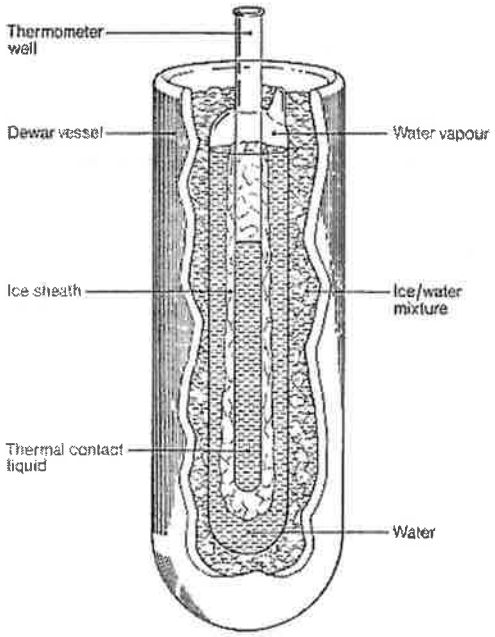
ITS - 90			
No	Temperature	Substance	State
1	3 to 5 K	He	V
2	13.8033K	H_2	T
3	17K	H_2 or He	V or G
4	20.3K	H_2 or He	V or G
5	24.5561K	Ne	T
6	54.3584K	O_2	T
7	83.8058K	Ar	T
8	234.3156K	Hg	T
9	0.01 °C	H_2O	T
10	29.7646 °C	Ga	M
11	156.5985 °C	In	F
12	231.928 °C	Sn	F
13	419.527 °C	Zn	F
14	660.323 °C	Al	F
15	961.78 °C	Ag	F
16	1064.18 °C	Au	F
17	1084.62 °C	Cu	F

V : vapor pressure point

T : triple point (temperature at which the solid, liquid and vapor phases are in equilibrium)

G : gas thermometer point

Water Triple Point (0.01 °C)



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Galium Point (29.7646 °C)







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Ice Point

- Historically this was a defining point for temperature scales
- The ice point is still an important point as it is an easily made reference point.

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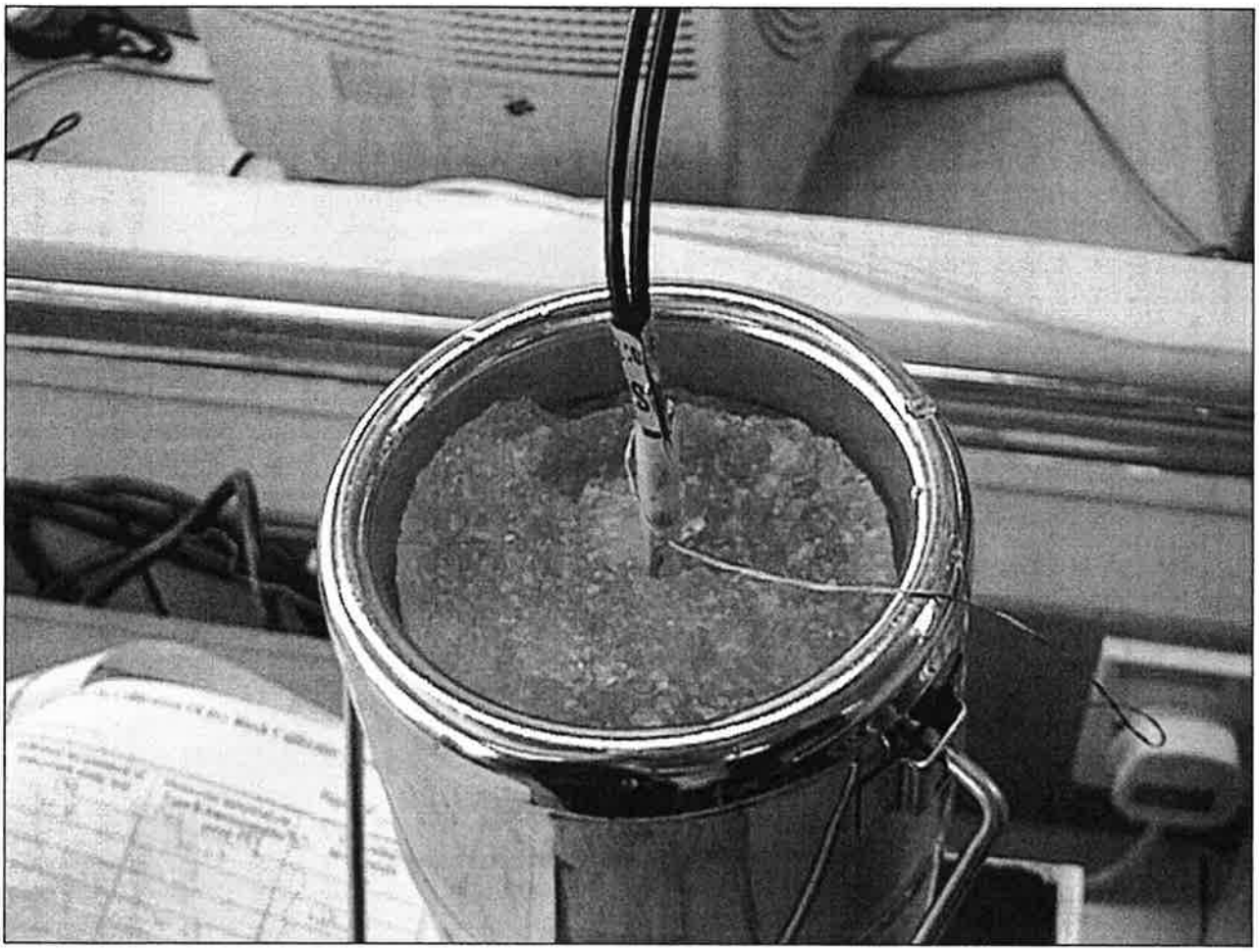

Incorrect Ice Point Check

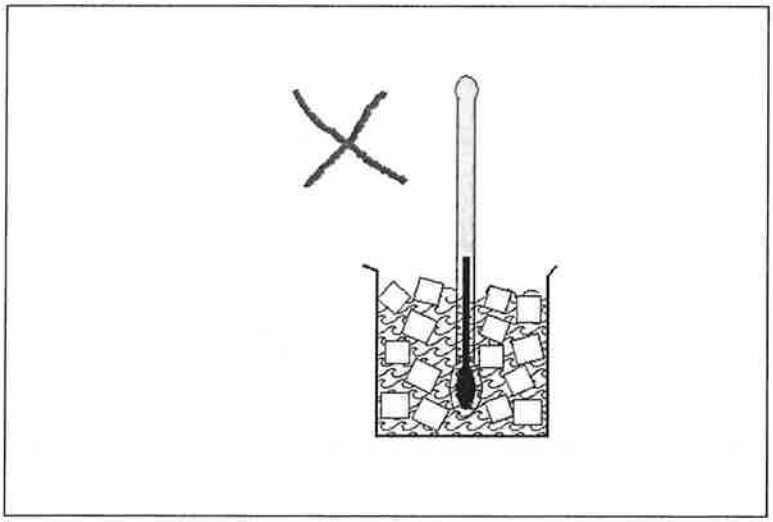

Figure 8 Using ice cubes

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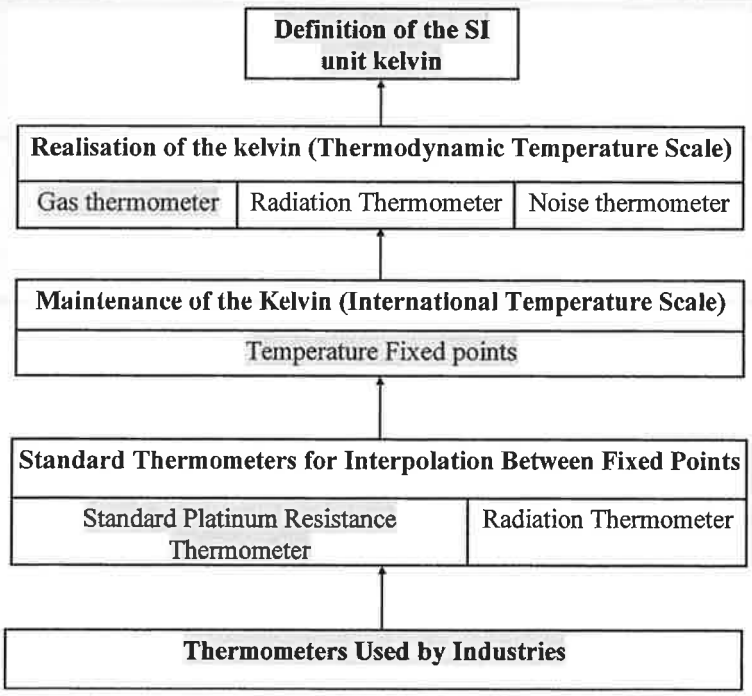
International Traceability of Temperature Measurements



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End of presentation

Thank you

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What is Measurement Uncertainty?

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I. Introduction

What is measurement uncertainty (MU)?

- Uncertainty means "doubt"



- Doubt exists about the result of any measurement

- **Accuracy of the measuring instrument**
- **Repeatability of the measurement**
- **Stability of the measurand**

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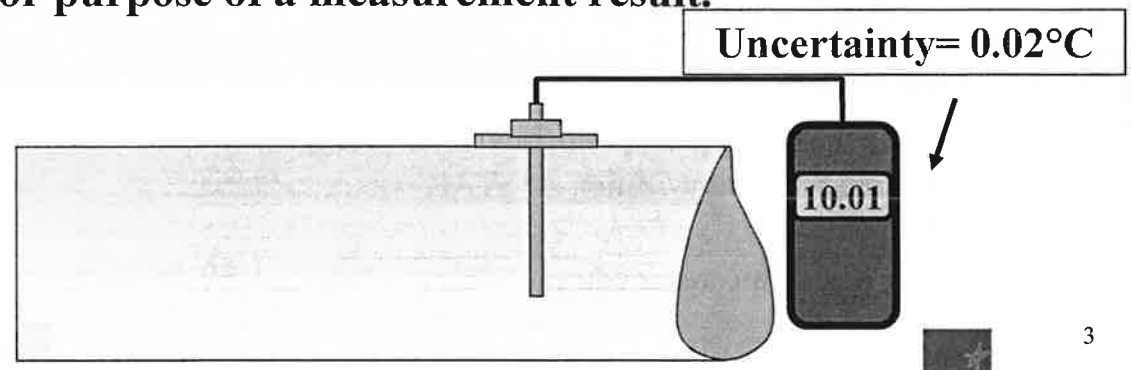
Introduction

- **Measurement Uncertainty (MU) is a quantitative indication of the quality and reliability of the measurement result.**

  10.01°C ± 0.02°C

- **Ultimately, it plays a key role in judging the fitness for purpose of a measurement result.**



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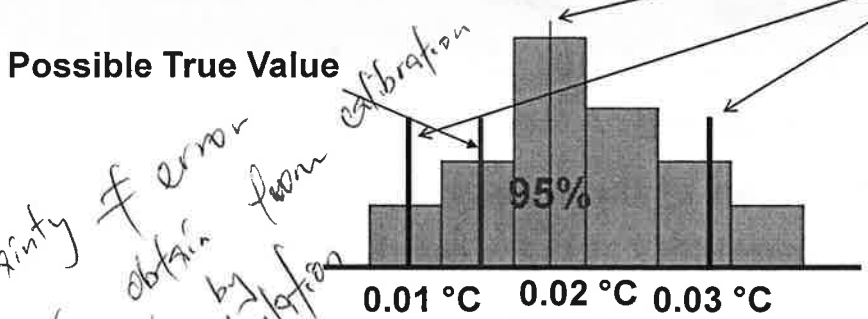
Introduction

Expressing MU

- **Width of the margin of doubt (or interval)**
- **How sure the 'true value' lies within the stated margin**
- **Confidence level = percentage of data that lies within the margin**

Eg : The calibration result of a thermometer shows an error of 0.02 °C ± 0.01 °C at approximately 95% confidence level.



Uncertainty of error obtain from calibration
error uncertainty by calculation

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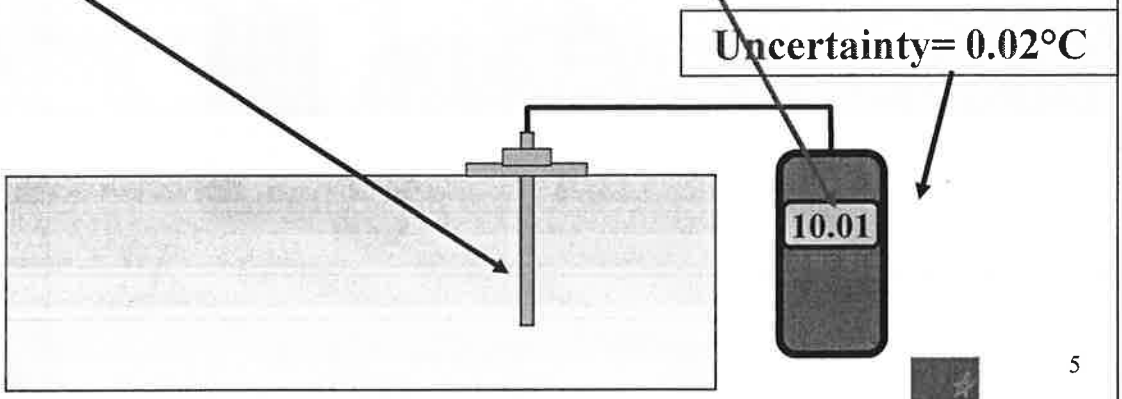
Introduction

The result of measurement (y) is only an approximation or best estimate of the value of the quantity that is subject to measurement (Y).



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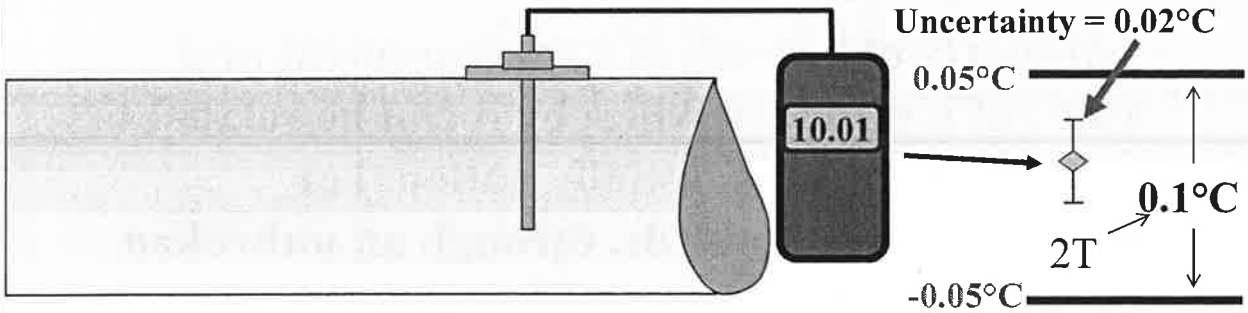
Why MU is Important ?

The ratio U:T is a measure of the ability of the test method in distinguishing compliance from non-compliance.

U = Uncertainty of measurement

2T = Upper specified limit minus lower specified limit



Generally, without MU, end-user is not able to quantify the risk in stating a compliance or non-compliance statement.

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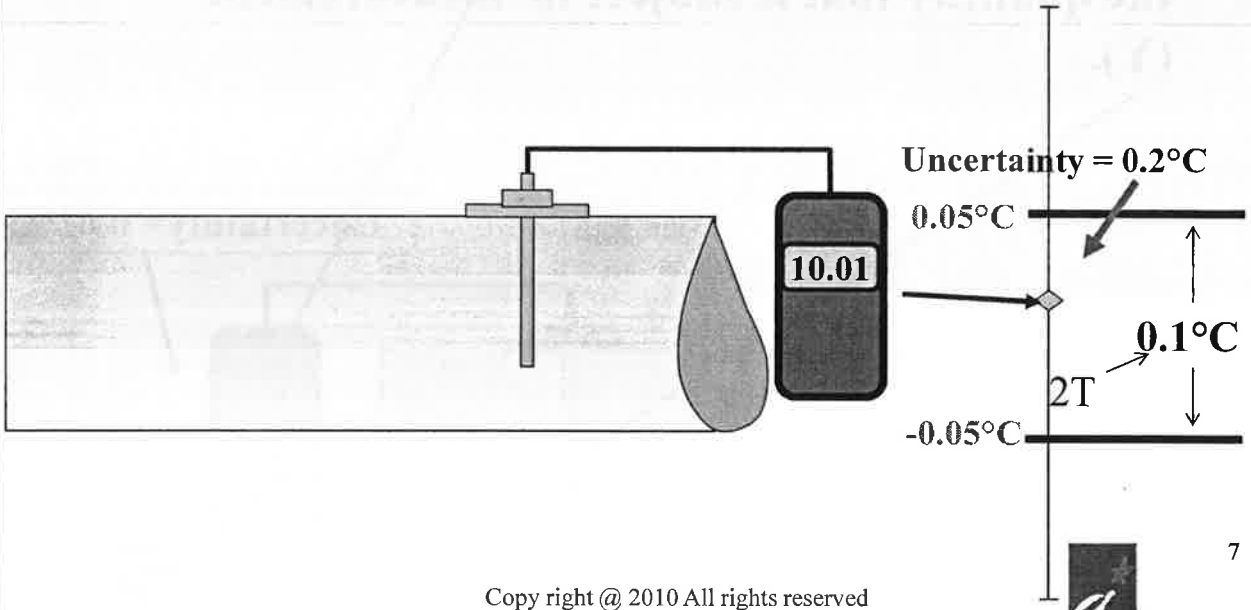
Why MU is Important ?



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measured value + uncertainty < limit ✓

Why MU is Important ?

MU is part of the requirements in fulfilling traceability in the result of a measurement.

Traceability (VIM) -

- property of a result of a measurement or a value of a standard whereby it can be related to a stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainty.

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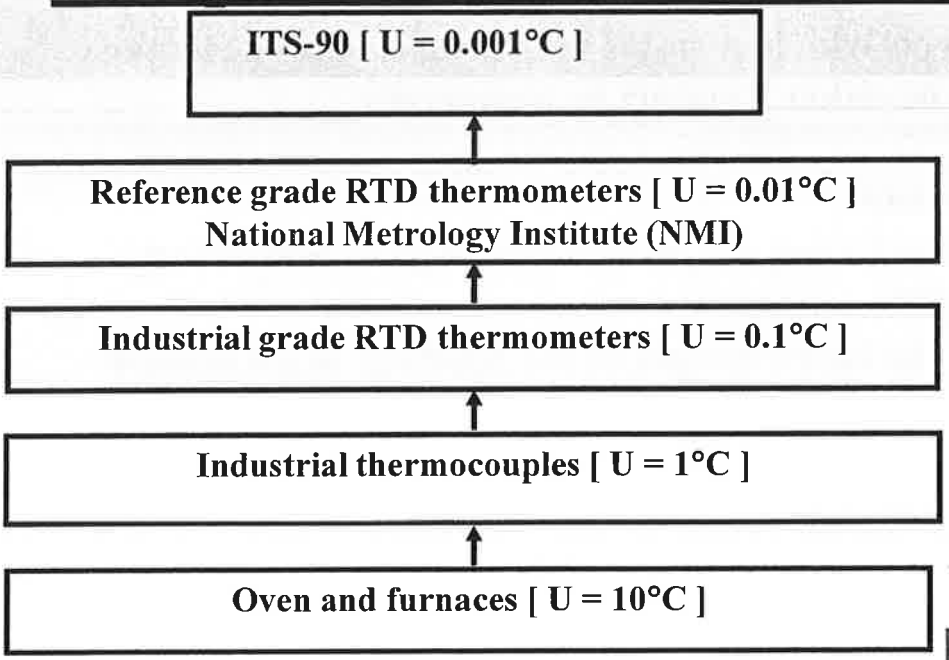
www. bipm. org

Example : Traceability of Temperature Measurements



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Why MU is Important ?

Uncertainty Analysis

- **Leads to better understanding of the uncertainty contribution of various input quantities**
- **Identify major uncertainty components so as to provide direction for improvement**

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Nature of Measurement and Uncertainty

The effects which give rise to measurement uncertainty can be either Random or Systematic

- **Random**
  - **Repeating the measurement gives a randomly different result**
  - **The best estimate of the readings is the sample mean**
  - **Dispersion of the readings is usually quantified by standard deviation**
    - **precision of the measurement data**

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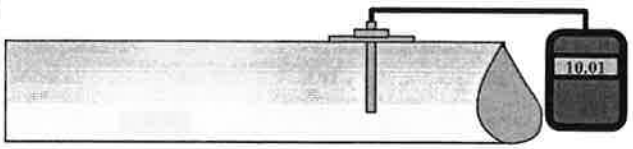
Random Variation

Time	Reading (°C)
10:00:00	10.01
10:00:30	10.02
10:01:00	10.03
10:01:30	10.02
10:02:00	10.01
10:02:30	10.00
10:03:00	10.01



Average = 10.01

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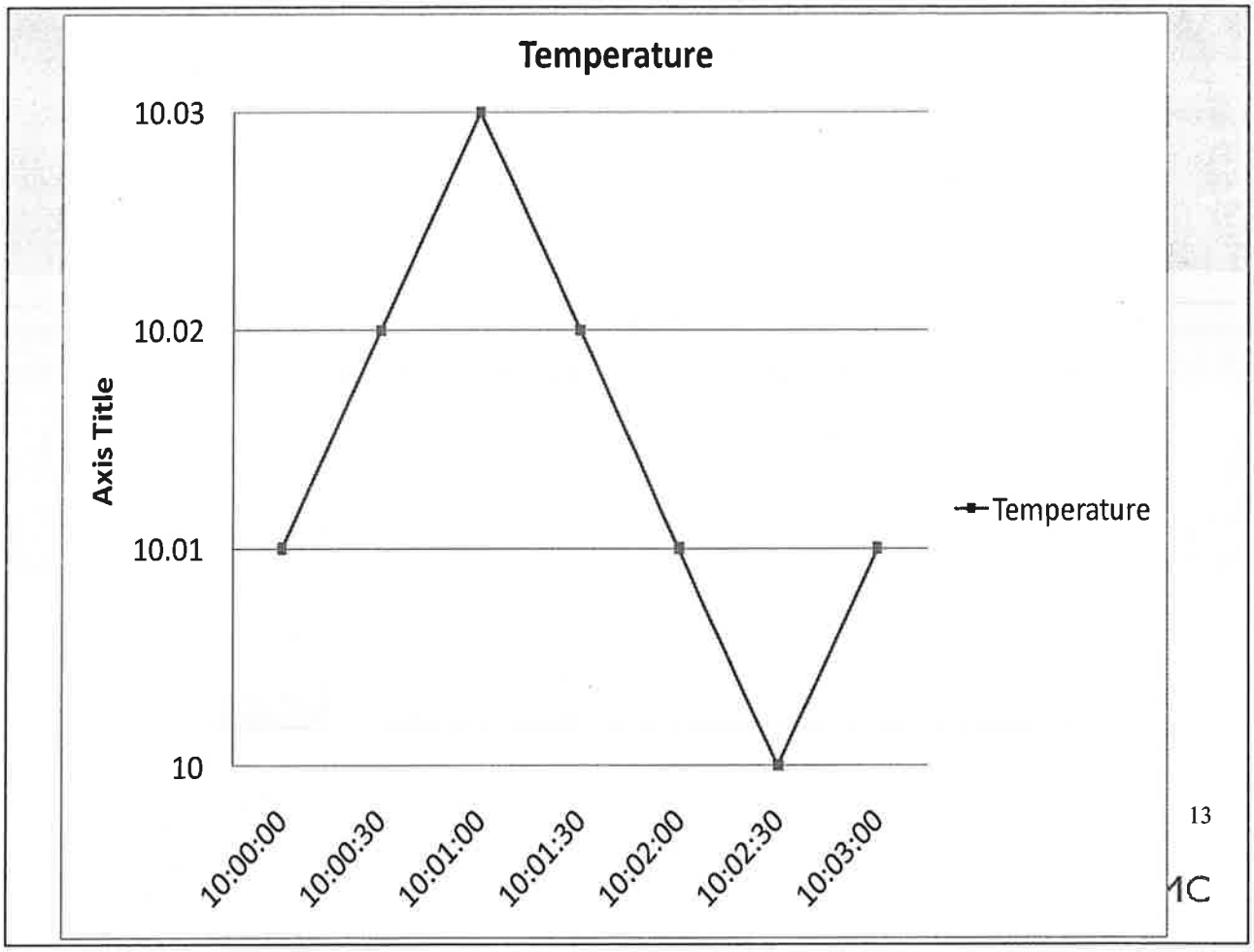

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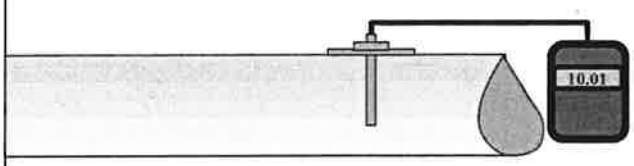
1C

Nature of Measurement and Uncertainty

- **Systematic**
  - **The same influence affects the result for each of the repeated measurements**
  - **It's presence may be unknown to you**



- The thermometer has an error of - 0.02 °C (from the calibration report)

14

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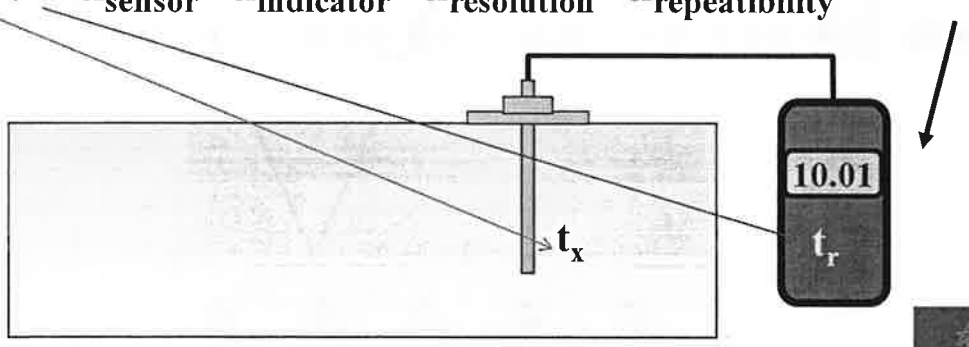
Step 1 Modeling the Measurement

A mathematical model $Y = f(X_1 , X_2 , X_3 , X_4 , \ldots, X_N)$

-lists down all the input quantities, including all correction terms, and their relationships with respect to the measurand (Y).

Uncertainty= 0.02°C

- **$t_x = t_r + u_{sensor} + u_{indicator} + u_{resolution} + u_{repeatibility}$**



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Step 2 Evaluating Standard Uncertainty

- **Each input estimate x_i has an associated uncertainty component.**
- **Most pessimistic total uncertainty**
  - **Direct sum:**

    $u_{sensor} + u_{indicator} + u_{resolution} + u_{repeatibility}$
- **Quite large!**

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SAC SINGAS

Step 2 Evaluating Standard Uncertainty

- **GUM requires all the uncertainty component be expressed as one standard deviation.**

- **In GUM terminology one standard deviation is termed as one standard uncertainty u(x).**

- $u_{sensor} + u_{indicator} + u_{resolution} + u_{repeatibility}$

Type A

Type B

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Step 2 Evaluating Standard Uncertainty

- $\frac{u_{sensor}}{2}$ **(from calibration report)**

- $\frac{u_{indicator}}{\sqrt{3}}$ **(from spec)**



- $\frac{u_{resolution}}{2\sqrt{3}}$ **(due to A/D converter)**

- $\frac{u_{repeatibility}}{1}$ = Standard deviation of the mean of 10 readings $= \frac{\text{Standard Deviation}}{\sqrt{10}}$

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Step 3 Determining the Combined Standard Uncertainty

The standard deviation of the measurand Y is estimated by the combined standard uncertainty

($u_c(y)$), which is given by the Uncertainty Equation.

Uncertainty Equation :

$$u_c(y) = \sqrt{\sum_{i=1}^{N}\left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i) + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j}u(x_i)u(x_j)r(x_i,x_j)}$$

Variance of X_i 's

Estimated correlation coefficient between input quantities X_i and X_j.

$$\frac{\partial f}{\partial x_i} = sensitivity\ coefficient$$

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Step 3 Determining the Combined Standard Uncertainty

Mathematical Model :

•$tx = tr + u_{sensor} + u_{indicator} + u_{resolution} + u_{repeatibility}$

Uncertainty Equation :

(Assuming no correlations among the input quantities.)

$$u_c(y) = \sqrt{\left[\frac{u_{sensor}}{2}\right]^2 + \left[\frac{u_{indicator}}{\sqrt{3}}\right]^2 + \left[\frac{u_{resolution}}{2\sqrt{3}}\right]^2 + \left[u_{repeatabilty}\right]^2}$$

The sensitive coefficients are not always equal to 1 and depend on the input estimate values.

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Step 4 Determining the Expanded Uncertainty

$$U = k \times u_c(y)$$

- Required by some commercial, industrial and regulatory applications
- Selection of a value of k (known as coverage factor)
  - Calculate the effective degrees of freedom

$$v_{eff} = \frac{u_c^4(y)}{\sum_{i=1}^{n} \frac{u_i^4(y)}{v_i}} = \frac{u_c^4}{\frac{[\frac{u_{sensor}}{2}]^4}{\infty} + \frac{[\frac{u_{indicator}}{\sqrt{3}}]^4}{\infty} + \frac{[\frac{u_{resolution}}{2\sqrt{3}}]^4}{\infty} + \frac{[\frac{u_{repeatability}}{1}]^4}{9}}$$

  - Use Students' t distribution table

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STUDENTS' T-DISTRIBUTION

Value of $t_p(\nu)$ from the t-distrubution for degrees of freedom ν that defines an interval $-t_p(\nu)$ to $+t_p(\nu)$ that encompasses the fraction p of the distribution

Degrees of freedom	Fraction p in percent					
ν	68.27[a]	90.00	95.00	95.45[a]	99.00	99.73[a]
1	1.84	6.31	12.71	13.97	63.66	235.80
2	1.32	2.92	4.30	4.53	9.92	19.21
3	1.20	2.35	3.18	3.31	5.84	9.22
4	1.14	2.13	2.78	2.87	4.60	6.62
5	1.11	2.02	2.57	2.65	4.03	5.51
6	1.09	1.94	2.45	2.52	3.71	4.90
7	1.08	1.89	2.36	2.43	3.50	4.53
8	1.07	1.86	2.31	2.37	3.36	4.28
9	1.06	1.83	2.26	2.32	3.25	4.09
10	1.05	1.81	2.23	2.28	3.17	3.96
11	1.05	1.80	2.20	2.25	3.11	3.85
12	1.04	1.78	2.18	2.23	3.05	3.76
13	1.04	1.77	2.16	2.21	3.01	3.69
14	1.04	1.76	2.14	2.20	2.98	3.64
15	1.03	1.75	2.13	2.18	2.95	3.59
16	1.03	1.75	2.12	2.17	2.92	3.54
17	1.03	1.74	2.11	2.16	2.90	3.51
18	1.03	1.73	2.10	2.15	2.88	3.48
19	1.03	1.73	2.09	2.14	2.86	3.45
20	1.03	1.72	2.09	2.13	2.85	3.42
25	1.02	1.71	2.06	2.11	2.79	3.33
30	1.02	1.70	2.04	2.09	2.75	3.27
35	1.01	1.70	2.03	2.07	2.72	3.23
40	1.01	1.68	2.02	2.06	2.70	3.20
45	1.01	1.68	2.01	2.06	2.69	3.18
50	1.01	1.68	2.01	2.05	2.68	3.16
100	1.005	1.660	1.984	2.025	2.626	3.077
∞	1.000	1.645	1.960	2.000	2.576	3.000

[a] For a quantity Z described by a normal distribution with expectation μ, and standard deviation σ the interval $\mu_z \pm k\sigma$ encompasses p = 68.27, 95.45, and 99.73 percent of the distribution for 1 and 3, respectively.

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Step 5 Reporting Uncertainty

GUM requires the following information to be reported :

- **full description on how the measurand Y is defined,**
- **result of the measurement as $Y = y \pm U$ and give the units of y and U,**
- **level of confidence (p) used in defining the interval of the expanded uncertainty,**
- **coverage factor k (or the effective degrees of freedom) used in defining the interval of the expanded uncertainty.**

Example : The temperature measured is 10.01 °C, according to the procedure described.

The expanded uncertainty of the temperature measurement is

0.02 °C, estimated at a level of confidence of approximately 95% with a coverage factor k = 2.

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Temperature Sensors Used in Chiller Plant

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Introduction

- **The sensors used in chiller plants are usually called Resistance Temperature Detector (RTD)**
  - **Platinum Resistance Thermometer (PRT)**
  - **Thermister**

T not RTD (not wired)

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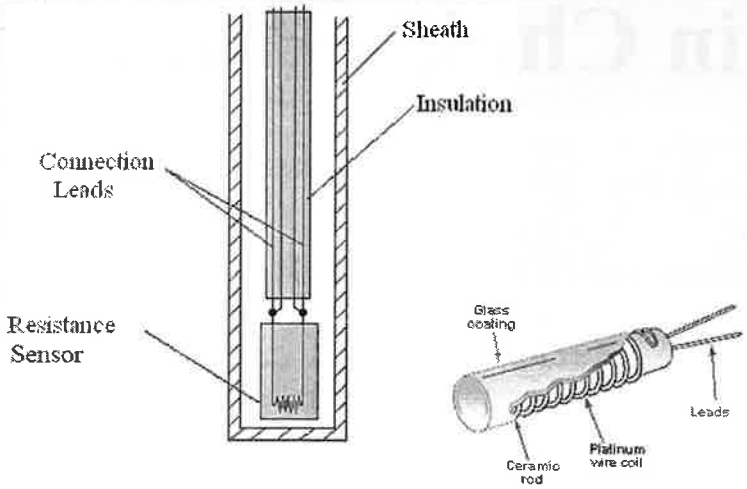
Platinum Resistance Thermometer (PRT)



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Platinum Resistance Thermometer (PRT)

- Pt 100: resistance = 100 Ω at 0 °C
- Resistance increase with increase in temperature
- PRT available with resistance from 25.5 Ω at 0 °C up to 10,000 Ω at 0 °C

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Resistance Measurement

- More difficult to achieve high accuracy for the resistance measuring circuit at low resistance
- 2-wire
- 3-wire
- 4-wire

high amps
→ Measurement current 1 mA for Pt 100
10 μA for thermistor
100 kΩ
data logger
not 10 kΩ → 10 mA

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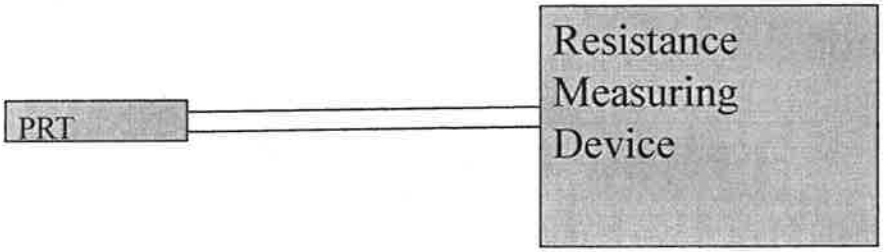
Resistance Measurement

- 2-wire
  - A small lead impedance can contribute a significant error to temperature measurement

(include resistance of wire)



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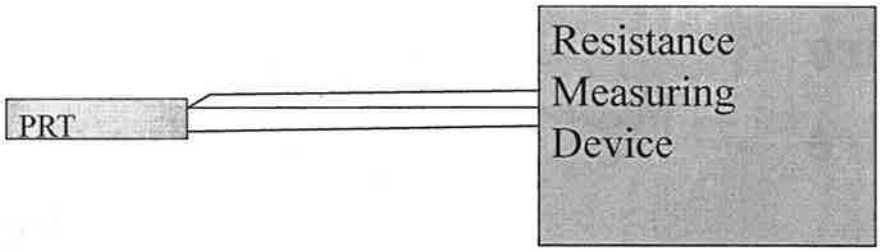
Resistance Measurement

- **3-wire**
  - **Error can be minimized by using a *three-wire bridge* configuration**



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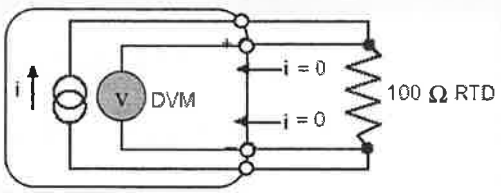
Wire resistance eliminated completely.

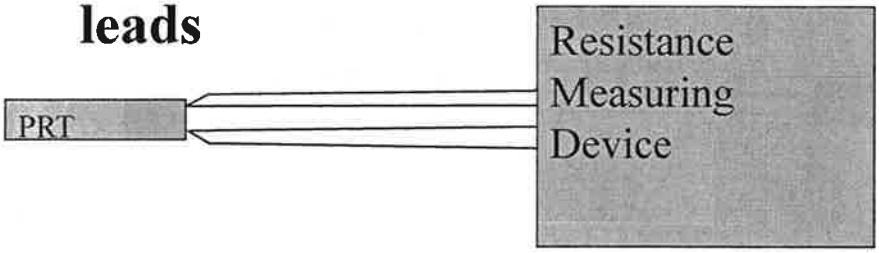
Resistance Measurement

- **4-wire**
  - **Most accurate**
  - **No current flows thruough the voltage leads**



4-WIRE OHMS MEASUREMENT

Figure 42



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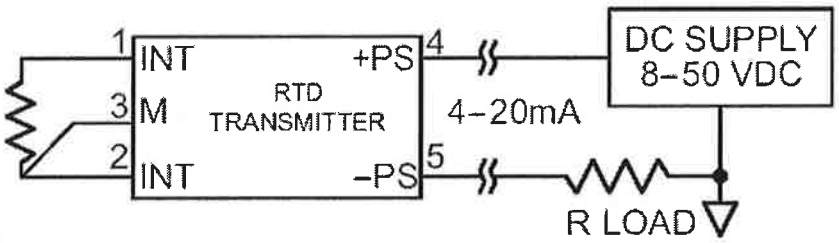
Transmitter

- **Lead error can be minimized through the use of a temperature transmitter mounted close to the RTD**



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Some Important Parameters to Consider When Selecting an RTD Temperature Transmitter

- **Transmitter input**
  - **Platinum, Nickel, Copper, Silver, Gold**
- **Features**
- **Sensor connections**
  - **2-wire, 3-wire, 4-wire**
- **User interfaces**
- **Environment**

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ABB PT100

Specifications of Transmitter

Table 1. Range Limits, Maximum Span, and Accuracy

Input Type	Model Code	See Note	Range Limits		Maximum Span		Digital Accuracy(a,k)	
			°C	°F	°C	°F	°C	°F
RTD (2, 3, or 4 wire)								
Pt100 DIN/IEC	Q	b	-200 and +850	-328 and +1562	1050	1890	±0.05	±0.09
Pt100 DIN/IEC	A	c	-200 and +850	-328 and +1562	1050	1890	±0.05	±0.09
Pt100 SAMA	P	d	-200 and +650	-328 and +1202	850	1530	±0.05	±0.09
Ni 200	D	e	-130 and +315	-202 and + 599	445	801	±0.44	±0.79
Ni 120, Minco	G		-80 and +320	-112 and + 608	400	720	±0.03	±0.05
Ni 100	I	f	-60 and +250	-76 and +482	310	558	±0.04	±0.07
Cu 10	F	g	-70 and +150	-94 and +302	220	396	±0.51	±0.92

Long-Term Stability
<0.05% of input reading per year
Ambient Temperature Effect
Error is less than 1/2 the reference accuracy plus 0.1°C per 28°C
Relative Humidity Effect (Noncondensing)
<0.01 mV; <0.05 Ω; from 0 to 95% RH



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PRT Output Equation

- **0 °C to 650°C**
- **$R(t) = R(0)[1 + At + Bt^2]$ (ASTM Specification E1137)**

Where:

t = temperature (to ITS-90), °C,
R(t) = resistance at temperature t,
R(0) = resistance at 0°C
$A = 3.9083 * 10^{-3}$
$B = -5.775 * 10^{-7}$

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RTD Classifications And Tolerance Limits per ASTM E1137

Temperature Degrees C	Grade A Limits		Grade B Limits	
	°C	Ohms	°C	Ohms
-200	0.47	0.20	1.1	0.47
0	0.13	0.05	0.25	0.10
100	0.30	0.11	0.67	0.25
400	0.81	0.28	1.9	0.66
650	1.24	0.40	3.0	0.94

Grade A Tolerance = ±[0.13 +0.0017 *|t|] °C
Grade B tolerance =±[0.25 +0.0042 *|t|] °C

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Send for Calibration

The DIN Standard

DIN Class A tolerance: ±[0.15 + 0.002*|t|] °C

DIN Class B tolerance: ±[0.30 + 0.005*|t|] °C

DIN Class C tolerance: ±[1.20 + 0.005*|t|] °C

1/10 DIN is 1/10 of Class B

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Callendar-van Dusen equation

- An additional correction term is required for temperature below 0°C:

$$R(t) = R(0°C)(1 + At + Bt^2 + C(t - 100)t^3)$$

- C is zero above 0°C

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Typical accuracy of PRT

0.02°C

- Between 2 and 20 mK, with a variable sensitivity to vibration and shock
- There is often a small amount of hysteresis and drift caused by the different thermal expansion of the wire and ceramic substrate

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Thermister



- **Semiconductor material**
  - **Exhibits a large change in resistance proportional to a small change in temperature**
  - **Usually has negative temperature coefficient**
  - **Response curve is exponential**

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Steinhart-Hart equation

$$\frac{1}{T} = A + B\ln(R) + C(\ln(R))^3$$

where:

- ***T*** **is the temperature (in kelvins)**
  - **t °C = T K - 273.15**
- ***R*** **is the resistance at** ***T*** **(in ohms)**
- ***A***, ***B***, **and** ***C*** **are the Steinhart-Hart coefficients which vary depending on the type and model of thermistor and the temperature range of interest.**

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Steinhart-Hart equation

- **The error in the Steinhart-Hart equation is generally less than 0.02 °C**

↑ for wide temperature ranges.

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Thermister Specifications

	Ordering Part Numbers Standard	Teflon	Zero Power Resistance Ω at 25°C	Beta 0-50°C (K)	Ratio Ω 25/125°C	Maximum Working Temperature	Best Storage & Working Temperature	Mix
±0.2°C Interchangeability Tolerance 0 to 70°C	44001A	44101A	100	2854	11.49	100°C	-80-+50°C	L
	44002A	44102A	300	3118	15.15	100°C	-80-+50°C	L
	44003A	44103A	1000	3271	17.33	100°C	-80-+50°C	L
	44004	44104	2252	3891	29.26	150°C	-80-+120°C	B
	44005	44105	3000	3891	29.26	150°C	-80-+120°C	B
	44007	44107	5000	3891	29.26	150°C	-80-+120°C	B
	44017	44117	6000	3891	29.26	150°C	-80-+120°C	B
	44016	44116	10K	3891	29.26	150°C	-80-+120°C	B
	44006	44106	10K	3574	23.51	150°C	-80-+120°C	H
	44008	44108	30K	3810	29.15	150°C	-80-+120°C	H
	44011	44111	100K	3988	34.82	150°C	-80-+120°C	H
	44014	44114	300K	4276	46.02	150°C	-80-+120°C	H
	44015	44115	1 meg	4582	61.96	150°C	-80-+120°C	H
±0.1°C Interchangeability Tolerance 0 to 70°	44035	-	1000	3271	17.33	100°C	-80-+50°C	L
	44033	-	2252	3891	29.26	150°C	-80-+75°C	B
	44030	-	3000	3891	29.26	150°C	-80-+75°C	B
	44034	-	5000	3891	29.26	150°C	-80-+75°C	B
	44037	-	6K	3891	29.26	150°C	-80-+75°C	B
	44036	-	10K	3891	29.26	150°C	-80-+75°C	B
	44031	-	10K	3574	23.51	150°C	-80-+75°C	H
	44032	-	30K	3810	29.15	150°C	-80-+75°C	H

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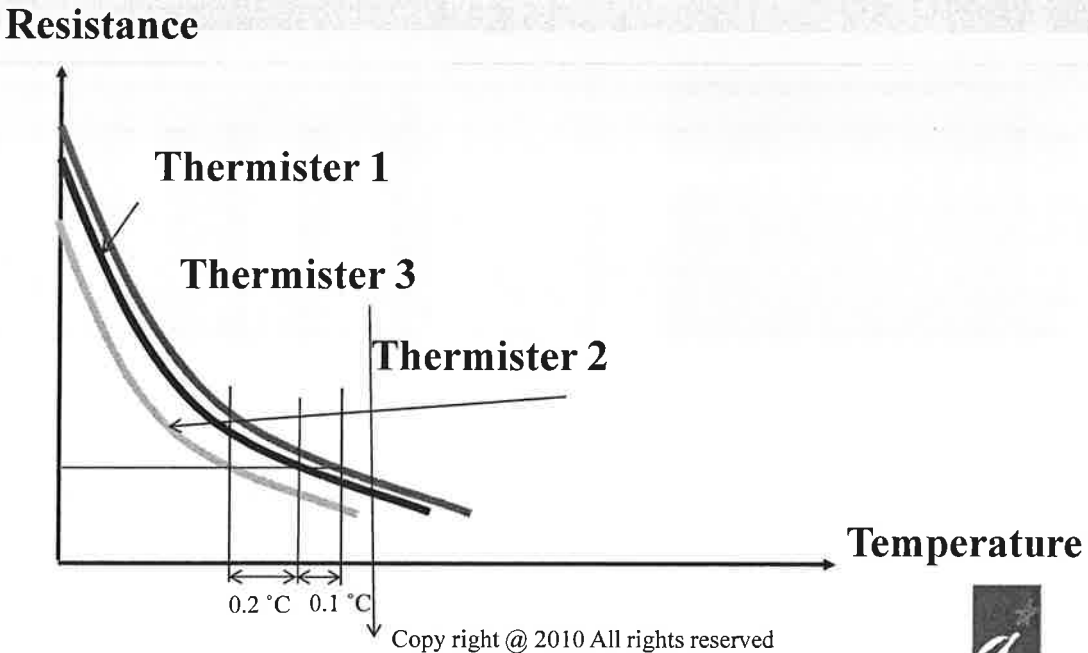
Interchangeability



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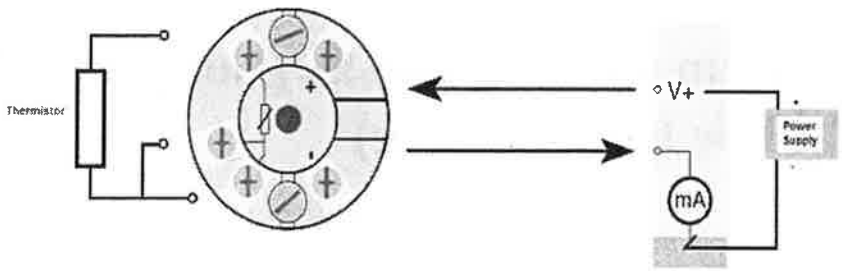
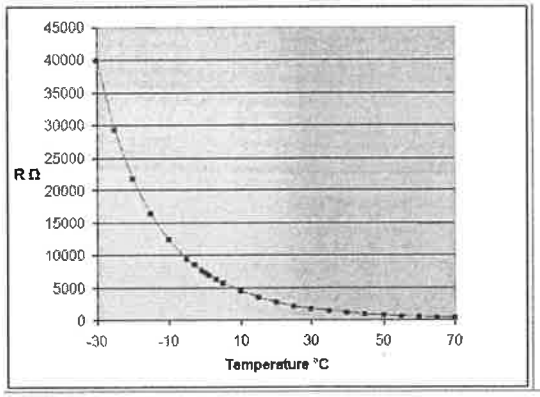
Thermister Transmitter Spec

Thermistor Transmitter for 400 series Probes
PR-5343-2252BW Designed 400 Series Probes and Thermistors.
Provides Linearization for 2252 ohm 400 Series Thermistors and Probes
4 - 20 mA linear output (-30° to +70°C)
Output Linear with Temperature
Custom Curves Available
Head or DIN Rail Mounted (with optional adapter)





Calibration Results



R[Ω]	Indicated T °C	Actual T °C	Error °C	mA
394.6	70.00	70.00	0.00	20.00
789.155	50.75	50.73	-0.02	16.92
1183.81	40.32	40.33	0.01	15.25
1578.47	33.35	33.30	-0.05	14.14
1973.12	28.08	28.04	-0.04	13.29
2367.78	23.88	23.86	-0.02	12.62
4341.06	10.71	10.67	-0.04	10.51
6706.98	1.81	1.81	0.00	9.09
7103.63	0.69	0.68	-0.01	8.90
7498.29	-0.37	-0.38	-0.01	8.74
7892.95	-1.36	-1.38	-0.02	8.58
8287.6	-2.31	-2.32	-0.01	8.43
8682.25	-3.21	-3.22	-0.01	8.29
9076	-4.06	-4.06	0.00	8.15
24468	-21.98	-21.92	0.06	5.28
34334	-27.43	-27.57	-0.14	4.41
39860	-30.00	-30.00	0.00	4.00

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Thermister

- **Advantages**
  - **More accurate than PRT over a narrow range**
  - **Fast response time**
  - **Lower cost**
  - **Higher resistance (easier to measure)**
- **Disadvantages**
  - **Long term stability not as good as PRT (ok at low temperature)**

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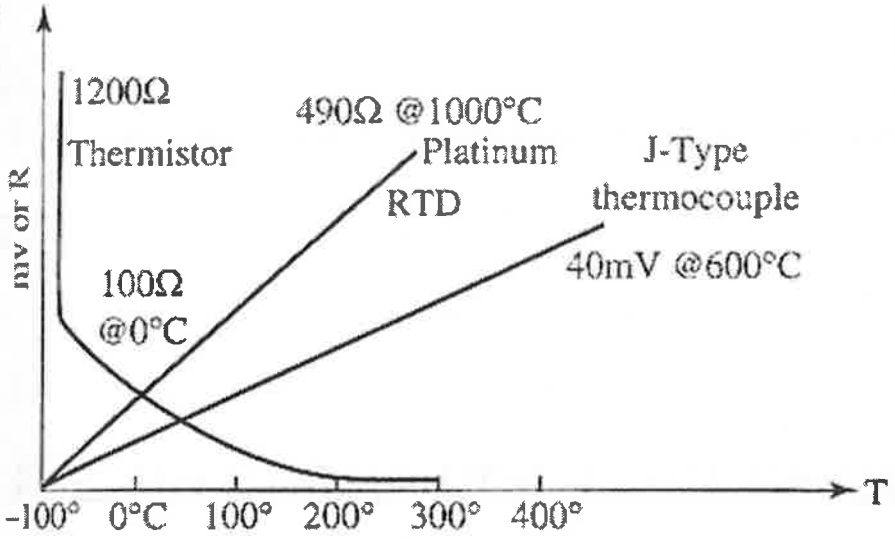
PRT Vs Thermister



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PRT Vs Thermister

	PRT	Thermister
Resistance	Lower (higher cost for accurate 4-wire resistance measuring circuit)	Higher (4-wire resistance measuring circuit is not required)
Stability	Good long term stability	Moderate long term stability
Sensitivity	Moderate	High
Temperature range	Wide	Narrow
Linearity	Good	Poor
Cost	Moderate	Low

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Immersion Error

- The size of the sensor is not small
- Insufficient immersion of PRT will cause error due to the effect of heat conduction along the sheath and the lead wires
- Approximate immersion length required = 20 X dia + sensor length

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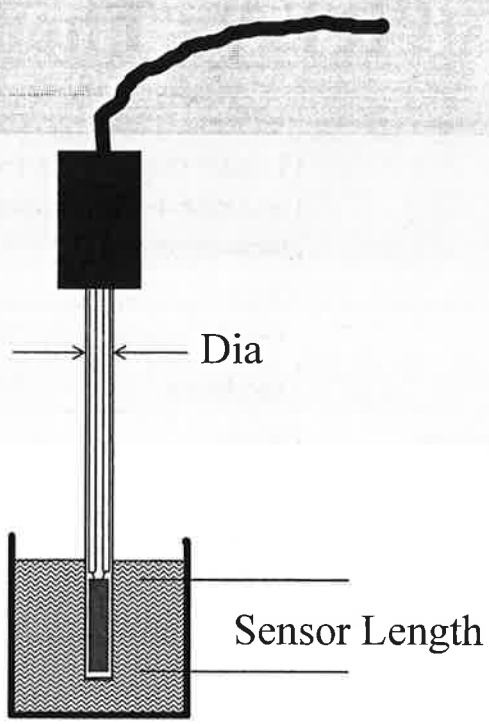
Diameter = 4 mm
Sensor Length = 15 mm
Immersion = 20 x 4 + 15
= 95 mm



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Calibration

- A high level of expertise is required
- Good algebraic and computing skills are required
- Understanding of least-square fitting

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Calibration

- Calibration points for the thermister/PRT
  - 0 °C or 0.01 °C(water triple point)
  - ≈ 15 °C
  - ≈ 30 °C or 29.7646 °C(gallium fixed point)
  - It is better to calibrate the sensors together with your own data logger

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Calibration Facility

- **Liquid bath with sufficient depth, temperature stability and uniformity (5 mK)**



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Calibration Facility

- **Standard Platinum Resistance Thermometer (SPRT: 5 mK)**



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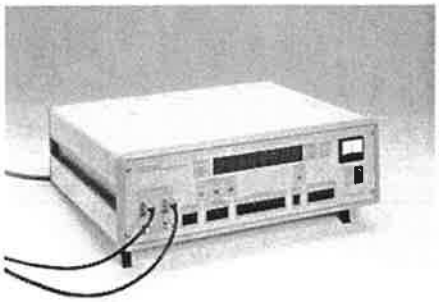
Calibration Facility

CMC = 0.01°C

- **Precision resistance bridge which is capable of eliminating thermal electric effects (5 mK)**







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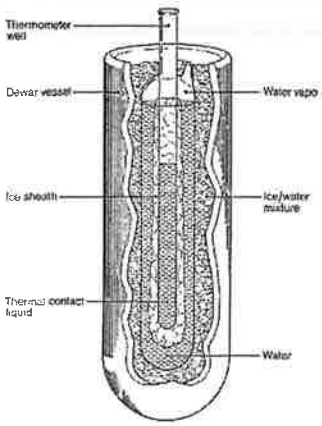
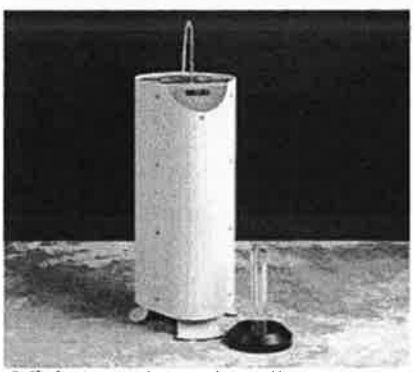
Calibration Facility

- **Using primary standards:**
  - **Water triple point**
  - **Gallium melting point**
- **Periodic calibration not required**
- **SPRT and resistance bridge not required**





Mini water triple point cell system



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End of presentation

Thank you

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How to Read Calibration Report?

Victor Tan
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62791958
victor_tan@nmc.a-star.edu.sg

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Information You Can Obtain from a Calibration Report

1. Traceability
2. Calibration Results
   - Correction or Error (+ve / -ve)
3. Expanded uncertainty
4. Drift
5. Verification

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Calibration Report - Temperature

No : TM007789

Submitted by : ABC Technology Pte Ltd
17 Burge Road #05-01
Singapore 59997

Date : 2009-06-12
Page 1 of 2
Ambient Temperature: 23 ± 2°C
Relative Humidity: 55 ± 10% rh

Subject	:	Digital Thermometer
Manufacturer	:	Fluke
Model	:	51 K/J
Serial No	:	600001
Calibrated Range	:	Type K

Date Calibrated : 2009-06-12

This Digital Thermometer has been calibrated at the XYZ Calibration Pte Ltd under the ambient conditions stated above.

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Method of Calibration

The Digital Thermometer was calibrated by applying a stable voltage, from a Thermocouple Simulator. The calibration was based upon the standard thermocouple reference tables (e.g. ASTM E 230, BS 4937).

The calibration was carried out using the following working standards traceable to national reference standards maintained at XYZ Calibration Pte Ltd:

1) Thermocouple Simulator (S/N: 17766)
2) Thermocouple Wire (S/N: K9850)

The calibration was carried out in terms of International Temperature Scale of 1990 (ITS90).

Results of Calibration

The results of this calibration are shown on page 2. The expanded uncertainty associated with the results is 0.5°C, estimated at a level of confidence of approximately 95% with a coverage factor k=2.

The results and their associated expanded uncertainties are applicable at the time of calibration

Since the calibration did not cover the full range of the instrument, the user should determine the suitability of this instrument for its intended use.

Yong Ling Ling
CALIBRATION OFFICER
Job No : 77885567

JOHN LEE
for DIRECTOR
XYZ Calibration Pte Ltd

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The calibration was carried out using the following working standards traceable to national reference standards maintained at NMC(Singapore), NPL(UK), NIST(USA):

Thermocouple Simulator (S/N: 17766)
Thermocouple Wire (S/N: K9850)

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The Digital Thermometer was calibrated by applying a stable voltage, from a Thermocouple Simulator. The calibration was based upon the standard thermocouple reference tables (e.g. ASTM E 230, BS 4937).

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Yong Ling Ling
CALIBRATION OFFICER
Job No : 77885567

JOHN LEE
for DIRECTOR
XYZ Calibration Pte Ltd

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Verification

Results of Calibration

Indicated Temperature Type K (°C)	Simulated Temperature (°C)	Correction (°C)	Expanded Uncertainty (°C)	Specified Limit (°C)
-100.0	-99.5	0.5	0.5	0.8
0.0	0.3	0.3	0.5	0.7
100.0	100.2	0.2	0.5	0.8
200.0	200.3	0.3	0.5	0.9
300.0	300.1	0.1	0.5	1.0
400.0	400.2	0.2	0.5	1.1
500.0	499.7	-0.3	0.5	1.2
600.0	599.6	-0.4	0.5	1.3
700.0	700.1	0.1	0.5	1.4
800.0	800.4	0.4	0.5	1.5
900.0	899.8	-0.2	0.5	1.6
1000.0	999.9	-0.1	0.5	1.7
1100.0	1099.6	-0.4	0.5	1.8
1200.0	1199.7	-0.3	0.5	1.9

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Cannot verify if it's within specification.

Report No : ######2 **Page 1 of 4**

Customer : Xxxxx Xxxx Pte Ltd
9 Xxxxx Unit 06-01
Xxxx Tower
Singapore #####9

Subject Details
Subject : Thermistor Probe
Manufacturer : -
Model : ####-TFE
Serial Number : 1####
Range : (28 to 31) °C

Sales Order No. : ####
Calibration Date : 08 August 2011

Ambient Conditions
Temperature : (22 ± 3) °C
Relative Humidity : (60 ± 10) % relative humidity

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Method of Calibration

The thermistor probe had been calibrated at the National Metrology Centre under the ambient conditions stated above. The calibration was carried out according to the calibration procedure TS/RT/002.

The thermistor probe was calibrated by comparing with a Standard Platinum Resistance Thermometer (SPRT, serial no.: 1523, traceable to national reference standards maintained at National Metrology Centre.

The resistance of the thermistor was measured using a multimeter (serial no.: 0982652) in a 2-wires configuration. The calibration was performed in a constant temperature bath. Reading was taken after the temperature had stabilised.

The calibration was in terms of the International Temperature Scale of 1990 (ITS-90).

Results of Calibration

The results of this comparison are given in Table 1 of this report. The expanded measurement uncertainty is 0.02 °C, estimated at a level of confidence of approximately 95% with a coverage factor k = 2.

The user should determine the suitability of this instrument for its intended used. The recalibration interval should be based on the user's requirements.

Table 1

Test temperature (°C)	Thermistor Reading (Ω)
28.010	8771.22
29.519	8219.67
31.032	7705.50

Remarks

The Steinhart and Hart empirical equation is used to interpolate the temperature between the calibration points.

$$\frac{1}{T} = a + b(\ln R) + c(\ln R)^3$$

where $a = 0.001\ 214\ 085$
$b = 2.204\ 298\ 637 \times 10^{-4}$
$c = 1.403\ 959\ 657 \times 10^{-7}$

R = *Resistance in ohms*
T = *Temperature in Kelvin (°C + 273.15)*

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Serial No: 10K2P9536 (Condenser water supply/CWS)

Temperature (°C)	Resistance (Ohm)	Temperature (°C)	Resistance (Ohm)	Temperature (°C)	Resistance (Ohm)
28.00	8775.0	28.60	8550.8	29.20	8332.9
28.02	8767.4	28.62	8543.4	29.22	8325.8
28.04	8759.9	28.64	8536.0	29.24	8318.6
28.06	8752.3	28.66	8528.7	29.26	8311.5
28.08	8744.7	28.68	8521.4	29.28	8304.4
28.10	8737.2	28.70	8514.0	29.30	8297.2
28.12	8729.6	28.72	8506.7	29.32	8290.1
28.14	8722.1	28.74	8499.4	29.34	8283.0
28.16	8714.6	28.76	8492.1	29.36	8275.9
28.18	8707.1	28.78	8484.8	29.38	8268.8
28.20	8699.5	28.80	8477.5	29.40	8261.7
28.22	8692.0	28.82	8470.2	29.42	8254.6
28.24	8684.5	28.84	8462.9	29.44	8247.6
28.26	8677.0	28.86	8455.6	29.46	8240.5
28.28	8669.6	28.88	8448.3	29.48	8233.4
28.30	8662.1	28.90	8441.1	29.50	8226.4
28.32	8654.6	28.92	8433.8	29.52	8219.3
28.34	8647.1	28.94	8426.6	29.54	8212.3
28.36	8639.7	28.96	8419.3	29.56	8205.2
28.38	8632.2	28.98	8412.1	29.58	8198.2
28.40	8624.8	29.00	8404.8	29.60	8191.2
28.42	8617.4	29.02	8397.6	29.62	8184.2
28.44	8609.9	29.04	8390.4	29.64	8177.2

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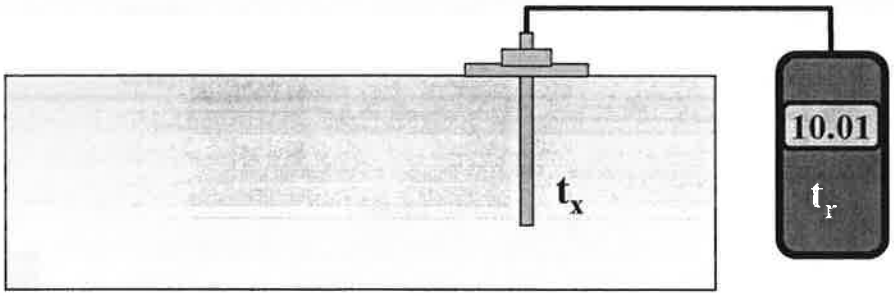
- $tx = tr + u_{sensor} + u_{indicator} + u_{resolution} + u_{repeatibility}$

  ↑

  0.02 °C



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End of presentation

Thank you

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How to Select a Calibration Laboratory?

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Introduction

- **Competent**
- **Quality system**
- **Calibration and measurement capability** (CMC)

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Competency

- **Calibration staff well trained**
- **Use the right procedures**
- **Use the right measurement standards and equipment**
  - **10 to 1 or 4 to 1 accuracy ratio**



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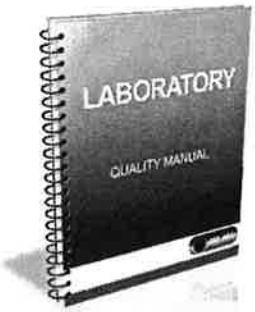
Quality System

- **The lab implements quality system that complies with relevant standards**





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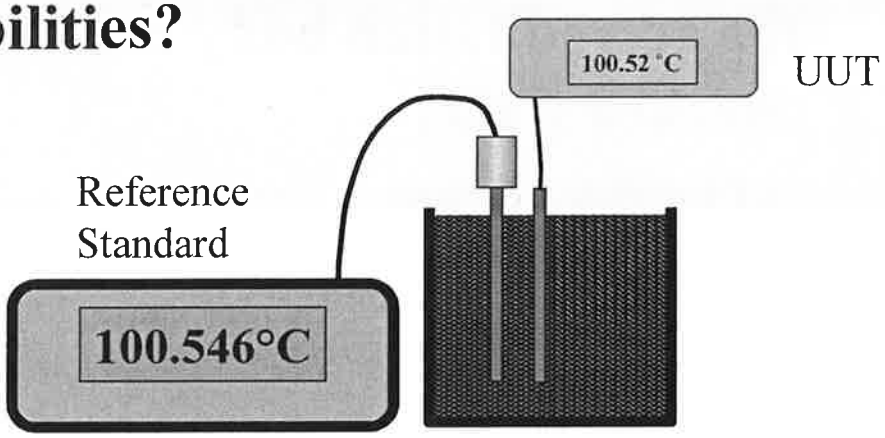
Capability

- **How do they indicate their capabilities?**



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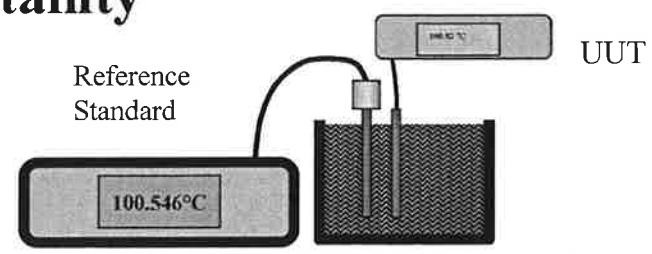
Capability

- **u_1: uncertainty from standards**
- **u_2: uncertainty from calibration bath**
- **u_3: uncertainty from repeatability**
- **u_4: uncertainty from resolution of UUT**
- **Calibration and Measurement Capability (CMC) = k factor times the combined uncertainty**



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Laboratory Accreditation

- **If a laboratory has been accredited, the accreditation body must have checked their:**
  - **Quality system**
  - **Technical competency**
  - **CMC**

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Capability

- **If you use accredited laboratory**
  - **Check their Terms Of Accreditation (TOA)**
    - **Available from accreditation body web site**

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TOA

0.02
0.03

Measurement Quantities/Instruments/ Range Be Calibrated	Method	Calibration and Measurement Capability Expressed as an Uncertainty
Resistance Thermometers	STCP-195 (Rev 0)	0.01 °C

- Check the Calibration and Measurement Capability (CMC) whether it is smaller than your measurement accuracy or instrument accuracy requirement
  - Your requirement: 0.05 °C
- Check the uncertainty in the calibration report
  - Should not be smaller than the CMC

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List of Accredited Laboratories

- **Laboratories with CMC of 0.01 °C or better**
  - **Isolab**
  - **Fluke** (calibrate sensor buy from them)
  - **NMC**

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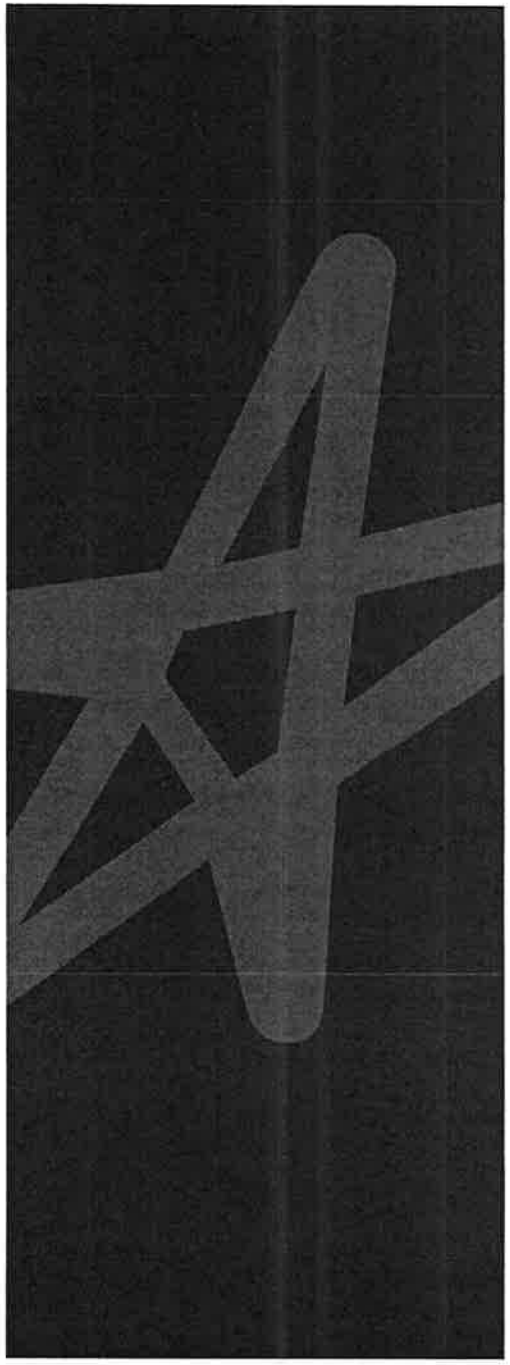

Measurement & Verification
of Central Chilled-Water Plant Efficiency

Fundamentals of Measuring Instruments

Electrical Power Measurement

Chua Sze Wey
Electrical Metrology Laboratory
National Metrology Centre

chua_sze_wey@nmc.a-star.edu.sg

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Outline of Presentation

- An overview of power measurement
- Power measurement instruments
- Calibration of power measurement instruments

Certain commercial equipment, instruments or materials are identified in this presentation in order to adequately elaborate the topics for training purpose. Such identification does not imply recommendation or endorsement by NMC, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

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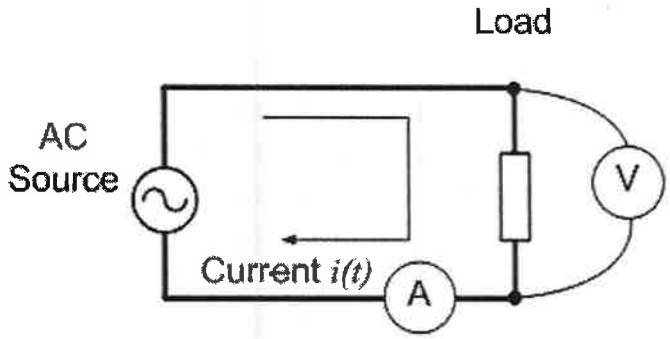
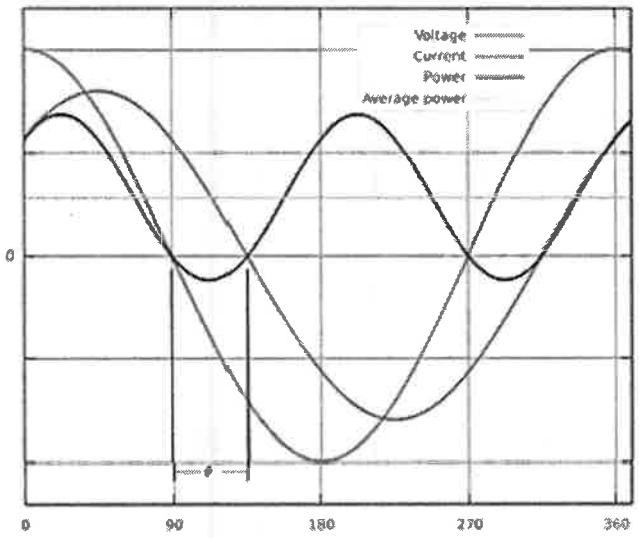
An Overview of Power Measurement





The instantaneous electrical power in watt (W) delivered to a load

$$p(t) = v(t) \cdot i(t)$$

where

- *$v(t)$ is the potential difference (or voltage drop) across the load, measured in volts (V).*
- *$i(t)$ is the current through the load, measured in amperes (A)*

*The average electrical delivered to a load over a periodic signal of period **T***

$$P_{average} = \frac{1}{T}\int_{t=0}^{T} p(t)\,dt$$

For sinusoidal waveform

$$P = V \cdot I \cdot \cos\theta = V \cdot I \cdot \text{power factor}$$

where

V:= RMS Voltage
I= RMS Current
θ:= Phase angle between current and voltage

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Root mean square (RMS) value of a waveform

Root mean square (RMS)

The RMS value of a signal is the amplitude of a DC signal which will transfer the same energy like the applied signal into an ohmic resistor in the same time.

For a periodic signal *x(t)*, i.e. the signal repeated after the period time *T*, the RMS value

$$X_{RMS} = \sqrt{\frac{1}{T}\int_{t=0}^{T} x(t)^2 \, dt}$$

Instrument usually states it measures "true RMS" value to indicate that the measured RMS value is independent from the wave shape of the signal.

"True RMS value"

In practice there are different measuring methods for RMS value.

- Some older instruments just measure the rectified value and multiply it with the form factor to get the RMS value of the signal. This is only valid when the signal is sinusoidal. For non sinusoidal signals you need another form factor.
- Some instruments measure the AC part of a signal only. The DC component produces a power consumption in a resistor too. These instruments might display a wrong value, if a DC component exists.

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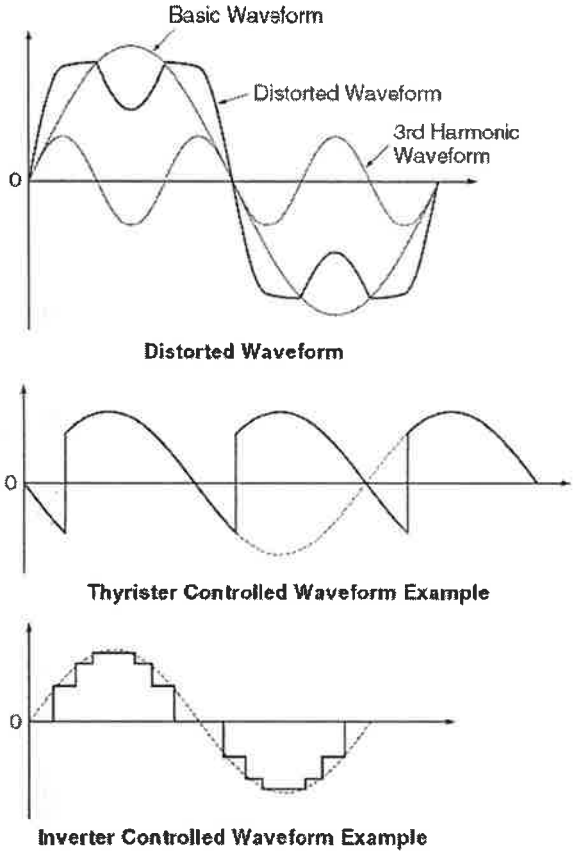
Root mean square (RMS) value of a waveform

Root mean square (RMS)

Wave type	Waveform	Peak magnitude (normalized)	RMS value	Crest factor
DC		1	1	1
Sine wave		1	$\frac{1}{\sqrt{2}} \approx 0.707$	$\sqrt{2} \approx 1.414$
Full-wave rectified sine		1	$\frac{1}{\sqrt{2}} \approx 0.707$	$\sqrt{2} \approx 1.414$
Half-wave rectified sine		1	$\frac{1}{2} = 0.5$	2
Triangle wave		1	$\frac{1}{\sqrt{3}} \approx 0.577$	$\sqrt{3} \approx 1.732$
Square wave		1	1	1
PWM-Signal		1	$\sqrt{\frac{t_1}{T}}$	$\sqrt{\frac{T}{t_1}}$

RMS value for distorted waveform ?



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Crest Factor (CF)

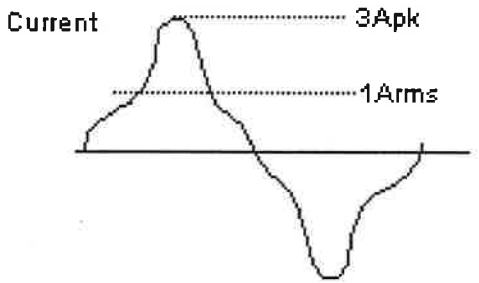
The peak value is important for measuring instruments. If it is too large for the chosen measuring range:

- analogue instruments could come into saturation, which would cause measuring errors
- the full scale of the ADC digital instruments could be reached thereby the signal is cut off which cause distortions and measuring errors.

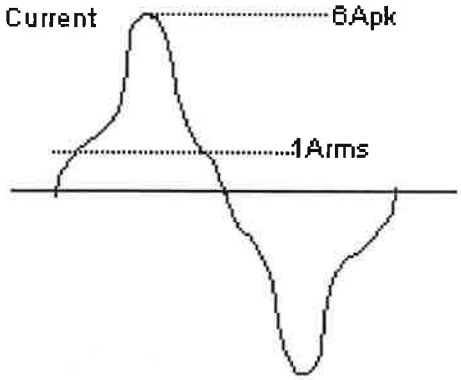
The crest factor specification of an instrument expresses the size of the dynamic range for the input signal based on rated range value (RMS value).

$$CF = \frac{Peak\ Value}{RMS\ Value}$$

CF=3



CF=6



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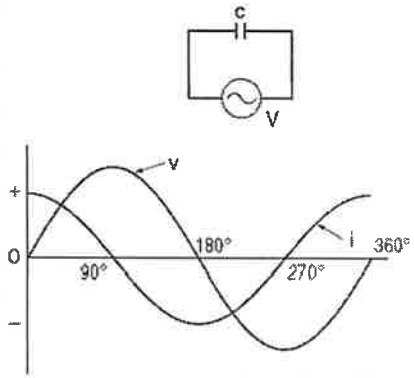
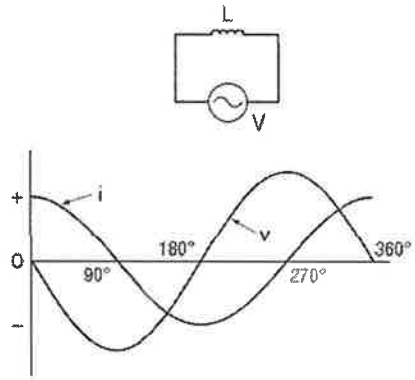
An Overview of Power Measurement

For sinusoidal waveform	
Instantaneous Voltage (V)	$v(t) = V_m \cdot \sin \omega t$
Instantaneous Current (A)	$i(t) = I_m \cdot \sin(\omega t + \theta)$
RMS Voltage (V)	$V = \frac{V_m}{\sqrt{2}}$
RMS Current (A)	$I = \frac{I_m}{\sqrt{2}}$
Active power (W)	$P = V \cdot I \cdot \cos\theta$
Reactive power *(VAR)*	$Q = V \cdot I \cdot \sin\theta$
Apparent power (VA)	$S = V \cdot I = \sqrt{P^2 + Q^2}$
Power Factor	$pf = \cos\theta = \frac{P}{V \cdot I} = \frac{P}{S}$
Pf=1	Resistive: $\theta = 0°$
0<Pf <1 leading	Capacitive: $-90° < \theta < 0°$
0<Pf <1 lagging	Inductive: $0° < \theta < 90°$
Crest Factor	$CF = \frac{Peak\ Value}{RMS\ Value} = \sqrt{2}$



Pure Capacitance Circuit



Pure Inductance Circuit

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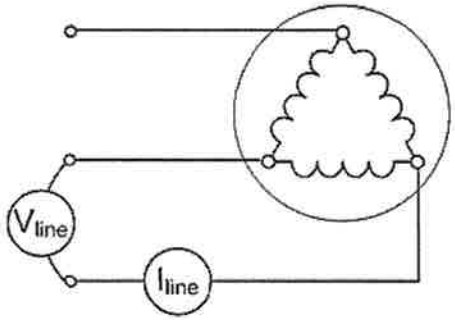
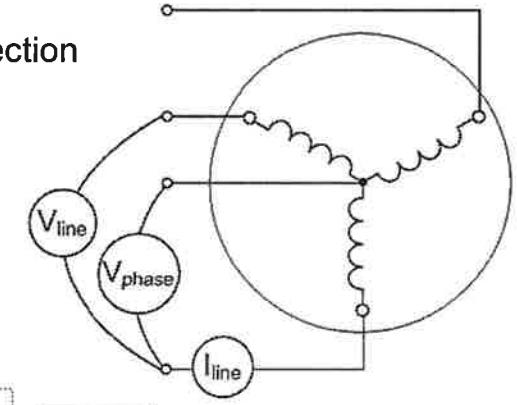
An Overview of Power Measurement

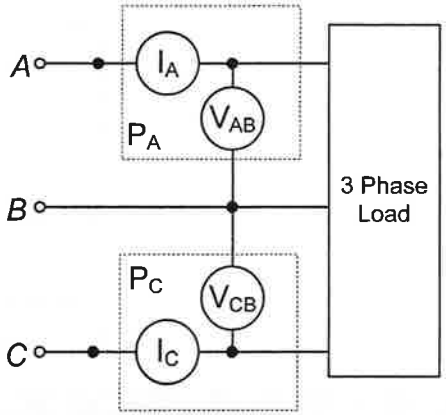
For sinusoidal waveform		
Connection	 Star/Wye	 Delta
Phase Voltage (V)	$V_{phase} = \frac{V_{line}}{\sqrt{3}}$	$V_{phase} = V_{line}$
Line Voltage (V)	$V_{line} = \sqrt{3} \cdot V_{phase}$	$V_{line} = V_{phase}$
Phase Current (A)	$I_{phase} = I_{linee}$	$I_{phase} = \frac{I_{line}}{\sqrt{3}}$
Line Current (A)	$I_{line} = I_{phase}$	$I_{line} = \sqrt{3} \cdot I_{phase}$
3 Phase Active Power (W)	Using 3 power meters: $P_{3\emptyset} = P_1 + P_2 + P_3$	
	Using 1 power meter: $P_{3\emptyset} = 3 \cdot P_{1\emptyset} = 3 \cdot V_{phase} \cdot I_{phase} \cdot pf = \sqrt{3} \cdot V_{line} \cdot I_{line} \cdot pf$ (Assumed ideal case)	
	Using 2 power meters: $P_{3\emptyset} = P_A + P_C$ $P_A = V_{AB} \cdot I_A \cdot \cos\theta_A$ $P_C = V_{CB} \cdot I_C \cdot \cos\theta_C$	

Delta Connection



Wye/Star Connection





Two power meters method (Blondel's Theorem)

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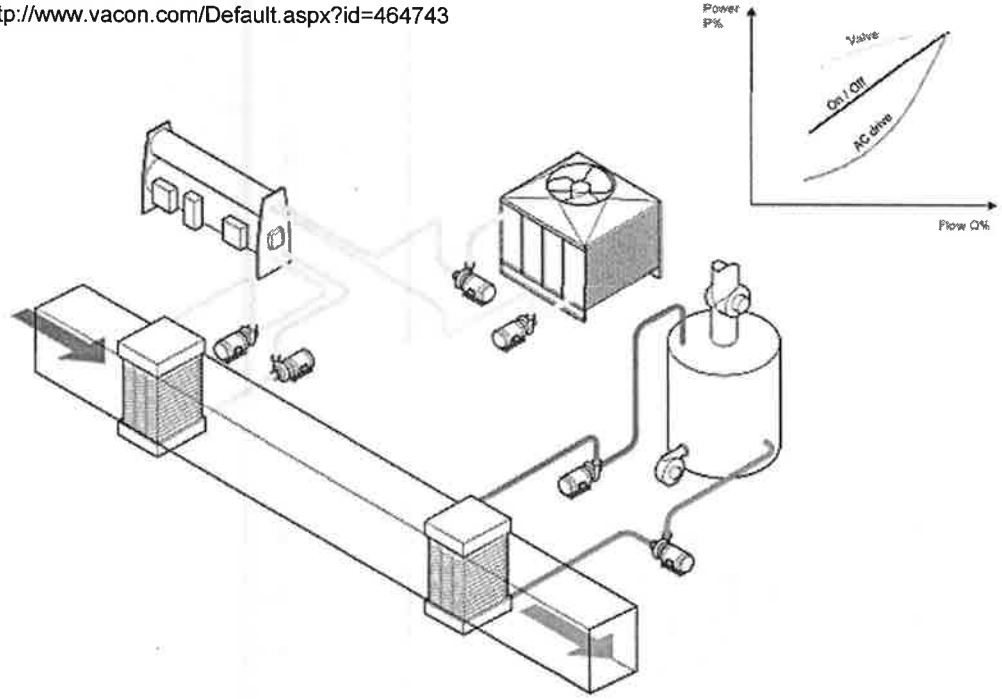
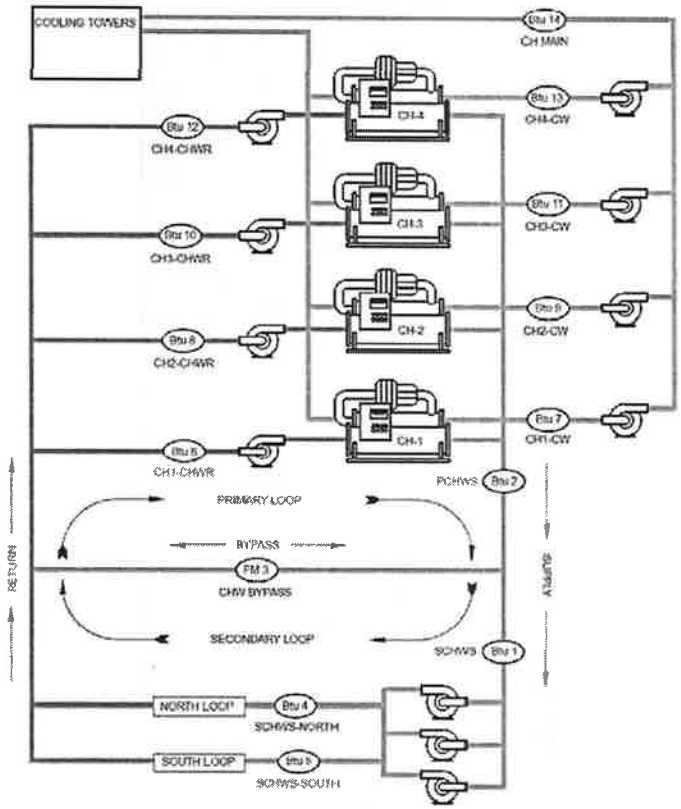
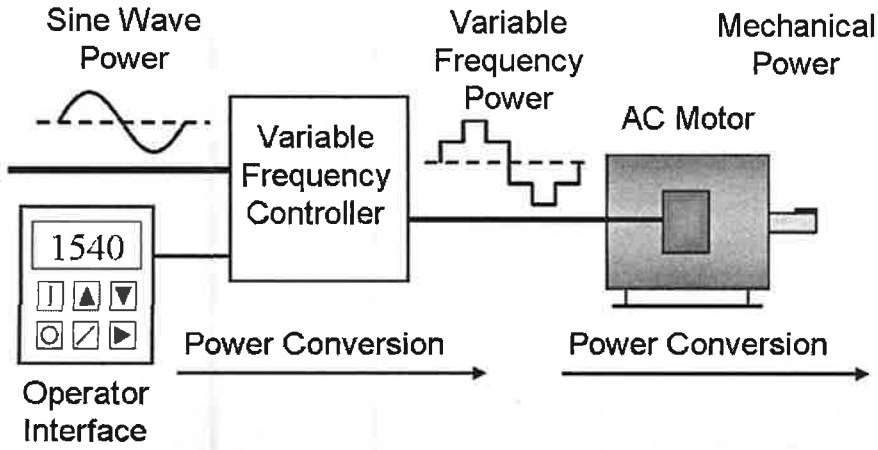
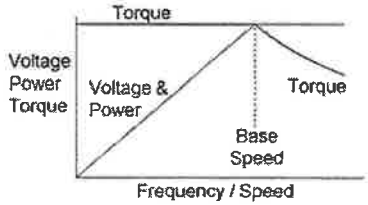
Power Measurement for Chilled-Water Plant

http://www.vacon.com/Default.aspx?id=464743









http://en.wikipedia.org/wiki/File:VFD_System.png

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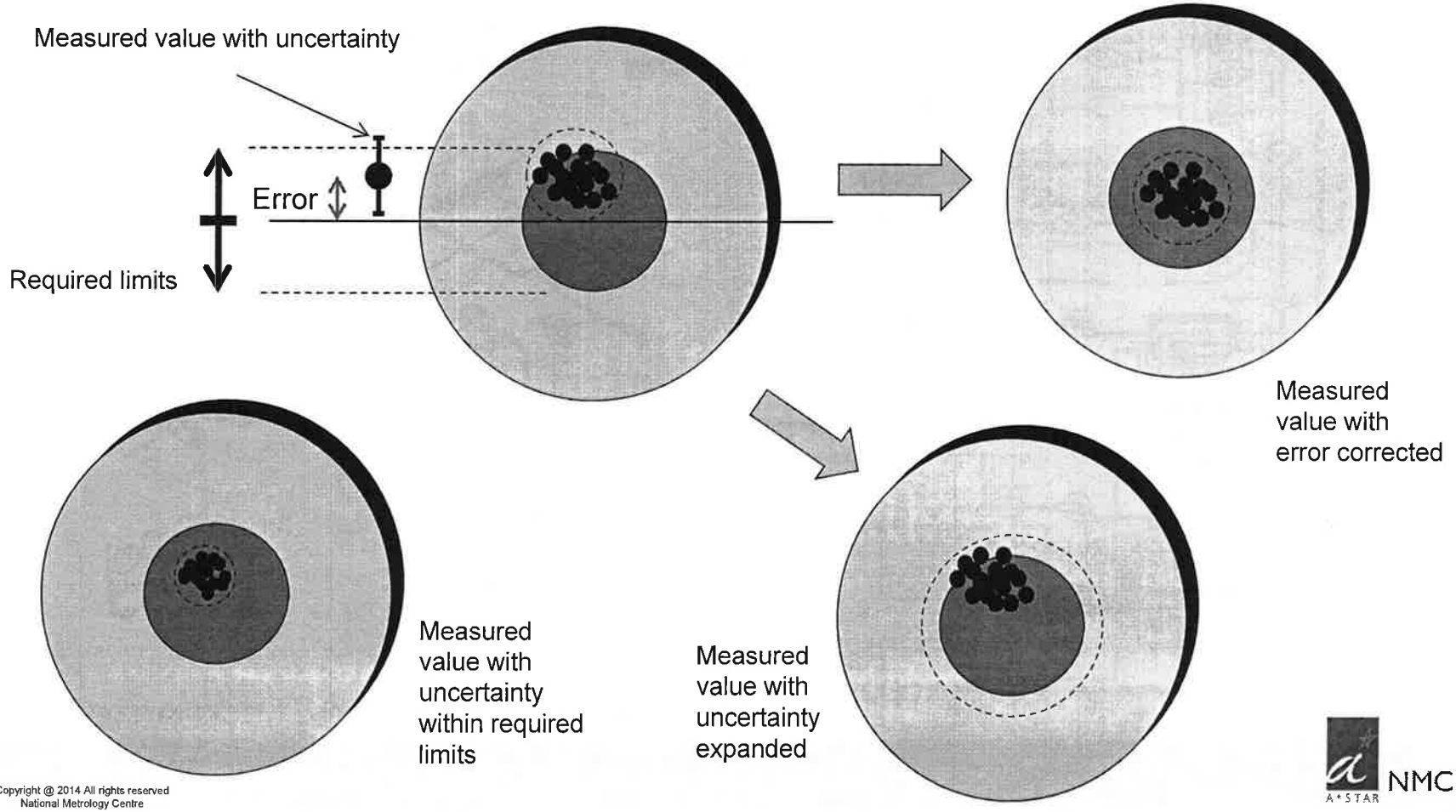
Selection of Instruments

Key points for instrument selection

- Range and magnitude of the measurand
- Tolerance required
- **Uncertainty of measurement ≠ Instrument accuracy**



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Selection of Instruments - Accuracy requirement

Parameter to be measured	Uncertainty of measurement	Test Uncertainty Ratio (TUR) is the ratio between the tolerance and the uncertainty present in the test of this tolerance. The higher the ratio, the better the performance of the test.
100 kW ± 1 kW (1%)	± 0.1 kW (0.1%)	TUR 10:1
100 kW ± 1 kW (1%)	± 0.25 kW (0.25%)	TUR 4:1
100 kW ± 1 kW (1%)	± 0.3 kW (0.3%)	TUR 3:1

- **Accuracy of the instrument complies with the desired accuracy requirement of the measurement (measurement uncertainty)**
- Effective measurement resolution of the measuring instrument should theoretically be one tenth of the tolerance and the uncertainty of the measurement about one forth of the tolerance.
- **The uncertainty of the measurement needs to take into consideration the accuracy of the measurement instrument, and any associated transducer/sensor, and other contributing factors (e.g. wiring, environmental, etc).**
- In practice instrument selection is done based on what is generally available in the market, cost, and operating requirements & conditions.

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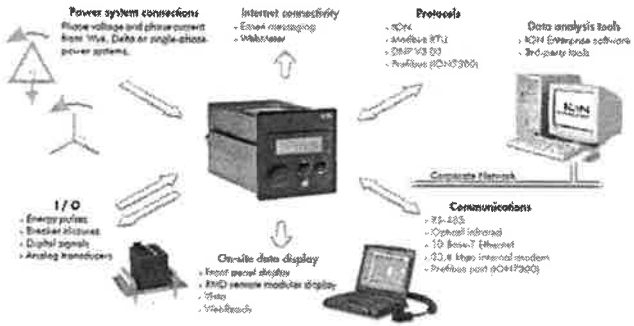
Different Types of Power Measurement Instruments

If variable speed drives, induction heaters, or other electronic loads are on the system, extreme voltage and current harmonics should be expected.

When selecting a power meter, some of the key considerations are:

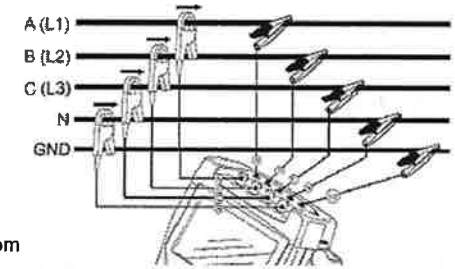
- capable to operate on a true RMS sensing principle
- have a sufficiently high crest factor
- capable to measure accurately across the frequency range of the harmonics

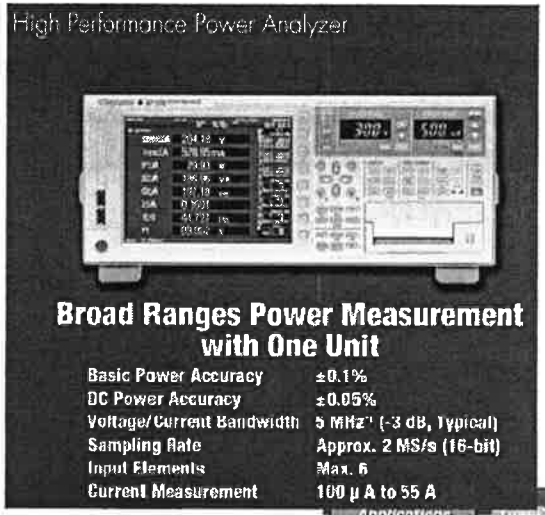


http://www.schneider-electric.com

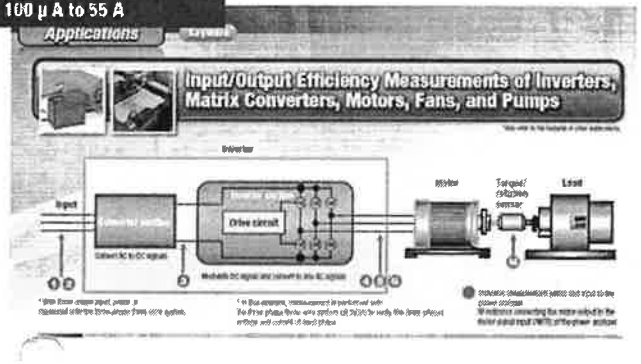


http://www.fluke.com





http://www.yokogawa.com



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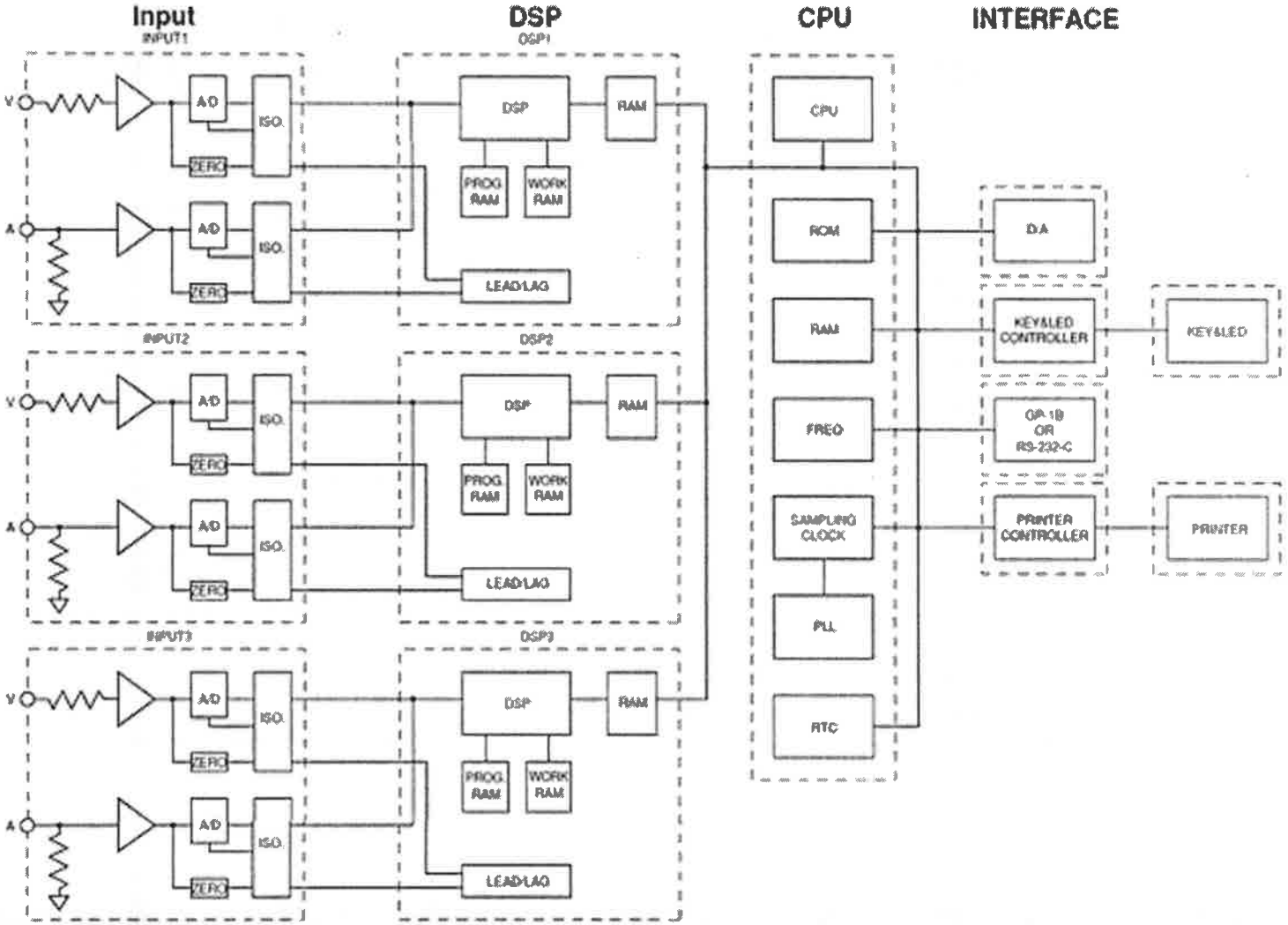
Power Meter Functional Diagram

AC Power Meter



Yokogawa Precision Power Analyser WT3000 User Manual

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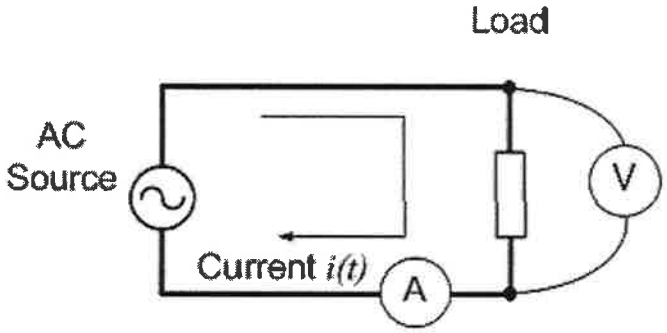
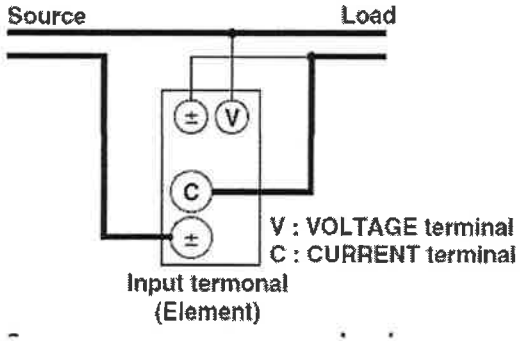
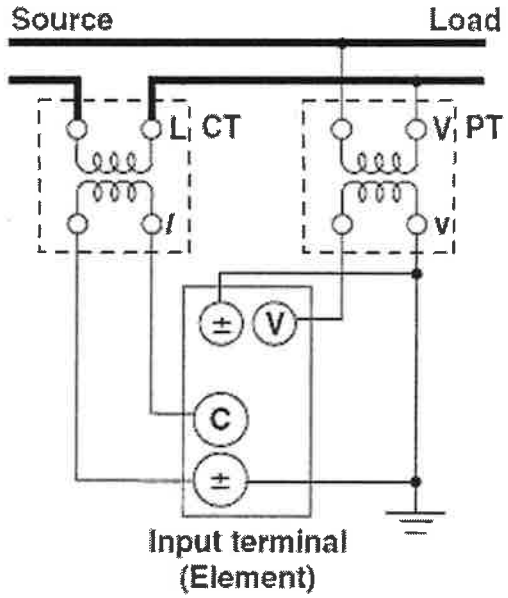
Power meter & range extension



$$P = V \cdot I \cdot \cos(\theta)$$





$$P = (ratio_{PT} \cdot V)(ratio_{CT} \cdot I) \cdot \cos(\theta)$$

Measurement range of power meter can be extended using voltage (potential) and current transformers.

The uncertainty of the power measurement needs to take into consideration the combined uncertainty of the power meter and any associated voltage and current transformers.

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Example: Measurement error from current transformer

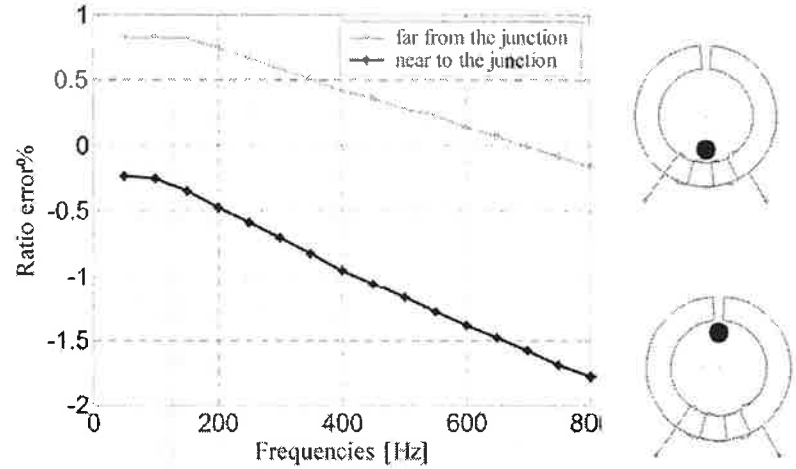


Fig. 3. Ratio error % of the clamp-on CT excited with 100-Arms sinusoidal current.

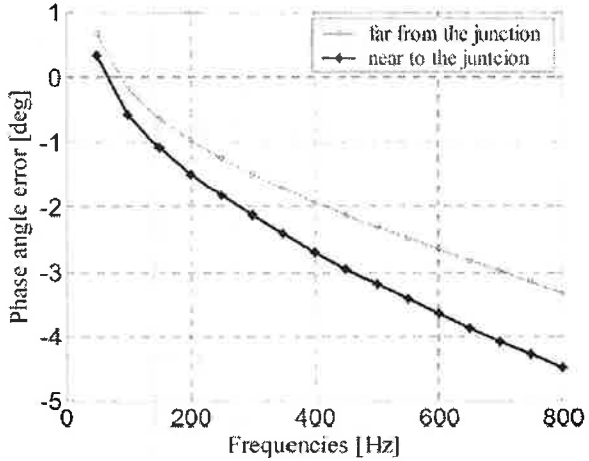
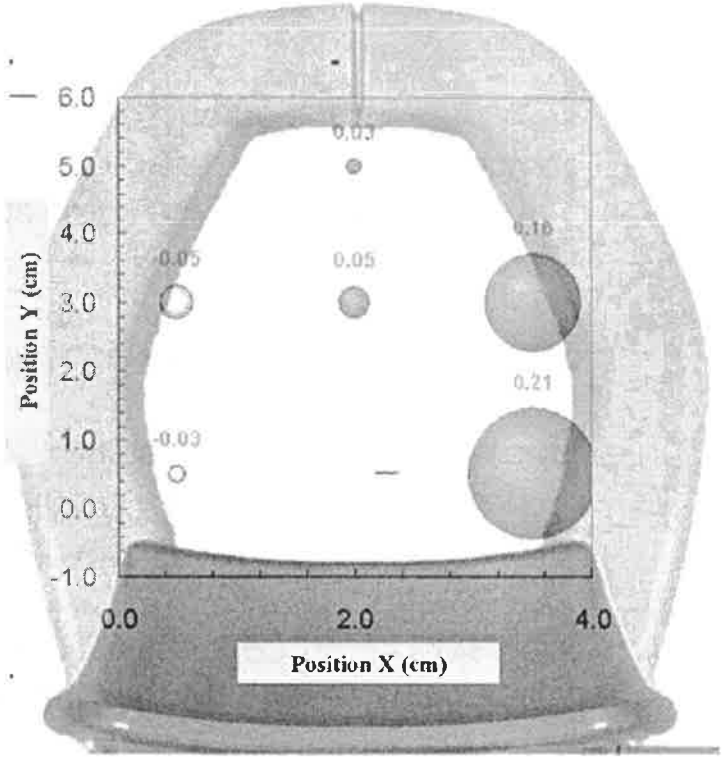


Fig. 4. Phase angle error ε of the clamp-on CT excited with 100 Arms sinusoidal current.



"Traceable Technique to Calibrate Clamp Meters in AC Current From 100 to 1500 A", Flavio Galliana and Pier Paolo Capra, *IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT*, VOL. 61, NO. 9, SEPTEMBER 2012, pp2512-2518

"Characterization of Clamp-On Current Transformers Under Nonsinusoidal Conditions", Antonio Cataliotti, Dario Di Cara, Alexander E. Emanuel, and Salvatore Nuccio, *IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 24, NO. 1, JANUARY 2009 pp.373-380*

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Current transformer

Current transformer (CT) enables power meter to measure power at current exceed its maximum current measuring range (usually 5 A with direct current input).

The CT manufacturer classifies its CT operating condition by a rated ratio and rated current which are labelled on the nameplate of the CT.

For example, a 0.2 accuracy class CT with rated ratio of 200A to 5A means that

- The CT is certified by the manufacturer to be accurate to within 0.2% of its rated ratio value for a primary current of 100% of rated ratio.
- CT can operate above the rated current and still remain with the certified accuracy as long as the upper limit of the primary current is within the CT's range rating factor.
- The accuracy class also defines the permissible phase angle displacement between primary and secondary currents.
- The CT is designed to operate accurately within 0.2% accuracy under certain burden conditions as specified.

If the CT is not an integrated part of the power meter, the accuracy of the power measurement needs to include accuracy of the CT ratio and phase. i.e. the accuracy of the power measurement may be worst than the specification of the power meter

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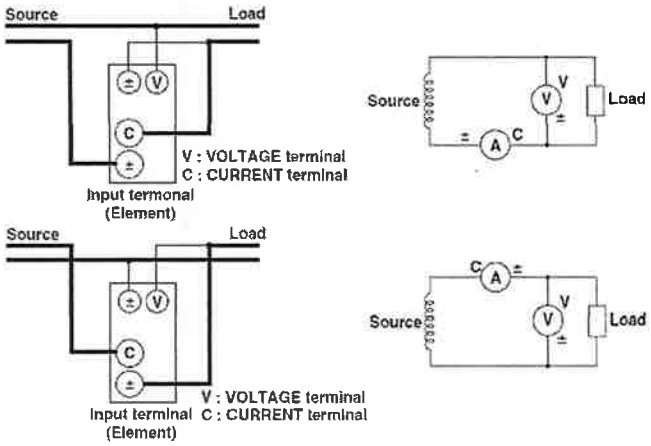
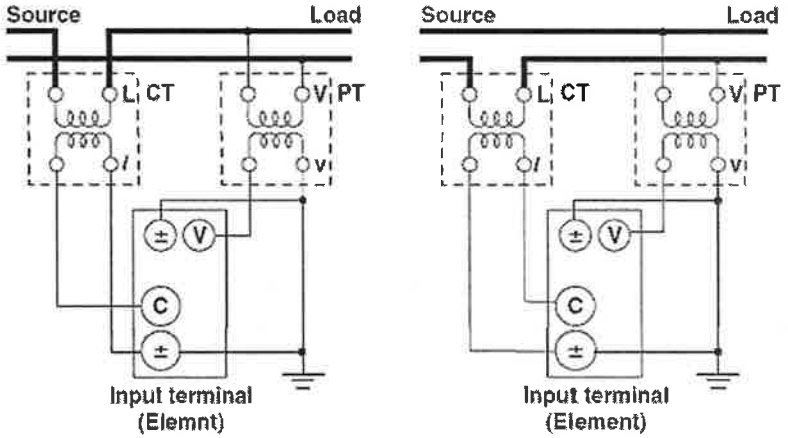
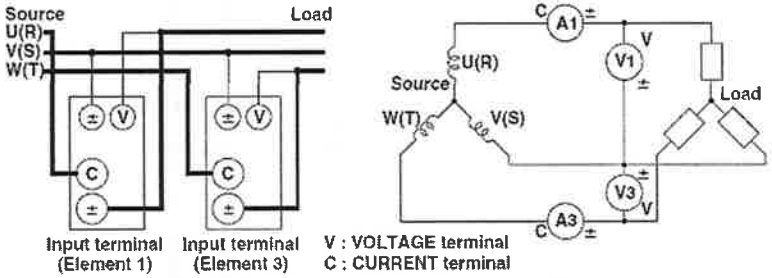
Wiring of power meter examples

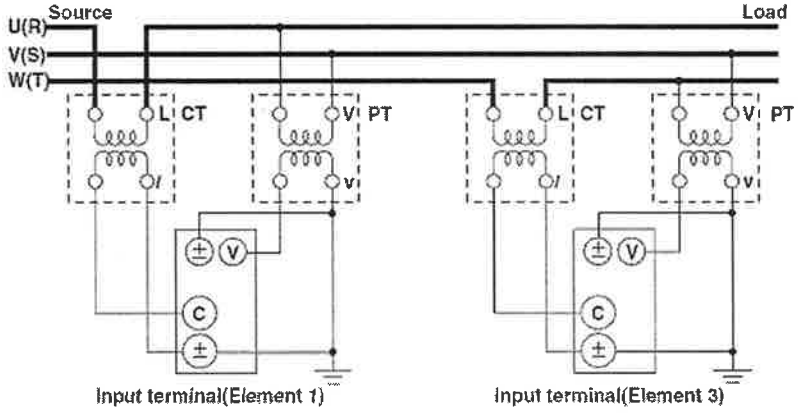
Single Phase Two-wire system





Three Phase Three-wire system





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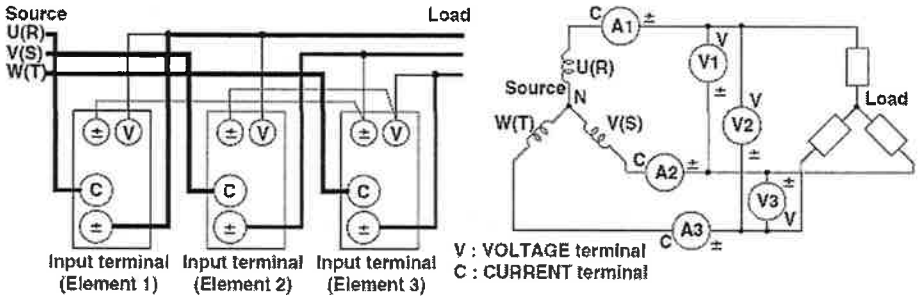
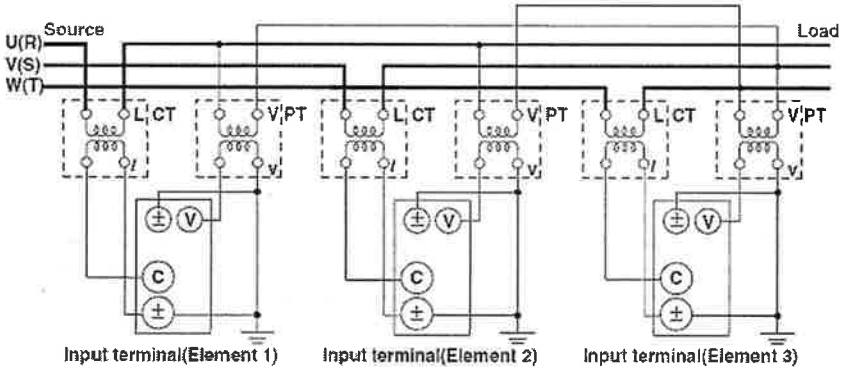
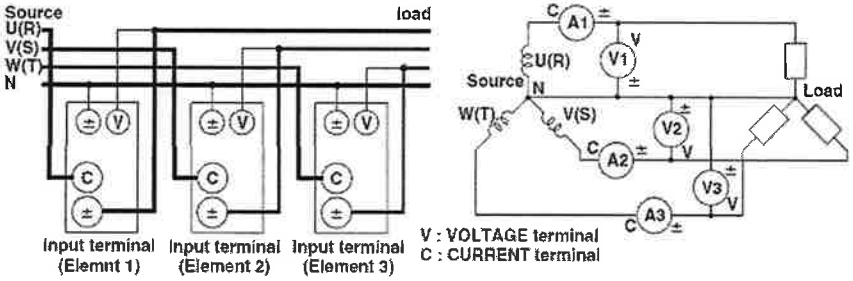
Wiring of Power Meter Examples

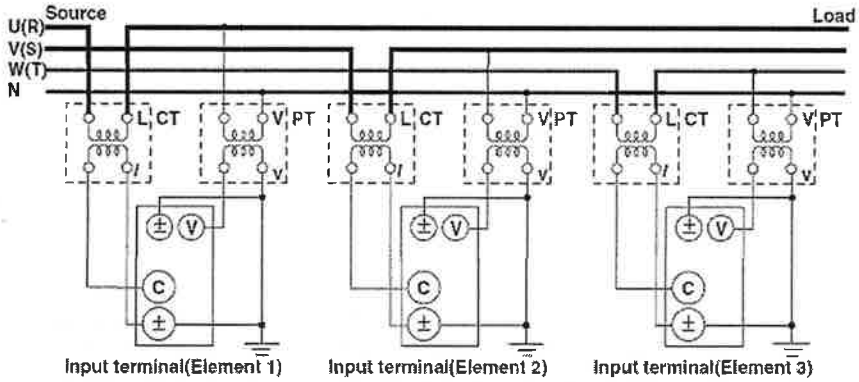
Three Phase Three-wire system





Three Phase Four-wire system





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Example: Connection Configurations of Power Meter

Computation

Item	Specifications

Computing equation of apparent power (VA), reactive power (var), power factor (PF), and phase angle (deg)

i: Input element number

Wiring System	Active Power (W)	Apparent Power (VA)	Reactive Power (var)	Power Factor (PF)	Phase Angle (deg)
Single-phase, two-wire	W	$VA=V \cdot A$	$var=\sqrt{(VA)^2-W^2}$	$PF=\frac{W}{VA}$	$deg=\cos^{-1}(\frac{W}{VA})$
Single-phase, three-wire (i=1, 3)	Wi $\Sigma W=W1+W3$	$VAi=Vi \cdot Ai$ $\Sigma VA=VA1+VA3$	$vari=\sqrt{(VAi)^2-Wi^2}$ $\Sigma var=var1+var3$	$PFi=\frac{Wi}{VAi}$ $\Sigma PF=\frac{\Sigma W}{\Sigma VA}$	$degi=\cos^{-1}(\frac{Wi}{VAi})$ $\Sigma deg=\cos^{-1}(\frac{\Sigma W}{\Sigma VA})$
Three-phase, three-wire (i=1, 3)	Wi $\Sigma W=W1+W3$	$VAi=Vi \cdot Ai$ $\Sigma VA=\frac{\sqrt{3}}{2}(VA1+VA3)$			
Three-phase, four-wire (i=1, 2, 3)	Wi $\Sigma W=W1+W2+W3$	$VAi=Vi \cdot Ai$ $\Sigma VA=VA1+VA2+VA3$	$vari=\sqrt{(VAi)^2-Wi^2}$ $\Sigma var=var1+var2+var3$		
Three-voltage, three-current (i=1, 2, 3)	Wi (W2 has no physical meaning) $\Sigma W=W1+W3$	$VAi=Vi \cdot Ai$ $\Sigma VA=\frac{\sqrt{3}}{3}(VA1+VA2+VA3)$	$vari=\sqrt{(VAi)^2-Wi^2}$ $\Sigma var=var1+var3$		

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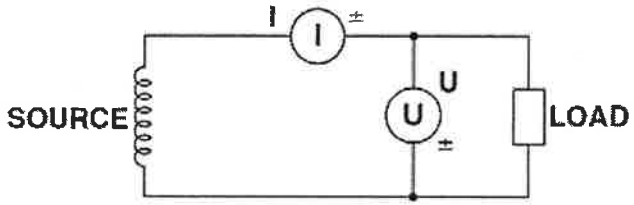
Wiring of Power Meter

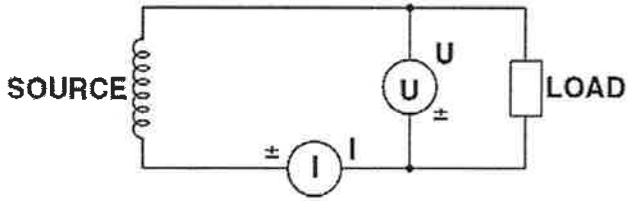
To make accurate measurements, wire the voltage input terminal and current input terminal by referring to the items below.

- **Effects of Stray Capacitance**
  When measuring a single-phase device, the effects of stray capacitance on the measurement accuracy can be minimized by connecting the current input terminal of the instrument to the side that is close to the earth potential of the power source (SOURCE).

• Easily affected

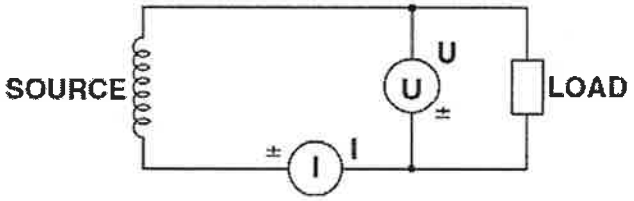


• Not easily affected

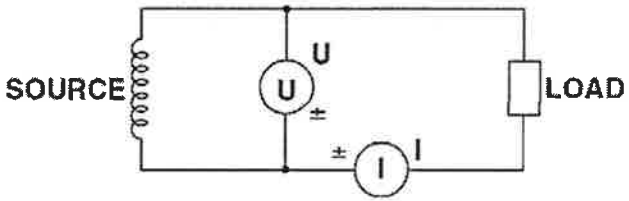


- **Effects due to the Amplitude of the Measured Voltage and Current**

• When the measurement current is relatively large
Connect the voltage measurement terminal to the load side.



• When the measurement current is relatively small
Connect the current measurement terminal to the load side.



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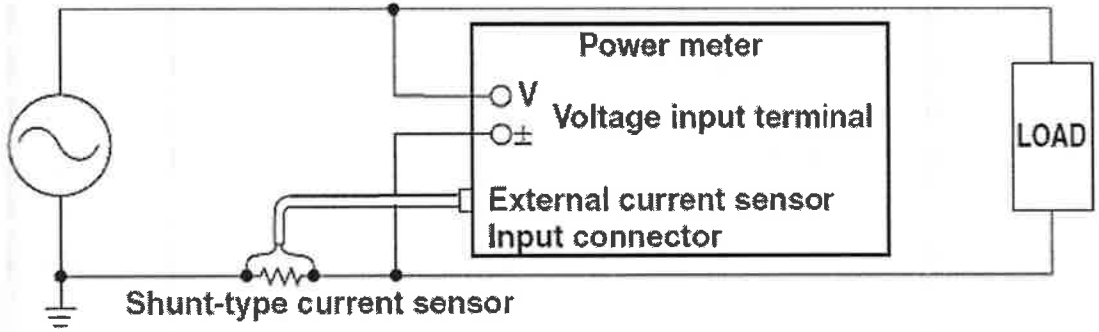
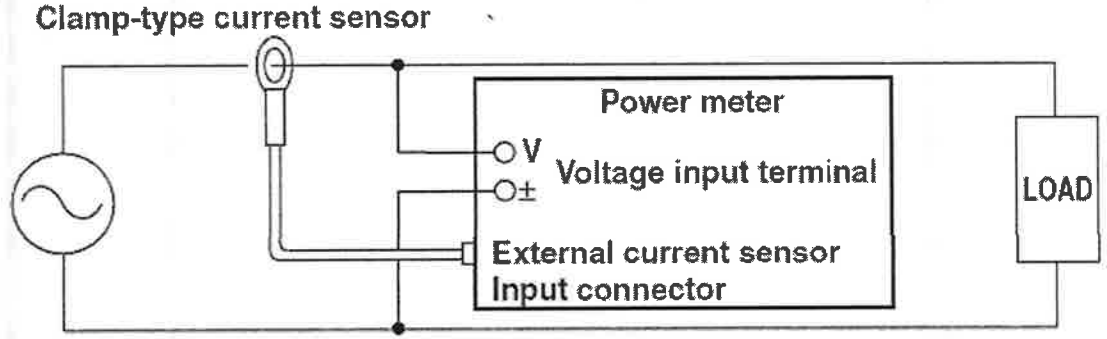
Wiring of power meter

- For a shunt-type current sensor, connect it to the power earth ground side as shown in the figure below. If you have to connect the sensor to the non-earth side, use a wire that is thicker than AWG18 (conductive cross-sectional area of approx. 1 mm^2) between the sensor and the instrument to reduce the effects of common mode voltage. Take safety and error reduction into consideration when constructing an external sensor cable.



- When the circuit under measurement is not grounded and the signal is high in frequency or large in power, the effects of the inductance of the connection cable for the shunt-type current sensor become large. In this case, use an isolation sensor (CT, DC-CT, or clamp).



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Wiring of power meter

During installation of a power meter with associated current measurement transformers (CTs) inputs:

- The voltage connections for the respective phases must match the voltage designated inputs to the meter.
- The current transformer connections for the respective phases must match the associated voltage phases to the meter. i.e.; Phase 'A' CT must be routed through the phase 'A' voltage conductor.
- The current transformer's polarity need to be polarity oriented as it is isolated from the power measurement circuit.
- When the conductor should be centred in the CT window, and perpendicular to the CT opening.
- Connect the current output of the CTs to the power meter before closing the CT around a live conductor.
- To meets the Green Mark power measurement class 1 accuracy requirement for the monitoring of the water-cooled chilled-water plant efficiency, the accuracy of a power meter needs to be better than 1% as the accuracy of the power measurement needs to take into consideration the accuracy of the power meter and any associated voltage (PT) and current (CT) transducer/sensor.

"Accuracy" of power meter ≠ "Accuracy" of power measurement

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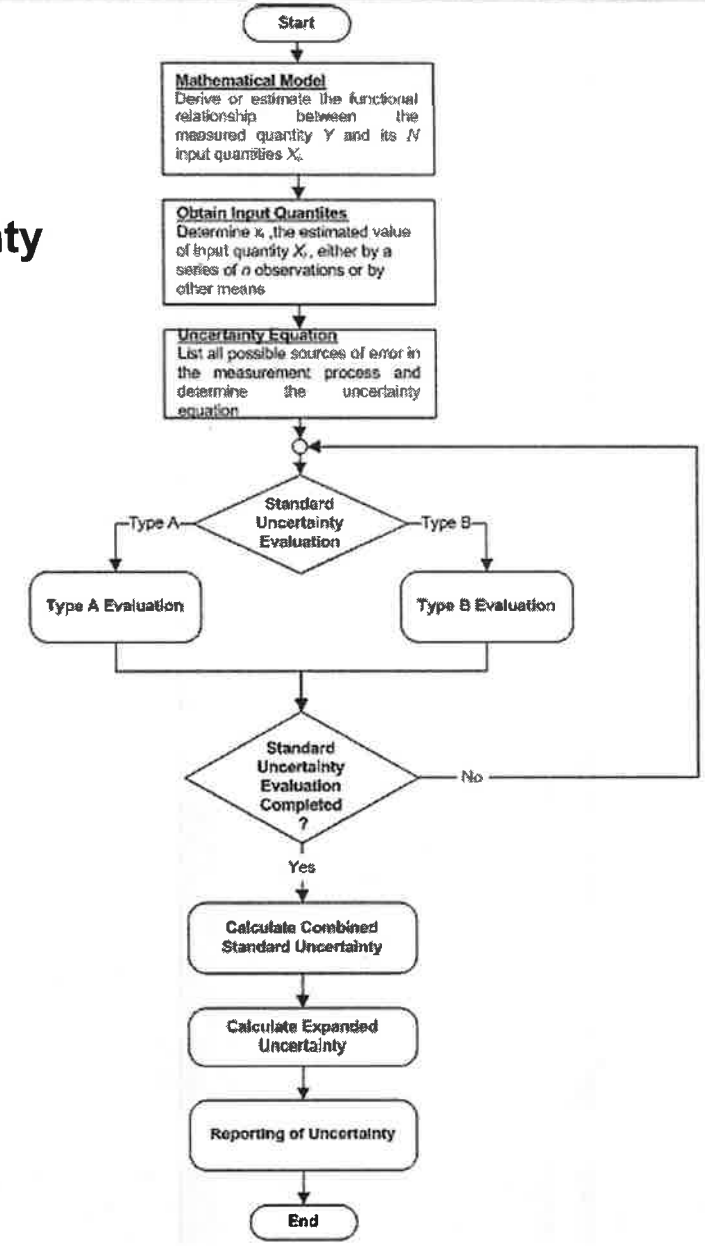
Measurement uncertainty

ISO/IEC Guide 98-1:2009
Uncertainty of measurement - Part 1: Introduction to the expression of uncertainty in measurement

measurement uncertainty: non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used.

ISO/IEC Guide 99:2007



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Power measurement for chilled-water plant

Instrumentation and Switch

3 phase
4 wire system
415V
28.5 A





Inverter

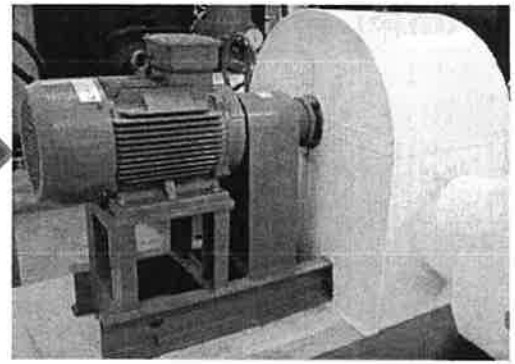
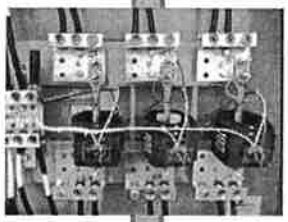


Photo: United World College
Mar 2012

Motor and Pump

Current
Transformers



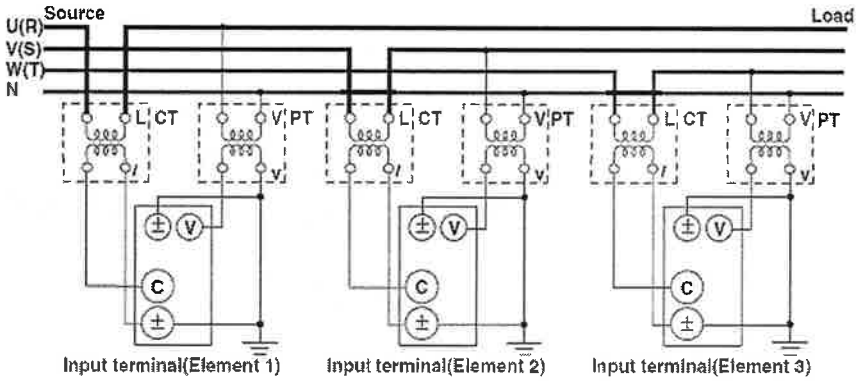
http://www.youtube.com/watch?v=jQsFWfN2PrQ

3 phase 415 V

3 phase 5 A

Power Meter





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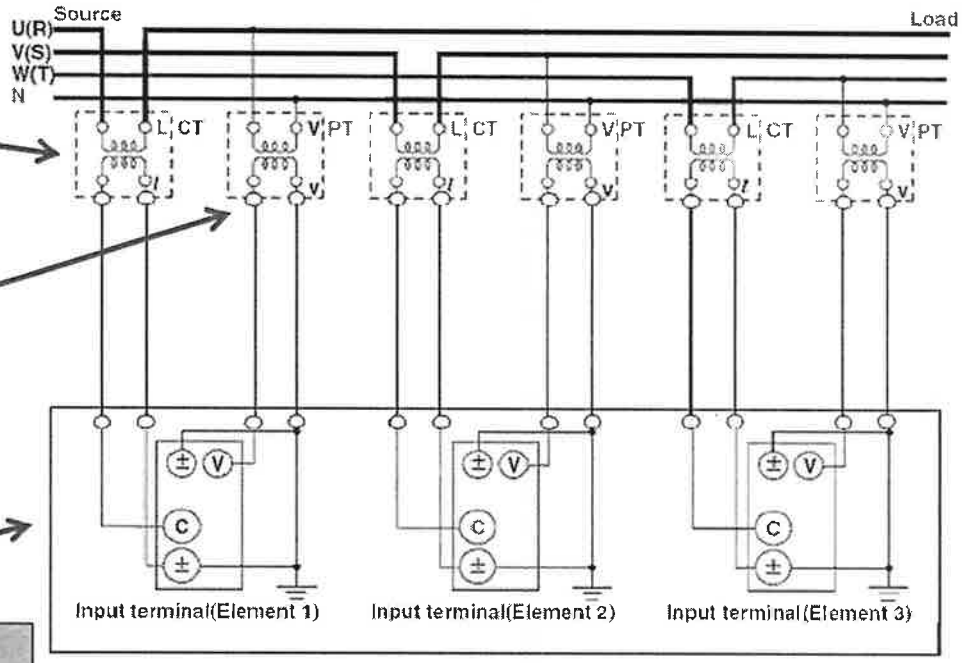
Example: Uncertainty estimation on power measurement

Current Transformers (CT)
Ratio $n_{CT}=I_{in}/I_{out}$
Ratio error Δ_{CT}
Phase error δ_{CT}

Potential Transformers (PT)
Ratio $n_{PT}=V_{in}/V_{out}$
Ratio error Δ_{PT}
Phase error δ_{PT}

Power Meter
Power error Δ_W
Phase error δ_W

Power Measurement
Input phase voltage V
Input phase current I
Phase angle θ
Per phase power P_{phase}
3 phase power $P_{3\,phase}$



3 Phase Power Meter

$$P_{phase}=[(1+\Delta_{PT})\cdot n_{PT}]\cdot[(1+\Delta_{CT})\cdot n_{CT}]\cdot(1+\Delta_W)\cdot V\cdot I\cdot\cos(\theta+\delta_{PT}-\delta_{CT}-\delta_W)$$

$$P_{3\,phase}=P_{phase\ 1}+P_{phase\ 2}+P_{phase\ 3}$$

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Measurement Uncertainty

$$y=f(x_1,x_2,.....x_N)$$

$$u_c(y)=\sqrt{\sum_{i=1}^{N}u_i^2(y)}=\sqrt{\sum_{i=1}^{N}\left(\frac{\partial f}{\partial x_i}\right)^2\cdot u_i^2(x_i)}$$

Describes the extent to which the output estimate y is influenced by variations of the input estimate x_i,

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Power meter specifications (example 1)

From brochure

Electrical characteristics		
Type of measurement		True rms up to the 15th harmonic (31st for ION7350) 32 samples/cycle (64 for ION7350)
Measurement accuracy	Current and voltage	0.25% + 0.05%
	Power	Real: 0.5% reading Apparent: 0.5% + 0.1% Reactive (>5% FS): 1.5% reading
	Frequency	±0.01 Hz
	Power factor (at Unity PF)	± 1.5% reading
	Energy[1]	kWh: 0.5% reading kVAh: 1.0% reading kvarh: 1.5% reading
Data update rate		1 second
Input-voltage characteristics	Measured voltage	50 - 347 VAC L-N 3-phase (87-600 L-L) 50 - 300 VAC L-N single phase (100 - 600 L-L)
	Metering over-range	25%
	Overload withstand	1500 VAC continuous 3250 VAC for 1 second non-recurring
	Impedance	>2 M Ohms/phase (phase - Vref)
	Frequency range	40 - 70 Hz
Input-current characteristics	CT ratings	5 A nominal / 10 A full scale
	Measurement range	20 mA - 10 A rms (+20%, 300 V rms to ground)
	Overload withstand	20 A continuous 500 A for 1 second non-recurring
	Burden	Worst case (at 10 A): 0.0625 VA
	Impedance	> 2 M Ohms/phase (phase-Vref)
Power supply	AC	95 - 240 VAC (± 10%), (47 - 440 Hz)
	DC	120 - 310 VDC (± 10%) 0.2 A worst case loading (12 W) at 100 VAC at 25°C
	P24 option	20 to 60 VDC (± 10%)
Input/outputs	4 Digital status inputs (7330/7350)	Self-excited (internal 30 VDC supply); Min pulse width: 25 msec; Max 40 transitions/sec
	4 digital outputs	Form A Solid State: Max forward current: 80 mA

From operation manual

1. Overload withstand: 1500 VAC continuous and 2500 VAC for 1 second on all voltage inputs.
2. Overload withstand of 300 A for 1 second on all four current inputs.
3. Meets the following accuracy and range specifications for measurements made at 1-second intervals (50Hz or 60Hz @ 25°C) for 1% to 100% of full scale (FS) rated input (100 mA to 10A) at unity power factor (PF=1):

Parameter	Accuracy ±(%rdg + %range)	Range
Voltage L-L	0.75% + 0.1%	0 to $2x10^6$
Voltage L-N	0.25% + 0.05%	0 to $1x10^6$
Frequency	0.01%	40 Hz to 70 Hz
Current	0.25%+0.05%	0 to $1x10^5$
kW (2.5% to 100% FS)	0.5%	0 to ± $3.3x10^7$
kW (1% to 2.5% FS)	1.0%	0 to ± $3.3x10^7$
kVAR (5% to 100% FS)	1.5%	0 to $3.3x10^7$
kVA	0.5%+0.1%	0 to $3.3x10^7$
kWh (2.5% to 100% FS)	0.5%	0 to $1x10^{38}$
kWh (1% to 2.5% FS)	1.0%	0 to $1x10^{38}$
kVARh	1.5% of rdg	0 to $1x10^{38}$
kVAh	1.0% of rdg	0 to $1x10^{38}$
Power Factor	1.5%	± 0.01 to ±100.00
Harmonics	1% FS	0.01 to 100.00
K Factor	5% FS	0 to $1x10^5$

4. Meets the following accuracy and range specifications for measurements made at 1-second intervals (50Hz or 60Hz @ 25°C) for 1% to 100% of full scale (FS) rated input (100 mA to 10A) at ±0.5 power factor (PF=0.5 Lead or Lag):

Parameter	Accuracy ±(%rdg + %range)	Range
Voltage L-L	0.75% + 0.1%	0 to $2x10^6$
Voltage L-N	0.25% + 0.05%	0 to $1x10^6$
Frequency	0.01%	40 Hz to 70 Hz
Current	0.25%+0.05%	0 to $1x10^5$
kW (10% to 100% FS)	0.6%	0 to ± $3.3x10^7$
kW (2% to 10% FS)	1.0%	0 to ± $3.3x10^7$
kVAR (5% to 100% FS)	1.5%	0 to $3.3x10^7$
kVA	0.5%+0.1%	0 to $3.3x10^7$
kWh (10% to 100% FS)	0.6%	0 to $1x10^{38}$
kWh (2% to 10% FS)	1.0%	0 to $1x10^{30}$
kVARh	1.5% of rdg	0 to $1x10^{38}$
kVAh	1.0% of rdg	0 to $1x10^{38}$
Power Factor	1.5%	± 0.01 to ±100.00
Harmonics	1% FS	0.01 to 100.00
K Factor	5% FS	0 to $1x10^5$

http://www.schneider-electric.com

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Power meter specifications (example 2)

Power Accuracy

Item	Specifications
Accuracy (accuracy at 6 months)	Conditions Same as the conditions for voltage and current.

Frequency	Accuracy ±(reading error + measurement range error)
DC	
• Voltage input • Current of a 30-A input element from direct input	0.05% of reading + 0.1% of range
• Current of a 2-A input element from direct input	0.05% of reading + 0.1% of range + 2 μA × voltage reading
0.1 Hz ≤ f < 30 Hz	0.2% of reading + 0.3% of range
30 Hz ≤ f < 45 Hz	0.05% of reading + 0.05% of range
45 Hz ≤ f ≤ 66 Hz	
• Current sensor input • Current of a 30-A input element from direct input • Current of a 2-A input element from direct input at the 500 mA to 2 A range	0.02% of reading + 0.04% of range
• Current of a 2-A input element from direct input at the 5 mA to 200 mA range	0.05% of reading + 0.05% of range
66 Hz < f ≤ 1kHz	0.05% of reading + 0.05% of range
1 kHz < f ≤ 10 kHz	0.15% of reading + 0.1% of range
10 kHz < f ≤ 50 kHz	0.3% of reading + 0.2% of range
50 kHz < f ≤ 100 kHz	0.014 × f% of reading + 0.3% of range
100 kHz < f ≤ 500 kHz	0.012 × f% of reading + 1% of range
500 kHz < f ≤ 1 MHz	(0.048 × f − 19)% of reading + 2% of range

* The unit of f in the read error equation is kHz.

- For temperature changes after zero level compensation or range change, add (voltage influence) × (current influence) to the DC accuracy. For details on voltage and current influence, see page 12-5.
- For self-generated heat caused by current input on an AC input signal, add the following values to the power accuracy.
  - 2-A input element: $0.004 \times I^2$% of reading
  - 30-A input element: $0.00002 \times I^2$% of reading
- For self-generated heat caused by current input on a DC input signal, add the following values to the power accuracy.
  - 2-A input element: $0.004 \times I^2$% of reading + $6 \times I^2$ μA
  - 30-A input element: $0.00002 \times I^2$% of reading + $3 \times I^2$ μA

  I is the current reading (A). The influence from self-generated heat continues until the temperature of the shunt resistor inside the WT3000 lowers even if the current input changes to a small value.
- When the data update interval is 50 ms, add 0.1% of reading to all accuracy figures.
- When the data update interval is 100 ms, add 0.05% of reading to all accuracy figures.
- All accuracy figures for 0.1 to 10 Hz are reference values.
- The power accuracy figures for 30 kHz to 100 kHz when the voltage exceeds 750 V are reference values.
- The power accuracy figures for 100 kHz to 1 MHz when the voltage (V) exceeds $2.2 \times 10^4/f$ (kHz) are reference values.
- The power accuracy figures for DC, 10 Hz to 45 Hz, and 400 Hz to 200 kHz when the current exceeds 20 A are reference values.
- The power accuracy figures for 200 kHz to 500 kHz when the current exceeds 10 A are reference values.
- The power accuracy figures for 500 kHz to 1 MHz when the current exceeds 5 A are reference values.

12.4 Accuracy

Item	Specifications
Effective input range	• 0 to ±130% of the power range (see section 5.2) for DC measurement. • ±130% of the power range for current measurement when the voltage and current are in the range of 1 to 130% of the measurement range. However, if the data update interval is 50 ms, 100 ms, 5 s, 10 s, or 20 s, the signal level of the synchronization source must satisfy the input signal level of frequency measurement (see section 12.5). • 110% for the maximum range of direct voltage and current inputs. The accuracy for 110% to 130% of the measurement range is reading error × 1.5.
Lower limit of measurement frequency	Same as the lower limit of measurement frequency for voltage and current.

Power factor (λ) influence	• When λ = 0
	  • 5 mA to 200 mA range of a 2-A input element
	  • Apparent power reading × 0.1% in the range of 45 to 66 Hz.
	  • For other frequency ranges, see below. However, the figures are reference values. Add apparent power reading × (0.1 + 0.05 × f (kHz))%
	  • 500 mA to 2 A range of a 2-A input element or 30-A input element
	  • Apparent power reading × 0.03% in the range of 45 to 66 Hz.
	  • For other frequency ranges, see below. However, the figures are reference values. Add apparent power reading × (0.03 + 0.05 × f (kHz))%
	• When 0 < λ < 1
	(Power reading) × [(power reading error %) + (power range error %) × (power range/apparent power indication value) × {tan ϕ × (influence when λ = 0)}] where ϕ is the phase angle between the voltage and current.

Line filter influence	When the cut-off frequency is 500 Hz 45 Hz ≤ f ≤ 66 Hz: Add 0.3% of reading. f < 45Hz: Add 1% of reading. When the cut-off frequency is 5.5 kHz f ≤ 66 Hz: Add 0.3% of reading. 66 Hz < f ≤ 500 Hz: Add 1% of reading. When the cut-off frequency is 50 kHz f ≤ 500 Hz: Add 0.3% of reading. 500 < f ≤ 5 kHz: Add 1% of reading.
Temperature coefficient	Same as the temperature coefficient for voltage and current.
One year accuracy	Add (reading error of accuracy at 6 months × 0.5) to the accuracy at 6 months.
Accuracy when the crest factor is set to 6	Accuracy obtained by doubling the measurement range error for the accuracy when the crest factor is set to 3

Accuracy of Other Parameters and Computation Accuracy

- Accuracy of apparent power S: Voltage accuracy + current accuracy
- Accuracy of reactive power Q: $\frac{\text{Accuracy of apparent power} + }{(\sqrt{(1.0004 - \lambda^2)} - \sqrt{(1 - \lambda^2)})} \times 100\%$ of range
- Accuracy of power factor λ: ±[(λ − λ/1.0002) + |cosϕ − cos{ϕ + sin⁻¹(influence from the power factor when λ = 0%/100)}|] ± 1 digit when voltage and current is at rated input of the measurement range
- Accuracy of phase difference ϕ: ±[|ϕ − cos⁻¹(λ/1.0002)| + sin⁻¹{(influence from the power factor when λ = 0%)/100}] deg ± 1 digit when voltage and current is at rated input of the measurement range
- For the accuracy of frequency fU and fI, see "Frequency Measurement" in section 12.5, "Functions."
- For the accuracy of measured values WP, WP+, WP-, q, q+, and q- and the integration time, see "Integration" in section 12.5, "Functions."
- For the accuracies of voltage, current, and power during harmonic measurement; the accuracies of rotating speed and torque; and the accuracy of D/A output; see the respective sections in the *Expansion Function User's Manual IM760301-51E*.

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Power meter specifications (example 3)

Electrical characteristics			
Type of measurement			True RMS
Measurement accuracy* at current operating range: For 5A Nominal CT: 0.25A to 6A. For 1A nominal CT: 0.15A to 1.2A	Power	Active	+/-0.5% of reading at Cos Ø=1 for EM1250 and EM1251
		Apparent	+/-0.5% of reading at Cos Ø=1 for EM1250 and EM1251
		Reactive	+/- 1.0% of reading at Cos Ø=1 for EM1250 and EM1251
	Power factor		+/- 0.5% of reading at Cos Ø=1 for EM1250 and EM1251
	Energy	Active	Class 0.5 as per IEC 62053-22 for EM1250 and EM1251
		Apparent	+/- 0.5% of reading for EM1250 and EM1251
		Reactive	Class 1.0 as per IEC 62053-24 for EM1250 and EM1251
Note: * PF error limit is same as W error limit in %			
Data update rate			1s
Input-voltage characteristics	Inputs		V1, V2, V3, VN
	Measured voltage		80 to 480 VAC L-L without PTs Up to 999 kV with external PTs
	Permissable overload		600 VLL
→	Burden		0.2 VA per phase max.
	Impedance		VLL - 3 MΩ, VLN – 3 MΩ (with communication
	Frequency		50/60 Hz+/-5%
Input-current	CT ratings	Primary	1A - 99.0KA for 1A meter 5 A- 99.0KA for 5A meter
		Secondary	1A for EM1251 5A for EM1250
	Measurement range		250mA to 6A with 0.5% accuracy for EM1250 . Starting current 5mA 150mA to 1.2 A with 0.5% accuracy for EM1251 . Starting current 1mA
	Permissible overload		10A for EM1250 and 2A for EM1251
→	Burden		<0.2 VA per phase
	Impedance		< 0.1 ohm
Auxiliary supply	AC		44 to 277 V
	DC		44 to 277 V
	Burden		4 VA max.

http://www.metersusa.com/index.html

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Power meter specifications (example 4)

Electrical characteristics			
Type of measurement			True RMS up to the 9th harmonic 20 samples per cycle at 50 Hz
Measurement accuracy*	Current and voltage		1.0 % of reading
	Frequency		0.1 % of reading
	Power factor		1.0 % of reading
* Additional error of 0.05% of full scale, for meter input current below 100mA			
Data update rate			1 second
Input-voltage characteristics	Inputs		V1, V2, V3, Vn
	Measured voltage		80 - 480 V AC L-L without PTs Up to 999 kV with external PTs
	Permissible overload		1.10 Un (480 V L-L)
	Burden		0.2 VA per phase max.
	Impedance		VLL - 4 Mohms, VLN – 2 Mohms
	Frequency range		45 - 65 Hz
Input-current characteristics	CT ratings	Primary	1 A - 99.0 kA
		Secondary	1 A - 5 A
	Measurement range		50 mA - 6 A (5 mA is the starting)
	Permissible overload		10 A continuous
	Burden		0.2 VA per phase max.
	Impedance		< 0.1 ohm
Power supply	AC		44 - 277 V AC at 50 Hz/60 Hz
	DC		44 - 277 V DC
	Ride-through time		100 ms at 50V
	Burden		3 VA max.

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Power meter specifications (example 5)

VERIS INDUSTRIES

Enercept® Networked Power Transducers (Modbus® RTU)

Integral Monitoring Solution Eliminates The Need For Separate Enclosures

APPLICATIONS

- Energy managing & performance contracting
- Monitoring for commercial tenants
- Activity-based costing in commercial and industrial facilities
- Real-time power monitoring

FEATURES

The world's most cost-effective power transducer

- Monitor energy parameters (kW, kWh, kVAR, PF, Amps, Volts) at up to 63 locations on a single RS-485 network...greatly reduces wiring time and cost
- Fast split-core installation eliminates the need to remove conductors...saves time and labor
- Precision electronics and current transformers in a single package...reduces the number of installed components...huge labor savings
- Smart electronics eliminate CT orientation concerns...fast trouble-free installation

High accuracy

- ±1% total system accuracy, (10% to 100% of CT rating)



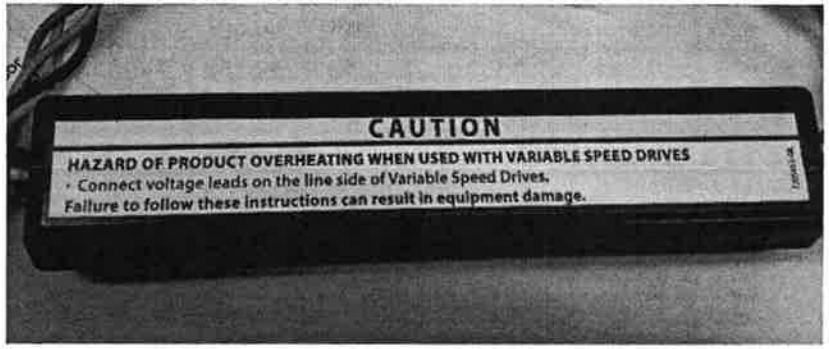
5 Year Warranty

DESCRIPTION

The Enercept H8035/8036 are innovative three-phase networked (Modbus RTU) power transducers that combine measurement electronics and high accuracy industrial grade CTs in a single package. The need for external electrical enclosures is eliminated, greatly reducing installation time and cost.

There are two application-specific platforms to choose from. The Basic Enercept energy transducers (H8035) are ideal for applications where only kW and kWh are required. The Enercept Enhanced power transducers (H8036) output 26 variables including kW, kWh, volts, amps, and power factor, making them ideal for monitoring and diagnostics.

Color-coordination between voltage leads and CTs makes phase matching easy. Additionally, the Enercept automatically detects and compensates for phase reversal, eliminating the concern of CT load orientation. Up to 63 Enercepts can be daisy-chained on a single RS-485 network.



SPECIFICATIONS

Inputs:	
Voltage Input	208 to 480VAC, 50/60 Hz RMS †(††)
Current Input	Up to 2400A continuous per phase †
Accuracy:	
System Accuracy	±1% of reading from 10% to 100% of the rated current of the CTs, accomplished by matching the CTs with electronics and calibrating them as a system
Outputs:	
Type	Modbus RTU**(*)
Baud Rate	9600, 8N1 format
Connection	RS-485, 2-wire + shield
Environmental:	
Operating Temperature Range	0° to 60°C (32° F to 140°F), 50°C (122°F) for 2400A
Humidity Range	0 - 95% non-condensing

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Power meter specifications (example 6)

1.1. Specifications

Measurement Accuracy:	
Real Power and Energy	IEC 62053-22 Class 0.5S, ANSI C12.20 0.5%
Reactive Power and Energy	IEC 62053-23 Class 2, 2%
Current	0.4% (+0.015% per °C deviation from 25°C) from 5% to 100% of range; 0.8% (+0.015% per °C deviation from 25°C) from 1% to 5% of range
Voltage	0.4% (+0.015% per °C deviation from 25°C) from 90V $_{L-L}$ to 600VAC $_{L-L}$
Sample Rate	2520 samples per second
Data Update Rate	1 sec
Type of Measurement	True RMS up to the 21st harmonic 60 Hz One to three phase AC system
Input Voltage Characteristics:	
Measured AC Voltage	Minimum 90V_{L-N} (156V_{L-L}) for stated accuracy; UL Maximums: 600V_{L-L} (347V_{L-N}) CE Maximums: 300V_{L-N} (520V_{L-L})
Metering Over-Range	+20%
Impedance	2.5 MΩ $_{L-N}$ /5 MΩ $_{L-L}$
Frequency Range	45 to 65 Hz
Input Current Characteristics:	
CT Scaling	Primary: Adjustable from 5A to 32,000A
Measurement Input Range	0 to 0.333VAC or 0 to 1.0VAC (+20% over-range)
Impedance	10.6kΩ (1/3 V mode) or 32.1kΩ (1 V mode)

ISO/IEC 62053-22 Static Meters for active energy (class 0.2s and 0.5s)

Table 4 – Percentage error limits
(single-phase meters and polyphase meters with balanced loads)

Value of current	Power factor	Percentage error limits for meters of class	
		0,2 S	0,5 S
0,01 $I_n \le I < 0,05\ I_n$	1	±0,4	±1,0
0,05 $I_n \le I \le I_{max}$	1	±0,2	±0,5
0,02 $I_n \le I < 0,1\ I_n$	0,5 inductive	±0,5	±1,0
	0,8 capacitive	±0,5	±1,0
0,1 $I_n \le I \le I_{max}$	0,5 inductive	±0,3	±0,6
	0,8 capacitive	±0,3	±0,6
When specially requested by the user: from 0,1 $I_n \le I \le I_{max}$	0,25 inductive	±0,5	±1,0
	0,5 capacitive	±0,5	±1,0

Source: Emerson 250-5000 Energy Meter Installation and Operation Manual

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Terms commonly used in calibration of instrument

ISO/IEC 17025:2005
General requirements for the competence of testing and calibration laboratories

ISO/IEC Guide 99:2007, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*

- **measurement error :** measured quantity value minus a reference quantity value
- **correction :** compensation for an estimated systematic effect
- **metrological traceability:** property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty
- **calibration:** operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.
- **adjustment:** set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured
- **accuracy class:** class of measuring instruments or measuring systems that meet stated metrological requirements that are intended to keep measurement errors or instrumental uncertainties within specified limits under specified operating conditions

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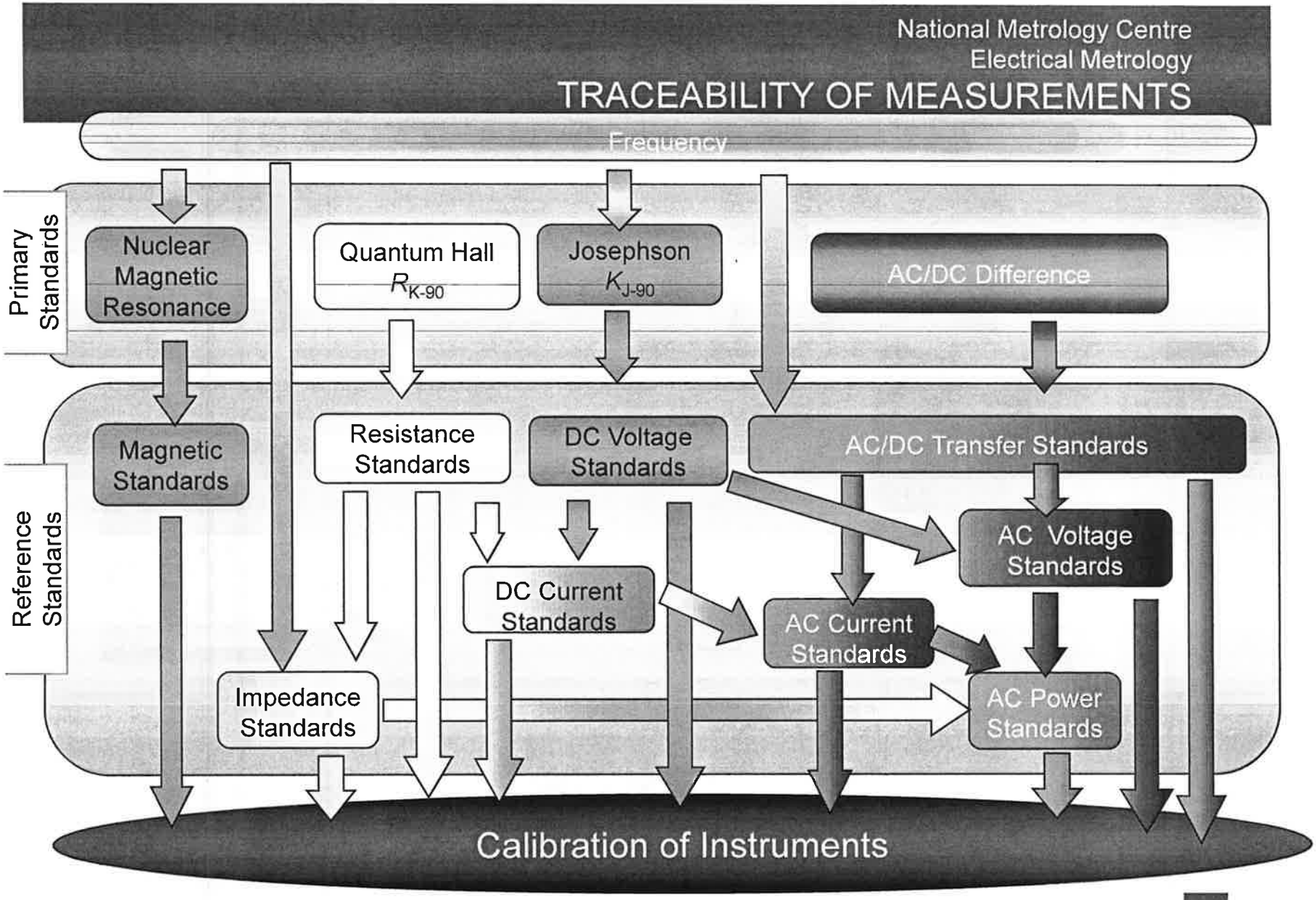

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NMC

Calibration of power meter and instrumentation transformers

Reference Standard for Power

AC Voltage standard
AC Current Standard
Phase standard

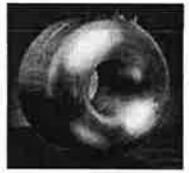


3 Phase
Power
Standard



3 Phase
Power meter

Reference Standard for Current Transformer





Stationary, automatic
CT/VT test system

Customized
connection table



Current
Transformer



Reference Standard for Voltage Transformer





Transformer
Calibration System



Voltage
Transformer

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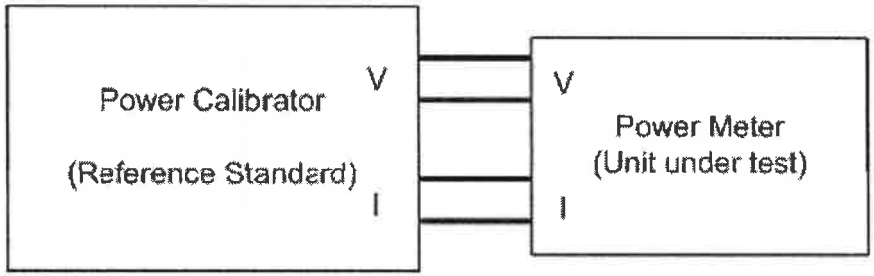
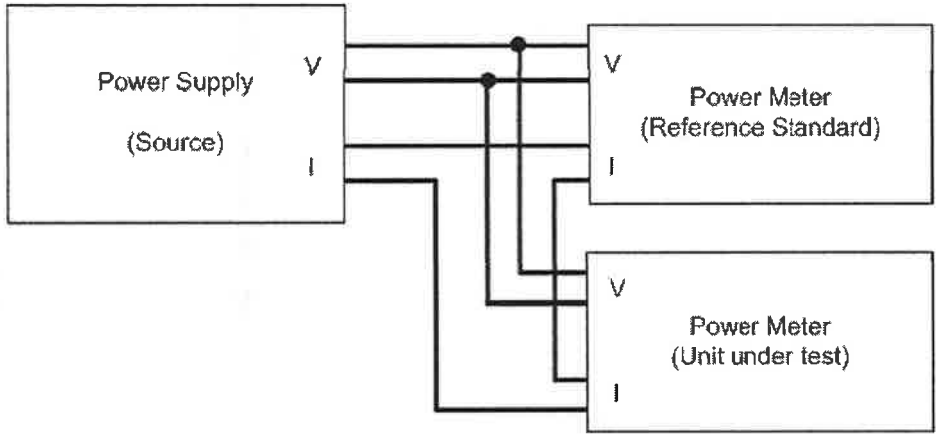
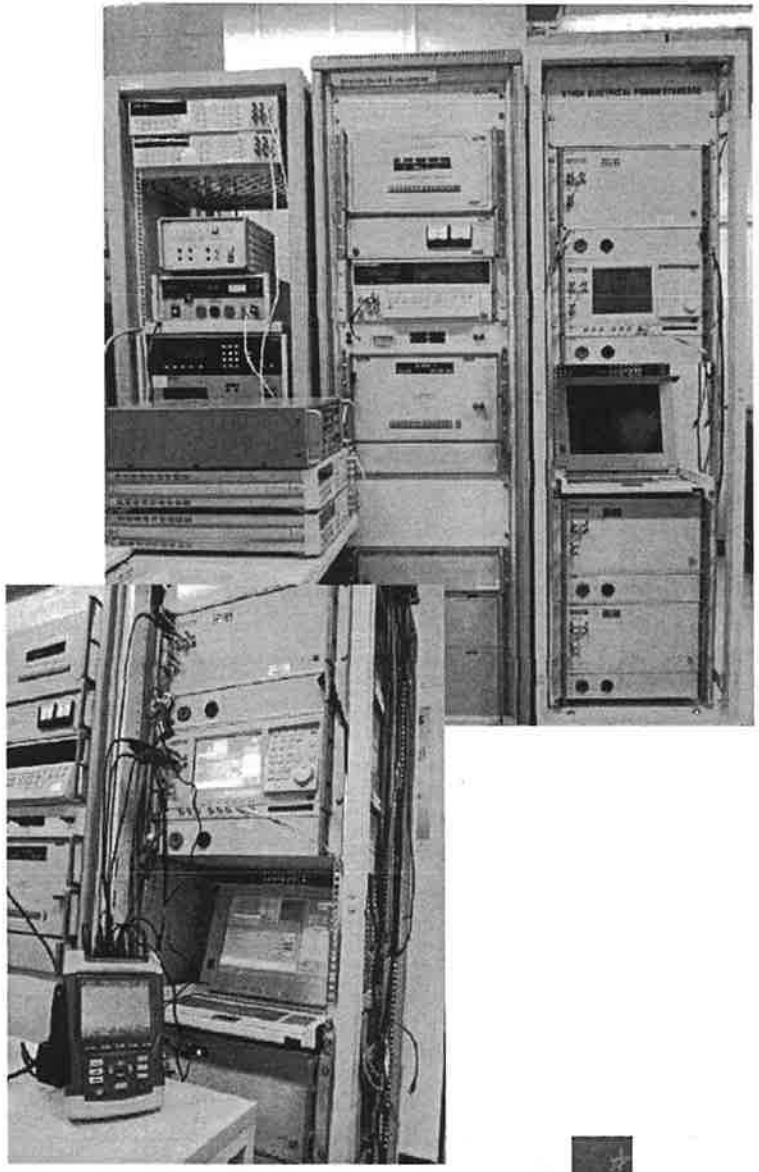
Calibration of power meter



Direct Calibration



Comparison Calibration



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Power Meter calibration report (example)

National Metrology Centre
A*STAR

CALIBRATION REPORT

Report No. : [redacted] **Page 1 of 4**

Customer : [redacted]

Subject Details

Subject	:	Power HiTester
Manufacturer	:	
Model	:	
Serial Number	:	[redacted]
Sales Order No.	:	[redacted]
Calibration Date	:	2013-11-26

Ambient Conditions

Temperature	:	(23 ± 1) °C
Relative Humidity	:	(55 ± 5) % relative humidity

[redacted]
Calibration Officer

[redacted]
Approving Officer
Electrical Metrology

For further enquiries, please contact the calibration officer at Tel: [redacted], Fax: +65 6279 1992 or Email: [redacted]

National Metrology Centre
1 Science Park Drive Singapore 118221
Tel: (65) 6279 1900 Fax: (65) 6279 1992
Website: www.nmc.a-star.edu.sg

Science and Engineering Institute Limited (Co.Reg.No. 200720829Z)

Note : This Report is issued subject to the "Terms and Conditions for Services" available at www.nmc.a-star.edu.sg and on request from National Metrology Centre. This Report is not a Certificate of Quality. It only applies to the sample of the specific product/equipment given at the time of its testing/calibration.

SAMPLE

Method of Calibration

This Power HiTester has been calibrated at the National Metrology Centre under the stated ambient conditions. The calibration of the instrument was carried out following the manufacturer's instructions given in the [redacted] User's Manual.

The measurement points were performed on the instrument in accordance with customer's request.

The calibration was carried out using the following standards traceable to national reference standards maintained at National Metrology Centre:

1) Calibrator (serial no.: [redacted])
2) Electrical Power Standard (serial no.: [redacted])

Results of Calibration

The results of this calibration are shown on pages 3 to 7. The expanded measurement uncertainties were estimated at a level of confidence of approximately 95% with a coverage factor k=2.

The results and their associated uncertainties are applicable at the time of calibration.

The calibration did not cover the full ranges of the instrument. The user should determine the suitability of this instrument for its intended use.

The recalibration interval should be determined based on the user's requirements.

[redacted]
Calibration Officer

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Power meter calibration report (example)

Report No. :

Test	Applied Value	Indicated Value		Estimated Uncertainty
		Before Adjustment	After Adjustment	
Range: 150 V, 50 mA, 50 Hz	7.500 0 W	7.500 1 W	-	0.033 %
150 V, 100 mA, 50 Hz	15.000 0 W	15.001 W	-	0.029 %
150 V, 200 mA, 50 Hz	30.000 0 W	29.995 W	-	0.026 %
150 V, 500 mA, 50 Hz	75.000 W	75.003 W	-	0.027 %
150 V, 1 A, 50 Hz	150.000 W	149.98 W	-	0.023 %
150 V, 2 A, 50 Hz	300.000 W	299.95 W	-	0.021 %
150 V, 5 A, 50 Hz	750.000 W	750.14 W	-	0.021 %
150 V, 10 A, 50 Hz	1 500.00 W	1.500 6 kW	-	0.024 %
150 V, 20 A, 50 Hz	3 000.00 W	2.998 9 kW	-	0.027 %
150 V, 50 A, 50 Hz	3 000.00 W	2.998 6 kW	-	0.027 %
2) Energy Check, PF = 1, 1 hour				
Range: Auto,	230 V, 10 A, 50 Hz (2.300 0 kWh)	2.300 57 kWh	-	0.042 %

Calibration Officer

SAMPLE

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Calibration providers

First preference should be given to a calibration laboratory or national metrology institute (NMI) that is accredited/conformed to ISO/IEC 17025 General requirements for the competence of testing and calibration laboratories. (For example, in Singapore, SAC-SINGLAS accredited laboratories, other countries – accredited laboratories under the ILAC MRA accreditation scheme, NMI under the CIPM global metrology MRA)

The laboratory's scope of accreditation should be examined to see whether the laboratory has the capability of calibrating a particular measuring instrument.

If accredited calibration laboratory is not available, calibration laboratory/manufacturer could be used based on an assessment of the laboraotry's capability. For example:

- Traceability of the standard.
- Correct test uncertainty ratio.
- Detailed data, measurement uncertainty and result stated in the report
- Technical competency.
- Market reputation.
- Other information on capability e.g. proficiency test result
- etc

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Question ?

End of Presentation

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A*STAR NMC

Flow & Pressure measurements For Energy Meter

Training for BCA Energy Saving Programme

Wu Jian
National Metrology Centre
A*STAR

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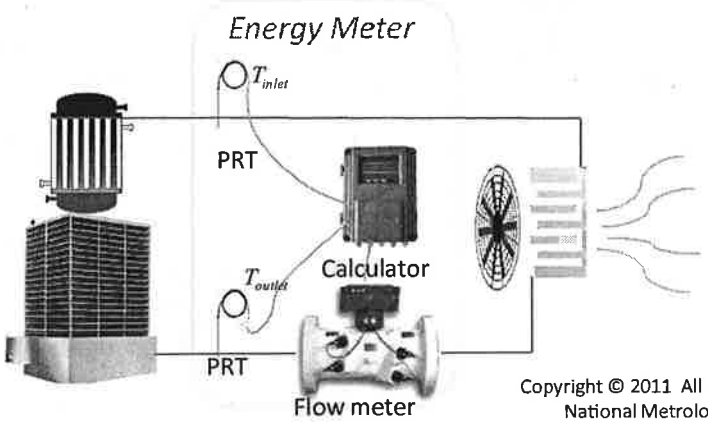
Energy meter

$$W = \dot{m} \cdot \Delta h$$

$$\Delta h = Cp(\theta) \cdot (T_{inlet} - T_{outlet})$$

Specific heat capacity

W: Energy quantity
$\dot{m}$ Mass flow rate
Δh: Enthalpy





Turbine Cold Water Meters

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Accuracy requirements for energy meter

INTERNATIONAL RECOMMENDATION

OIML R 75-1
Edition 2002 (E)

Heat meters
Part 1: General requirements

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

FINAL DRAFT
prEN 1434-1

English Version

Heat meters - Part 1: General requirements

BRITISH STANDARD

BS EN
14154-1:2005
Incorporating amendment no. 1

Water meters —

Part 1: General requirements

OIML R 75-1 Edition 2002 (E)

ORGANISATION INTERNATIONALE DE METROLOGIE LEGALE
INTERNATIONAL ORGANIZATION OF LEGAL METROLOGY

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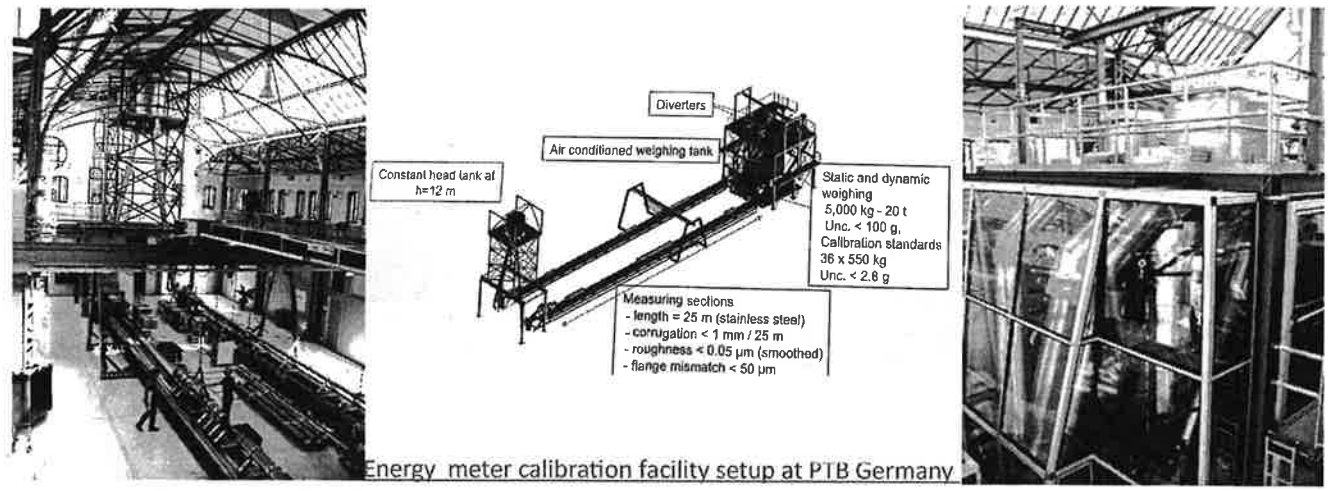
Calibration of energy meter

Calibration requirements for the energy meter

1. *Flow meter*
2. *Temperature*
3. *Calculator for the specific heat*

   ** Integrated calibration for performance on W (energy) is also required*



Energy meter calibration facility setup at PTB Germany

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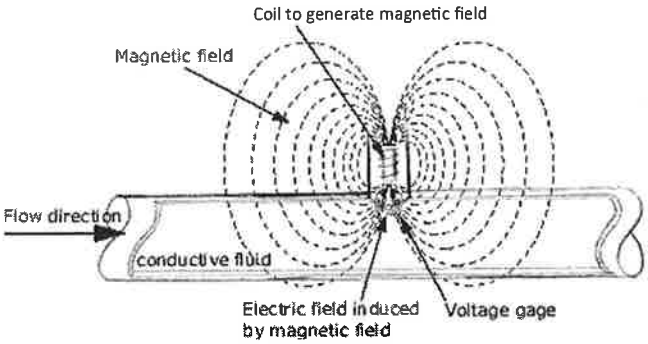
Flowmeters -Electromagnetic Flow Measurement



$$Q = U_i \frac{\pi \cdot D}{4 \cdot k \cdot B}$$



Ui = (v x B) • L

where:

Ui: *induced voltage (vector)*
B: *induction (vector)*
L : *length of conductor moving through a magnetic field, and*
V: *its velocity (vector)*
K: *non-dimensional constant*

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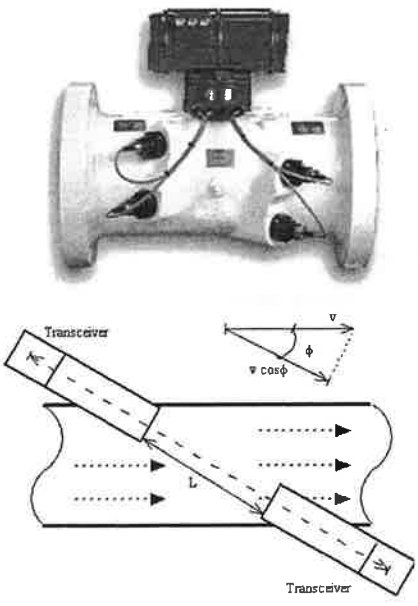
Flowmeters – Ultrasonic Flow Measurement



$$Q = V * A$$

Where: V is the water velocity
A is the cross area of meter

$$V = \frac{L^2}{2X}\left(\frac{T_{21} - T_{12}}{T_{21} \cdot T_{12}}\right)$$

L&X : *the direct and lateral (along the pipe axis and in the flowing liquid) distances between the two transducers*
V: *velocity*
T12 and T21: *transit times in each direction.*

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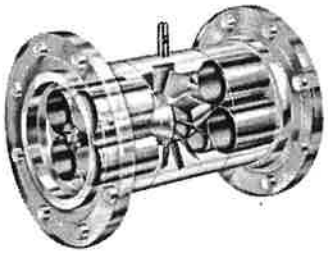
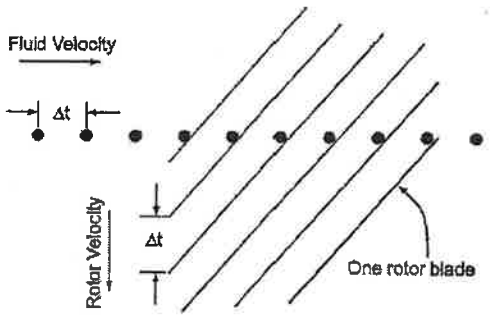
Flowmeters – Turbine Flow Measurement



$$Q_v = \frac{\omega}{\left(\frac{\tan\beta}{r_a \cdot A}\right)}$$

ω = rotor angular velocity
β = blade angle
r_a = average blade radius
A = flow area
q_v = volumetric flowrate





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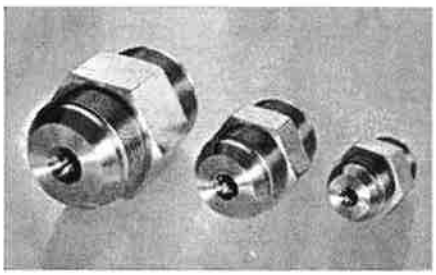
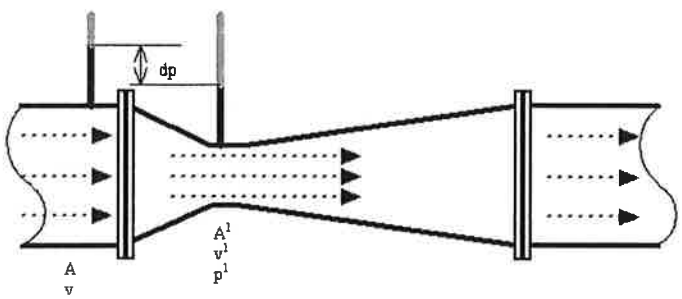
Flowmeters – Sonic Nozzle Flow Measurement



$$q_m = \frac{\pi}{4} \frac{C_d Y d^2}{\sqrt{1-\beta^4}} \sqrt{2\rho\Delta P}$$

where:

$\beta = d/D$
D = pipe diameter
d = throat diameter
ρ = density
ΔP = differential pressure



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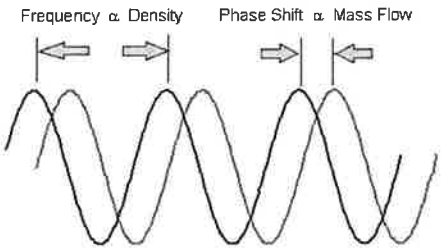
Flowmeters –Coriols Flow Measurement

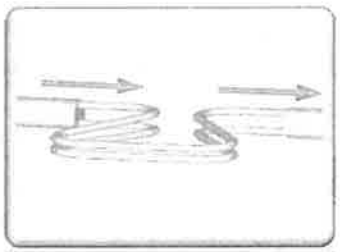


$$Q_m = \frac{k}{8 \cdot r^2 \cdot L} \cdot \Delta T$$

where

K	a shape-dependent factor
d	the width
τ	the time lag
ω	the vibration frequency
I_u	the inertia of the tube





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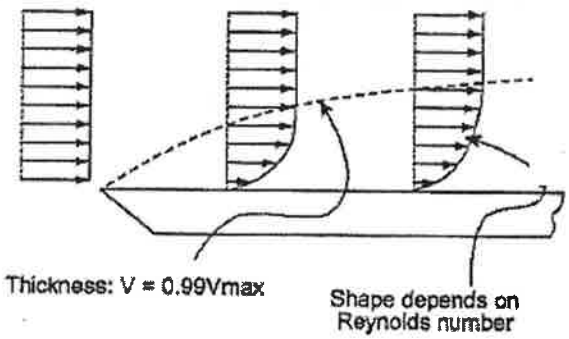
Flow profile

Boundary Layer

Shown below is the development of the boundary layer on flat plate in a region of uniform velocity:



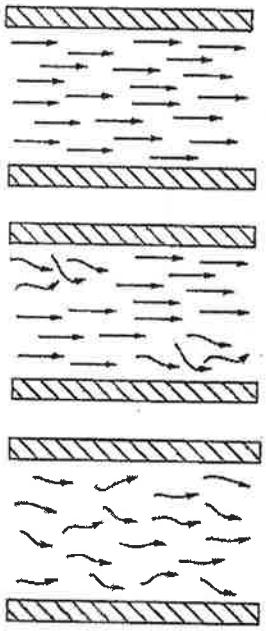
Mass and volume flow rate

Laminar Flow

- No fluid layer mixing
- Straight dye line
- Reynolds number usually less than 2300
- Infrequently encountered in flow measurement (exception is the LFE)

Turbulent Flow

- Adjacent fluid layers are mixed
- Dye line dispersed
- Reynolds number usually greater than 2300
- Most flows of practical interest



Flow profile

Flow Profile Distortion

Fully Developed Flow Profile

- Theoretical profiles are "fully developed"
- Actual profiles depend on installation
- Flowmeter performance effects vary based on technology

Fully developed flow profile (ASME):

"A velocity distribution, in a straight length of pipe, that has zero radial and azimuthal fluid velocity components and an axisymmetric axial velocity profile that is independent of axial position along the pipe."

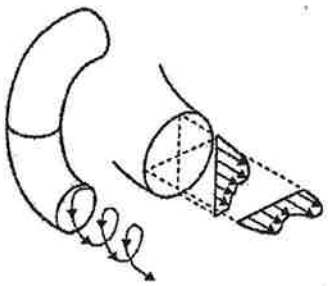
Distortion

Distortion sources

- Elbow(s) in or out of plane
- Spiral welded pipe
- Expanders and reducers
- Valves especially when partially open

Double Out of Plane Elbows

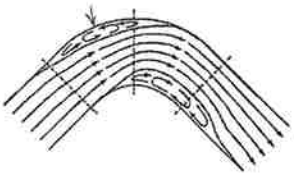
- Classic worst case
- Common pipe fitting
- Produces swirl and profile distortion

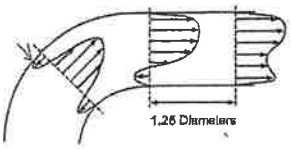


Flow profile

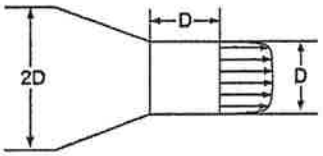
Flow Profile Disturbances

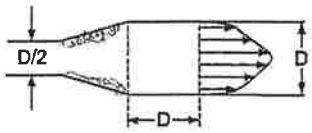
Single Elbow





Converging and Diverging Sections

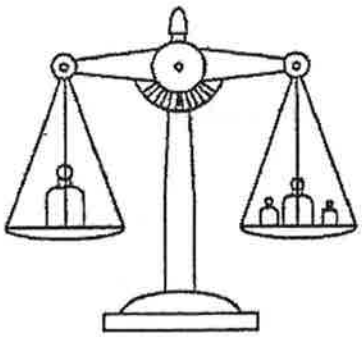


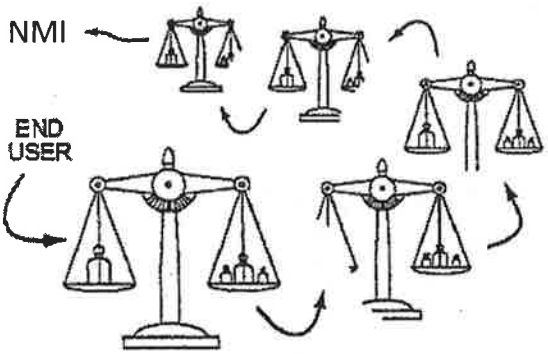


Traceability & Calibration of Flowmeter

Traceability

Mass Measurement

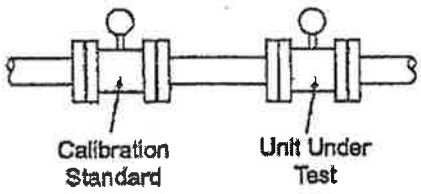


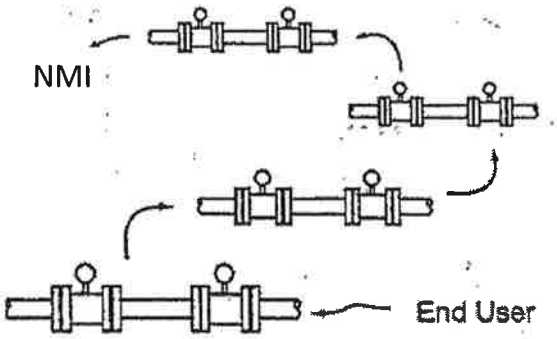


Traceability & Calibration of Flowmeter

Traceability

Flow Measurement

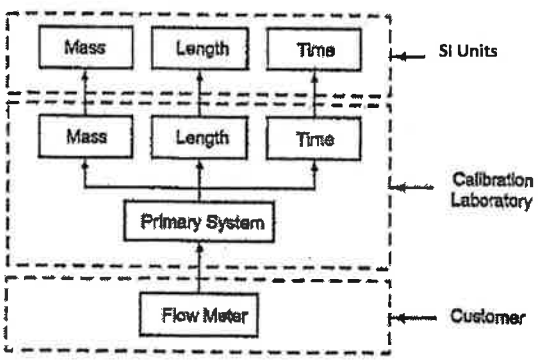


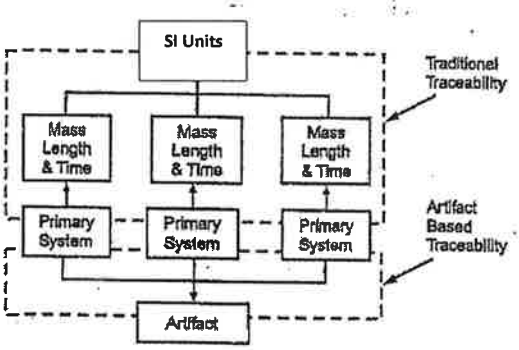


Traceability & Calibration of Flowmeter

- Sample of Meter Manufacture's traceability chart

Flow Measurement Traceability



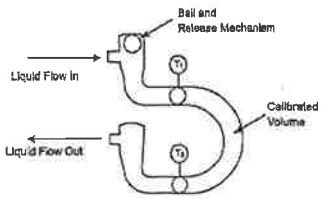


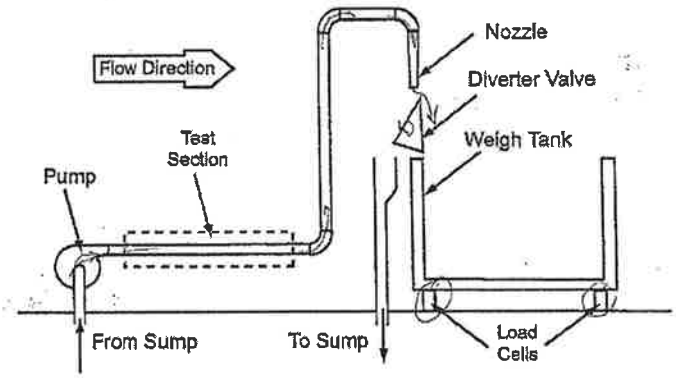
Traceability & Calibration of Flowmeter

Primary Calibration Systems

- Traceable via mass, length, and time
- Gravimetric: direct mass measurement
- Volumetric: mass determined from length (volume) and density
- Volumetric:
  - Fixed density, variable volume
  - Fixed volume, variable density

Volumetric Liquid System - Ball Prover





Mass Flow Calibration Facility

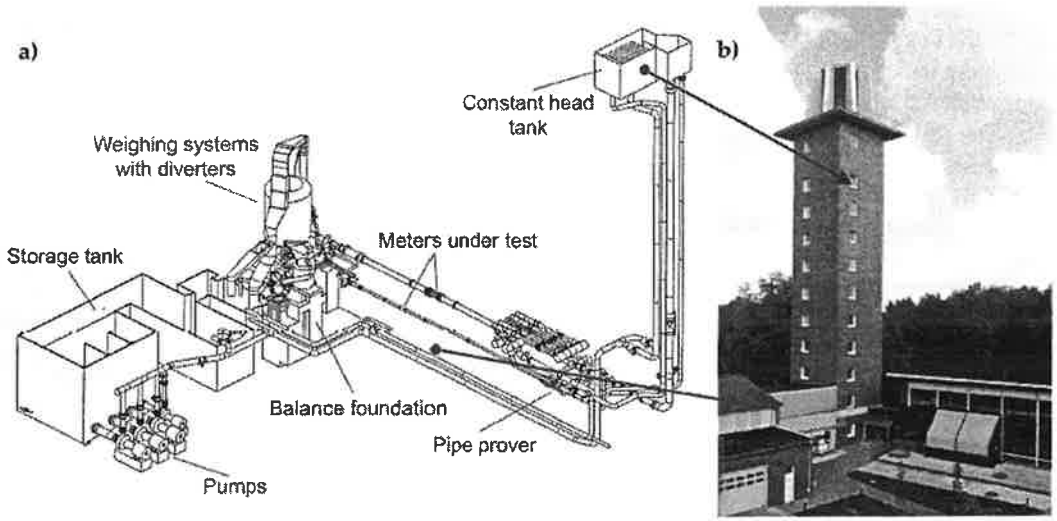
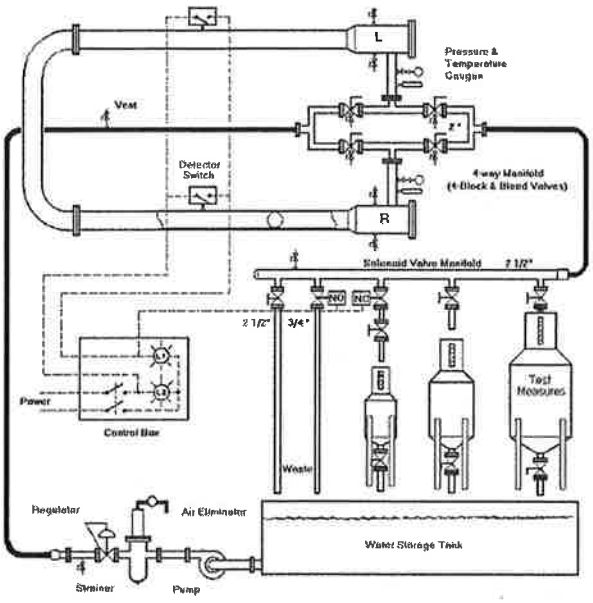
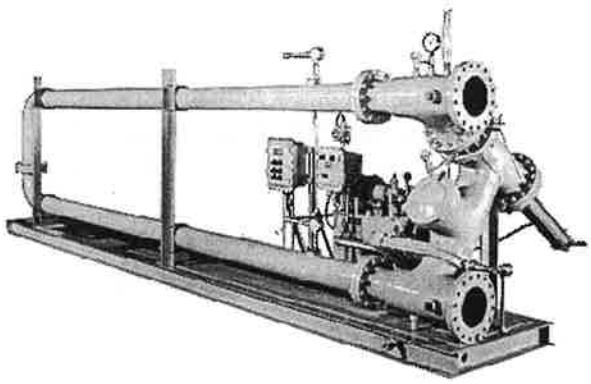


Figure 2:
a) Cutaway view of PTB's water flow calibration plant
b) PTB's Willy Wien Tower
(housing the constant-head tank of the standard flow facility on the 9th floor, at a hight of 35 m)

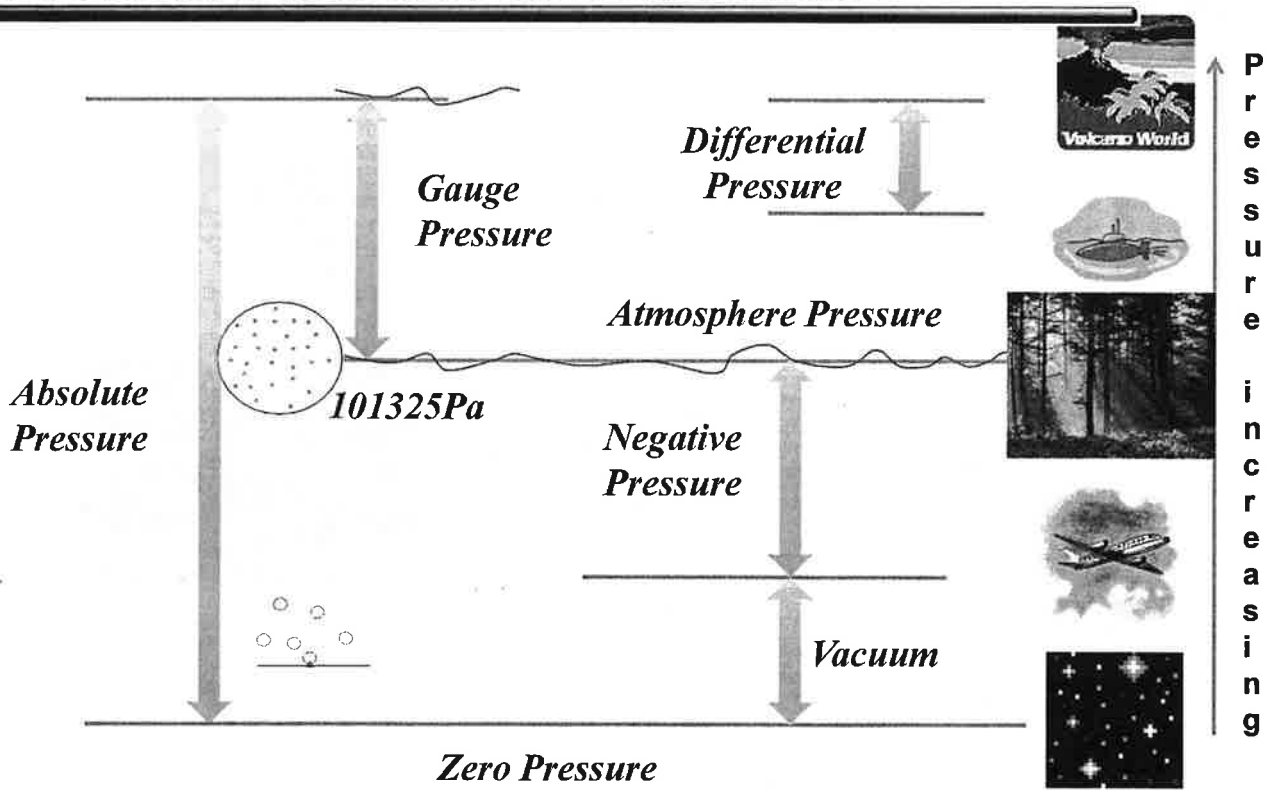
Water flow calibration facility setup at PTB Germany

Volume Flow Calibration Facility





Pressure Measurement Scales



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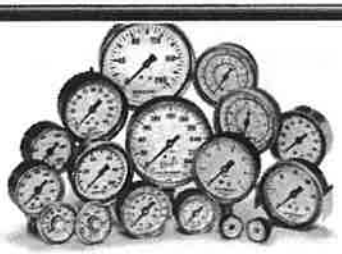
Pressure Measurement Devices



Industrial Pressure Gauges



Manometer



Industrial Pressure Transducers



Pressure Reference Standards



Primary Pressure Standards

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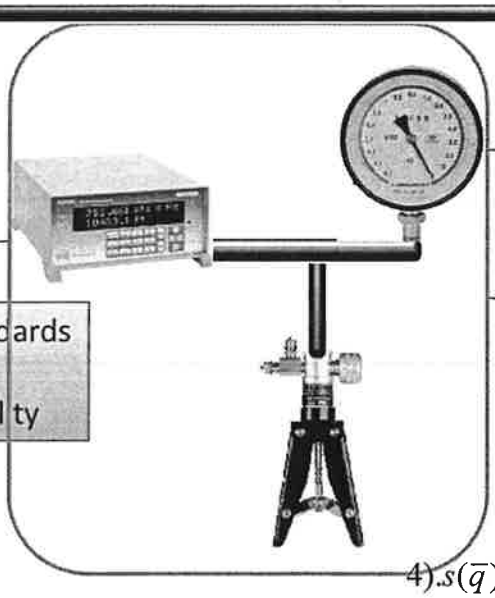
Measurement Uncertainty Estimation for a Calibration



1. Uncertainty of standards
2. The long term stability
3. Resolution
4. Repeatability

1). $u_{ref}(y) = \frac{U_{ref}}{k}$

2). $u(x_a) = \frac{a}{\sqrt{3}}$

3). $u(x_{res}) = \frac{resolution}{2\sqrt{3}}$

4). $s(\bar{q}) = \frac{s(q_k)}{\sqrt{n}} = \sqrt{\frac{1}{n-1}\sum_{k=1}^{n}(q_k - \bar{q})^2} \times \frac{1}{\sqrt{n}}$

Combined Uncertainty

$c_i = \frac{\partial f}{\partial x_i}$

$u_c(y) = \sqrt{\sum_{i=1}^{N}\{c_i u(x_i)\}^2}$

$\nu_{eff} = \frac{u_c^4(y)}{\sum_{i=1}^{n}\frac{[c_i u(x_i)]^4}{\nu_i}}$

$U = k u_c(y)$

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National Metrology Centre

Thank you for your attention!

If you need further help, please contact :

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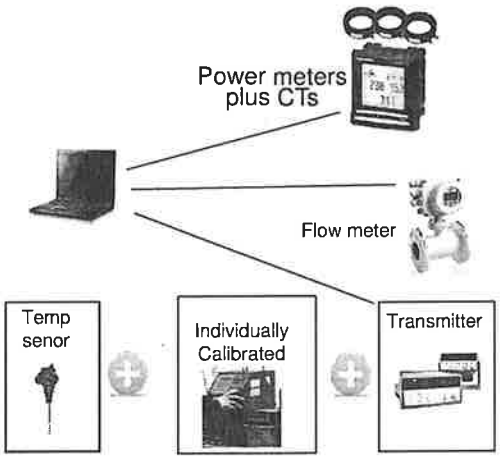
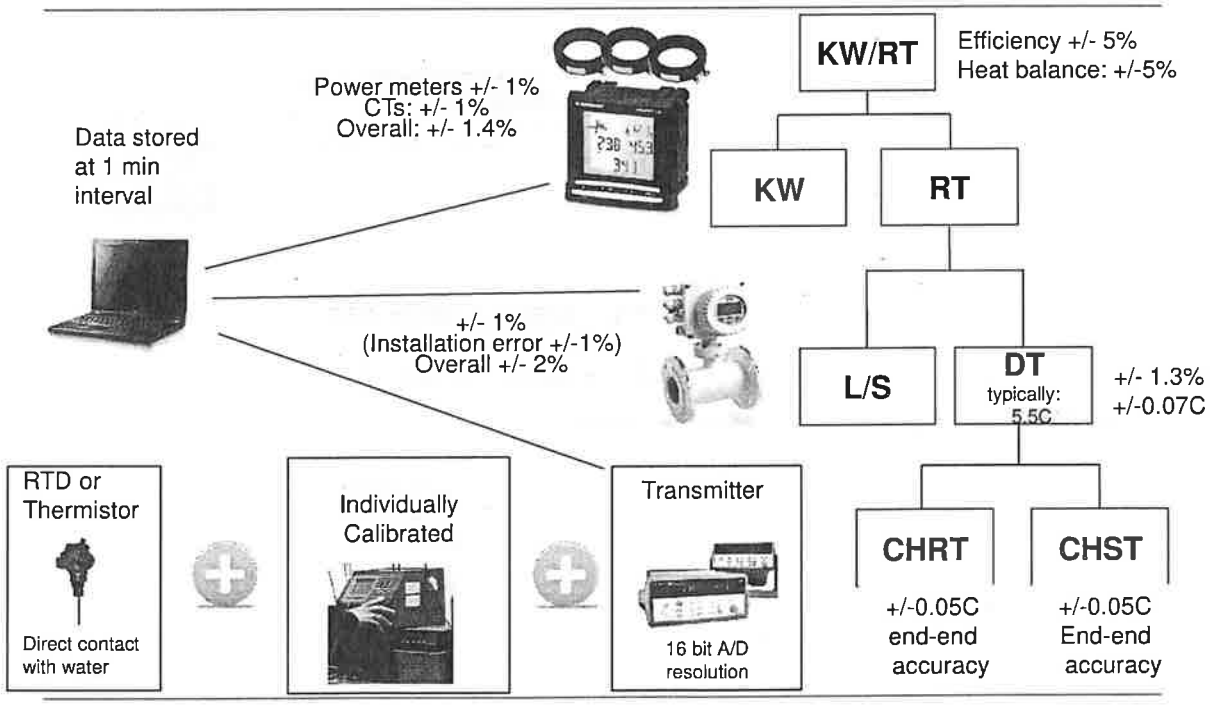
Demostration of chiller plant instruments



Instrument accuracy



Temperature measurement

Steinhart-Hart Thermistor Equation

The Steinhart-Hart equation is the best method to describe the Resistance vs Temperature relationship of Negative Temperature Coeff (NTC) thermistors. The Steinhart-Hart equation is an empirically derived polynomial formula.

$$1/T = a + b\,(\mathrm{Ln}R) + c\,(\mathrm{Ln}\,R)^3$$

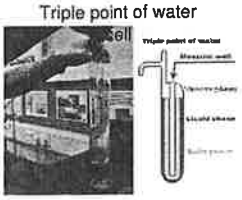
T: Temperature in K (C + 273)
R: Resistance in ohms
a, b, c: Coeff derived from calibration

Calibration of thermistors

Calibration is carried at 3 temperature points to provide the a, b, c constants that characterize the thermistors to an accuracy of 0.012C.

High accuracy calibration uses two International Temperature Scale (ITS) fixed temperature points: triple point of water (0.0100C) and melting point of gallium (29.7464C) plus a 3rd temperature point (15.000C) using a precision water bath verified by Standard Platinum Resistant Thermometer (SPRT) and Super-thermometer.

Triple point of water



0.0100 C

Gallium cell

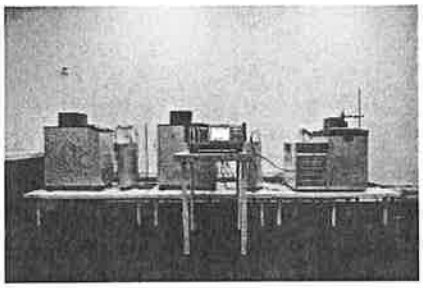


29.7646 C

Temp bath with SPRT



15.000 C



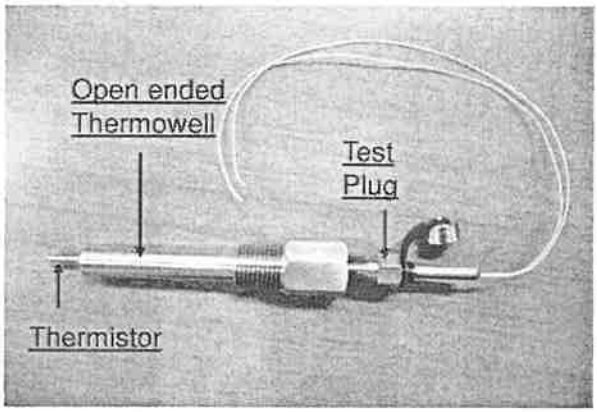
Calibrated Thermistors

Adobe Acrobat Document

Installation of Thermistor

To improve accuracy and response time:

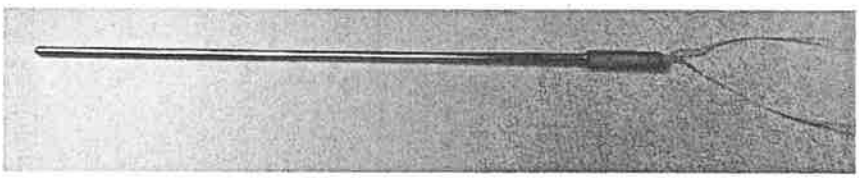
Thermistor is in direct contact with fluid



Thermistor and accessories



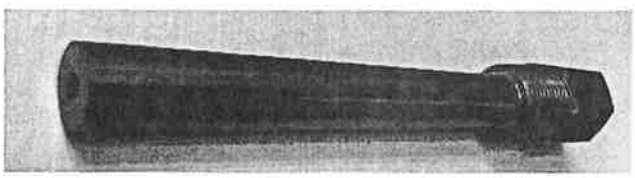
Test plug



Thermistor in 3mm diameter SS sheath stem



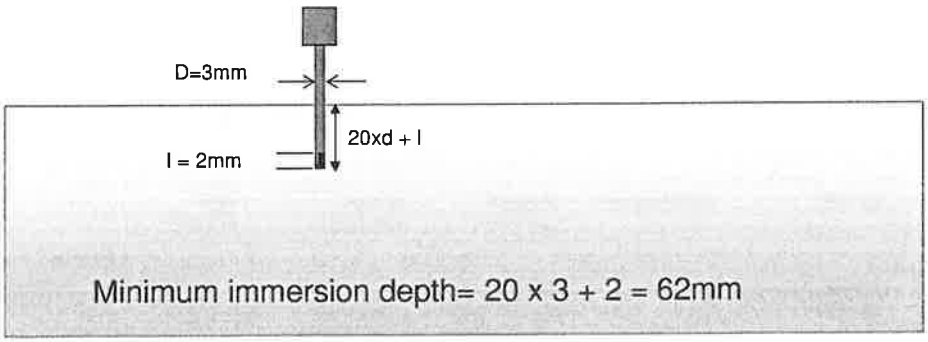
Open ended
thermal well



Immersion depth

Insufficient immersion of temperature probe will cause measurement error due to the effect of heat conduction along the steel stem.

Recommended minimum immersion length = 20 x Diameter of steel stem (d) + sensor length (l).

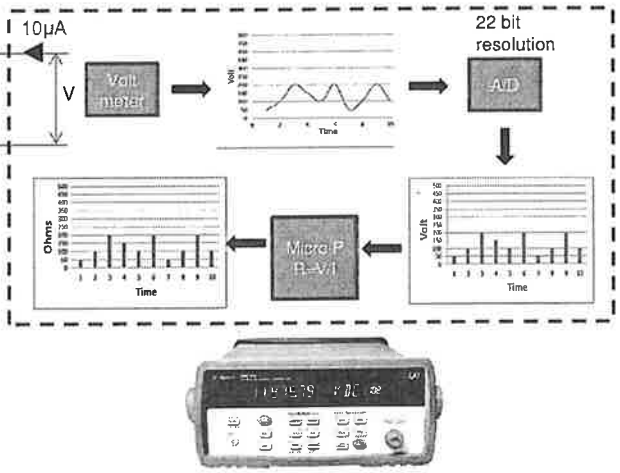


Temperature measurement chain

Calibrated thermistor with a/b/c constants



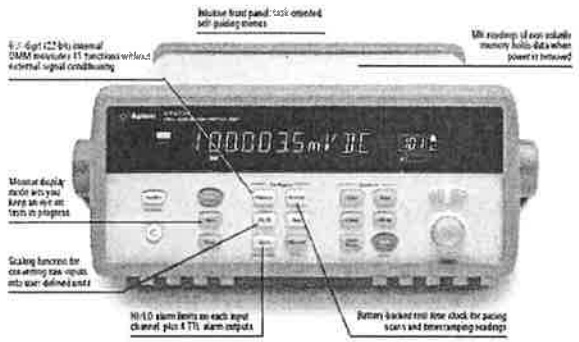
Agilent 34970 Data logger



R(Ω)

In Nov 2014, Agilent spin off its electronic measurement business to become Keysight.

Measurement of thermistor resistance



- Measurements include dc volts, ac volts, thermocouple, thermistor and RTD temperature measurements, 2- and 4-wire Ohms, dc current, ac current, frequency, and period
- 6½ digits (22 bits) of resolution with 0.004% basic 1-year dcV accuracy

Resistance measurement uncertainty
+/- (% reading + % range)

	Range[3]	Frequency, etc.	24 Hour[2] 23°C±1°C	90 Day 23°C±5°C	1 Year 23°C±5°C
Resistance[6]					
	100.0000	1 mA current source	0.0030 + 0.0035	0.008 + 0.004	0.010 + 0.004
	1.000000 k	1 mA	0.0020 + 0.0006	0.008 + 0.001	0.010 + 0.001
	10.00000 k	100 µA	0.0020 + 0.0005	0.008 + 0.001	0.010 + 0.001
	100.0000 k	10 µA	0.0020 + 0.0005	0.008 + 0.001	0.010 + 0.001
	1.000000 M	5.0 µA	0.002 + 0.001	0.008 + 0.001	0.010 + 0.001
	10.00000 M	500 nA	0.015 + 0.001	0.020 + 0.001	0.040 + 0.001
	100.0000 M	500 nA/10 M	0.300 + 0.010	0.800 + 0.010	0.800 + 0.010

Uncertainty for a 10k thermistor at CHW range
=23kΩ x 0.01%
+ 100kΩ x 0.001%
= +/- 3.3Ω

+/- 3.3Ω uncertainty at 950Ω/C
= +/- 0.003C

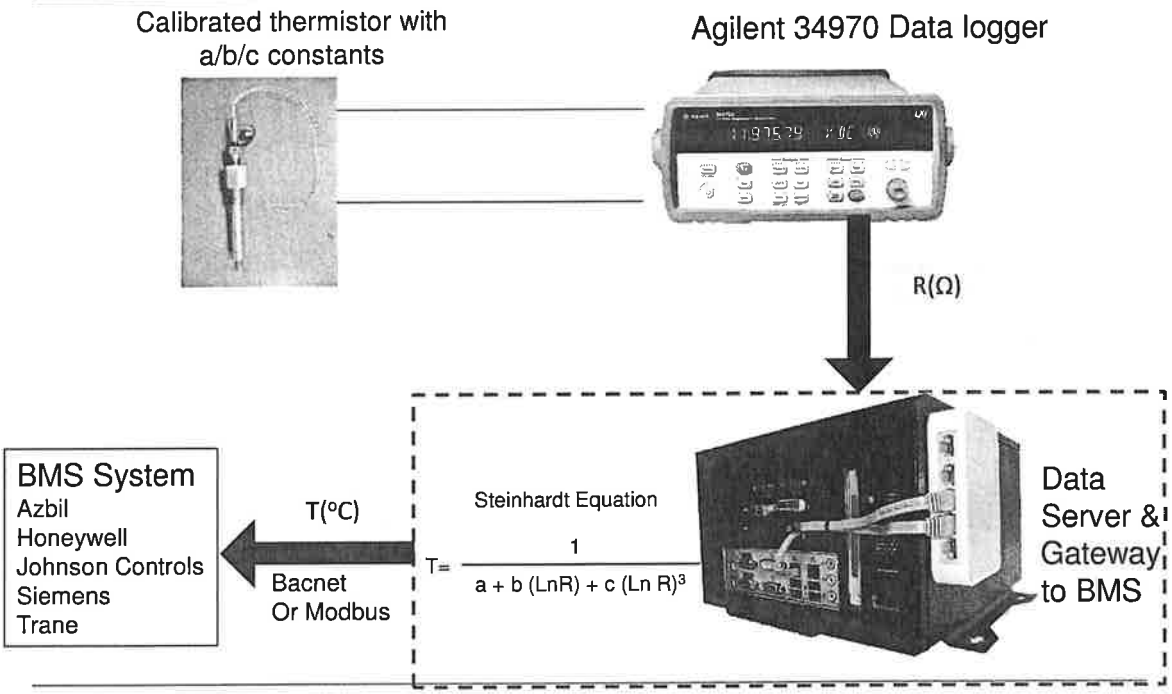
Agilent RTD and Thermistor measurement accuracy

Temperature	Type	1-Year Accuracy[9]	
Thermocouple[10]	B	1100°C to 1820°C	1.2°C
	E	-150°C to 1000°C	1.0°C
	J	-150°C to 1200°C	1.0°C
	K	-100°C to 1200°C	1.0°C
	N	-100°C to 1300°C	1.0°C
	R	300°C to 1760°C	1.2°C
	S	400°C to 1760°C	1.2°C
	T	-100°C to 400°C	1.0°C
RTD	R_0 from 49Ω to 2.1 kΩ	-200°C to 600°C	0.06°C
Thermistor	2.2 k, 5k, 10k	-80°C to 150°C	0.08°C

Cannot use Agilent to measure RTD and thermistors directly as the accuracy cannot meet BCA 0.05C end to end accuracy specs!

Need to use Agilent to measure resistance and then convert to temp using individually calibrated thermistors.

BMS Gateway for Agilent Data Logger

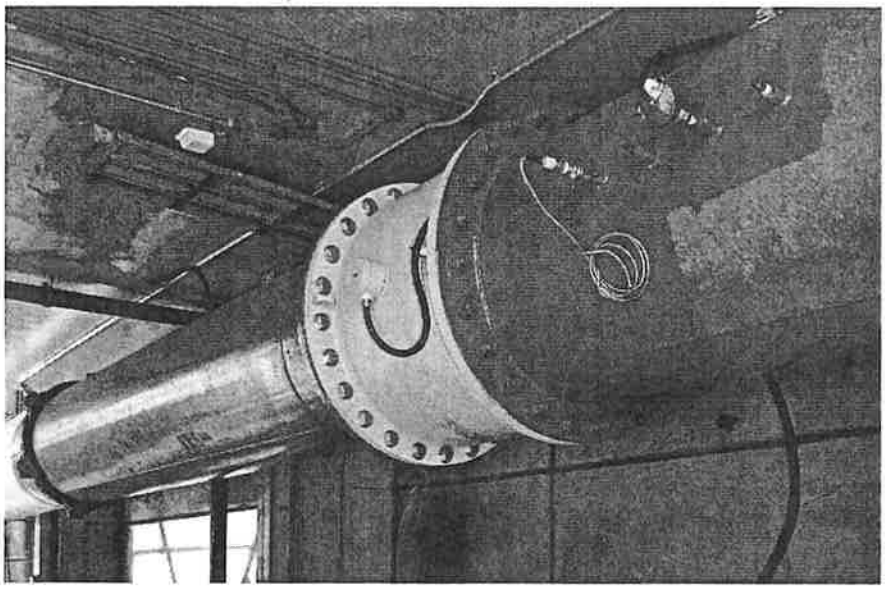


Flow measurement

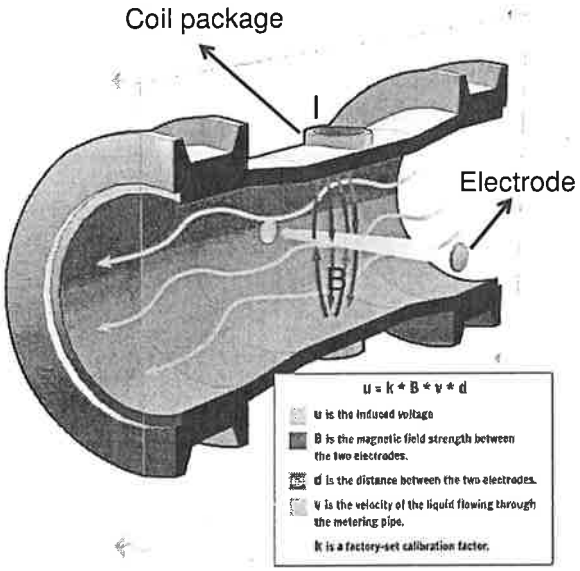
Flow measurements

	Full bore magnetic flow meter	Ultrasonic clamp on flow meter
Principle	The principle of operation is based on the Faraday Law which states that a voltage is created as conductor moves through a magnetic field. The fluid is the conductor in this case. The voltage created is proportional to the velocity of the fluid.	The principle of operation is based on sound transit time in a moving fluid. The sound transit time in the direction of flow is faster than the sound transit time in the opposite to the direction of flow.
Accuracy	0.5-1%	1-2%

Full bore electromagnetic flow meter



Full bore electromagnetic flow meter



The principle of operation for the magnetic flowmeter is based on the Faraday's Law of Electromagnetic Induction.

An electrical current (I) is applied to a coil package inside the flowmeter. As a result, a magnetic field (B) is created across the metering pipe.

When a conductive liquid flows through the magnetic field, a small voltage (V) is induced. This voltage is proportional to the velocity of the flow and is accurately measured by two stainless steel electrodes mounted opposite each other inside the metering pipe. The two electrodes are connected to an advanced electronic input circuitry which processes the signal and in turn feeds it to the a microprocessor inside the electronics module. The microprocessor then calculates the volumetric flow and controls the various outputs on the terminal board.

Full bore magnetic flow meter

Advantages of full bore magnetic flow meter:

1. Proven packaged metering solution which has accuracy of 0.5 % or better when installed according to manufacturer's instructions.
2. Accuracy is enhanced as the magnetic field used to measure the flow rate cover the cross section of the pipe (versus ultrasonic which uses a linear sound wave).
3. Requirement of straight pipe before and after the flow meter is least stringent.
4. The installation & set-up is very straight forward, thereby reducing installation and site error.
5. Virtually no risk of clogging or narrowing of pipe internally.
6. Accuracy does not depend on pipe characteristics such as material, thickness, diameter etc
7. No moving parts & almost non-intrusive so long term reliability is higher compared to turbine, orifice/pitot, vortex type of flow meter.

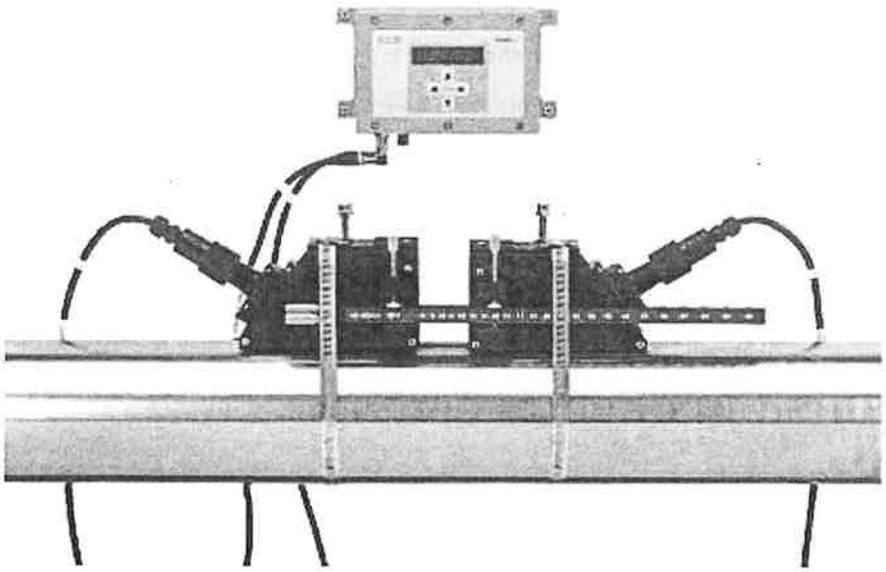
8.

Full bore magnetic flow meter

Drawbacks of full bore magnetic flow meter:

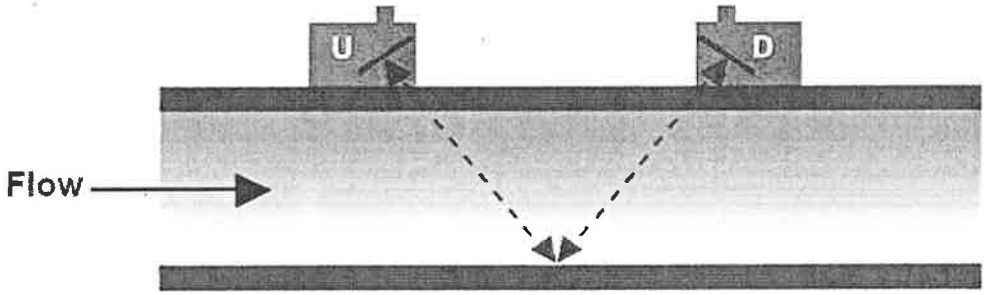
1. Need to shut down the pipe section and drain off water to install.
2. Sometimes need to freeze pipes to stop flow when there are no valves to isolate the pipe section leading to higher cost.
3. Very costly for large diameter pipes (eg > 500mm)

Ultrasonic clamp-on flow meter



Ultrasonic clamp-on flow meter

The measuring principle of ultrasonic flow meter is based on ultrasound transmission through a liquid. Transit time measuring technique utilizes two transducers, which function as both ultrasonic transmitters and receivers. The ultrasound waves traveling in the direction of the flow of the liquid require less time than when traveling in the opposite direction, therefore the difference in time taken by the ultrasonic waves to travel over the same distance but in opposite directions is an indication of the velocity of the liquid.



Ultrasonic flow meter

<u>The advantages of clamp-on ultrasonic flow meters (USFM):</u>

1. Externally clamped-on transducer. So no need to cut pipe or disrupt flow operation.
2. Can measure different pipe diameters with the same set of USFM. Can measure from 25mm diameter (1") to more than 2500mm (100")
3. The cost of USFM is much lower for large diameter pipes compared to full bore magnetic flow meter(MFM). Cost of USFM is higher than MFM for small pipe diameter but becomes comparable when the diameter reaches 250mm (10").

Ultrasonic flow meter

The drawbacks of clamp-on ultrasonic flow meters (USFM):

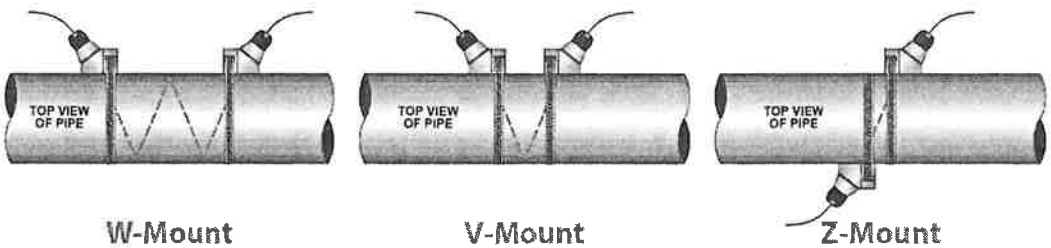
1. Accuracy of 1 to 2% is lower than magnetic flow meter.
2. Require longer straight pipe at inlet and outlet of flow meter.
3. Existing pipe may have significant corrosion on the inside surface affecting pipe thickness and diameter.
4. Existing pipe may have air pockets or internal clogging that cause flow turbulences.
5. Dirty fluid will reduce measurement accuracy.
6. Installation and setup errors can cause significant errors:

Inputs required for Ultrasonic Flow meter

3. Enter the following data into the transmitter via the integral keypad or the software utility:

1	Transducer mounting method	**7**	Pipe liner thickness
2	Pipe O.D. (Outside Diameter)	**8**	Pipe liner material
3	Pipe wall thickness	**9**	Fluid type
4	Pipe material	**10**	Fluid sound speed*
5	Pipe sound speed*	**11**	Fluid viscosity*
6	Pipe relative roughness*	**12**	Fluid specific gravity*

NOTE: * Nominal values for these parameters are included within the flow meter operating system. The nominal values may be used as they appear or may be modified if the exact system values are known.



Installation guideline for clamp-on ultrasonic flow meters

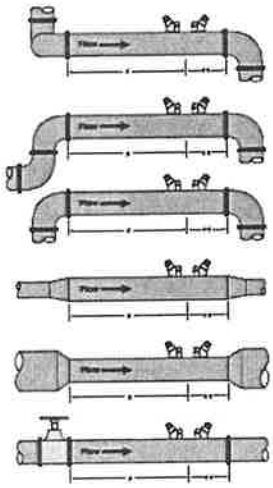
Piping Configuration and Transducer Positioning	Upstream Pipe Diameters *	Downstream Pipe Diameters **
	24	5
	14	5
	10	5
	10	5
	10	5
	24	5

TABLE Q.1 - PIPING CONFIGURATION AND TRANSDUCER POSITIONING

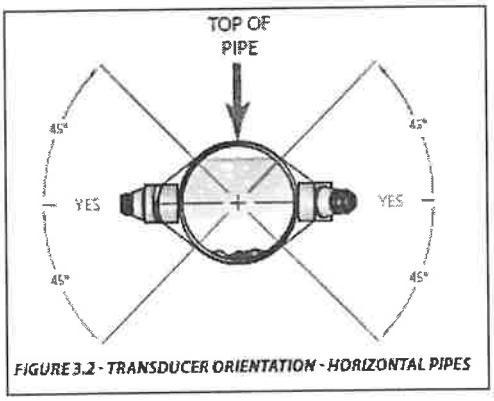


FIGURE 3.2 - TRANSDUCER ORIENTATION - HORIZONTAL PIPES

Power measurement

Power measurement



Class 1 CT



Class 1 power meter

Power Meter

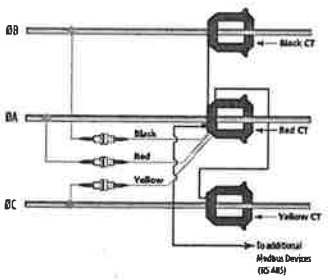
Integrated meter (Power meter and CT as a set) with Modbus RTU output

- Plug & play

Split core CT

- Able to install CT without dismantling cable or bus-bar





Integrated power meter specifications

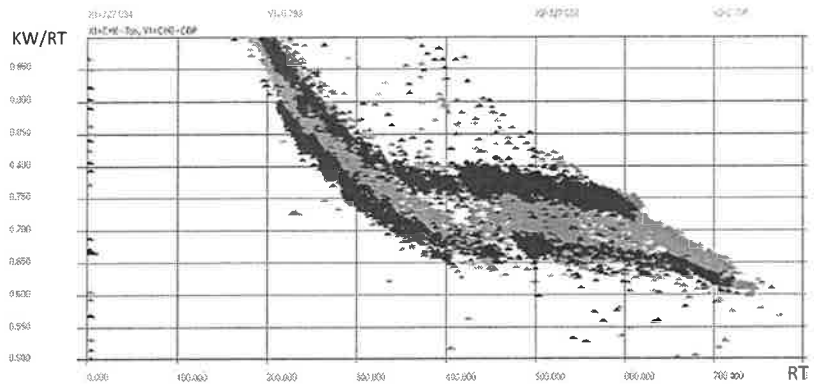
SPECIFICATIONS

Input Primary Voltage	208 to 480VAC RMS[††]
Number of Phases Monitored	One to Three
Frequency	50/60Hz
Primary Current	Up to 2400 amps cont. per phase[††]
Internal Isolation	2000VAC RMS
Insulation Class	600VAC RMS[†††]
Temperature Range	0° to 60°C (32° F to 140°F), 50°C (122°F) for 2400A
Humidity Range	0 - 95% non-condensing
Systems Accuracy	±1% of reading from 10% to 100% of the rated current of the CTs...accomplished by matching the CTs with a meter and calibrating them as a system
Output Physical Characteristics	RS-485, 2 wire + shield
Baud Rate	9600, 8N1 format
Protocol	Modbus RTU**(*)

Data output:
kWh, Consumption
kW, Real Power
kVAR, Reactive power
kVA, Apparent power
Power factor
Average Real power
Minimum Real power
Maximum Real power
Voltage, line to line
Voltage, line to neutral[†]
Amps, Average current
kW, Real power ØA[†]
kW, Real power ØB[†]
kW, Real power ØC[†]

[†] *Based on derived neutral voltage.*

Chiller Plant Performance Measurement & Verification



Agenda

1. Impacts of chiller plant M&V accuracy
2. Instruments and sensors for chiller plant M&V
3. Common pitfalls & recommended good practices
4. Presentation of data

Agenda

1. Impacts of chiller plant M&V accuracy

Common uses of M&V



Electric meters:
+/- 1% accuracy



Water meters:
+/- 1% accuracy

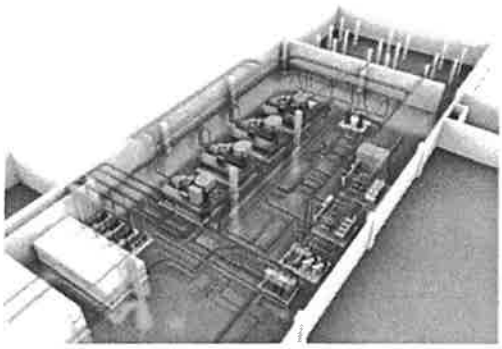


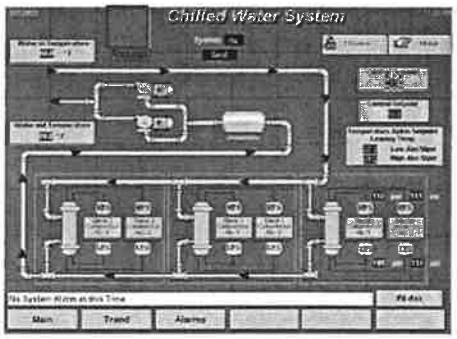
Gas meters:
+/- 1% accuracy





M&V practice in chiller plant

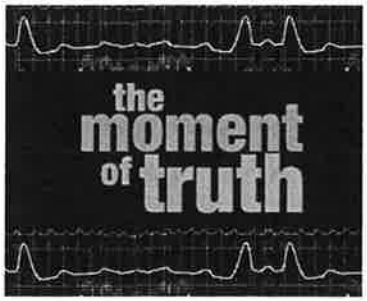




- Cooling RT and KW/RT not often measured
- RT and KW/RT data widely inaccurate & often ignored

The power of information

- No information drives no action
- Inaccurate information drives wrong action
- Accurate information drives right action



Impact of inaccurate M&V

	CHWS Temp	CHWR Temp	DT Temp	CHW Flow	Cooling capacity	Elect power input	Efficiency
	C	C	C	L/S	tons	Kwi	Kwi/ton
Actual performance	7.00	12.00	5.00	168.2	1000	780	0.780
Error in temp	-0.50	0.50					
Claimed performance	6.50	12.50	6.00	168.2	1200	780	0.650
						Error in efficiency	**0.130**
						% error	**16.7%**

Ave Cooling capacity	Annual operating Hrs	Cooling load	Error in efficiency	Error in energy savings	Tarrif rate	Error in energy savings
tons	Hr	ton-hr	kwi/ton	KWH	$/KWH	$
1,000	8760	8,760,000	0.130	1,138,800	0.20	227,760

+/- 0.5C temp error results in +/- $228K saving error!



Wrong data leading to wrong decision

Action:
Facility people sees high CHWR~12C,more than 100% Load of 2-chillers from TA-display

Fact:
Wrong reading on CHWR
Wrong calculation on tonnage

Action
Turn on 3rd chiller and observe 100%load displayed on micro-panel of all chillers

Fact :
Display on micropanel
100% electrical ≠100% cooling load
Chiller2(520RT) 100%electrical load but only 50% cooling part load
and operating around 1.35kW/RT

Waste of 400kW power,3,456,000kWh
$320,000 electrical bill per year

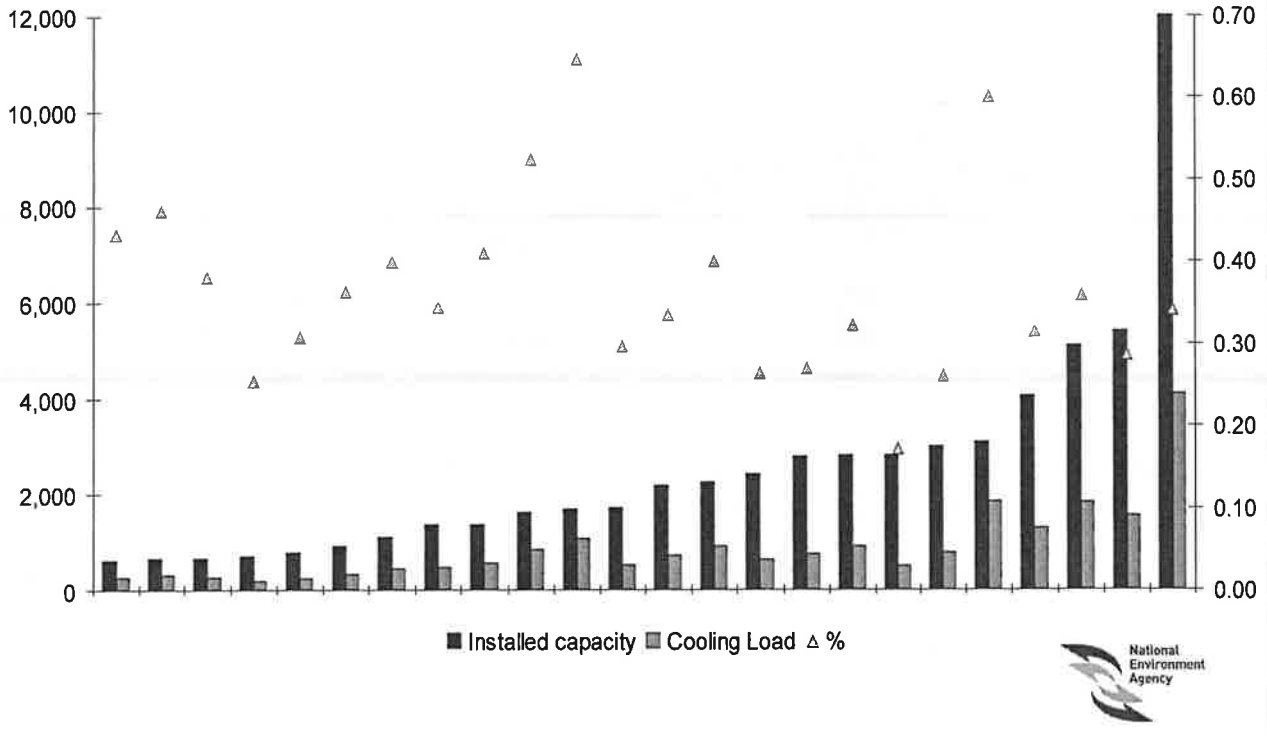
Impact of inaccurate M&V

Singapore annual cooling RT-H 3,000M X Average KW/RT 1.0 X 5% error X Elect tariff rate $0.22/KWH

= $33M

Commercial building only

Installed Capacity vs Cooling Load

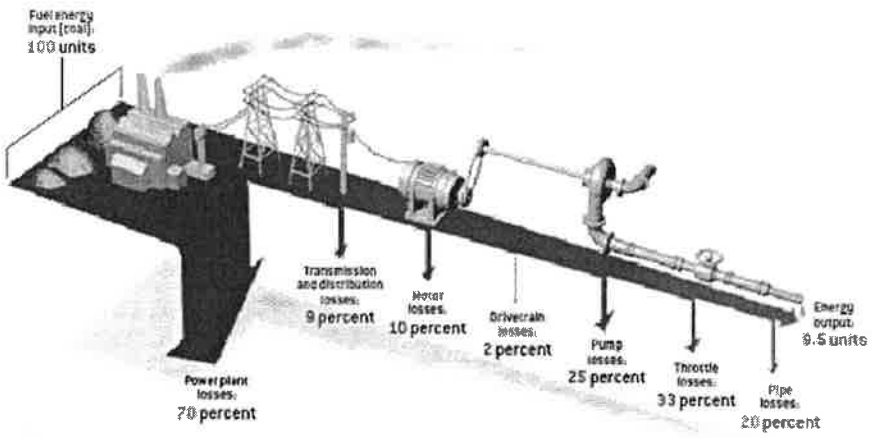


Implications

- Sizing of the airside in comparison to waterside
  - Expect airside to be about 100 - 115% tonnage of chiller plant running at 100% loading for office buildings
  - If chiller plant is sized at 300% of actual load then the airside is more than 300%!
  - Space, electricals, operating cost, maintenance costs, noise of fans, ceiling heights, etc, etc.
- Cost of overbuilding and poor efficiency
  - Assume
    - Air-conditioning equipment costs on average $4k/ton
    - Cooling demand ~ 0.025 ton/m2 of air-conditioned space
    - Air-conditioned office space in large buildings ~ 100 million m^2.
    - Average oversizing is 2x
    - Wasted capital stock = 2 x 0.025 x 100m x $4k = **$20b**
  - Assume
    - Average efficiency of existing air-conditioning is 1.2 kW/t
    - Energy cost of air-conditioning over-consumption is (1.2 – 0.75) x 0.025 x 100m x 4000 hrs/a x $0.25/kWh = **$1.125b**
  - Electrical demand on grid?
  - Standing losses of under-loaded transformers?

National Environment Agency

The energy value chain



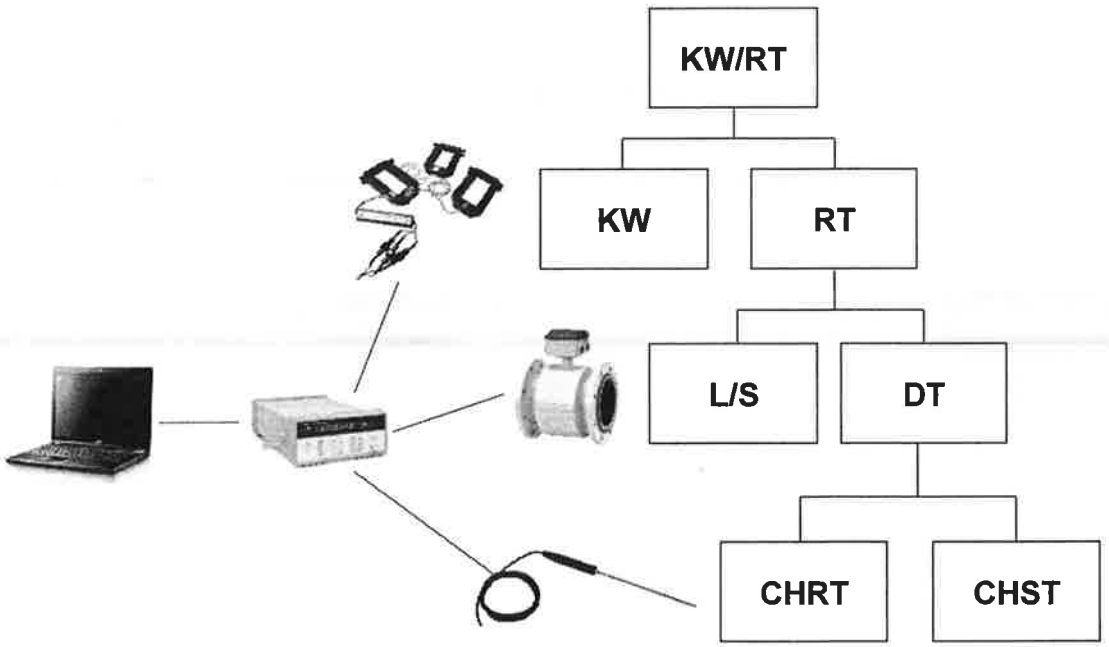
Every unit of flow (or friction) saved in the pipe will save approximately ten units of fuel, cost, pollution, and at the power station

To save the most primary energy and the most capital cost, therefore, efficiency efforts should start all the way downstream, by asking: How little flow can actually deliver the desired service? How small can the piping friction become? How small, well-matched to the flow regime, and efficient can the pump be made? Its coupling? Its motor? Its controls and electrical supplies?

Agenda

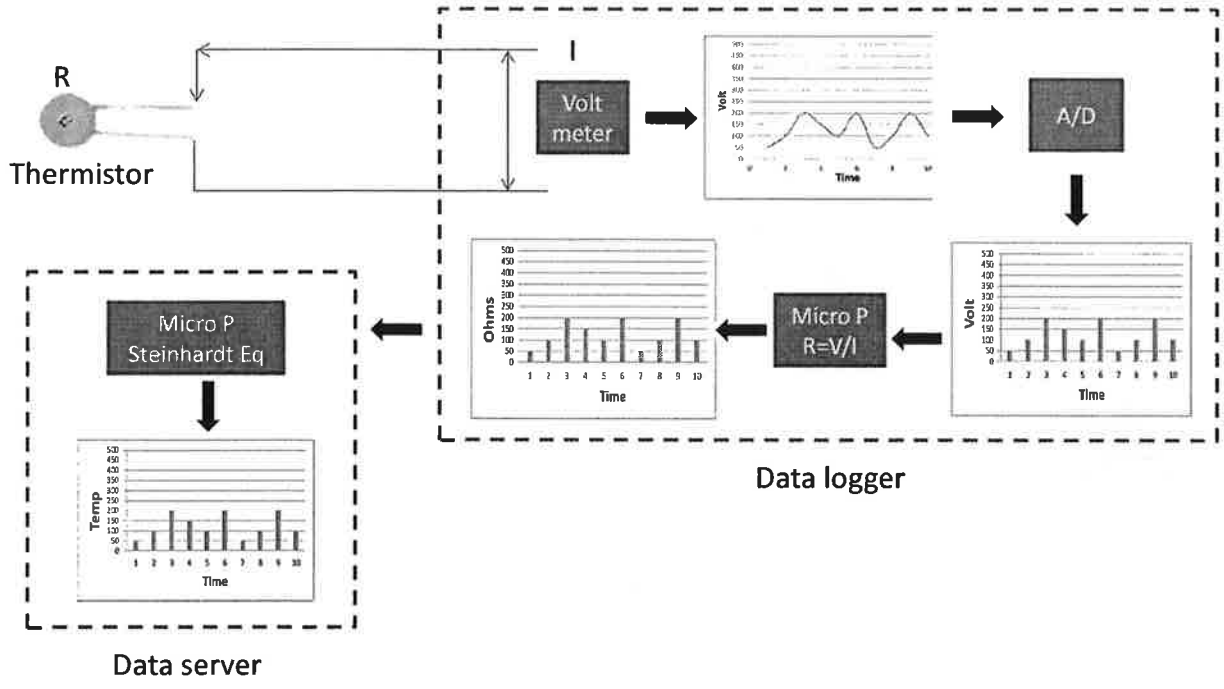
2. Instruments and sensors for chiller plant M&V

Chiller Plant M&V accuracy

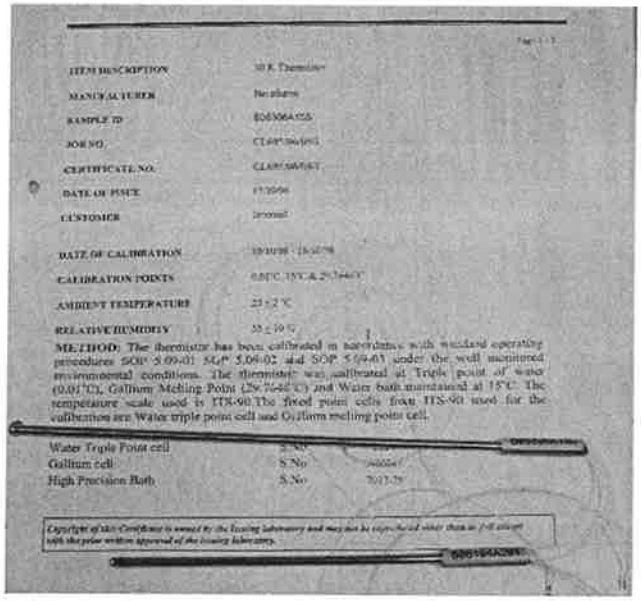


Temperature sensor

Temperature measurement chain



Thermistors



Calibrated 30K ohms hermetic tubular thermistors

Thermistors

Steinhart-Hart Thermistor Equation

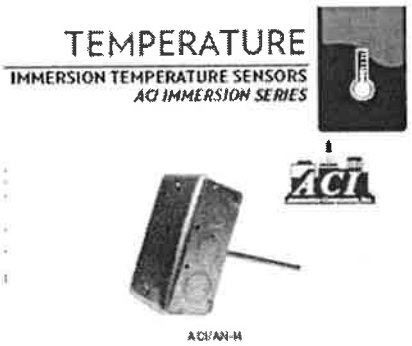
The Steinhart-Hart equation is the best method to describe the Resistance vs Temperature relationship of Negative Temperature Coeff (NTC) thermistors. The Steinhart-Hart equation is an empirically derived polynomial formula.

$$1/T = a + b\,(LnR) + c\,(Ln\,R)^3$$

T: Temperature in K (C + 273)
R: Resistance in ohms
a, b, c: Coeff derived from calibration

Each thermistor can be calibrated to an accuracy of +/- 0.01C by solving for the a, b, c constants with 3 fixed temperature scale.

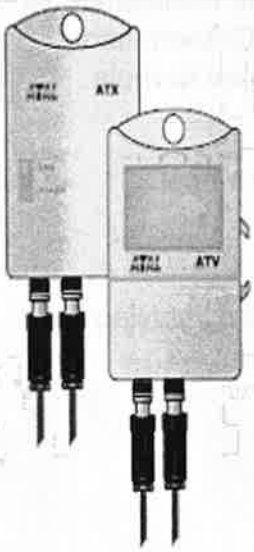
Commercial temperature sensor accuracy



SPECIFICATIONS	
Accuracy	Thermistor ±0.36°F (0.2°C), RTD ±0.27°F (0.15°C) ±0.06%
Sensor types	
Thermistor	20K: 20,000Ω @ 77°F (25°C) CP: 10,000Ω @ 77°F (25°C) AN:10,000Ω @ 77°F (25°C)
RTD	1000-2:1000Ω @ 32°F (0°C) 385 platinum curve
Temperature range	-40° to 302°F (-40° to 150°C)
Stability	
Thermistor	0.24°F (0.13°C) over five years
RTD	<±0.1°C drift
Heat dissipation	Thermistor, 3 mW/°C (power needed to raise the temperature by 1°C)
Ambient RH	10% to 90% RH non-condensing
Connections	10" of 22 AWG wire or terminal strip
Enclosure	Metal
Weight	1.2 lb (0.54 kg)
Warranty	2 years

Commercial temperature sensor accuracy

Data Recording Solutions 2003-2004



2-channel temperature (2 x external)

ATX-03
Without display

ATV-03
With display

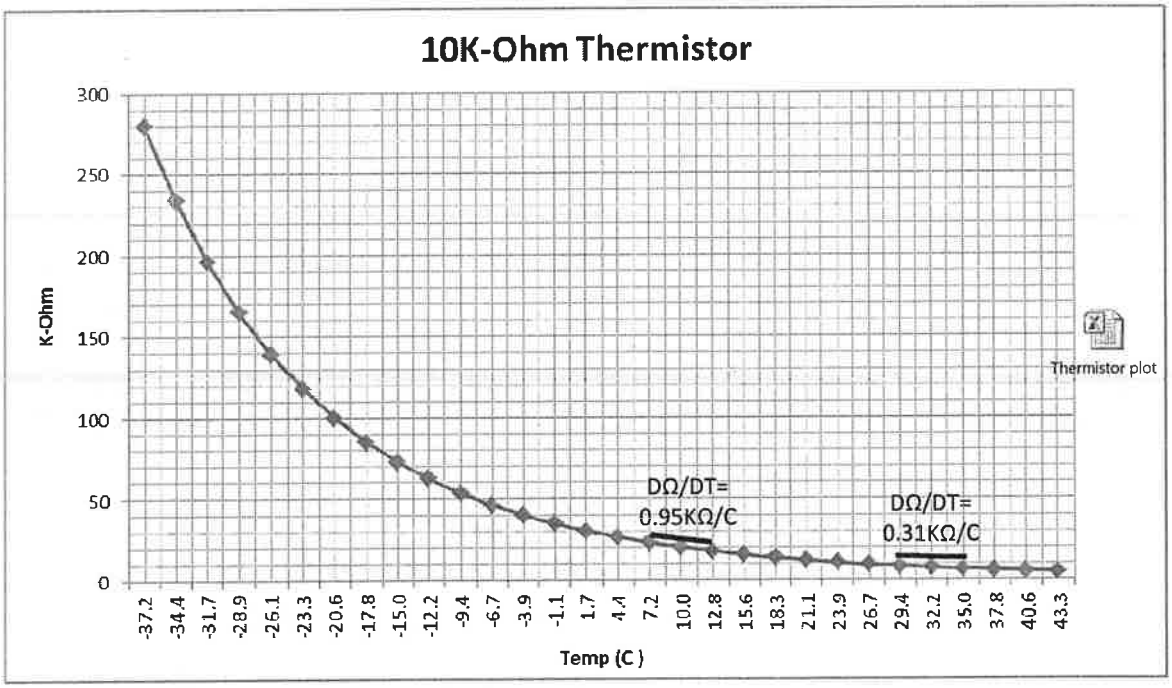
No. of channels:	2
External sensor:	Pt1000 or Ni1000 temperature sensor (software selectable)
Range Pt1000:	-90 to +260°C
Range Ni1000:	-50 to +150°C
Resolution:	0,1°C
Accuracy:	± 0,4°C (from -50 to +100°C) ± 0,5% from reading (other range)

Typical BAS Sensor Specs

The PreCon sensor has a dissipation constant in still air at 25°C of 2.7 mW/°C. The heat dissipation constant is an expression in milliwatts of the power required to raise the temperature of a thermistor 1°C above the ambient.

	PreCon TYPE II				PreCon TYPE III	PreCon TYPE IV
	Model 21 2,252 ohm at 77°F ±0.36°F from 32°F to 158°F	Model 22 3,000 ohm at 77°F ±0.36°F from 32°F to 158°F	Model 24 10,000 ohm at 77°F ±0.36°F from 32°F to 158°F	Model 27 100,000 ohm at 77°F ±0.36°F at 77°F ±1.3°F from 32° to 158°F	Model 3 10,000 ohm at 77°F ±0.36°F from 32°F to 158°F	Model 42 20,000 ohm at 77°F ±0.36°F from 32°F to 158°F
TEMP°F	RESISTANCE	RESISTANCE	RESISTANCE	RESISTANCE	RESISTANCE	RESISTANCE
-35	63.08K	84.09K	280.1K	2801K	203.6K	
-30	52.72K	70.27K	234.1K	2341K	170.6K	
-25	44.20K	58.92K	196.3K	1963K	148.3K	
-20	37.19K	49.56K	165.1K	1651K	127.1K	
-15	31.38K	41.83K	139.3K	1393K	109.2K	
-10	26.57K	35.41K	118.0K	1180K	94.07K	270.6K
-5	22.57K	30.07K	100.2K	1002K	81.23K	226.0K
0	19.22K	25.61K	85.35K	853.5K	70.32K	192.6K
5	16.42K	21.88K	72.91K	729.1K	61.02K	163.1K
10	14.07K	18.74K	62.48K	624.8K	53.07K	138.7K
15	12.08K	16.10K	53.64K	536.4K	46.27K	118.3K
20	10.41K	13.87K	46.23K	462.3K	40.42K	101.0K
25	8988	11.98K	39.91K	399.1K	35.39K	86.60K
30	7762	10.37K	34.56K	345.6K	31.06K	74.40K
35	6755	8999	30.00K	300.0K	27.31K	64.10K
40	5877	7830	26.10K	261.0K	24.06K	55.30K
45	5126	6830	22.76K	227.6K	21.24K	47.89K
50	4482	5971	19.90K	199.0K	18.79K	41.40K
55	3927	5231	17.44K	174.4K	16.65K	36.10K
60	3448	4594	15.31K	153.1K	14.78K	31.44K
65	3035	4043	13.48K	134.8K	13.15K	27.46K
70	2676	3565	11.88K	118.8K	11.72K	24.02K
75	2365	3150	10.50K	105.0K	10.46K	21.06K
80	2094	2789	9298	92.98K	9354	18.50K
85	1858	2475	8250	82.50K	8378	16.29K
90	1651	2200	7331	73.31K	7516	14.37K
95	1471	1959	6532	65.32K	6754	12.69K
100	1312	1748	5826	58.26K	6078	11.24K
105	1173	1562	5209	52.09K	5479	9.97K
110	1050	1399	4663	46.63K	4947	8.86K

Typical BAS Sensor Specs

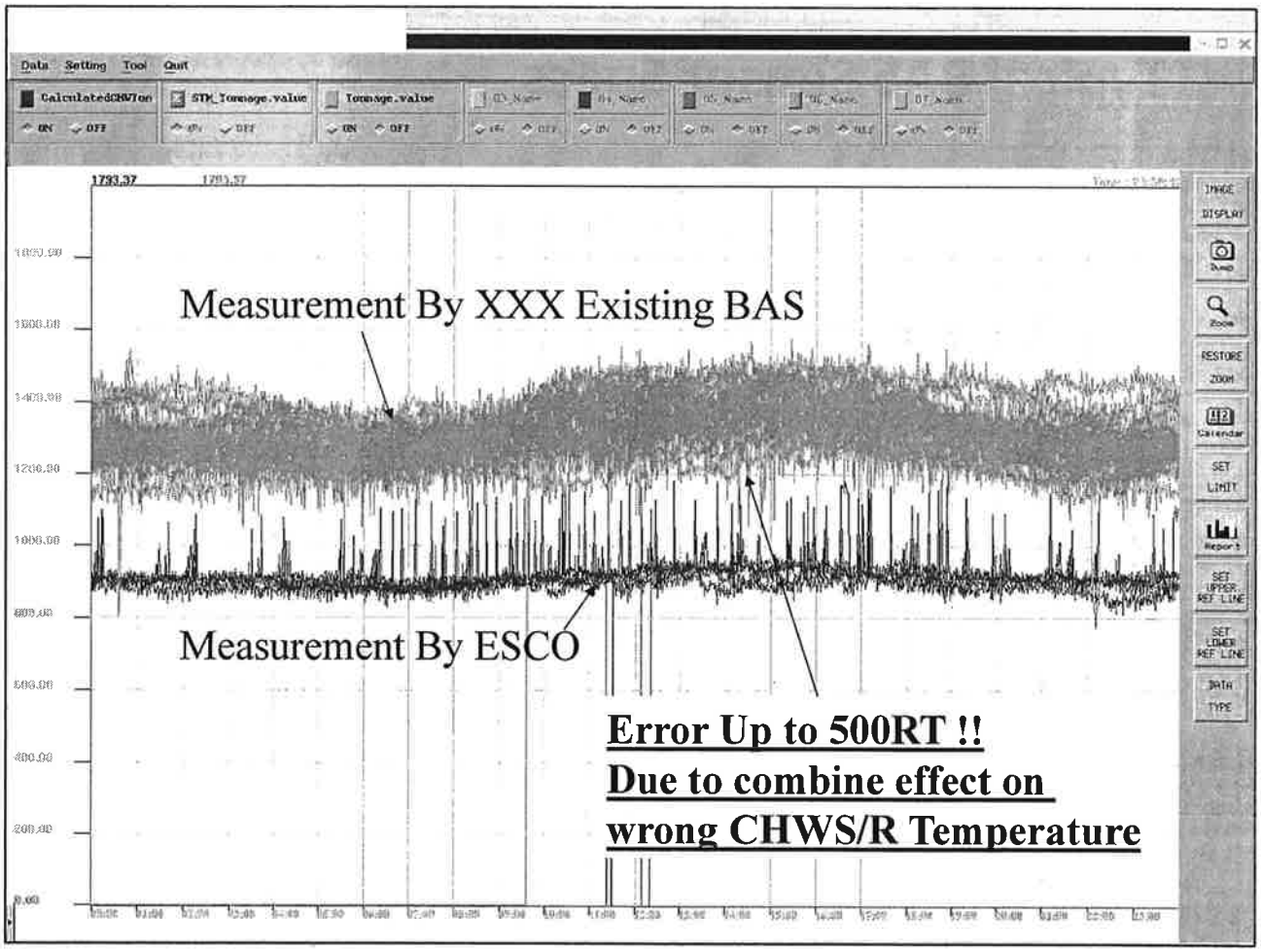


Typical industrial temp sensor specs

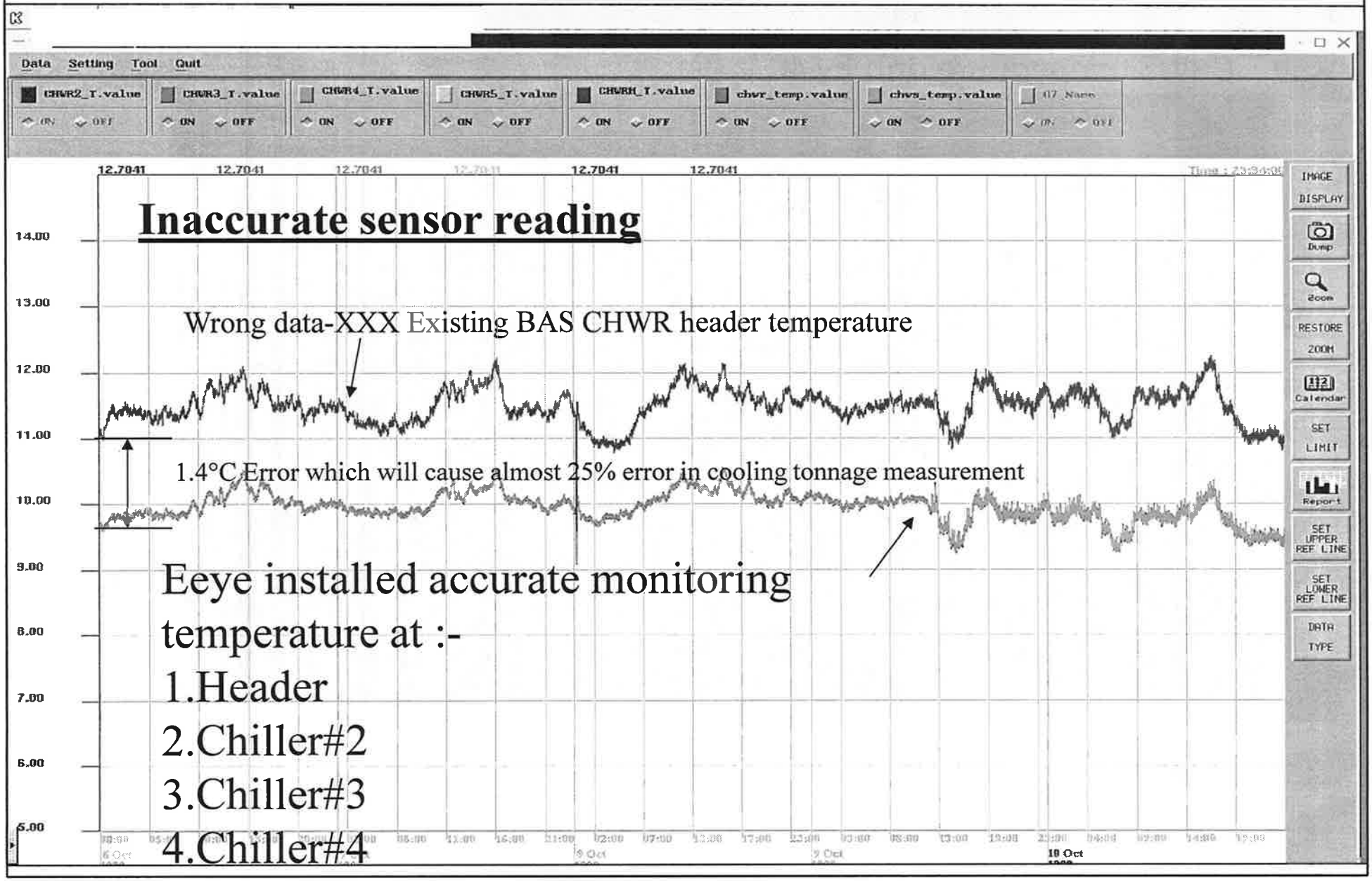
Technical Specifications

TE-6300 Series Temperature Sensors (Part 1 of 2)

Sensor Reference Resistance	**1k ohm Nickel**	1k ohms at 70°F (21°C)
	1k ohm Nickel Averaging	
	1k ohm Platinum	1k ohms at 32°F (0°C)
	100 ohm Platinum Averaging	100 ohms at 32°F (0°C)
	1k ohm Platinum Averaging	1k ohms at 32°F (0°C)
	2.2k ohm Thermistor	2,252 ohms at 77°F (25°C)
	10k ohm Thermistor	10.0k ohms at 77°F (25°C)
Sensor Accuracy	**1k ohm Nickel**	±0.34F° at 70°F (±0.19C° at 21°C)
	1k ohm Nickel Averaging	±3.4F° at 70°F (±1.9C° at 21°C)
	1k ohm Platinum	±0.73F° at 70°F (±0.41C° at 21°C), DIN Class B
	100 ohm Platinum Averaging	±1.0F°at 70°F (± 0.58C° at 21°C)
	1k ohm Platinum Averaging	
	2.2k ohm Thermistor	±0.36F° (±0.2C°) in the range: 32 to 158°F (0 to 70°C)
	10k ohm Thermistor	±0.9F° (±0.5C°) in the range: 32 to 158°F (0 to 70°C)

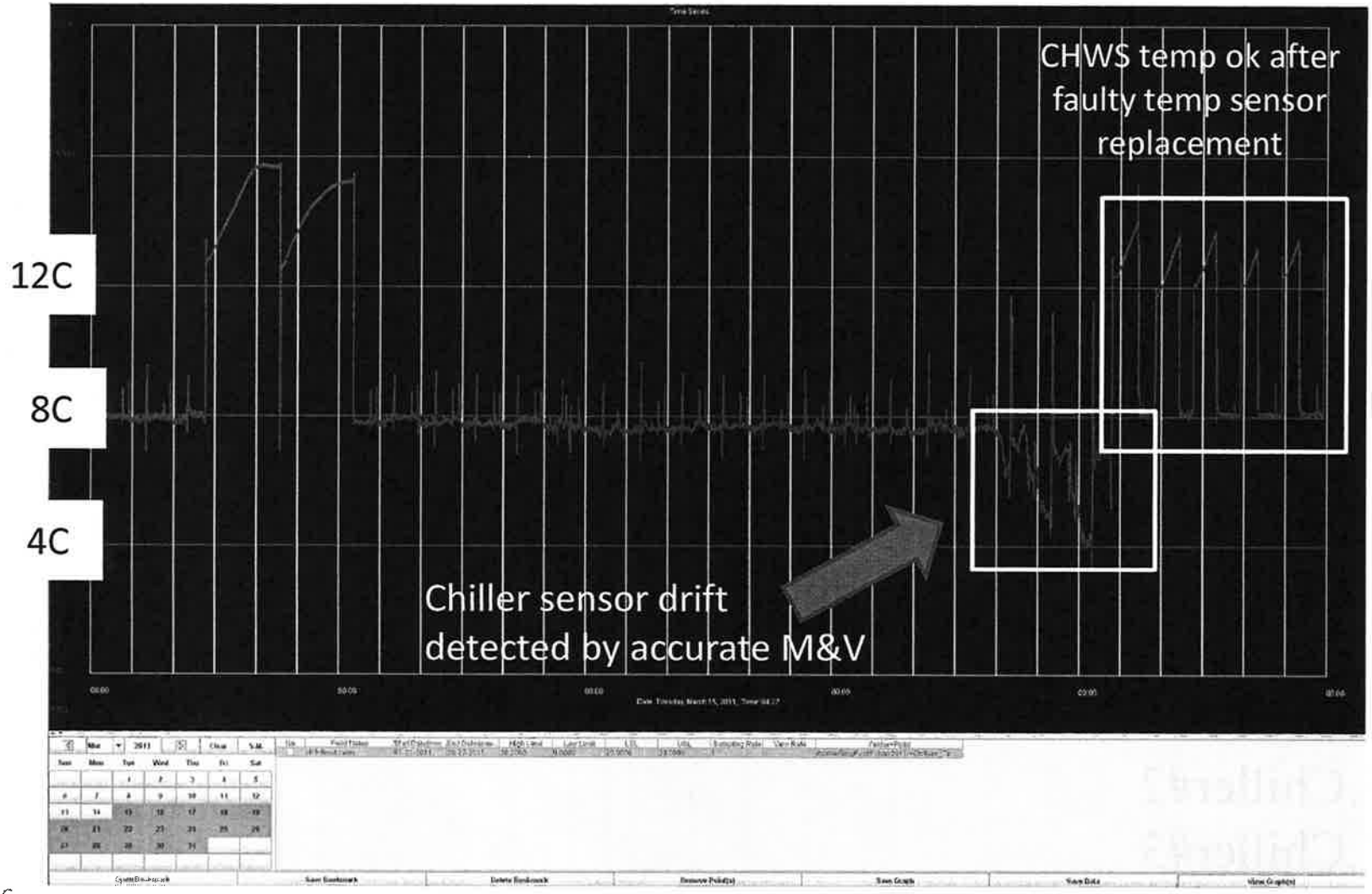


New BAS at Semiconductor Company

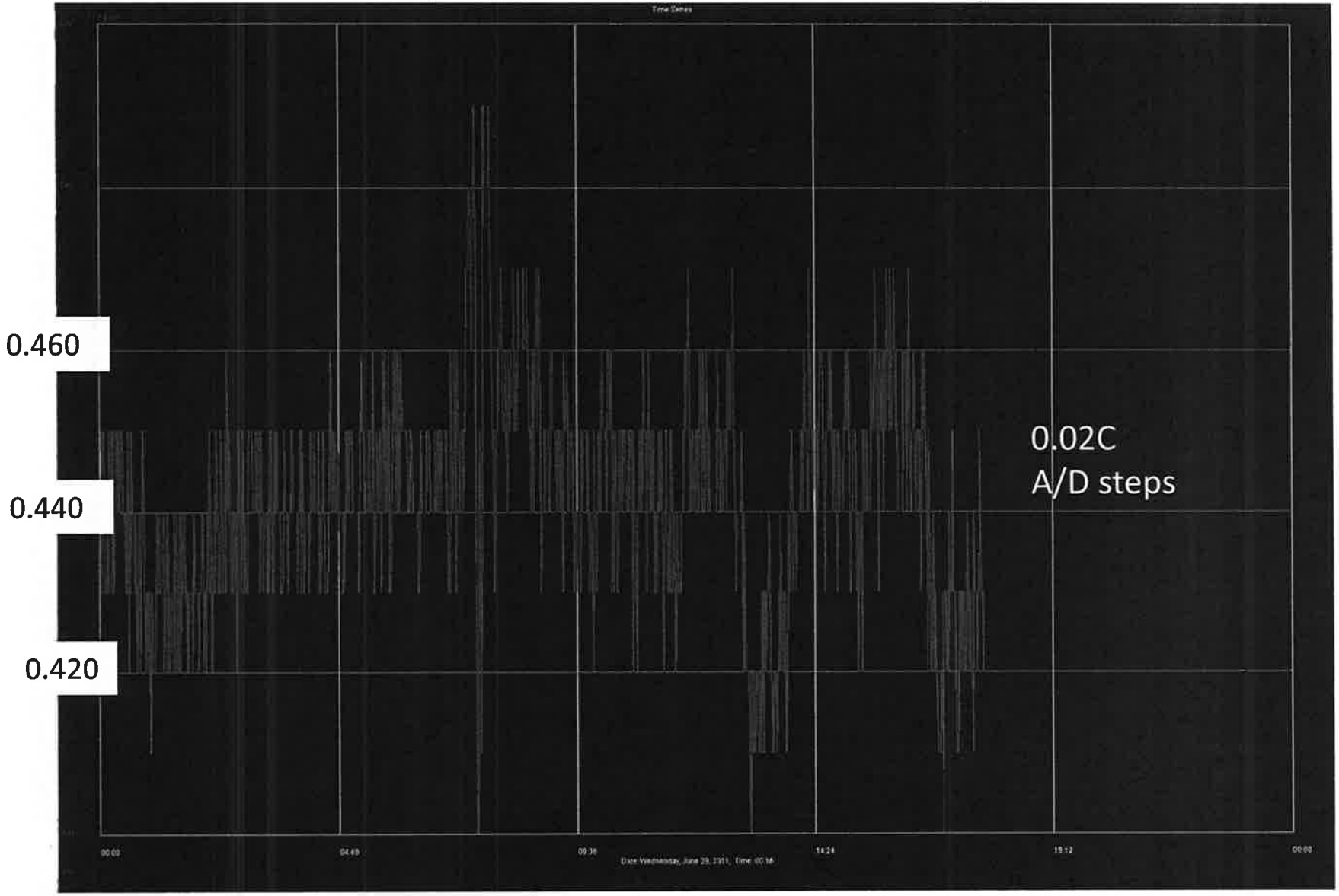


Temperature sensors in chillers not accurate

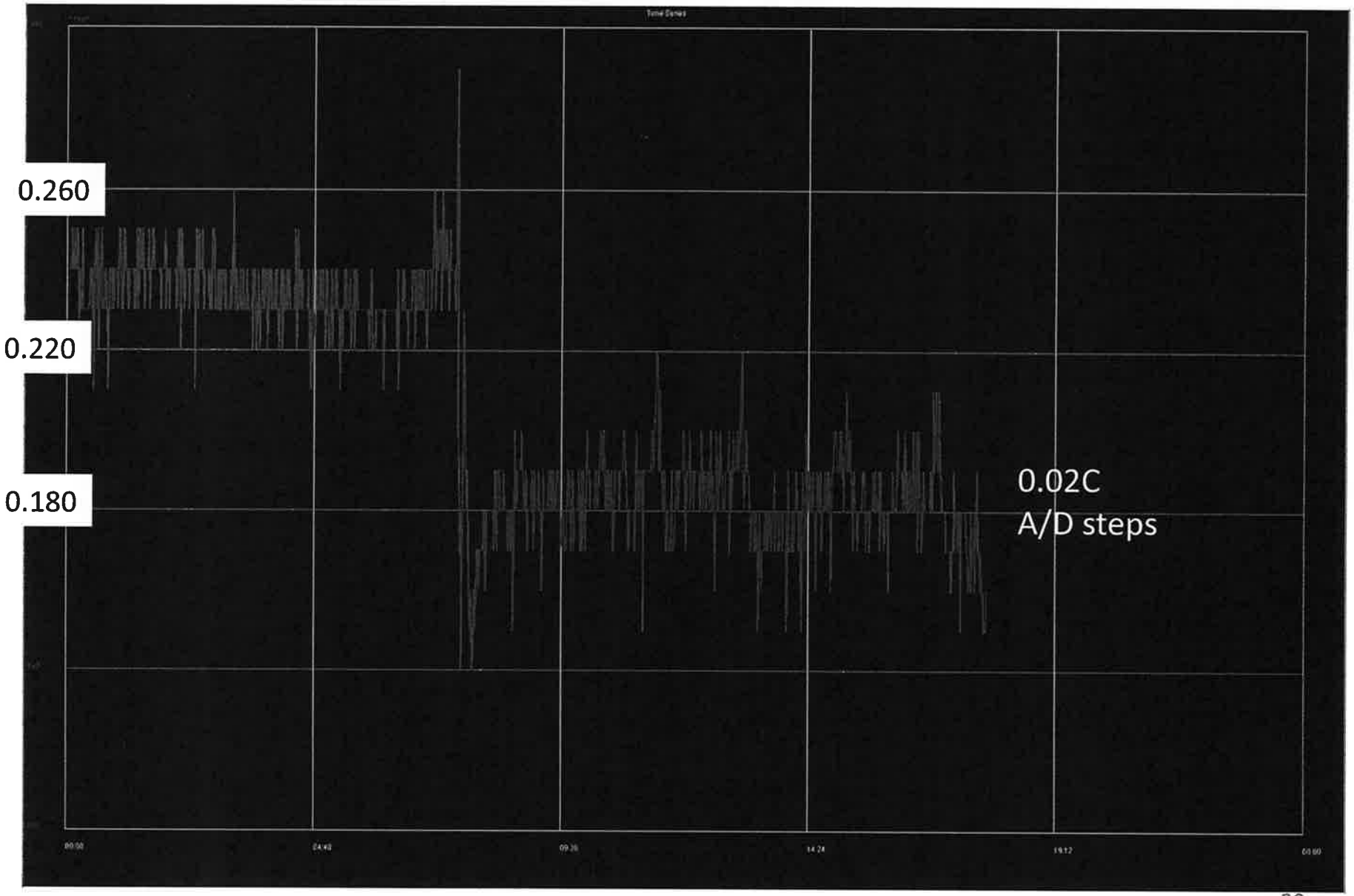
- CHWS temperature drift by 4C



Chiller micro panel evap approach temp reading

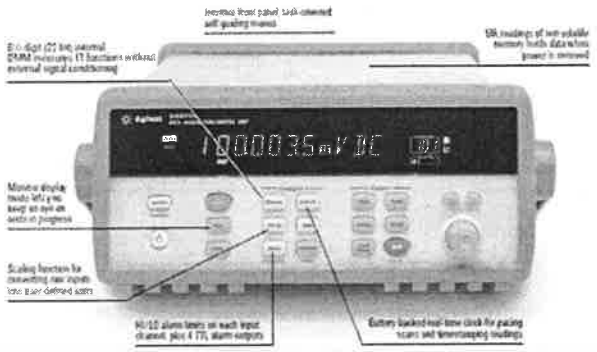


Chiller micro panel cond approach temp reading



Data logger
A/D converter

High accuracy data logger



- Measurements include dc volts, ac volts, thermocouple, thermistor and RTD temperature measurements, 2- and 4-wire Ohms, dc current, ac current, frequency, and period
- 6½ digits (22 bits) of resolution with 0.004% basic 1-year dcV accuracy

	Range[3]	Frequency, etc.	24 Hour[2] 23°C±1°C	90 Day 23°C±5°C	1 Year 23°C±5°C	Temperature Coefficient 0°C–18°C, 28°C–55°C
Resistance[6]						
	100.0000	1 mA current source	0.0030 + 0.0035	0.008 + 0.004	0.010 + 0.004	0.0006 + 0.0005
	1.000000 k	1 mA	0.0020 + 0.0006	0.008 + 0.001	0.010 + 0.001	0.0006 + 0.0001
	10.00000 k	**100 µA**	**0.0020 + 0.0005**	**0.008 + 0.001**	**0.010 + 0.001**	**0.0006 + 0.0001**
	100.0000 k	10 µA	0.0020 + 0.0005	0.008 + 0.001	0.010 + 0.001	0.0006 + 0.0001
	1.000000 M	5.0 µA	0.002 + 0.001	0.008 + 0.001	0.010 + 0.001	0.0010 + 0.0002
	10.00000 M	500 nA	0.015 + 0.001	0.020 + 0.001	0.040 + 0.001	0.0030 + 0.0004
	100.0000 M	500 nA/10 M	0.300 + 0.010	0.800 + 0.010	0.800 + 0.010	0.1500 + 0.0002

Laboratory grade data logger

Digital Multimeters

8½ Digit Multimeter



HP 3458A

Resistance

Range	Full scale	Maximum resolution	Current through unknown	1-Year Accuracy* (4-wire Ω) ppm of rdg+ppm of range
10 Ω	12.00000	10 μΩ	10 mA	15 + 5
100 Ω	120.00000	10 μΩ	1 mA	12 + 5
1 kΩ	1.2000000	100 μΩ	1 mA	10 + 0.5
10 kΩ	12.000000	1 mΩ	100 μA	10 + 0.5
100 kΩ	120.00000	10 m Ω	50 μA	10 + 0.5
1 MΩ	1.2000000	100 m Ω	5 μA	15 + 2
10 MΩ	12.000000	1 Ω	500 nA	50 + 10
100 MΩ	120.00000	10 Ω	500 nA	500 + 10
1 GΩ	1.2000000	100 Ω	500 nA	0.5% + 10

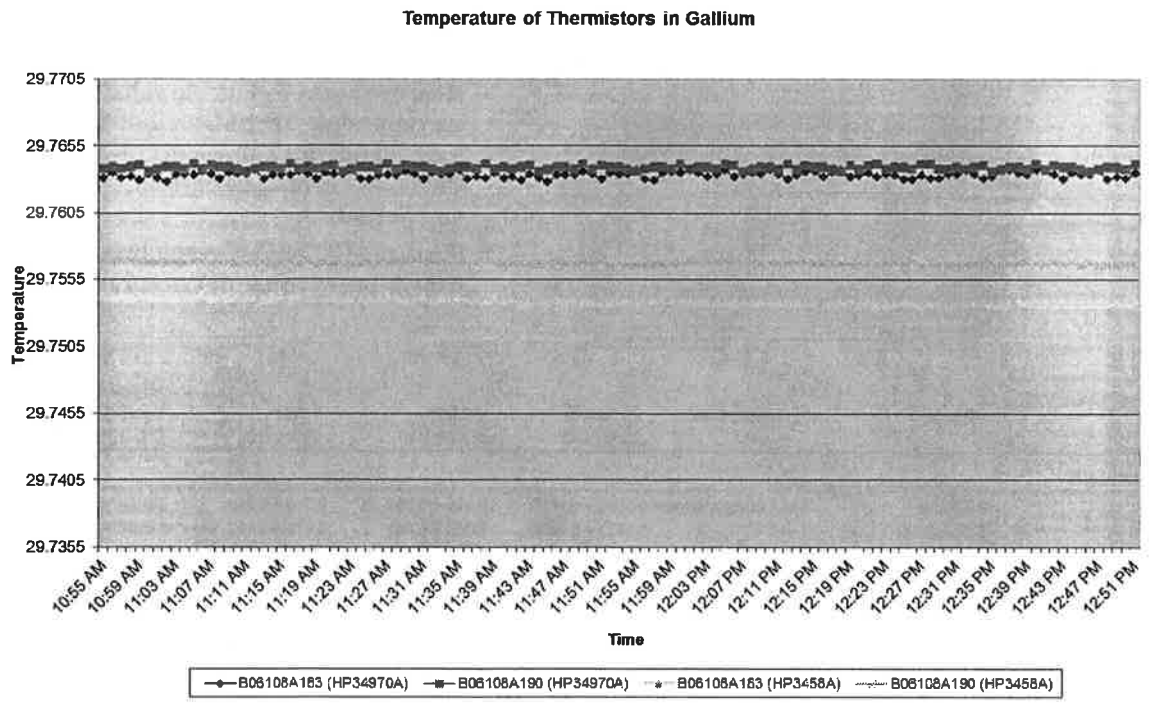
*Specifications for 100 NPLC, offset compensation on, within 24 hours and ± 1° C of last ACAL, Tcal ±5° C. Add 3 ppm of reading additional error for HP factory traceability of 10 kΩ to US NIST.

HP 3458A Multimeter Performance Features

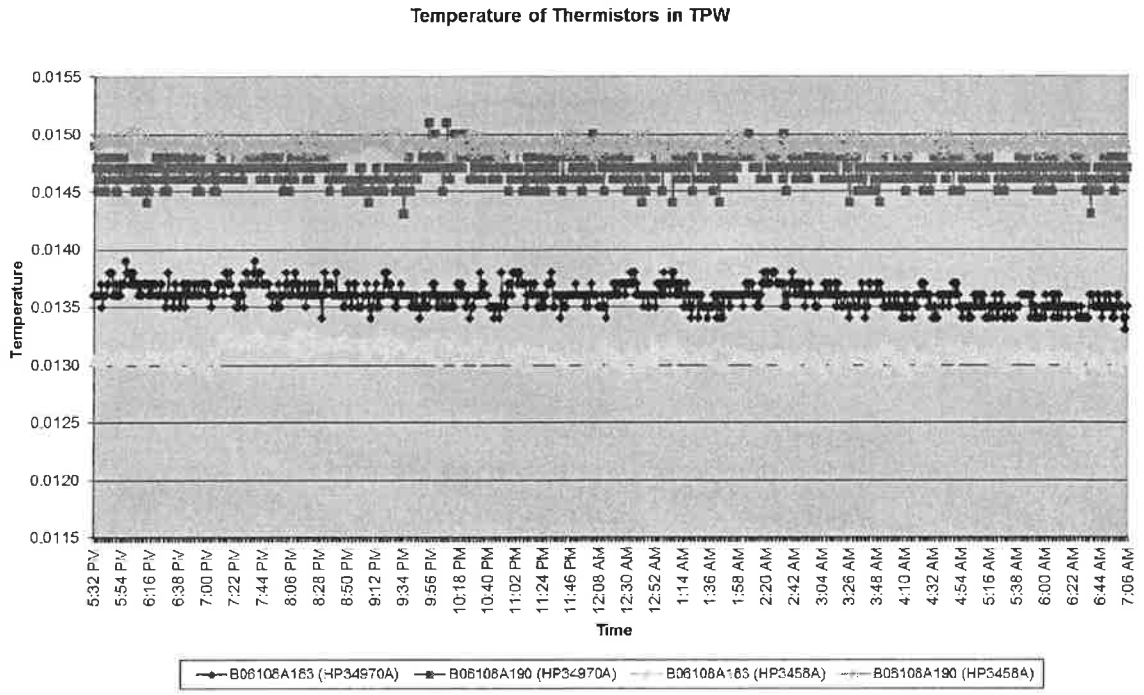
DC Volts
- 5 ranges: 0.1 V to 1000 V
- 8½ to 4½ digits resolution
- Up to 100,000 readings/s (4½ digits)
- Maximum sensitivity: 10 nV
- 0.6 ppm 24-hour accuracy
- 8 ppm (4 ppm optional)/year voltage reference stability

Resistance
- 9 ranges: 10 Ω to 1 GΩ
- 2-wire and 4-wire Ω with offset compensation
- Up to 50,000 readings/second (5½ digits)
- Maximum sensitivity: 10 μΩ
- 2.2 ppm 24-hour accuracy

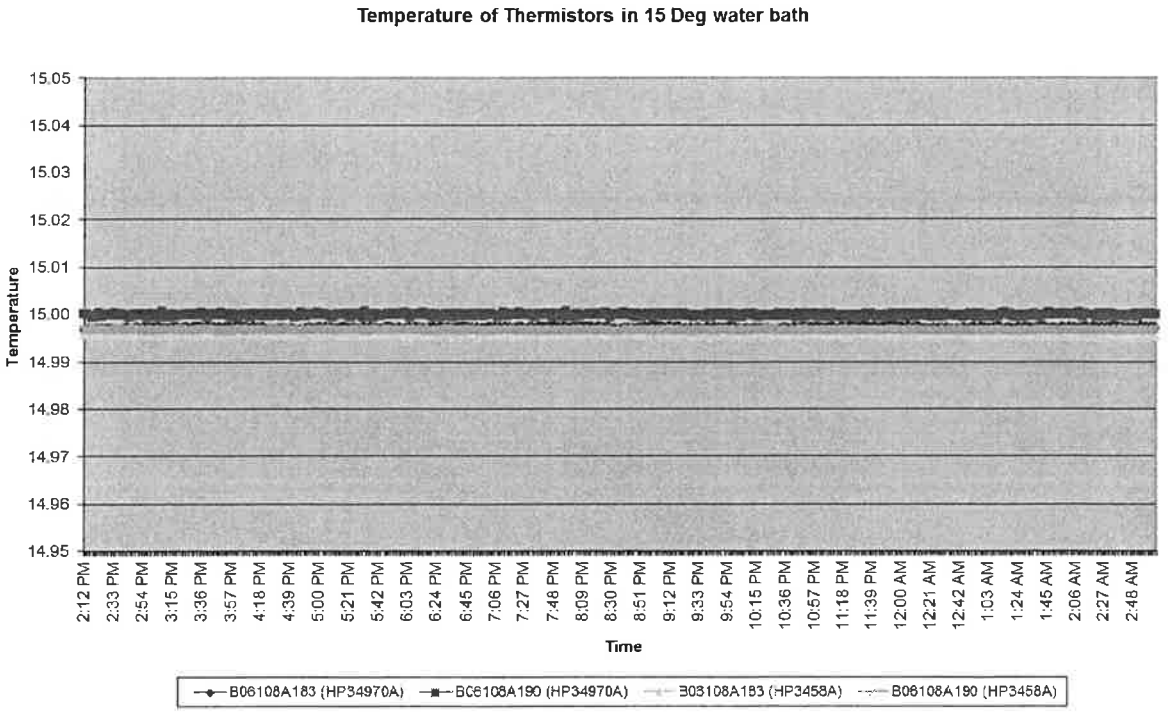
High accuracy data loggers



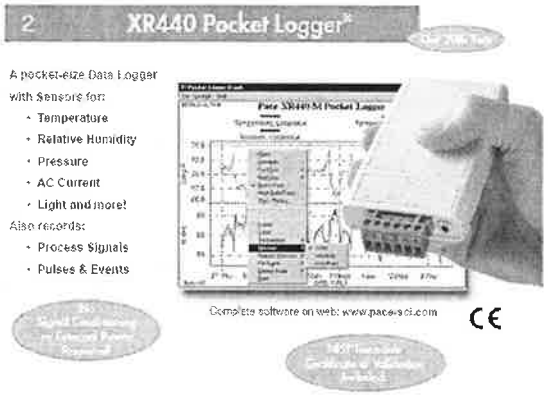
High accuracy data loggers



High accuracy data loggers



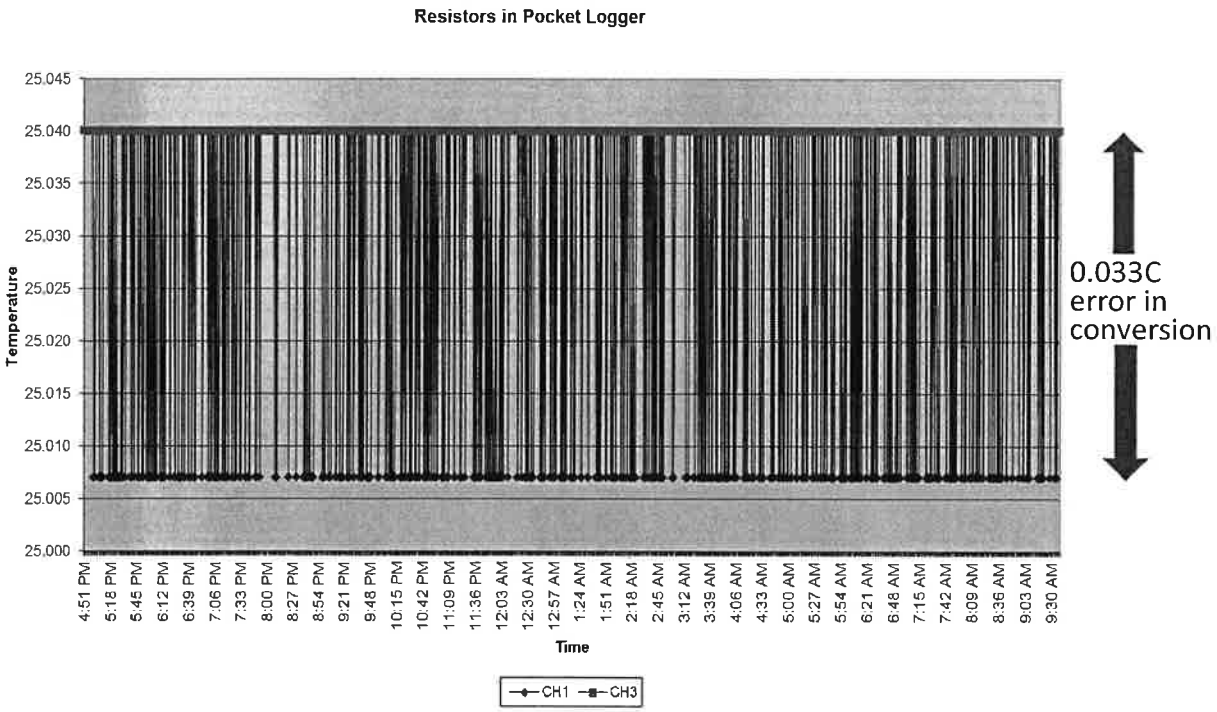
Popular pocket logger



12 BIT RESOLUTION

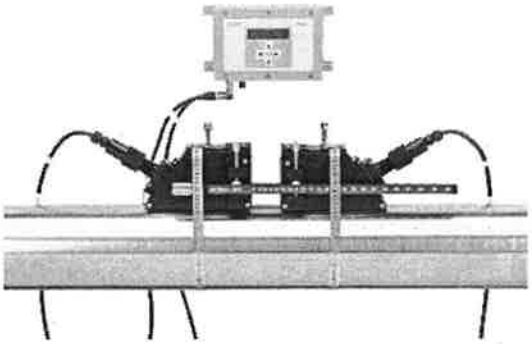
Memory capacity:	21,504 readings (86,016 with -M option)
Temperature accuracy:	±0.15°C from 0 to 40°C.
(logger + probe)	*(±0.27°F from 32 to 104°F).*
	±0.3°C from -25 to 85°C.
	(±0.55°F from -13 to 185°F).
Voltage input accuracy:	±0.25% of full scale.
Resolution:	0.025°C from 0 to 40°C.
	0.063°C or better from -25 to 75°C.
	0.125°C or better from -45 to 100°C.
	0.025% of full scale.

A/D convertor of popular pocket loggers

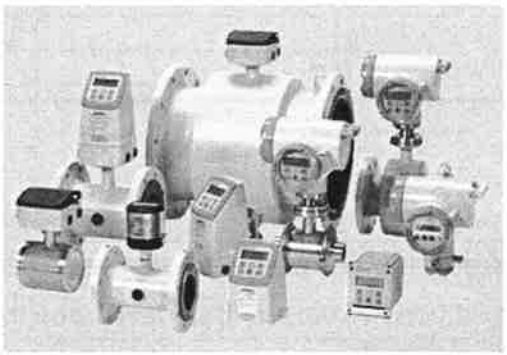


Flow meter

Flow meter



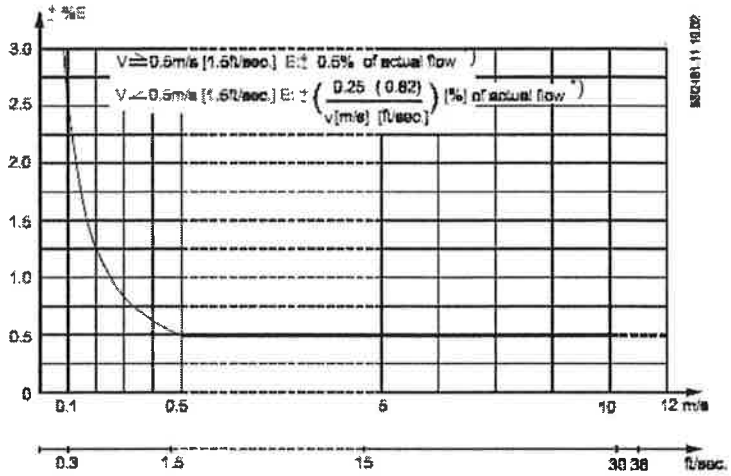
Ultrasonic flow meter



Full bore magnetic flow meter

Full bore magnetic flow meter specifications

MAG 5000 or MAG 6000 used with MAG 1100 (PFA) or MAG 1100 F (PFA)



*) ±1.25 mm/s zero-point for MAG 5100 W DN 350 ... DN 1200
V: Actual flow velocity [m/s]
E: Meter uncertainty as a percentage of actual flow

Full bore magnetic flow meter specifications

Reference conditions (ISO 9104 and DIN/EN 29104)

Medium temperature	20°C ±5°C (68°F ±9°F)
Ambient temperature	20°C ±5°C (68°F ±9°F)
Supply voltage	U_n ±1%
Warming-up time	30 minutes
Incorporation in conductive pipe section	
• Inlet section	10×DN (DN ≤ 1200/48")
	5×DN (DN > 1200/48")
• Outlet section	5×DN (DN ≤ 1200/48"),
	3×DN (DN > 1200/48")
Flow conditions	Fully developed flow profile

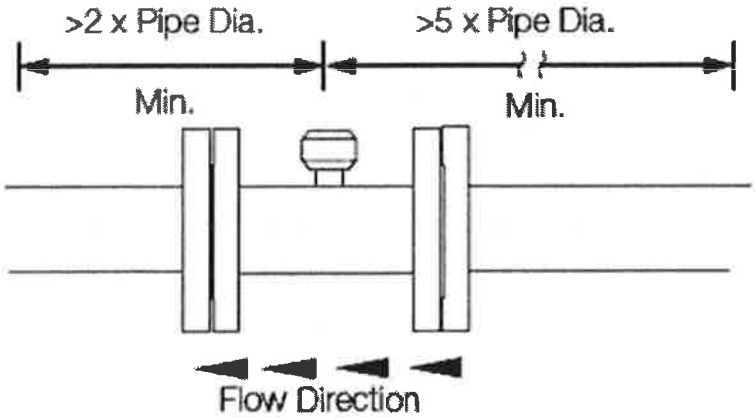
Additions in the event of deviations from reference conditions

Current output	As pulse output ±(0.1% of actual flow +0.05% FSO)
Effect of ambient temperature	
• Display/frequency/pulse output:	< ±0.003% / °C act.
• Current output:	< ±0.005% / °C act.
Effect of supply voltage	< 0.005% of measuring value on 1% change
Repeatability	±0.1% of actual flow for V ≥ 0.5 m/s (1.5 ft/s) and conductivity ≥ 10 µS/cm³

Full bore magnetic flow meter specifications

		Standard cable (electrode/coil)	*Special cable (electrode)*
Basic data	No. of conductors	3	3
	Sqr. area	1.5 mm^2/18 gage	0.25 mm^2/22 gage
	Screen	Yes	Double
	Color code	Brown, blue, black	Brown, blue, black
	Outside color	Grey	Grey
	Ext. diameter	7.8 mm/0,3"	8.1 mm/0,32"
	Conductor	Flexible CU	Flexible CU
	Isolation material	PVC	PVC
Amb. temperature	Flexible installation	–5 ... 70°C/–23 ... 160°F	–5 ... 70°C/–23 ... 160°F
	Non-flexible installation	–30 ... 70°C/–20 ... 160°F	–30 ... 70°C/–20 ... 160°F
Cable parameter	Capacity	161.50 pF/m / 49.24 pF/ft.	N/A
	Inductance	0.583 µH/m / 0.178 µH/ft.	N/A
	L/R	43.83 µH/Ω	N/A

Full bore electromagnetic flow meter



Ultrasonic Flow meter specification

Flow Accuracy (% of Reading)	Accuracy specifications assume a fully developed flow profile and a straight run of 10 pipe diameters upstream and 5 pipe diameters downstream. *Pipe Diameter (ID) >6 in. (150 mm):* Velocity > 1 ft/s (> 0.3 m/s); ± 2% typical (± 0.5 to 1% with calibration). Velocity ≤ 1 ft/s (≤ 0.3 m/s); ± 0.03 ft/s (± 0.01 m/s) typical. *Pipe Diameter (ID) ≤ 6 in. (150 mm):* Velocity > 1 ft/s (> 0.3 m/s); ± 2 to 5% typical. Velocity < 1 ft/s (< 0.3 m/s); ± 0.03 ft/s (± 0.01 m/s) typical.
Range	-40 to 40 ft/s (-12.2 to 12.2. m/s).
Rangeability	400:1.
Repeatability	*Wetted Transducers*: ± 0.2% of full scale *Clamp-on Transducers*: ± 0.2 to 0.5% of full scale.

Note: *Specifications assume a fully developed flow profile, with a straight run of pipe 20 diameters upstream and 10 diameters downstream.*

Ultrasonic flow meter

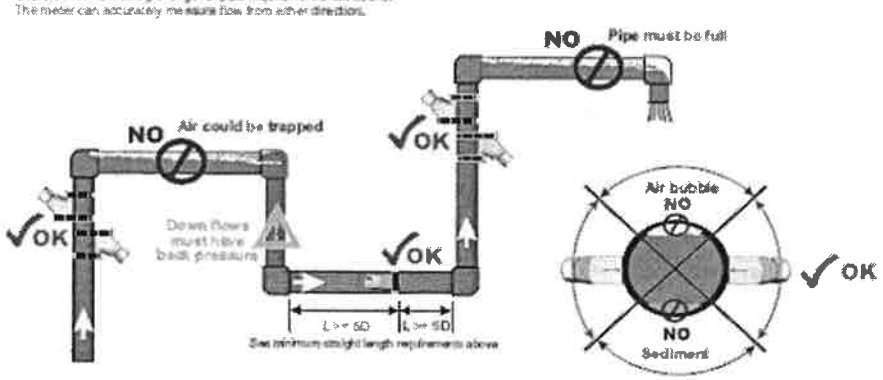
Minimum Straight Pipe Length Requirements

The meter's accuracy is affected by disturbances such as pumps, elbows, tees, valves, etc., in the flow stream. Install the meter in a straight run of pipe as far as possible from any disturbances. The distance required for accuracy will depend on the type of disturbance.

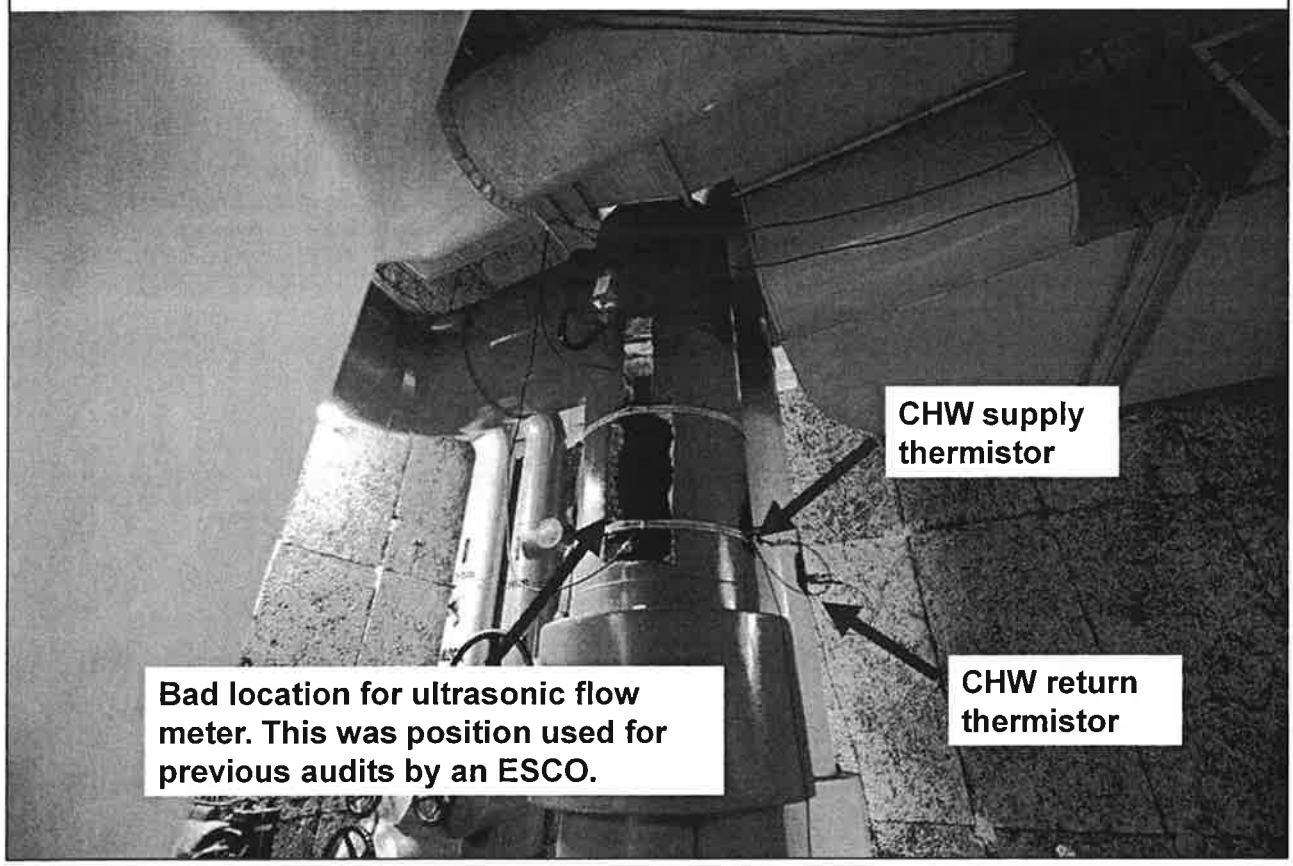
Type of Disturbance	Straight Lengths of Pipe Required	
	Upstream from Transducers	Downstream from Transducers
Flange	5 x Nominal Pipe Size	5 x Nominal Pipe Size
Reducer	7 x Nominal Pipe Size	5 x Nominal Pipe Size
90° Elbow	10 x Nominal Pipe Size	5 x Nominal Pipe Size
Two 90° Elbows - 1 Direction	15 x Nominal Pipe Size	5 x Nominal Pipe Size
Two 90° Elbows - 2 Directions	20 x Nominal Pipe Size	5 x Nominal Pipe Size
Gate valve or Pump	25 x Nominal Pipe Size	5 x Nominal Pipe Size

Transducer Mounting Location

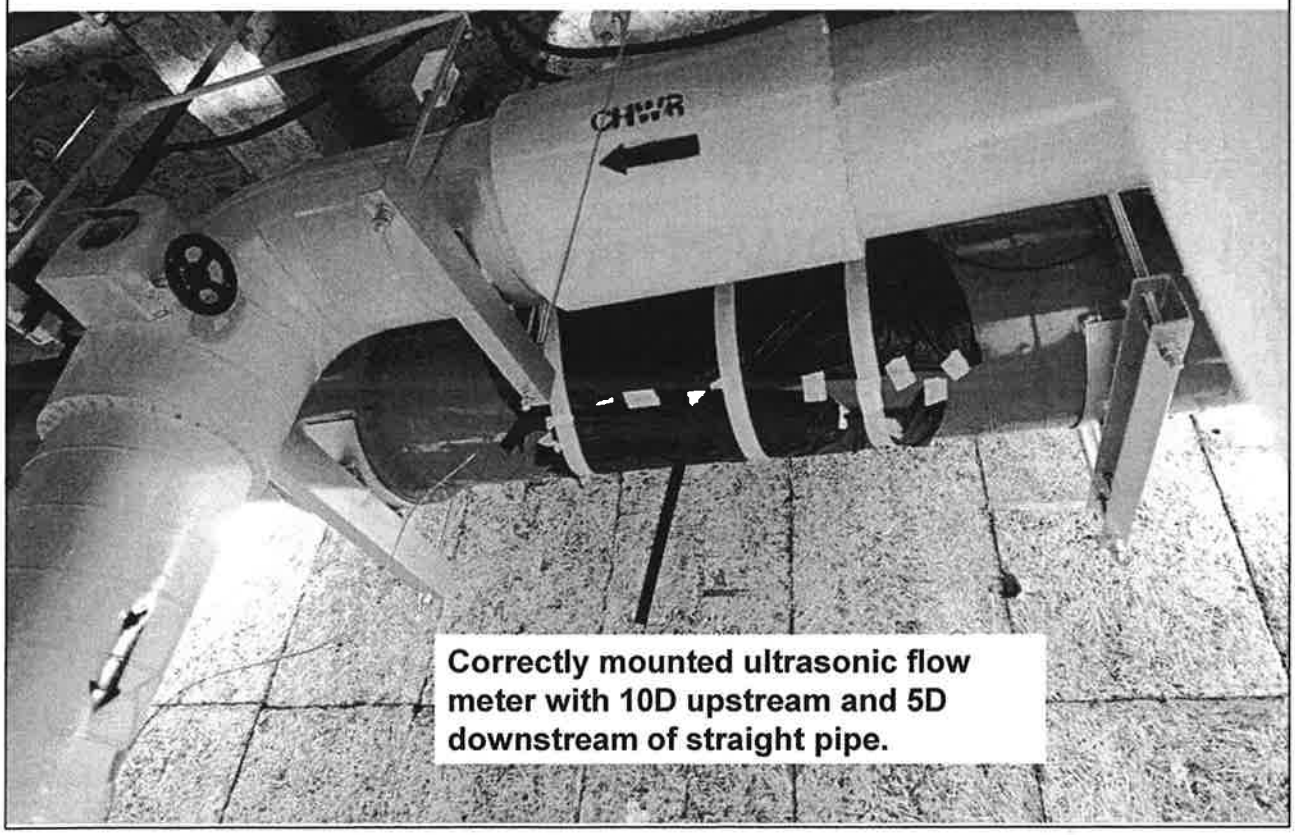
- The meter can be mounted on horizontal or vertical runs of pipe.
- Mounting on the sides (3 o'clock and 9 o'clock) position on horizontal pipe is recommended.
- Mounting anywhere around the diameter of vertical pipe is acceptable, however, the pipe must be completely full of fluid at all times.
- Back pressure is required on downward flows to ensure a full pipe.
- See the minimum straight length of pipe requirement chart above.
- The meter can accurately measure flow from either direction.



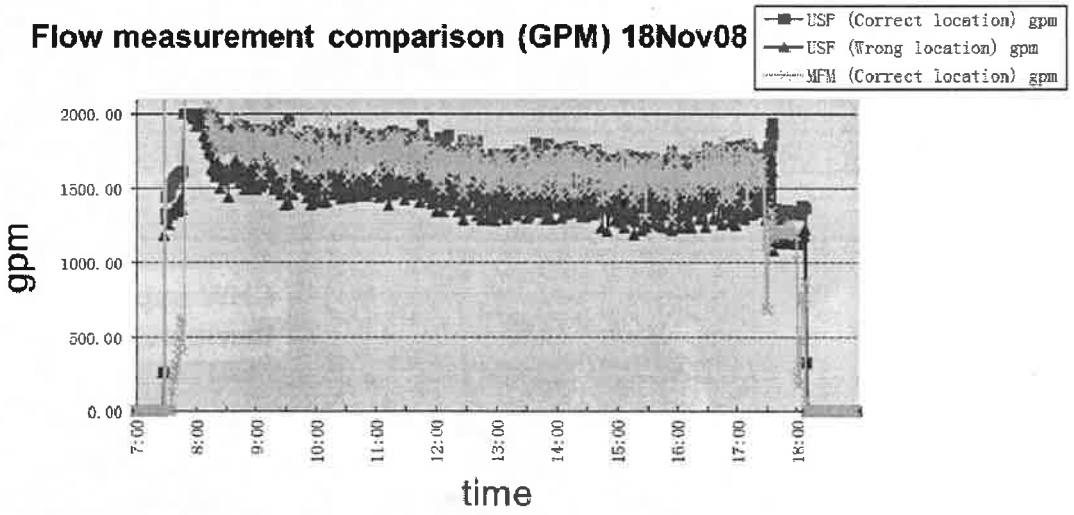
Flow measurement



Flow measurement



Flow measure comparison



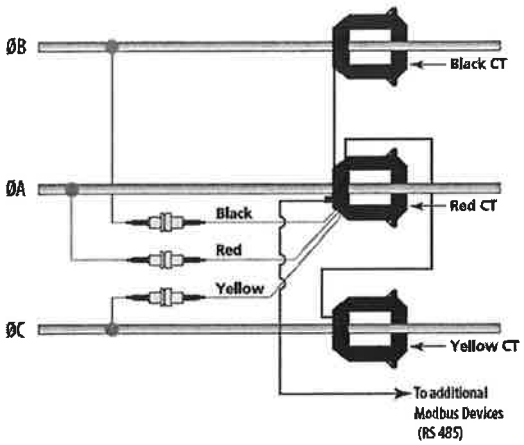
1) Correctly mounted ultrasonic flow meter reading matches the existing magnetic flow reading
2) Improperly mounted ultrasonic flow meter reading is 15% lower than correctly mounted ultrasonic flow meter and the existing magnetic flow meter

Power meter

Power Meter

- Integrated meter to measure Volt, Amps & PF
- Yield true RMS power





Integrated power meter specifications

SPECIFICATIONS

Input Primary Voltage	208 to 480VAC RMS††
Number of Phases Monitored	One to Three
Frequency	50/60Hz
Primary Current	Up to 2400 amps cont. per phase††
Internal Isolation	2000VAC RMS
Insulation Class	600VAC RMS†††
Temperature Range	0° to 60°C (32° F to 140°F), 50°C (122°F) for 2400A
Humidity Range	0 - 95% non-condensing
Systems Accuracy	±1% of reading from 10% to 100% of the rated current of the CTs...accompilshed by matching the CTs with a meter and calibrating them as a system
Output Physical Characteristics	RS-485, 2 wire + shield
Baud Rate	9600, 8N1 format
Protocol	Modbus RTU**(*)

Data output: kWh, Consumption
kW, Real Power
kVAR, Reactive power
kVA, Apparent power
Power factor
Average Real power
Minimum Real power
Maximum Real power
Voltage, line to line
Voltage, line to neutral†
Amps, Average current
kW, Real power ØA†
kW, Real power ØB†
kW, Real power ØC†

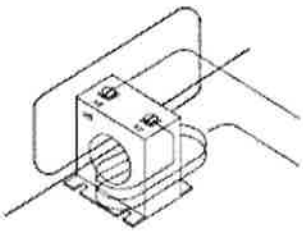
† *Based on derived neutral voltage.*

Errors in power measurement

- Power meters that are not integrated may be prone to error due to wrong settings.
- For example, an energy audit revealed that power measurement error existed in BAS for 15 years because of a wrong CT ratio setting.

Field Adjustment of Current Transformer Ratio

The ratio of current transformers can be field adjusted to fulfill the needs of the application. Passing more secondary turns or more primary turns through the window will increase or decrease the turns ratio.



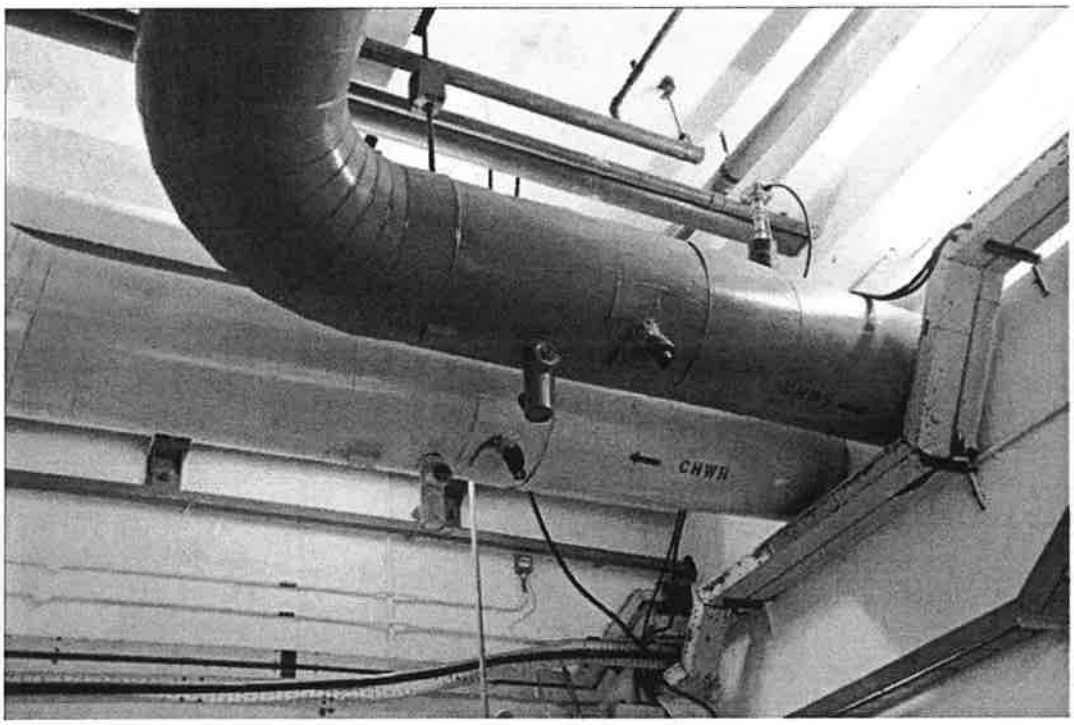
$$\text{ACTUAL TURNS RATIO} = \frac{\text{NAMEPLATE RATIO} * \text{SECONDARY TURNS ADDED}}{\text{PRIMARY TURNS}}$$



Agenda

3. Common pitfalls and recommended good practices

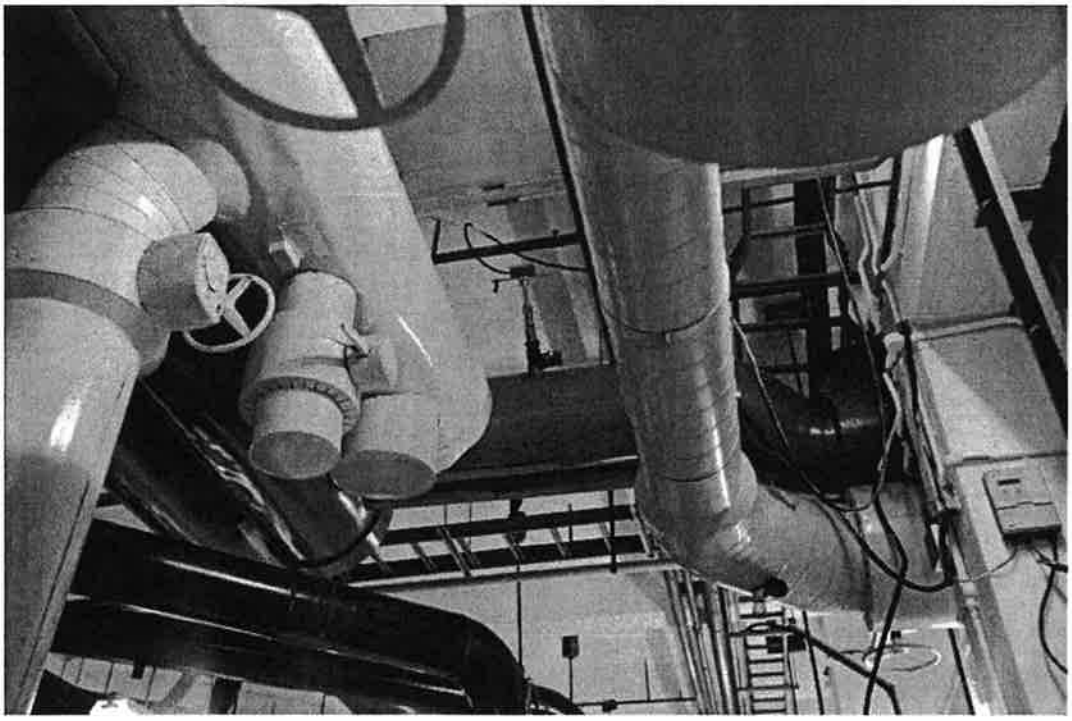
Common pitfalls



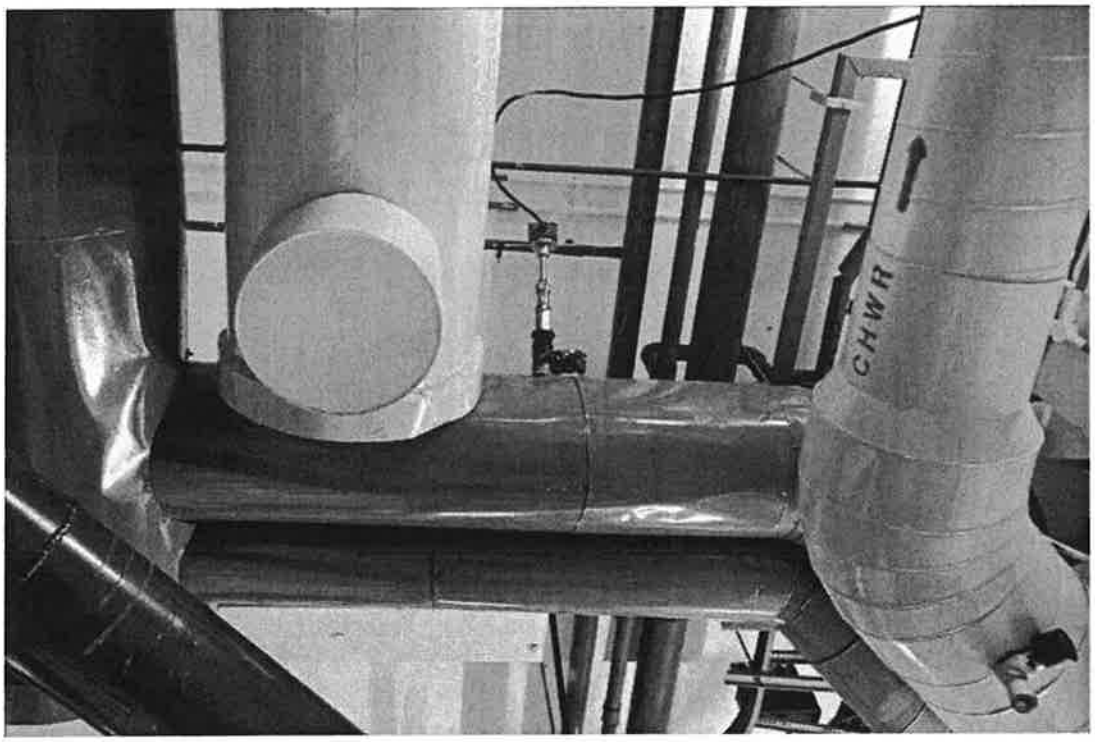


Pitot tube flow meter mounted on top

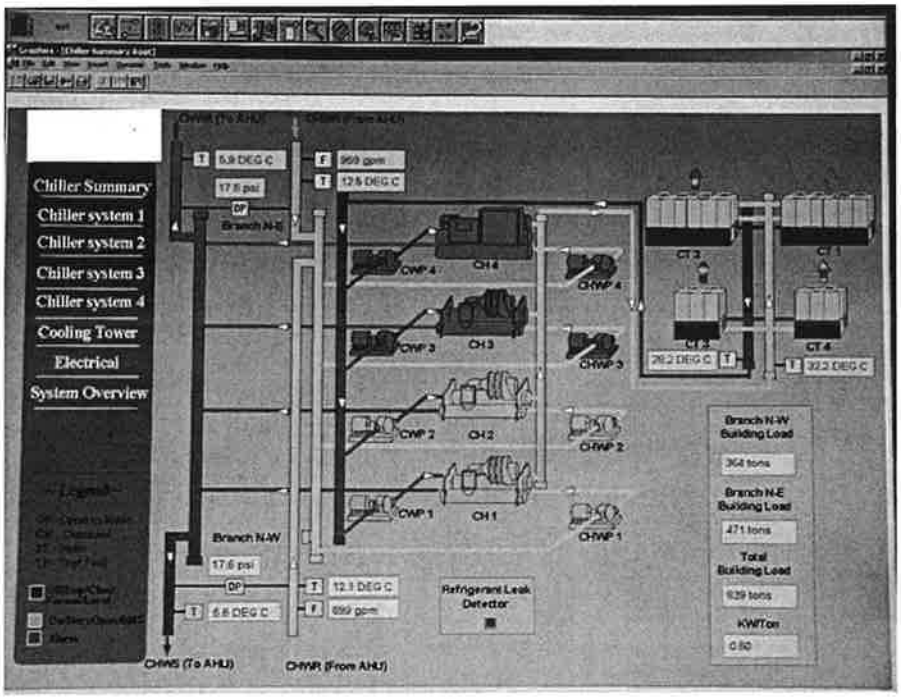
55



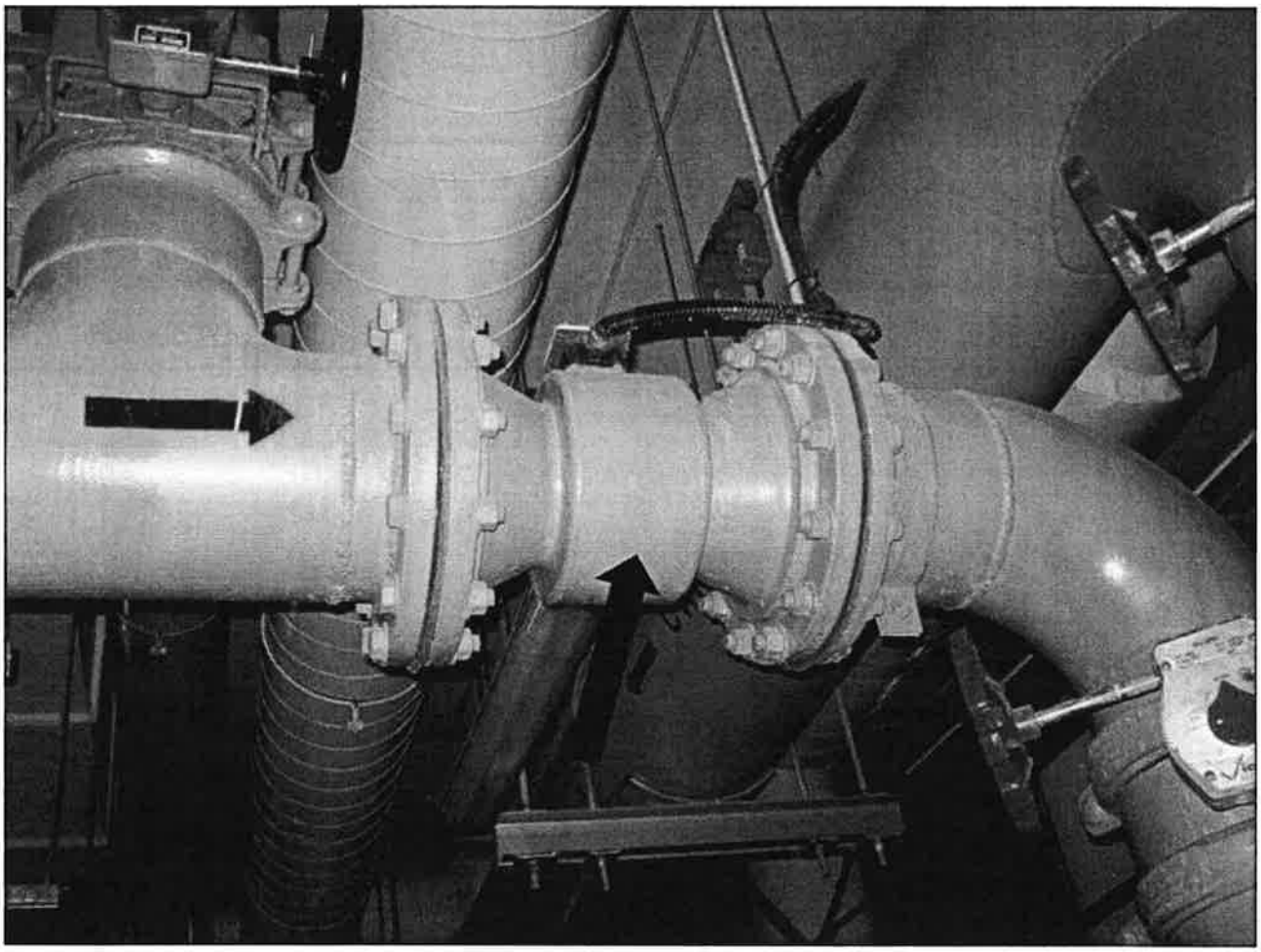
56


CHWR

57

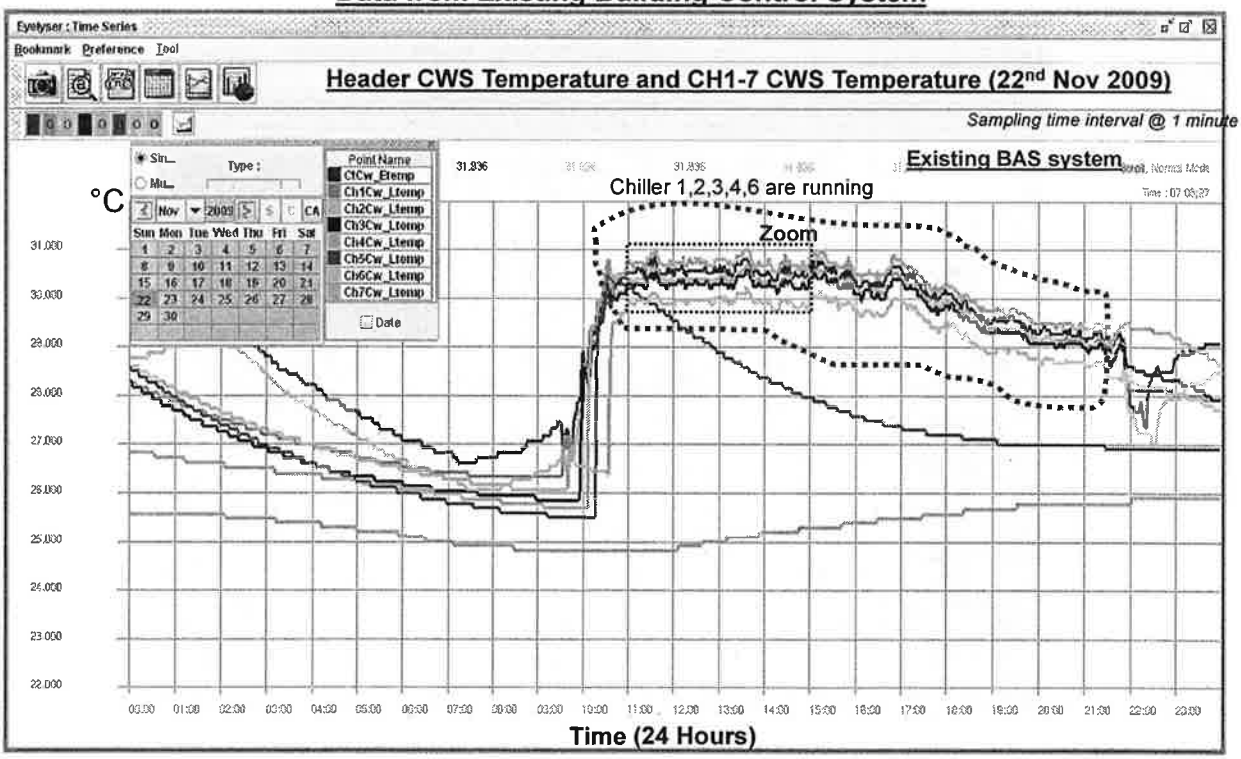

Chiller Summary
Chiller system 1
Chiller system 2
Chiller system 3
Chiller system 4
Cooling Tower
Electrical
System Overview
Branch N-W
Branch N-E
Refrigerant Leak Detector
CHWS (To AHU)
CHWR (From AHU)

58



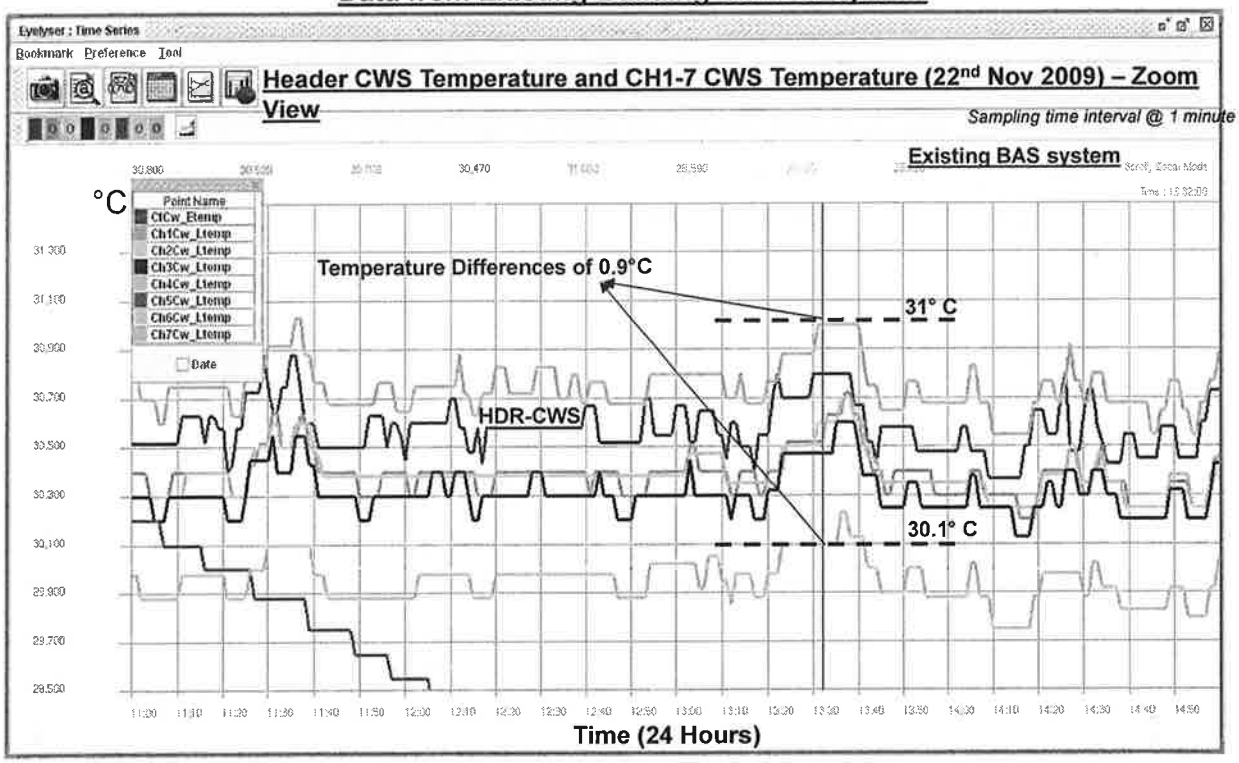
BAS and EMS

Data from Existing Building Control System



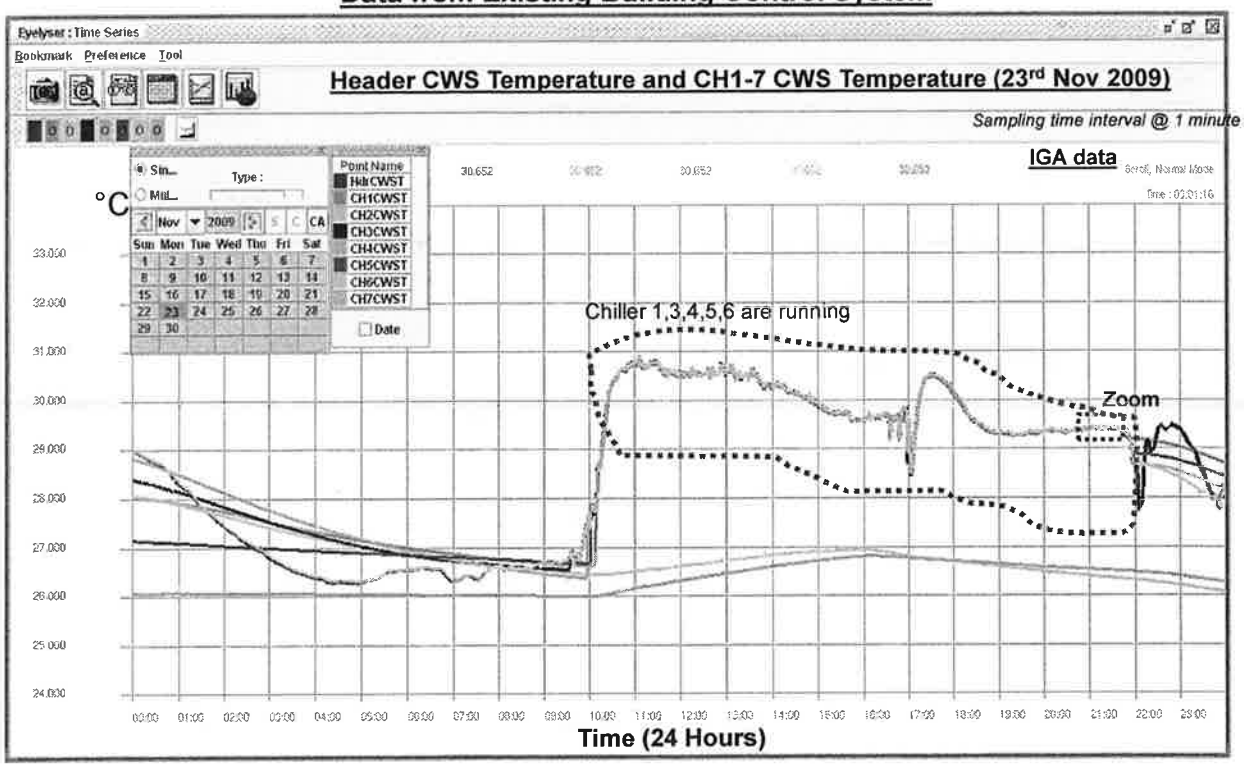
BAS and EMS

Data from Existing Building Control System



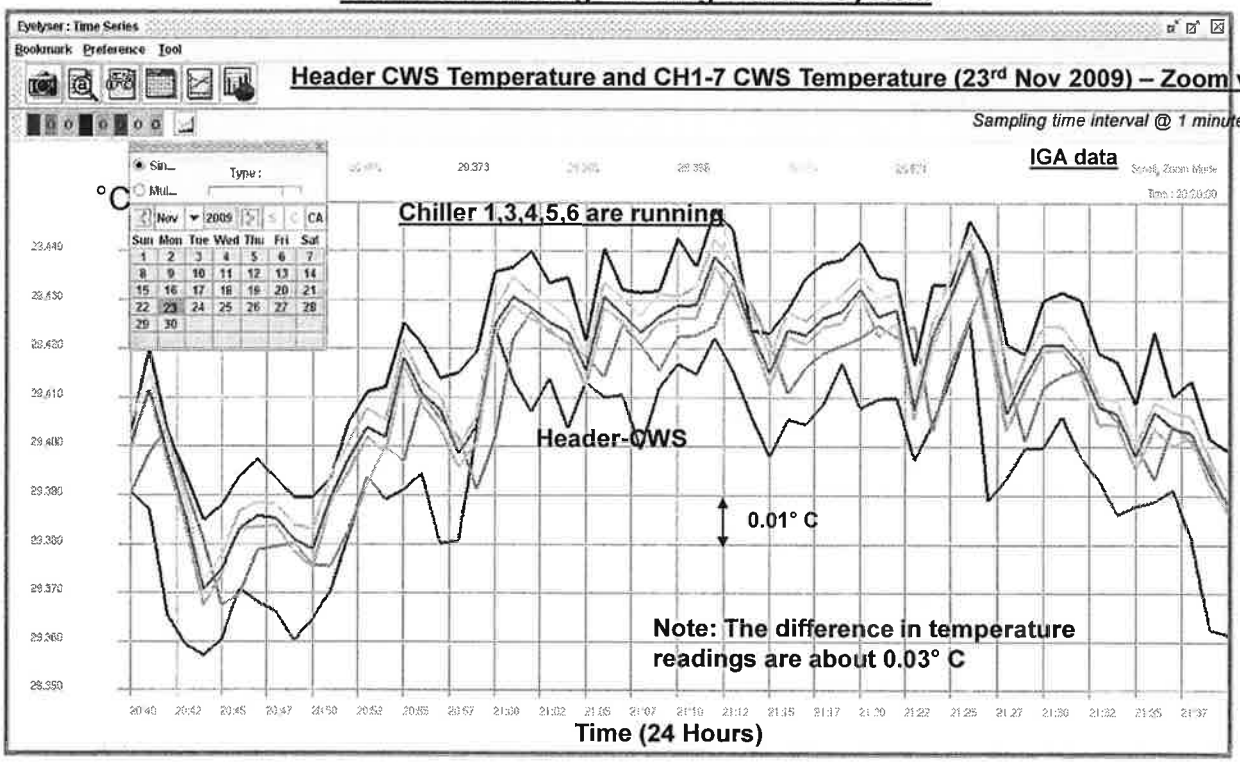
BAS and EMS

Data from Existing Building Control System



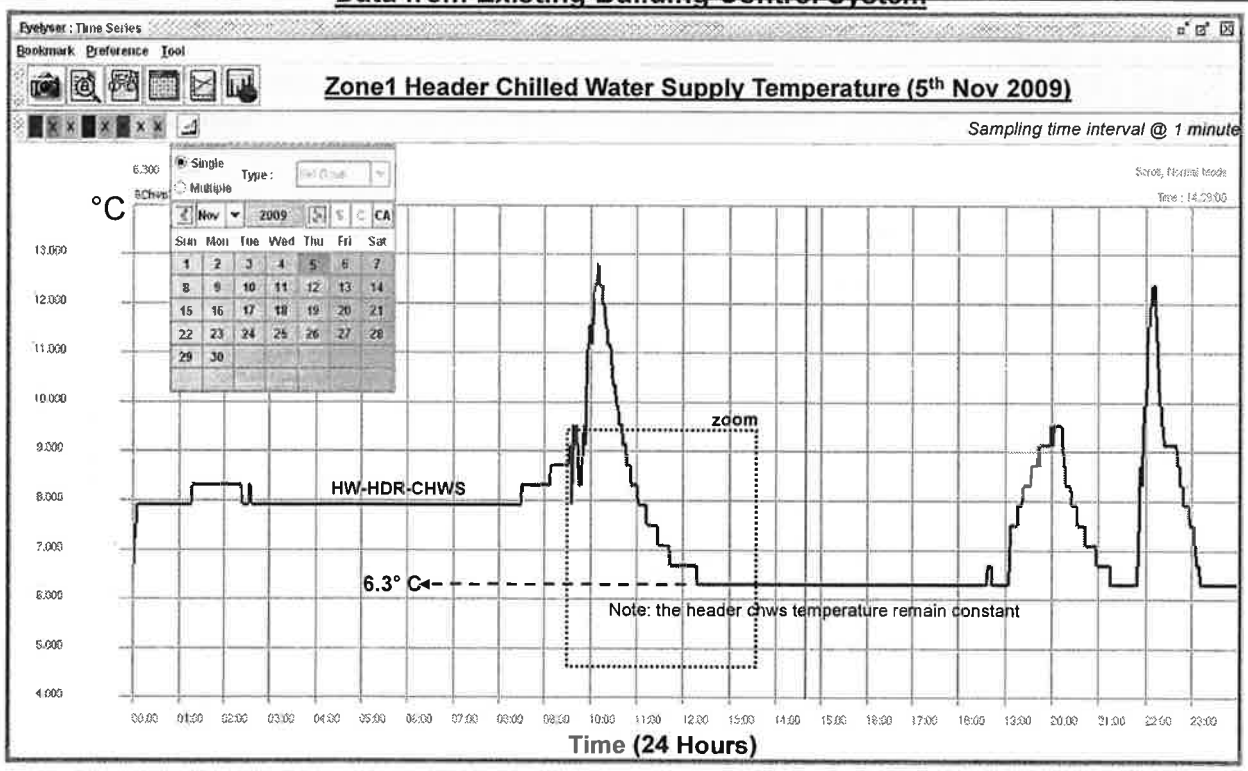
BAS and EMS

Data from Existing Building Control System



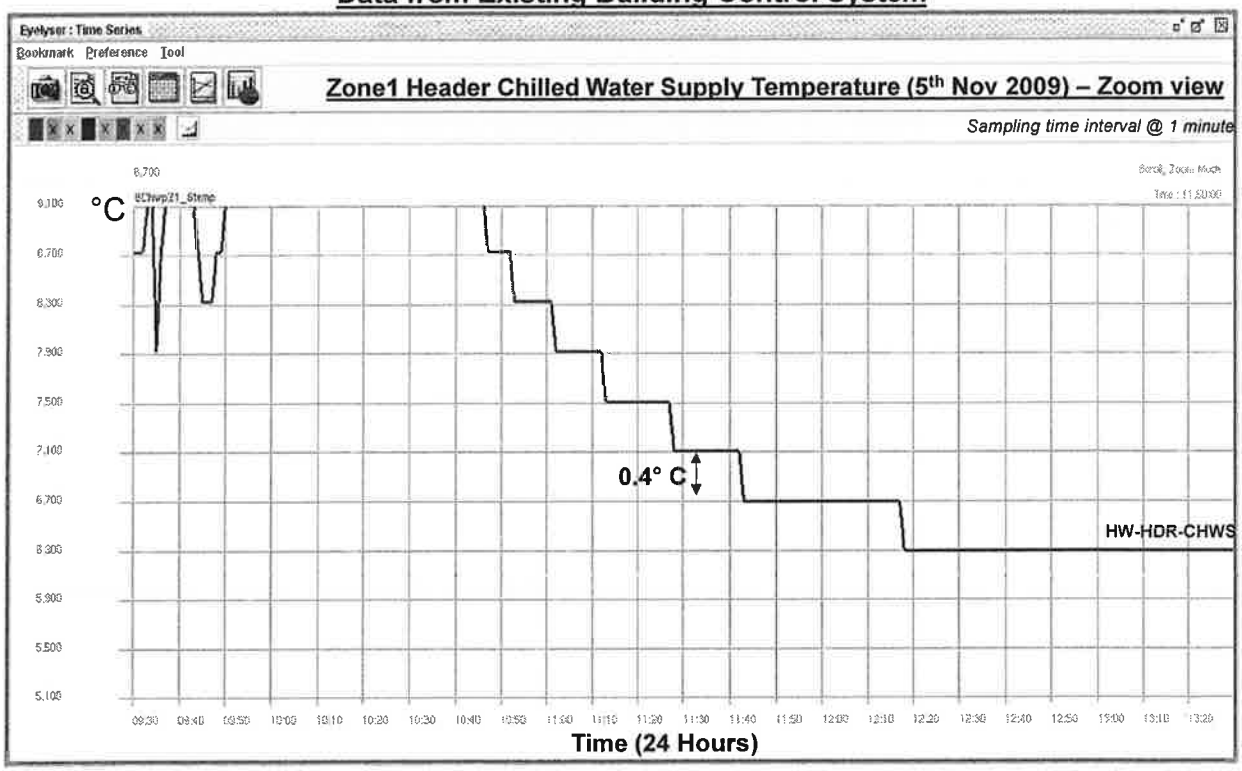
BAS and EMS

Data from Existing Building Control System



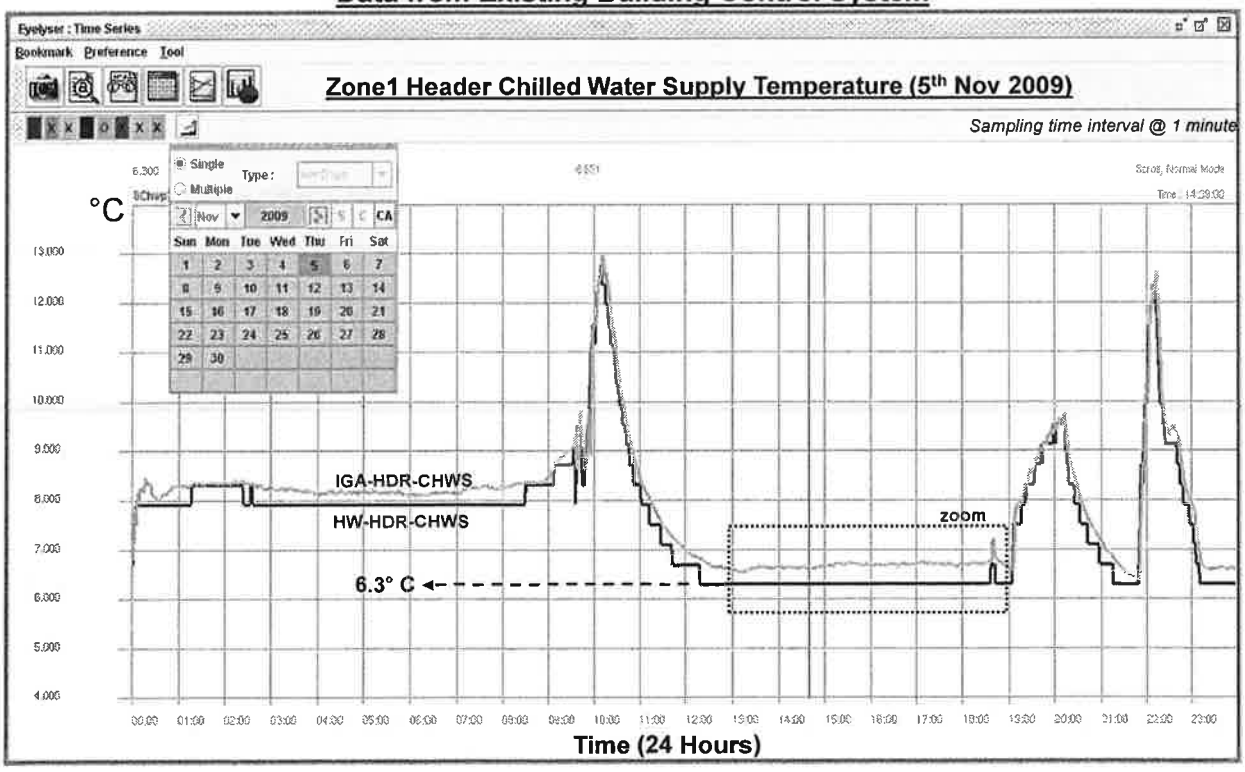
BAS and EMS

Data from Existing Building Control System



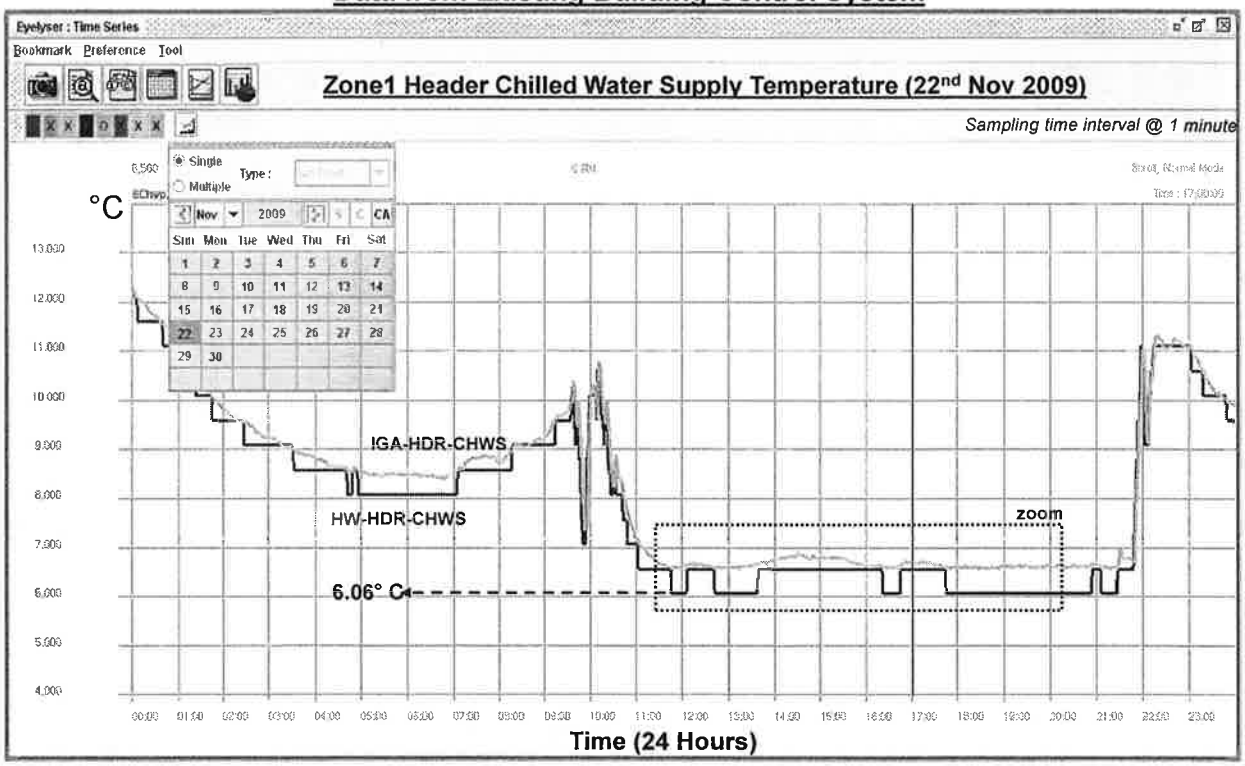
BAS and EMS

Data from Existing Building Control System



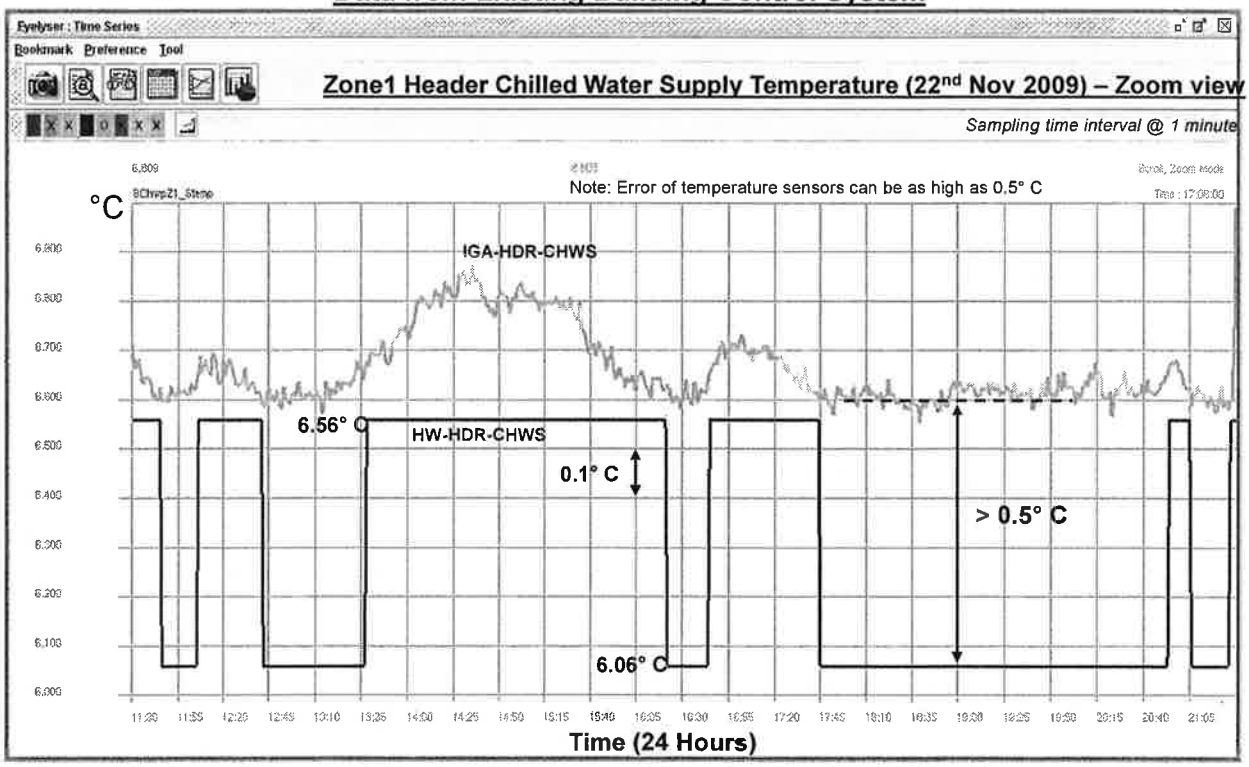
BAS and EMS

Data from Existing Building Control System



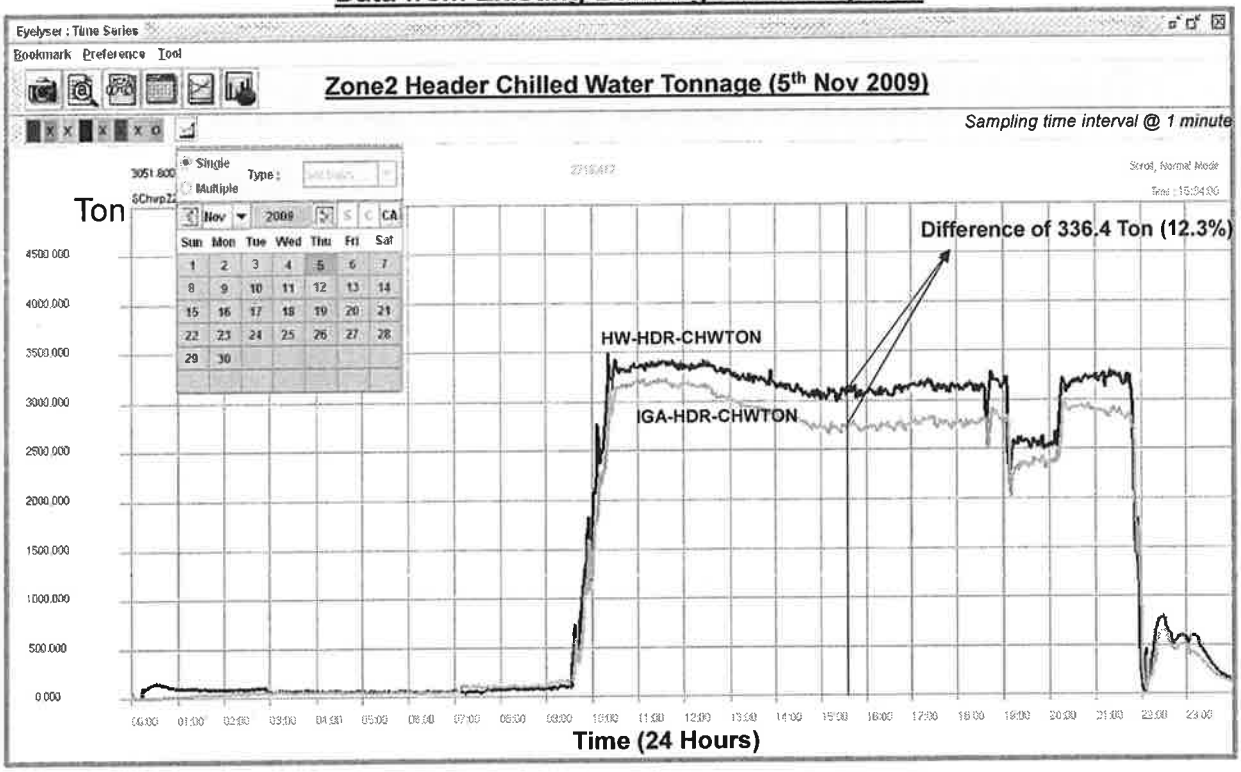
BAS and EMS

Data from Existing Building Control System



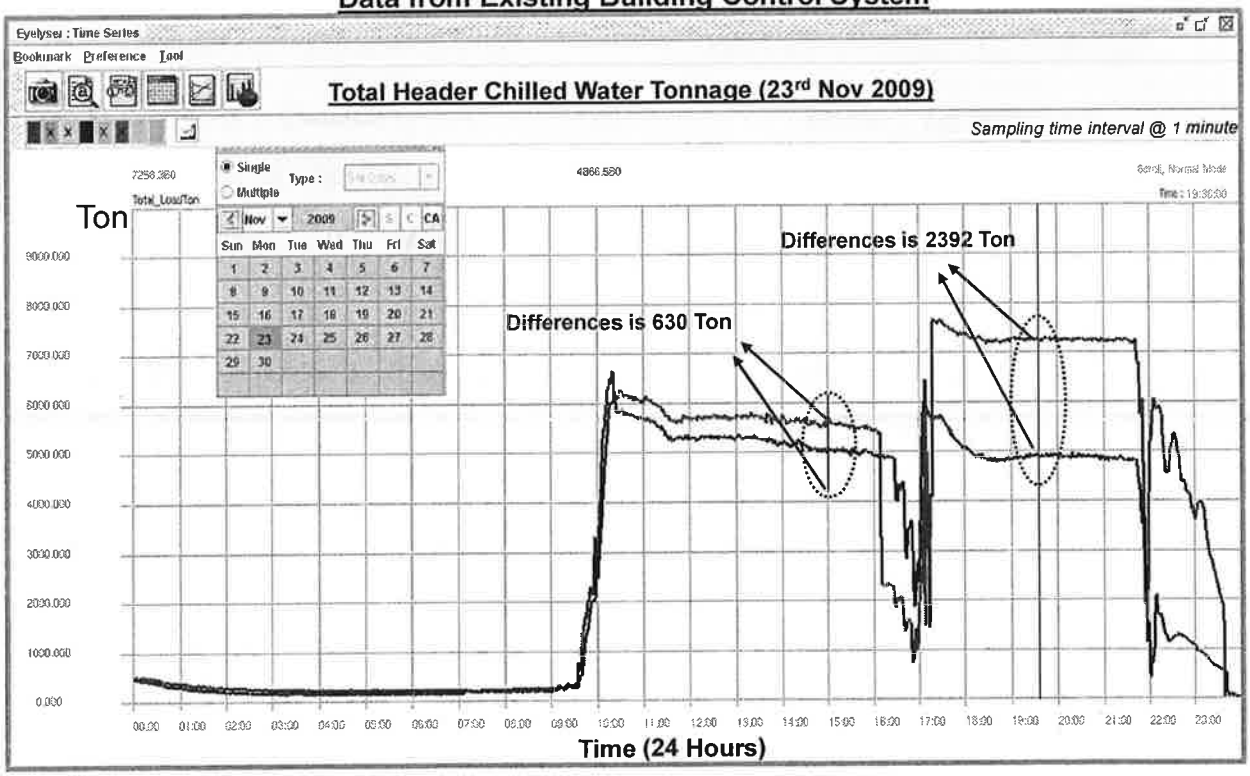
BAS and EMS

Data from Existing Building Control System



BAS and EMS

Data from Existing Building Control System



Recommended good practices

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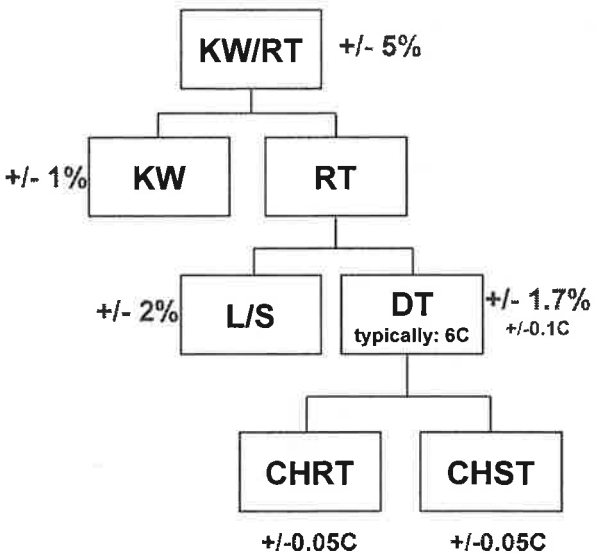
Err on the conservative side for long term accuracy

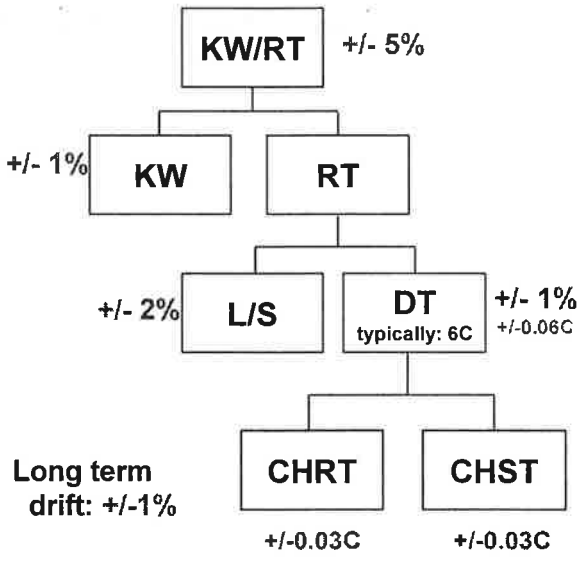
RMS error calculation (Green Mark)



$$Error_{rms} = \sqrt{2^2 + 1^2 + 1.7^2}$$

$$= 2.8\%$$

Strict arithmetic error calculation



$$Error_{arithmetic} = 1+2+1+1$$

$$= 5\%$$

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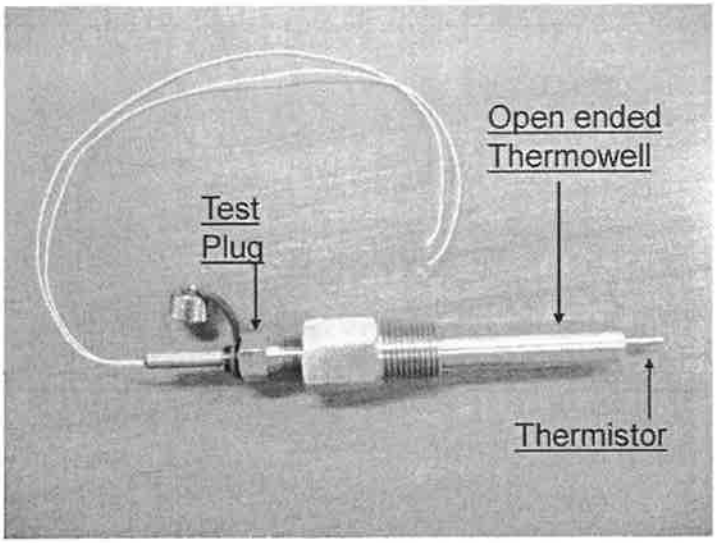
Thermistors

- Thermistor in direct contact with CHW and CW
- Use 30K ohms thermistors



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Thermistors

Steinhart-Hart Thermistor Equation

$1/T = a + b\,(\mathrm{Ln}R) + c\,(\mathrm{Ln}\,R)^3$

T: Temperature in K (C + 273)
R: Resistance in ohms
a, b, c: Coeff derived from calibration

Each thermistor can be calibrated to an accuracy of +/- 0.01C by solving for the a, b, c constants with 3 fixed temperature scale:

The uncertainty of measurement is as follows:

Fixed Temp Scale	Temperature oC	Uncertainty (+/- oC)
Triple point of water	0.0100	0.002
Thermal bath (SPRT)	15.000	0.003
Melting pt of Galium	29.7646	0.002

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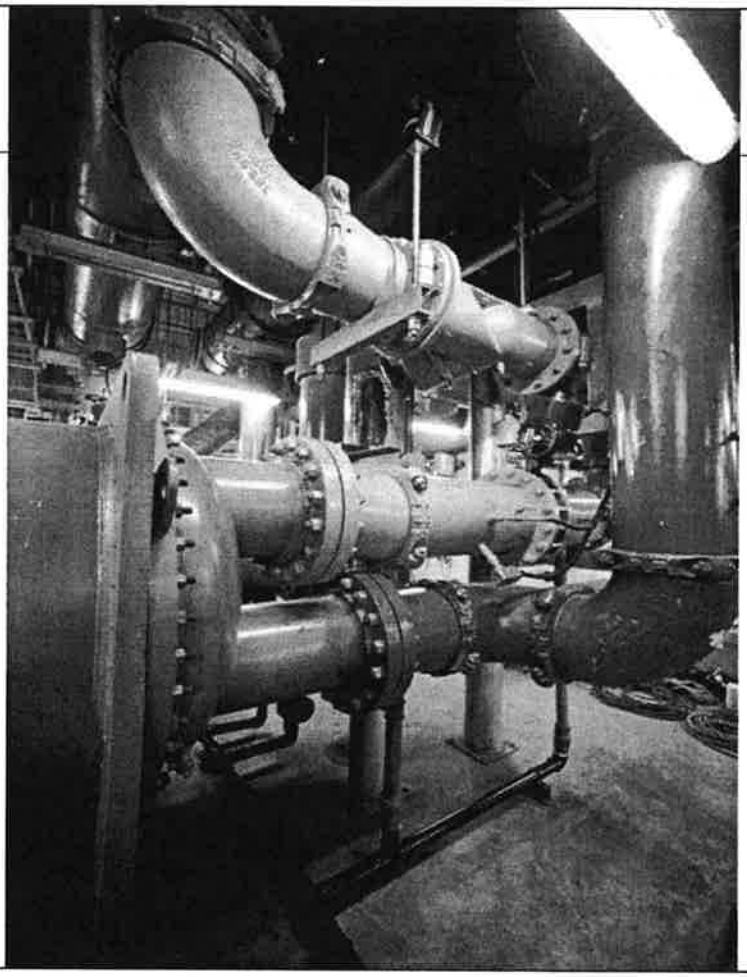



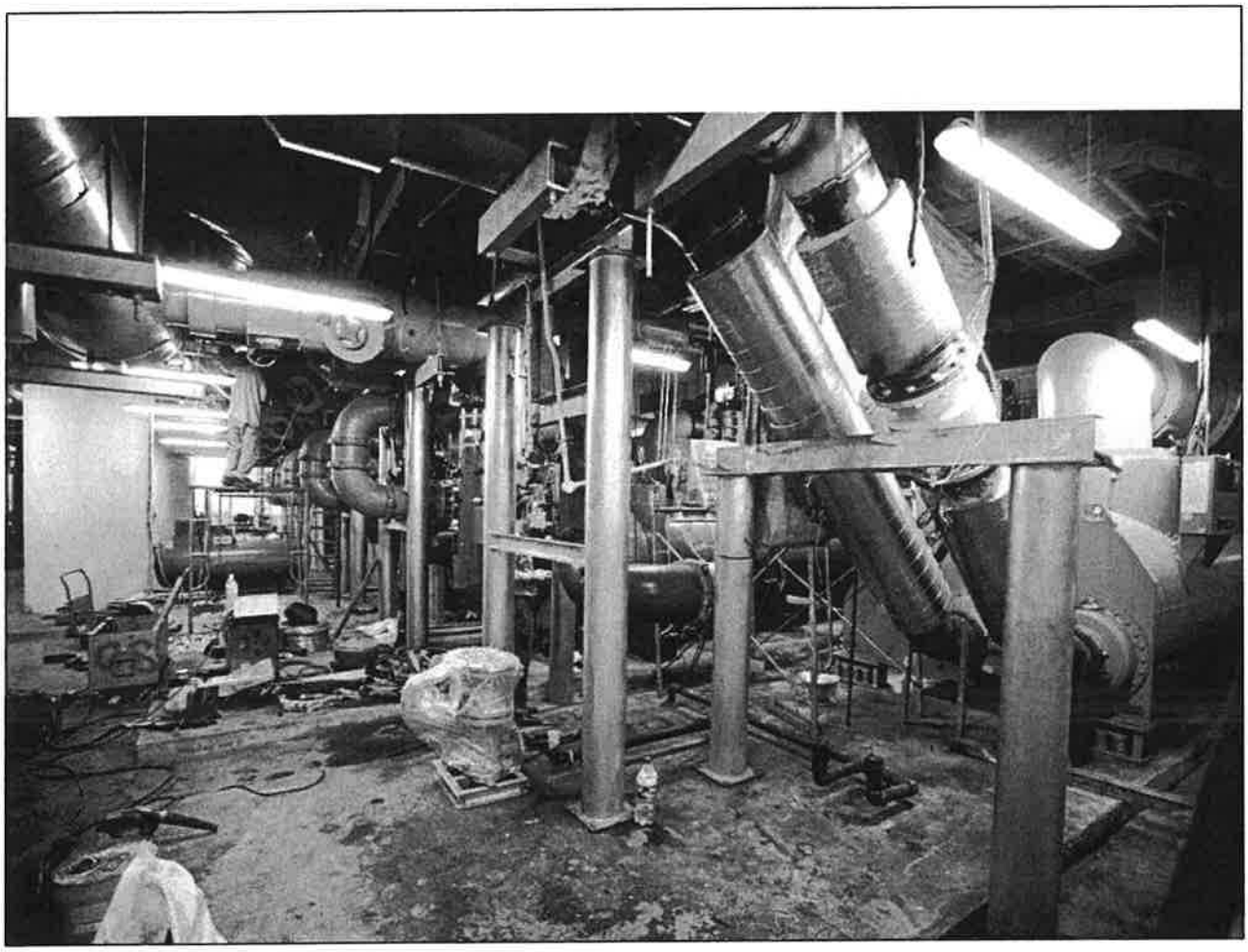

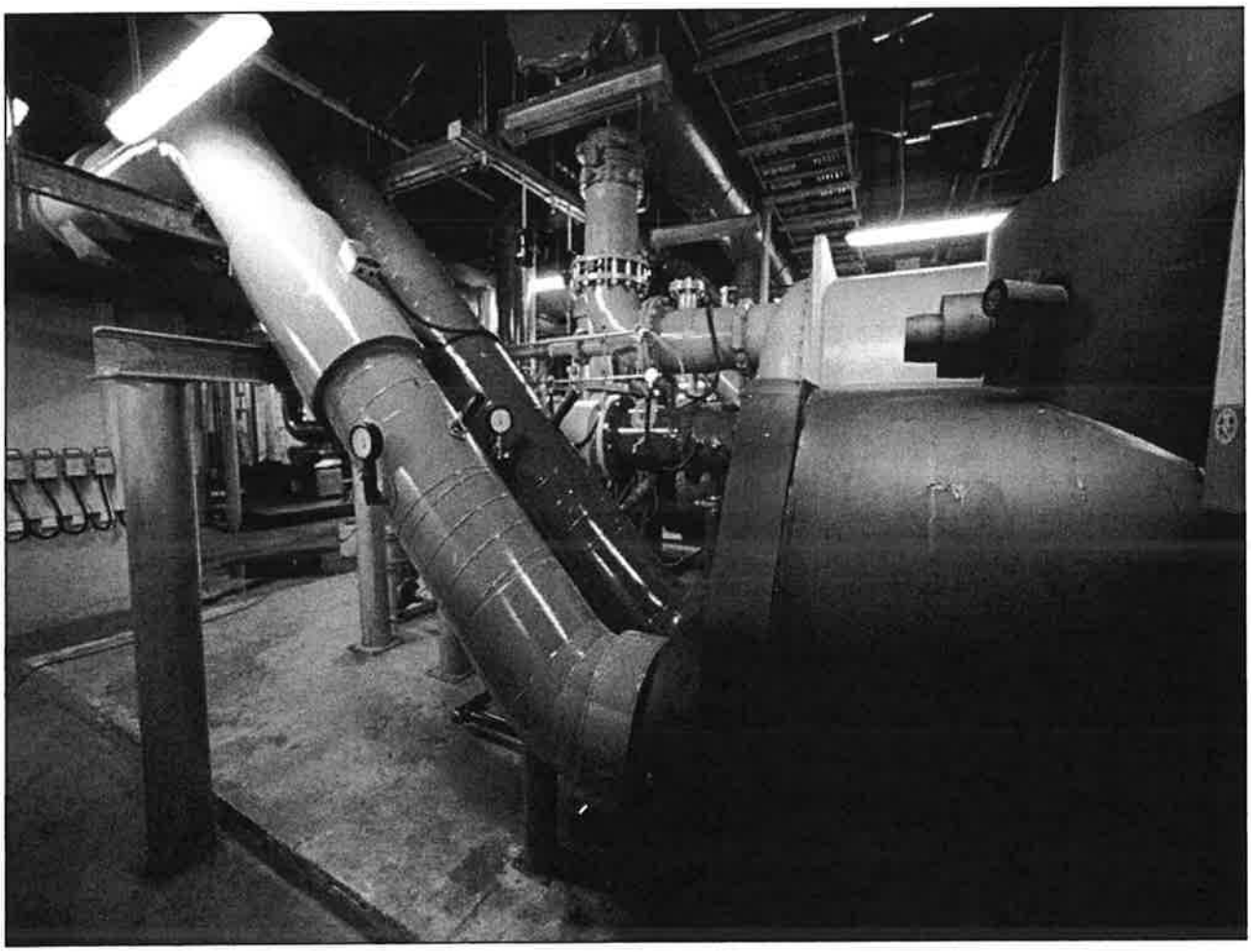

M&V validation check

Multiple sensors allow for consistency check:

1. Temperature at chiller inlet vs header
2. Sum of flow at chiller = header
3. Sum of KW = Incoming KW
4. Heat balance

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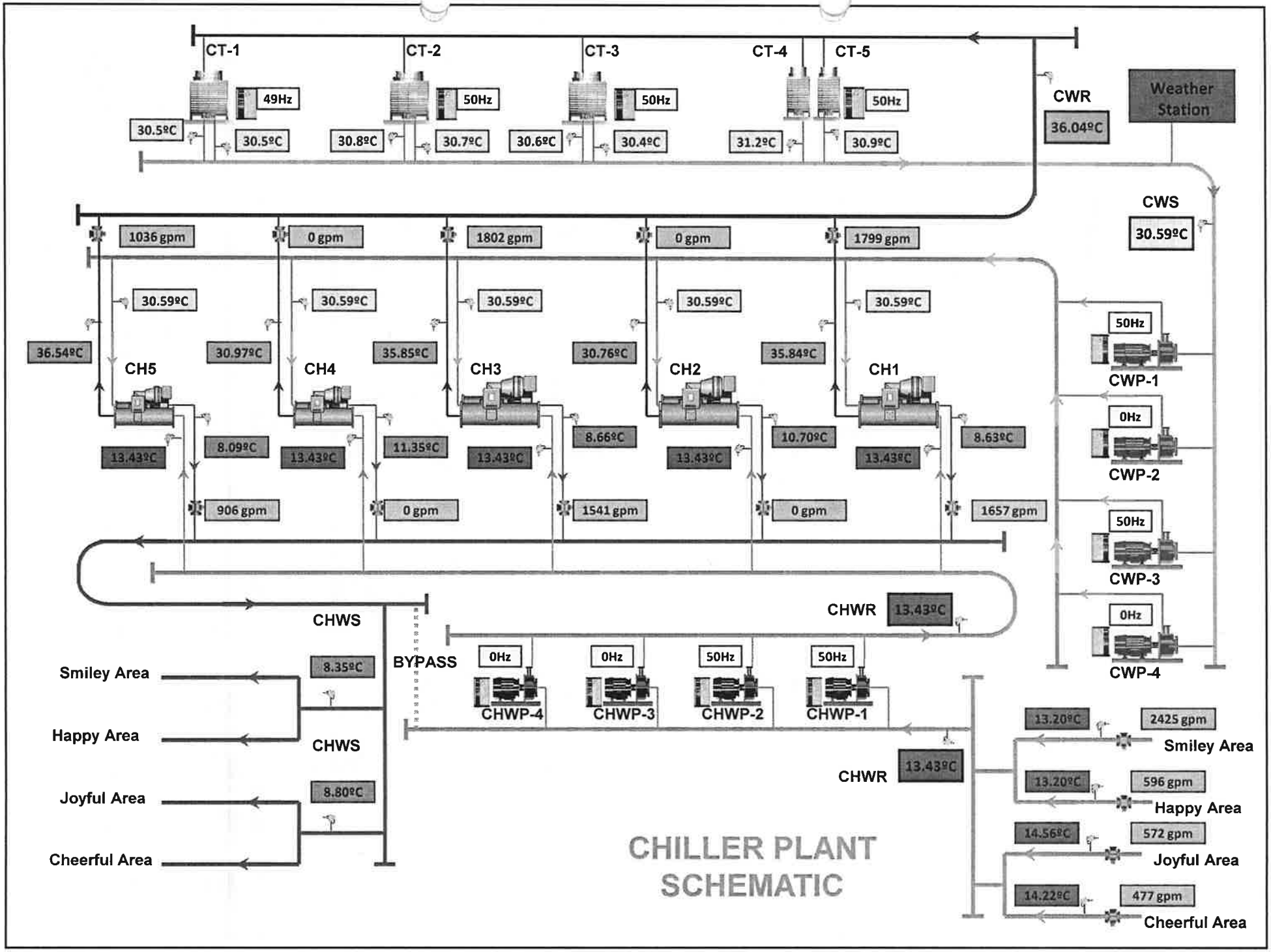
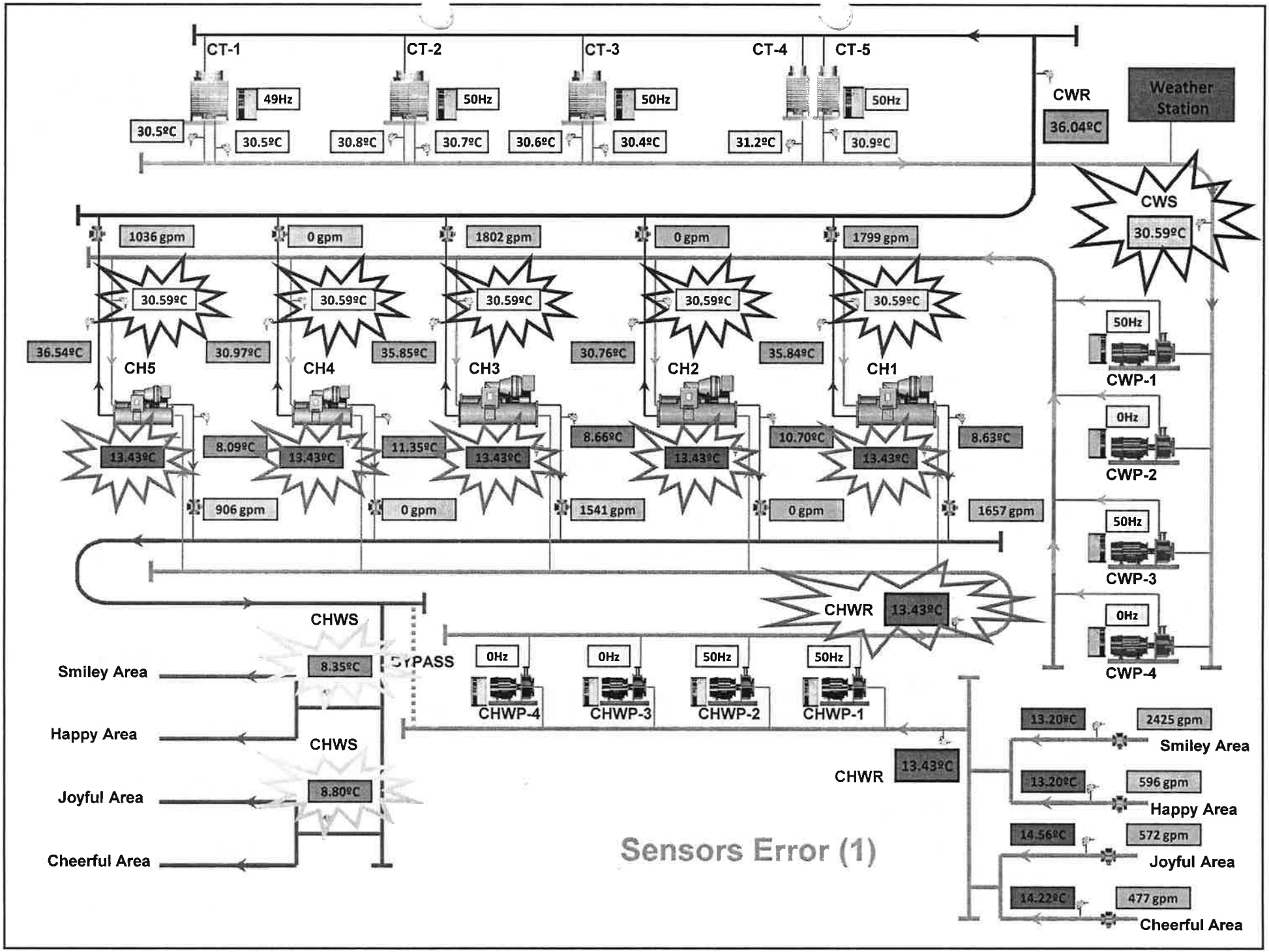
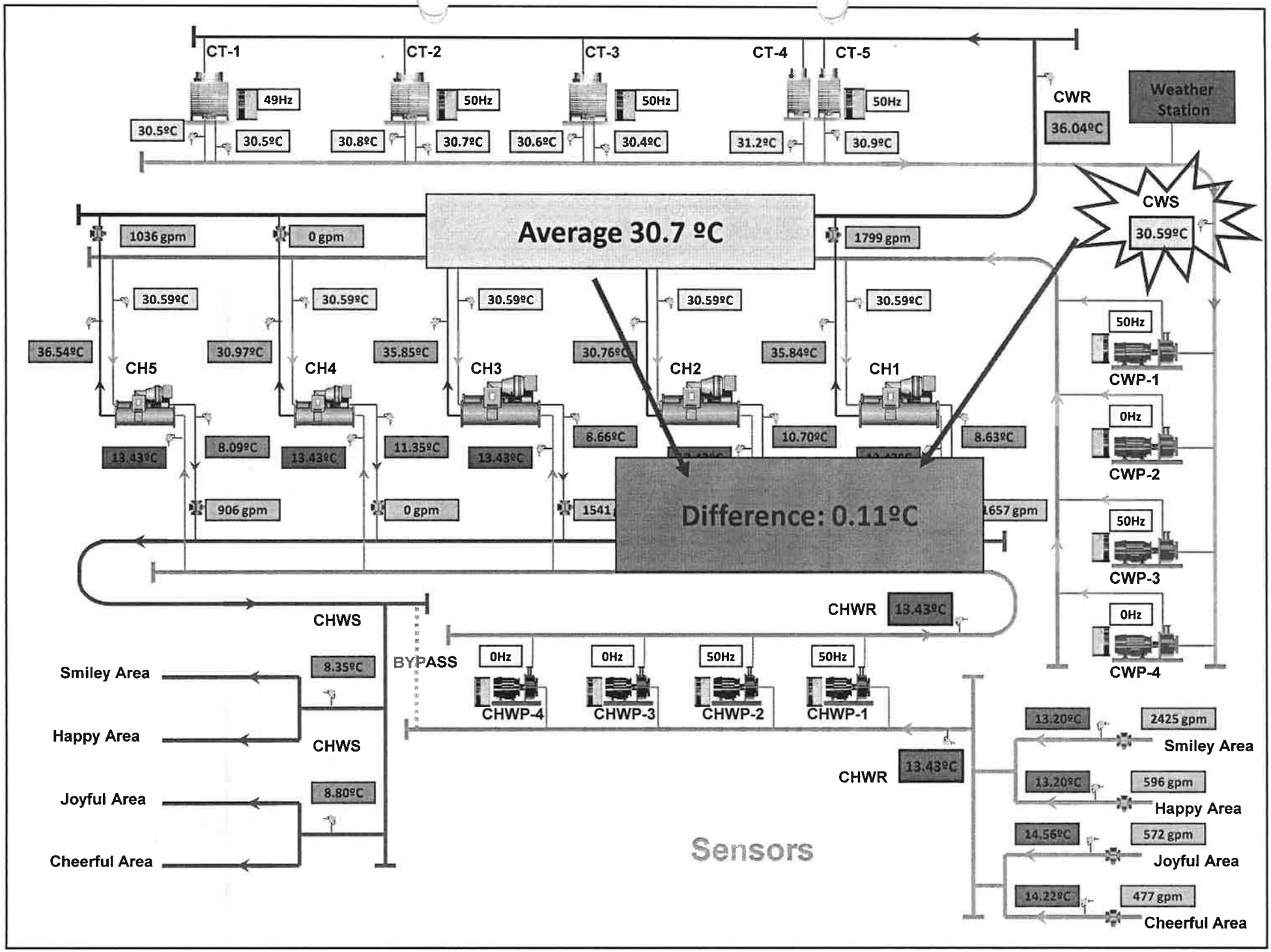
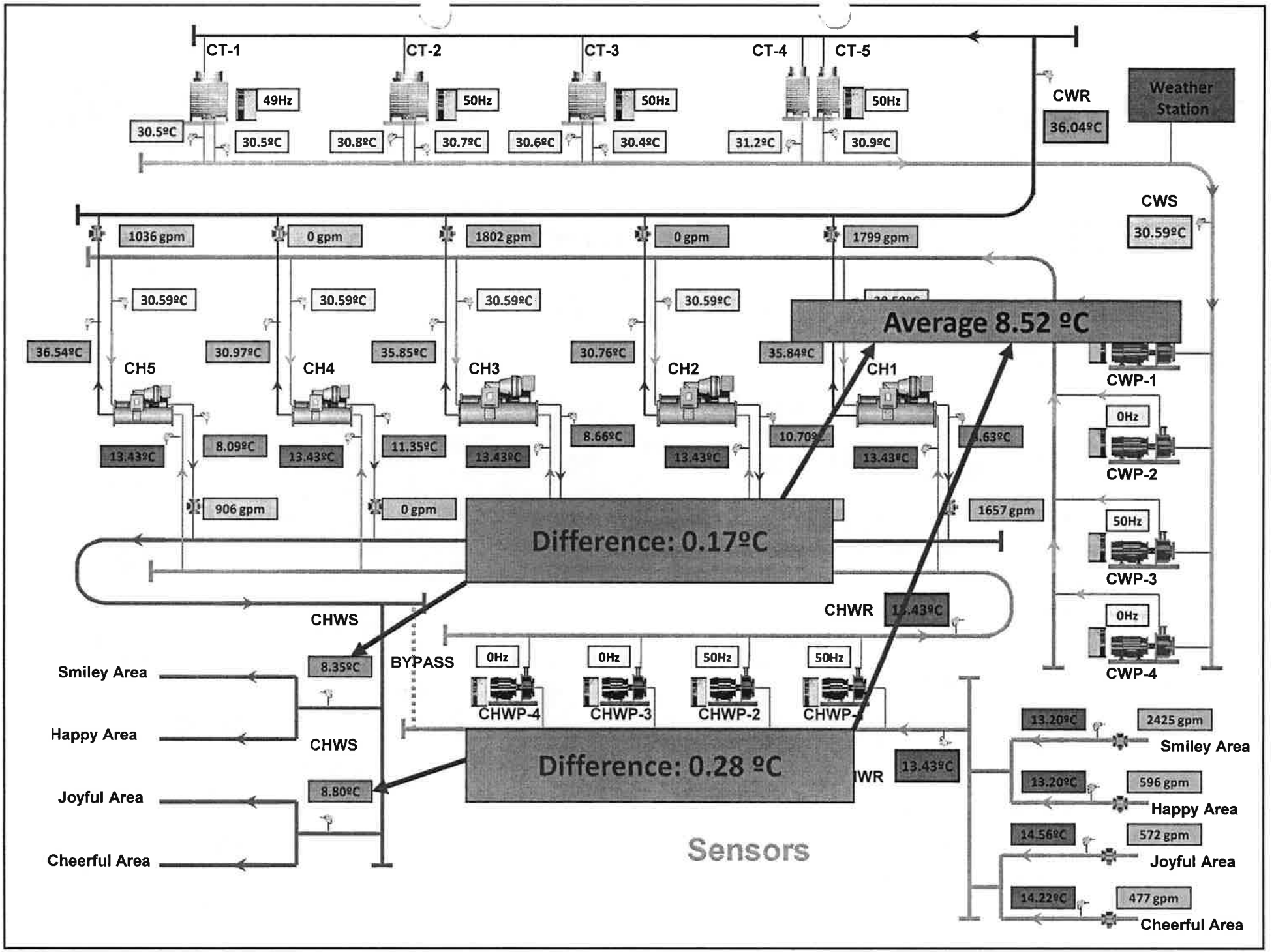
Example of how to check for measurement accuracy.

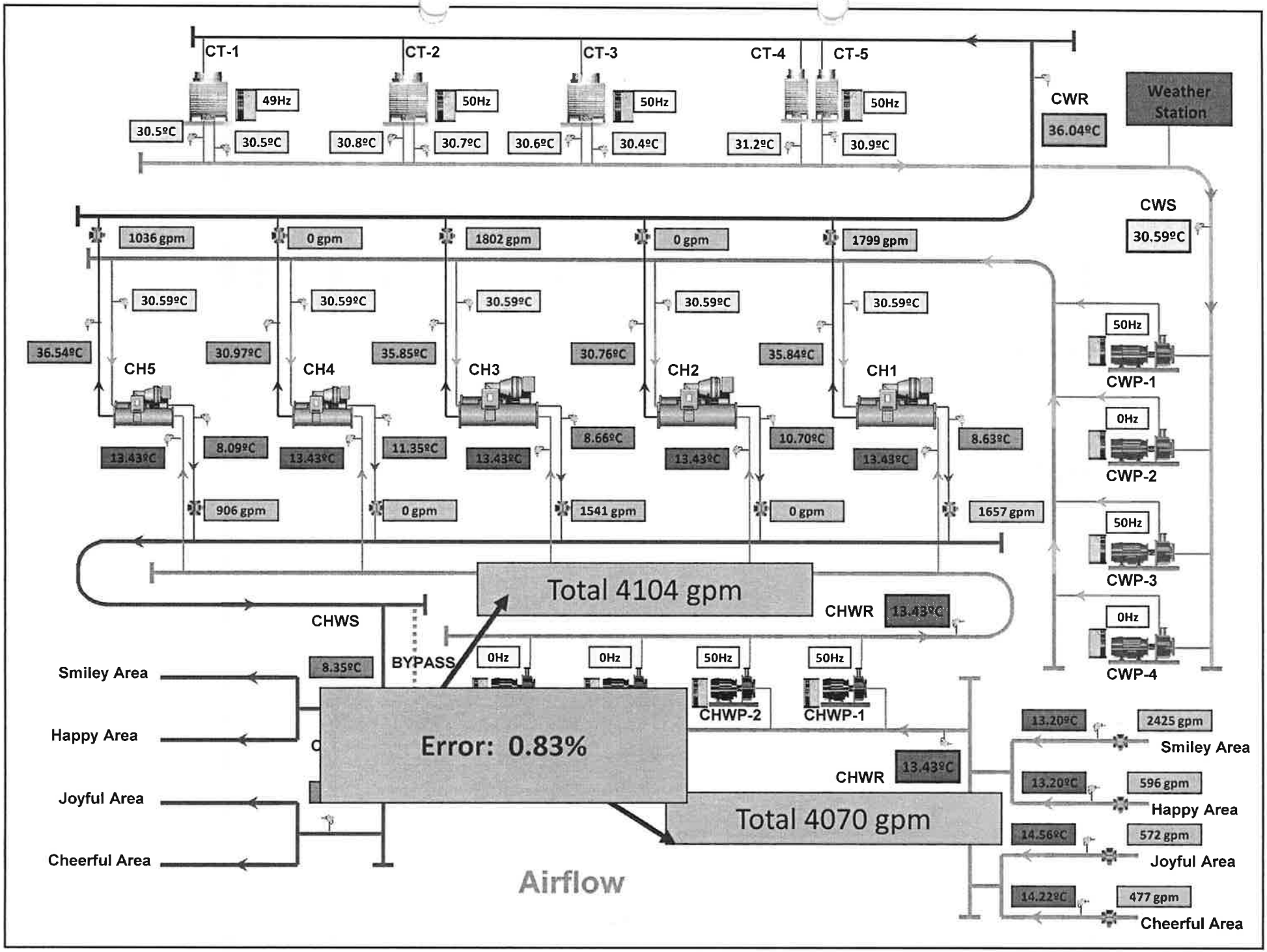
Project A


CT-1
CT-2
CT-3
CT-4
CT-5
49Hz
50Hz
50Hz
50Hz
30.5ºC
30.5ºC
30.8ºC
30.7ºC
30.6ºC
30.4ºC
31.2ºC
30.9ºC
CWR
36.04ºC
Weather Station
CWS
30.59ºC
1036 gpm
0 gpm
1802 gpm
0 gpm
1799 gpm
30.59ºC
36.54ºC
30.97ºC
35.85ºC
30.76ºC
35.84ºC
CH5
CH4
CH3
CH2
CH1
13.43ºC
8.09ºC
13.43ºC
11.35ºC
13.43ºC
8.66ºC
13.43ºC
10.70ºC
13.43ºC
8.63ºC
906 gpm
0 gpm
1541 gpm
0 gpm
1657 gpm
CHWS
CHWR
13.43ºC
BYPASS
0Hz
0Hz
50Hz
50Hz
CHWP-4
CHWP-3
CHWP-2
CHWP-1
50Hz
CWP-1
0Hz
CWP-2
50Hz
CWP-3
0Hz
CWP-4
Smiley Area
8.35ºC
Happy Area
CHWS
Joyful Area
8.80ºC
Cheerful Area
CHWR
13.43ºC
13.20ºC
2425 gpm
Smiley Area
13.20ºC
596 gpm
Happy Area
14.56ºC
572 gpm
Joyful Area
14.22ºC
477 gpm
Cheerful Area
CHILLER PLANT
SCHEMATIC


CT-1
CT-2
CT-3
CT-4
CT-5
49Hz
50Hz
50Hz
50Hz
30.5ºC
30.5ºC
30.8ºC
30.7ºC
30.6ºC
30.4ºC
31.2ºC
30.9ºC
CWR
36.04ºC
Weather Station
CWS
30.59ºC
1036 gpm
0 gpm
1802 gpm
0 gpm
1799 gpm
30.59ºC
30.59ºC
30.59ºC
30.59ºC
30.59ºC
36.54ºC
30.97ºC
35.85ºC
30.76ºC
35.84ºC
CH5
CH4
CH3
CH2
CH1
13.43ºC
8.09ºC
13.43ºC
11.35ºC
13.43ºC
8.66ºC
13.43ºC
10.70ºC
13.43ºC
8.63ºC
906 gpm
0 gpm
1541 gpm
0 gpm
1657 gpm
50Hz
CWP-1
0Hz
CWP-2
50Hz
CWP-3
0Hz
CWP-4
CHWS
CHWR
13.43ºC
Smiley Area
8.35ºC
BYPASS
0Hz
0Hz
50Hz
50Hz
CHWP-4
CHWP-3
CHWP-2
CHWP-1
Happy Area
CHWS
Joyful Area
8.80ºC
Cheerful Area
CHWR
13.43ºC
13.20ºC
2425 gpm
Smiley Area
13.20ºC
596 gpm
Happy Area
14.56ºC
572 gpm
Joyful Area
14.22ºC
477 gpm
Cheerful Area
Sensors Error (1)

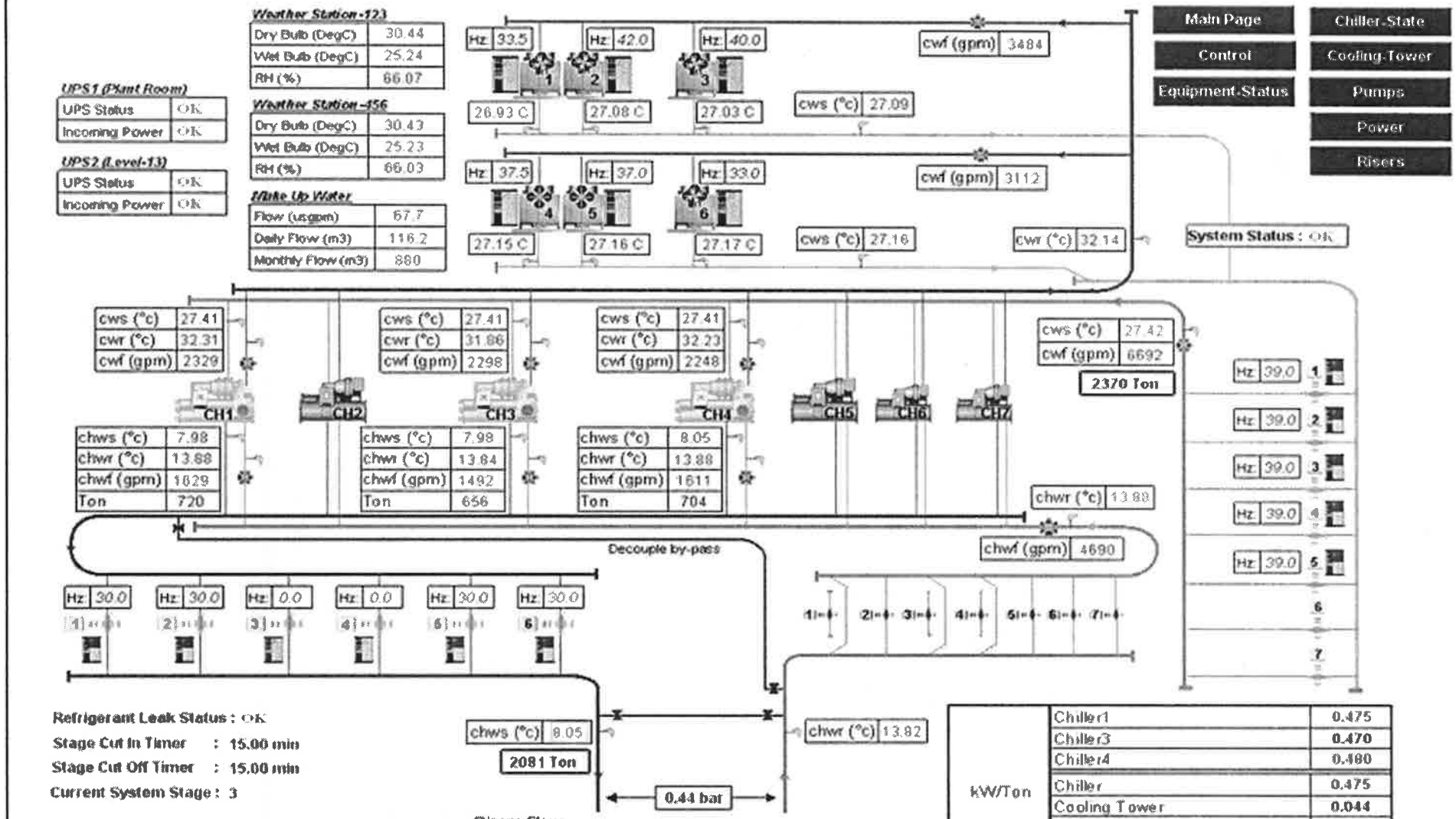

CT-1
CT-2
CT-3
CT-4
CT-5
49Hz
50Hz
50Hz
50Hz
30.5ºC
30.5ºC
30.8ºC
30.7ºC
30.6ºC
30.4ºC
31.2ºC
30.9ºC
CWR
36.04ºC
Weather Station
CWS
30.59ºC
Average 30.7 ºC
1036 gpm
0 gpm
1799 gpm
30.59ºC
36.54ºC
30.97ºC
35.85ºC
30.76ºC
35.84ºC
CH5
CH4
CH3
CH2
CH1
13.43ºC
8.09ºC
13.43ºC
11.35ºC
13.43ºC
8.66ºC
10.70ºC
8.63ºC
906 gpm
0 gpm
1657 gpm
Difference: 0.11ºC
50Hz
CWP-1
0Hz
CWP-2
50Hz
CWP-3
0Hz
CWP-4
CHWS
CHWR
13.43ºC
BYPASS
0Hz
0Hz
50Hz
50Hz
CHWP-4
CHWP-3
CHWP-2
CHWP-1
Smiley Area
8.35ºC
Happy Area
CHWS
Joyful Area
8.80ºC
Cheerful Area
CHWR
13.43ºC
13.20ºC
2425 gpm
Smiley Area
13.20ºC
596 gpm
Happy Area
14.56ºC
572 gpm
Joyful Area
14.22ºC
477 gpm
Cheerful Area
Sensors


CT-1
CT-2
CT-3
CT-4
CT-5
49Hz
50Hz
50Hz
50Hz
30.5ºC
30.5ºC
30.8ºC
30.7ºC
30.6ºC
30.4ºC
31.2ºC
30.9ºC
CWR
36.04ºC
Weather Station
CWS
30.59ºC
1036 gpm
0 gpm
1802 gpm
0 gpm
1799 gpm
30.59ºC
30.59ºC
30.59ºC
30.59ºC
Average 8.52 ºC
36.54ºC
30.97ºC
35.85ºC
30.76ºC
35.84ºC
CH5
CH4
CH3
CH2
CH1
CWP-1
0Hz
CWP-2
13.43ºC
8.09ºC
13.43ºC
11.35ºC
13.43ºC
8.66ºC
13.43ºC
13.43ºC
906 gpm
0 gpm
1657 gpm
50Hz
CWP-3
Difference: 0.17ºC
CHWS
CHWR
13.43ºC
0Hz
CWP-4
Smiley Area
8.35ºC
BYPASS
0Hz
0Hz
50Hz
50Hz
CHWP-4
CHWP-3
CHWP-2
CHWP-1
Happy Area
CHWS
Difference: 0.28 ºC
13.43ºC
13.20ºC
2425 gpm
Smiley Area
Joyful Area
8.80ºC
13.20ºC
596 gpm
Happy Area
Cheerful Area
14.56ºC
572 gpm
Joyful Area
Sensors
14.22ºC
477 gpm
Cheerful Area


CT-1
CT-2
CT-3
CT-4
CT-5
49Hz
50Hz
50Hz
50Hz
30.5ºC
30.5ºC
30.8ºC
30.7ºC
30.6ºC
30.4ºC
31.2ºC
30.9ºC
CWR
36.04ºC
Weather Station
CWS
30.59ºC
1036 gpm
0 gpm
1802 gpm
0 gpm
1799 gpm
30.59ºC
36.54ºC
30.97ºC
35.85ºC
30.76ºC
35.84ºC
CH5
CH4
CH3
CH2
CH1
13.43ºC
8.09ºC
13.43ºC
11.35ºC
13.43ºC
8.66ºC
13.43ºC
10.70ºC
13.43ºC
8.63ºC
906 gpm
0 gpm
1541 gpm
0 gpm
1657 gpm
50Hz
CWP-1
0Hz
CWP-2
50Hz
CWP-3
0Hz
CWP-4
Total 4104 gpm
CHWS
CHWR
13.43ºC
8.35ºC
BYPASS
0Hz
0Hz
50Hz
50Hz
CHWP-2
CHWP-1
Smiley Area
Happy Area
Joyful Area
Cheerful Area
Error: 0.83%
CHWR
13.43ºC
Total 4070 gpm
13.20ºC
2425 gpm
Smiley Area
13.20ºC
596 gpm
Happy Area
14.56ºC
572 gpm
Joyful Area
14.22ºC
477 gpm
Cheerful Area
Airflow

Example of how to check for measurement accuracy.

Project B

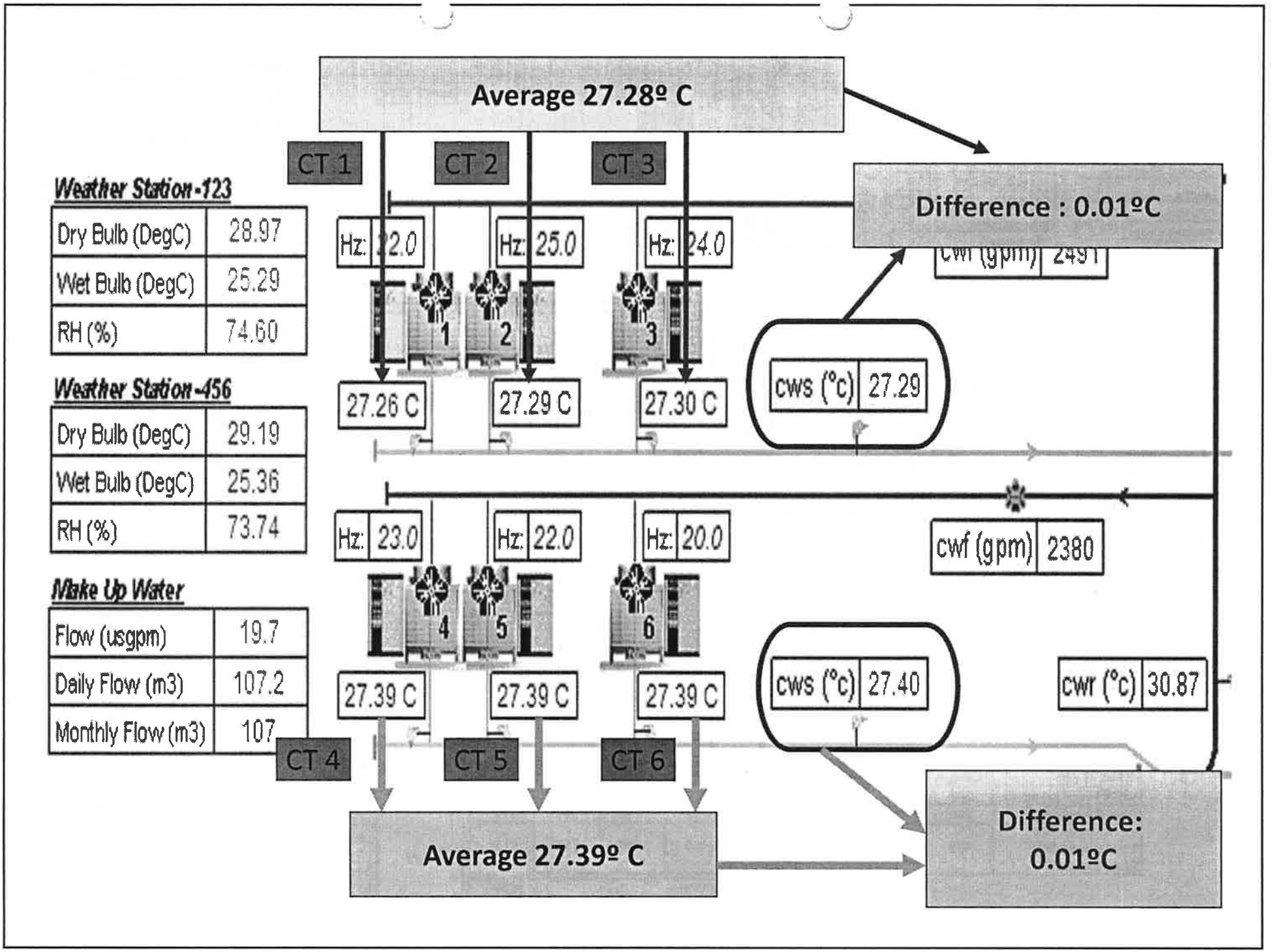


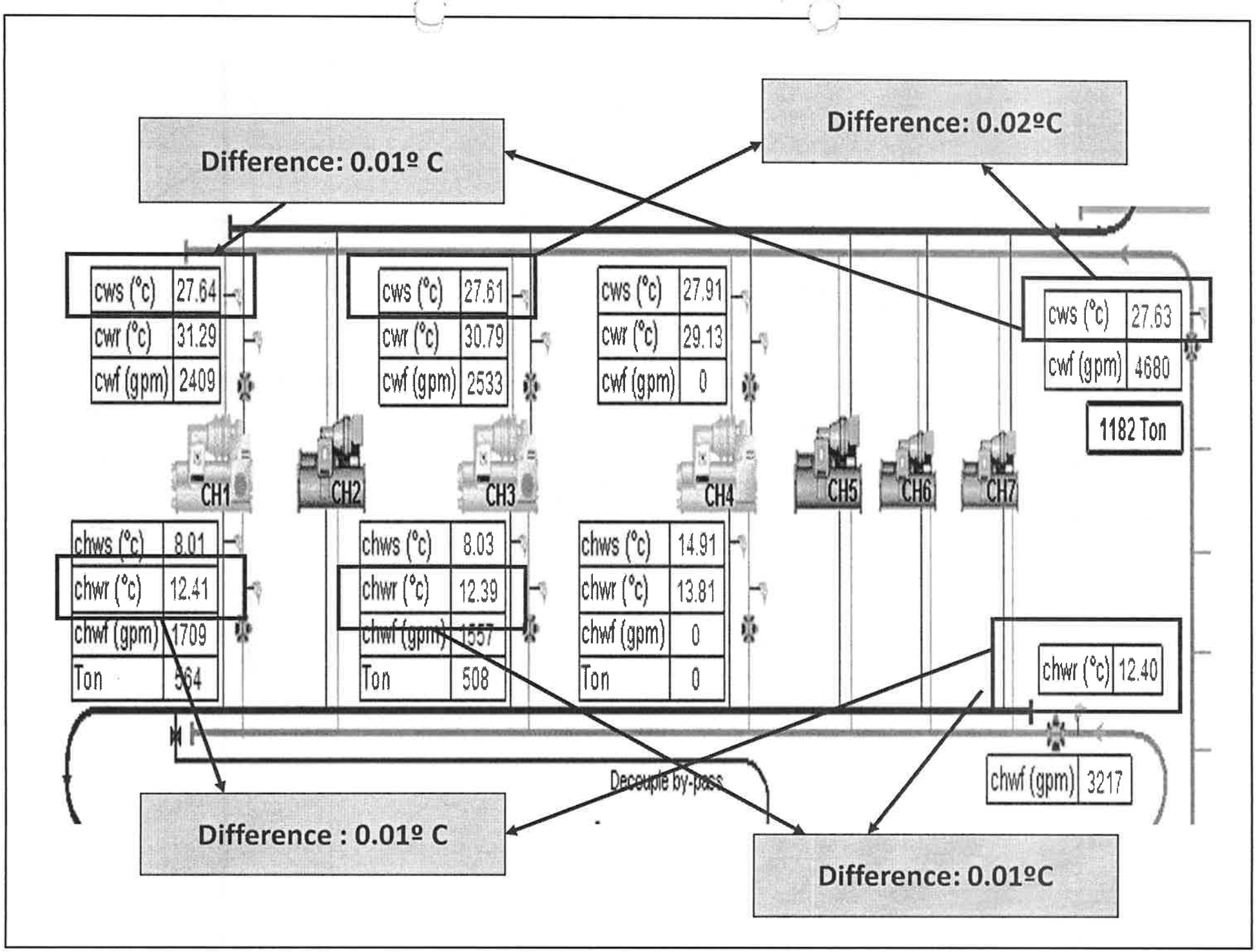
Risers Flow

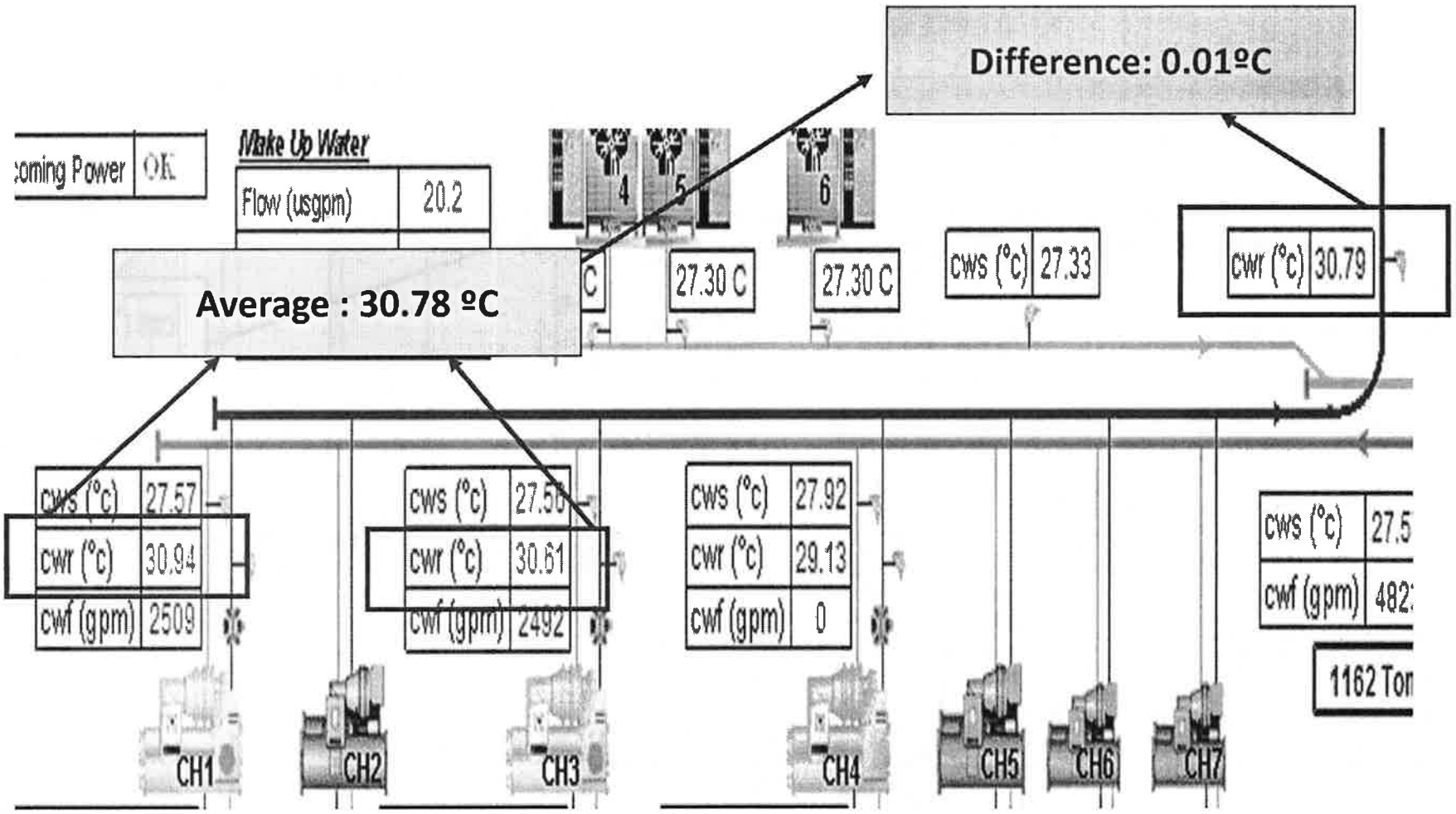
Riser Name	Core-A	Core-B	Core-C	Core-D	Core-E	Core-F	Core-G	Core-H
CHW Flow (usgpm)	259	92	157	252	828	688	1207	743
Pipe Size (mm)	200	200	200	200	350	250	350	250
Recommended Maximum CHW Flow (usgpm)	800	800	800	800	3100	1400	3100	1400

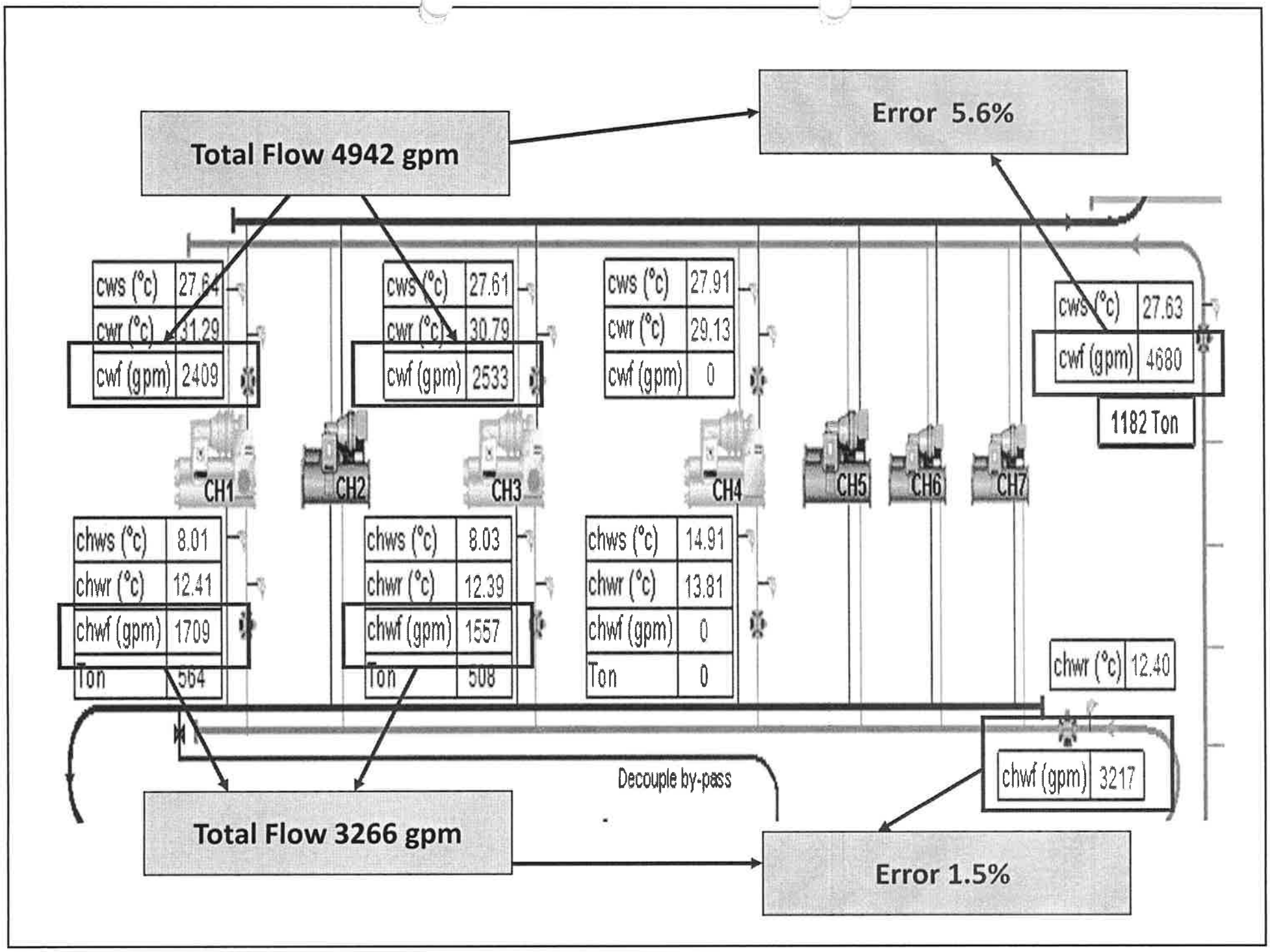
USgpm/Ton	Chilled Water	2.254
	Condenser Water	3.215

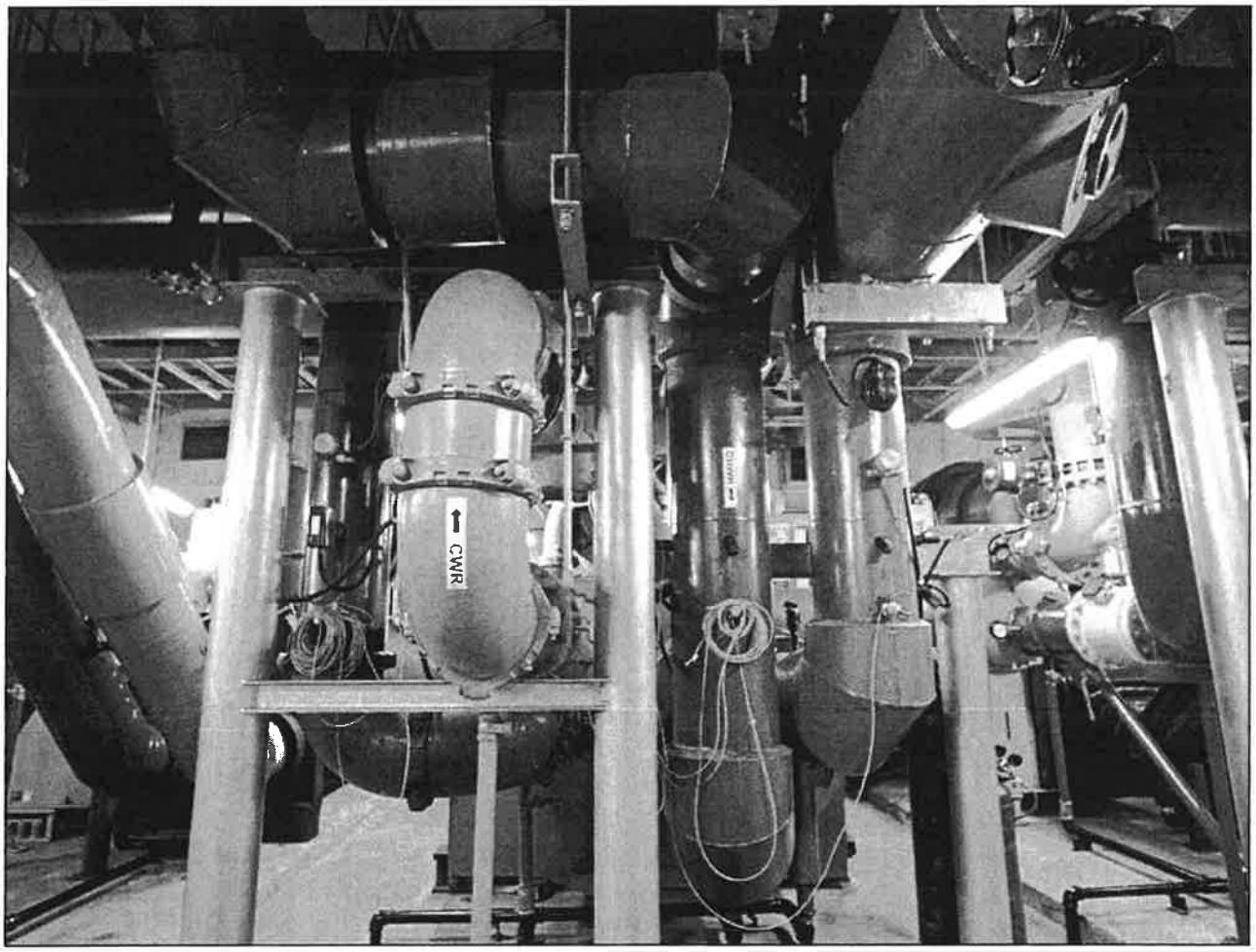
kW/Ton	Chiller1	0.475
	Chiller3	0.470
	Chiller4	0.480
	Chiller	0.475
	Cooling Tower	0.044
	Condenser Water Pump	0.038
	Secondary Chilled Water Pump	0.018
	SYSTEM	0.576
kW	Chiller	988
	Cooling Tower	91
	Condenser Water Pump	80
	Secondary Chilled Water Pump	38
	SYSTEM	1198
	Main Incoming Total	1266

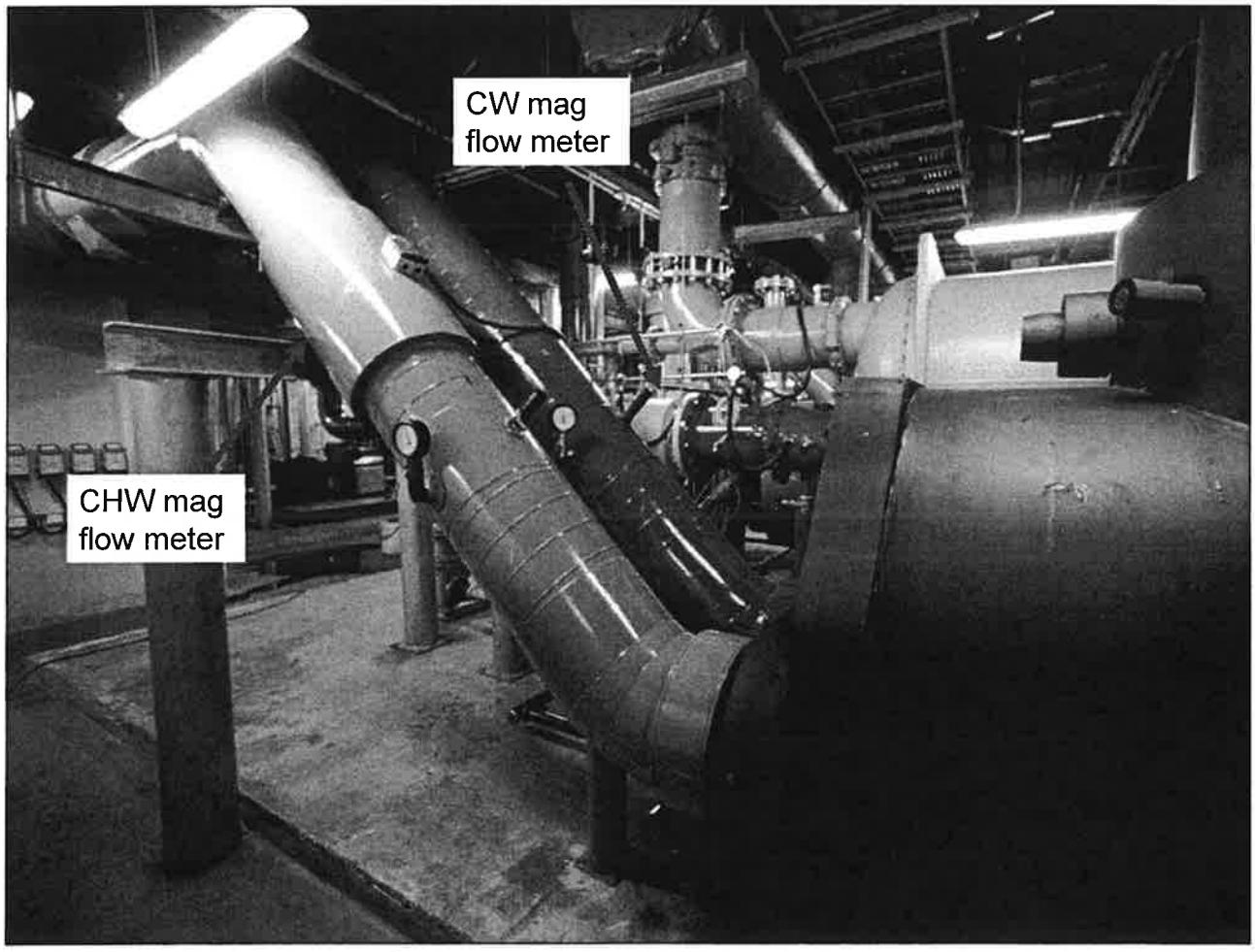

Average 27.28º C
CT 1
CT 2
CT 3
Difference : 0.01ºC
Weather Station-123
Dry Bulb (DegC) 28.97
Wet Bulb (DegC) 25.29
RH (%) 74.60
Hz: 22.0
Hz: 25.0
Hz: 24.0
1
2
3
27.26 C
27.29 C
27.30 C
cws (°c) 27.29
cwr (gpm) 2491
Weather Station-456
Dry Bulb (DegC) 29.19
Wet Bulb (DegC) 25.36
RH (%) 73.74
Hz: 23.0
Hz: 22.0
Hz: 20.0
4
5
6
cwf (gpm) 2380
Make Up Water
Flow (usgpm) 19.7
Daily Flow (m3) 107.2
Monthly Flow (m3) 107
27.39 C
27.39 C
27.39 C
cws (°c) 27.40
cwr (°c) 30.87
CT 4
CT 5
CT 6
Average 27.39º C
Difference: 0.01ºC


Difference: 0.01º C
Difference: 0.02ºC
cws (°c) 27.64
cwr (°c) 31.29
cwf (gpm) 2409
cws (°c) 27.61
cwr (°c) 30.79
cwf (gpm) 2533
cws (°c) 27.91
cwr (°c) 29.13
cwf (gpm) 0
cws (°c) 27.63
cwf (gpm) 4680
1182 Ton
CH1
CH2
CH3
CH4
CH5
CH6
CH7
chws (°c) 8.01
chwr (°c) 12.41
chwf (gpm) 1709
Ton 564
chws (°c) 8.03
chwr (°c) 12.39
chwf (gpm) 1557
Ton 508
chws (°c) 14.91
chwr (°c) 13.81
chwf (gpm) 0
Ton 0
chwr (°c) 12.40
chwf (gpm) 3217
Decouple by-pass
Difference : 0.01º C
Difference: 0.01ºC


Difference: 0.01ºC
Average : 30.78 ºC
coming Power
OK
Make Up Water
Flow (usgpm)
20.2
4
5
6
27.30 C
27.30 C
cws (°c) 27.33
cwr (°c) 30.79
cws (°c) 27.57
cwr (°c) 30.94
cwf (gpm) 2509
cws (°c) 27.56
cwr (°c) 30.61
cwf (gpm) 2492
cws (°c) 27.92
cwr (°c) 29.13
cwf (gpm) 0
cws (°c) 27.5
cwf (gpm) 482
1162 Ton
CH1
CH2
CH3
CH4
CH5
CH6
CH7


Total Flow 4942 gpm
Error 5.6%
cws (°c) 27.64
cwr (°c) 31.29
cwf (gpm) 2409
cws (°c) 27.61
cwr (°c) 30.79
cwf (gpm) 2533
cws (°c) 27.91
cwr (°c) 29.13
cwf (gpm) 0
cws (°c) 27.63
cwf (gpm) 4680
1182 Ton
CH1
CH2
CH3
CH4
CH5
CH6
CH7
chws (°c) 8.01
chwr (°c) 12.41
chwf (gpm) 1709
Ton 564
chws (°c) 8.03
chwr (°c) 12.39
chwf (gpm) 1557
Ton 508
chws (°c) 14.91
chwr (°c) 13.81
chwf (gpm) 0
Ton 0
chwr (°c) 12.40
chwf (gpm) 3217
Decouple by-pass
Total Flow 3266 gpm
Error 1.5%


CWR

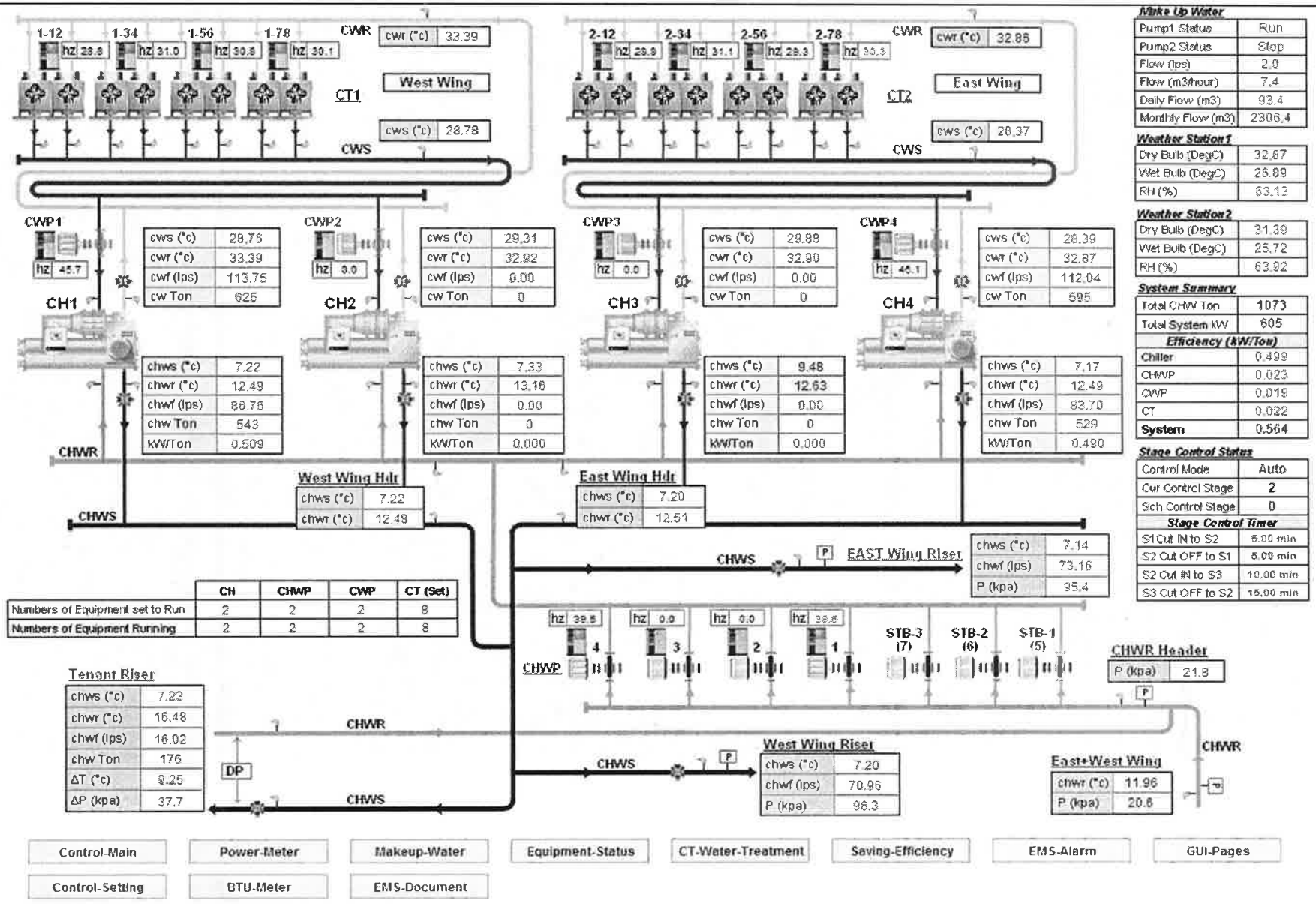

CW mag
flow meter
CHW mag
flow meter

Agenda

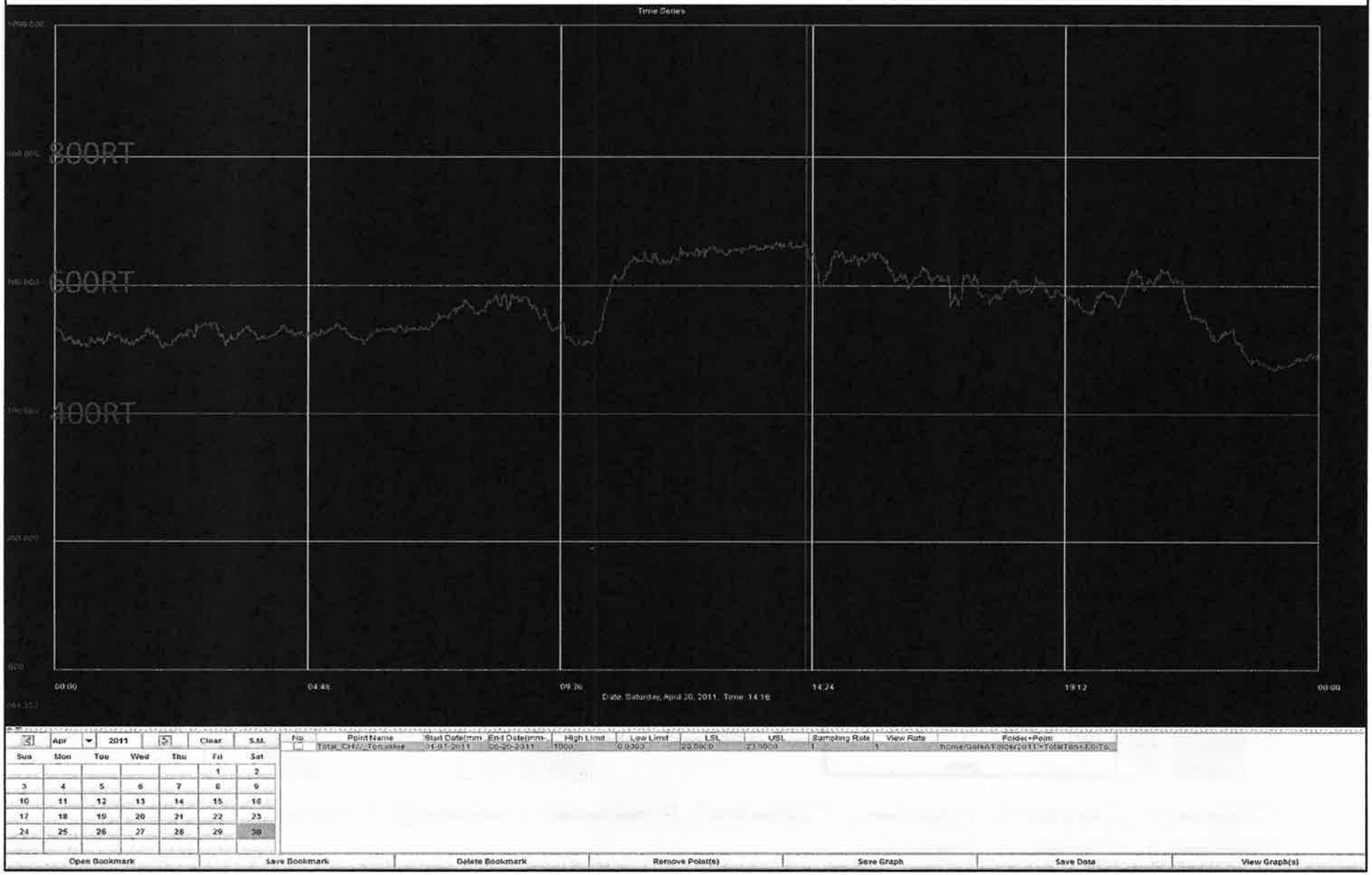
4. Representation of data

Copyright Steven Kang B L

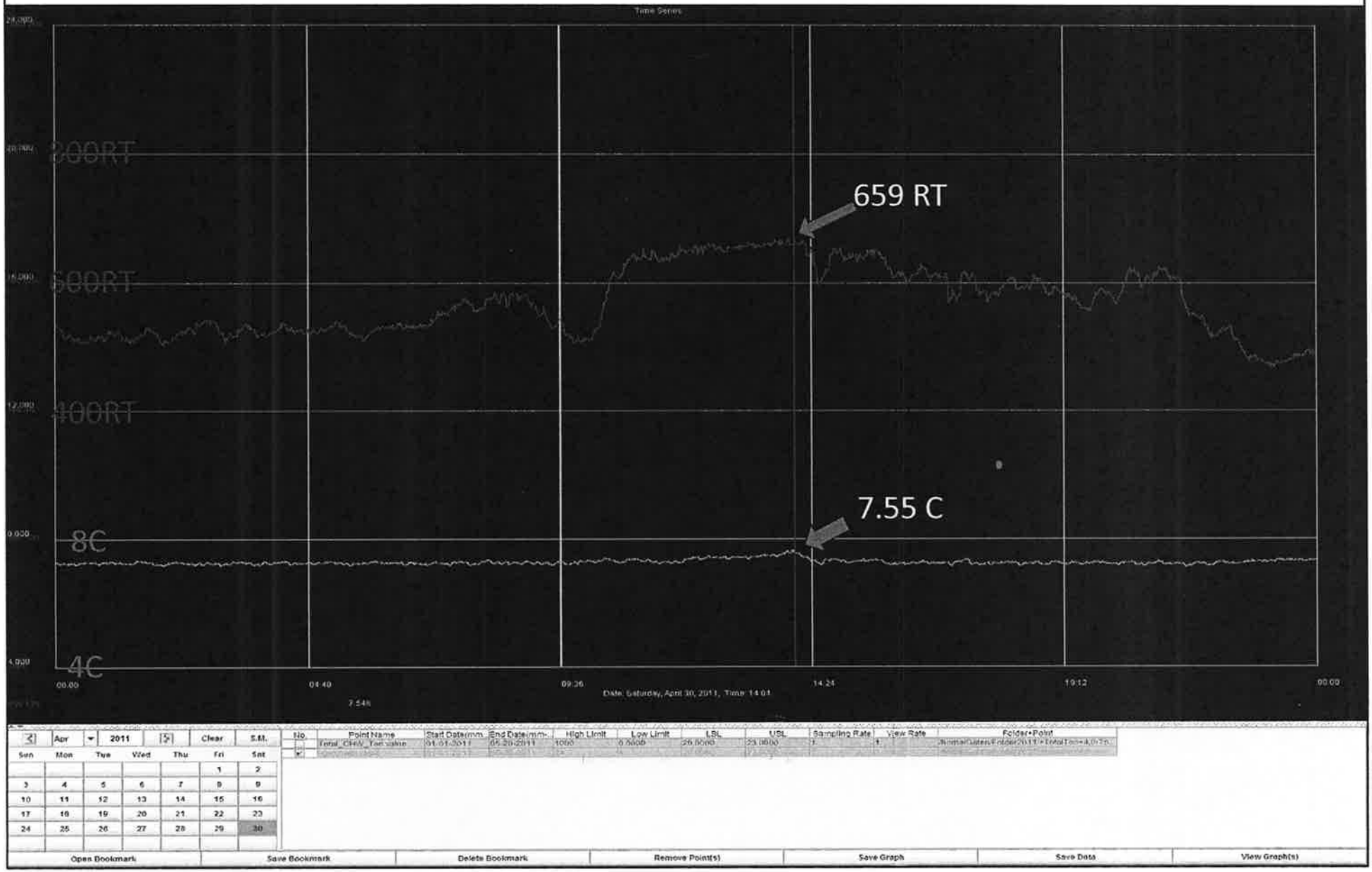
Two Years on, Four more to go — System Performance in BioTech Factory



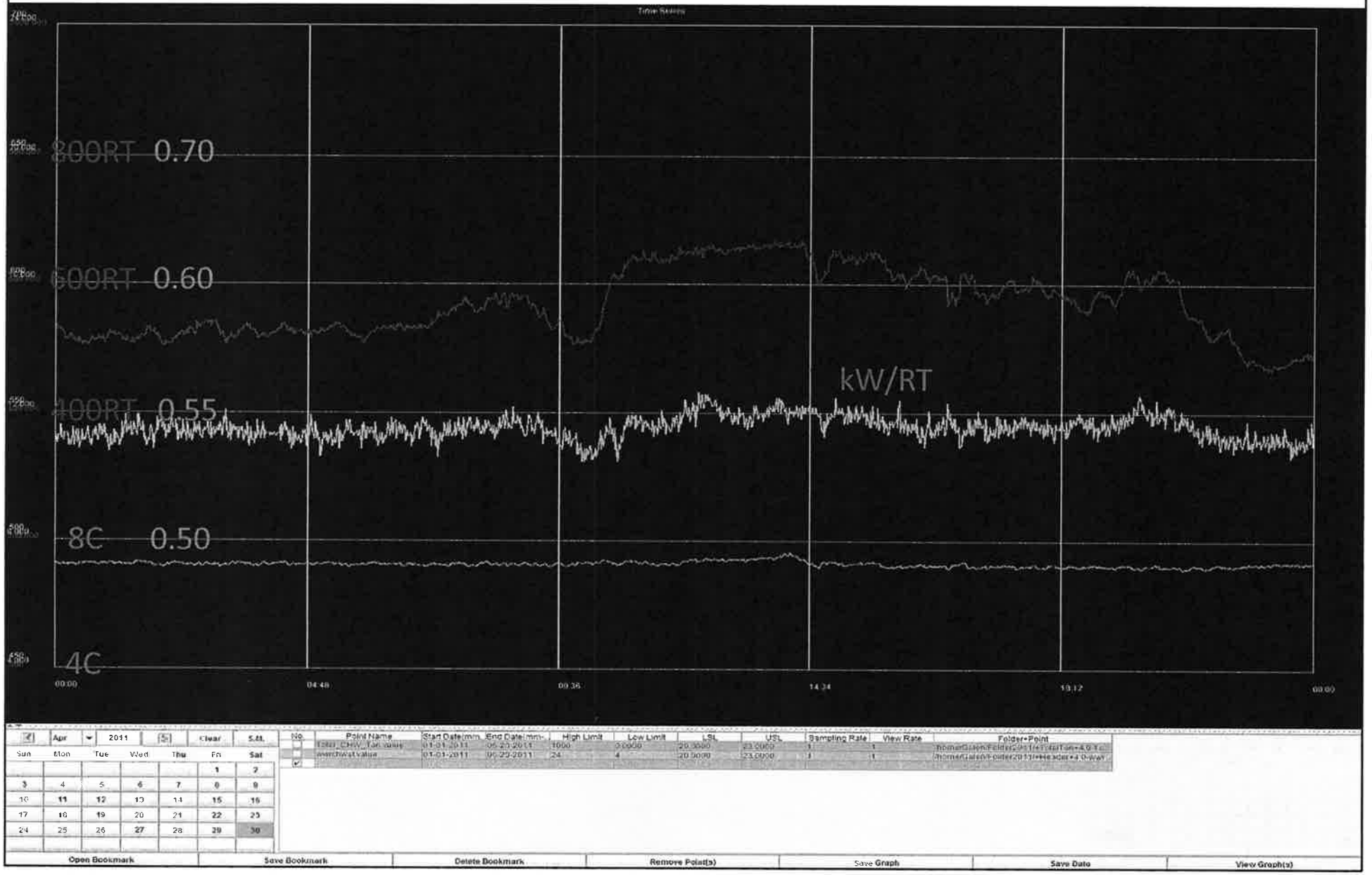
Weekend 1 x 600 TR chiller operation



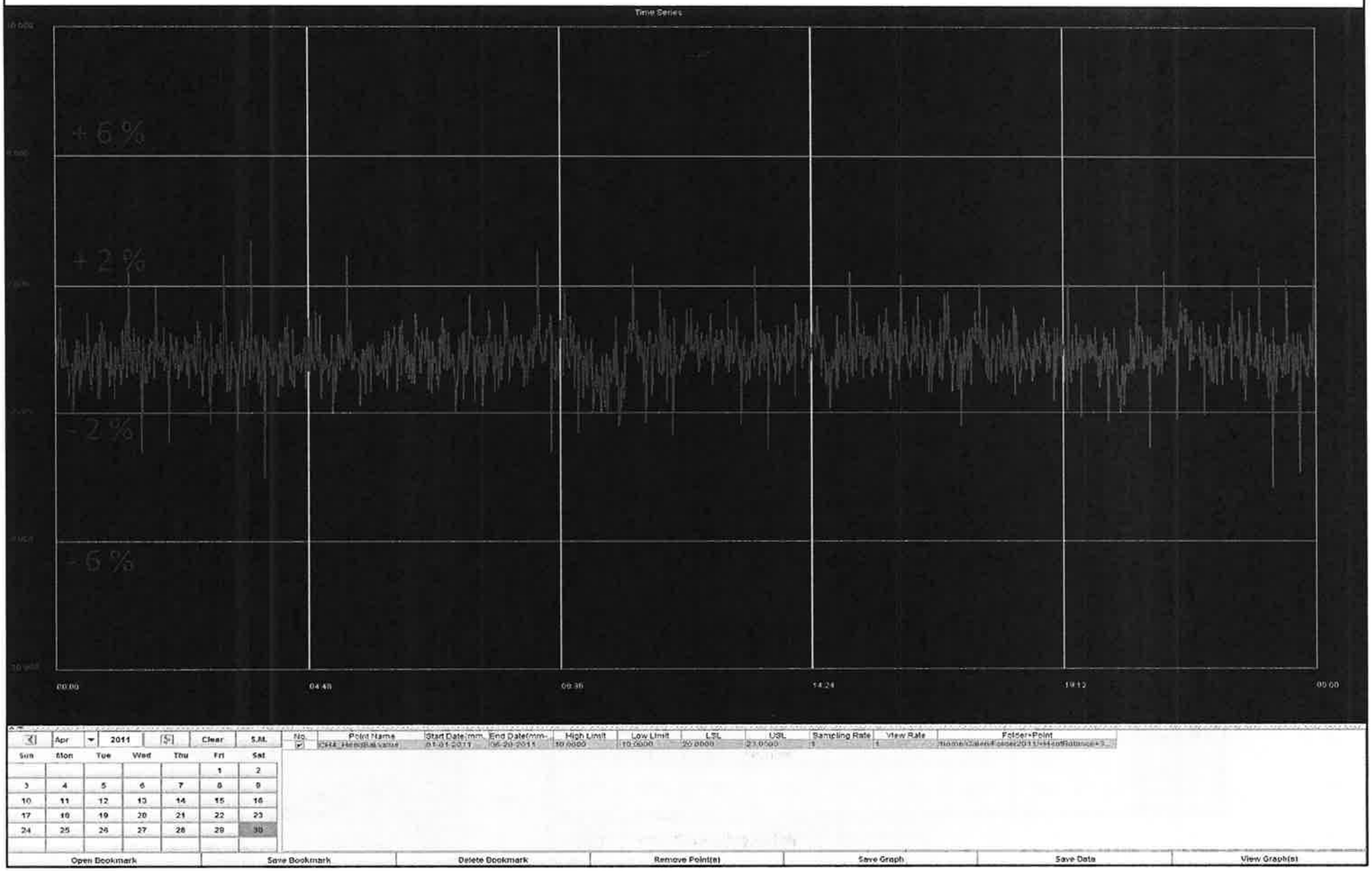
600 RT Chiller at 110 % Capacity



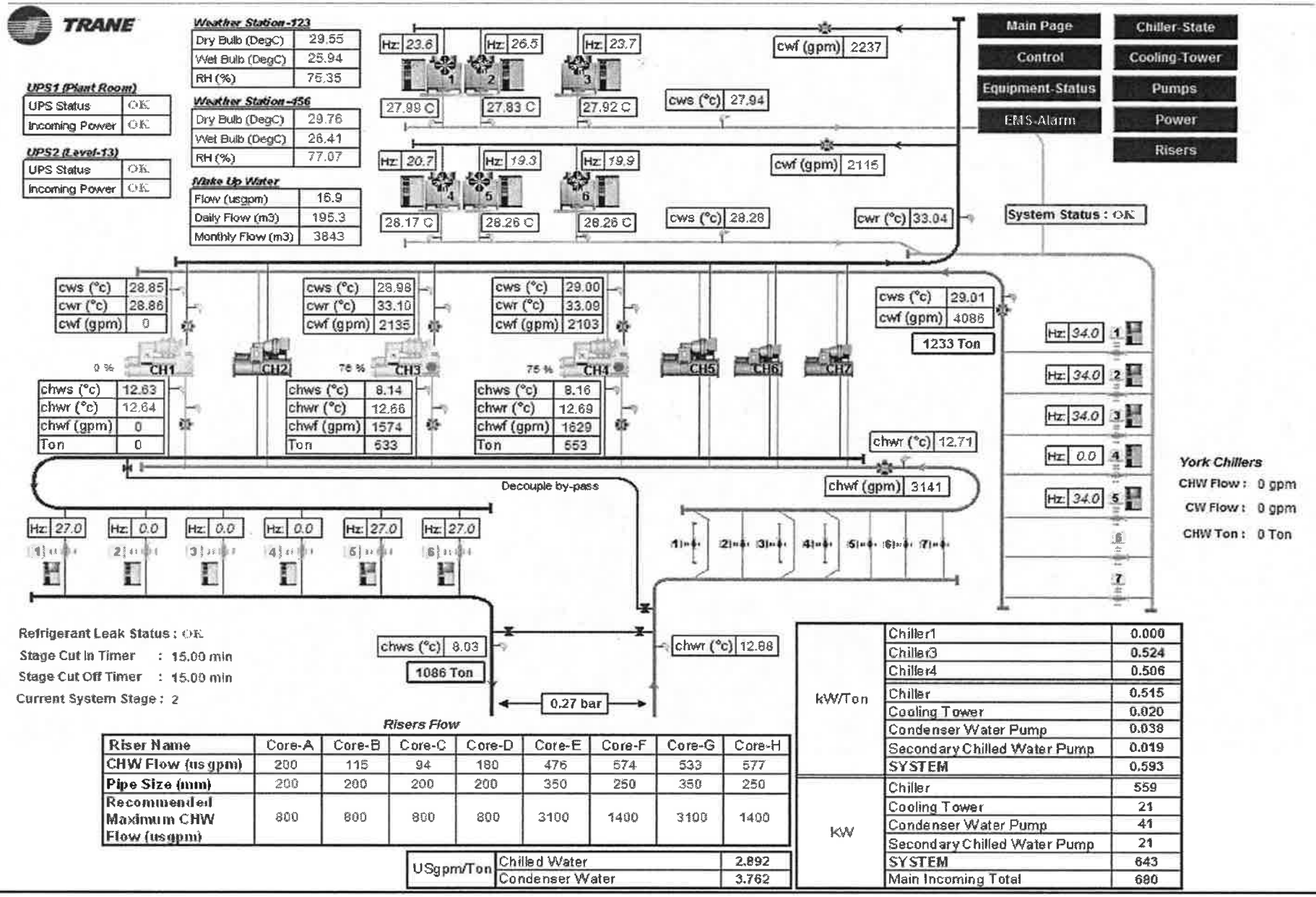
System kW/RT for 1 x 600 RT



Heat Balance for 1 x 600 RT



Four Years on……



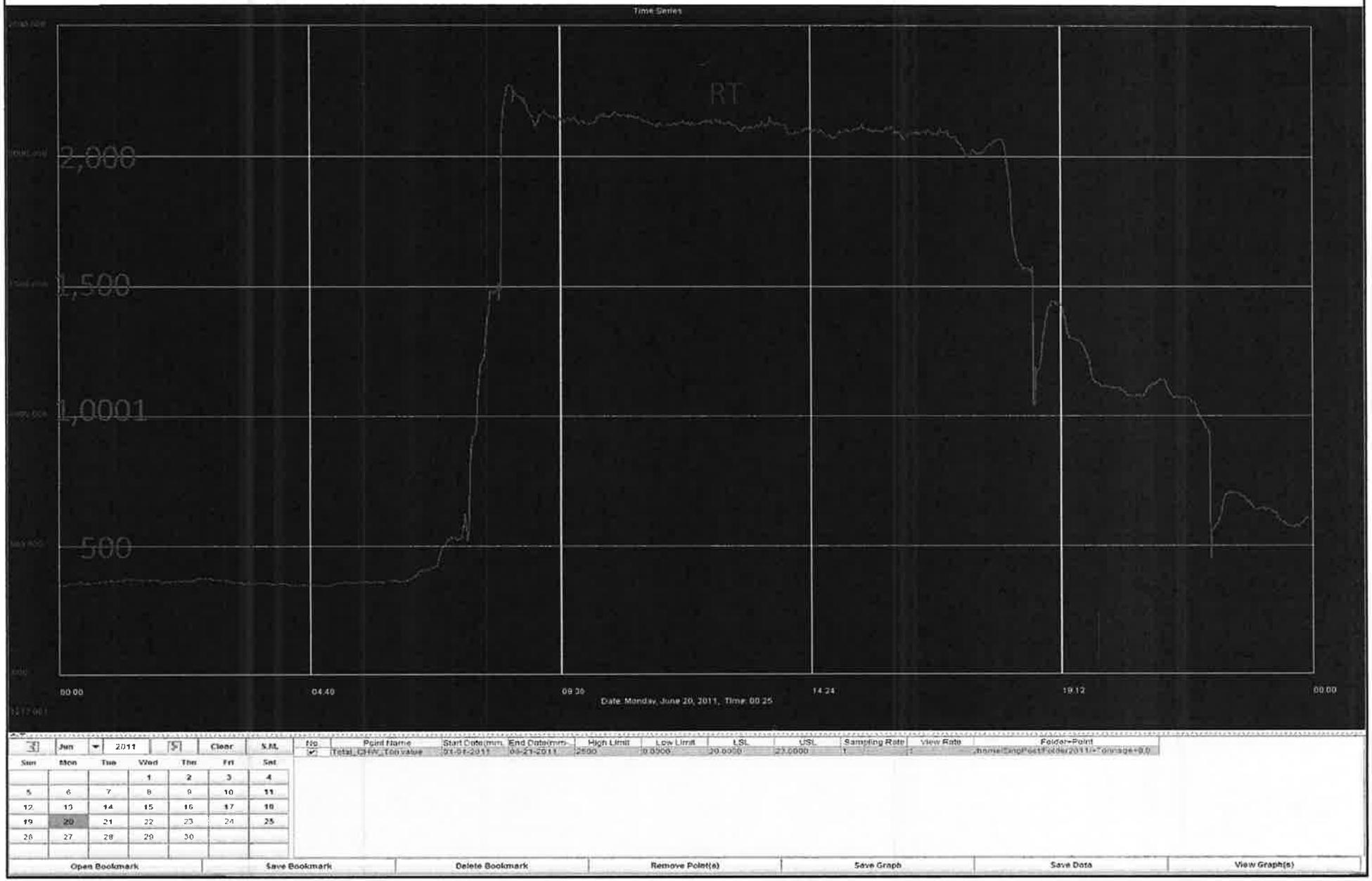
Risers Flow

Riser Name	Core-A	Core-B	Core-C	Core-D	Core-E	Core-F	Core-G	Core-H
CHW Flow (usgpm)	200	115	94	180	476	574	533	577
Pipe Size (mm)	200	200	200	200	350	250	350	250
Recommended Maximum CHW Flow (usgpm)	800	800	800	800	3100	1400	3100	1400

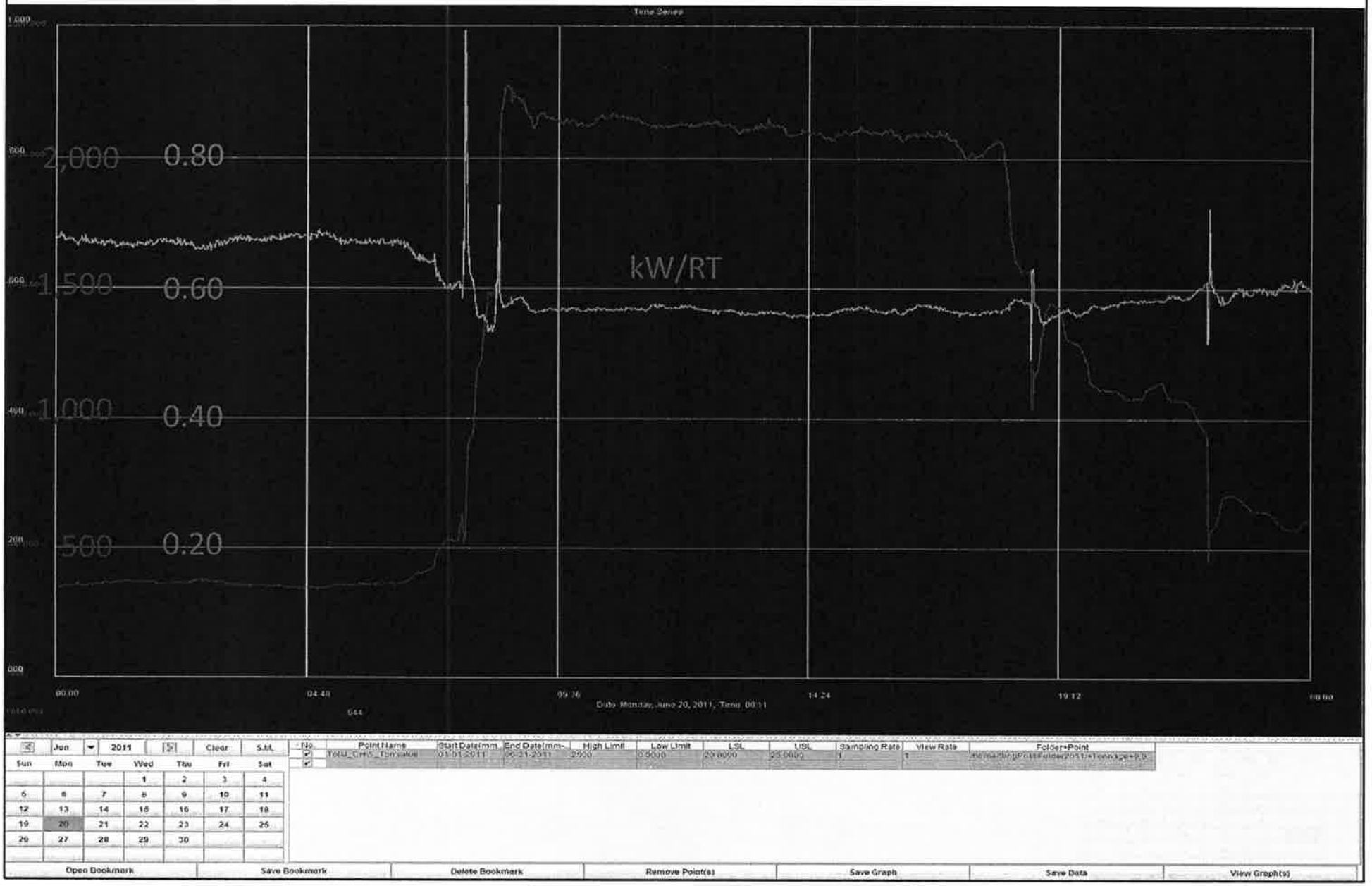
USgpm/Ton	Chilled Water	2.892
	Condenser Water	3.762

kW/Ton	Chiller1	0.000
	Chiller3	0.524
	Chiller4	0.506
	Chiller	0.515
	Cooling Tower	0.020
	Condenser Water Pump	0.038
	Secondary Chilled Water Pump	0.019
	SYSTEM	0.593
kW	Chiller	559
	Cooling Tower	21
	Condenser Water Pump	41
	Secondary Chilled Water Pump	21
	SYSTEM	643
	Main Incoming Total	690

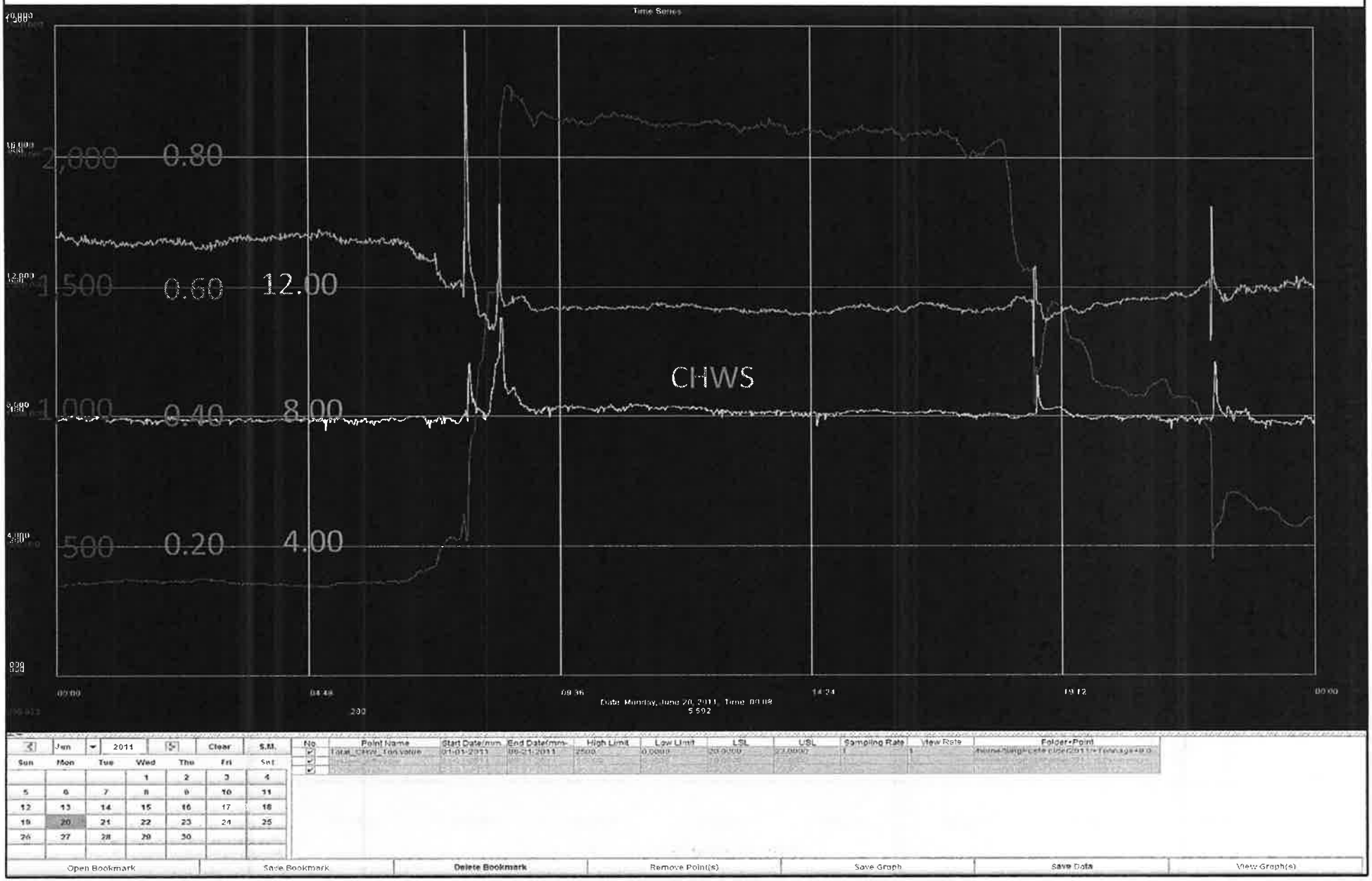
3 x 700 RT in large mixed use building

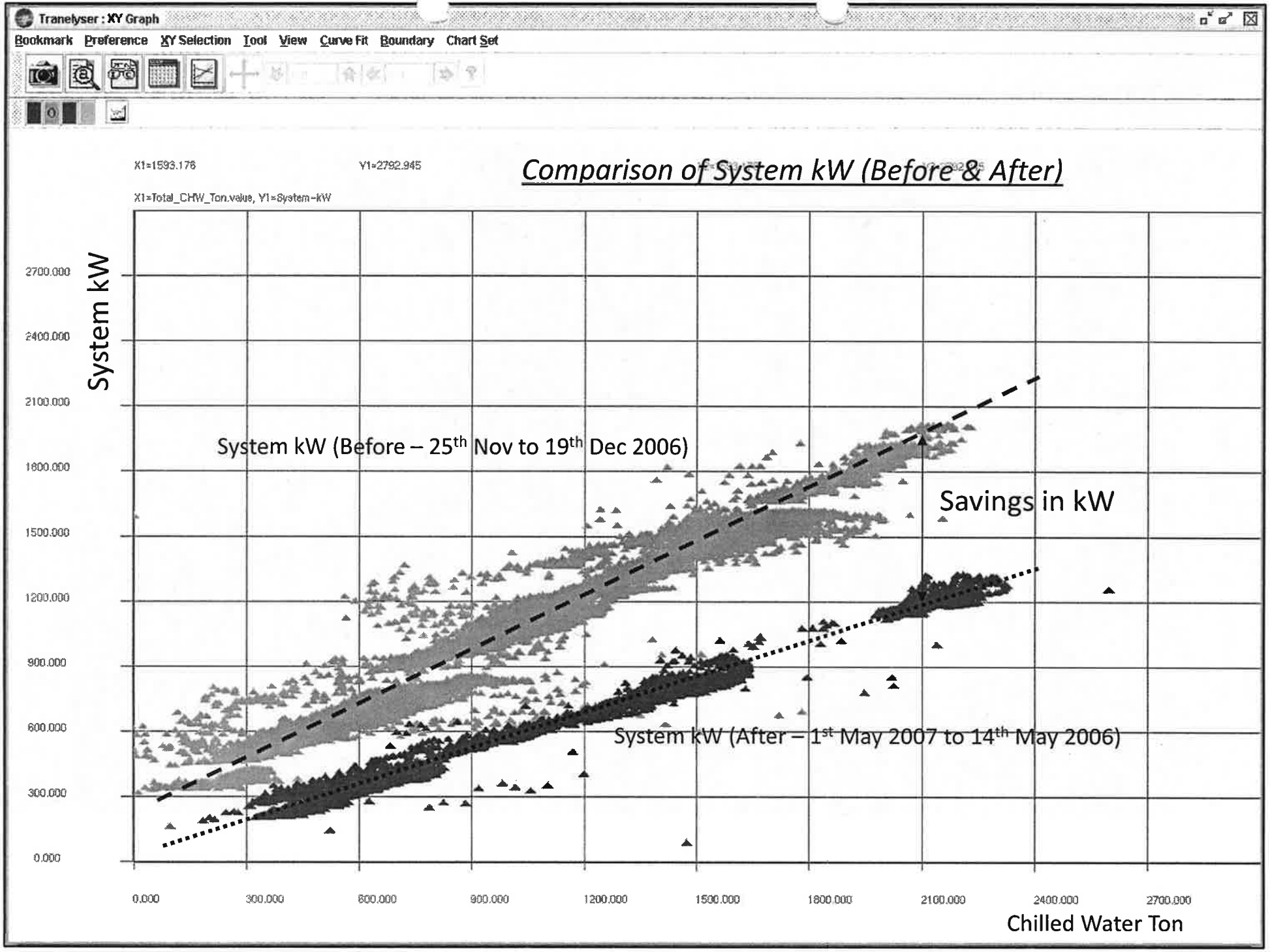


3 x 700 RT system tons and kW/RT

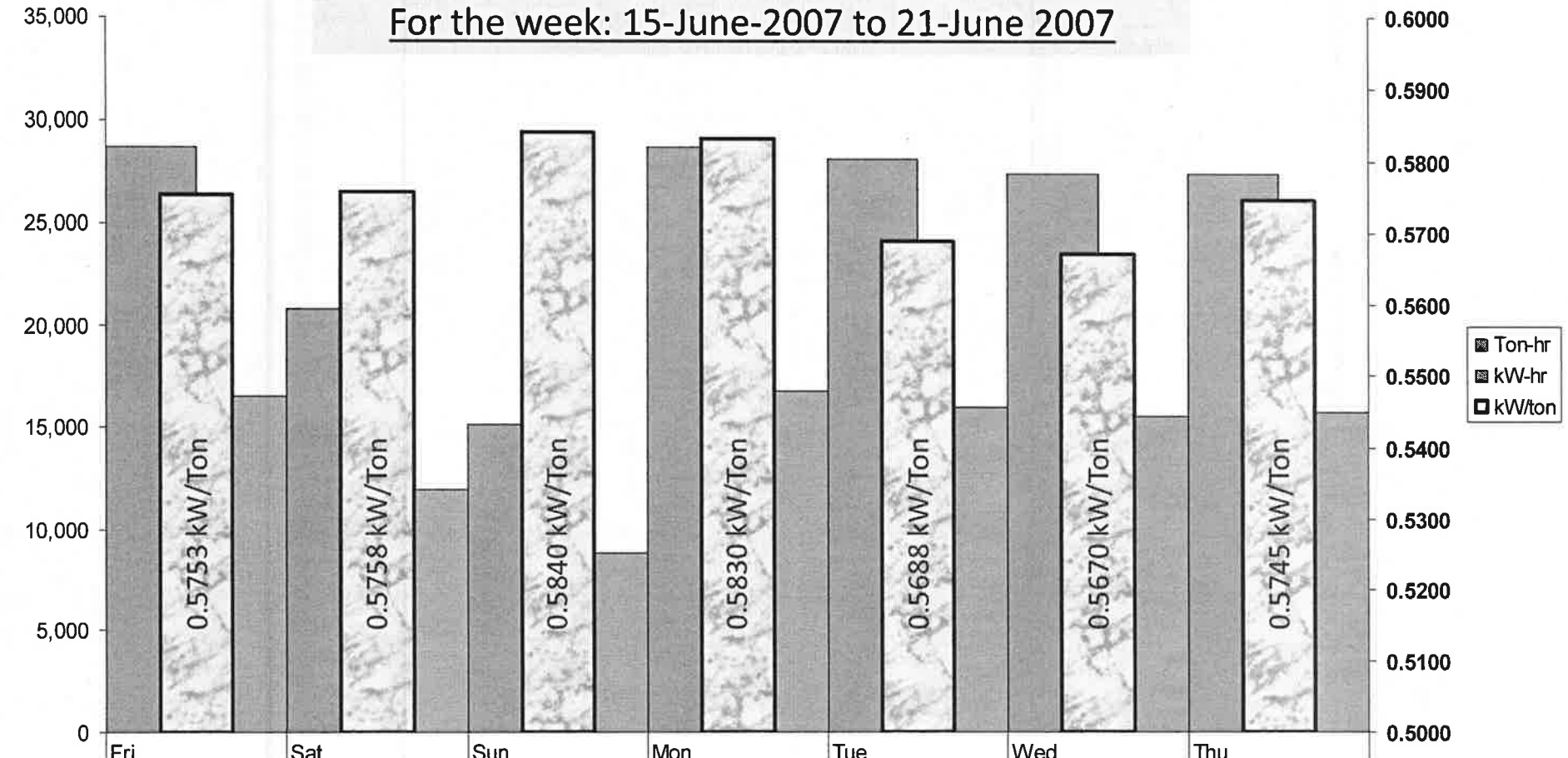


3 x 700 RT chilled water temperature



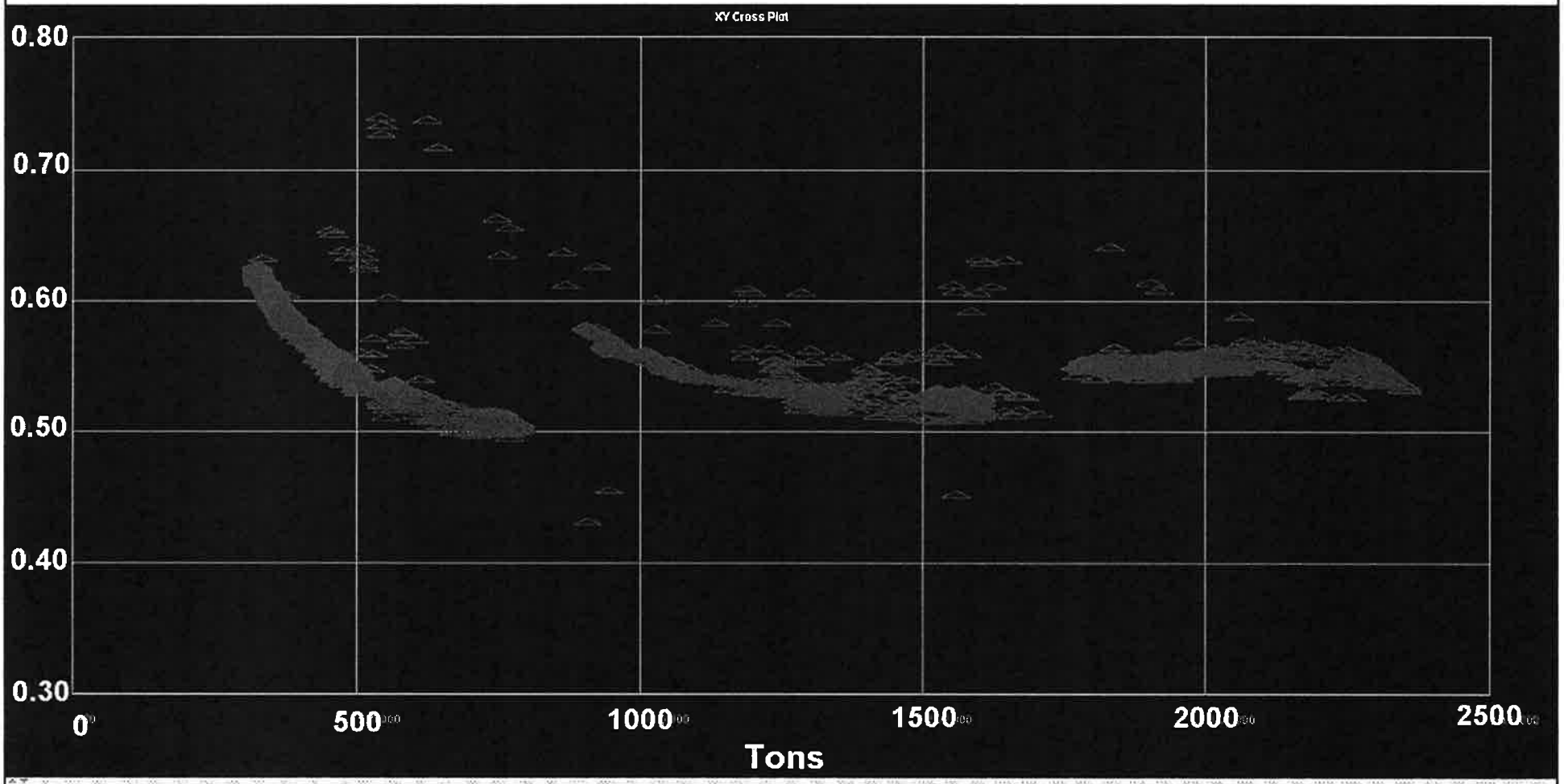

Tranelyser : XY Graph
Bookmark Preference XY Selection Tool View Curve Fit Boundary Chart Set
X1=1593.176 Y1=2792.945
X1=Total_CHW_Ton.value, Y1=System-kW
Comparison of System kW (Before & After)
System kW
2700.000
2400.000
2100.000
1800.000
1500.000
1200.000
900.000
600.000
300.000
0.000
System kW (Before – 25th Nov to 19th Dec 2006)
Savings in kW
System kW (After – 1st May 2007 to 14th May 2006)
0.000
300.000
600.000
900.000
1200.000
1500.000
1800.000
2100.000
2400.000
2700.000
Chilled Water Ton

Singapore Post Centre
System Efficiency (kW/Ton) – Daily/Weekly Analysis



	Fri	Sat	Sun	Mon	Tue	Wed	Thu	
	15-Jun-07	16-Jun-07	17-Jun-07	18-Jun-07	19-Jun-07	20-Jun-07	21-Jun-07	Average
Ton-hr	28,652	20,811	15,133	28,707	28,071	27,379	27,404	25,165
kW-hr	16,483	11,982	8,838	16,736	15,968	15,525	15,744	14,468
kW/ton	0.5753	0.5758	0.5840	0.5830	0.5688	0.5670	0.5745	0.5755

System kW/RT 18~20 Feb 2008



Feb 2008 Clear S.M.

Sun	Mon	Tue	Wed	Thu	Fri	Sat
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	

No.	Point Name	Start Date(mm-	End Date(mm-	High Limit	Low Limit	LSL	USL	Sampling Rate	View Rate	Folder+Point
✔	System_Eff.value	01-01-2008	02-20-2008	0.8	0.3	20.0000	23.0000	1	1	/home/SingPost/Folder2008/+Efficiency+
	Total_CHW_Ton.value	01-01-2008	02-20-2008	2500	0	20.0000	23.0000	1	1	/home/SingPost/Folder2008/+Tonnage+9.0

Open Bookmark | Save Bookmark | Delete Bookmark | Remove Point(s) | Save Graph | Save Data | View Graph(s)

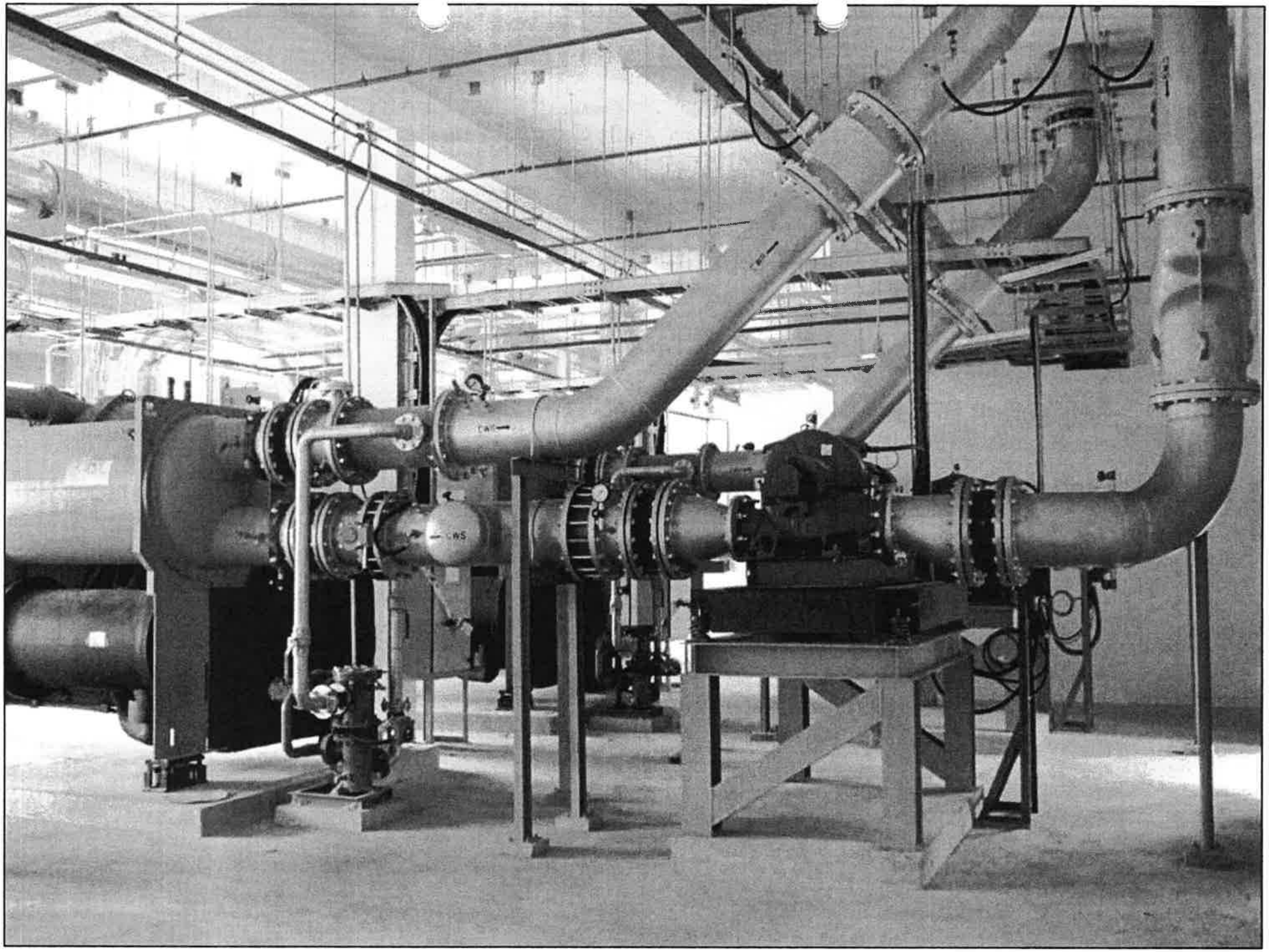
Pharma Factory 2 x 700 RT retrofit,

5 degC Chws

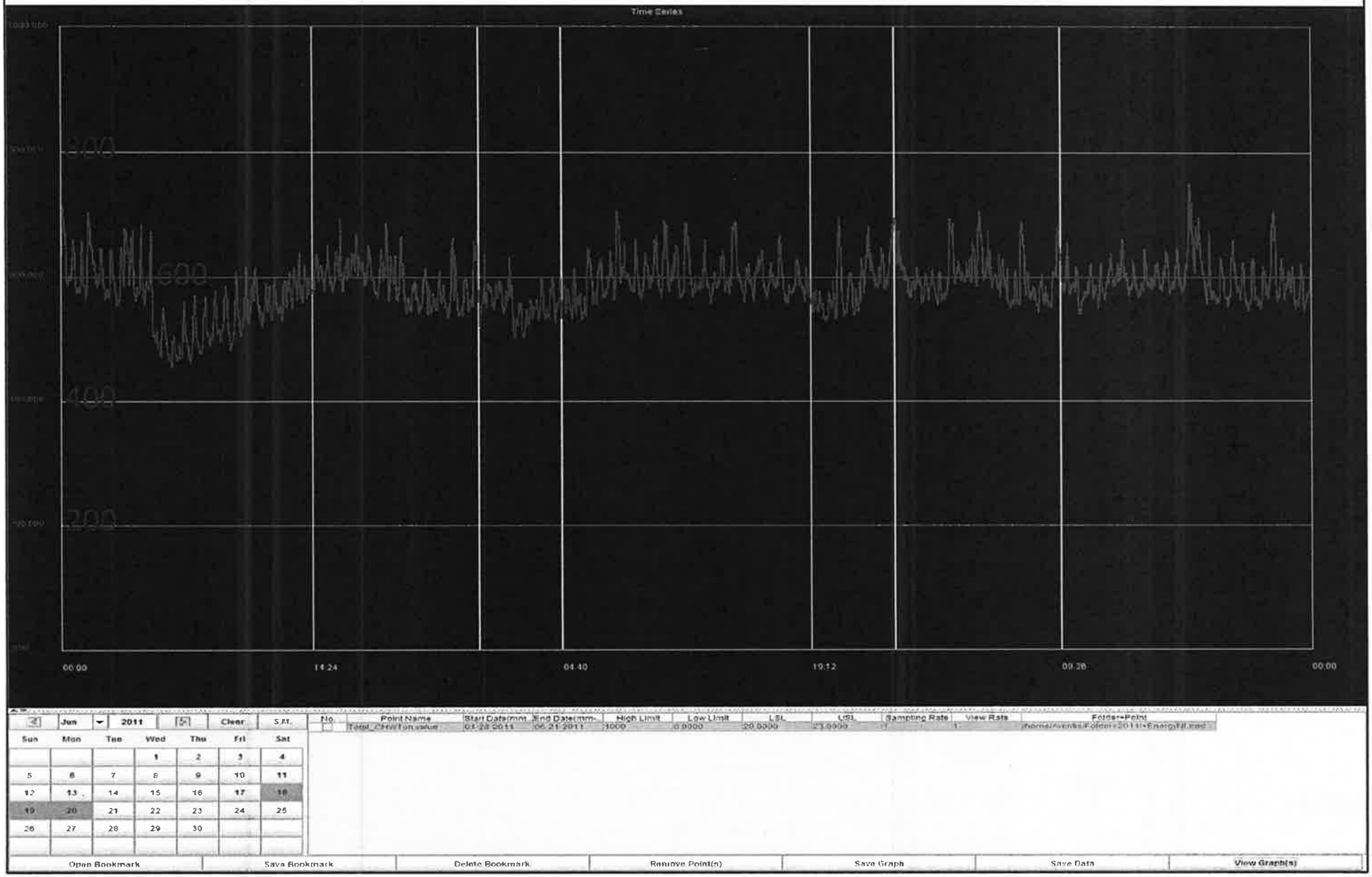
Refrigerant HFC R-134a

High Pressure CHW for process use

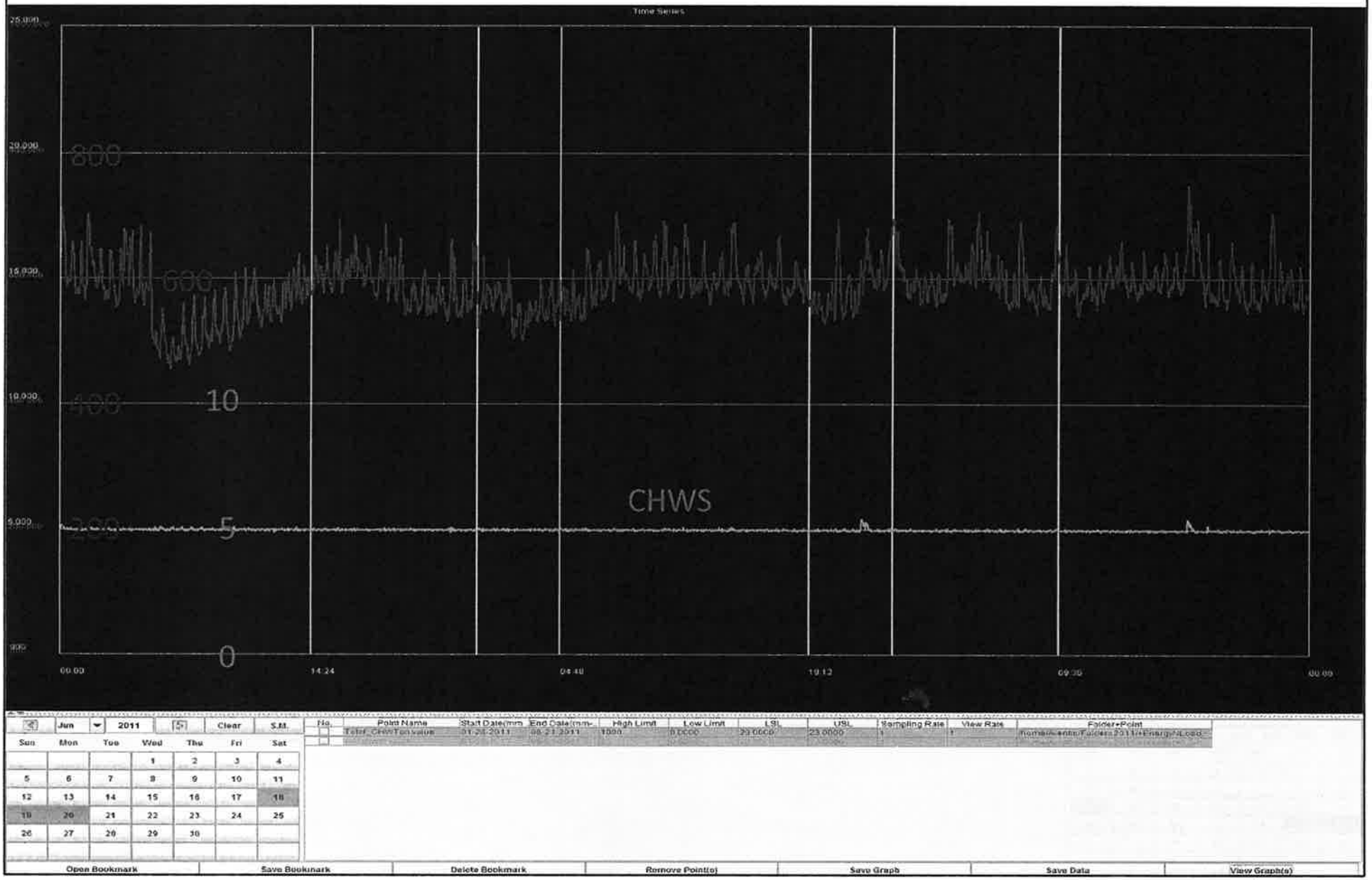
Future Expansion space and utilities



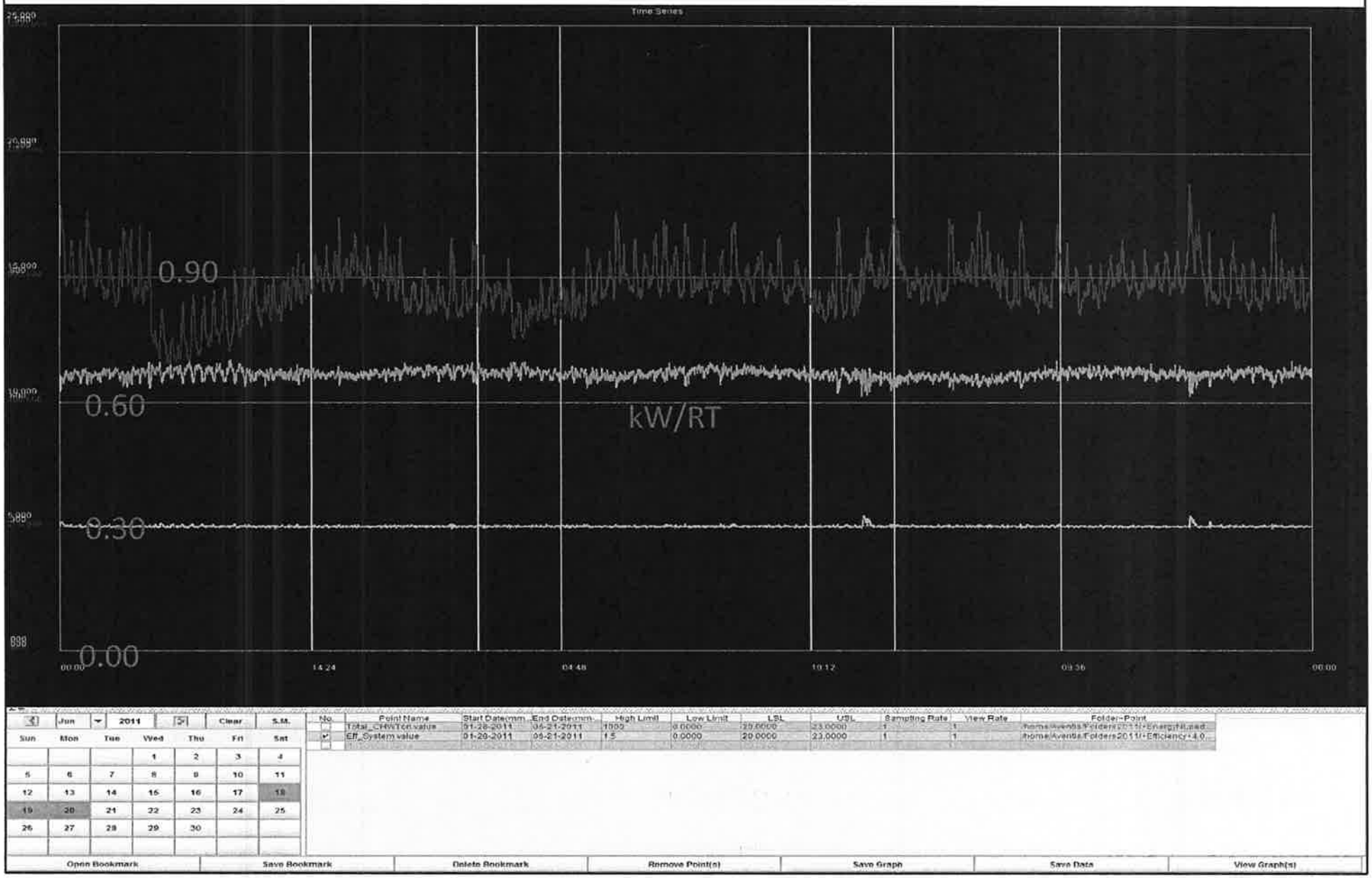
Pharma Factory 1 x 700 RT Heat Load



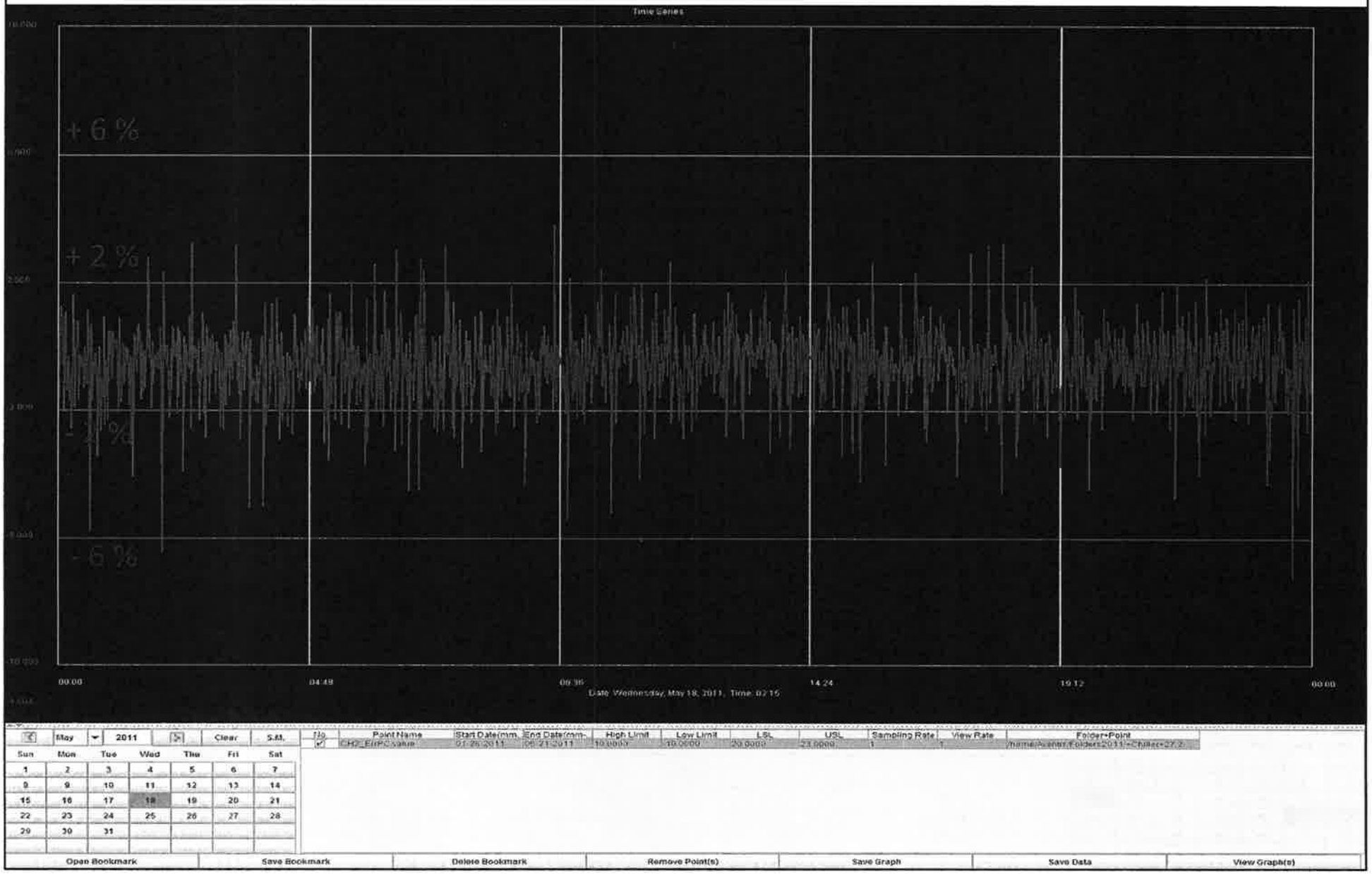
Pharma Factory Heat Load and CHWS Temp



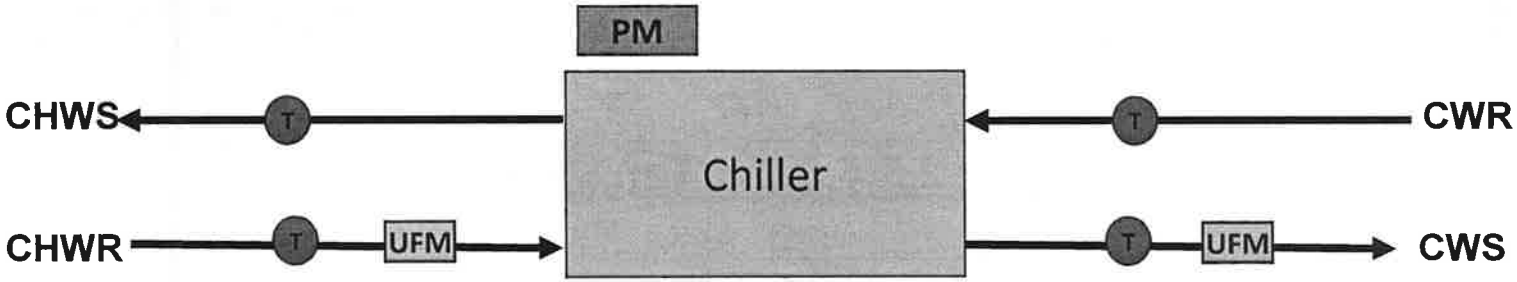
Pharma Factory System kW/RT



1 x 700 RT Heat Balance



Chillers monitoring points



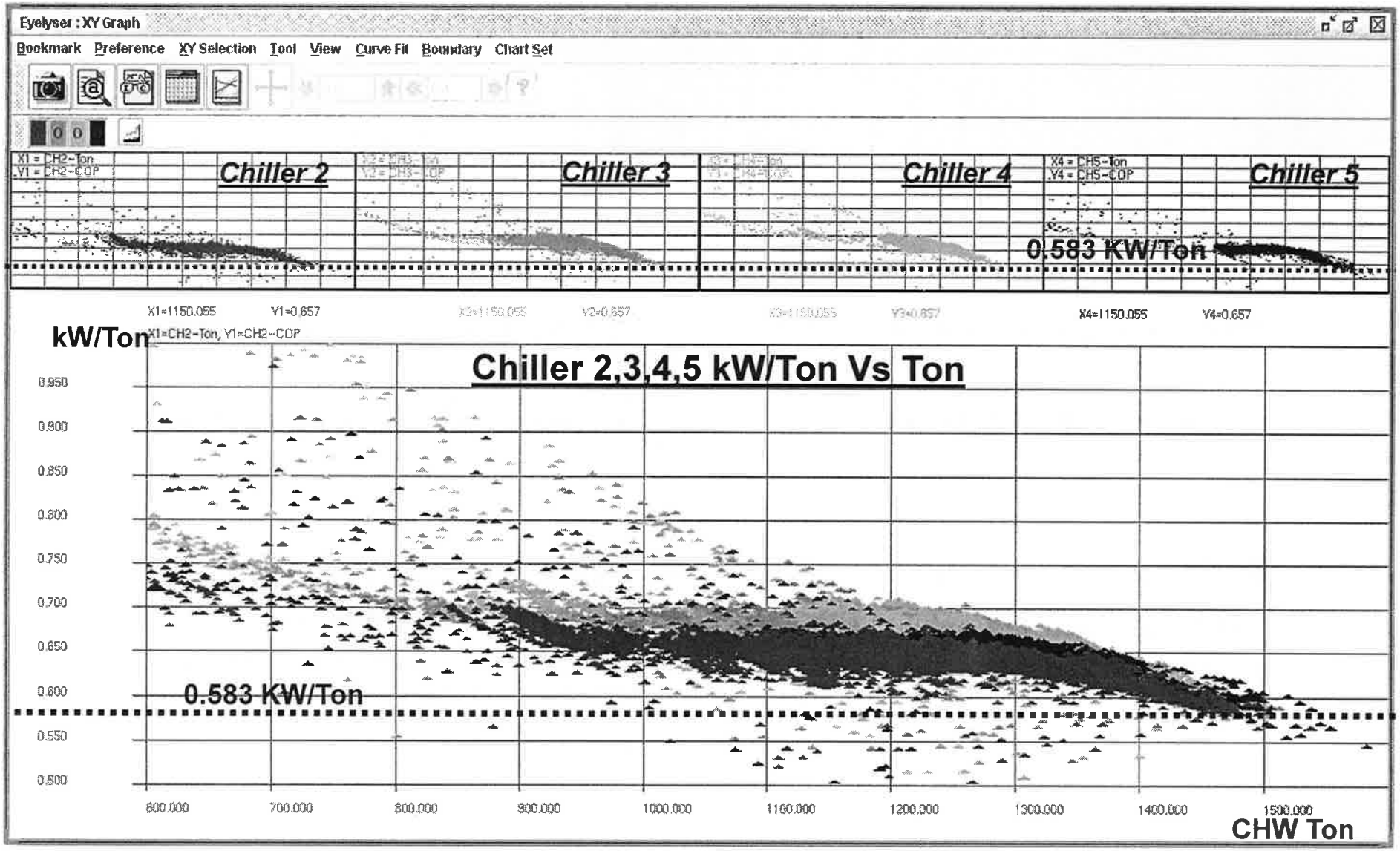
PM Existing power meter

UFM Ultrasonic flow meter

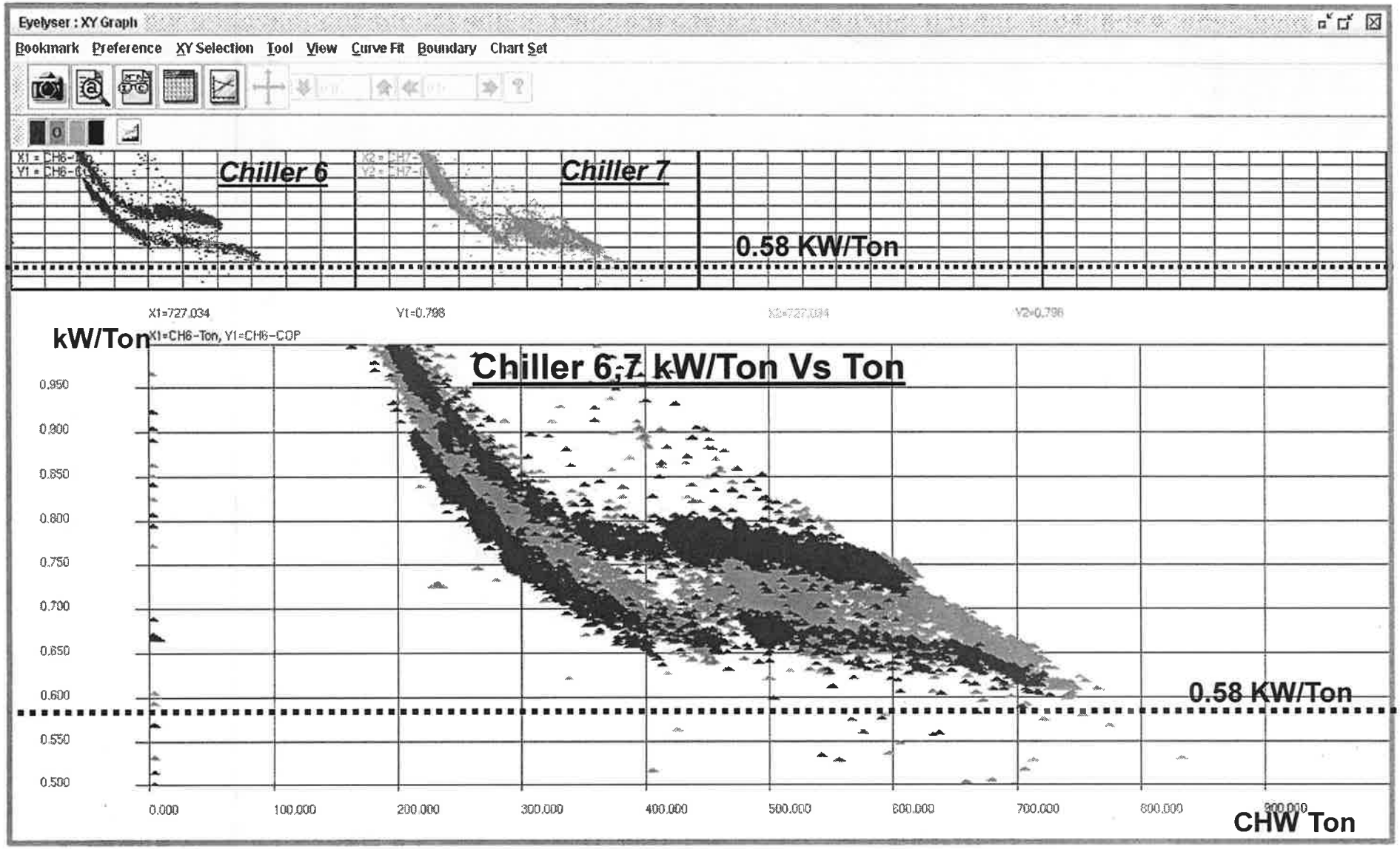
T Temperature sensor

CHW Ton = ΔT (CHWDT) X Flow (CHWFlow)
CW Ton = ΔT (CWDT) X Flow (CWFlow)
HB = (CW Ton – (CHW Ton + CHkW))/CHW Ton

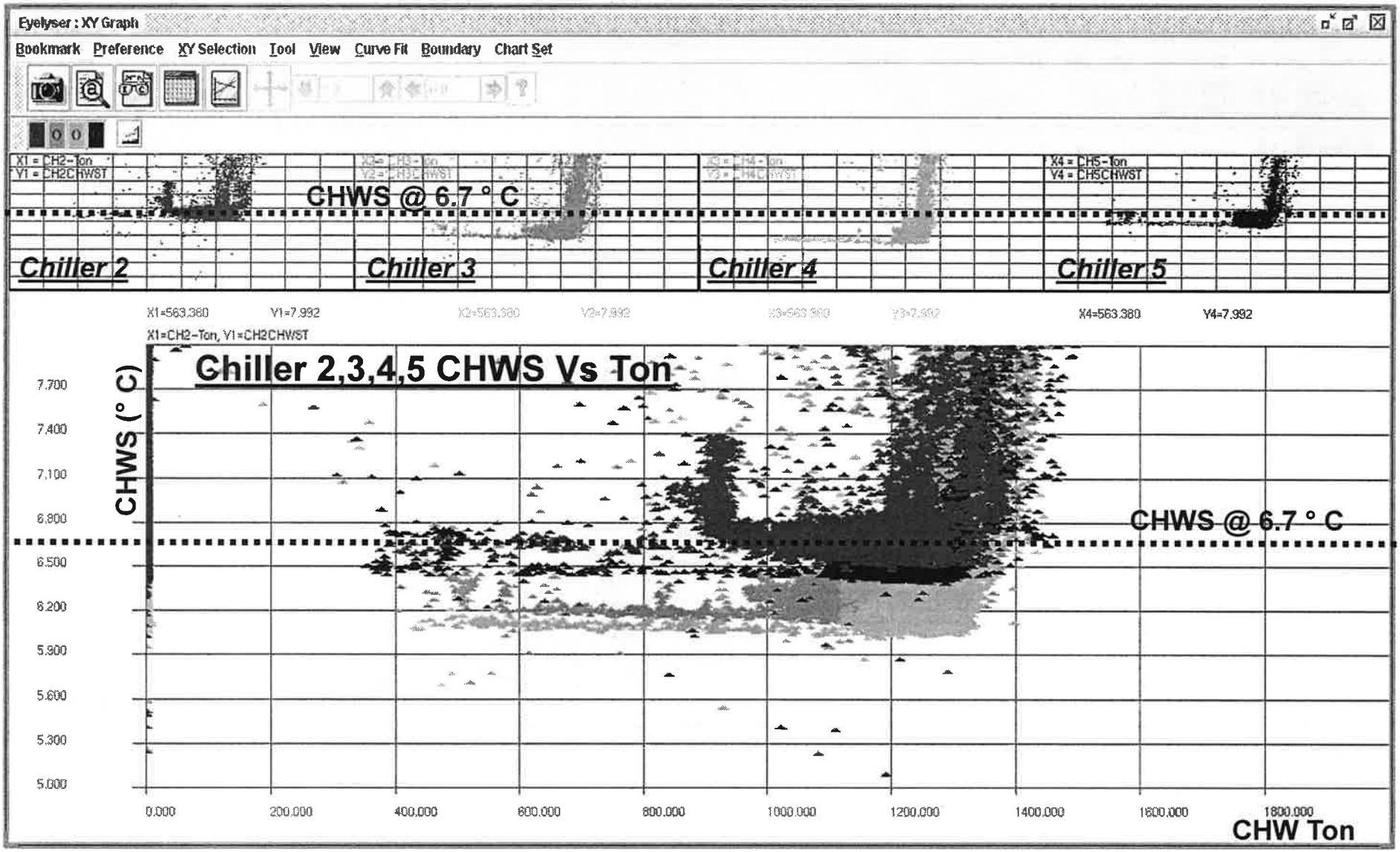
Chillers


Eyelyser : XY Graph
Bookmark Preference XY Selection Tool View Curve Fit Boundary Chart Set
X1 = CH2-Ton
Y1 = CH2-COP
Chiller 2
Chiller 3
Chiller 4
X4 = CH5-Ton
Y4 = CH5-COP
Chiller 5
0.583 KW/Ton
X1=1150.055 Y1=0.657
X4=1150.055 Y4=0.657
kW/Ton
X1=CH2-Ton, Y1=CH2-COP
Chiller 2,3,4,5 kW/Ton Vs Ton
0.950
0.900
0.850
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.583 KW/Ton
600.000
700.000
800.000
900.000
1000.000
1100.000
1200.000
1300.000
1400.000
1500.000
CHW Ton

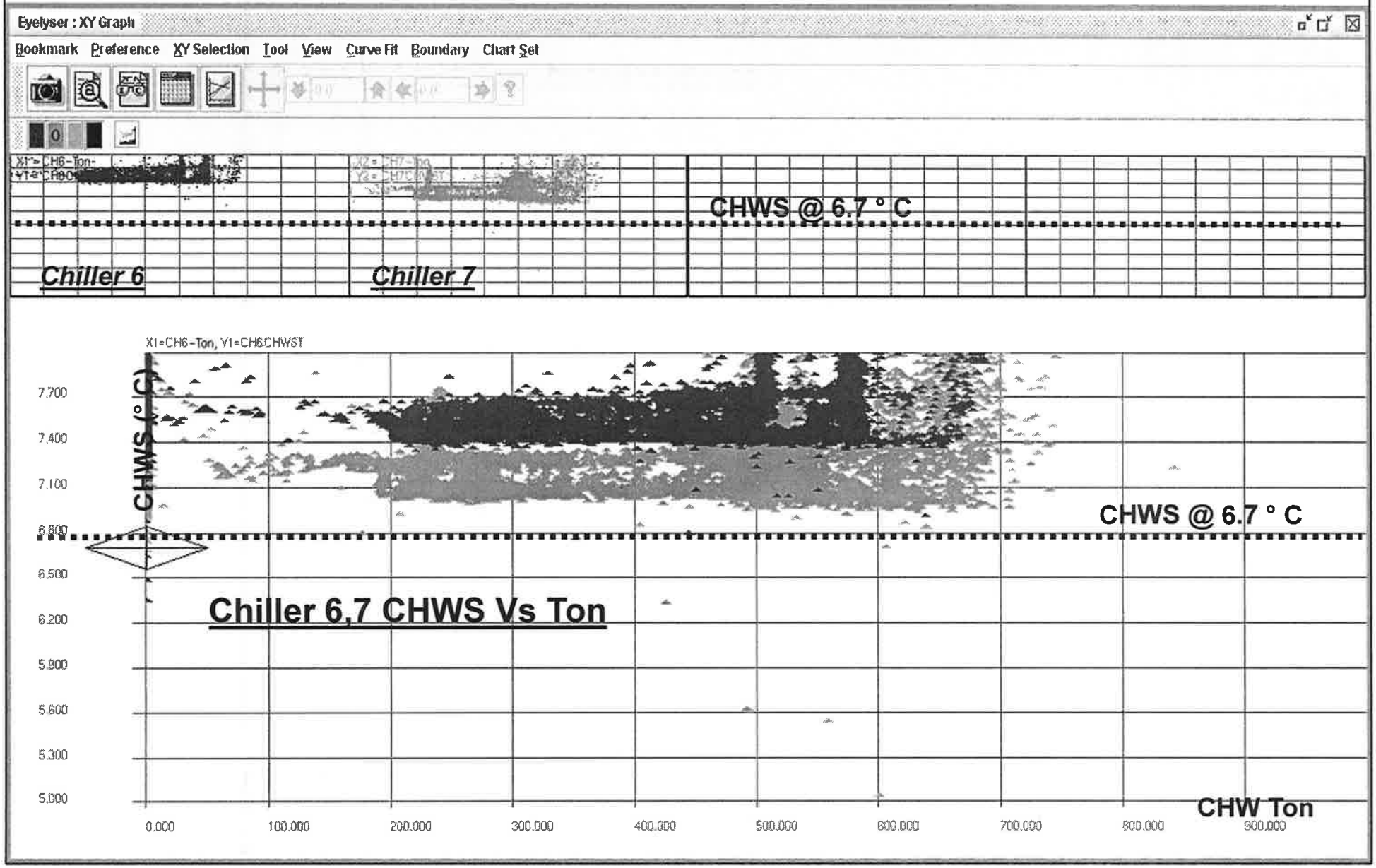
Chillers


Eyelyser : XY Graph
Bookmark Preference XY Selection Tool View Curve Fit Boundary Chart Set
Chiller 6
Chiller 7
0.58 KW/Ton
X1=727.034
Y1=0.798
X1=CH6-Ton, Y1=CH6-COP
kW/Ton
Chiller 6,7 kW/Ton Vs Ton
0.950
0.900
0.850
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.000
100.000
200.000
300.000
400.000
500.000
600.000
700.000
800.000
900.000
0.58 KW/Ton
CHW Ton

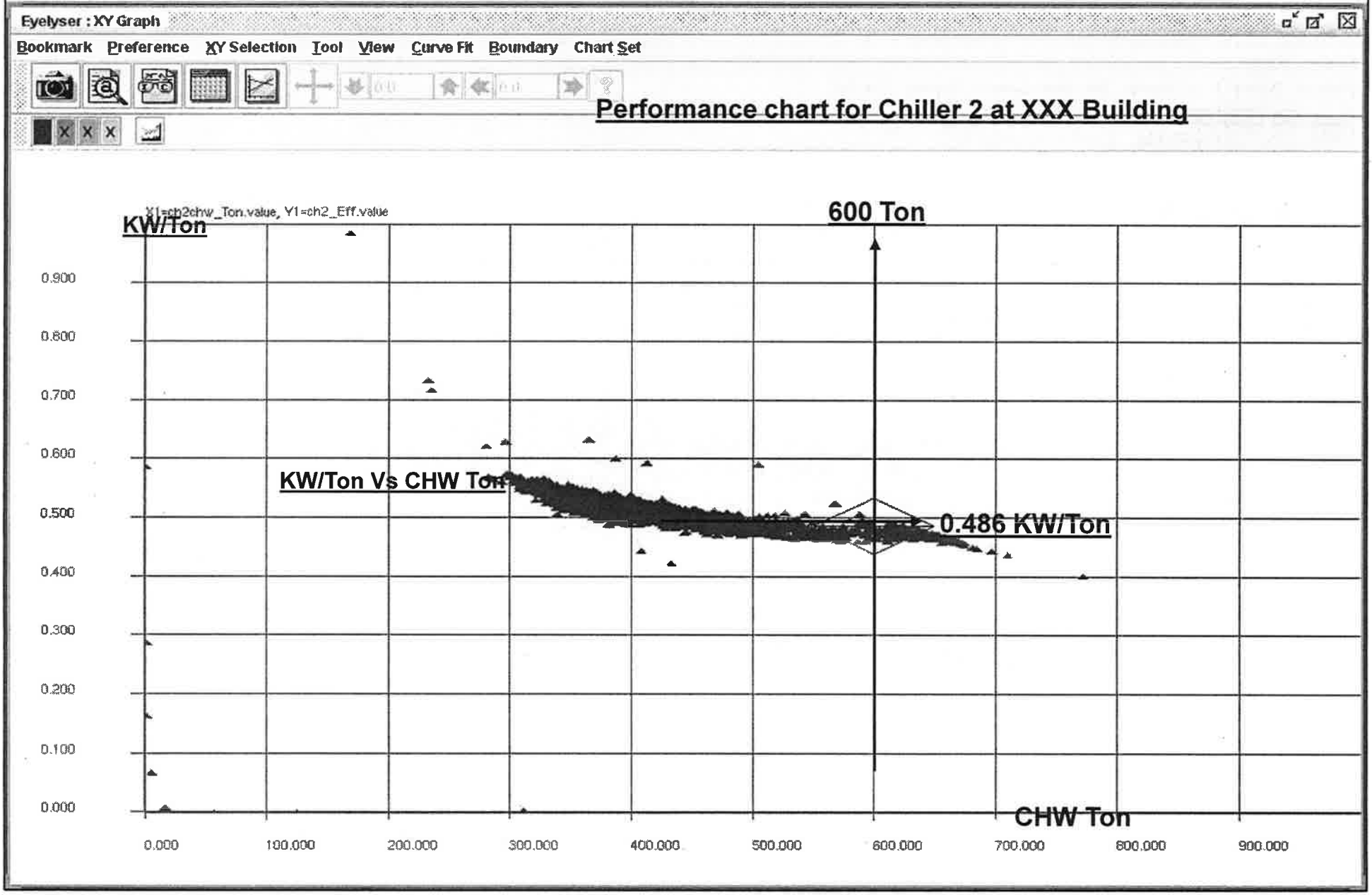
Chillers


Eyelyser : XY Graph
Bookmark Preference XY Selection Tool View Curve Fit Boundary Chart Set
X1 = CH2-Ton
Y1 = CH2CHWST
CHWS @ 6.7 ° C
Chiller 2
Chiller 3
Chiller 4
Chiller 5
X4 = CH5-Ton
Y4 = CH5CHWST
X1=563.380 Y1=7.992
X4=563.380 Y4=7.992
X1=CH2-Ton, Y1=CH2CHWST
Chiller 2,3,4,5 CHWS Vs Ton
CHWS (° C)
7.700
7.400
7.100
6.800
6.500
6.200
5.900
5.600
5.300
5.000
CHWS @ 6.7 ° C
0.000
200.000
400.000
600.000
800.000
1000.000
1200.000
1400.000
1600.000
1800.000
CHW Ton

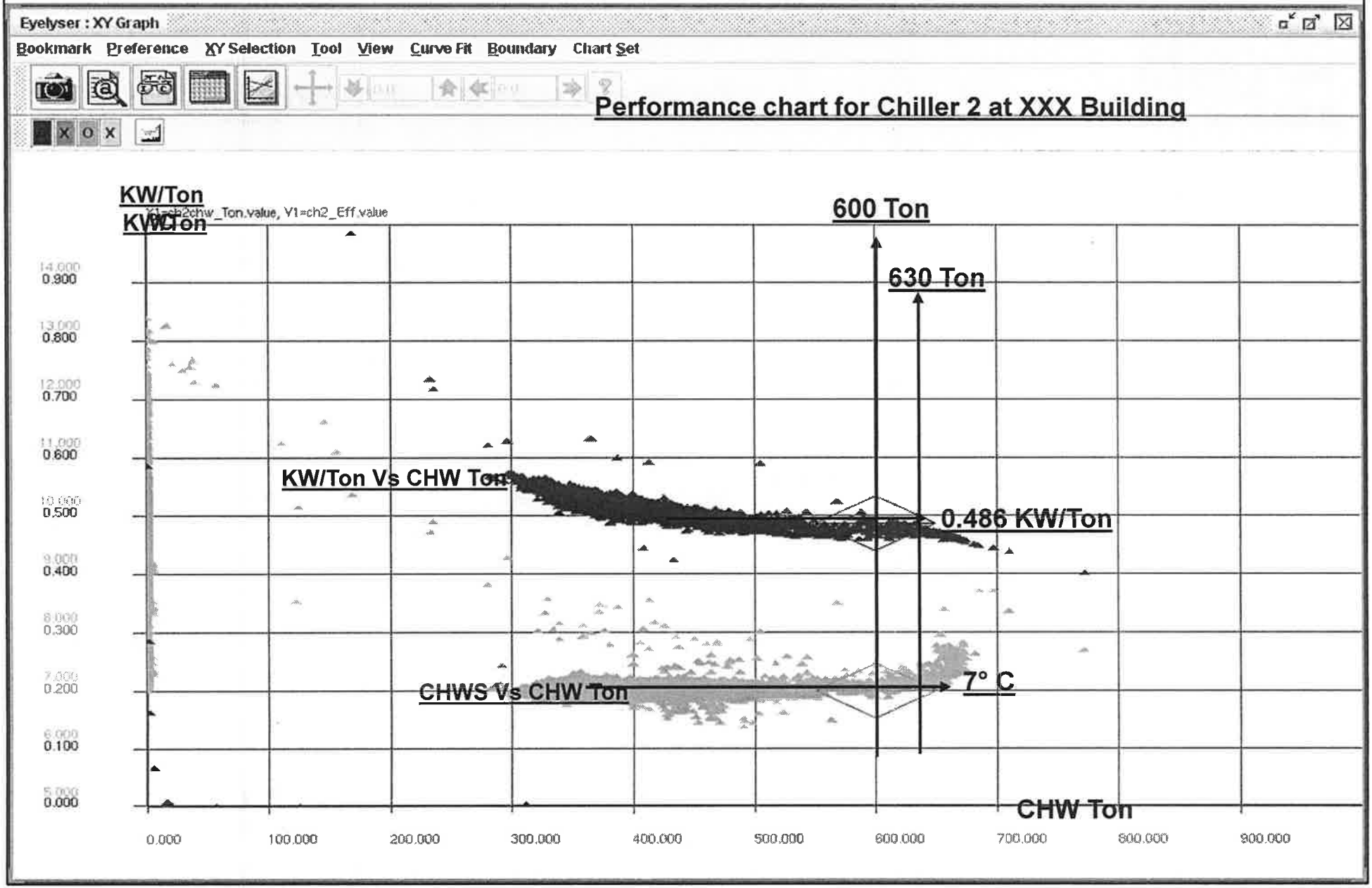
Chillers


Eyelyser : XY Graph
Bookmark Preference XY Selection Tool View Curve Fit Boundary Chart Set
CHWS @ 6.7 ° C
Chiller 6
Chiller 7
X1=CH6-Ton, Y1=CH6CHWST
CHWS (° C)
7.700
7.400
7.100
6.800
6.500
6.200
5.900
5.600
5.300
5.000
CHWS @ 6.7 ° C
Chiller 6,7 CHWS Vs Ton
0.000
100.000
200.000
300.000
400.000
500.000
600.000
700.000
800.000
900.000
CHW Ton

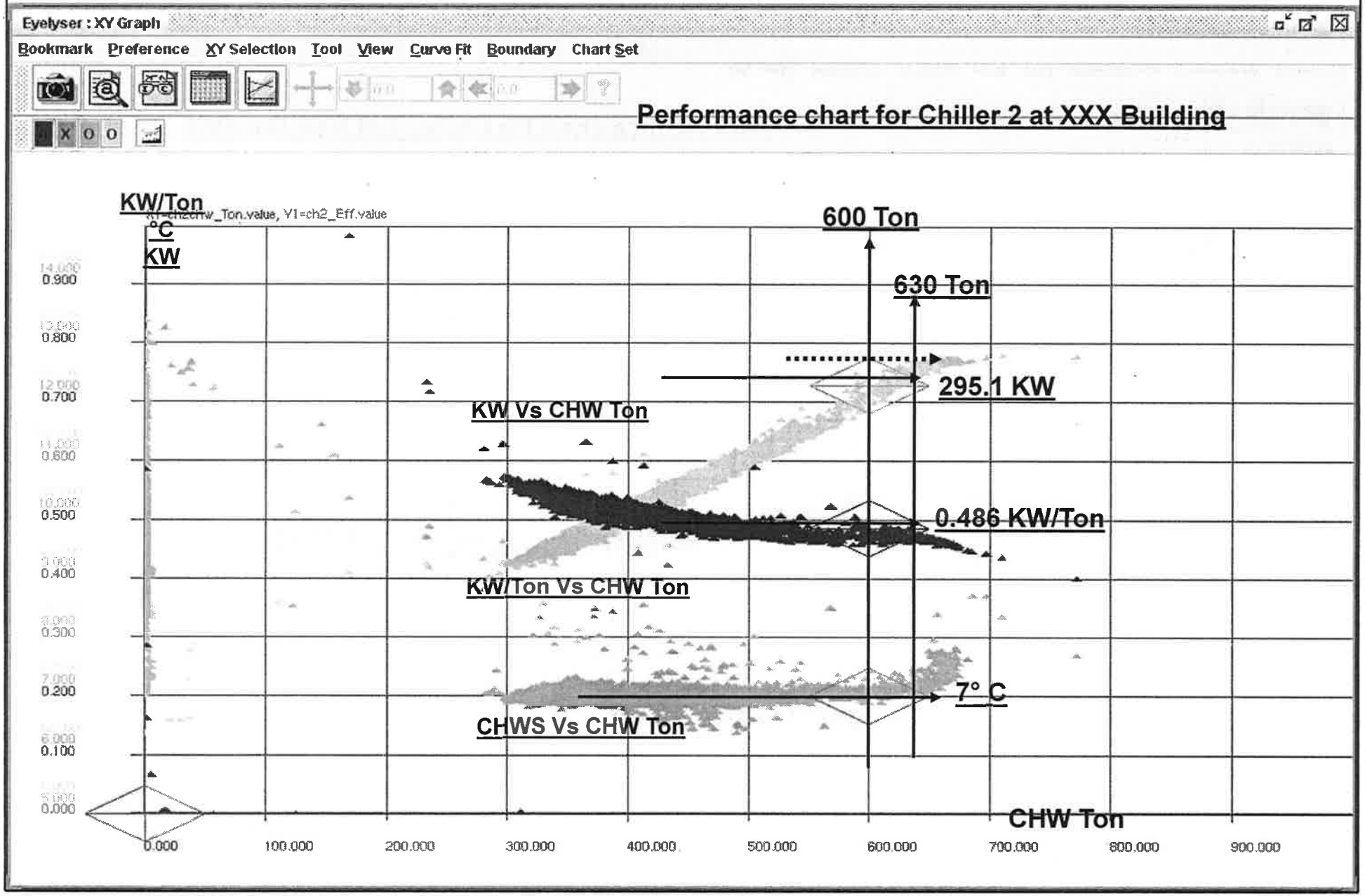
Retrofit Project Chillers



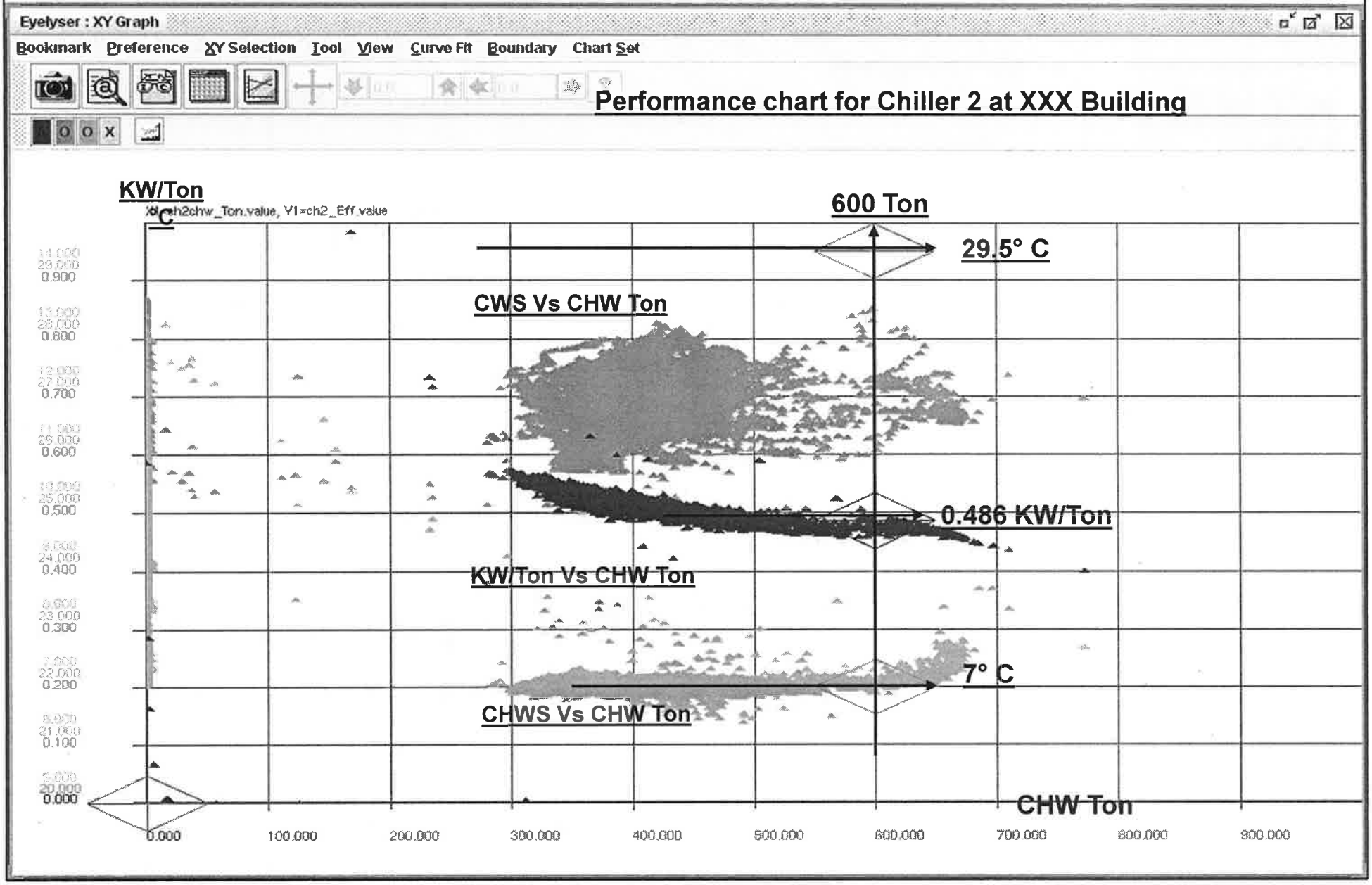
Retrofit Project Chillers



Retrofit Project Chillers

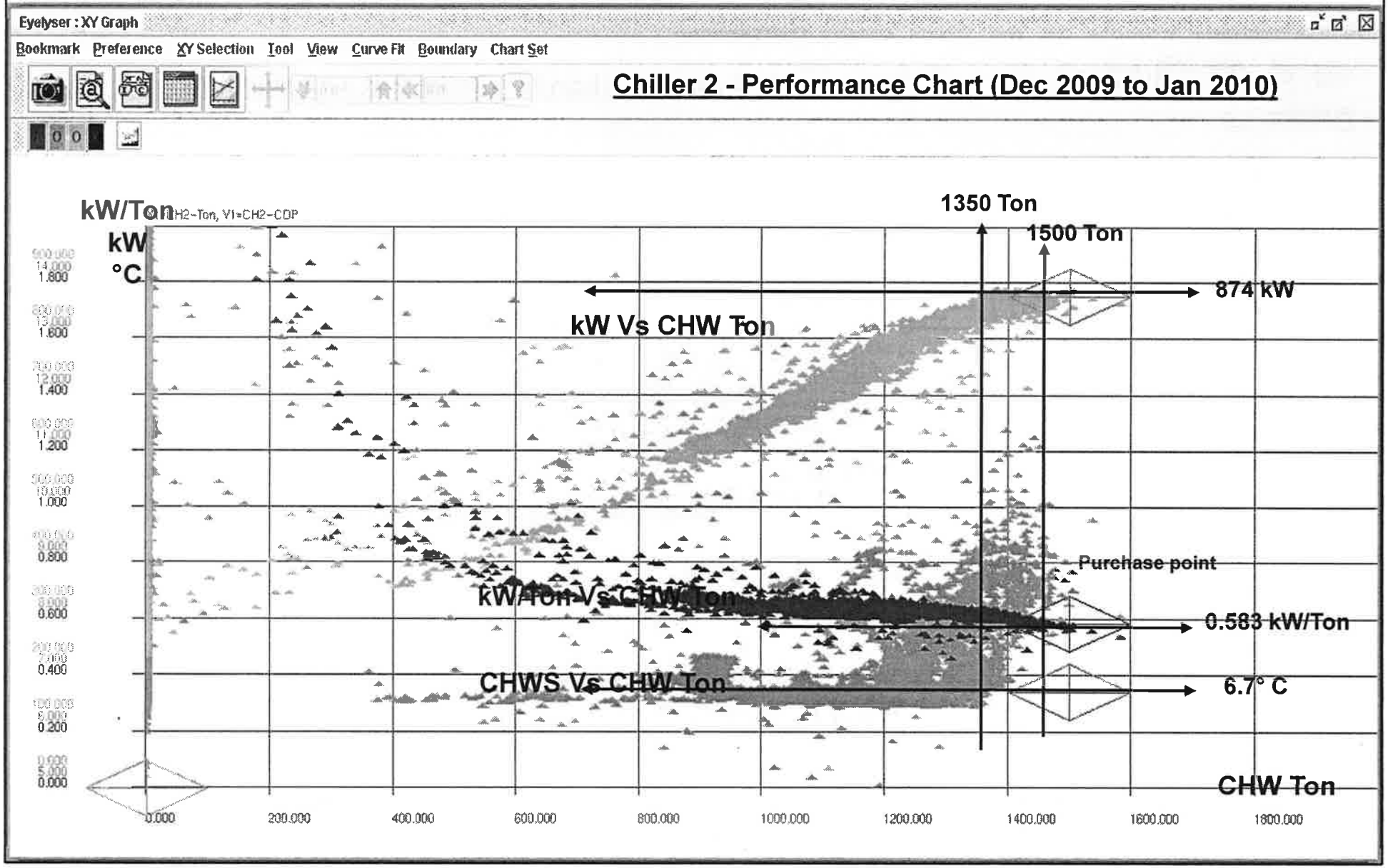


Retrofit Project Chillers

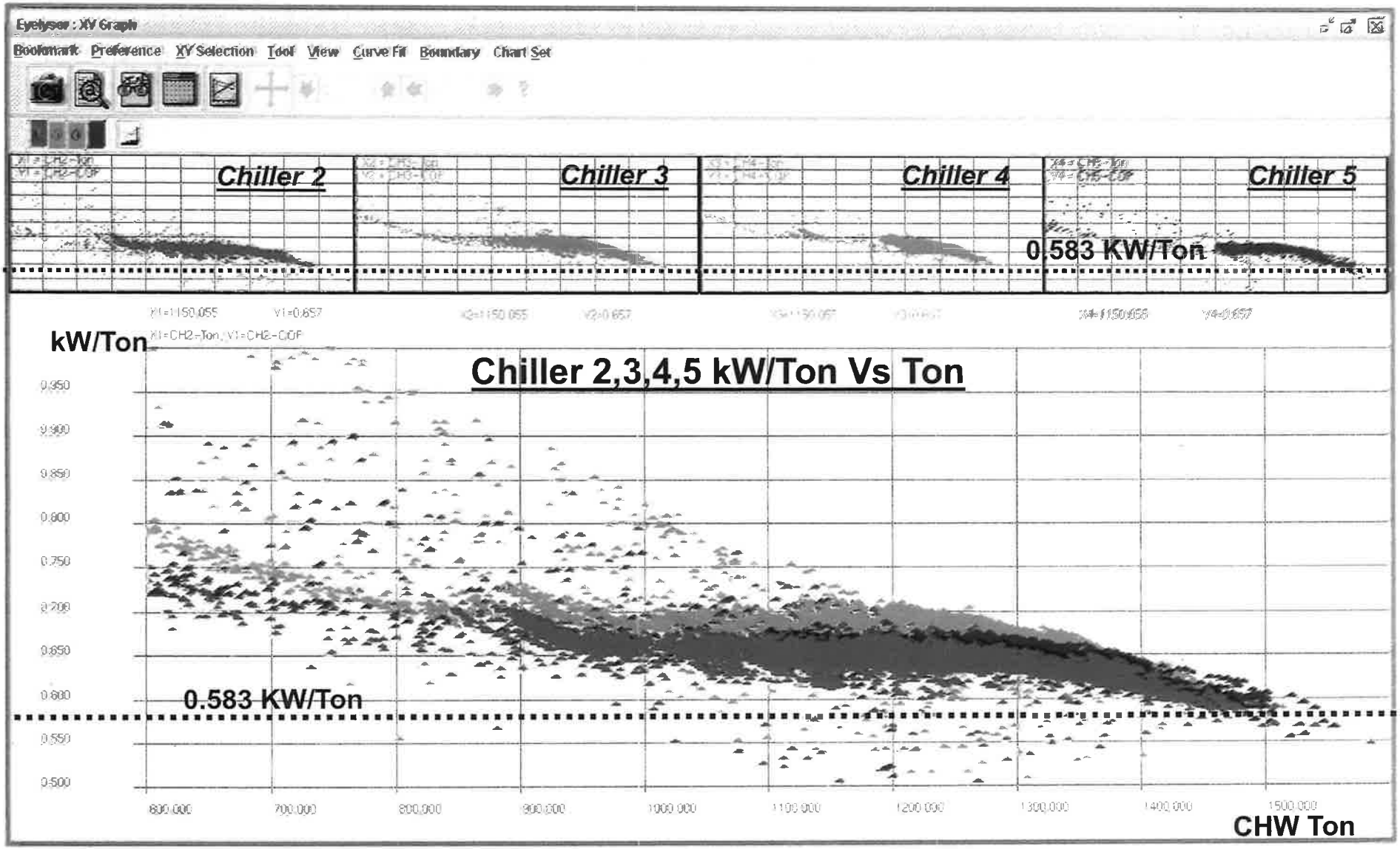


Chillers

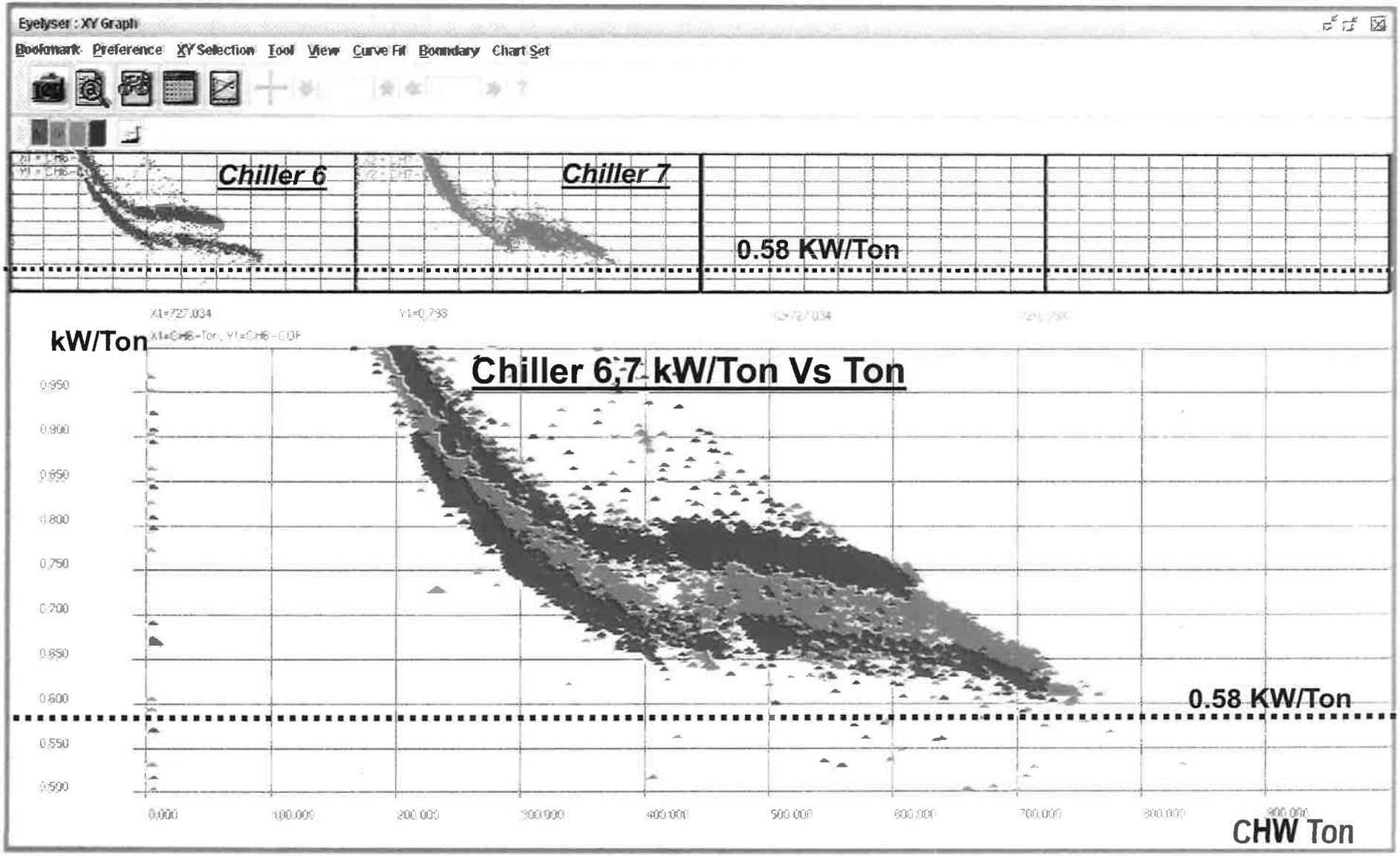
Performance Measurement of Chiller xx



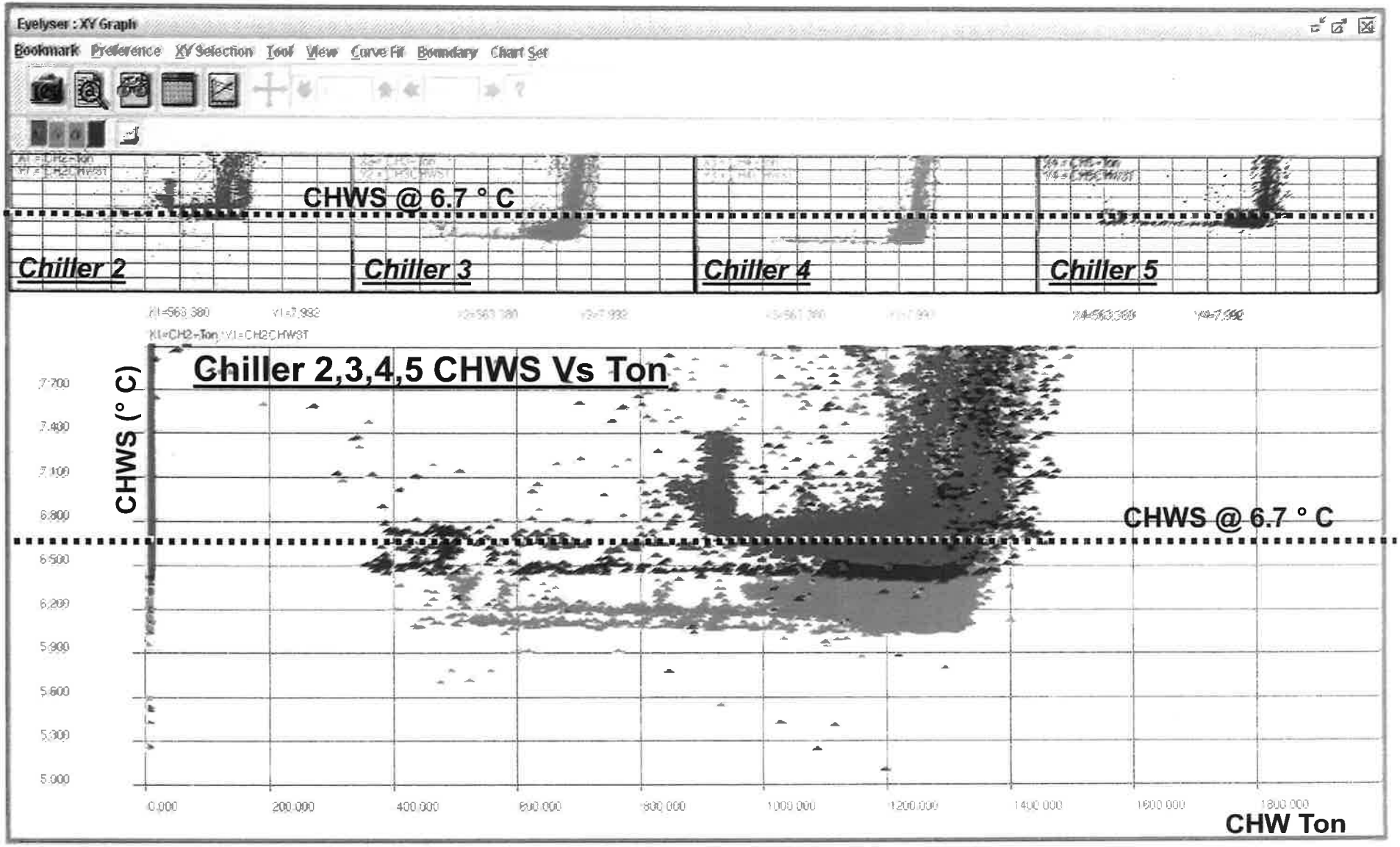
Chillers


Eyelyser : XY Graph
Bookmark Preference XY Selection Tool View Curve Fit Boundary Chart Set
Chiller 2
Chiller 3
Chiller 4
Chiller 5
0.583 KW/Ton
kW/Ton
Chiller 2,3,4,5 kW/Ton Vs Ton
0.583 KW/Ton
CHW Ton

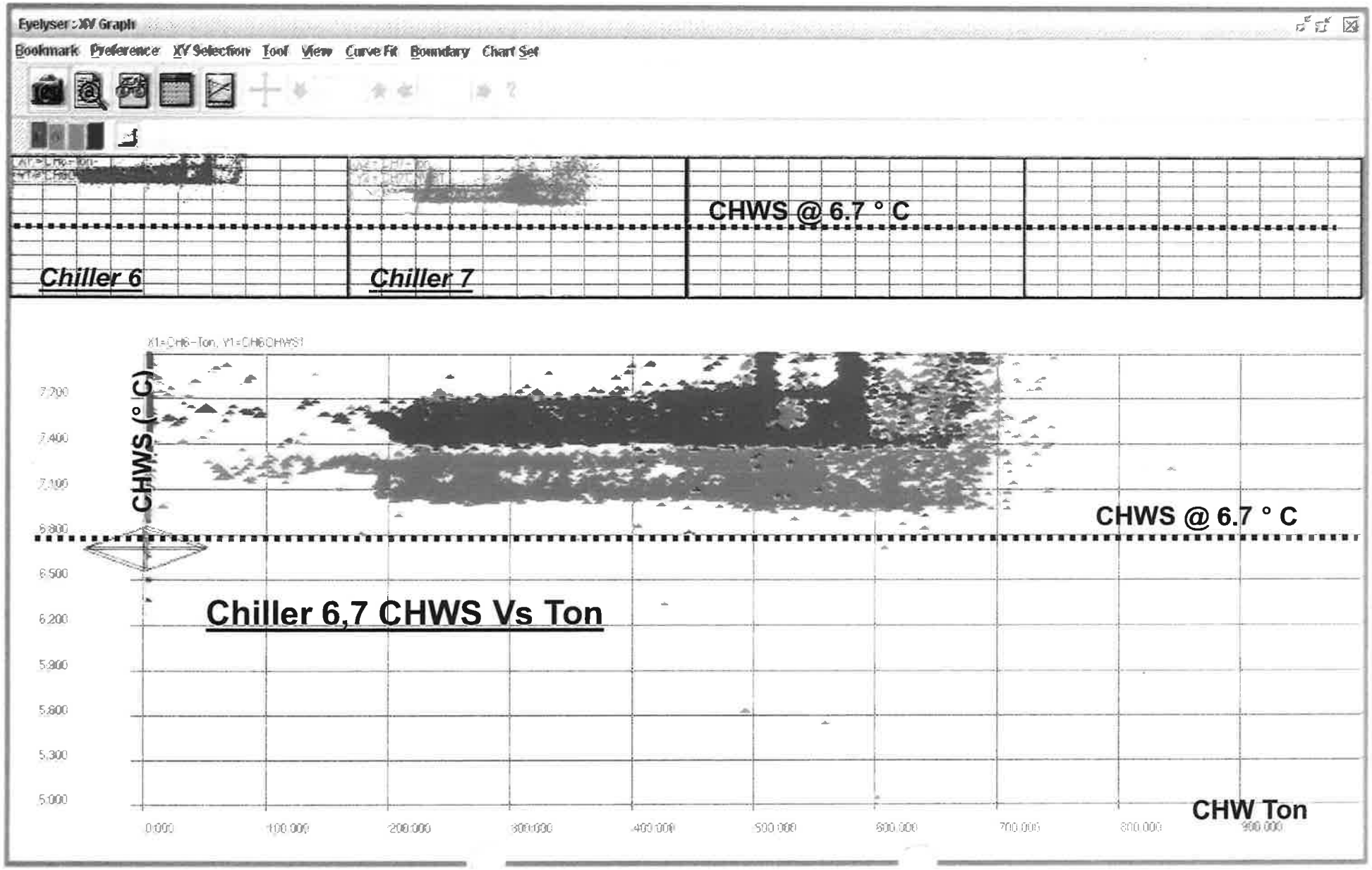
Chillers


Eyelyser : XY Graph
Bookmark Preference XY Selection Tool View Curve Fit Boundary Chart Set
Chiller 6
Chiller 7
0.58 KW/Ton
kW/Ton
Chiller 6,7 kW/Ton Vs Ton
0.950
0.900
0.850
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.000
100.000
200.000
300.000
400.000
500.000
600.000
700.000
800.000
900.000
0.58 KW/Ton
CHW Ton

Chillers

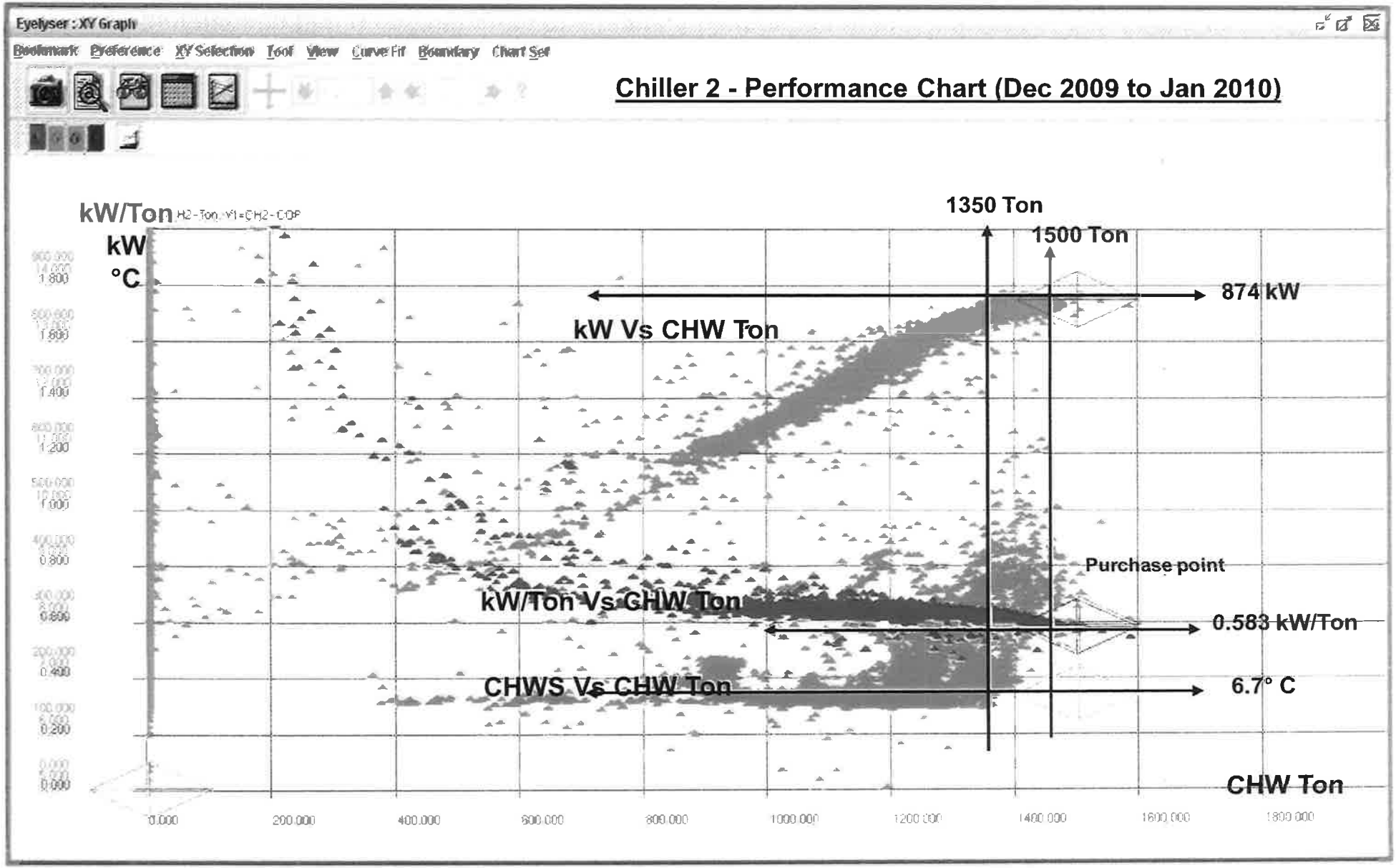

Eyelyser : XY Graph
Bookmark Preference XY Selection Tool View Curve Fit Boundary Chart Set
CHWS @ 6.7 ° C
Chiller 2
Chiller 3
Chiller 4
Chiller 5
Chiller 2,3,4,5 CHWS Vs Ton
CHWS (° C)
7.700
7.400
7.100
6.800
6.500
6.200
5.900
5.600
5.300
5.000
CHWS @ 6.7 ° C
0.000
200.000
400.000
600.000
800.000
1000.000
1200.000
1400.000
1600.000
1800.000
CHW Ton

Chillers


Eyelyser : XY Graph
Bookmark Preference XY Selection Tool View Curve Fit Boundary Chart Set
CHWS @ 6.7 ° C
Chiller 6
Chiller 7
X1=CH6-Ton, Y1=CH6CHWST
CHWS (° C)
7.700
7.400
7.100
6.800
6.500
6.200
5.900
5.600
5.300
5.000
CHWS @ 6.7 ° C
Chiller 6,7 CHWS Vs Ton
0.000
100.000
200.000
300.000
400.000
500.000
600.000
700.000
800.000
900.000
CHW Ton

Chillers

Performance Measurement of Chiller xx



Fundamentals of heat balance



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Agenda

1. Fundamentals of heat balance
2. Sources of heat inputs and outputs
3. Common types of chiller plant configuration
4. Effect of sensor location
5. Heat balance substantiating test
6. Exercises

Agenda

1. Fundamentals of heat balance

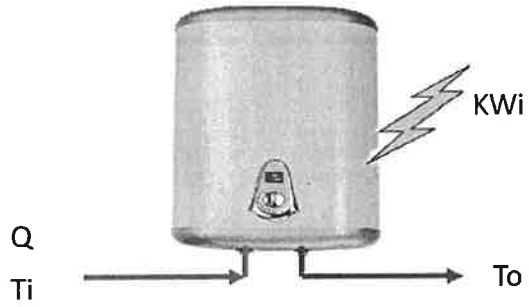
The law of conservation of energy

The law of conservation of energy is a law of physics. It states that the total amount of energy in a system remains constant over time (is said to be conserved over time).

A consequence of this law is that energy can neither be created nor destroyed: it can only be transformed from one state to another.

The only thing that can happen to energy in a system is that it can change form: for instance electrical energy can become heat energy.

COE: Example 1

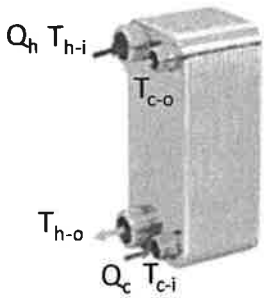


$$\text{Energy in} = \text{Energy out}$$

$$KW = 4.19 \times Q \times (To - Ti)$$

Q: Water flow in L/S
T: Water temperature in C

COE: Example 2





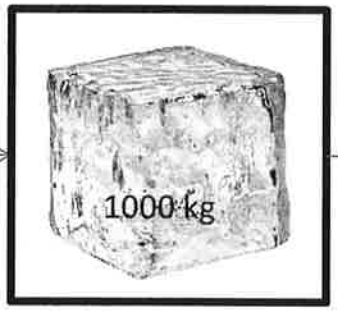
$$\text{Energy in} = \text{Energy out}$$

$$4.19 \times Q_h \times (T_{h-i} - T_{h-o}) = 4.19 \times Q_c \times (T_{c-o} - T_{c-i})$$

Q: Water flow in L/S
T: Water temperature in C

COE: Example 3

1 MT of ice melted in 24 Hrs



Q_h T_{h-i} → → T_{h-o}

$$\text{Energy in} = \text{Energy out}$$

$$4.19 \times Q_h \times (T_{h-i} - T_{h-o}) = M \times L_f$$

What is the cooling capacity of 1 Mton (1000kg) of ice melted over 24hrs?

Q: Water flow in L/S
T: Water temperature in C
M_f: Latent heat of fusion of water, 333 KJ/kg

7

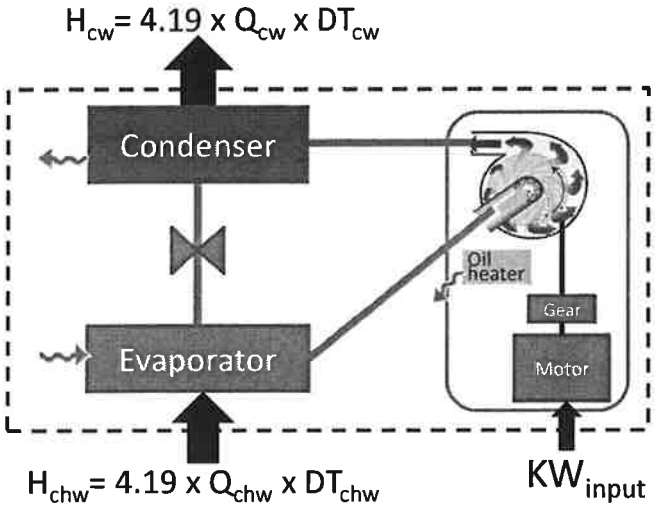
$$\frac{1000kg \times 333 kJ/kg}{24 \times 60 \times 60\ s} = 4.85\ kJ/s = kw$$

Agenda

2. Sources of heat inputs and outputs

8

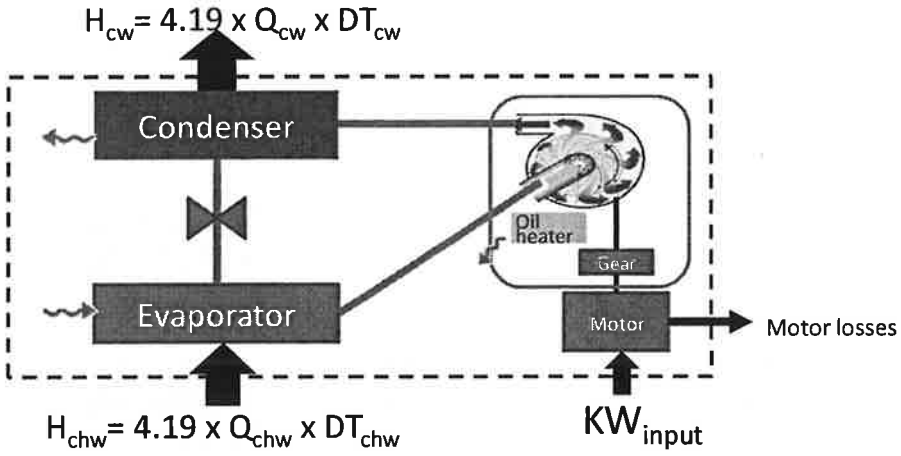
Hermetic motor chiller



Energy in = Energy out

$4.19 \times Q_{chw} \times DT_{chw} + KW_{input} = 4.19 \times Q_{cw} \times DT_{cw}$

Open motor chiller



Energy in = Energy out

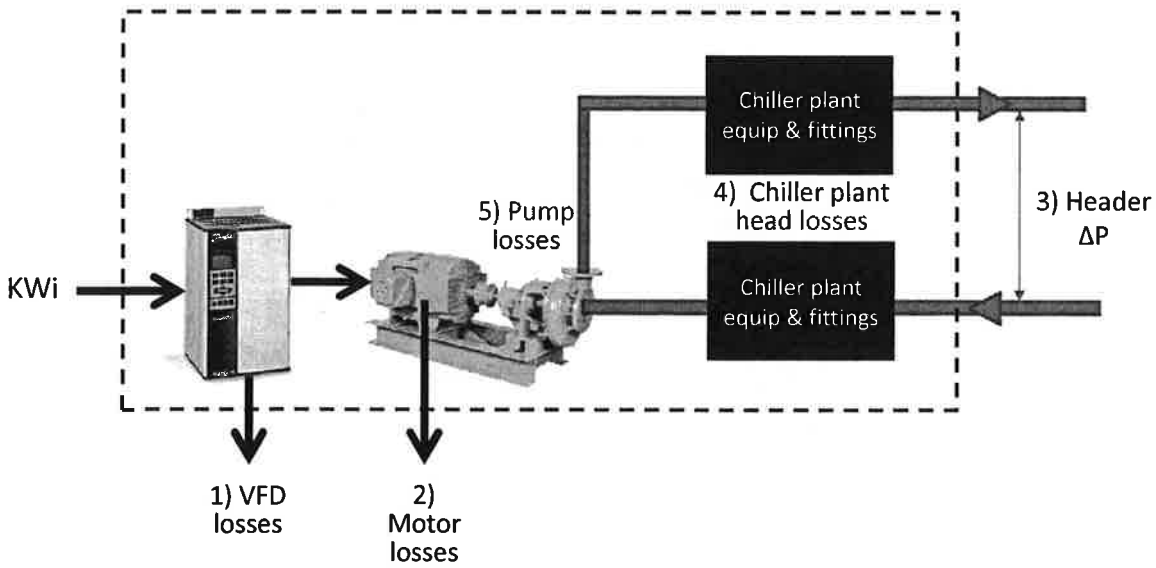
$4.19 \times Q_{chw} \times DT_{chw} + KW_{input} = 4.19 \times Q_{cw} \times DT_{cw} +$ Motor losses

$4.19 \times Q_{chw} \times DT_{chw} + KW_{input} = 4.19 \times Q_{cw} \times DT_{cw} + KW_{input} \times (1 - Eff_{motor})$

Water pump heat

- SS553 states power limitation of pumps as
  - CHWP as 349 $KW_i/m^3/s$
  - CWP as 301 $KW_i/m^3/s$
- AHRI 550 standard rating conditions are
  - CHW 0.043 L/S per KW_c @ 6.7C (or 0.151 L/S per RT)
  - CW: 0.054 L/S per KW_c @ 29.4C (0.190 L/S per RT)
- Therefore, the required pumps efficiency in KW/RT are:
  - CHWP efficiency = 349 / (1000/0.151) = 0.053 KW_i/RT
  - CWP efficiency = 301 / (1000/0.190) = 0.057i KW_i/RT

Water pump heat



Water pump heat – 1000RT example

- Chiller KWi = 0.58KW/RT x 1000RT = 580KW
- CHWP KWi = 0.053KW/RT x 1000RT = 53KW
- CWP KWi = 0.057KW/RT x 1000RT = 57KW

- CHW pump losses = KWi x VFD eff x motor eff x pump losses
  = 53 x 98% x 90% x 25%
  = 11.7KW

$11.7 = 4.19 \times 181 \times \eta$

$\Rightarrow \eta = 0.02$

- CW pump losses = KWi x VFD eff x motor eff x pump losses
  = 57 x 98% x 90% x 25%
  = 12.6KW

- Total pump losses = 24.3 KW

Water pump heat – 1000RT example con't

- Chiller plant head losses = Hydraulic energy x $\frac{\text{Chiller plant } \Delta P}{\text{Pump } \Delta P}$

- Hydraulic energy = KWi x VFD eff x Motor eff x Pump eff

Assuming $\frac{\text{Chiller plant } \Delta P}{\text{Pump } \Delta P}$ = 40%

- CHW head losses in plant room = 53KW x 98% x 90% x 75% x 40%
  = 14.0KW

- CW head losses in plant room = 57KW x 98% x 90% x 75% x 40%
  = 15.1KW

Total CHWP + CWP head losses in plant room = 29.1KW

Water pump heat – 1000RT example con't

Total CHW pump heat = Pump losses + Chiller plant head losses
= 11.7 + 14.0
= 25.7KW

Total CW pump heat = Pump losses + Chiller plant head losses
= 12.6 + 15.1
= 27.7KW

CHW load + Chiller KWi = 3517 + 580
= 4097KW

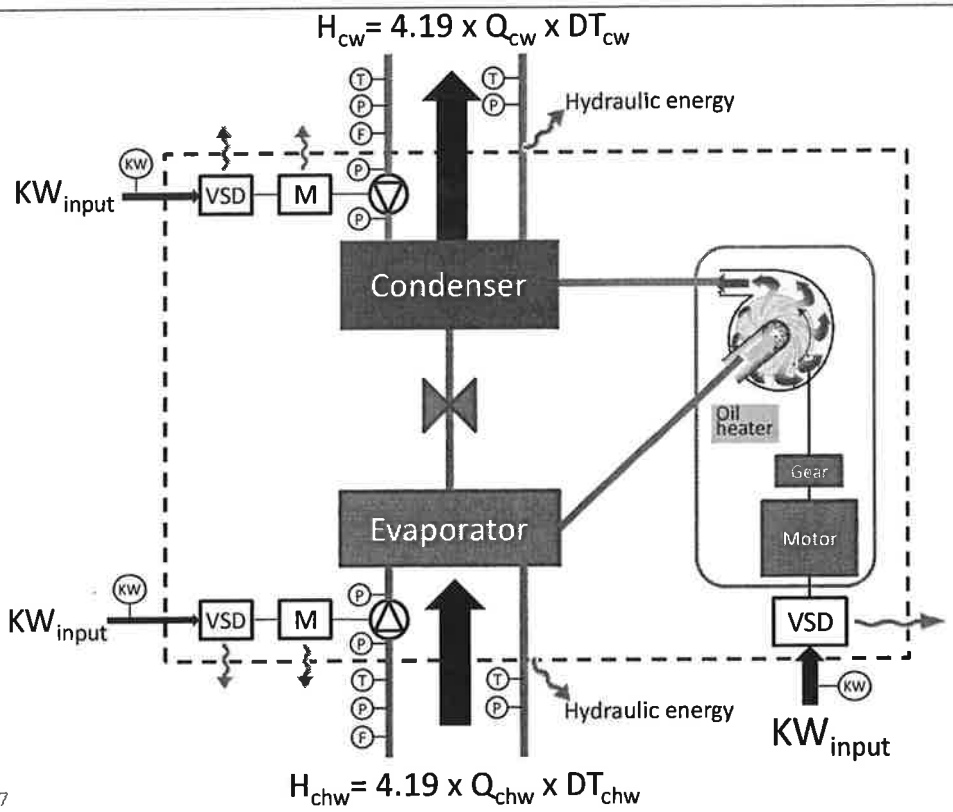
$$\frac{\text{CHW Pump heat}}{\text{CHW load + Chiller KWi}} = \frac{25.7}{4097} = 0.63\%$$

$$\frac{\text{CW Pump heat}}{\text{CHW load + Chiller KWi}} = \frac{27.7}{4097} = 0.68\%$$

Water pump heat

- The pump heat is usually small compared to the cooling load and the compressor power input.
- Therefore, in most cases, it is reasonable to exclude the effects of pump heat in the heat balance error computation.
- In cases where pump efficiency is very poor and/or the head losses within the chiller plant is very large, pump heat might become significant and will need to be considered in the heat balance.

Chiller plant heat balance



Plant heat balance

Chilled water heat in

1. CHW heat = 4.19 x L/S x DT

Chiller power heat in

2. Chiller KW_i

CHW pump power heat in

3. CHWP KW_i

CHW pump power heat in

4. CWP KW_i

Effects of pumps often excluded because "pump heat in" is relatively small compared to CHW heat and chiller KWi.

Plant heat balance

Condenser water heat out

1. CW heat = 4.19 x L/S x DT

Chiller heat out

2. Chiller VSD heat out (Applicable for VSD drive chiller only)

= Kwi x %VSD loss

3. Chiller motor heat out (applicable for open motor chiller only)

= KWi x %VSD eff x % motor loss

Plant heat balance

CHWP heat out (Continue)

4. CHWP VSD heat out

= CHWP KWi x VSD loss

5. CHWP motor heat out

= CHWP KWi x VSD eff x Motor loss

6. CHWP header hydraulic energy out

= CHWP KWi x VSD eff x Motor eff x Pump eff x $\frac{\text{CHW header DP}}{\text{CHWP head}}$

Effects of pumps often excluded because "Pump heat out" is relatively small compared to CHW heat and chiller KWi.

Plant heat balance

CWP heat out (Continue)

7. CWP VSD heat out
= CWP KWi x VSD loss

8. CWP motor heat out
= CWP KWi x VSD eff x Motor loss

9. CWP header hydraulic energy out
= CWP KWi x VSD eff x Motor eff x Pump eff x $\frac{\text{CW header DP}}{\text{CWP head}}$

Effects of pumps often excluded because "Pump heat out" is relatively small compared to CHW heat and chiller KWi.

Plant heat balance example

Chiller plant configuration

- 2 x 500RT operating + 1 x 500 RT standby
- Hermetic, VSD drive, centrifugal chillers
- Variable primary CHWP system
- Variable speed CWP system

Header temps, flow & DP measurements		
CHWS temp	C	6.67
CHWR temp	C	12.22
CHW flow rate	L/S	151.20
% CHW header DP / CHWP head	%	60%
CWS temp	C	29.44
CWR temp	C	35.00
CW flow rate	L/S	177.57
% CW header DP / CWP head	%	60%
Equipment power measurements		
Chillers total power input	KW	580.00
CHWP total power input	KW	53.00
CWP total power input	KW	57.00
Equipment efficiency from supplier		
Chiller VSD efficiency	%	98%
CHWP VSD efficiency	%	97%
CHWP motor efficiency	%	94%
CHWP pump efficiency	%	80%
CWP VSD efficiency	%	97%
CWP motor efficiency	%	94%
CWP pump efficiency	%	80%

Plant heat balance

Chilled water heat in

1. CHW heat = 4.19 x L/S x DT

4.19 x 151.20 x (12.22 - 6.67) = 3516.0804

Chiller power heat in

2. Chiller KW_i

580 =

CHW pump power heat in

3. CHWP KW_i

53 =

CW pump power heat in

4. CWP KW_i 57 =

Total heat in = 4206.0804

Plant heat balance

Condenser water heat out

1. CW heat = 4.19 x L/S x DT

4.19 x 177.17 x (35 - 29.44) = 4136.74

Chiller heat out

2. Chiller VSD heat (Applicable for VSD drive chiller only) = Kwi x %VSD loss

580 x 2 % = 11.6

3. Chiller motor heat (applicable for open motor chiller only) = KWi x %VSD eff x % motor loss

N/A =

Plant heat balance

CHWP heat out (Continue)

4. CHWP VSD heat out = CHWP KWi x VSD loss

53 x 3% = 1.59

5. CHWP motor heat out = CHWP KWi x VSD eff x Motor loss

53 x 0.97 x 6% = 3.08

6. CHWP header hydraulic energy out

= CHWP KWi x VSD eff x Motor eff x Pump eff x $\frac{\text{CHW header DP}}{\text{CHWP head}}$

53 x 0.97 x 0.94 x 0.8 x 60% = 23.20

Plant heat balance

CWP heat out (Continue)

7. CWP VSD heat out = CWP KWi x VSD loss

57 x 3% = 1.71

8. CWP motor heat out = CWP KWi x VSD eff x Motor loss

57 x 0.97 x 6% = 3.32

9. CWP header hydraulic energy out

= CWP KWi x VSD eff x Motor eff x Pump eff x $\frac{\text{CW header DP}}{\text{CWP head}}$

57 x 0.97 x 0.94 x 0.8 x 60% = 24.95

Total heat out = 4206.19

Plant heat balance example

$$\text{Heat balance} = \frac{\text{Sum of heat in} - \text{Sum of heat out}}{\text{Sum of heat out}}$$

$$\text{Heat balance} = \frac{4206.08 - 4206.19}{4206.19} = -0.000026$$

Heat balance neglecting effects of CHWP & CWP

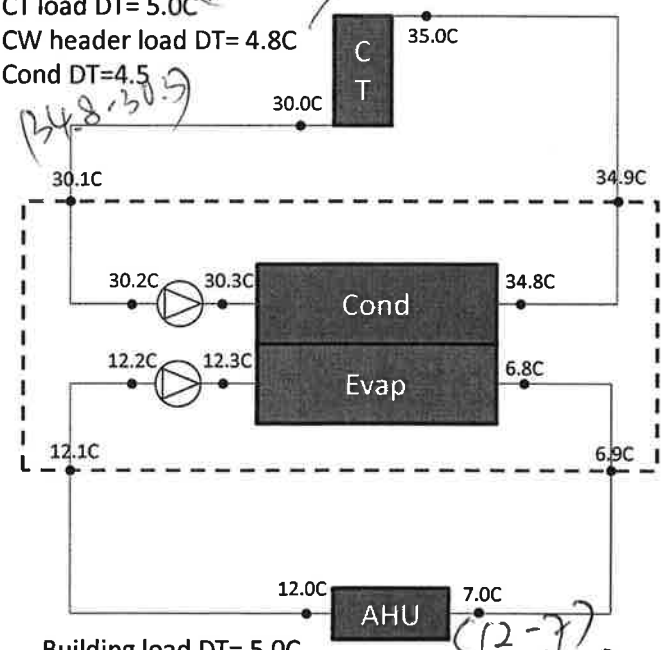
$$\text{Heat balance} = \frac{\text{Sum of heat in} - \text{Sum of heat out}}{\text{Sum of heat out}}$$

$$\text{Heat balance} = \frac{(3516.08 + 580) - (4136.74 + 11.6)}{(4136.74 + 11.6)} = -0.0126$$

Plant heat balance example

Another method to rationalize heat balance

CT load DT= 5.0C
CW header load DT= 4.8C
Cond DT=4.5



Building load DT= 5.0C
CHW header load DT= 5.2C
Evap load DT=5.5

Heat in
1) CHW header load
2) Compressor heat of compression
3) CHW Pump eff loss
4) CHW hydraulic friction within plant room
5) CW pump eff loss
6) CW hydraulic friction within plant room

Heat out
1) CW header load

Microsoft Excel Worksheet

Copyright Steven Kang B L

Heat in

1. CHW heat in = 3516.08
2. Compressor heat of compression = 580 × 98% = 568.4
3. CHW pump heat = 53 × 97% × 94% × (1-80%) = 9.67 kW
4. CHW hydraulic friction within chiller plant = 53 × 97% × 94% × 80% × (1-60%) = 15.46 kW
5. CW pump heat = 87 × 97% × 94% × (1-80%) = 10.39 kW
6. CW hydraulic friction within chiller plant = 57 × 97% × 94% × 80% × (1-60%) = 16.63 kW

Total heat in = 4136.64

Heat out

1. CW heat out = 4136.74

Total heat out =

Plant heat balance example

Heat balance = $\frac{\text{Sum of heat in} - \text{Sum of heat out}}{\text{Sum of heat out}}$

Heat balance = $\frac{4136.64 - 4136.72}{4136.72} =$

Heat balance neglecting effects of CHWP & CWP

Heat balance = $\frac{\text{Sum of heat in} - \text{Sum of heat out}}{\text{Sum of heat out}}$

Heat balance = $\frac{3816.08 + 568.4 - 4136.72}{4136.72} = -1.3\%$

31 If Exclude Hydraulic Friction only.

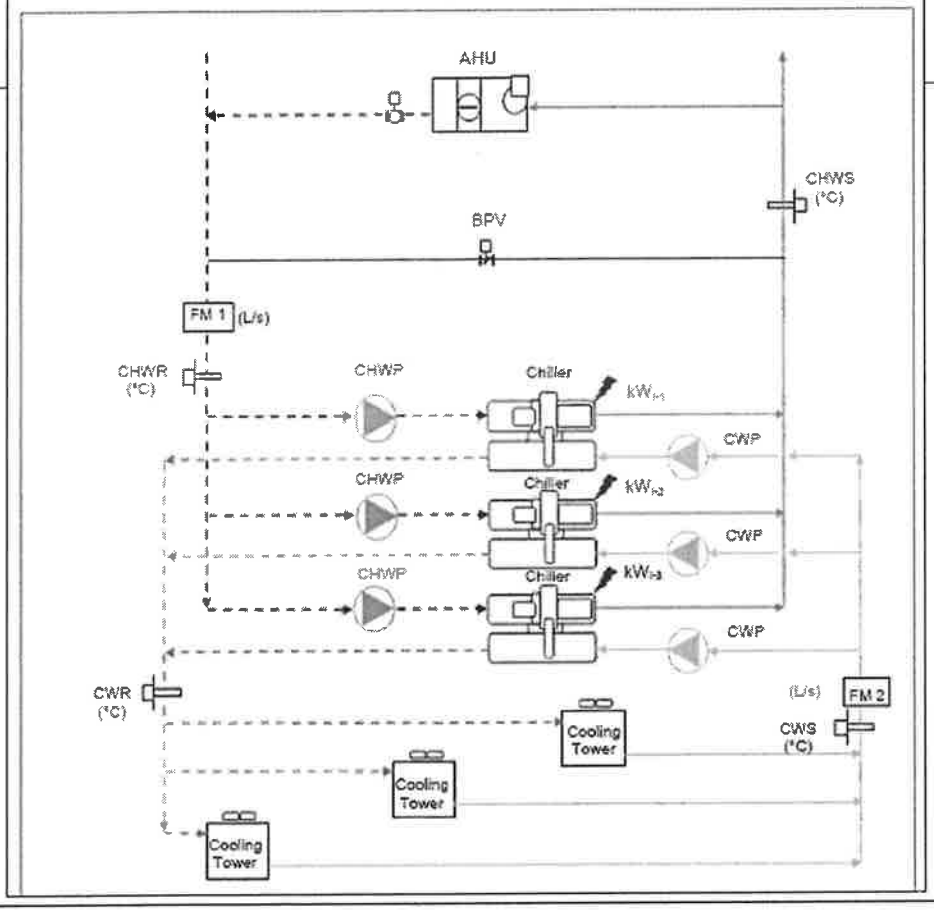
Heat Balance = $\frac{(3816.08 + 568.4 + 9.67 + 10.39) - (4136.72)}{4136.72}$

$= -0.8\%$

Agenda

3. Common types of chiller plant configuration

Plant A – Constant Primary Chilled-Water System



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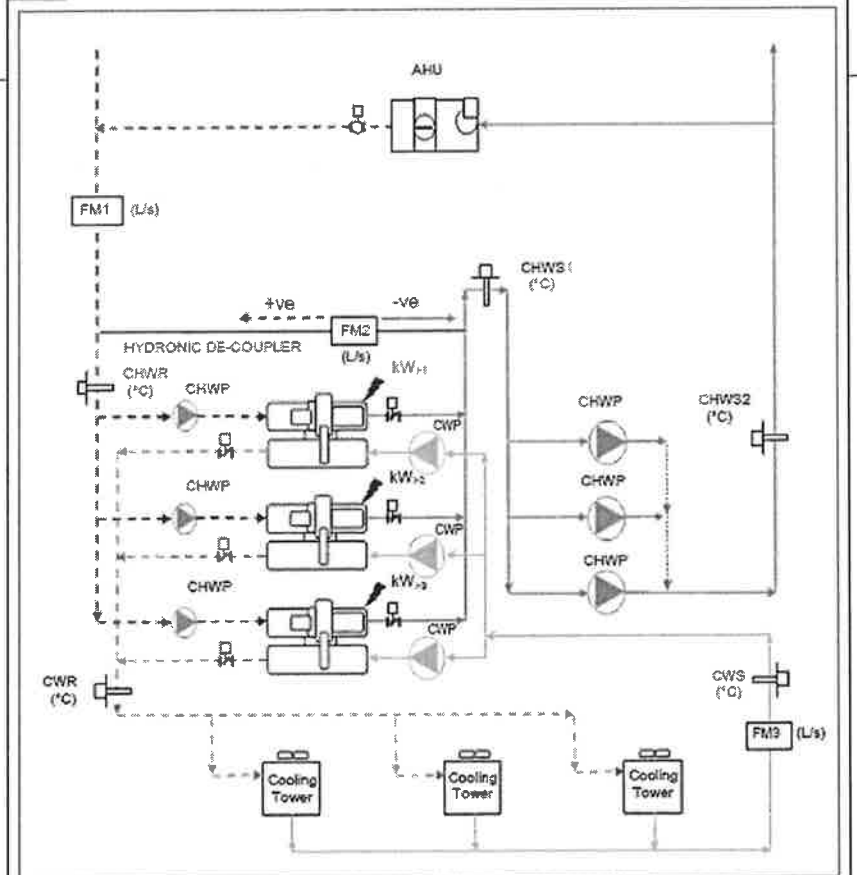
Plant C – Constant Primary & Variable Secondary Chilled-Water System

Zoom



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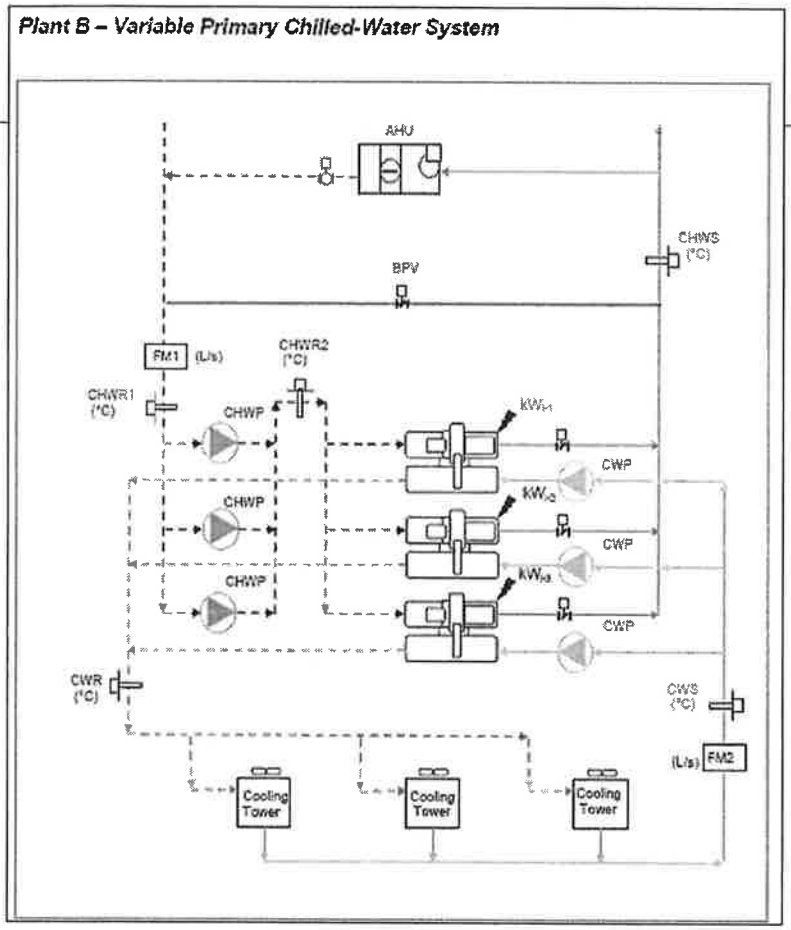
Plant B – Variable Primary Chilled-Water System



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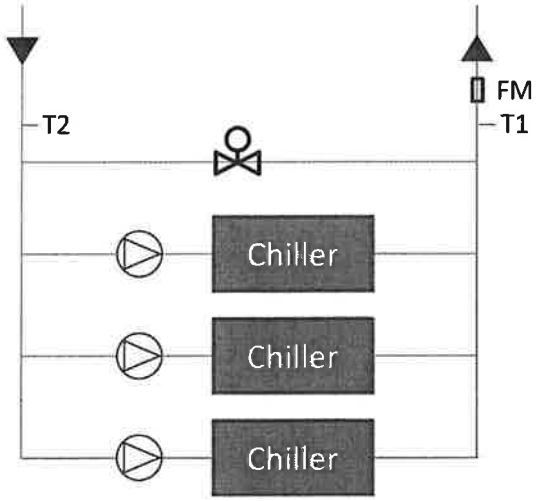
Agenda

4. Effect of sensor location

36

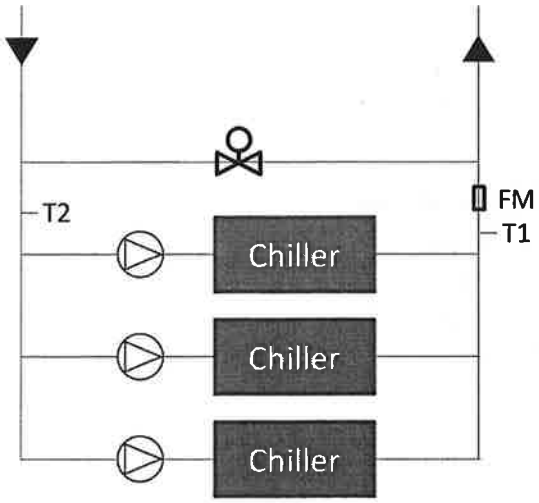
Example 1

$$H_{chw} = 4.19 \times Q_{chw} \times DT_{chw}$$



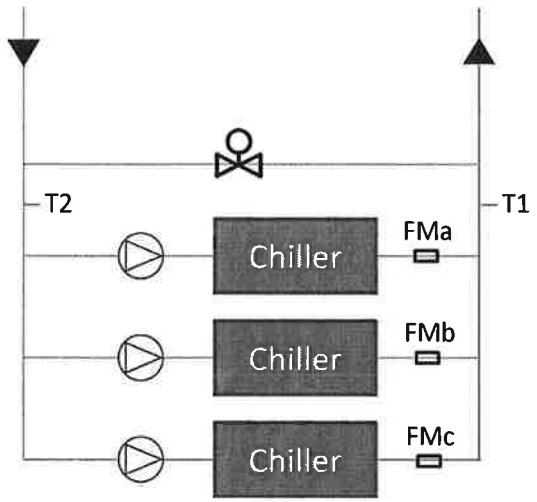
Example 2

$$H_{chw} = 4.19 \times Q_{chw} \times DT_{chw}$$

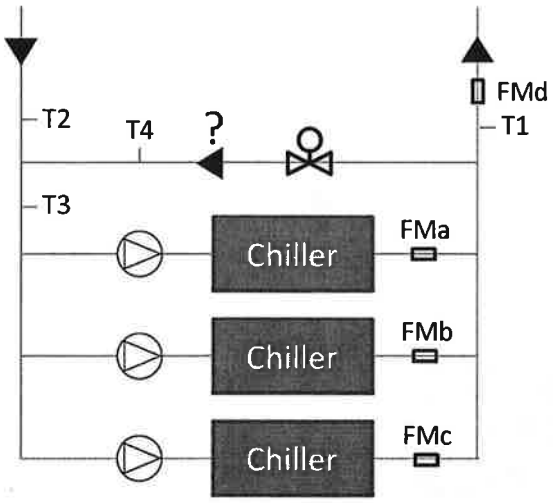


Example 3

$$H_{chw} = 4.19 \times Q_{chw} \times DT_{chw}$$



Example 4



$Q3 = Q2 + Q4$

$Q2 \times T2 + Q4 \times T4 = Q3 \times T3$

$Q2 \times T2 + Q4 \times T4 = (Q2 + Q4) \times T3$

$$Q4 = Q2 \times \frac{T2 - T3}{T3 - T4}$$

Flow check

FMa + FMb + FMc = FMd + Q4

Agenda

5. Heat balance substantiating test

Heat balance substantiating test

$$\frac{\text{Heat input} - \text{Heat output}}{\text{Heat output}} <= 5\%$$

80% of data point must fall with +/-5% for 1 week operating period .

Heat balance substantiating test

From a practical approach point of view

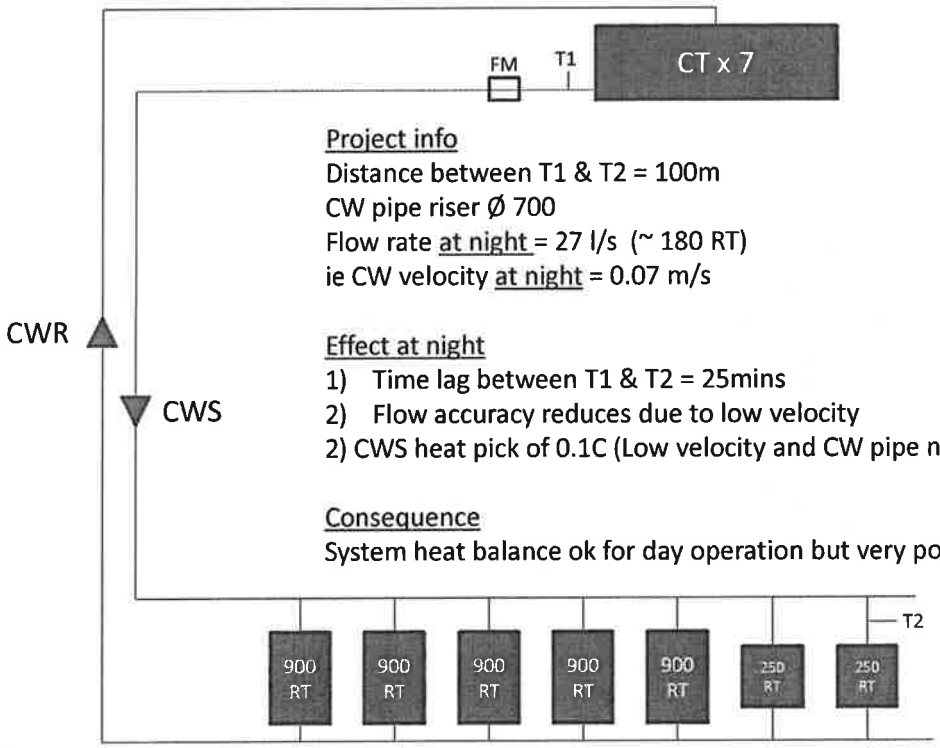
1. It is recommended to conduct heat balance for each chiller instead of plant heat balance.
2. Plant heat balance using temperature sensors and flow meters at headers has more variable factors that might affect the heat balance:
   a) Low flow velocity at header during part load will lead to higher inaccuracy of the flow meter.
   b) Time difference effect at low velocity is magnified when the CHW and CW temperature sensors are at unequal distance from chillers.
   c) Effects of CHWP and CWP heat are difficult to quantify.
   d) Effects of heat gain & loss in CW pipe which is not insulated are difficult to quantify.
3. Installation of flow meters for each chillers will allow control of individual CHWP and CWP flow rate.
4. Installation of flow meters for each chiller will allow measurement of KW/RT for individual chiller, CHWP, CWP and CT.

Heat balance substantiating test

Common pit falls that cause high heat balance errors

- 1. Temperature sensor accuracy has drifted. This may be caused by RTD/Thermistors drift due to vibration or data logger electronics drift.
- 2. Flow meter installed at turbulent flow location.
- 3. Unstable operation of CHW control valves resulting in unstable CHW flow and CHW return temp.
- 4. Unstable operation of chiller resulting in unstable CHW supply temp.
- 5. Unstable operation of pump / VSD resulting in unstable CHW and CW flow & temp.
- 6. Unstable operation of CT / VSD resulting in unstable CWS temp.
- 7. Time difference in capturing of temperature, flow or KW.
- 8. Small DT during off-peak period increases the error of temp measurement.

Example of heat balance error



Project info

Distance between T1 & T2 = 100m

CW pipe riser Ø 700

Flow rate at night = 27 l/s (~ 180 RT)

ie CW velocity at night = 0.07 m/s

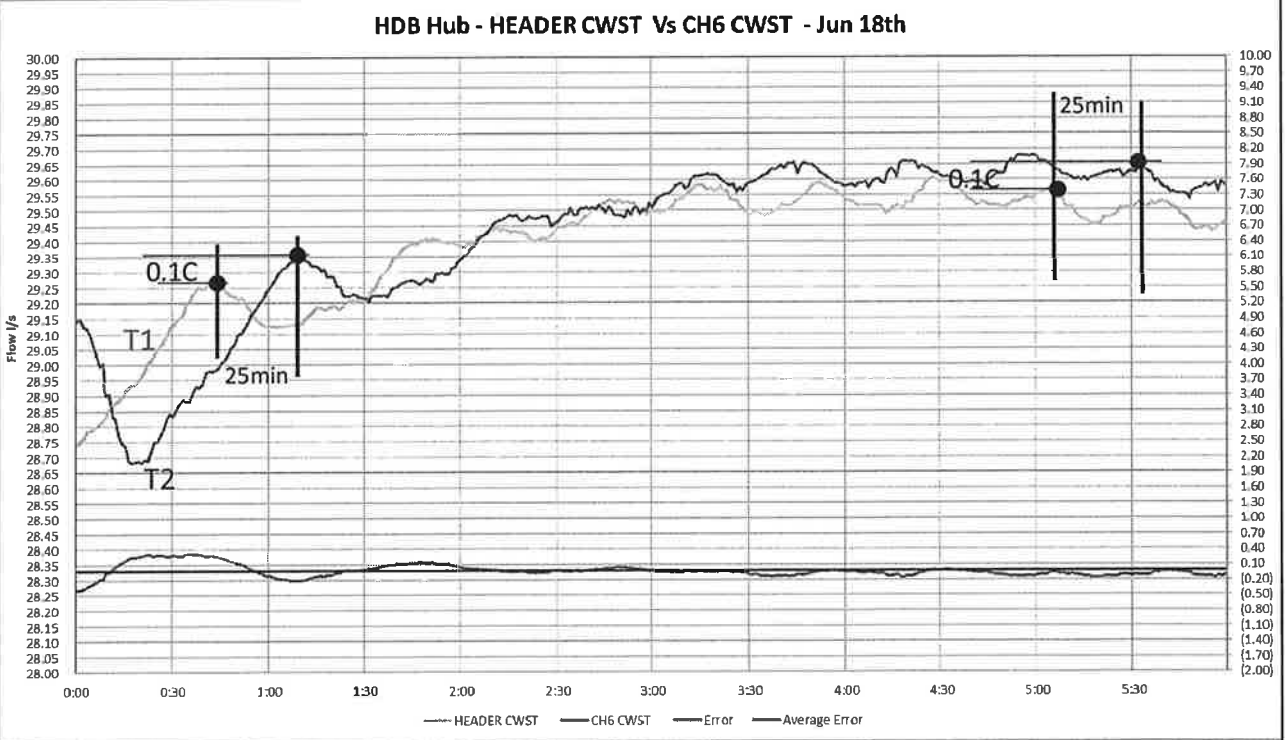
Effect at night

1) Time lag between T1 & T2 = 25mins
2) Flow accuracy reduces due to low velocity
2) CWS heat pick of 0.1C (Low velocity and CW pipe no insulation)

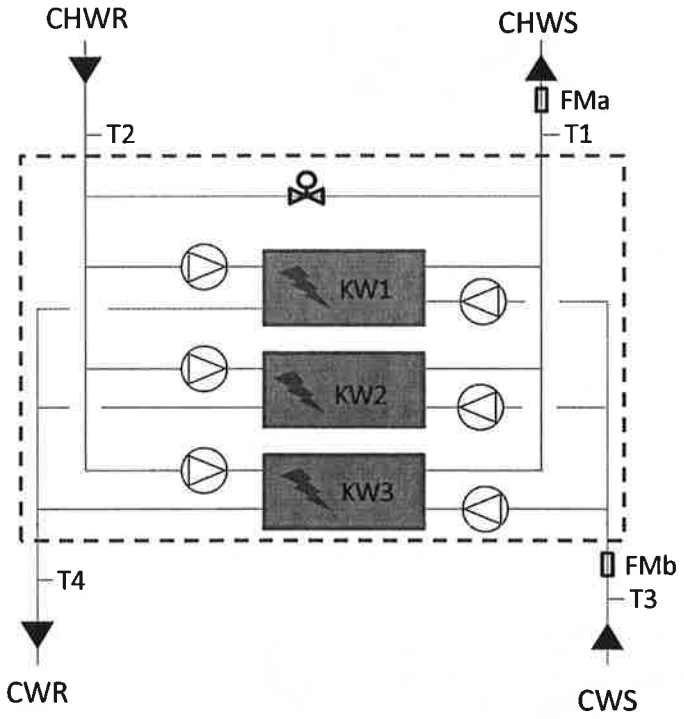
Consequence

System heat balance ok for day operation but very poor at night.

Example of heat balance error



Calculate heat balance error



T1= 6.8C
T2 = 12.1C
T3 = 28.6C
T4 = 34C

KW1= 500KW
KW2 = 490KW
KW3 = 0KW

FMa = 150 L/S
FMb = 195 L/S

Heat balance error = ?

Thank You

for your attention

Q&A

Plant heat balance example

Heat in

CHW heat	KW	3,516.08
Chiller power	KW	580.00
CHWP power	KW	53.00
CWP power	KW	57.00
Total heat in	**KW**	**4,206.08**

Heat out

CW heat	KW	4,136.72	
Chillers			
Chiller VSD heat	KW	11.60	
Chiller motor heat	KW	0.00	
Chiller gear heat	KW	0.00	% of CW heat
Sub-total	KW	11.60	0.28%
CHWPs			
CHWP VSD heat	KW	1.59	
CHWP motor heat	KW	3.08	
CHWP hydraulic energy	KW	23.20	% of CW heat
Sub-total	KW	27.87	0.67%
CWPs			
CWP VSD heat	KW	1.71	
CWP motor heat	KW	3.32	
CWP hydraulic energy	KW	24.95	% of CW heat
Sub-total	KW	29.97	0.72%
Total heat out	**KW**	**4,206.17**	

Plant heat balance example

$$\text{Heat balance} = \frac{\text{Sum of heat in} - \text{Sum of heat out}}{\text{Sum of heat out}}$$

Heat balance error (Considering all major heat sources)	**%**	**0.0%**

Heat balance error (Neglecting effects of CHWPs & CWPs)	**%**	**-1.3%**

Neglecting effects of CHWP & CWP

Heat in= 3516.08 + 580= 4096.08

Heat out = 4136.72+11.60=4148.32

Heat balance error = (4096.08 – 4148.32) / 4148.32 = -1.3%



Plant heat balance example

Another method to rationalize heat balance

Heat in

CHW header load	KW	3,516.08
Heat of compression	KW	568.40
CHWP losses	KW	9.67
CHW hydraulic friction within plant room	KW	15.46
CWP losses	KW	10.39
CW hydraulic friction within plant room	KW	16.63
Total heat in	**KW**	**4,136.64**

Heat out

CW heat	KW	4,136.72
Total heat out	**KW**	**4,136.72**

Heat Balance

Heat balance error (Considering all major heat sources)	**%**	**0.0%**

Heat balance error (Neglecting effects of CHWPs & CWPs)	**%**	**-1.26%**

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Heat balance exercise



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Agenda

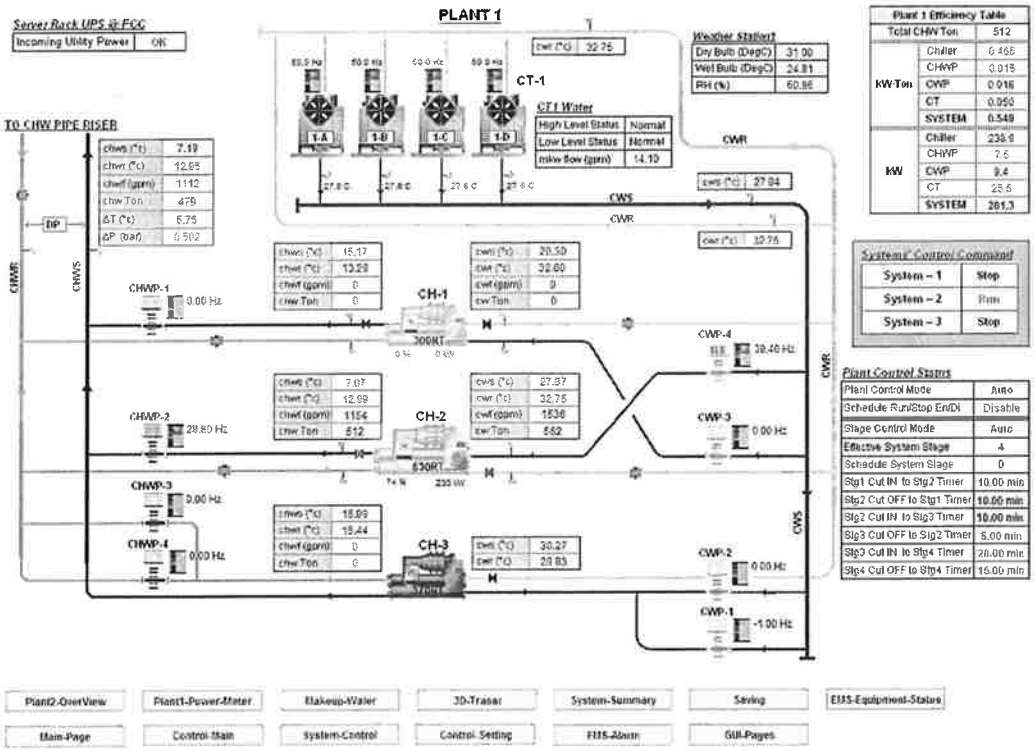
1. Heat balance exercises
2. Heat balance substantiating test submission requirements
3. Project heat balance assignments

Project heat balance assignment

Heat balance exercises

- Five heat balance exercises
- Divide yourselves into 5 groups
- Do all 5 exercises
- Some people will be selected to present the findings

Example 1



Example 1 continue....

Consistency check

- What is the temperature consistency error?
- What is the flow consistency error?

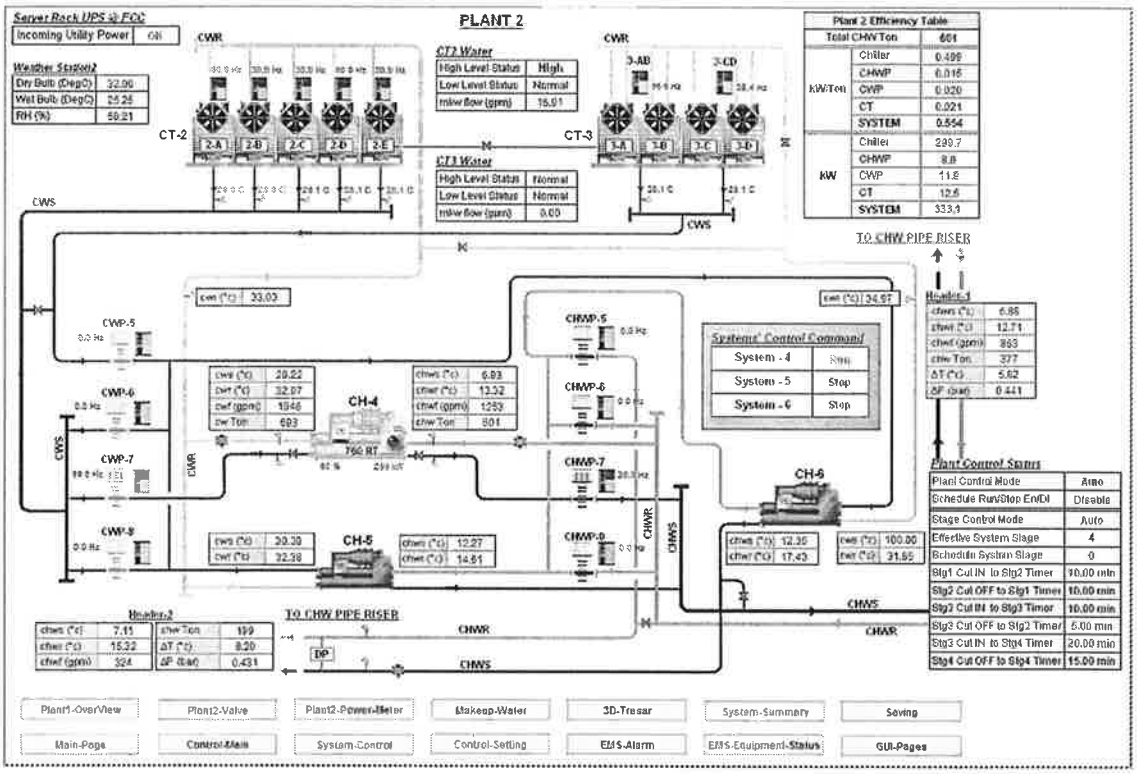
Chiller heat balance

- What is the heat in?
- What is the heat out?
- What is the heat balance error?

System heat balance

- What is the heat in?
- What is the heat out?
- What is the heat balance error?

Example 2



Example 2 continue....

Consistency check

- What is the temperature consistency error?
- What is the flow consistency error?

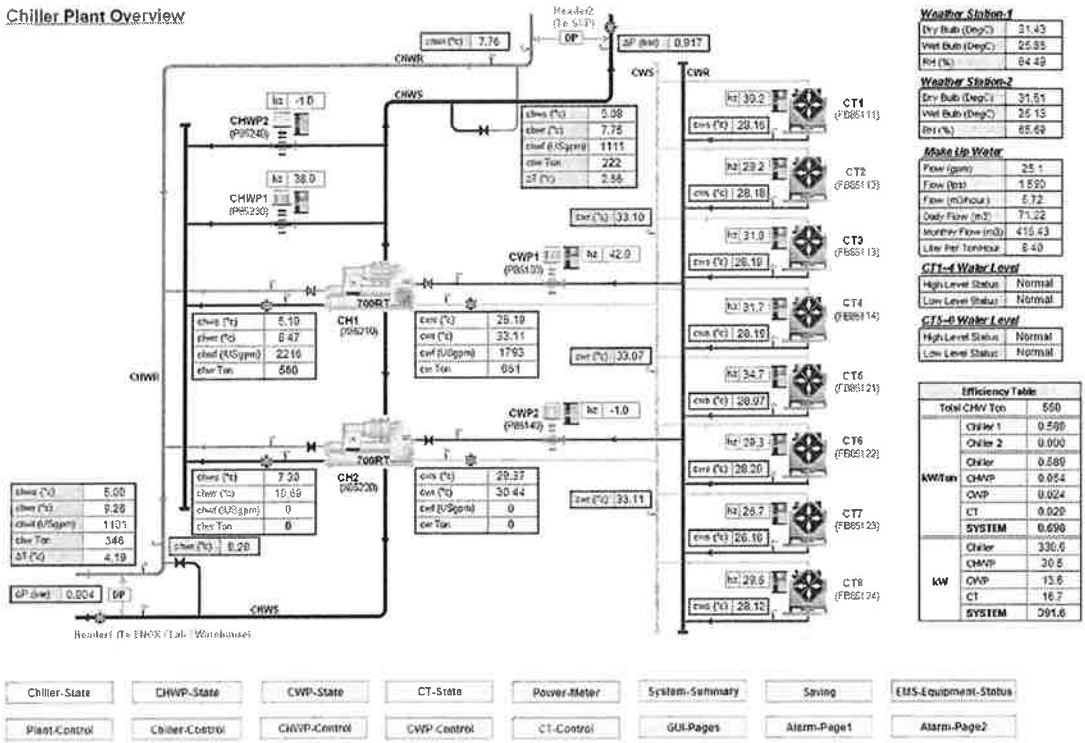
Chiller heat balance

- What is the heat in?
- What is the heat out?
- What is the heat balance error?

System heat balance

- What is the heat in?
- What is the heat out?
- What is the heat balance error?

Example 3



Example 3 continue....

Consistency check

- What is the temperature consistency error?
- What is the flow consistency error?

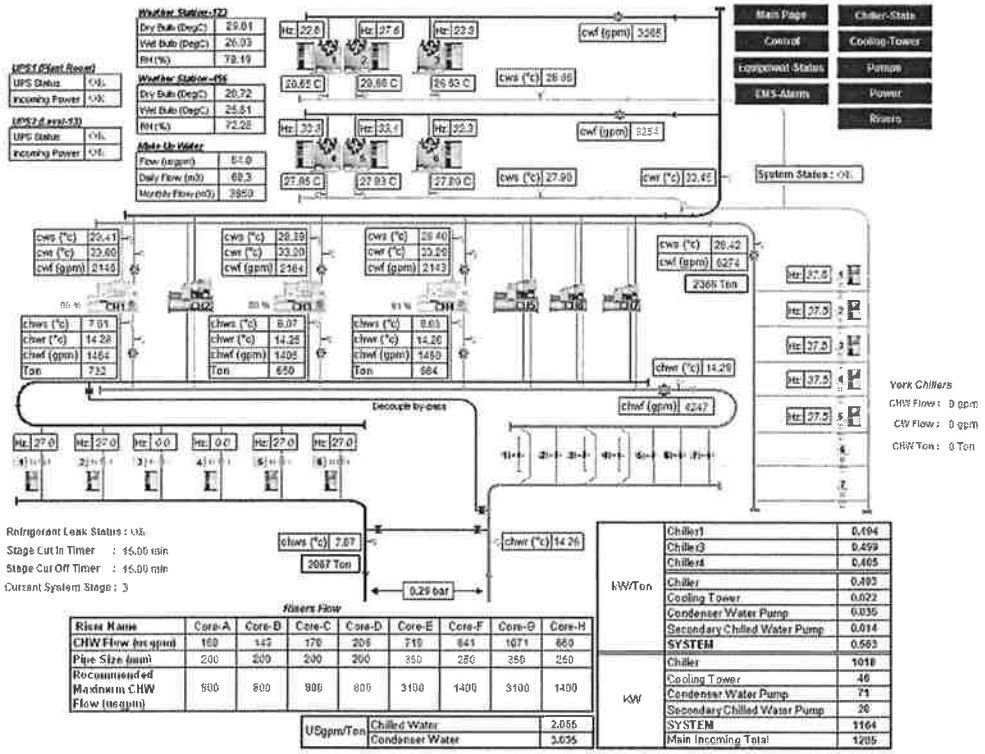
Chiller heat balance

- What is the heat in?
- What is the heat out?
- What is the heat balance error?

System heat balance

- What is the heat in?
- What is the heat out?
- What is the heat balance error?

Example 4



Riser Name	Core-A	Core-B	Core-C	Core-D	Core-E	Core-F	Core-G	Core-H
CHW Flow (in gpm)	160	142	170	206	719	641	1071	660
Pipe Size (mm)	200	200	200	200	350	250	350	250
Recommended Maximum CHW Flow (in gpm)	900	900	900	900	3100	1400	3100	1400

USgpm/Ton	Chilled Water	2.055
	Condenser Water	3.035

kW/Ton	Chiller1	0.494
	Chiller3	0.499
	Chiller4	0.495
	Chiller	0.493
	Cooling Tower	0.022
	Condenser Water Pump	0.035
	Secondary Chilled Water Pump	0.014
	SYSTEM	0.563
kW	Chiller	1018
	Cooling Tower	46
	Condenser Water Pump	71
	Secondary Chilled Water Pump	29
	SYSTEM	1164
	Main Incoming Total	1205

Example 4 continue....

Consistency check

- What is the temperature consistency error?
- What is the flow consistency error?

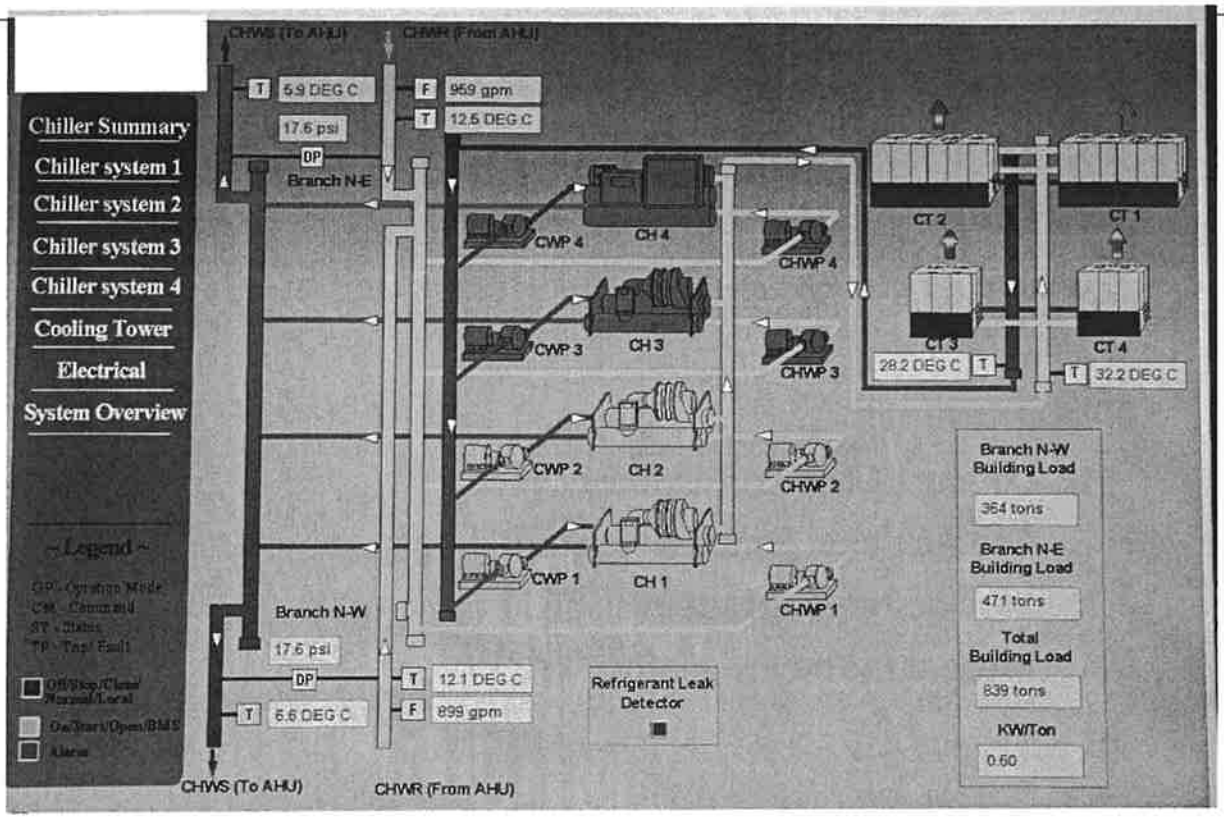
Chiller heat balance

- What is the heat in?
- What is the heat out?
- What is the heat balance error?

System heat balance

- What is the heat in?
- What is the heat out?
- What is the heat balance error?

Example 5



Example 5 continue....

Consistency check

- What is the temperature consistency error?
- What is the flow consistency error?

Chiller heat balance

- What is the heat in?
- What is the heat out?
- What is the heat balance error?
- What additional data is needed to compute heat balance?
- What are the values of the missing data for the heat to balance.

System heat balance

- What is the heat in?
- What is the heat out?
- What is the heat balance error?
- What additional data is needed to compute heat balance?
- What are the values of the missing data for the heat to balance.

Project heat balance assignment

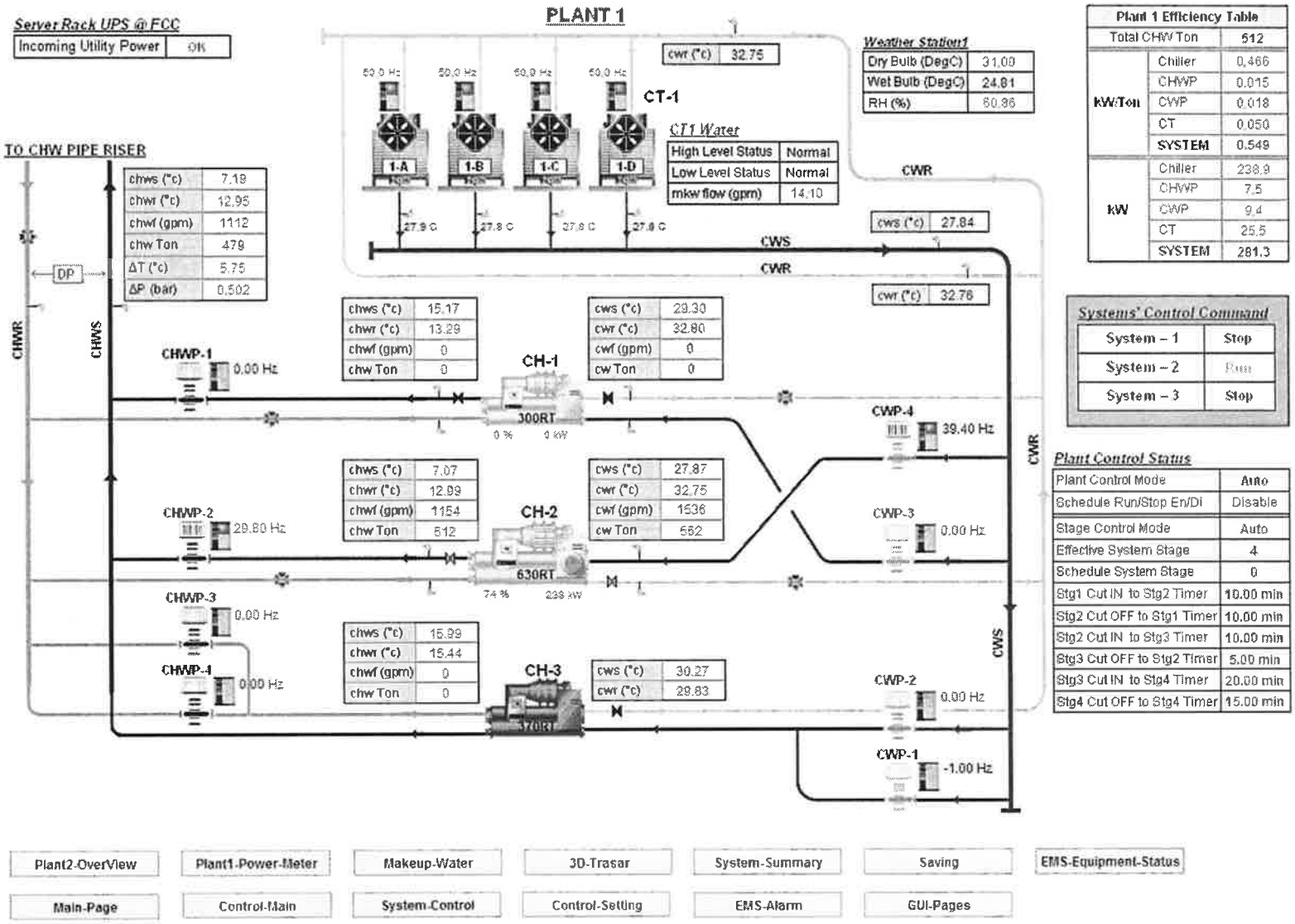
- Each trainee has to successfully complete this assignment to qualify for the certificate of successful completion.
- Two project heat balance exercises will be given out in excel file.
- Assignment:
  1. Conduct M&V consistency check
  2. Conduct heat balance substantiating test
  3. Provide required submission information
  4. Present to the invigilator

Thank You

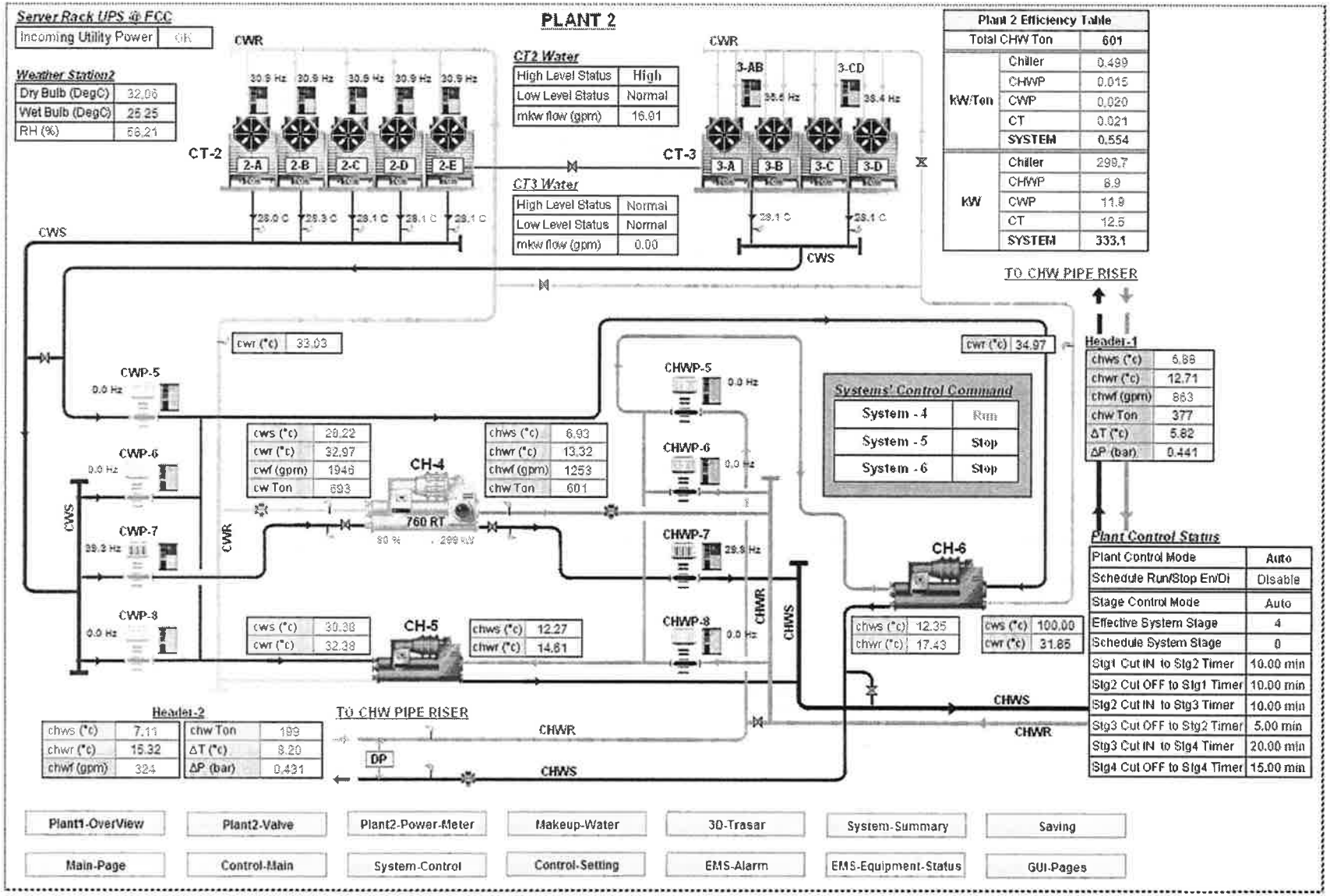
for your attention

Q&A

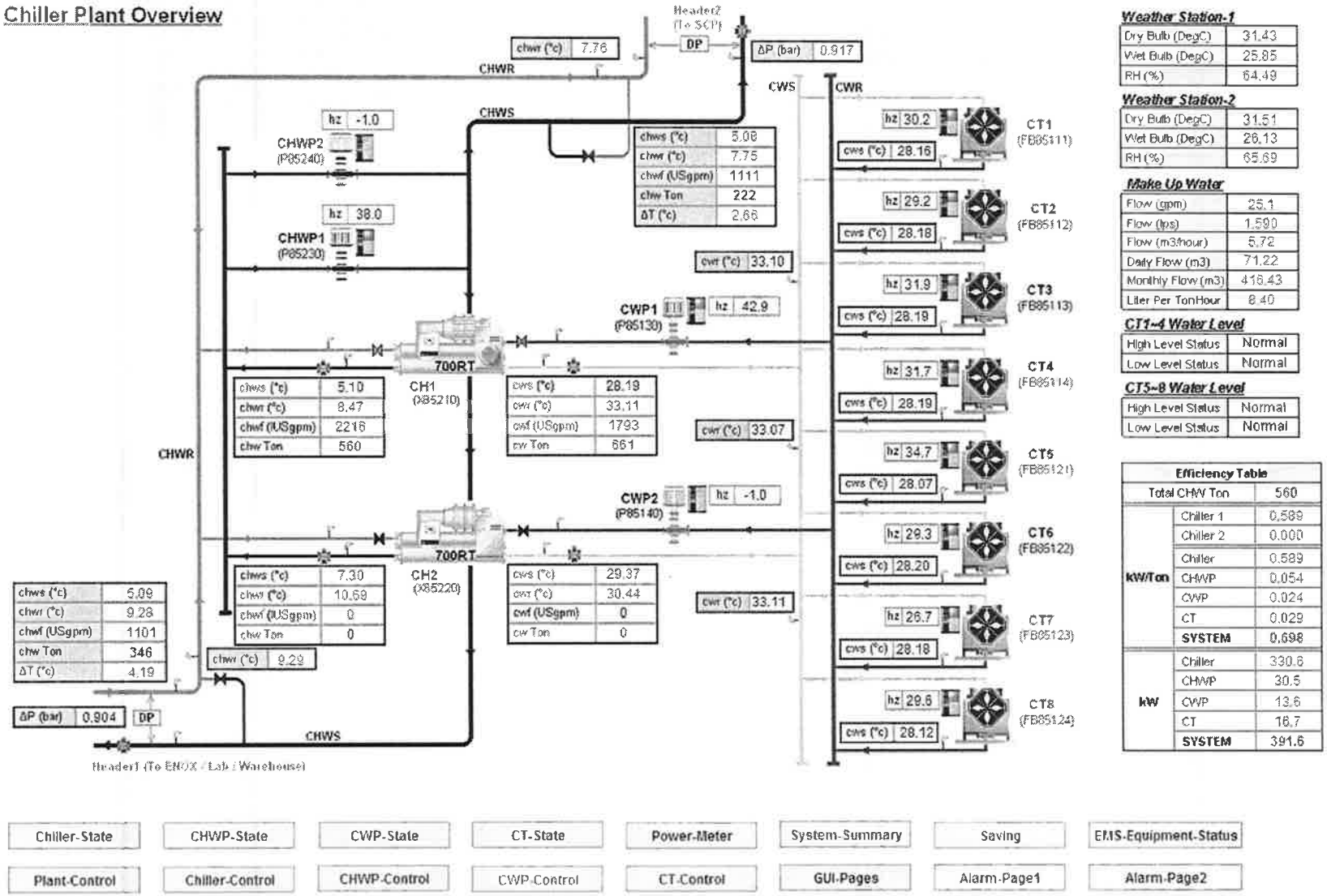
Example 1


Server Rack UPS @ FCC
Incoming Utility Power OK
PLANT 1
cwr (°c) 32.75
Weather Station1
Dry Bulb (DegC) 31.09
Wet Bulb (DegC) 24.81
RH (%) 60.86
CT-1
CT1 Water
High Level Status Normal
Low Level Status Normal
mkw flow (gpm) 14.10
1-A
1-B
1-C
1-D
27.9 C
27.8 C
27.8 C
27.8 C
TO CHW PIPE RISER
chws (°c) 7.19
chwr (°c) 12.95
chwf (gpm) 1112
chw Ton 479
ΔT (°c) 5.75
ΔP (bar) 0.502
DP
CHWR
CHWS
CWR
CWS
cws (°c) 27.84
cwr (°c) 32.76
chws (°c) 15.17
chwr (°c) 13.29
chwf (gpm) 0
chw Ton 0
cws (°c) 29.30
cwr (°c) 32.80
cwf (gpm) 0
cw Ton 0
CHWP-1
0.00 Hz
CH-1
300RT
0 %
0 kW
CWP-4
39.40 Hz
chws (°c) 7.07
chwr (°c) 12.99
chwf (gpm) 1154
chw Ton 512
cws (°c) 27.87
cwr (°c) 32.75
cwf (gpm) 1536
cw Ton 562
CHWP-2
29.80 Hz
CH-2
630RT
74 %
238 kW
CWP-3
0.00 Hz
CHWP-3
0.00 Hz
CHWP-4
0.00 Hz
chws (°c) 15.99
chwr (°c) 15.44
chwf (gpm) 0
chw Ton 0
CH-3
cws (°c) 30.27
cwr (°c) 29.83
CWP-2
0.00 Hz
CWP-1
-1.00 Hz
Plant 1 Efficiency Table
Total CHW Ton 512
kW/Ton Chiller 0.466
kW/Ton CHWP 0.015
kW/Ton CWP 0.018
kW/Ton CT 0.050
kW/Ton SYSTEM 0.549
kW Chiller 238.9
kW CHWP 7.5
kW CWP 9.4
kW CT 25.5
kW SYSTEM 281.3
Systems' Control Command
System – 1 Stop
System – 2 Run
System – 3 Stop
Plant Control Status
Plant Control Mode Auto
Schedule Run/Stop En/Di Disable
Stage Control Mode Auto
Effective System Stage 4
Schedule System Stage 0
Stg1 Cut IN to Stg2 Timer 10.00 min
Stg2 Cut OFF to Stg1 Timer 10.00 min
Stg2 Cut IN to Stg3 Timer 10.00 min
Stg3 Cut OFF to Stg2 Timer 5.00 min
Stg3 Cut IN to Stg4 Timer 20.00 min
Stg4 Cut OFF to Stg4 Timer 15.00 min
Plant2-OverView
Plant1-Power-Meter
Makeup-Water
3D-Trasar
System-Summary
Saving
EMS-Equipment-Status
Main-Page
Control-Main
System-Control
Control-Setting
EMS-Alarm
GUI-Pages

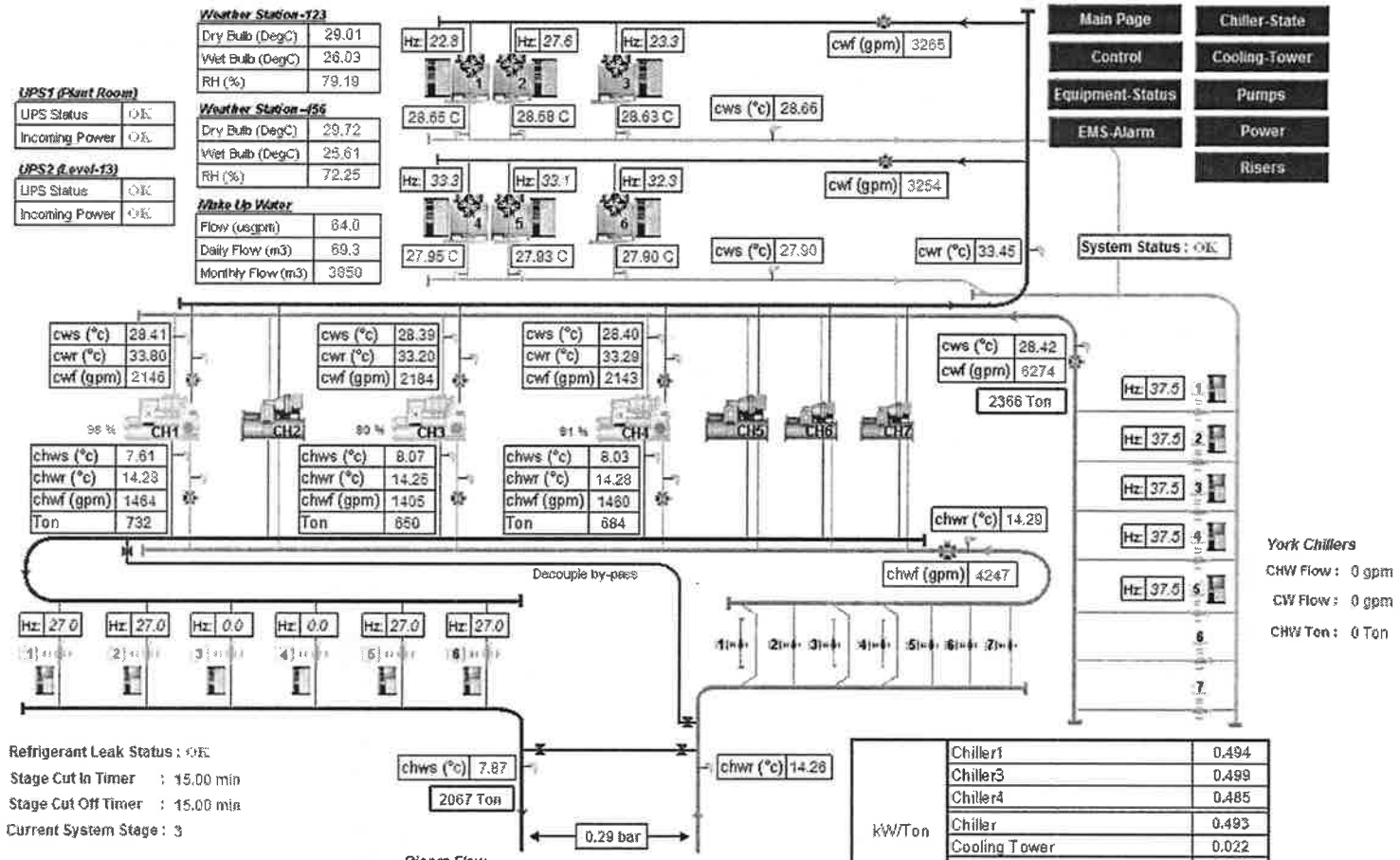
Example 2


PLANT 2
Server Rack UPS @ FCC
Incoming Utility Power OK
Weather Station2
Dry Bulb (DegC) 32.06
Wet Bulb (DegC) 25.25
RH (%) 58.21
CT2 Water
High Level Status High
Low Level Status Normal
mkw flow (gpm) 16.91
CT3 Water
High Level Status Normal
Low Level Status Normal
mkw flow (gpm) 0.00
Plant 2 Efficiency Table
Total CHW Ton 601
kW/Ton Chiller 0.499
CHWP 0.015
CWP 0.020
CT 0.021
SYSTEM 0.554
kW Chiller 299.7
CHWP 8.9
CWP 11.9
CT 12.5
SYSTEM 333.1
CWR
CWS
CT-2
CT-3
2-A
2-B
2-C
2-D
2-E
3-A
3-B
3-C
3-D
3-AB
3-CD
TO CHW PIPE RISER
CWP-5
CWP-6
CWP-7
CWP-8
CHWP-5
CHWP-6
CHWP-7
CHWP-8
cwr (°c) 33.03
cwr (°c) 34.97
cws (°c) 29.22
cwr (°c) 32.97
cwf (gpm) 1946
cw Ton 693
CH-4
760 RT
chws (°c) 6.93
chwr (°c) 13.32
chwf (gpm) 1253
chw Ton 601
Systems' Control Command
System - 4 Run
System - 5 Stop
System - 6 Stop
Header-1
chws (°c) 6.86
chwr (°c) 12.71
chwf (gpm) 863
chw Ton 377
ΔT (°c) 5.82
ΔP (bar) 0.441
CH-6
chws (°c) 12.35
chwr (°c) 17.43
cws (°c) 100.00
cwr (°c) 31.85
CH-5
cws (°c) 30.38
cwr (°c) 32.39
chws (°c) 12.27
chwr (°c) 14.61
Plant Control Status
Plant Control Mode Auto
Schedule Run/Stop En/Di Disable
Stage Control Mode Auto
Effective System Stage 4
Schedule System Stage 0
Stg1 Cut IN to Stg2 Timer 10.00 min
Stg2 Cut OFF to Stg1 Timer 10.00 min
Stg2 Cut IN to Stg3 Timer 10.00 min
Stg3 Cut OFF to Stg2 Timer 5.00 min
Stg3 Cut IN to Stg4 Timer 20.00 min
Stg4 Cut OFF to Stg4 Timer 15.00 min
Header-2
chws (°c) 7.11
chwr (°c) 15.32
chwf (gpm) 324
chw Ton 199
ΔT (°c) 8.20
ΔP (bar) 0.431
TO CHW PIPE RISER
CHWR
CHWS
DP
CHWS
CHWR
Plant1-OverView
Plant2-Valve
Plant2-Power-Meter
Makeup-Water
3D-Trasar
System-Summary
Saving
Main-Page
Control-Main
System-Control
Control-Setting
EMS-Alarm
EMS-Equipment-Status
GUI-Pages

Example 3


Chiller Plant Overview
Header2 (To SCP)
chwr (°c) 7.76
DP
ΔP (bar) 0.917
CHWR
CWS
CWR
CHWS
hz -1.0
CHWP2 (P85240)
hz 38.0
CHWP1 (P85230)
chws (°c) 5.08
chwr (°c) 7.75
chwf (USgpm) 1111
chw Ton 222
ΔT (°c) 2.66
cwr (°c) 33.10
CWP1 (P85130)
hz 42.9
700RT
CH1 (X85210)
chws (°c) 5.10
chwr (°c) 8.47
chwf (USgpm) 2216
chw Ton 560
cws (°c) 28.19
cwr (°c) 33.11
cwf (USgpm) 1793
cw Ton 661
cwr (°c) 33.07
CWP2 (P85140)
hz -1.0
700RT
CH2 (X85220)
chws (°c) 7.30
chwr (°c) 10.69
chwf (USgpm) 0
chw Ton 0
cws (°c) 29.37
cwr (°c) 30.44
cwf (USgpm) 0
cw Ton 0
cwr (°c) 33.11
chws (°c) 5.09
chwr (°c) 9.28
chwf (USgpm) 1101
chw Ton 346
ΔT (°c) 4.19
chwr (°c) 9.29
ΔP (bar) 0.904
DP
CHWS
Header1 (To ENOX / Lab / Warehouse)
CT1 (FB85111)
hz 30.2
cws (°c) 28.16
CT2 (FB85112)
hz 29.2
cws (°c) 28.18
CT3 (FB85113)
hz 31.9
cws (°c) 28.19
CT4 (FB85114)
hz 31.7
cws (°c) 28.19
CT5 (FB85121)
hz 34.7
cws (°c) 28.07
CT6 (FB85122)
hz 29.3
cws (°c) 28.20
CT7 (FB85123)
hz 26.7
cws (°c) 28.18
CT8 (FB85124)
hz 29.6
cws (°c) 28.12
Weather Station-1
Dry Bulb (DegC) 31.43
Wet Bulb (DegC) 25.85
RH (%) 64.49
Weather Station-2
Dry Bulb (DegC) 31.51
Wet Bulb (DegC) 26.13
RH (%) 65.69
Make Up Water
Flow (gpm) 25.1
Flow (lps) 1.590
Flow (m3/hour) 5.72
Daily Flow (m3) 71.22
Monthly Flow (m3) 418.43
Liter Per TonHour 8.40
CT1~4 Water Level
High Level Status Normal
Low Level Status Normal
CT5~8 Water Level
High Level Status Normal
Low Level Status Normal
Efficiency Table
Total CHW Ton 560
kW/Ton
Chiller 1 0.589
Chiller 2 0.000
Chiller 0.589
CHWP 0.054
CWP 0.024
CT 0.029
SYSTEM 0.698
kW
Chiller 330.6
CHWP 30.5
CWP 13.6
CT 16.7
SYSTEM 391.6
Chiller-State
CHWP-State
CWP-State
CT-State
Power-Meter
System-Summary
Saving
EMS-Equipment-Status
Plant-Control
Chiller-Control
CHWP-Control
CWP-Control
CT-Control
GUI-Pages
Alarm-Page1
Alarm-Page2

Example 4



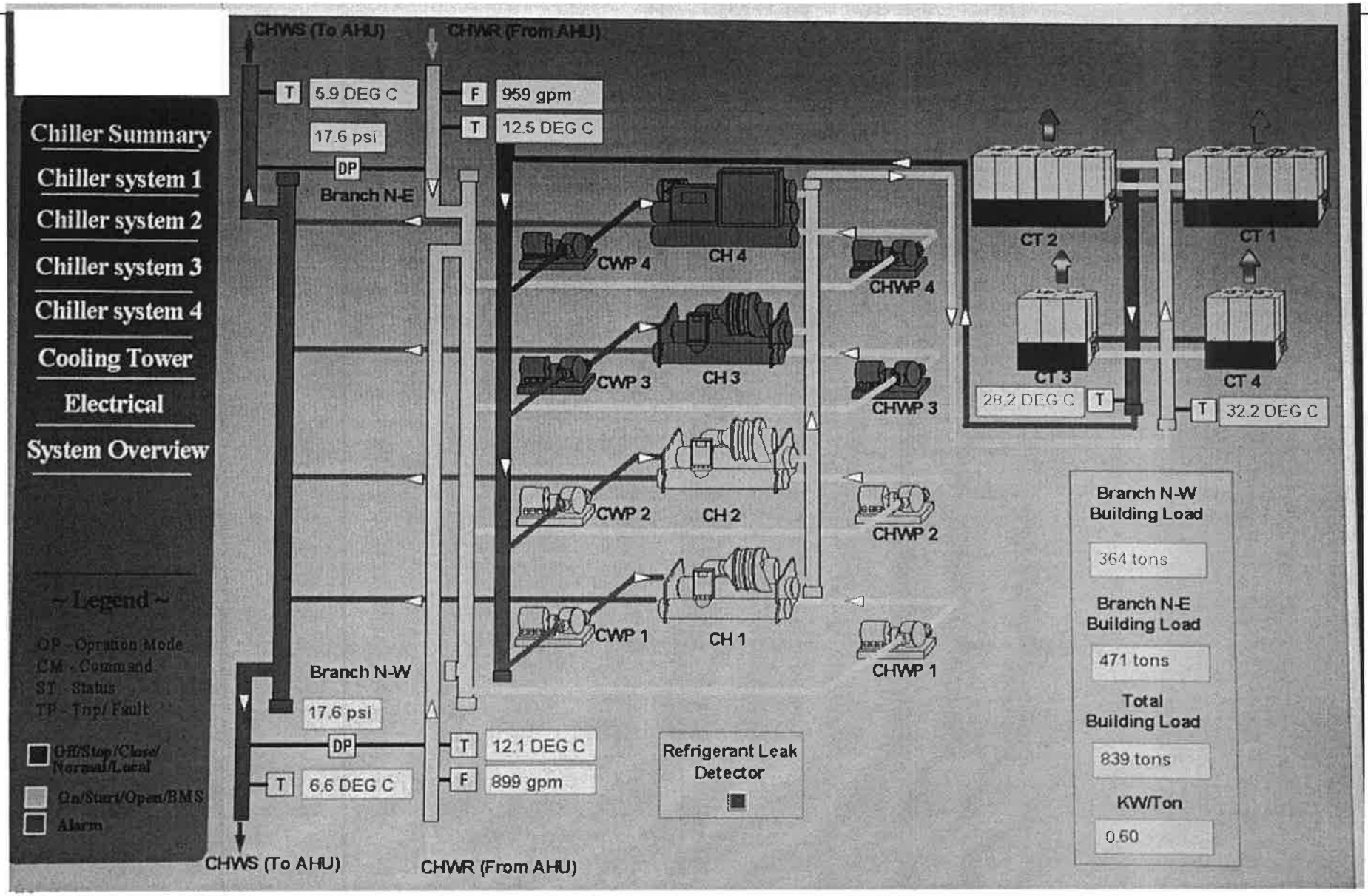
Risers Flow

Riser Name	Core-A	Core-B	Core-C	Core-D	Core-E	Core-F	Core-G	Core-H
CHW Flow (us gpm)	168	143	179	206	719	641	1071	660
Pipe Size (mm)	200	200	200	200	350	250	350	250
Recommended Maximum CHW Flow (usgpm)	800	800	800	800	3100	1400	3100	1400

USgpm/Ton	Chilled Water	2.055
	Condenser Water	3.035

kW/Ton	Chiller1	0.494
	Chiller3	0.499
	Chiller4	0.485
	Chiller	0.493
	Cooling Tower	0.022
	Condenser Water Pump	0.035
	Secondary Chilled Water Pump	0.014
	SYSTEM	0.563
kW	Chiller	1018
	Cooling Tower	46
	Condenser Water Pump	71
	Secondary Chilled Water Pump	28
	SYSTEM	1164
	Main Incoming Total	1205

Example 5


Chiller Summary
Chiller system 1
Chiller system 2
Chiller system 3
Chiller system 4
Cooling Tower
Electrical
System Overview
~ Legend ~
OP - Operation Mode
CM - Command
ST - Status
TP - Trip/ Fault
Off/Stop/Close/ Normal/Local
On/Start/Open/BMS
Alarm
CHWS (To AHU)
CHWR (From AHU)
T 5.9 DEG C
17.6 psi
DP
Branch N-E
F 959 gpm
T 12.5 DEG C
CWP 4
CH 4
CHWP 4
CWP 3
CH 3
CHWP 3
CWP 2
CH 2
CHWP 2
CWP 1
CH 1
CHWP 1
CT 2
CT 1
CT 3
CT 4
28.2 DEG C
T
T 32.2 DEG C
Branch N-W
17.6 psi
DP
T 6.6 DEG C
T 12.1 DEG C
F 899 gpm
Refrigerant Leak Detector
Branch N-W Building Load
364 tons
Branch N-E Building Load
471 tons
Total Building Load
839 tons
KW/Ton
0.60
CHWS (To AHU)
CHWR (From AHU)

Mandatory Periodic Energy Audit of Building Cooling System

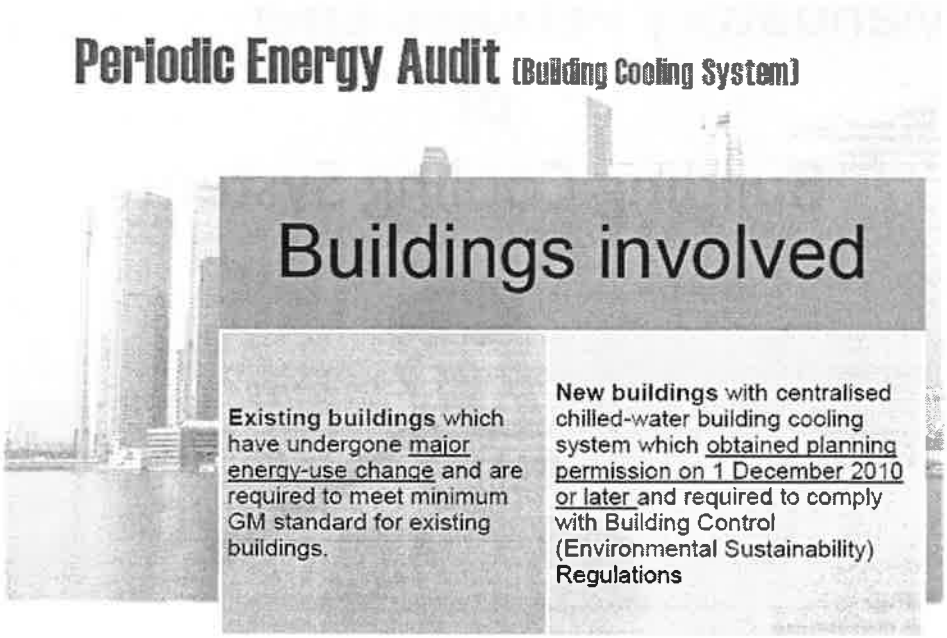


Steven Kang
GMP, SCEM, US CEM, LEED AP
steven.kang.bl@gmail.com

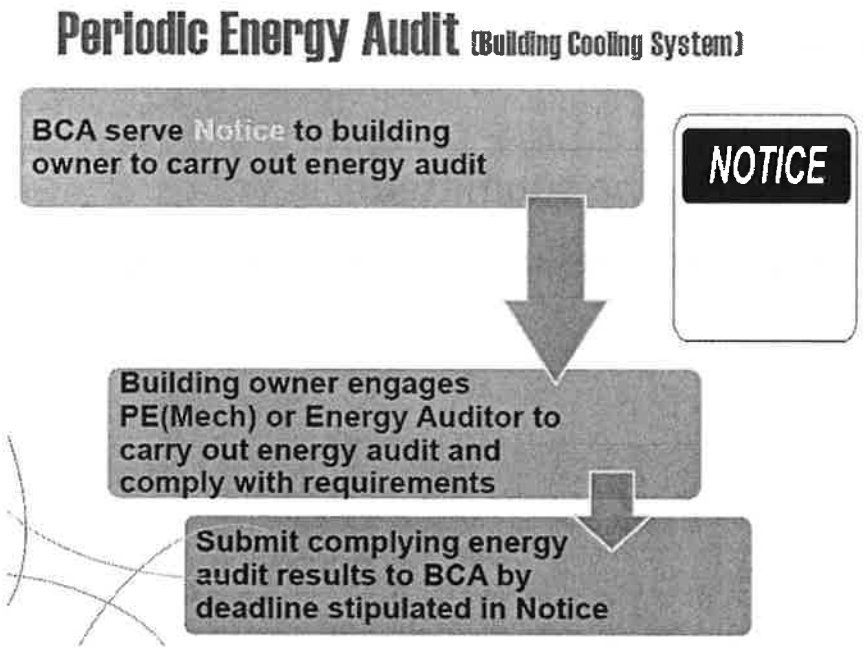
Agenda

1. Scope of legislation
2. Process
3. Requirements
4. Documents to be submitted
5. Hands-on exercise in preparing audit report

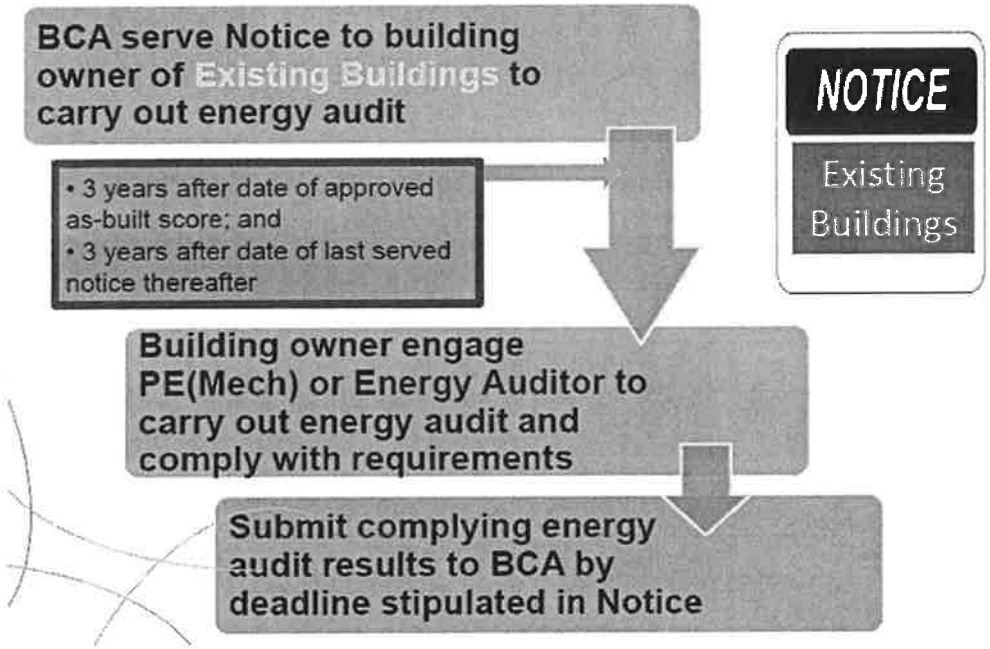
Buildings Involved



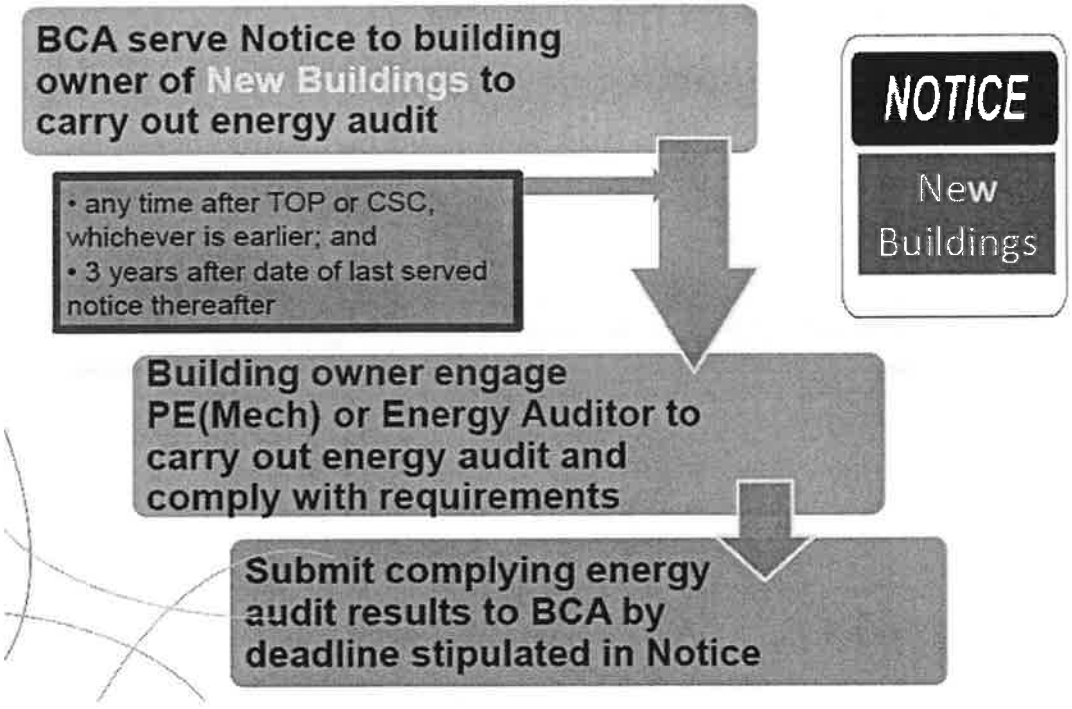
Periodic Energy Audit Process



Requirements for Existing Buildings



Requirements for New Buildings



Minimum Operating System Efficiency

For Buildings using **Water-Cooled Chilled-Water Plant**				
	New Buildings		Existing Buildings	
	Building Cooling Load (RT)			
	< 500	≥ 500	< 500	≥ 500
Minimum OSE, (kW/RT)	0.80	0.70	0.85	0.75

Operating Period

Performance shall be reported for

- 1 week of continuous operation
- At 1 minute interval
- Operating hours:

Normal Building Operating Period for Energy Audit Report Submission	
Office Building	**Hotels**
Monday to Friday: 9am to 6pm	Monday to Sunday: 24 hours
	[Day time 7am – 11pm]
	[Night time 11pm – 7am]
Retail Malls	**Other building types**
Monday to Sunday: 10am to 9pm	To be determined based on the operating hours

Documents to be submitted

Documents to be submitted (via CORENET)

1. BCA's notice for the submission
2. As-built drawings (to scale) & schematic drawings of chiller plant room indicating instrumentation location
3. 1 week raw data in excel format include all the chart plots (in accordance with Periodic Energy Audit Code – Annex B)
4. Energy Audit report (Periodic Energy Audit Code – Annex B)

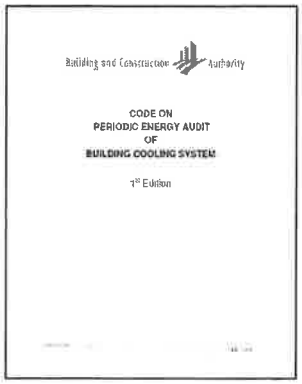
Periodic Energy Audit Report Format

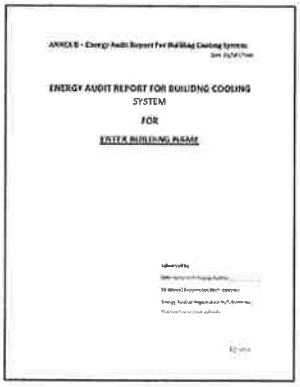
- Annex B

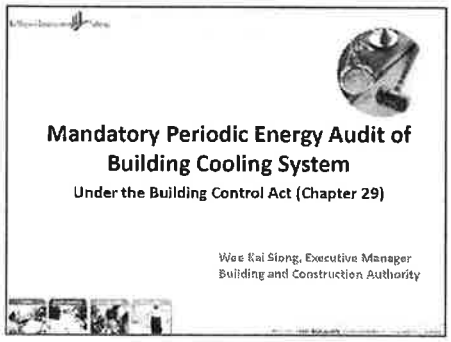


Periodic Energy Audit Report

Useful Information







https://www.bca.gov.sg/envsuslegislation/existing_building_legislation.html

Exercise in preparing periodic audit report

Important Excel tools/commands to be familiar

1. Count
2. Countif
3. Plotting of line chart
4. Plotting of scatter chart
5. Plotting of histogram

ANNEX B – Energy Audit Report For Building Cooling System

Date: DD/MM/YEAR

ENERGY AUDIT REPORT FOR BUILIDNG COOLING SYSTEM

FOR

ENTER BUILDING NAME

Submitted By

Enter name of PE/Energy Auditor

PE (Mech) Registration No*: Enter No.

Energy Auditor Registration No*: Enter No.

*Delete whichever is not applicable

Contents

1.0 Building Information 3

2.0 Energy Audit Information For Building Cooling System 3

2.1 Chilled Water Plant information* 4

2.2 Chilled Water Plant Normal Operating Hours 5

3.0 Instrumentations 5

4.0 Chiller Plant Performance Analysis 6

4.1 Summary of Chilled Water Plant Performance 8

5.0 Summary of Heat Balance 8

Table 1: Chiller Information (Example) 4

Table 2: Ancillary equipment Information (Example) 4

Table 3: Instrumentation Table (Example) 5

Table 4: Heat Balance Summary 9

Figure 1: Super-imposed plot of daily Cooling Load Profile (Example) 6

Figure 2: Histogram of Cooling Load Occurrences (Example) 6

Figure 3:Super-imposed plot of daily chiller plant efficiency (Example) 7

Figure 4: Scatter plot of chiller plant efficiency over cooling load (Example) 7

Figure 5: System Level Heat Balance Plot (Example) 8

Ctrl - Shift ↓

1.0 Building Information

Enter a brief description of the building here.

Project Reference Number	:	Enter project reference indicated in CORENET submission
Building Name	:	
Building Address	:	
Postal Code	:	
Building Type	:	
Building Age	:	
Date of last Energy Audit Submission	:	
Gross floor area (GFA), m^2	:	
Air conditioned area, m^2	:	

2.0 Energy Audit Information For Building Cooling System

Enter PE(Mech)(Mechanical)/ Energy Auditor Name was appointed by Enter Owner Name/ MCST, owner of Enter Building Name to be the Energy Auditor for the 3 yearly submission of the operating system efficiency (OSE) of the centralized Chilled Water Plant. The report will present the performance of centralized Chilled Water Plant efficiency based on the measurements from the permanent instrumentations installed on site.

Location	:	Enter location of Chilled Water Plant
Energy Audit Period	:	Enter Energy Audit period *Note: Minimum 1 week
Date of notice served	:	Enter date of notice served by BCA
Date of submission in notice	:	Enter submission deadline stipulated in BCA notice
Data Logging Interval	:	1 minute sampling
Trend Logged Parameters*	:	Chilled Water Supply main header temperature
		Chilled Water Return main header temperature
		Chilled Water flow rate at chilled water return main header

Condenser Water Supply main header temperature

Condenser Water Return main header temperature

Condenser water flow rate at condenser water return main header

Power input to Chiller(s)

Power input to Chilled water pump(s)

Power input to Condenser water pump(s)

Power input to Cooling tower(s)

**** Trend logged parameters are not limited to the above and may vary depending on the piping and electrical circuit design.***

2.1 Chilled Water Plant information*

ID	Description	Type	Name plate motor (kW)	Cooling Capacity (RT)	Chilled water LWT	Chilled water ΔT	Rated Efficiency kW/RT	Year Installed
CH01	Chiller 1	Centrifugal	150	1000	6.7 °C	5.5°C	0.55	2012
CH02	Chiller 2	VSD Screw	90	500	6.7 °C	5.5°C	0.52	2012

Table 1: Chiller Information (Example)

ID	Description	Name plate motor (kW)	Pump Head (m)	Flow rate (L/S)	Rated Pump/ Fan efficiency	Rated Motor Efficiency
CHWP01	Chilled water pump 1	55	30	151.2	85%	95%
CHWP02	Chilled water pump 2	30	30	75.6	85%	95%
CWP01	Condenser water pump 1	45	20	189	85%	95%
CWP02	Condenser water pump 2	22	20	94.5	85%	95%
CT01	Cooling tower 1	45	-	130	75%	92%
CT02	Cooling tower 2	45	-	130	75%	92%

Table 2: Ancillary equipment Information (Example)

****Based on equipment design specifications and name plate ratings.***

2.2 Chilled Water Plant Normal Operating Hours

Monday to Friday	:	0730 – 1900 Hrs
Saturday	:	No operations
Sunday	:	No operations

Note: The operating hours should follow the table in clause 6.1.4

3.0 Instrumentations

Accurate measuring instruments complying with the Code on Environmental Sustainability Measures for Existing Buildings or the Code for Environmental Sustainability of Buildings (2nd edition and onwards) that is prevailing at the time of installation were used during the audit to gather information on the power consumption, temperatures and flow rate.

The points of measurements are listed in the following table:

ID	Description	Sensor Type	Installation Location	Measurement/ Calibration range	Measurement Uncertainty (%)	Last Calibration Date
TT01	CHWS Temperature	10K Ω Thermistor	CHWS Header	0°C - 40°C	±0.03 °C	15/10/2012
TT02	CHWR Temperature	10K Ω Thermistor	CHWR Header	0°C - 40°C	±0.03 °C	15/10/2012
TT03	CWS Temperature	10K Ω Thermistor	CWS Header	0°C - 40°C	±0.03 °C	15/10/2012
TT04	CWR Temperature	10K Ω Thermistor	CWR Header	0°C - 40°C	±0.03 °C	15/10/2012
FM01	CHW Flow	Magnetic Full Bore	CHWR Header	30 l/s- 200 l/s	0.5%	20/10/2012
FM02	CW Flow	Magnetic Full Bore	CWR Header	30 l/s- 200 l/s	0.5%	20/10/2012
kW01	Chiller 1 Power	True RMS, 3 phase	ACMSB1	60 – 600 kW	0.5%	30/10/2012
kW02	Chiller 2 Power	True RMS, 3 phase	ACMSB2	60 – 600 kW	0.5%	30/10/2012
kW03	CHW Pump 1 & 2 Power	True RMS, 3 phase		20 – 200 kW	0.5%	30/10/2012
kW04	CW Pump 1 & 2 Power	True RMS, 3 phase	CHW SB	20 – 200 kW	0.5%	30/10/2012
kW05	CT 1 & 2 Power	True RMS, 3 phase	CT Panel	15 – 150 kW	0.5%	30/10/2012

Table 3: Instrumentation Table (Example)

4.0 Chiller Plant Performance Analysis

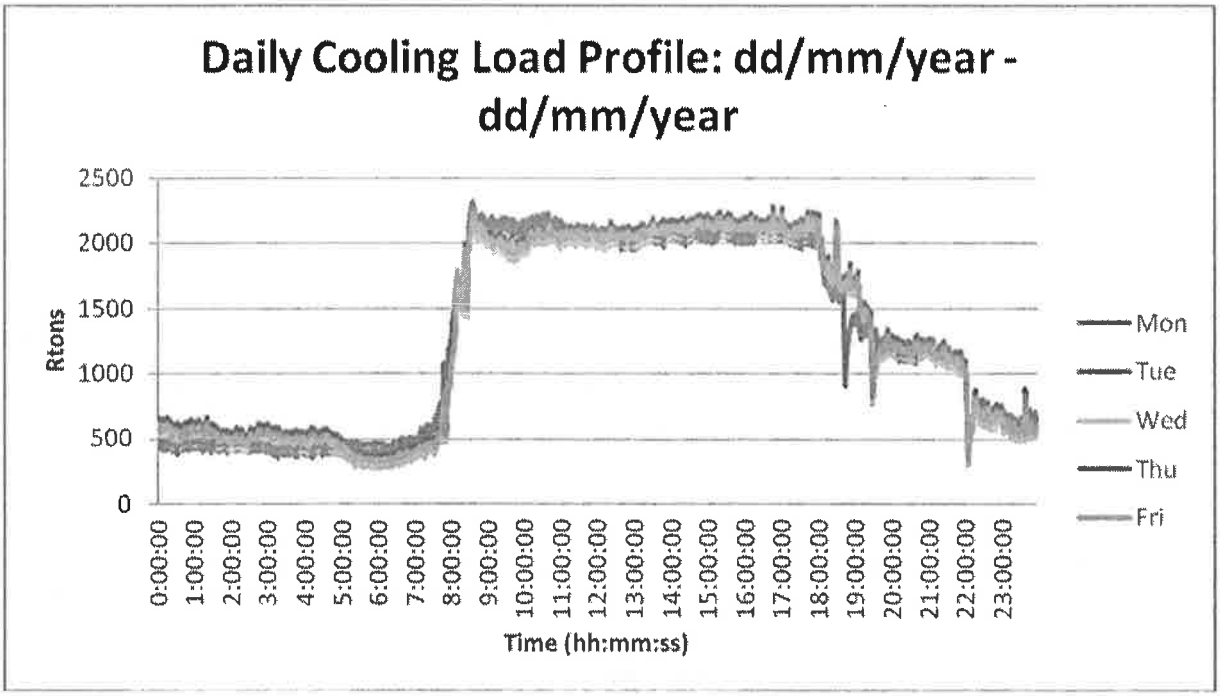


Figure 1: Super-imposed plot of daily Cooling Load Profile (Example)

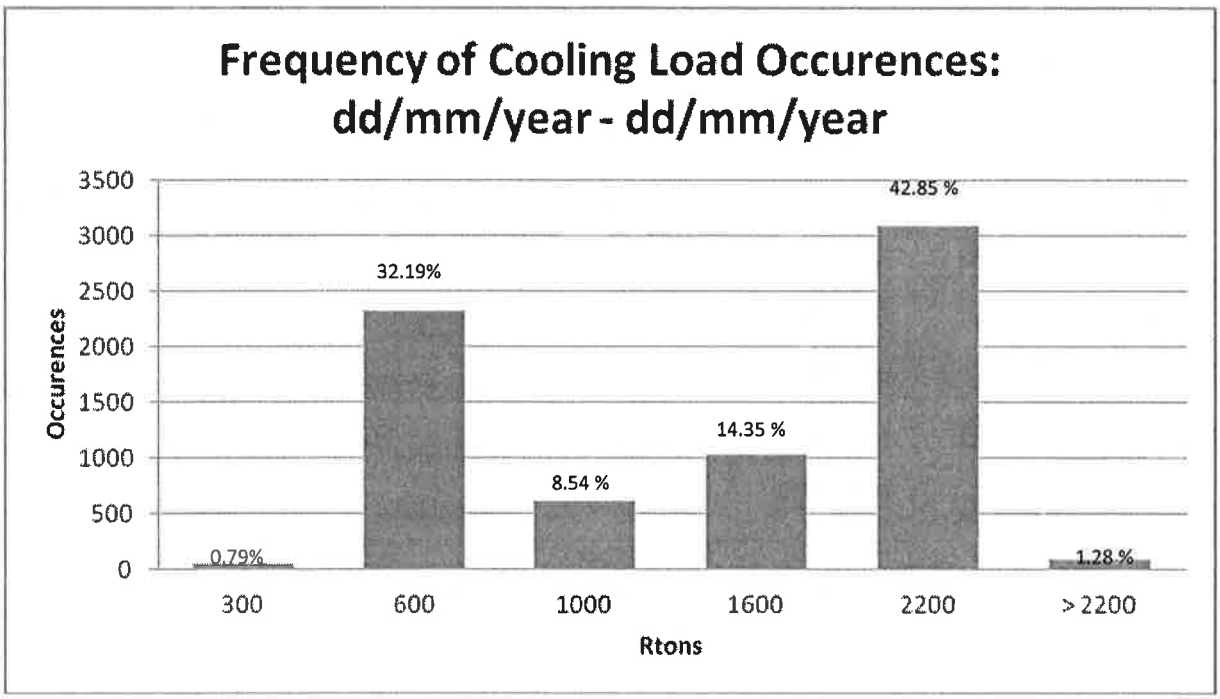


Figure 2: Histogram of Cooling Load Occurrences (Example)

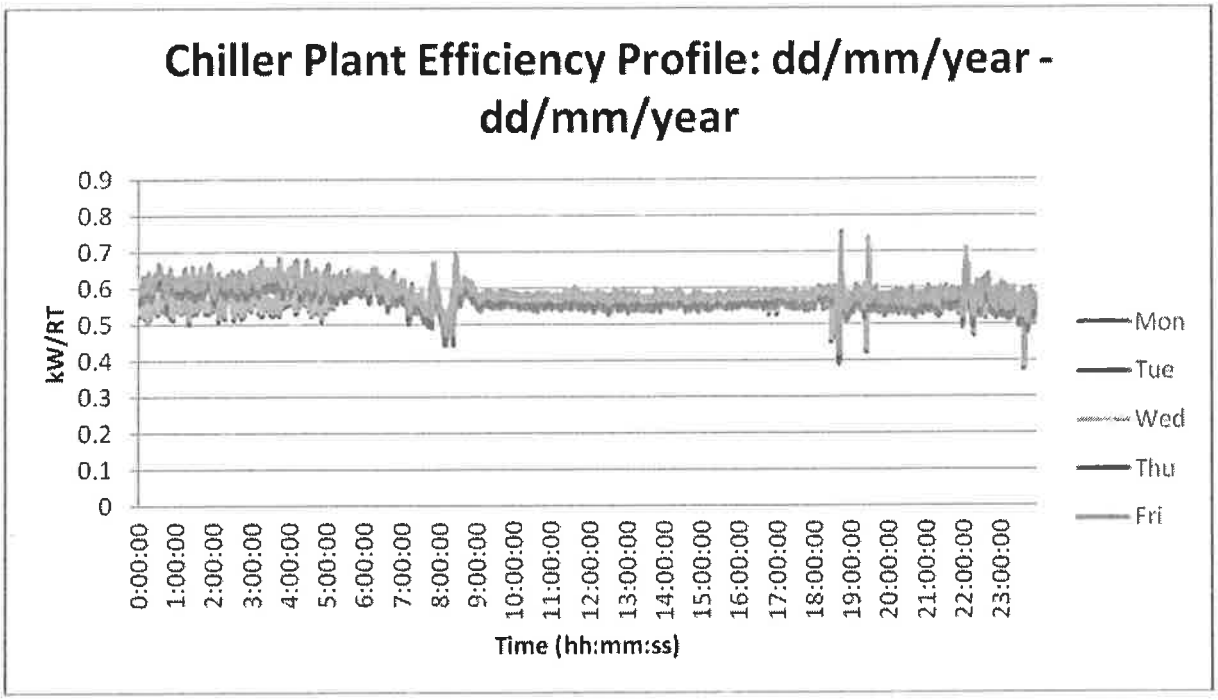


Figure 3:Super-imposed plot of daily chiller plant efficiency (Example)

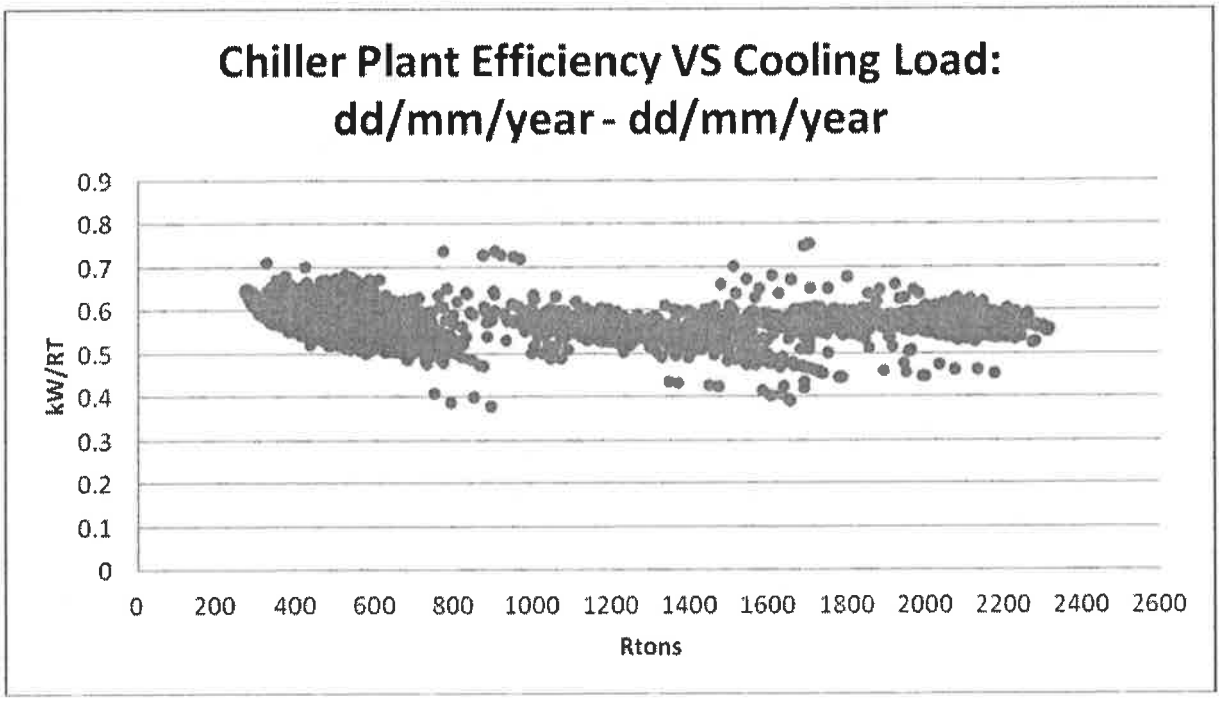


Figure 4: Scatter plot of chiller plant efficiency over cooling load (Example)

Ctrl + Shift + Arrow

→ select entire row

F4 is "#" sign (absolute position)

4.1 Summary of Chilled Water Plant Performance

	Efficiency		Unit
	Daytime^	Night-time~	
Chiller(s) efficiency			kW/RT
Chilled water pump(s) efficiency			kW/RT
Condenser water pump(s) efficiency*			kW/RT
Cooling tower(s) efficiency*			kW/RT
Overall chiller plant efficiency			kW/RT

*Not applicable to air-cooled Chilled Water Plant

~For hotels and other developments with 24-hour operations only; Night-time shall refer to the period from 11pm – 7am;

^ For hotels and other developments with 24-hour operations, day-time shall refer to the period from 7am – 11pm; for all other developments, daytime shall refer to the normal operating hours stipulated in clause 6.1.4

5.0 Summary of Heat Balance

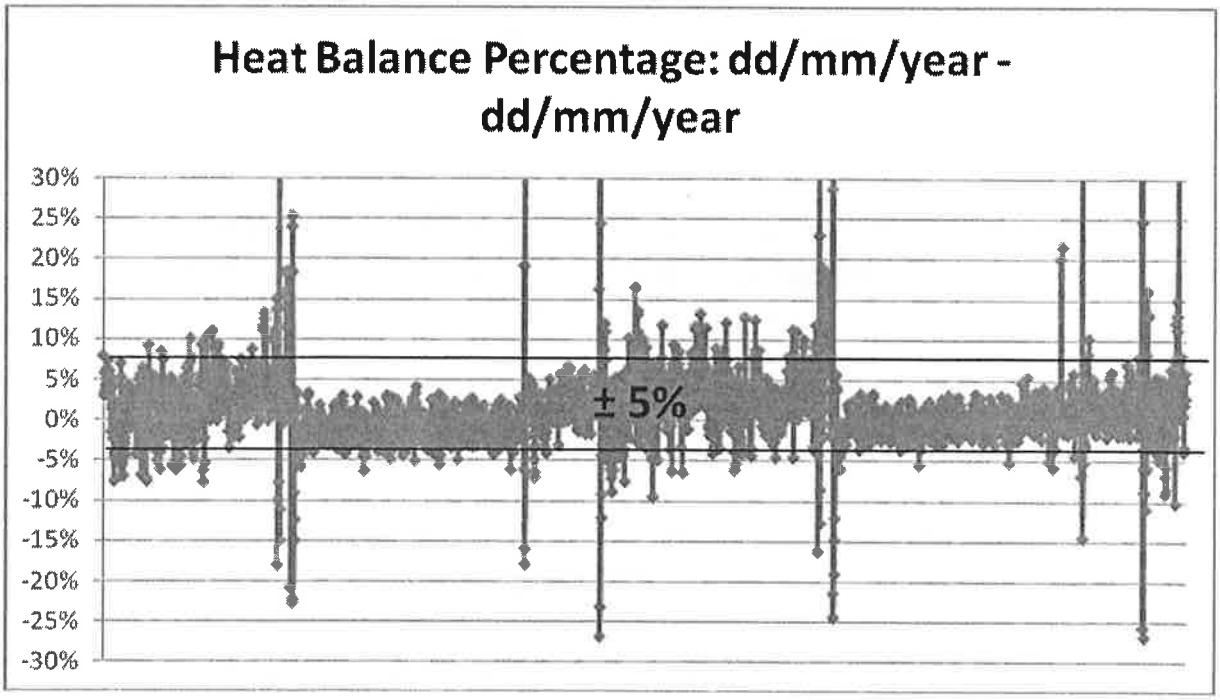


Figure 5: System Level Heat Balance Plot (Example)

RT1 fRT~

	Quantity	Unit	Formula
Sum of total electrical energy used		kWh	(A)
Sum of total cooling produced		RTh	(B)
Sum of total heat rejected		RTh	(C)
Chiller Plant Efficiency		kW/RT	(A) / (B)
Total Heat Balance Data Count		-	(D)
Data Count > + 5% error		-	(E)
Data Count < - 5% error		-	(F)
Data Count within ±5% error		-	(G) = (D) – (E) – (F)
% Heat Balance within ±5% error		%	100 x (G) / (D)

Table 4: Heat Balance Summary

2 Pump + Chiller + CT

CHW Load (kW) | CHW Load (RT) | CW Load (kW) | CW Load (RT) | Total Chilled Plant Power (kW) | CP Efficiency (kW/RT)

Heat In / Heat Out | HB Error

Chiller Power + Chiller Load

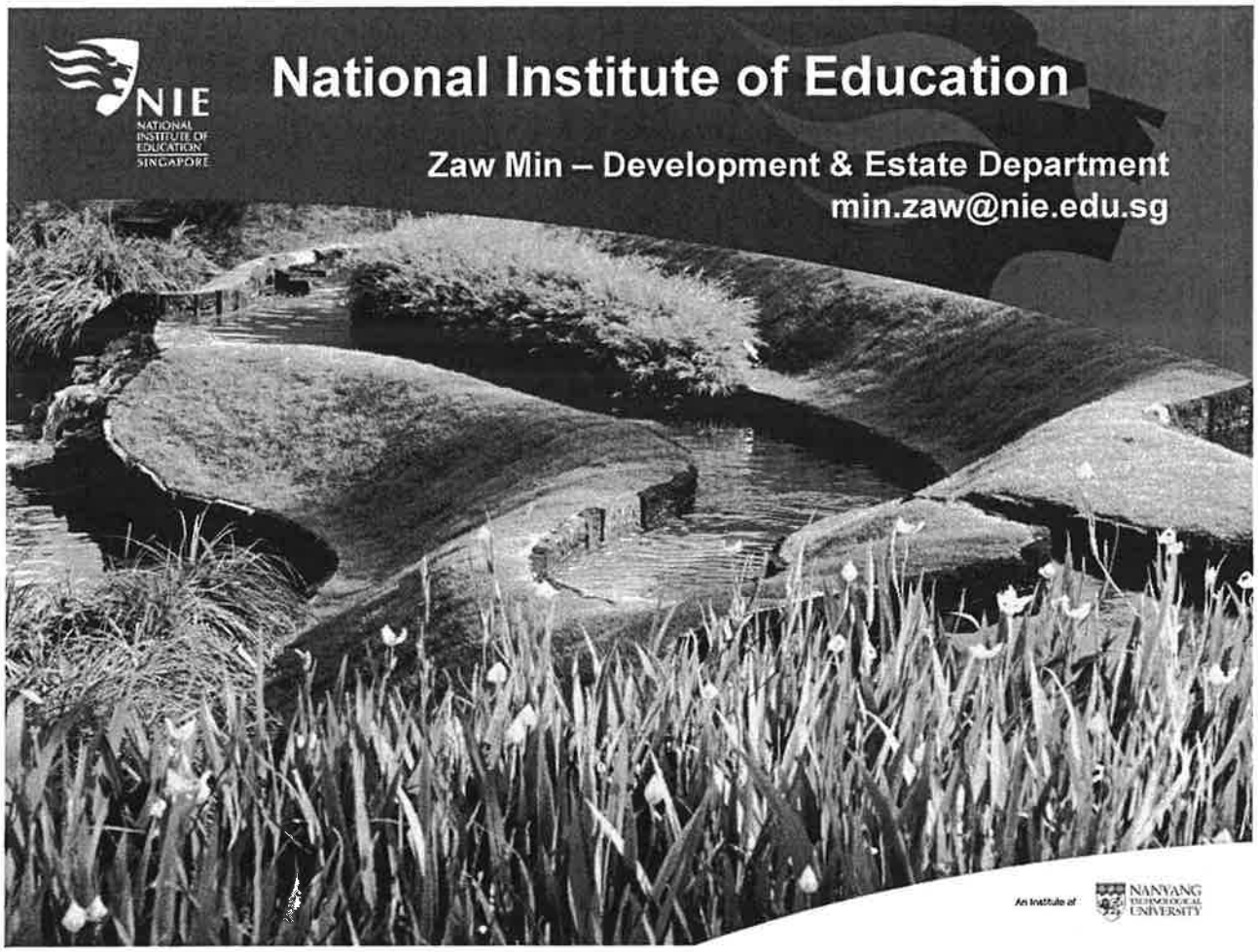
@ Count

@ countif > 5%

@ countif < -5%

Formulas → more functions

" >50% "



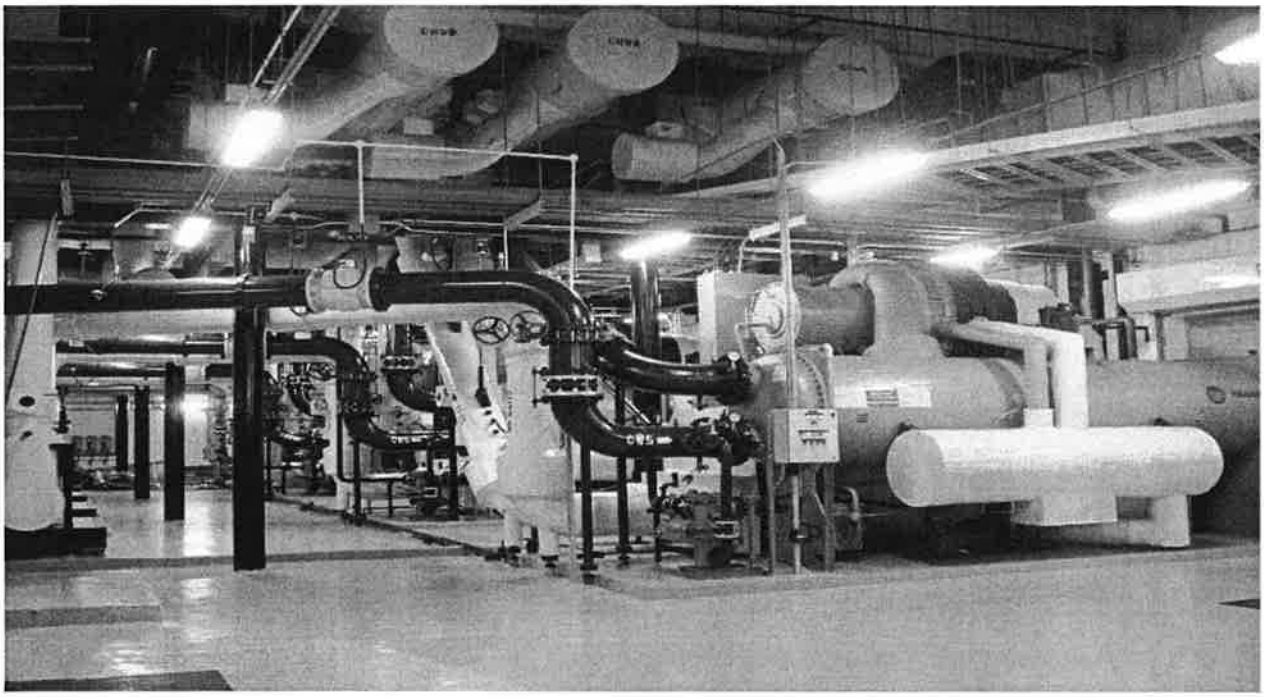
NIE CHILLER PLANT UPGRADE WORKS

BEFORE (01/07/2011)



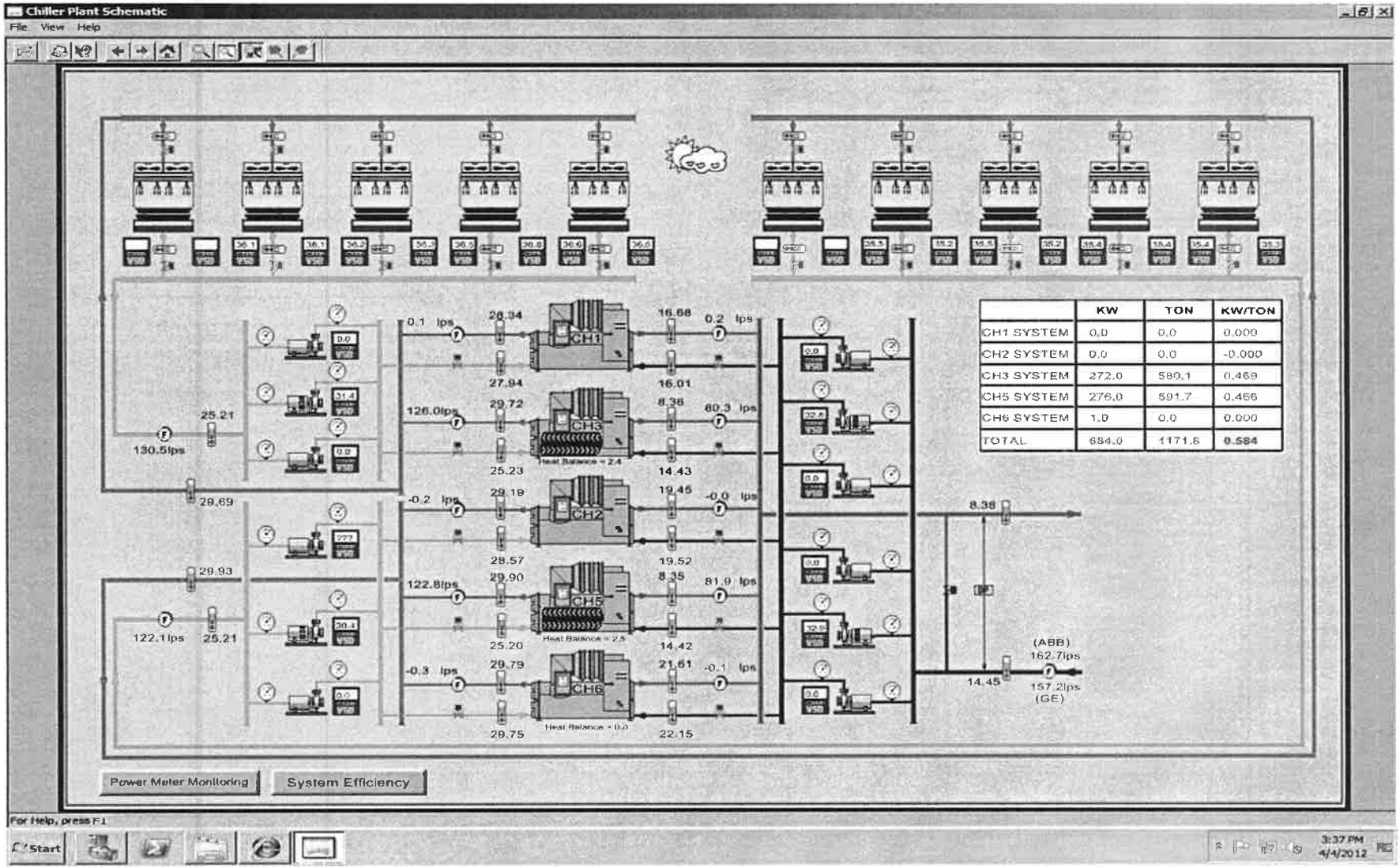
NIE CHILLER PLANT UPGRADE WORKS

AFTER (28/02/2012)



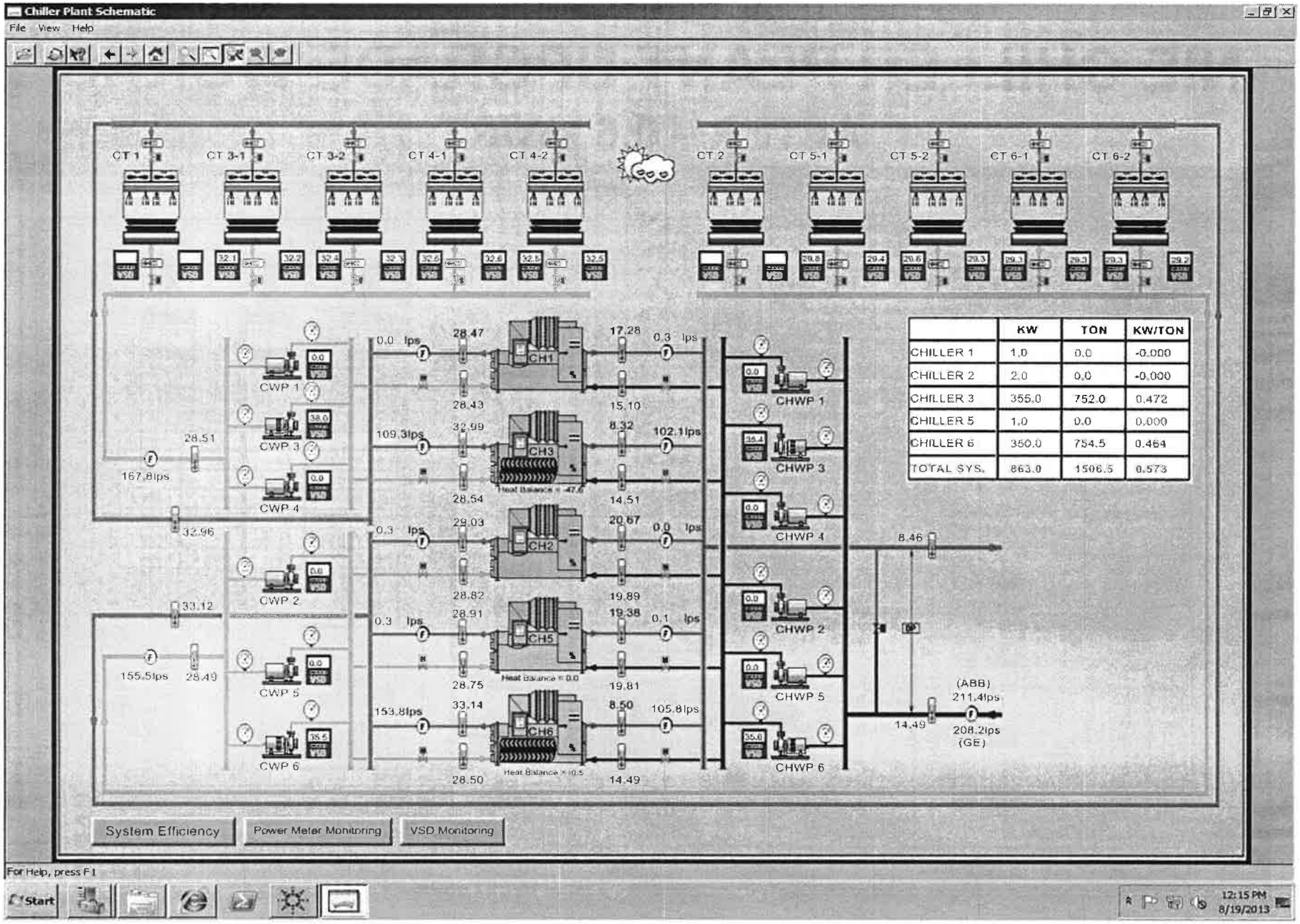
NIE CHILLER PLANT UPGRADE WORKS

AFTER – 0.6 kW/RT



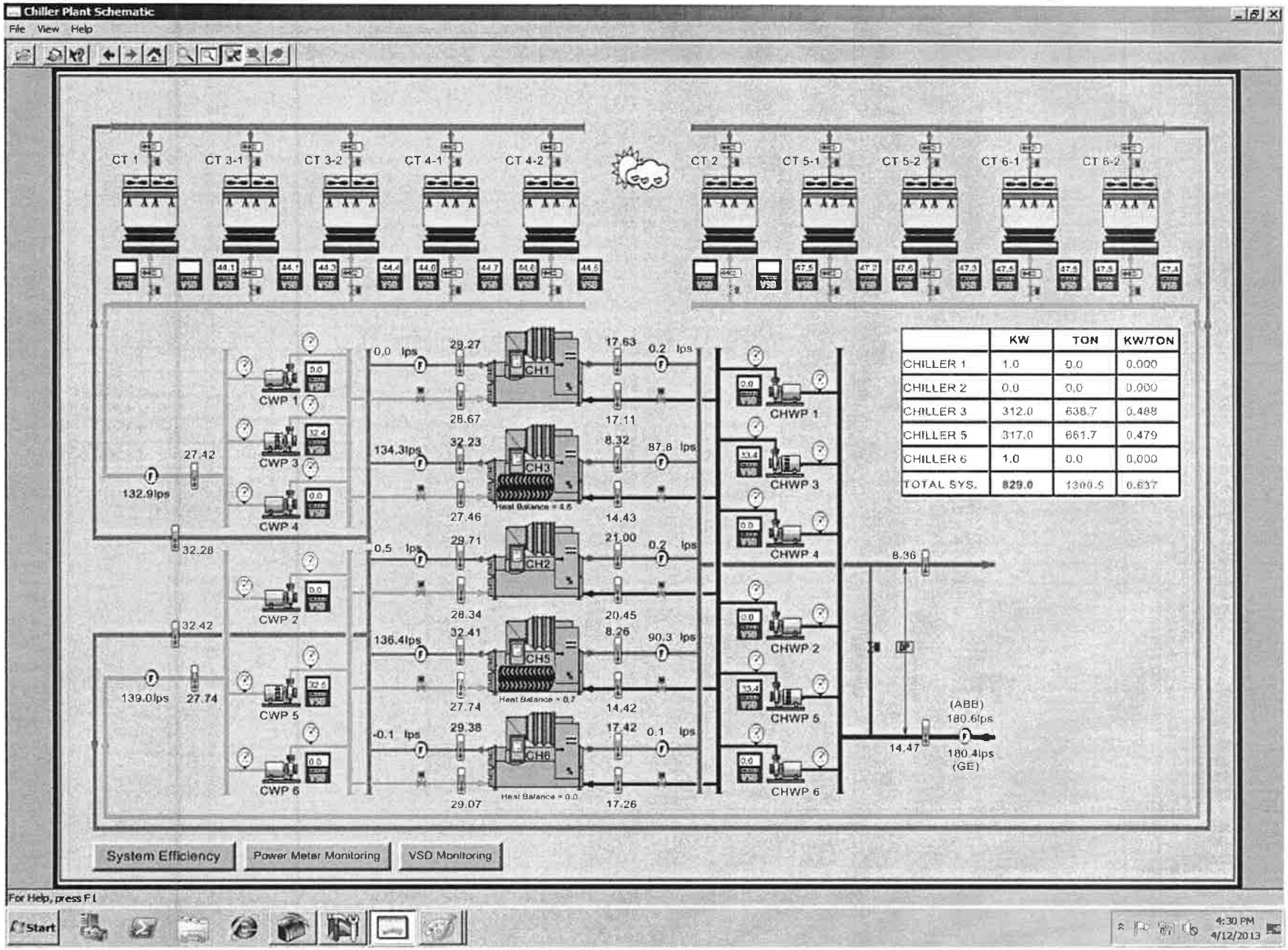
	KW	TON	KW/TON
CH1 SYSTEM	0.0	0.0	0.000
CH2 SYSTEM	0.0	0.0	-0.000
CH3 SYSTEM	272.0	580.1	0.469
CH5 SYSTEM	276.0	591.7	0.466
CH6 SYSTEM	1.0	0.0	0.000
TOTAL	684.0	1171.8	0.584

NOW – <0.6 kW/RT & Value of Extra Sensor



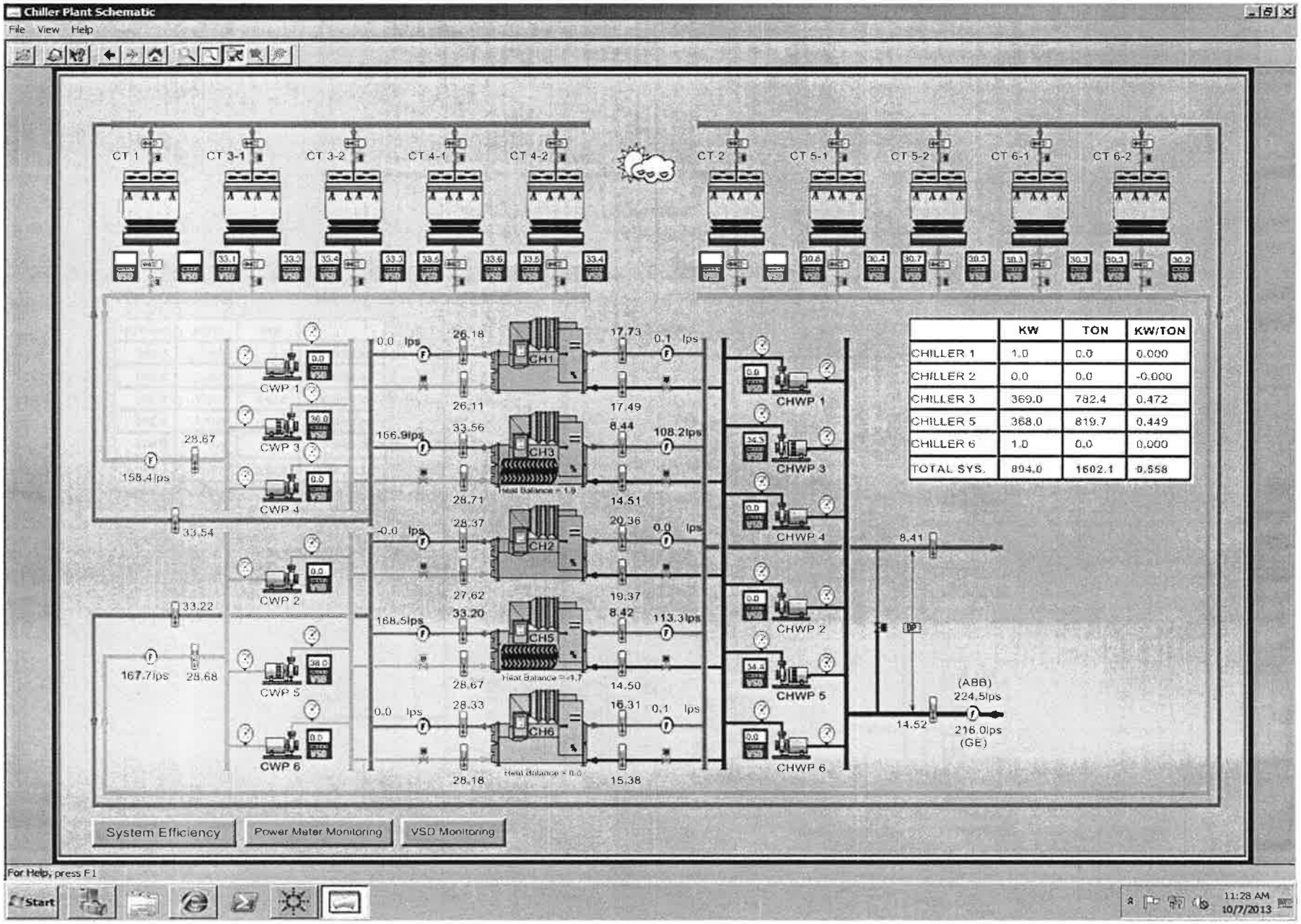
	KW	TON	KW/TON
CHILLER 1	1.0	0.0	-0.000
CHILLER 2	2.0	0.0	-0.000
CHILLER 3	355.0	752.0	0.472
CHILLER 5	1.0	0.0	0.000
CHILLER 6	350.0	754.5	0.464
TOTAL SYS.	863.0	1506.5	0.573

NOW – Value of Continuous Monitoring



	KW	TON	KW/TON
CHILLER 1	1.0	0.0	0.000
CHILLER 2	0.0	0.0	0.000
CHILLER 3	312.0	636.7	0.488
CHILLER 5	317.0	661.7	0.479
CHILLER 6	1.0	0.0	0.000
TOTAL SYS.	829.0	1300.5	0.637

NOW – <0.6 kW/RT



	KW	TON	KW/TON
CHILLER 1	1.0	0.0	0.000
CHILLER 2	0.0	0.0	-0.000
CHILLER 3	369.0	782.4	0.472
CHILLER 5	368.0	819.7	0.449
CHILLER 6	1.0	0.0	0.000
TOTAL SYS.	894.0	1602.1	0.558

HOW YOU CAN GET 0.6 kW/RT ?

- Design correct size for Chiller – based on measured data
- Choose efficient Chiller
- Size the pumps based on measured data
- Try to further reduce the size of pumps by fat pipes, less bends – reduce losses
- Do not underestimate your cooling towers
- Apply meticulous details throughout
- Get good Consultant & Contractor
- After all - $$$$$$$
- After all – you need your management's support
- After all – you need to monitor & maintain continuously

HOW DO YOU KNOW?

0.6 kW/RT you got is <u>almost Real & Acceptable</u>

- Bottom Line – HEAT BALANCE +/- 5%
- But Heat Balance is just an equation

  kW Condenser = kW Cooler + kW Compressor

  Const. x Flow x Delta T = Const. x Flow x Delta T + kW
- Need to be very sure the accuracy of one side & if you get the heat balance +/- 5%. That is.
- Which side? What you finally want is the accuracy of your KPI – kW/RT

0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

First – kW measurement of compressor

- Acceptable +/- 1.00% error for measurements
- PM 800 (external CT + Class 0.5S digital power meter) vs Veris (integrated power meter)
- Both PM 800 and Veris sent to NMC to calibrate
- NMC confirmed both are in acceptable accuracy

National Metrology Centre
A*STAR

CALIBRATION REPORT

Report No : EL014415

Page 1 of 4

Customer : Trane Distribution Pte Ltd
27 Benoi Sector
Singapore 629959

Subject Details
Subject : PowerLogic Meter
Manufacturer : Schneider Electric
Model : PM800
Serial Number : 0018104461

Sales Order No. : 2NB900564
Calibration Date : 26 September 2011.

Ambient Conditions
Temperature : (23 ± 1) °C
Relative Humidity : (55 ± 5) % relative humidity

Slgn: Chua Kwong Justin
Calibration Officer

Dr Jing Tao
Approving Officer
Electrical Metrology

For further enquiries, please contact the calibration officer at Tel: +65 6279 1917, Fax: +65 6279 1992 or Email: Justin_Ks@nmc.a-star.edu.sg

Report No.: EL014415 Page 2 of 3

Method of Calibration

This PowerLogic Meter PM800 has been calibrated at the National Metrology Centre under the stated ambient conditions. The calibration of the instrument was carried out according to National Metrology Centre's calibration procedure EC7.1b.

The calibration was carried out using an electrical power standard (serial no.: 69751124, 897950846 & 897951024) traceable to national reference standards maintained at National Metrology Centre.

Results of Calibration

The results of this calibration are shown on page 3. The expanded measurement uncertainties were estimated at a level of confidence of approximately 95% with a coverage factor k=2.

The results and their associated uncertainties are applicable at the time of calibration.

The calibration did not cover the full function of the instrument. The user should determine the suitability of this instrument for its intended use.

The recalibration interval should be determined based on the user's requirements.

0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

First – kW measurement of compressor



Report No.: EL014415 Page 3 of 3

Test		Applied Value		Indicated Value	Expanded Uncertainty
Calibration of PowerLogic Meter PM800.					
1) Voltage,	1-N	230.000 V		231 V	0.25 %
	2-N	230.000 V		230 V	0.25 %
	3-N	230.000 V		230 V	0.25 %
		Applied Value	Applied Value at CT's Rated 1000:5		
2) Current,	L-1	1.5625 A	500 A	485 A	0.12 %
	L-2	1.5625 A	500 A	499 A	0.12 %
	L-3	1.5625 A	500 A	490 A	0.12 %
3) Power,	P1, PF 1	359.375 W	115.00 kW	115 kW	0.50 %
	PF 0.866*	311.228 W	99.60 kW	99 kW	0.50 %
	P2, PF 1	359.375 W	115.00 kW	115 kW	0.50 %
	PF 0.866*	311.228 W	99.59 kW	99 kW	0.50 %
	P3, PF 1	359.375 W	115.00 kW	115 kW	0.50 %
	PF 0.866*	311.228 W	99.59 kW	100 kW	0.50 %

*Inductive load.

National Metrology Centre
A*STAR

Report No.: EL014417 Page 3 of 3

Test		Applied Value	Indicated Value	Expanded Uncertainty
Calibration of Veris Enercept H8036 Network Power Transducer Set.				
1) Voltage,	P_{ab}	398.372 V_{rms}	394.713 V_{rms}	0.067 %
	P_{bc}	398.372 V_{rms}	394.625 V_{rms}	0.067 %
	P_{ac}	398.372 V_{rms}	393.300 V_{rms}	0.067 %
2) Current,	P_A	500.00 A_{rms}	494.57 A_{rms}	0.86 %
	P_B	500.00 A_{rms}	495.86 A_{rms}	0.86 %
	Pc	500.00 A_{rms}	494.14 A_{rms}	0.86 %
3) Power,	P_A, PF = 1	115.000 kW	112.851 kW	0.86 %
	PF = 0.866*	99.590 kW	97.409 kW	0.86 %
	P_B, PF = 1	115.000 kW	112.837 kW	0.86 %
	PF = 0.866*	99.590 kW	97.300 kW	0.86 %
	P_C, PF = 1	115.000 kW	112.376 kW	0.86 %
	PF = 0.866*	99.590 kW	96.892 kW	0.86 %

*Inductive load.



National Metrology Centre
A*STAR

CALIBRATION REPORT

Report No : EL014417

Page 1 of 3

Customer : Trane Distribution Pte Ltd
27 Benoi Sector
Singapore 629959

Subject Details
Subject : Network Power Transducer Set
Manufacturer : Veris
Model : Enercept H8036
Serial Number : 4B0607C9-0F-8F

Sales Order No. : 2NB900564/5
Calibration Date : 27 September 2011

Ambient Conditions
Temperature : (23 ± 1) °C
Relative Humidity : (55 ± 5) % relative humidity

Slgn: Chua Kwong Justin
Calibration Officer

Dr Jing Tao
Approving Officer
Electrical Metrology

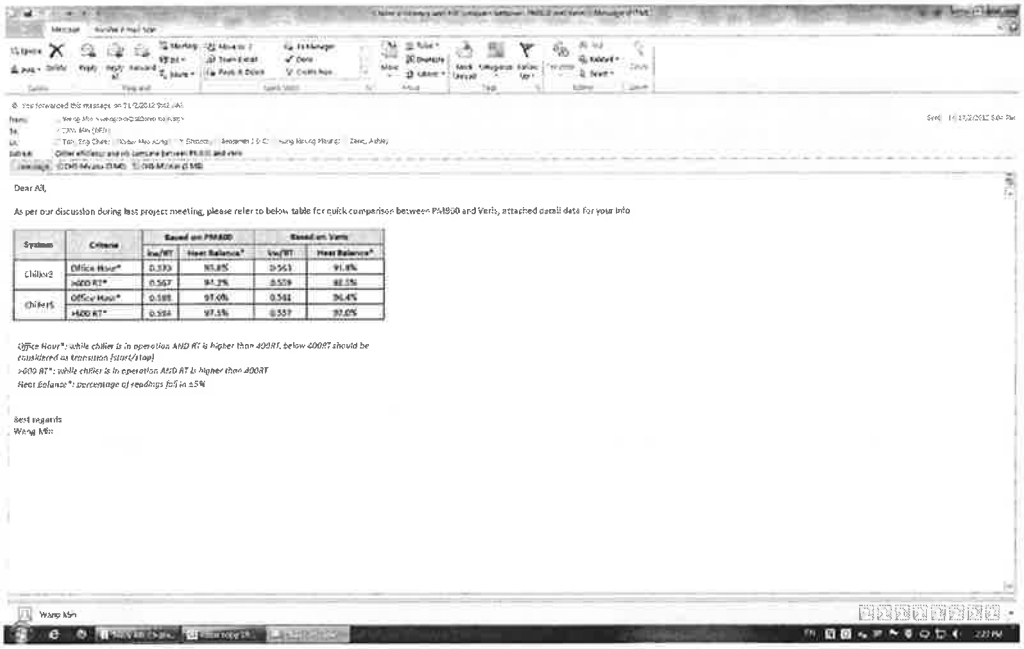
For further enquiries, please contact the calibration officer at Tel: +65 6279 1917, Fax: +65 6279 1992 or Email: Justin_Ks@nmc.a-star.edu.sg

Calibration Officer

0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

First – kW measurement of compressor

- Now, we put site measurements of both meters into Heat Balance
- Both measured data satisfied – CH3-MV.xlsx CH5-MV.xlsx



Dear All,

As per our discussion during last project meeting, please refer to below table for quick comparison between PM800 and Veris, attached detail data for your info

System	Criteria	Based on PM800		Based on Veris	
		kw/RT	Heat Balance*	kw/RT	Heat Balance*
Chiller2	Office Hour*	0.593	93.8%	0.563	91.8%
	>600 RT*	0.567	94.2%	0.529	92.5%
Chiller5	Office Hour*	0.588	97.0%	0.561	96.4%
	>600 RT*	0.554	97.5%	0.557	97.0%

Office Hour: while chiller is in operation AND RT is higher than 400RT, below 400RT should be considered as transition (start/stop)*

>600 RT: while chiller is in operation AND RT is higher than 600RT*

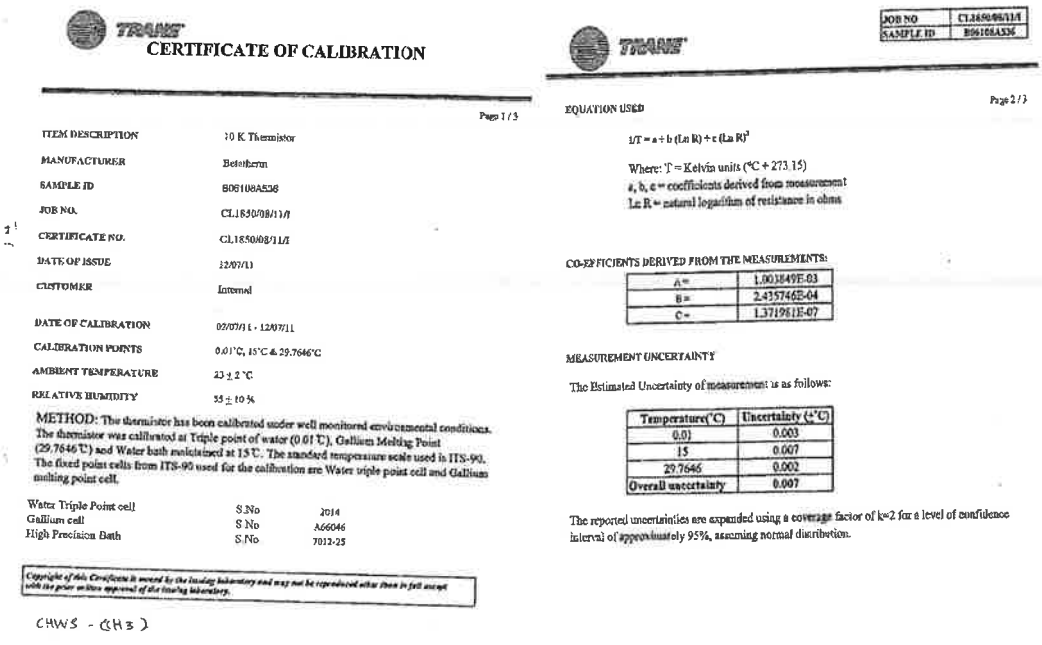
Heat Balance: percentage of readings fall in ±5%*

Best regards
Wong Min

0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

Second – Temperature Sensors for Delta T

- Acceptable +/- 1.00% error for measurements
- Use International Temp Scale (ITS-90)



TRANE

CERTIFICATE OF CALIBRATION

Page 1 / 3

ITEM DESCRIPTION	10 K Thermistor
MANUFACTURER	Betatherm
SAMPLE ID	B06108A536
JOB NO.	CL1850/08/11/I
CERTIFICATE NO.	CL1850/08/11/I
DATE OF ISSUE	12/07/11
CUSTOMER	Internal
DATE OF CALIBRATION	02/07/11 - 12/07/11
CALIBRATION POINTS	0.01°C, 15°C & 29.7646°C
AMBIENT TEMPERATURE	23 ± 2 °C
RELATIVE HUMIDITY	55 ± 10 %

METHOD: The thermistor has been calibrated under well monitored environmental conditions. The thermistor was calibrated at Triple point of water (0.01°C), Gallium Melting Point (29.7646°C) and Water bath maintained at 15°C. The standard temperature scale used is ITS-90. The fixed point cells from ITS-90 used for the calibration are Water triple point cell and Gallium melting point cell.

Water Triple Point cell	S.No	2014
Gallium cell	S No	A66046
High Precision Bath	S.No	7012-25

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CHWS - (CH3)

TRANE

JOB NO	CL1850/08/11/I
SAMPLE ID	B06108A536

Page 2 / 3

EQUATION USED

$1/T = a + b(\ln R) + c(\ln R)^3$

Where: T = Kelvin units (°C + 273.15)
a, b, c = coefficients derived from measurement
ln R = natural logarithm of resistance in ohms

CO-EFFICIENTS DERIVED FROM THE MEASUREMENTS:

A=	1.001849E-03
B=	2.435746E-04
C=	1.371981E-07

MEASUREMENT UNCERTAINTY

The Estimated Uncertainty of measurement is as follows:

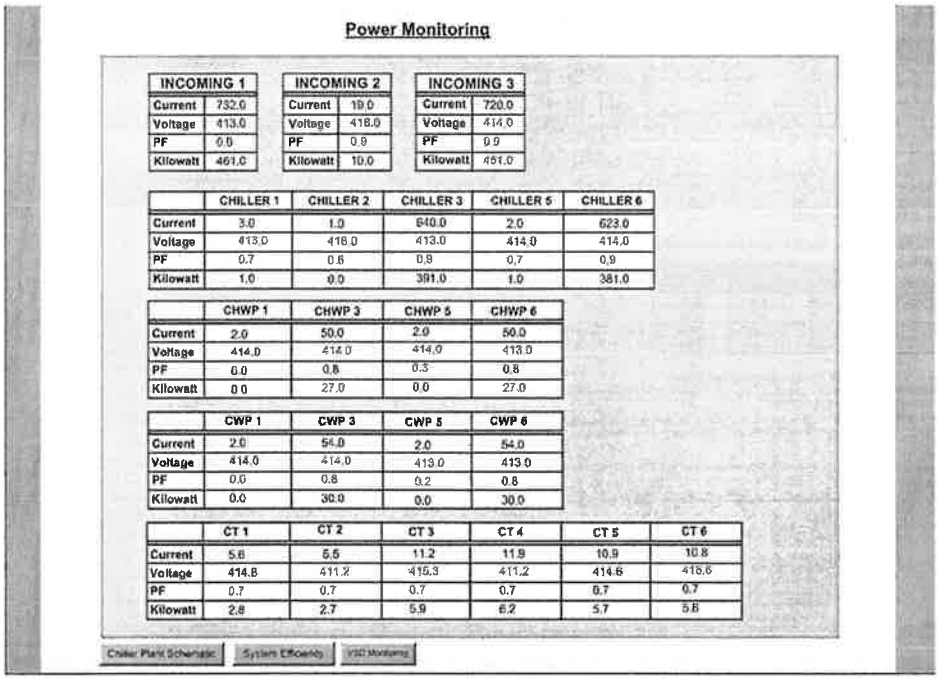
Temperature(°C)	Uncertainty (±°C)
0.01	0.003
15	0.007
29.7646	0.002
Overall uncertainty	0.007

The reported uncertainties are expanded using a coverage factor of k=2 for a level of confidence interval of approximately 95%, assuming normal distribution.

0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

kW measurement of total plant

- We have 3 main incomings in Chiller Plant – these total kW are used for determining of plant efficiency –kW/RT



Power Monitoring

INCOMING 1	
Current	732.0
Voltage	413.0
PF	0.6
Kilowatt	461.0

INCOMING 2	
Current	19.0
Voltage	418.0
PF	0.9
Kilowatt	10.0

INCOMING 3	
Current	720.0
Voltage	414.0
PF	0.9
Kilowatt	451.0

	CHILLER 1	CHILLER 2	CHILLER 3	CHILLER 5	CHILLER 6
Current	3.0	1.0	640.0	2.0	623.0
Voltage	413.0	418.0	413.0	414.0	414.0
PF	0.7	0.6	0.9	0.7	0.9
Kilowatt	1.0	0.0	391.0	1.0	381.0

	CHWP 1	CHWP 3	CHWP 5	CHWP 6
Current	2.0	50.0	2.0	50.0
Voltage	414.0	414.0	414.0	413.0
PF	0.0	0.8	0.3	0.8
Kilowatt	0.0	27.0	0.0	27.0

	CWP 1	CWP 3	CWP 5	CWP 6
Current	2.0	56.0	2.0	54.0
Voltage	414.0	414.0	413.0	413.0
PF	0.0	0.8	0.2	0.8
Kilowatt	0.0	30.0	0.0	30.0

	CT 1	CT 2	CT 3	CT 4	CT 5	CT 6
Current	5.8	5.5	11.2	11.9	10.9	10.8
Voltage	414.8	411.2	415.3	411.2	414.6	415.6
PF	0.7	0.7	0.7	0.7	0.7	0.7
Kilowatt	2.8	2.7	5.9	6.2	5.7	5.8

Chiller Plant Schematic | System Efficiency | VSD Monitoring

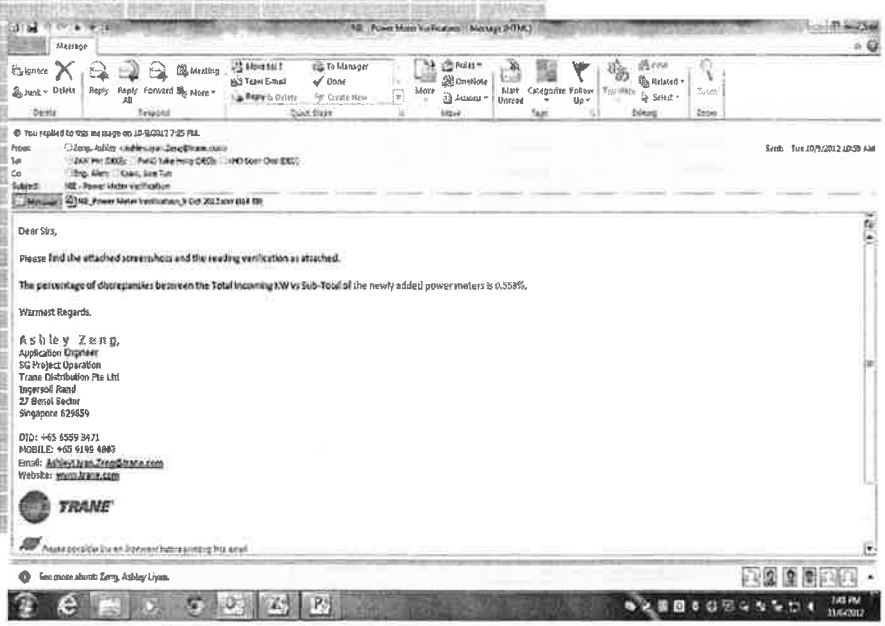
0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

kW measurement of total plant

BASED ON SCREENSHOT TAKEN ON 9 OCT 2012 - 10:25AM

	INCOMING 1 KW	461
a)	CH 1 KW	1
b)	CH3 KW	391
c)	CT1 KW	2.8
d)	CT3 KW	5.9
e)	CHWP1 KW	0
f)	CHWP3 KW	27
g)	CWP1 KW	0
h)	CWP3 KW	30
Total of (a) to (h)		457.7
Differences		3.3
	INCOMING 2 KW	10
i)	CH2 KW	0
j)	CT2 KW	2.7
k)	CT4 KW	6.2
Total of (i) to (k)		8.9
Differences		1.1
	INCOMING 3 KW	451
l)	CH5 KW	1
m)	CH6 KW	381
n)	CT5 KW	5.7
o)	CT6 KW	5.6
p)	CHWP5 KW	0
q)	CHWP6 KW	27
r)	CWP5 KW	0
s)	CWP6 KW	30
Total of (l) to (s)		450.3
Differences		0.7

TOTAL INCOMING KW	922
TOTAL of (a) to (s)	916.9
% Discrepancies	0.553145



Dear Sirs,

Please find the attached screenshots and the reading verification as attached.

The percentage of discrepancies between the Total Incoming KW vs Sub-Total of the newly added power meters is 0.553%.

Warmest Regards,

Ashley Zeng,
Application Engineer
SG Project Operation
Trane Distribution Pte Ltd
Ingersoll Rand
27 Benoi Sector
Singapore 629859

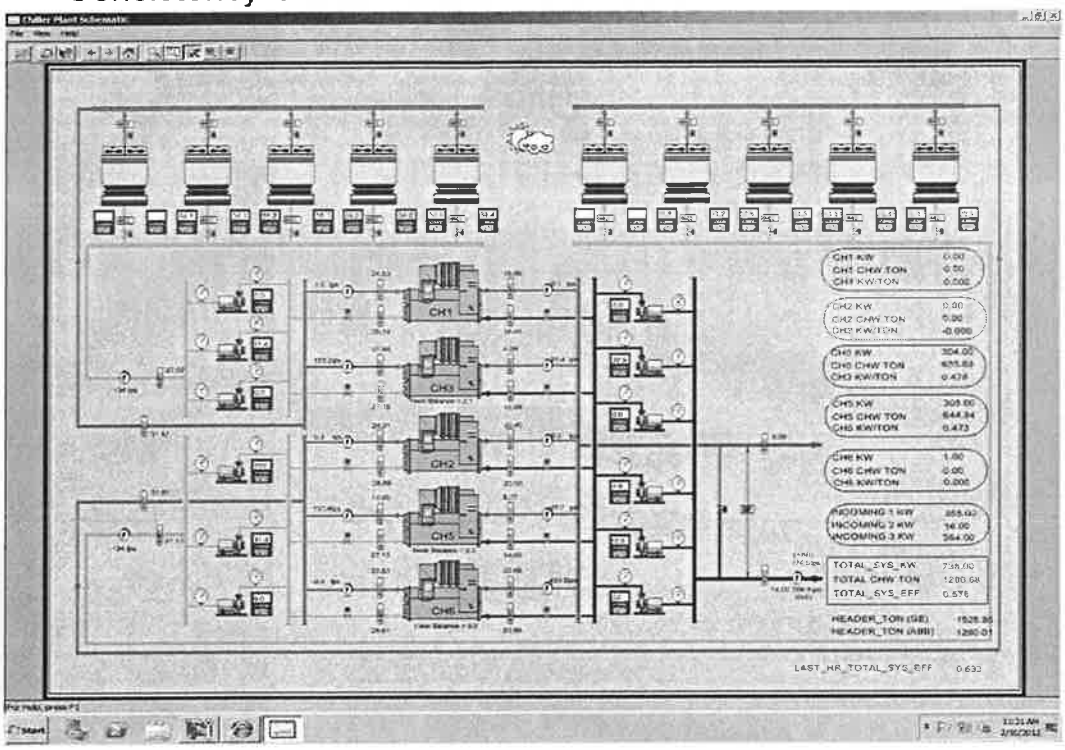
DID: +65 6559 3471
MOBILE: +65 9195 4803
Email: Ashley.Yuan.Zeng@Trane.com
Website: www.trane.com

TRANE

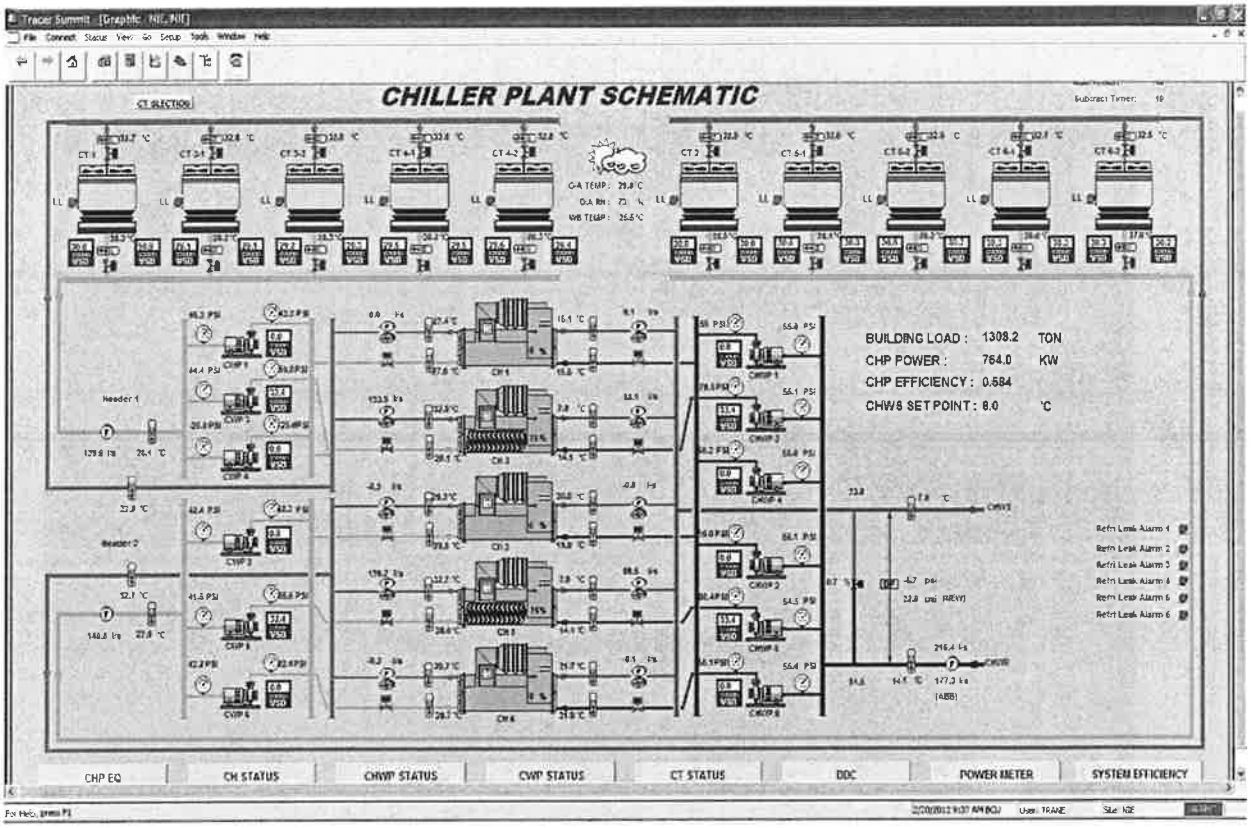
0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

Second – Temperature Sensors for Delta T

- Consistency Check for installed sensors



0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?



0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

Third – Flow Measurement

- Acceptable +/- 2.00% error for measurements

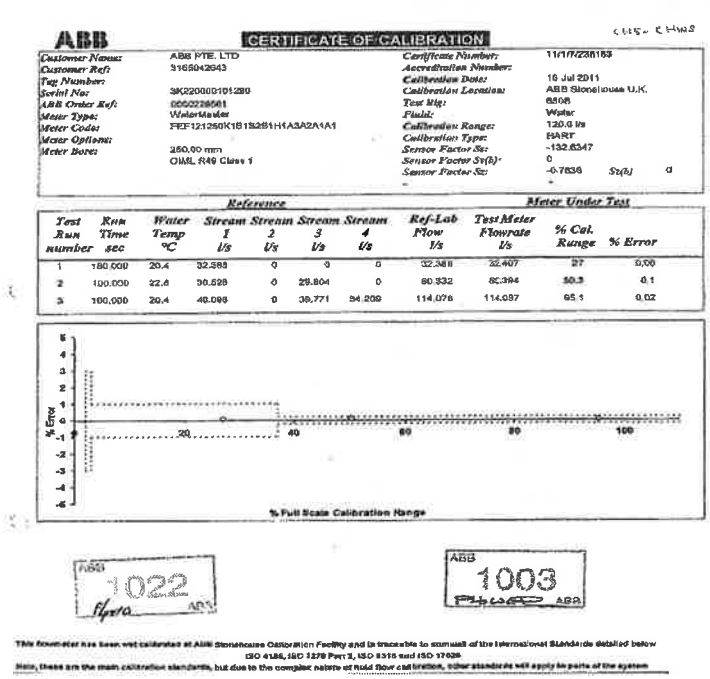


ABB — CERTIFICATE OF CALIBRATION

Customer Name:	ABB PTE. LTD	Certificate Number:	11/1/1/Z36183
Customer Ref:	3168042643	Accreditation Number:	
Tag Number:		Calibration Date:	18 Jul 2011
Serial No:	3K2200001101280	Calibration Location:	ABB Stonehouse U.K.
ABB Order Ref:	0002236581	Test Rig:	6508
Meter Type:	WaterMaster	Fluid:	Water
Meter Code:	FEF12:1250K1B1S2S1H1A3A2A1A1	Calibration Range:	120.0 l/s
Meter Options:		Calibration Type:	HART
Meter Bore:	250.00 mm OIML R49 Class 1	Sensor Factor Sx:	-132.6347
		Sensor Factor Sy(k):	0
		Sensor Factor Sz:	-0.7836 Sz(k) 0

		Reference					Meter Under Test			
Test Run number	Run Time sec	Water Temp °C	Stream 1 l/s	Stream 2 l/s	Stream 3 l/s	Stream 4 l/s	Ref-Lab Flow l/s	Test Meter Flowrate l/s	% Cal. Range	% Error
1	180.000	20.4	32.388	0	0	0	32.388	32.407	27	0.06
2	100.000	22.6	36.528	0	29.804	0	66.332	66.394	55.3	0.1
3	100.000	20.4	40.098	0	38.771	34.209	114.078	114.087	95.1	0.02

ABB 1022

ABB 1003

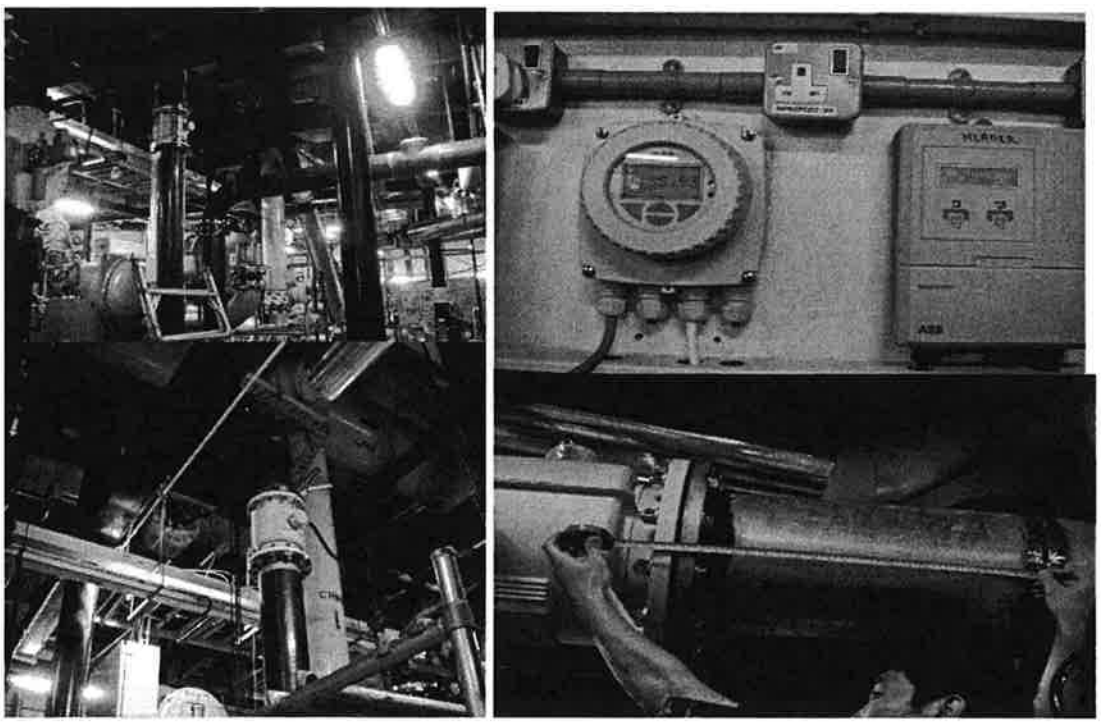
This flowmeter has been wet calibrated at ABB Stonehouse Calibration Facility and is traceable to accredited of the International Standards detailed below
ISO 4185, ISO 1270 Part 2, ISO 8316 and ISO 17026
Note, these are the main calibration standards, but due to the complex nature of fluid flow calibration, other standards will apply to parts of the system



0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

Third – Flow Measurement

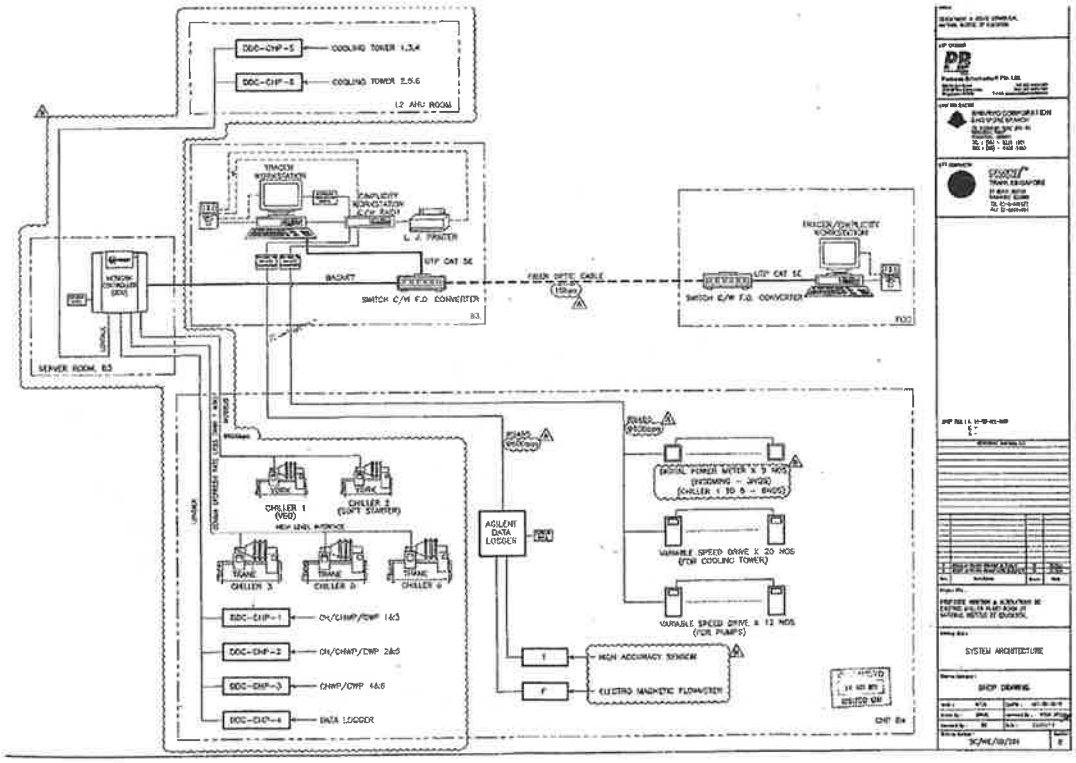
- 5D & 2D must be correct in installation



0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

Third – Flow Measurement

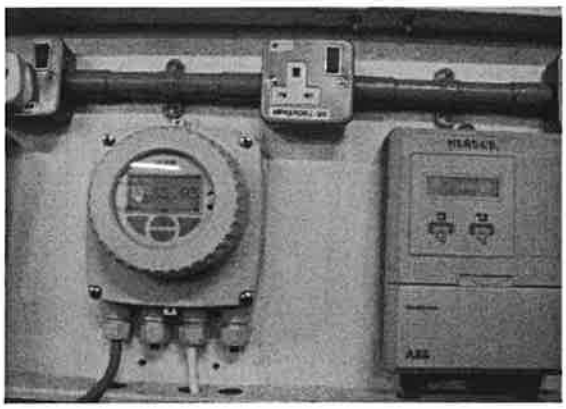
- Flow Sensor is O.K and Transmitter is also O.K. What's next?



0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

Third – Flow Measurement

- How about Transmitter to Agilent Data Logger (A to D)?
- How about Scan Rate? How about Rate of Transmission?
- In short, will you be receiving the same as what you see at Transmitter (at LCD screen) in your M&V server (Cimplicity)?

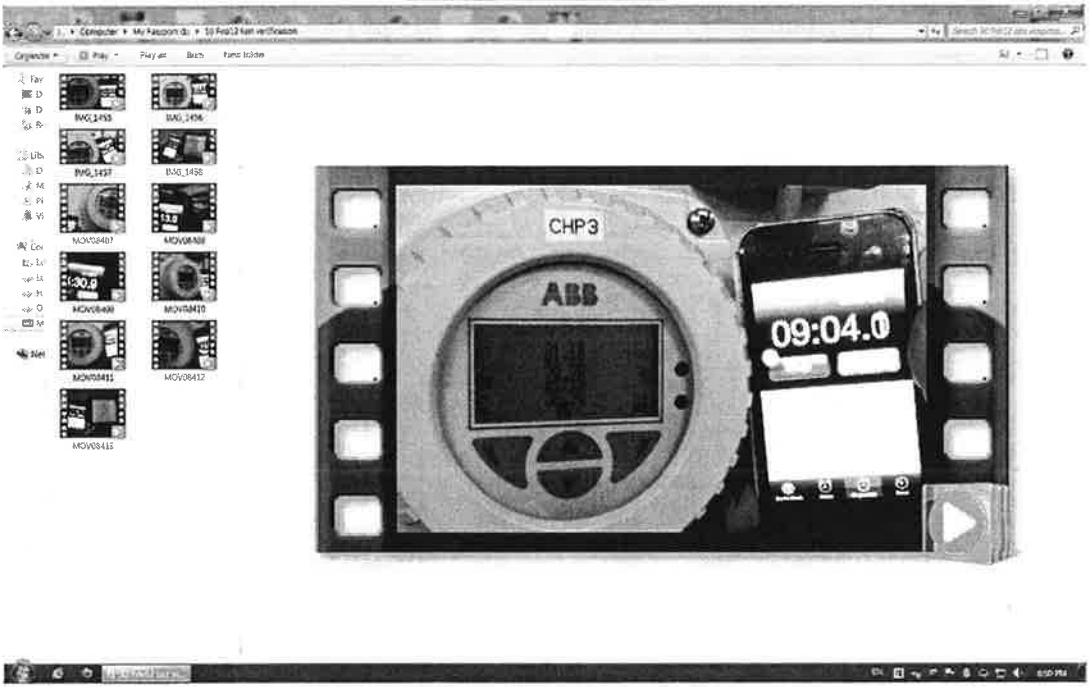




0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

Third – Flow Measurement

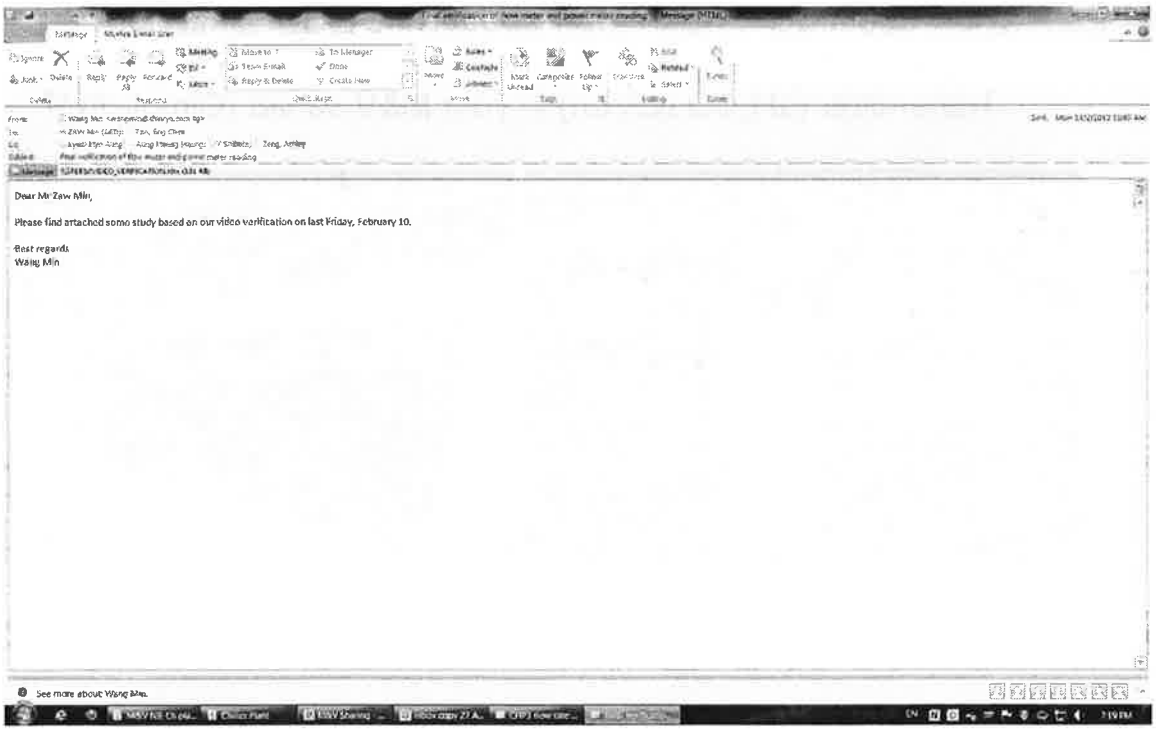
- Video verification! <u>IMG_1456.MOV</u>



0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

Third – Flow Measurement

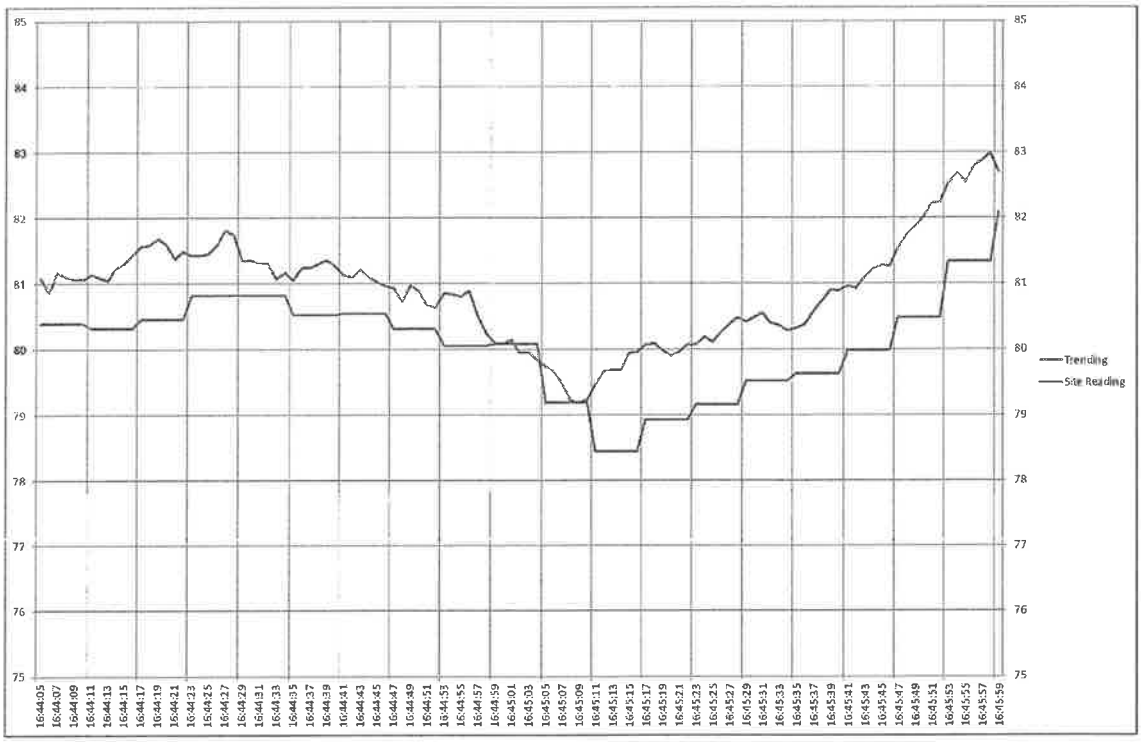
- Video verification!



0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

Third – Flow Measurement

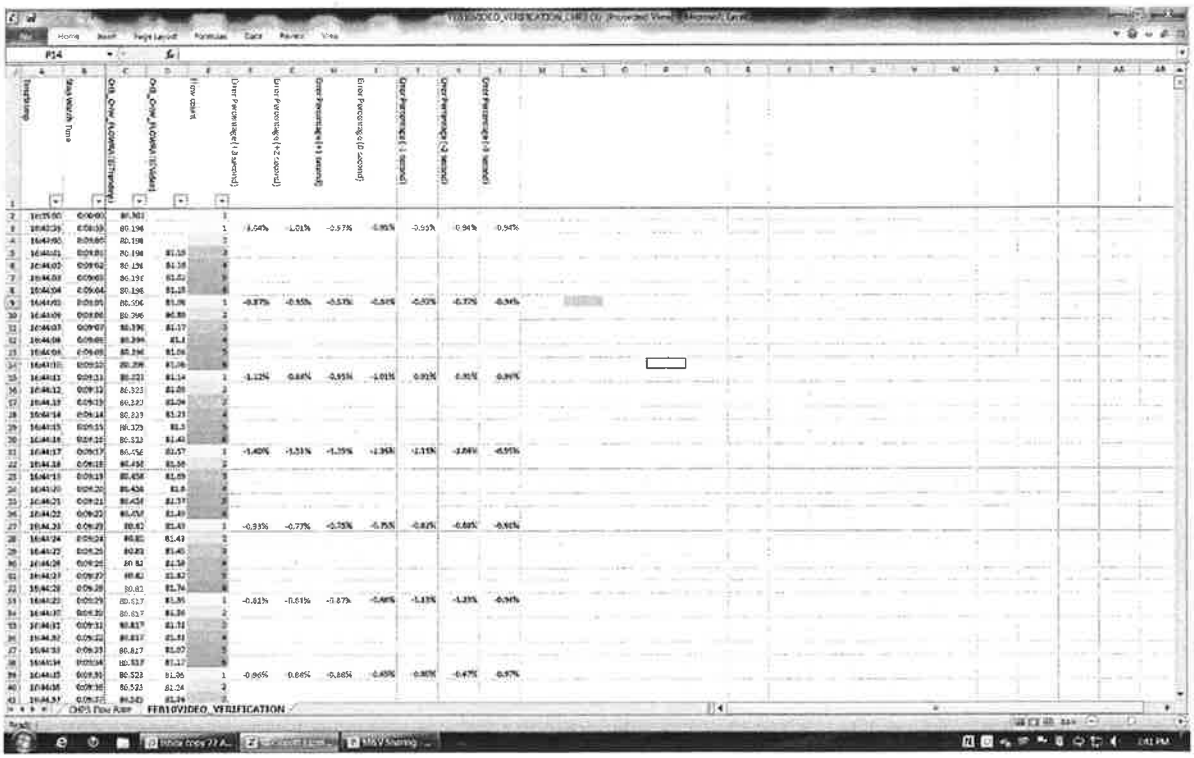
- Video verification!



0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

Third – Flow Measurement

- Video verification! <u>FEB10VIDEO_VERIFICATION_CHP3.xlsx</u>



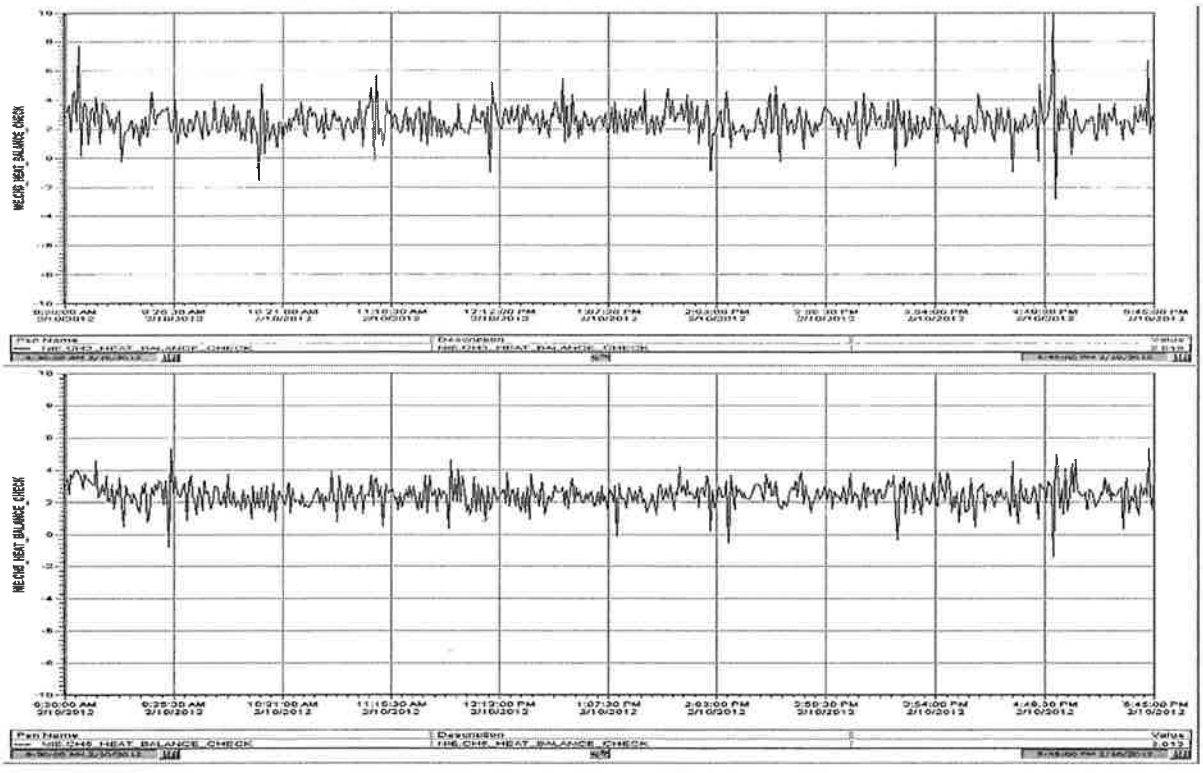
0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

Final – kW, Delta T and Flow

- kW, Delta T & Flow – Do they arrive at server almost at same time?
- Yes, Almost! within 5 Seconds
- Agilent scan rate is 5 Seconds
- Modbus transmission rate increased to 19200 bps
- <u>FEB10VIDEO_VERIFICATION.xlsx</u>

0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

- **Finally – The Heat Balance on which you have high confidence**



0.6 kW/RT you got is <u>almost Real & Acceptable</u> ?

- **Finally – On-site verified by BCA and it is accurate**

Project: NIE
Date of plant verification 18 Jul 2012

	CHWS (°C)		
Time	BCA	NIE	Δ
11:25:09	8.485	8.437	-0.048
11:25:19	8.479	8.439	-0.04
11:25:29	8.463	8.436	-0.027
11:25:39	8.455	8.406	-0.049
11:25:49	8.475	8.421	-0.054
11:25:59	8.467	8.424	-0.043
11:26:09	8.458	8.41	-0.048
11:26:19	8.454	8.421	-0.033
11:26:29	8.437	8.421	-0.016
11:26:39	8.434	8.425	-0.009
11:28:04	8.36	8.434	0.074
11:28:14	8.365	8.453	0.088
11:28:24	8.364	8.487	0.123
11:28:34	8.38	8.472	0.092
11:28:44	8.386	8.485	0.099
11:28:54	8.395	8.475	0.08
11:29:04	8.408	8.483	0.075
11:29:14	8.426	8.496	0.07
11:29:24	8.436	8.503	0.067
11:29:34	8.441	8.5	0.059
Average	8.4284	8.4514	0.023

	CHWR (°C)		
Time	BCA	NIE	Δ
11:34:29	14.316	14.349	0.033
11:34:39	14.309	14.364	0.055
11:34:49	14.305	14.376	0.071
11:34:59	14.31	14.386	0.076
11:35:09	14.318	14.403	0.085
11:35:19	14.322	14.415	0.093
11:35:29	14.335	14.42	0.085
11:35:39	14.349	14.426	0.077
11:35:49	14.358	14.426	0.068
11:35:59	14.37	14.434	0.064
11:38:03	14.431	14.436	0.005
11:38:13	14.431	14.439	0.008
11:38:23	14.429	14.44	0.011
11:38:33	14.424	14.443	0.019
11:38:43	14.424	14.444	0.02
11:38:53	14.419	14.45	0.031
11:39:03	14.421	14.455	0.034
11:39:13	14.42	14.462	0.042
11:39:23	14.424	14.464	0.04
11:39:33	14.427	14.469	0.042
Average	14.3771	14.42505	0.04795

	CWS (°C)		
Time	BCA	NIE	Δ
11:43:01	28.648	28.723	0.075
11:43:11	28.668	28.726	0.058
11:43:21	28.674	28.733	0.059
11:43:31	28.682	28.738	0.056
11:43:41	28.685	28.741	0.056
11:43:51	28.688	28.741	0.053
11:44:01	28.692	28.747	0.055
11:44:11	28.695	28.756	0.061
11:44:21	28.701	28.762	0.061
11:44:31	28.707	28.766	0.059
11:47:46	28.813	28.799	-0.014
11:47:56	28.805	28.797	-0.008
11:48:06	28.794	28.793	-0.001
11:48:16	28.789	28.794	0.005
11:48:26	28.779	28.798	0.019
11:48:36	28.772	28.798	0.026
11:48:46	28.771	28.805	0.034
11:48:56	28.768	28.805	0.037
11:49:06	28.766	28.818	0.052
11:49:16	28.767	28.832	0.065
Average	28.7332	28.7736	0.0404

	CWR (°C)		
Time	BCA	NIE	Δ
11:54:42	33.075	32.971	-0.104
11:54:52	33.045	32.96	-0.085
11:55:02	33.02	32.957	-0.063
11:55:12	32.999	32.938	-0.061
11:55:22	32.974	32.921	-0.053
11:55:32	32.955	32.911	-0.044
11:55:42	32.94	32.952	0.012
11:55:52	32.93	33	0.07
11:56:02	32.92	33.002	0.082
11:56:12	32.904	33	0.096
11:58:32	32.798	32.795	-0.003
11:58:42	32.79	32.865	0.075
11:58:52	32.784	32.92	0.136
11:59:02	32.78	32.923	0.143
11:59:12	32.777	32.917	0.14
11:59:22	32.772	32.904	0.132
11:59:32	32.782	32.894	0.112
11:59:42	32.841	32.88	0.039
11:59:52	32.865	32.866	0.001
12:00:02	32.875	32.851	-0.024
Average	32.8913	32.92135	0.03005



UNITED WORLD COLLEGE SOUTH EAST ASIA (EAST CAMPUS)

Kenny Low

UWC SOUTH EAST ASIA



PROJECT INFORMATION:

International Standard Educational Buildings for 2500 students (aged 4 -18) and staff. Facilities include Classrooms, Science Facilities, Theaters, Sports Halls, Olympic Sized (50m) Swimming Pool, Residential Accommodation, Commercial Kitchen, Clinic etc.

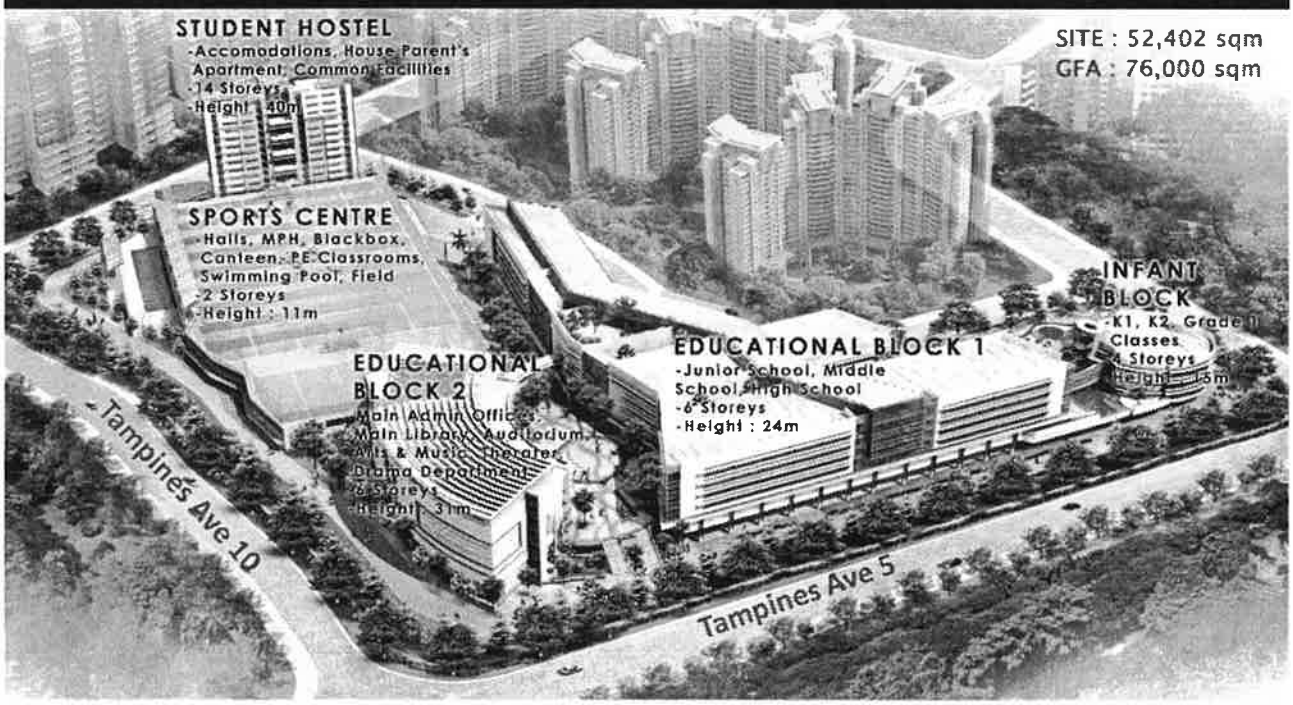
Site Area	**Constrained 5.2 Hectare – L Shaped Plot**
Allowable Plot Ratio	**1.5**
Gross Floor Area	**76,000 sq.m**
Date of Completion and Final Occupation	**Phase 1 – 5,000 sq.m – July 2010** **Phase 2 – 71,000 sq.m – April 2011**

Green Lane, Very Fast Track Project (36 months)

UWC SOUTH EAST ASIA



PROJECT KEY DATA - AERIAL VIEW OF THE CAMPUS



UWC SOUTH EAST ASIA



"GREEN" FACTORS OF UWCSEA East Campus



SOLAR RENEWABLE ENERGY

2,986,744 kWh/year of useful solar heat energy to power a 420Tref chiller and produce 15m3/day of hot water.



RECYCLED RAIN

Saving **10m3** of water daily with **50%** of the landscape areas rain-irrigated



GREEN SURFACE

Approx. **10ha** of green surfaces at Green Plot Ratio of **2.0** across campus

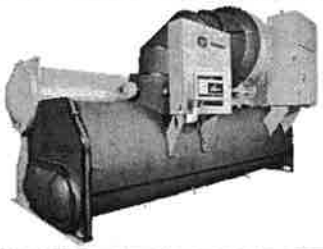


ORIENTATION

Minimal solar gain with ETTV of **39.55 W/M2**

EFFICIENT A/C

One of the most efficient A/C system at **0.58kW/ton**



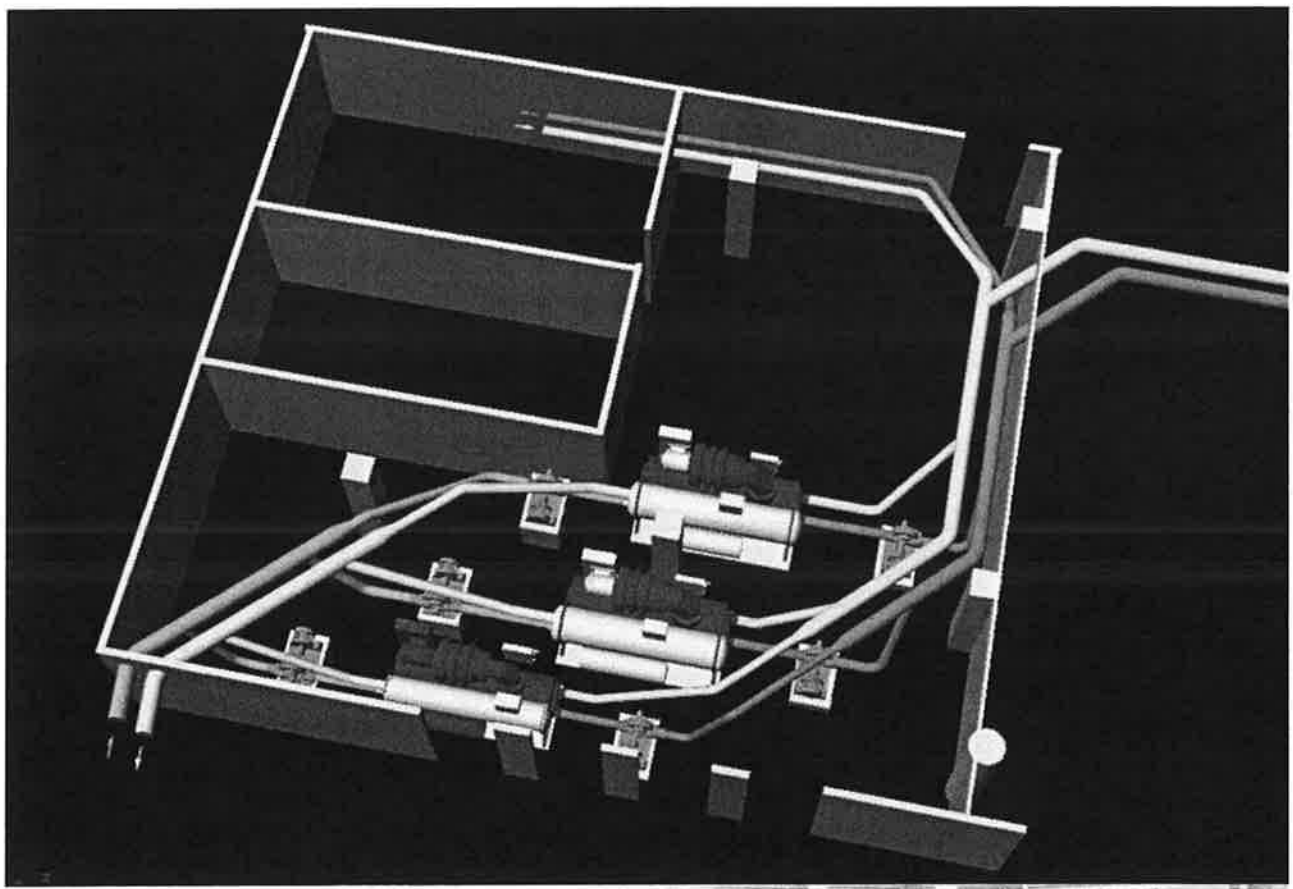


Chiller plant configuration

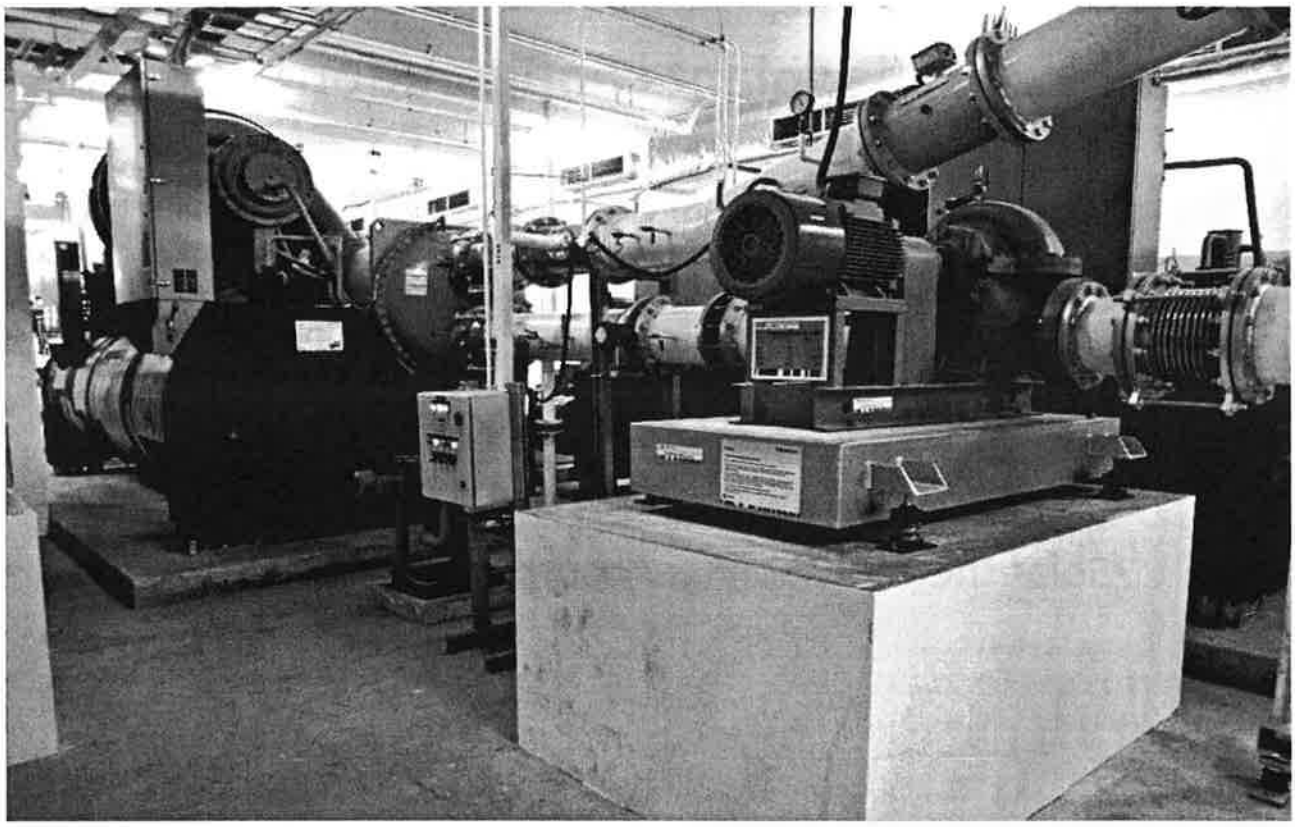
- Chillers: 2 x 600RT, 1 x400RT
- CHWPs: 2 x 15 KW, 1 x 11 KW
- CWPs: 2 x 15 KW, 1 x 11 KW
- CTs: 9 Cells x 7.5 KW
- Performance guarantee of 0.58KW/RT
- Solar thermal cooling: Absorption chiller 425RT

UWC SOUTH EAST ASIA



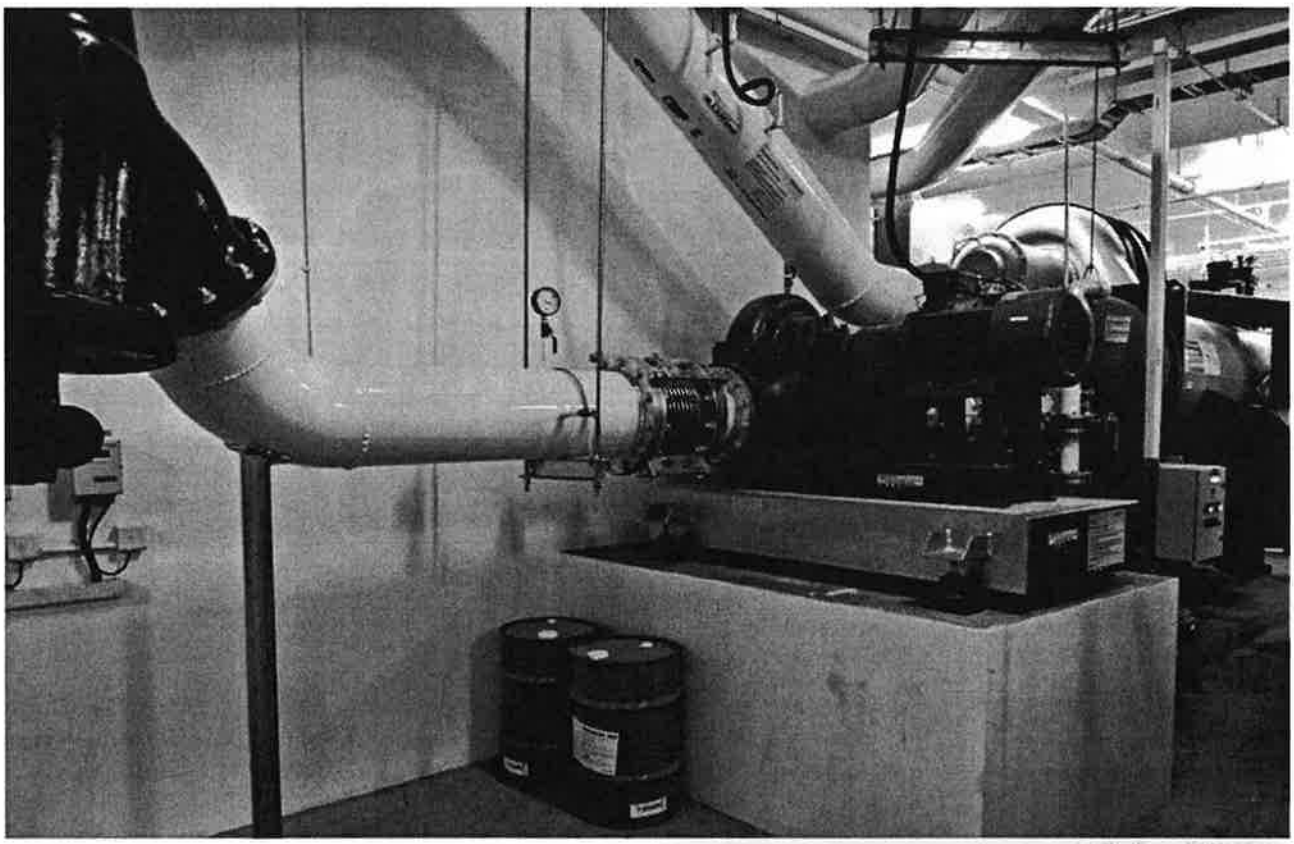


UWC SOUTH EAST ASIA



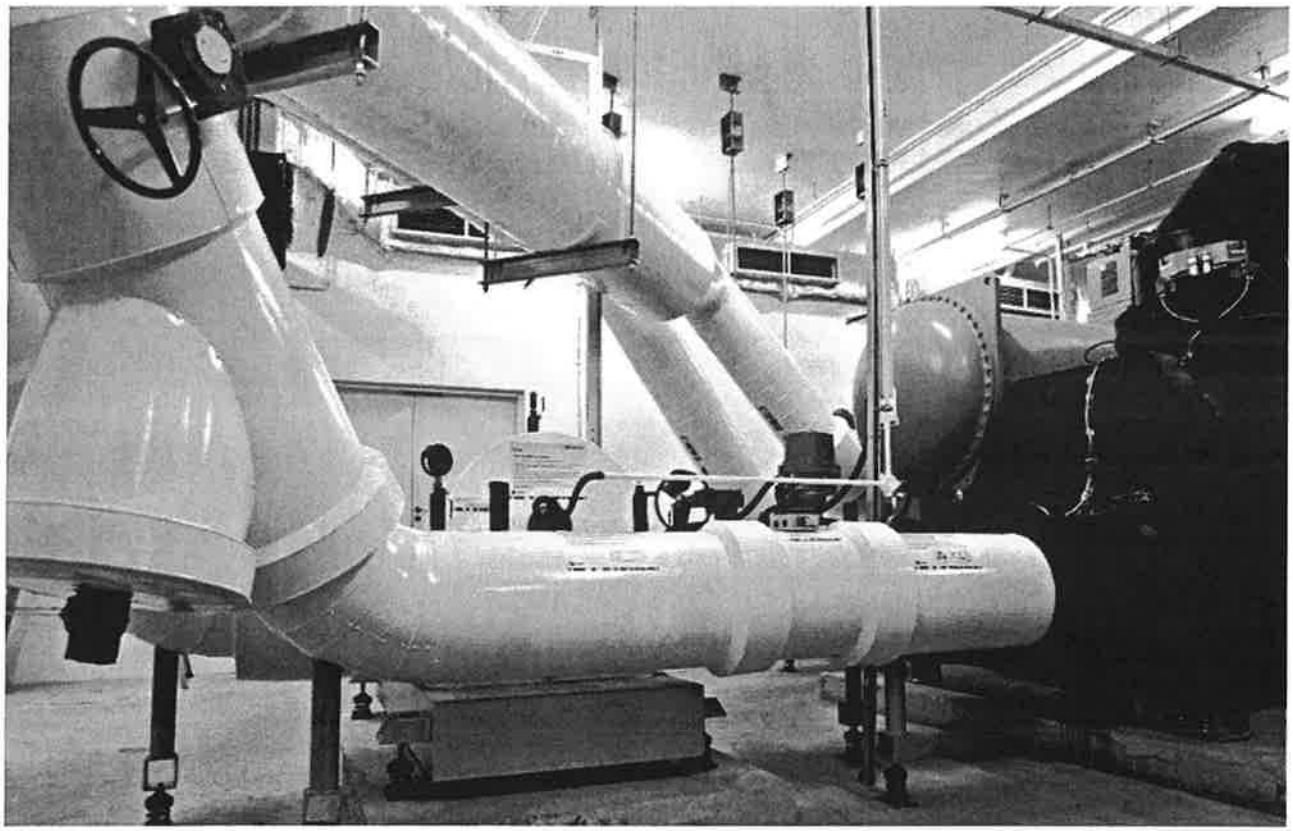
UWC SOUTH EAST ASIA





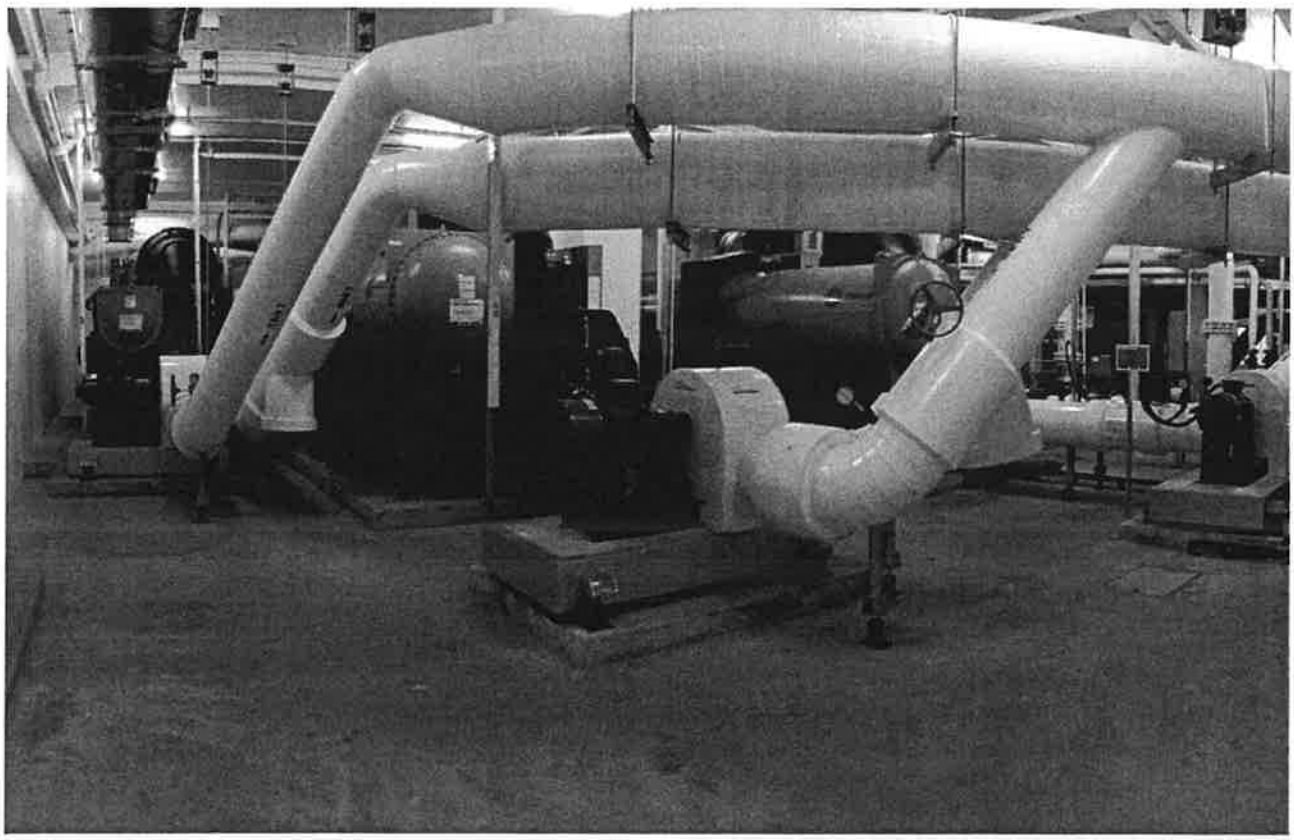
UWC SOUTH EAST ASIA





UWC SOUTH EAST ASIA





UWC SOUTH EAST ASIA

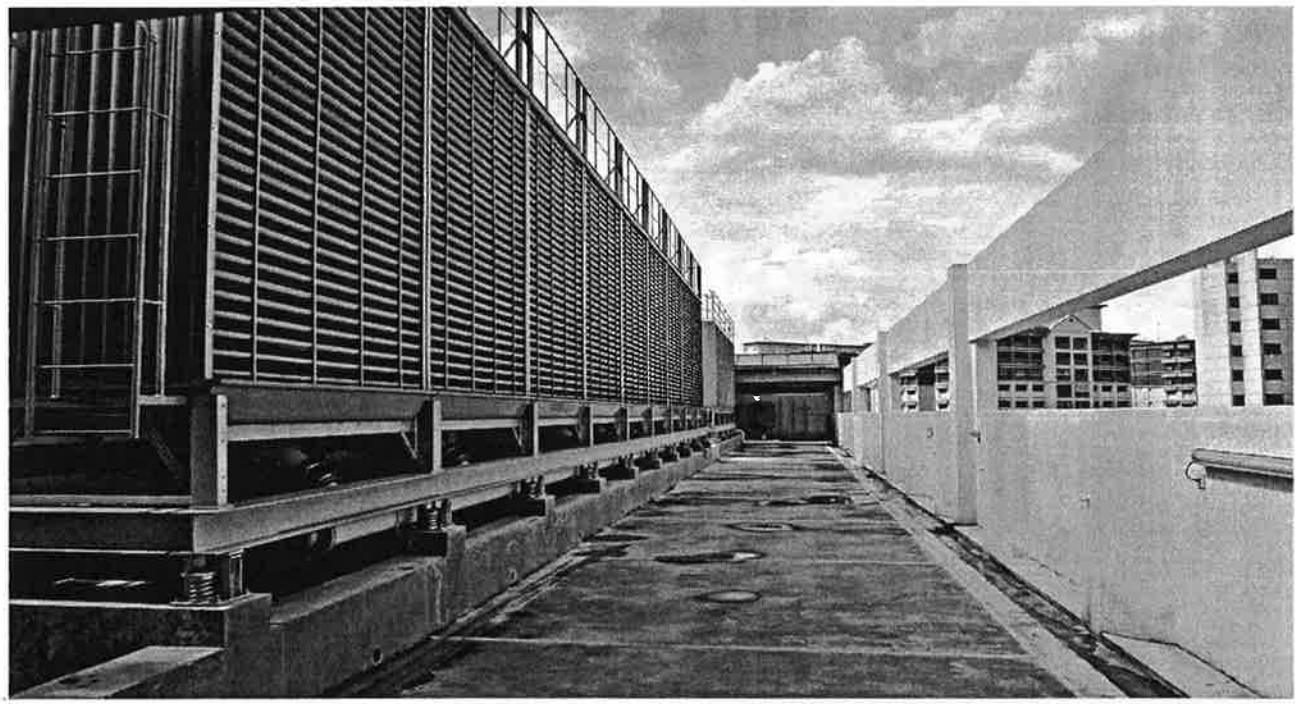




UWC SOUTH EAST ASIA



Cooling towers are arranged in a line to maximixze the heat rejection surface.



UWC SOUTH EAST ASIA

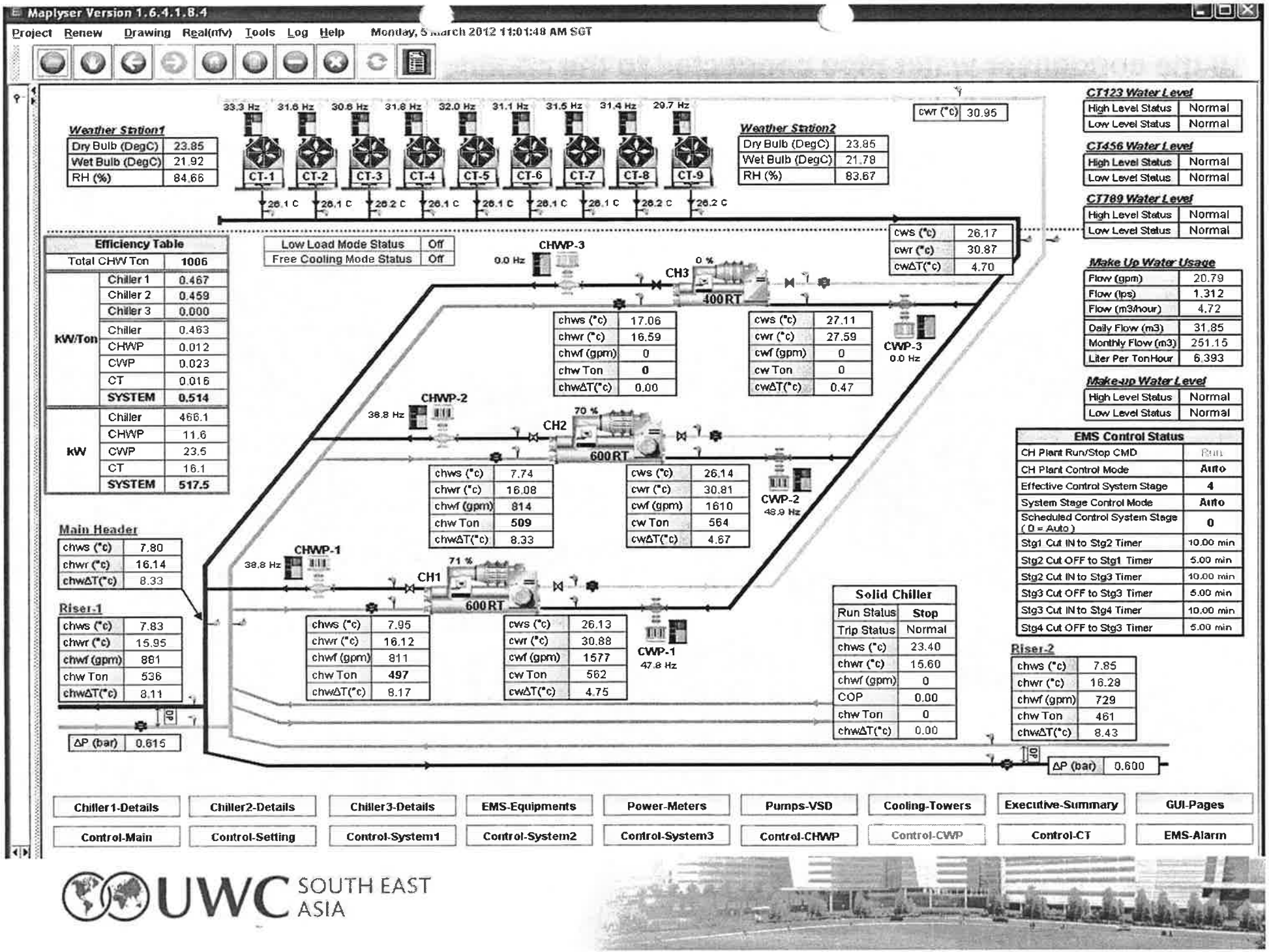


All the condenser water pipe connected to the cooling tower are in 45degree to reduce friction loss.



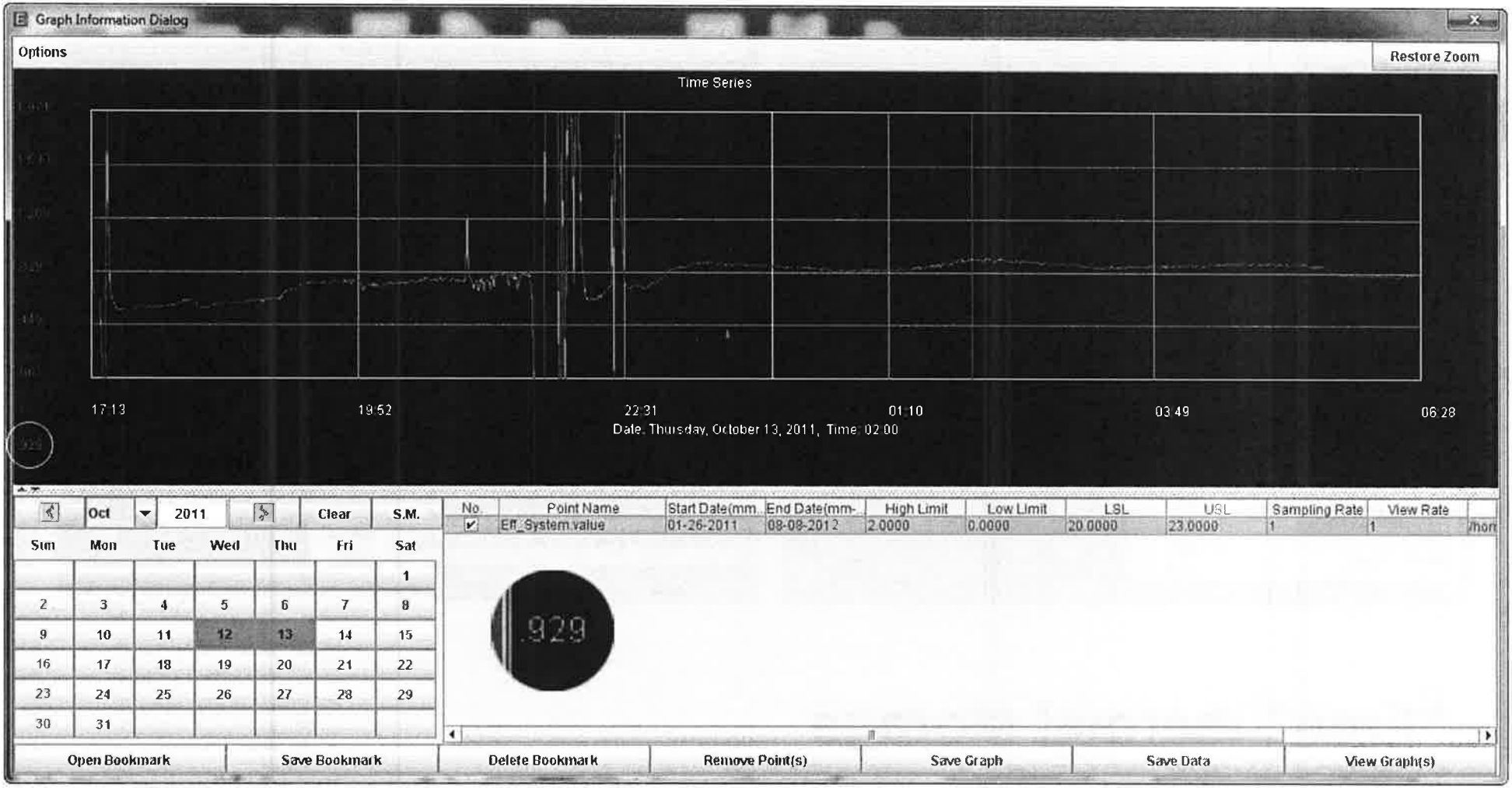
UWC SOUTH EAST ASIA





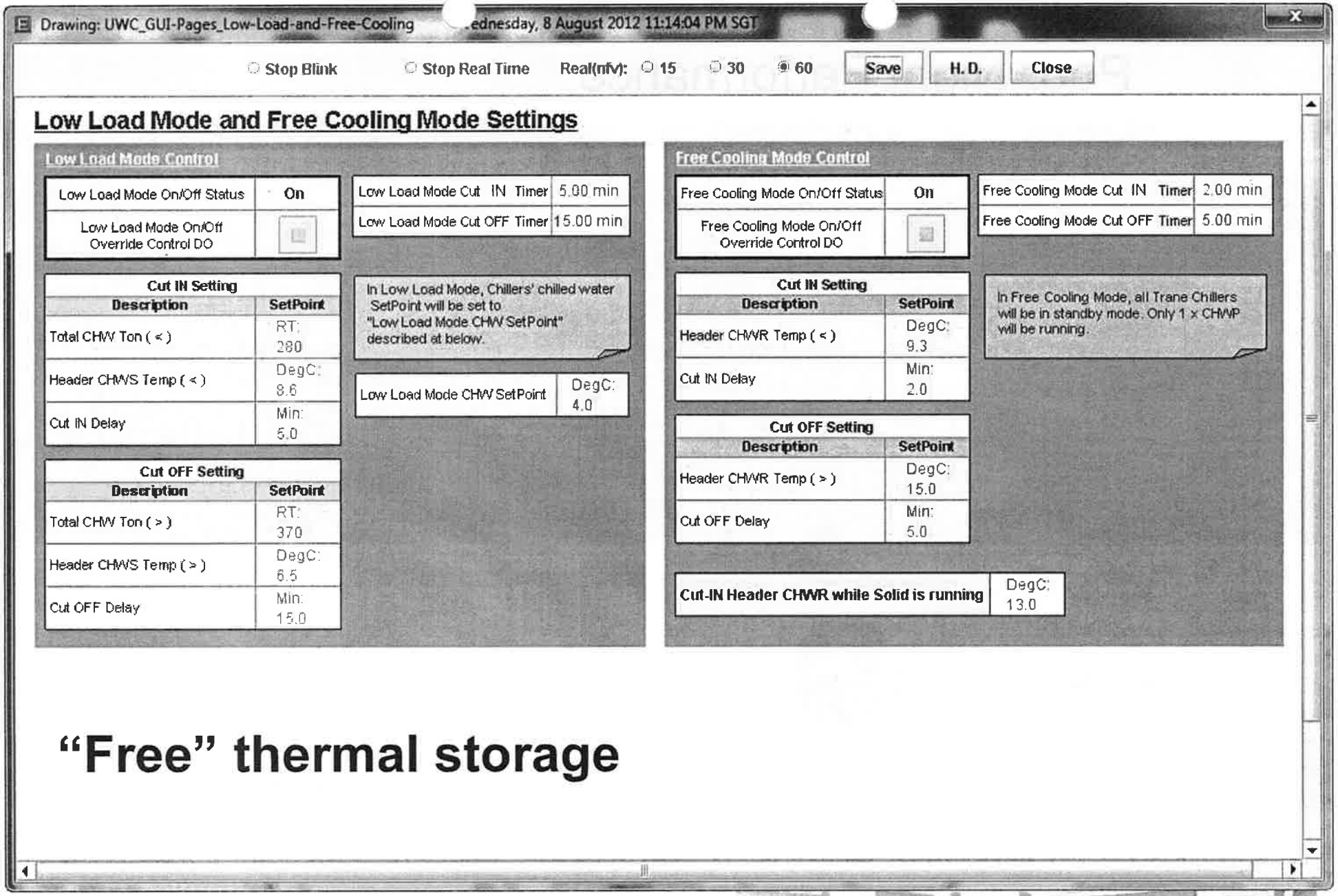
UWC SOUTH EAST ASIA

Poor Night Performance



UWC SOUTH EAST ASIA



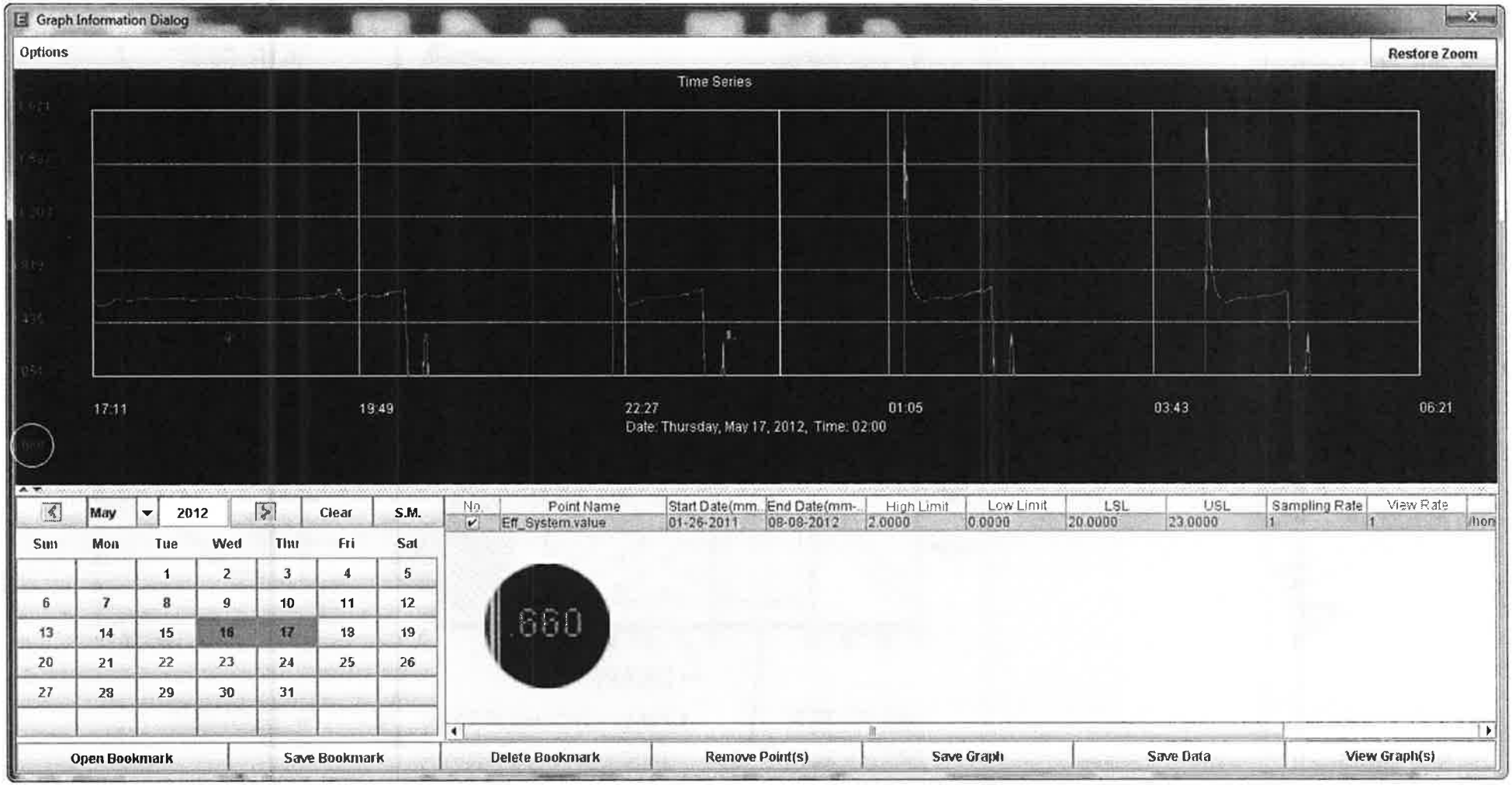


"Free" thermal storage

UWC SOUTH EAST ASIA



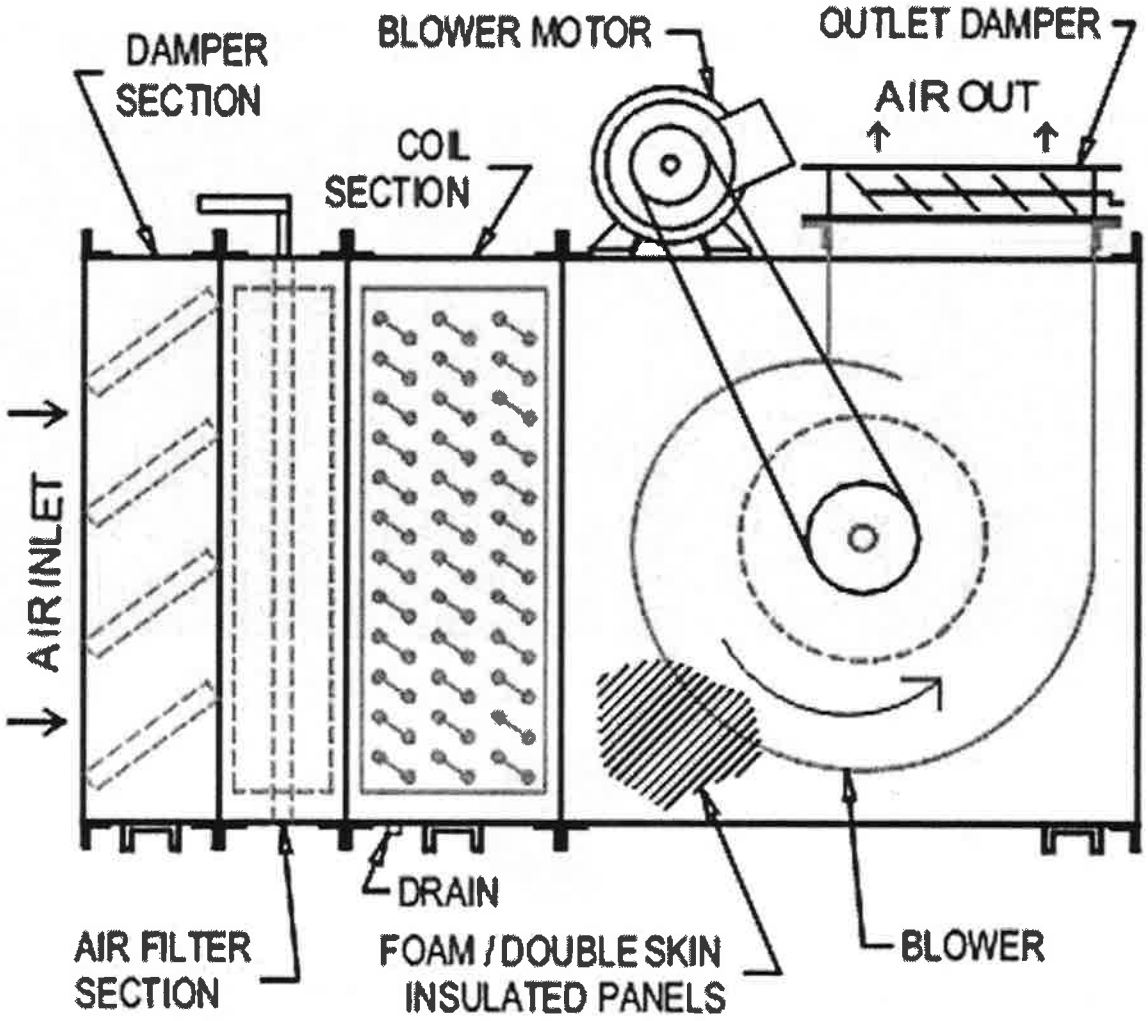
Good Night Performance



UWC SOUTH EAST ASIA



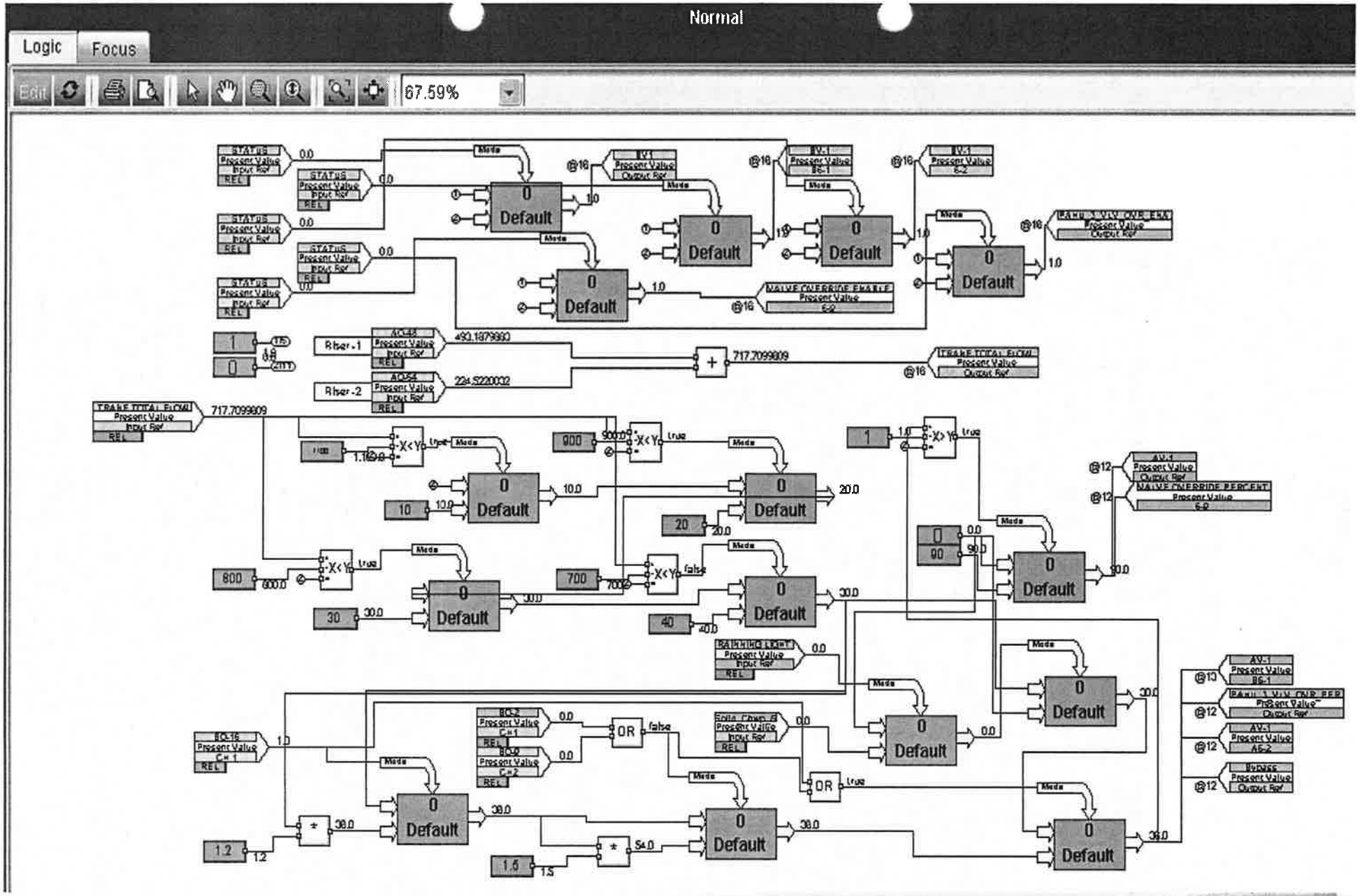
Air Site Control



UWC SOUTH EAST ASIA

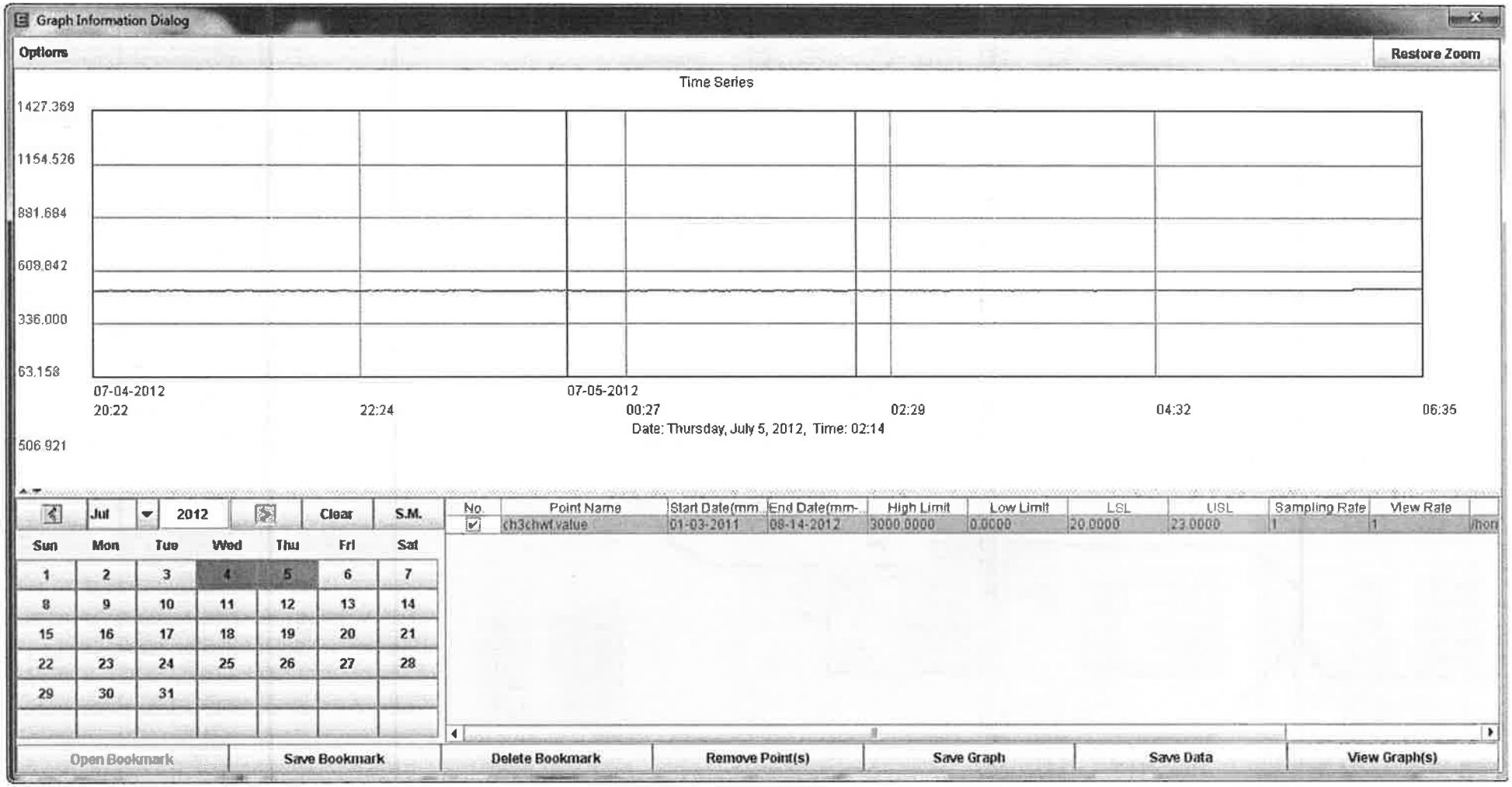



BLOCK A
BLOCK B,C,D
INFANT BLOCK
SPORT COMPLEX
BOARDING HOUSE
Fast Cooling
Auditorium
Disable
CR 1&2
Disable
B Box
Disable
MPH
Disable
UWCSEA
AHU Summary
Main Power Meter
TRANE Chiller



UWC SOUTH EAST ASIA





UWC SOUTH EAST ASIA



UWC SOUTH EAST ASIA

Home

EAST CAMPUS CHILLER SYSTEM

Johnson Controls

Weather Station1

Dry Bulb (DegC)	27.74
Wet Bulb (DegC)	24.69
RH (%)	78

Condensate Water Meter

m³	3,897

CT-1 CT-2 CT-3 CT-4 CT-5 CT-6 CT-7 CT-8 CT-9

normal
CT Water Level

Weather Station2

Dry Bulb (DegC)	27.79
Wet Bulb (DegC)	24.35
RH (%)	76

CW Header

cw Ton	444

Efficiency Table

Total CHW Ton		381
kW/Ton	Chiller 1	0.000
	Chiller 2	0.000
	Chiller 3	0.536
	Chiller	0.536
	CHWP	0.014
	CWP	0.022
	CT	0.013
	SYSTEM	0.585
kW	Chiller	206.06
	CHWP	5.15
	CWP	8.55
	CT	5.43
	SYSTEM	225

LLM	On
FCM	Off
Bypass	36.0 %

cws (c)	28.27
cwr (c)	33.33
cwf(gpm)	1,147

CHWP-3 — CH3 96 % — 400RT — Remote

chws (c)	5.79
chwr (c)	12.99
chwf (gpm)	707
chw Ton	380.6
chwΔT(c)	7.16

cws (c)	28.22
cwr (c)	33.38
cwf (gpm)	1,147
cw Ton	444.0
cwΔT(c)	5.18

CWP-3

CHWP-2 — CH2 0 % — 600RT — Remote

chws (c)	15.34
chwr (c)	12.81
chwf (gpm)	0
chw Ton	0.0
chwΔT(c)	0.00

cws (c)	26.94
cwr (c)	27.36
cwf (gpm)	0
cw Ton	0
cwΔT(c)	0.43

CWP-2

Main Header

chws (c)	5.83
chwr (c)	13.09
chwf (gpm)	702
chwΔT(c)	7.27

CHWP-1 — CH1 0 % — 600RT — Remote

chws (c)	9.98
chwr (c)	9.75
chwf (gpm)	0
chw Ton	0.0
chwΔT(c)	0.00

cws (c)	26.40
cwr (c)	26.78
cwf (gpm)	0
cw Ton	0.0
cwΔT(c)	0.38

CWP-1

Riser-1

chws (c)	5.86
chwr (c)	12.63
chwf (gpm)	476
chw Ton	241.4
chwΔT(c)	6.79

ΔP (bar) 0.608

Riser-2

chws (c)	5.88
chwr (c)	13.53
chwf (gpm)	226
chw Ton	130.0
chwΔT(c)	7.66

ΔP (bar) 0.630

System Stage

1 to 4	1

Heat Balance

> 5% <	-1.10 %

CT. Makeup Water

flow (gpm)	11.6

Absorption Chiller

status	Off
chw Ton	0.0

1 2 3 4 5 6 7 8 9 10 11 12

MASTER CONTROL Start

0.64 4.0

SYSTEM

COP	5.94

Building Total Load

chw Ton	371

Kenny Law Sll

AHU STATUS

A1-1	Stop	Off	22.5 deg C
A1-2	Stop	Off	25.2 deg C
A2-1	Stop	Off	22.5 deg C
A3-1	Stop	Off	23.1 deg C
A5-1A	Stop	Off	27.5 deg C
A5-1B	Stop	Off	25.7 deg C
A5-1C	Stop	Off	27.0 deg C
A5-1D	Stop	Off	26.5 deg C
A5-2	Stop	Off	26.1 deg C
A6-1	Stop	Off	26.8 deg C
A6-2	Stop	Off	24.0 deg C
B1-1	Stop	Off	24.5 deg C
B1-2	Stop	Off	25.2 deg C
B1-3	Stop	Off	24.8 deg C
EXAM	Stop	Off	22.2 deg C
B6-1	Stop	Off	24.4 deg C
B6-2	Stop	Off	22.1 deg C
B6-3	Stop	Off	23.4 deg C
B6-4	Stop	Off	0.0 deg C
C6-5	Stop	Off	24.8 deg C
C6-6	Stop	Off	25.1 deg C
D2-1	Stop	Off	21.3 deg C
D6-7	Stop	Off	25.0 deg C
D6-8	Stop	Off	25.1 deg C
D6-9	Stop	Off	15.1 deg C
HALL 1	Stop	Off	18.1 deg C
HALL 2	Stop	Off	20.6 deg C
HALL 3	Stop	Off	19.5 deg C
HALL 4	Stop	Off	23.8 deg C
B BOX	Start	On	19.1 deg C
MPH	Stop	Off	22.6 deg C
IB 1-1	Stop	Off	21.5 deg C
IB 1-2	Stop	Off	24.0 deg C
IB 1-3	Stop	Off	26.0 deg C
BH 1	Start	On	16.6 deg C
BH 2	Start	On	13.6 deg C

FCU STATUS

None	Stop	Off	24.7 deg C
Swit	Start	On	14.2 deg C
CP 1	Start	On	26.5 deg C
CP 2	Start	On	26.1 deg C
F E O	Start	On	24.7 deg C
Recpt	Stop	Off	23.2 deg C
D1-1	Stop	Off	25.2 deg C
D1-2	Stop	Off	26.6 deg C
D1-3	Stop	Off	24.0 deg C
BB Sgl	Start	On	25.3 deg C
BB Ga	Start	On	23.0 deg C
PE Off	Stop	Off	28.4 deg C
MPH	Stop	Off	26.0 deg C
Sport of	Stop	Off	25.5 deg C
PE Ga	Stop	Off	25.3 deg C

UWC SOUTH EAST ASIA



UWCSEA East SYSTEM HEAT BALANCE

UWC SOUTH EAST ASIA

Johnson Controls

Weather Station

Dry Bulb 27.9 deg C RH% 76.2 %

Chiller heat in

628 kW

CHW heat in

4,723 kW

CW heat out

5,356 kW

CW heat out

5,356 kW

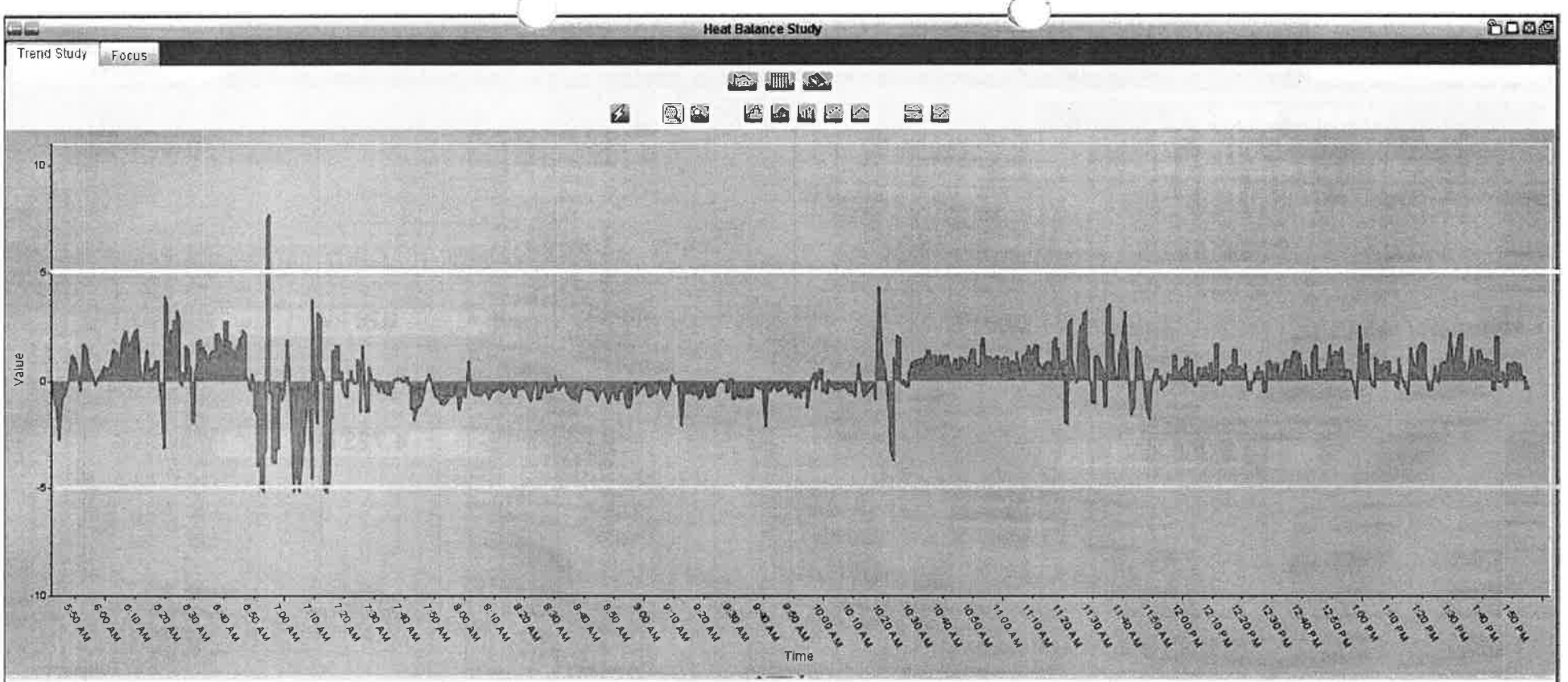
Heat Balance

0.09 %

System Stage	kW / RT
4	0.53

UWC SOUTH EAST ASIA



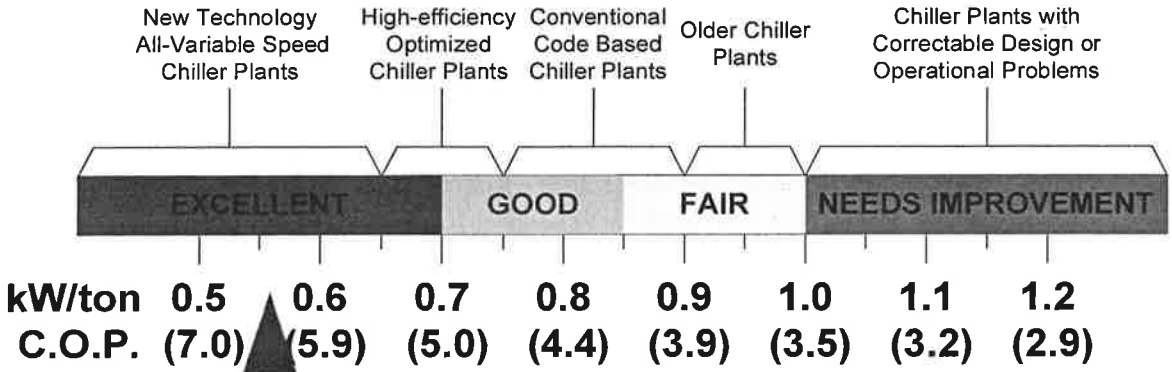


Show	Marker	Name	Reference
☑		HEAT BALANCE.Present Value	PC100818B:NAE55-5/Programming.HEAT BALANCE.Trend1
☐		Main Header chwst.Present Value	PC100818B:NAE55-3/TRANE.Device-51.Analog Outputs.AO-43.Trend1
☐		Main Header chwrt.	PC100818B:NAE55-3/TRANE.Device-51.Analog Outputs.AO-44.Trend1
☐		Free Cooling On/Off status BO 68.	PC100818B:NAE55-3/TRANE.Device-51.Binary Outputs.BO-68.Trend1
☐		Low Load Mode On/Off status BO 69.	PC100818B:NAE55-3/TRANE.Device-51.Binary Outputs.BO-69.Trend1
☐		Solid On/Off BO 70.	PC100818B:NAE55-3/TRANE.Device-51.Binary Outputs.BO-70.Trend1
☐		System Eff.Present Value	PC100818B:NAE55-3/TRANE.Device-51.Analog Outputs.AO-82.Trend1

UWC SOUTH EAST ASIA



The End Result - Ashrae--Chiller Plant Efficiency



AVERAGE ANNUAL CHILLER PLANT EFFICIENCY IN KW/TON (C.O.P.)

(Input energy includes chillers, condenser pumps, tower fans and chilled water pumping)

Based on electrically driven centrifugal chiller plants in comfort conditioning applications with 42F (5.6C) nominal chilled water supply temperature and open cooling towers sized for 85F (29.4C) maximum entering condenser water temperature and 20% excess capacity. Local Climate adjustment for North American climates is +/- 0.05 kW/ton

UWC SOUTH EAST ASIA



Cooling from the SUN ?

UWC SOUTH EAST ASIA



Solar thermal air conditioning system

- The Large Solar Thermal (LST) system will provide up to 100% of the school's Domestic Hot Water (DHW) demand and supplement the conventional chiller system of up to 425 tons (1500 kW) cooling load.
- Collector's area of over 3,800m2, will generate green energy granted for life time (> 25 years) years approx. 2,200 MWh/year. This LST system at UWCSEA East campus will be largest solar cooling plant in the world, and arguably also the first and only school in the world using a combi (AC +DHW) system powered by renewable energy.
- Designed & build by Austrain engineering company SOLID.
- Raiffeisen-Landesbank of Steiermark & Oesterreichische Kontrollbank will finance the investment of around EUR 4 million. EDB approved a grant of 15%.
- UWC will repay the investment within 15 years by paying the energy cost it saved with the help of the solar installation.
- http://www.solarthermalworld.org/node/1387

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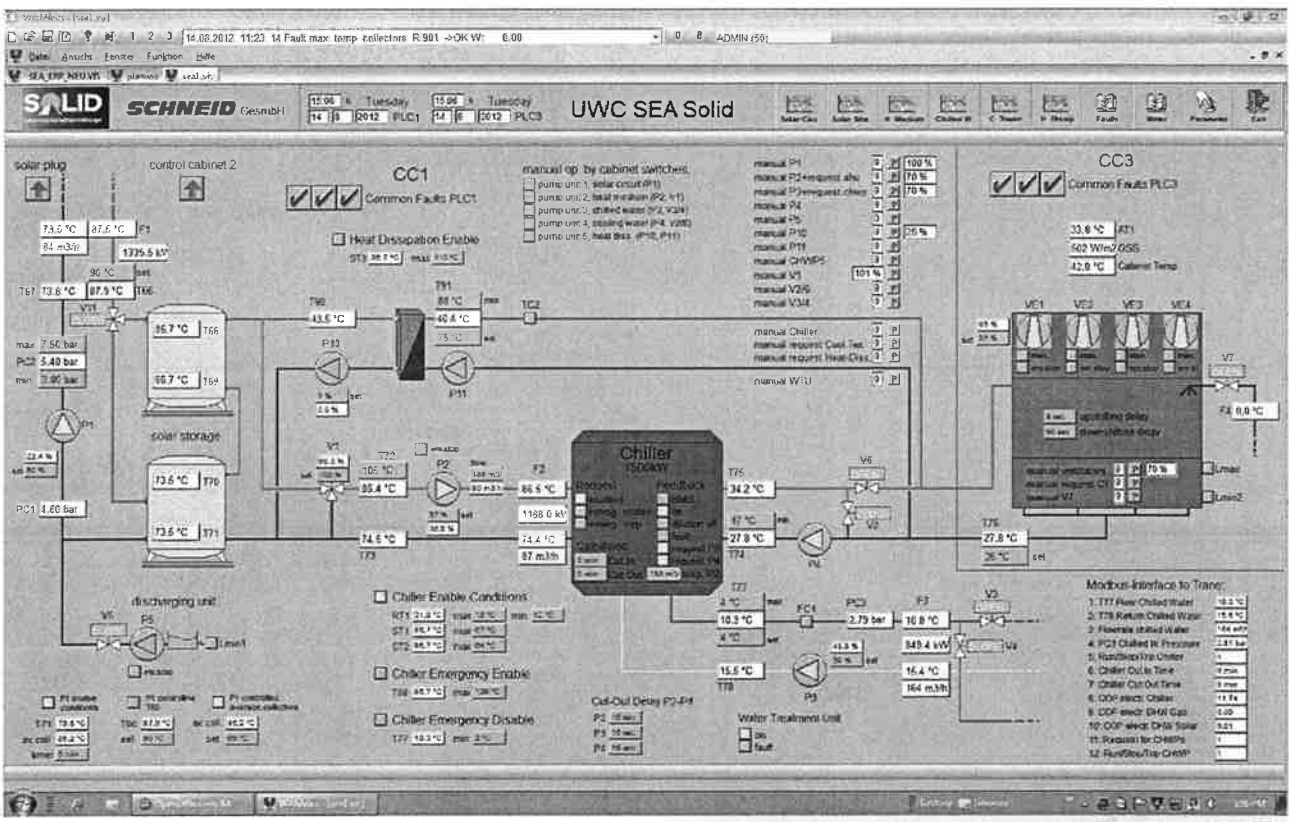
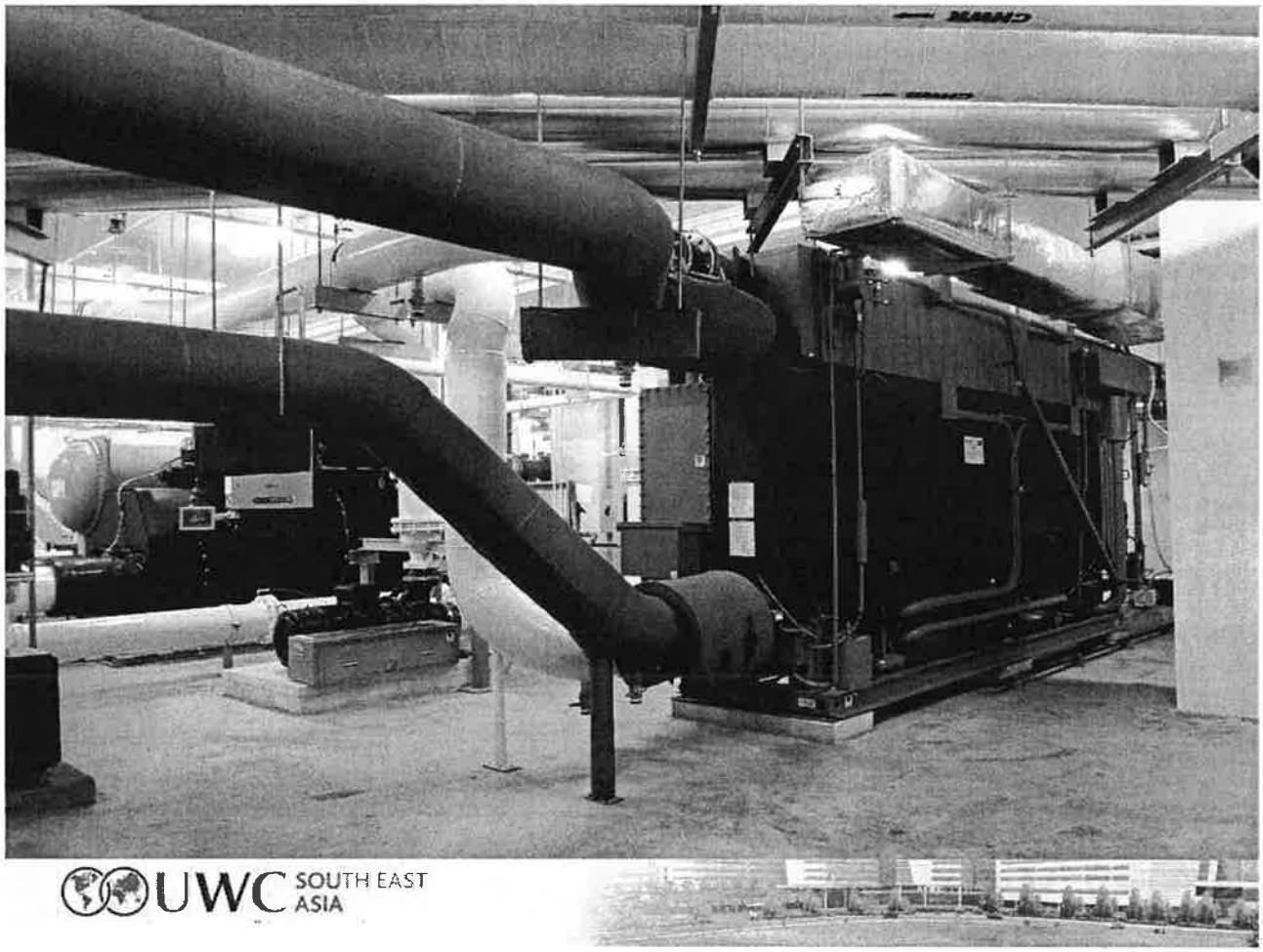
UWC SOUTH EAST ASIA



UWC SOUTH EAST ASIA



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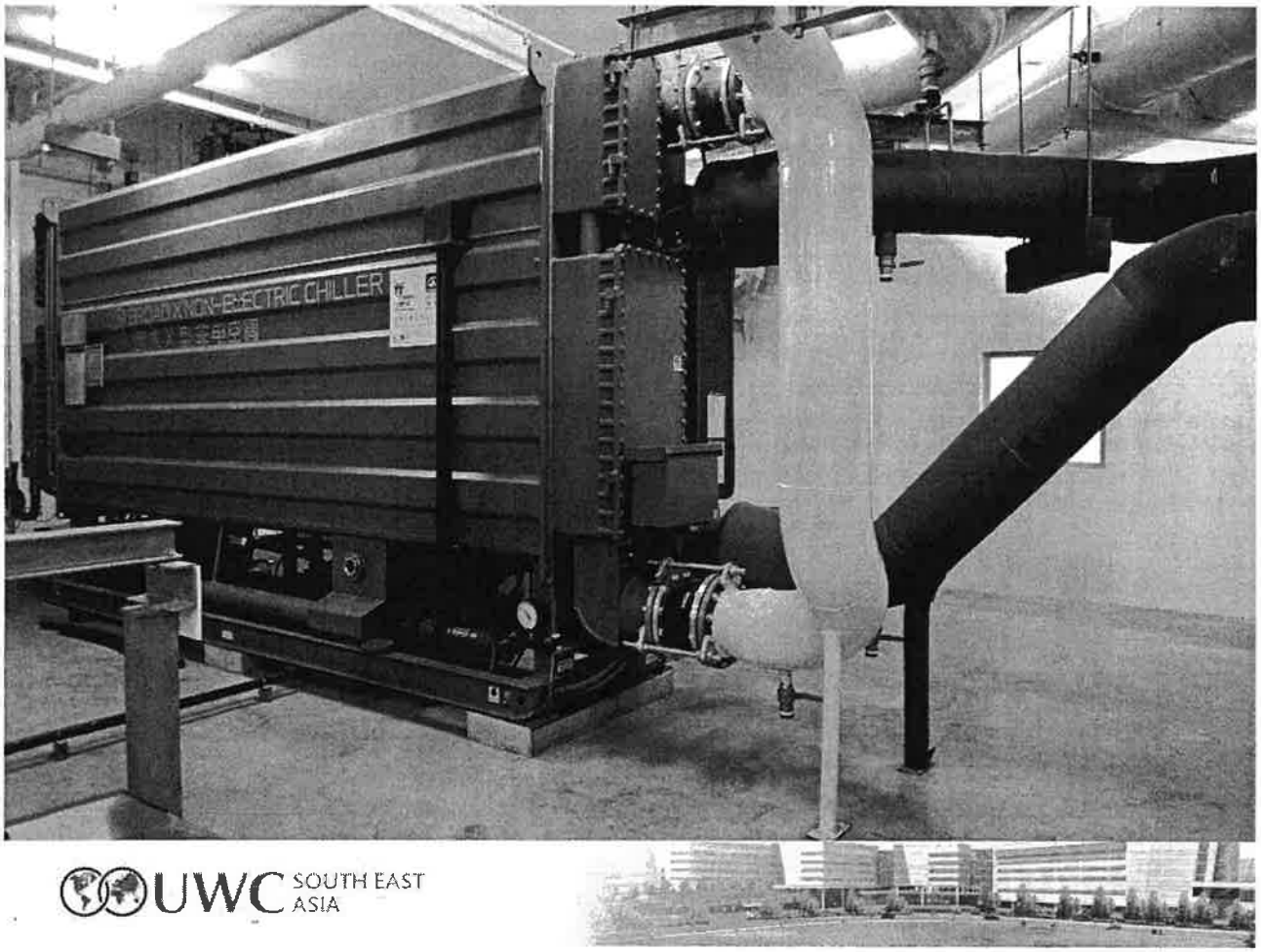

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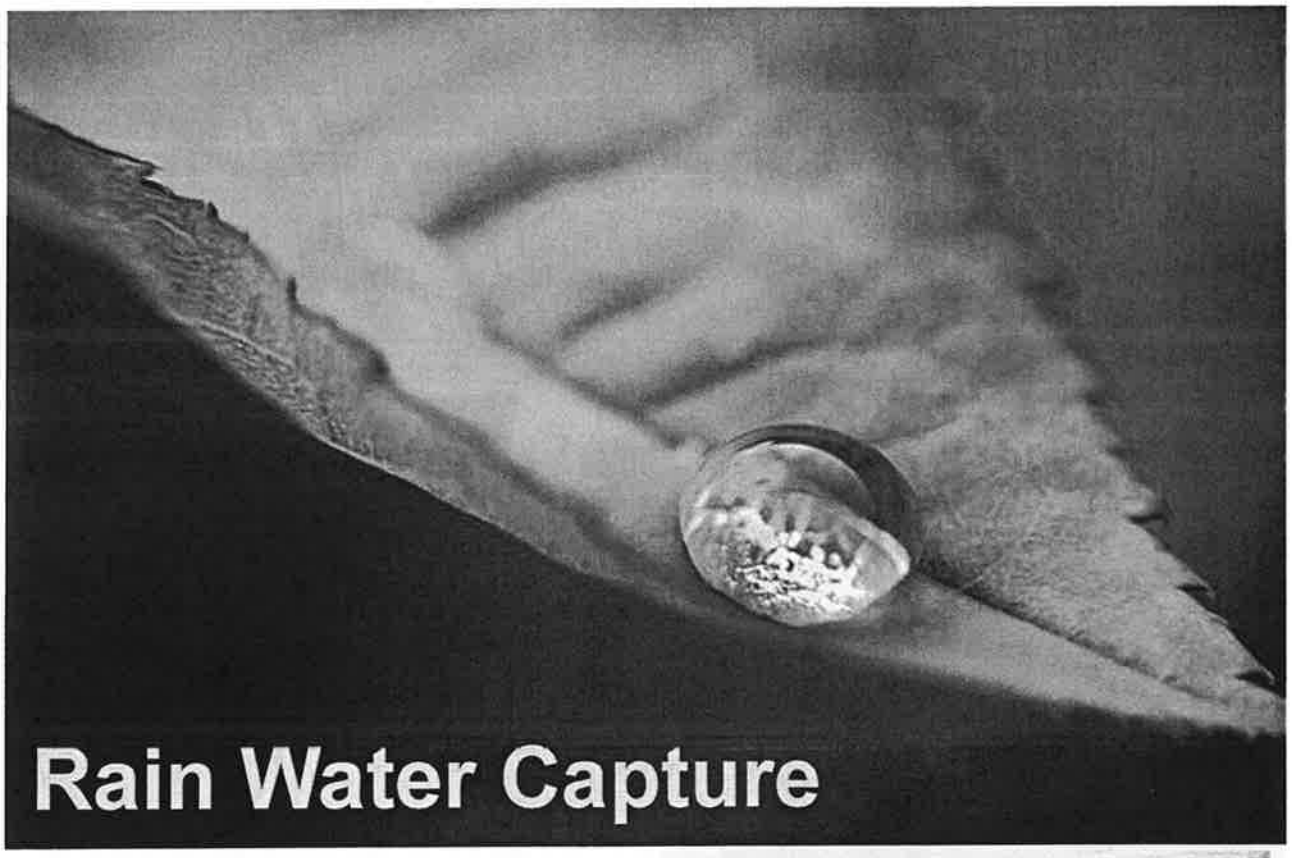
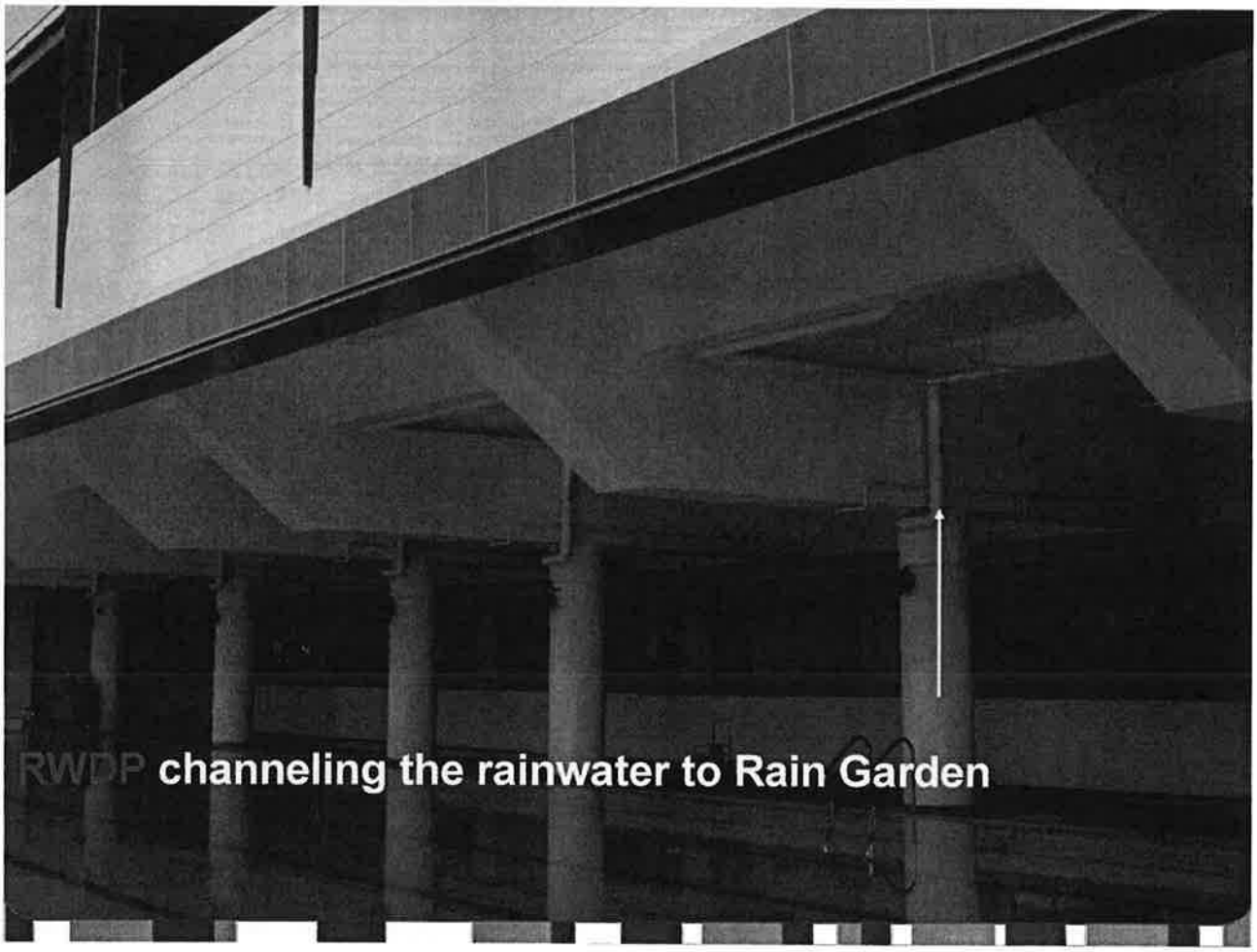


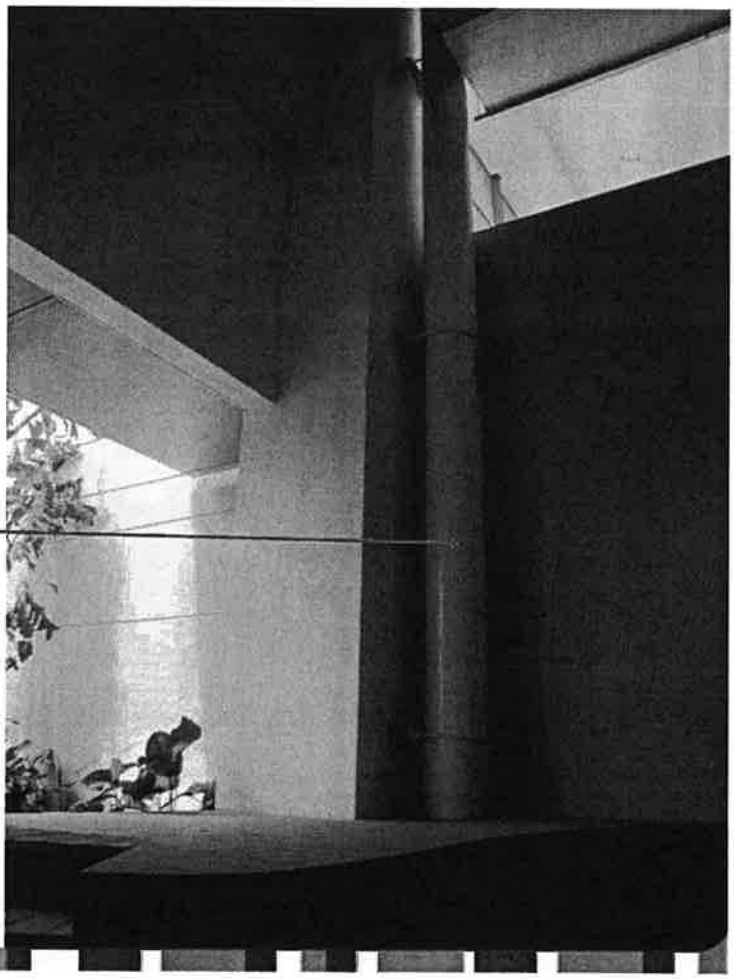
Rain Water Capture

UWC SOUTH EAST ASIA





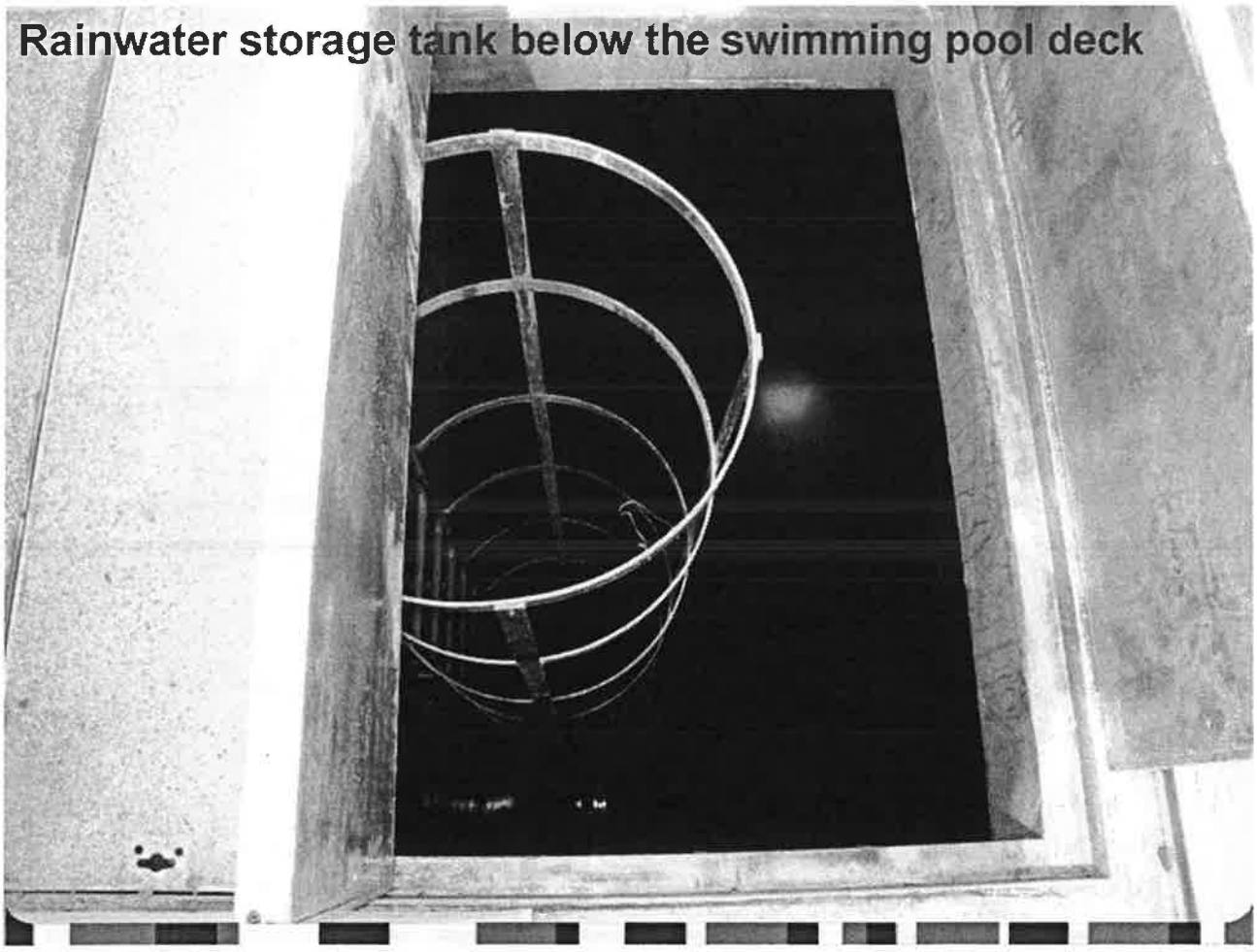


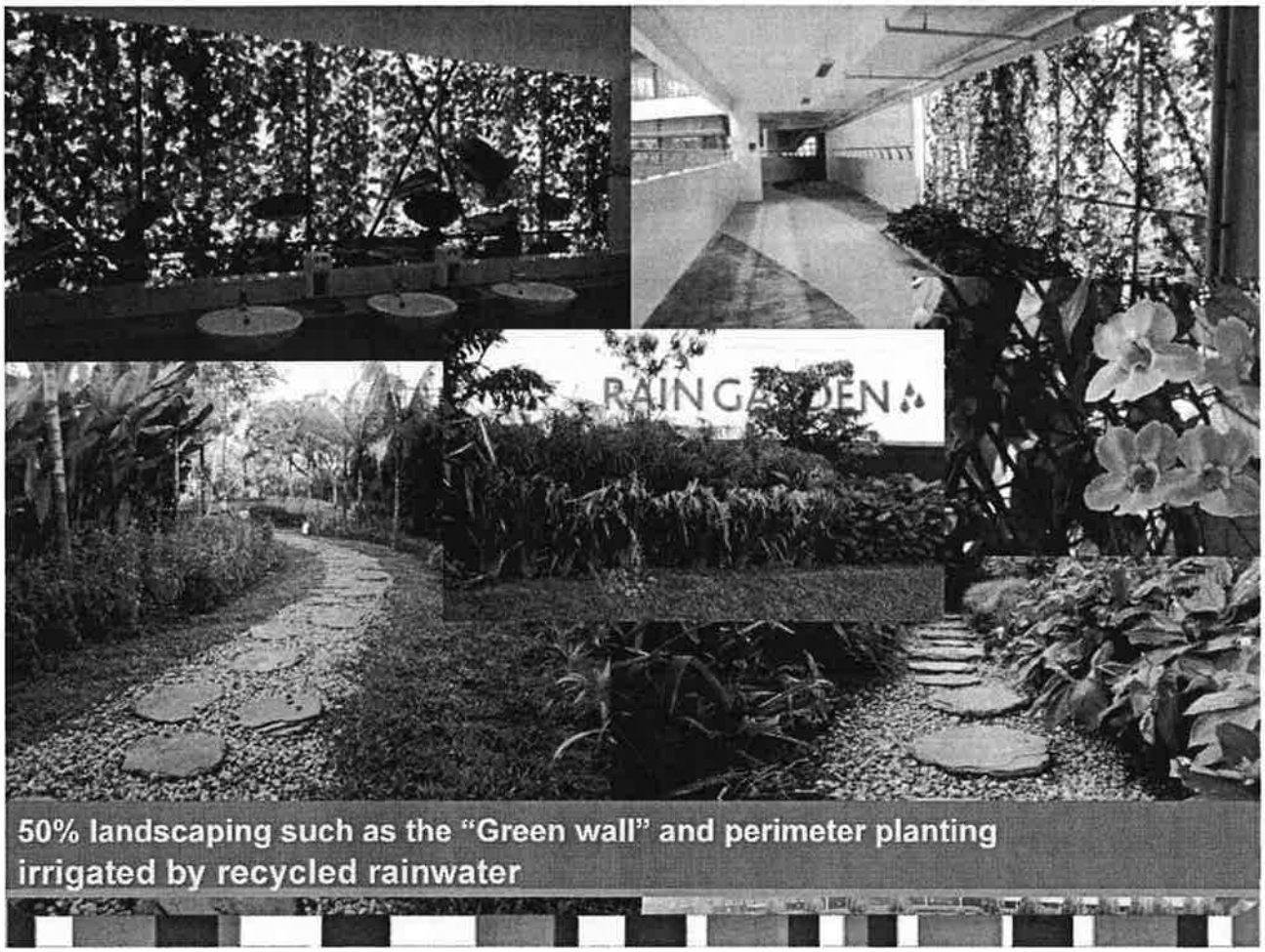


Main RWDP linking the drains at field level to the Rain Garden

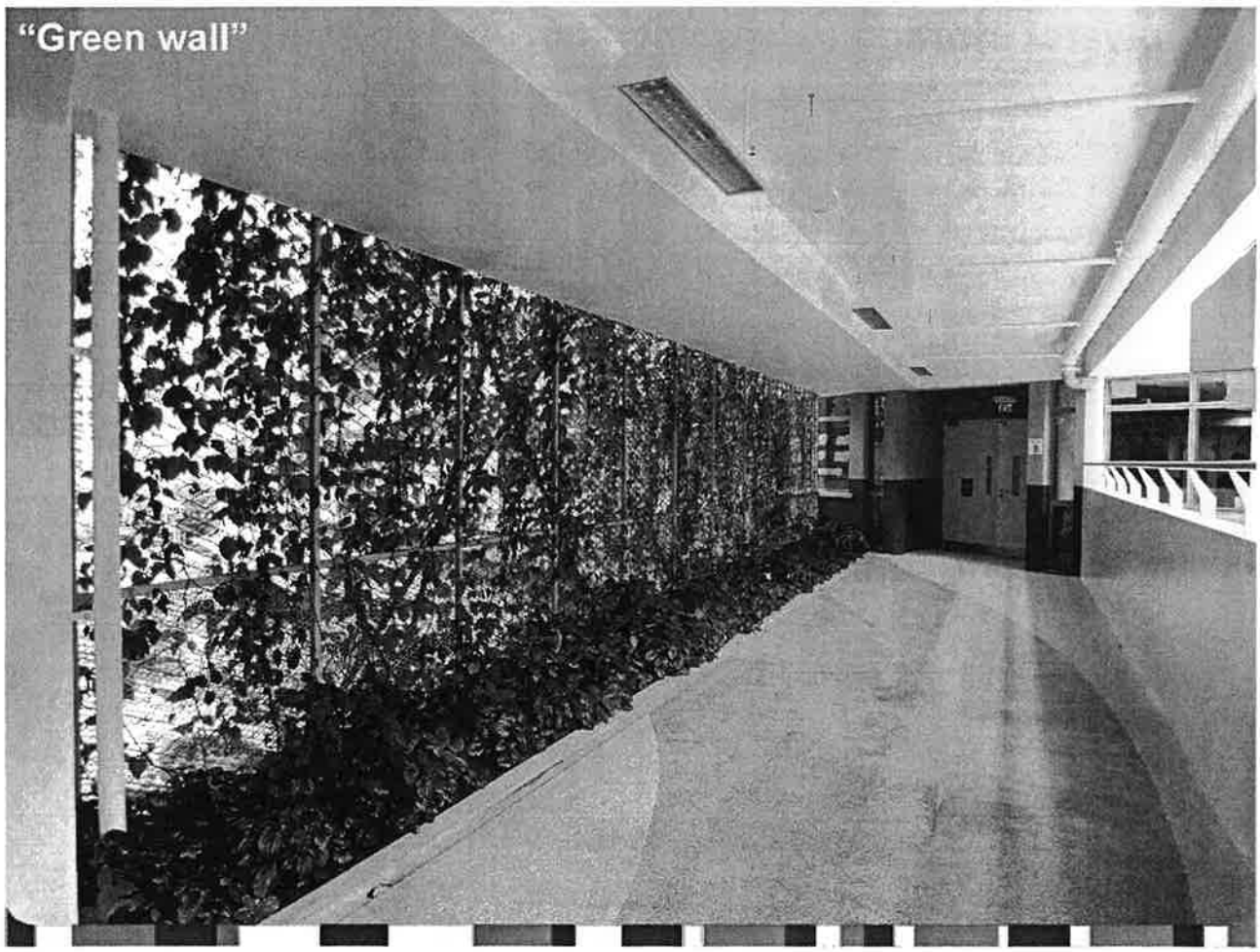
UWC SOUTH EAST ASIA


UWCSEA RAIN GARDEN


Rainwater storage tank below the swimming pool deck



50% landscaping such as the "Green wall" and perimeter planting irrigated by recycled rainwater



Date	Executive Summary for UWCSEA East Chiller Plant								
	Monthly Total Usage		Monthly Average Efficiency		Monthly Cooling Tower Water Usage		Cost per Ton base on $0.26kWh	Saving compare to other plant (kWh)	Saving ($)
	kWh	RT h	kW/RT	COP	Total m³	Liter/RT	$/RT	Base on 0.8kW/RT	Base on $0.26kWh
2011 Jun	83317.5	116509.1	0.715	4.9	719.2	6.173	0.186	9890 kWh	$2,571
Nov	177696.8	296561.1	0.599	5.9	1857.7	6.264	0.156	59552 kWh	$15,484
Dec	117865.7	189418.3	0.622	5.7	1227.3	6.479	0.162	33869 kWh	$8,754
2012 Jan	123850.1	204230.5	0.606	5.8	1341.8	6.570	0.158	39534 kWh	$10,279
Feb	166007.2	282820.2	0.587	6.0	1896.4	6.705	0.153	60249 kWh	$15,665
Mar	179174.3	309657.4	0.579	6.1	1890.7	6.106	0.150	68552 kWh	$17,823
Apr	127750.4	217463.1	0.587	6.0	1472.5	6.771	0.153	46220 kWh	$12,017
May	190676.5	329037.1	0.579	6.1	2192.2	6.663	0.151	72553 kWh	$18,864
Jun	146755.1	251669.9	0.583	6.0	1723.9	6.850	0.152	54581 kWh	$14,191
Jul	92924.2	158400.8	0.587	6.0	985.3	6.220	0.153	33796 kWh	$8,787
Aug	197158.3	347581.0	0.567	6.2	1987.1	5.717	0.147	80907 kWh	$21,036
Sept	184023.9	320378.1	0.574	6.1	1871.9	5.843	0.149	72279 kWh	$18,792
Oct	154610.8	267153.1	0.579	6.1	1510.9	5.656	0.150	59112 kWh	$15,369
Nov	196935.2	335387.5	0.587	6.0	1897.8	5.659	0.153	71375 kWh	$18,557
Dec	134982.7	233786.7	0.577	6.1	1165.3	4.984	0.150	52047 kWh	$13,532
2013 Jan	174239.1	306317.4	0.569	6.2	1623.0	5.298	0.148	70815 kWh	$18,412
Feb	134423.0	236161.1	0.569	6.2	1184.9	5.017	0.148	54506 kWh	$14,172
Mar	196683.0	341397.0	0.576	6.1	1965.0	5.756	0.150	76435 kWh	$19,873
Apr	162652.8	277299.0	0.587	6.0	1722.5	6.212	0.153	59186 kWh	$15,388
May	198267.9	345107.0	0.575	6.1	1828.0	5.297	0.149	77818 kWh	$20,233
Jun	153754.3	263444.1	0.584	6.0	1618.3	6.143	0.152	57001 kWh	$14,820
Jul	130754.2	218660.3	0.598	5.9	1133.7	5.185	0.155	44174 kWh	$11,485
Aug	164819.7	286432.6	0.575	6.1	1564.8	5.463	0.150	64328 kWh	$16,725
Sep	183946.4	319085.4	0.576	6.1	1761.3	5.520	0.150	71322 kWh	$18,544

UWC SOUTH EAST ASIA



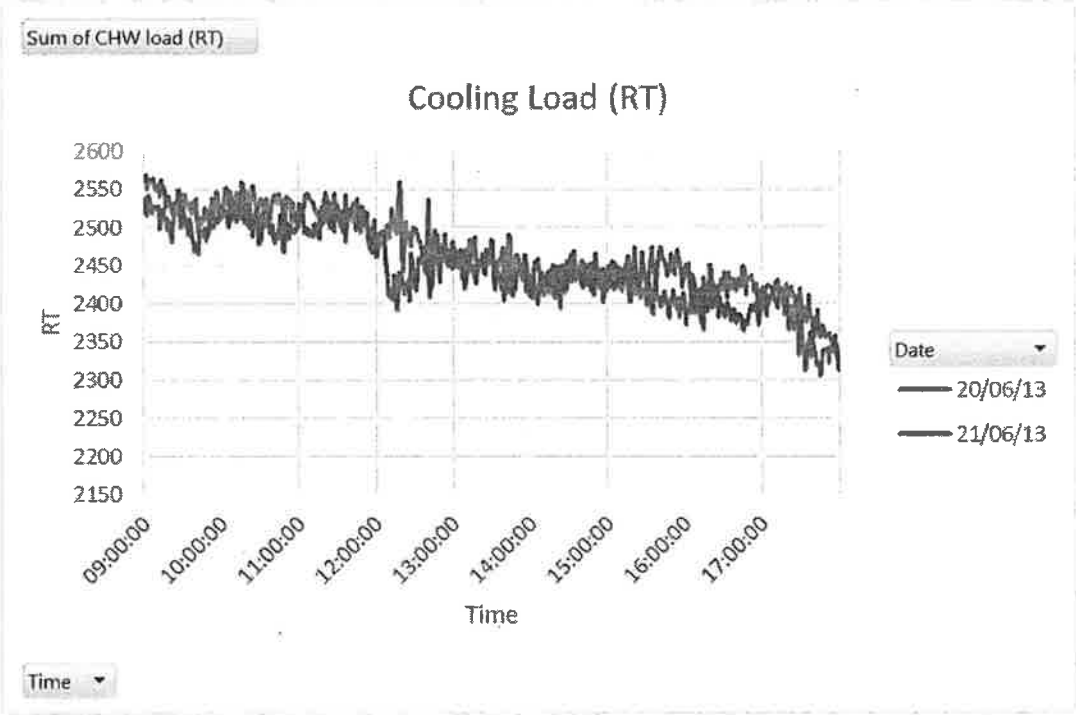
THANK YOU.

UWC SOUTH EAST ASIA

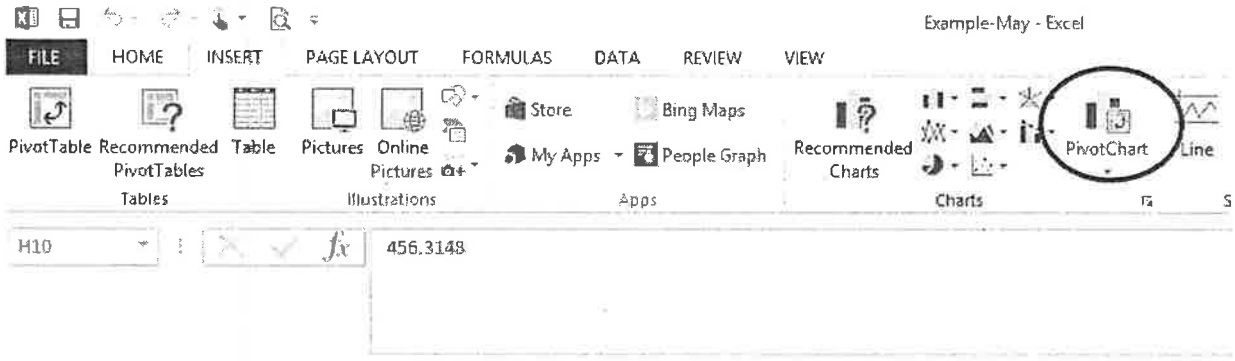


OSE report excel screenshots

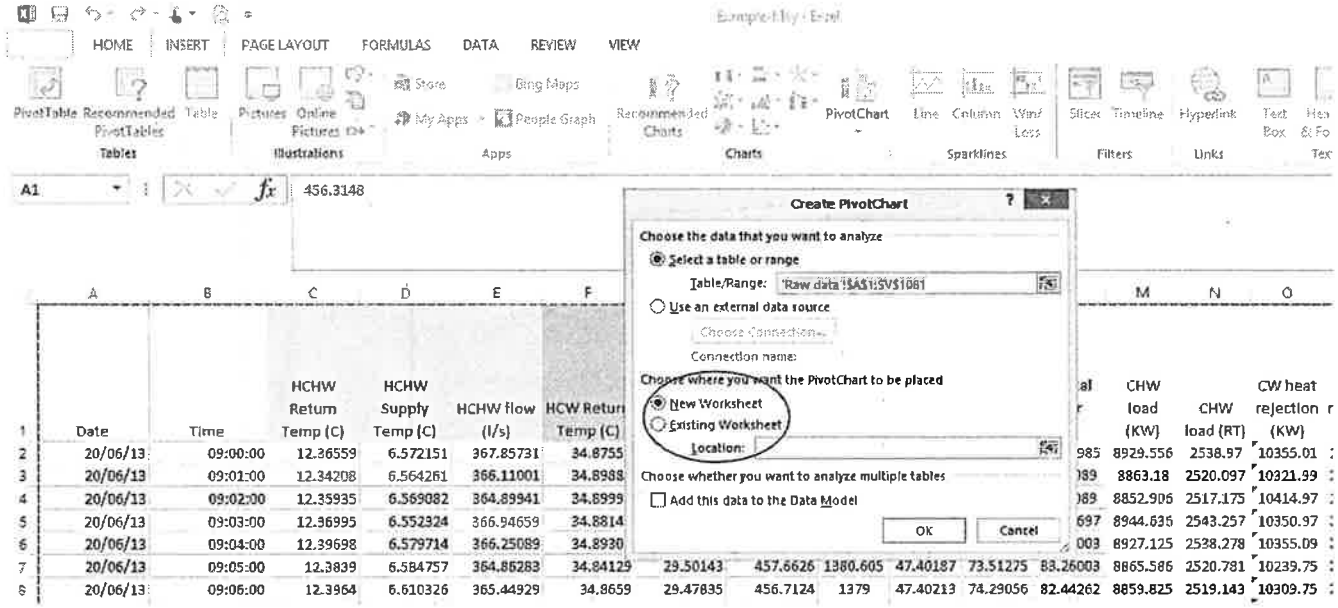
Cooling Load (RT)



Insert > PivotChart



Create Pivot Chart > Select a table or range , save as new worksheet



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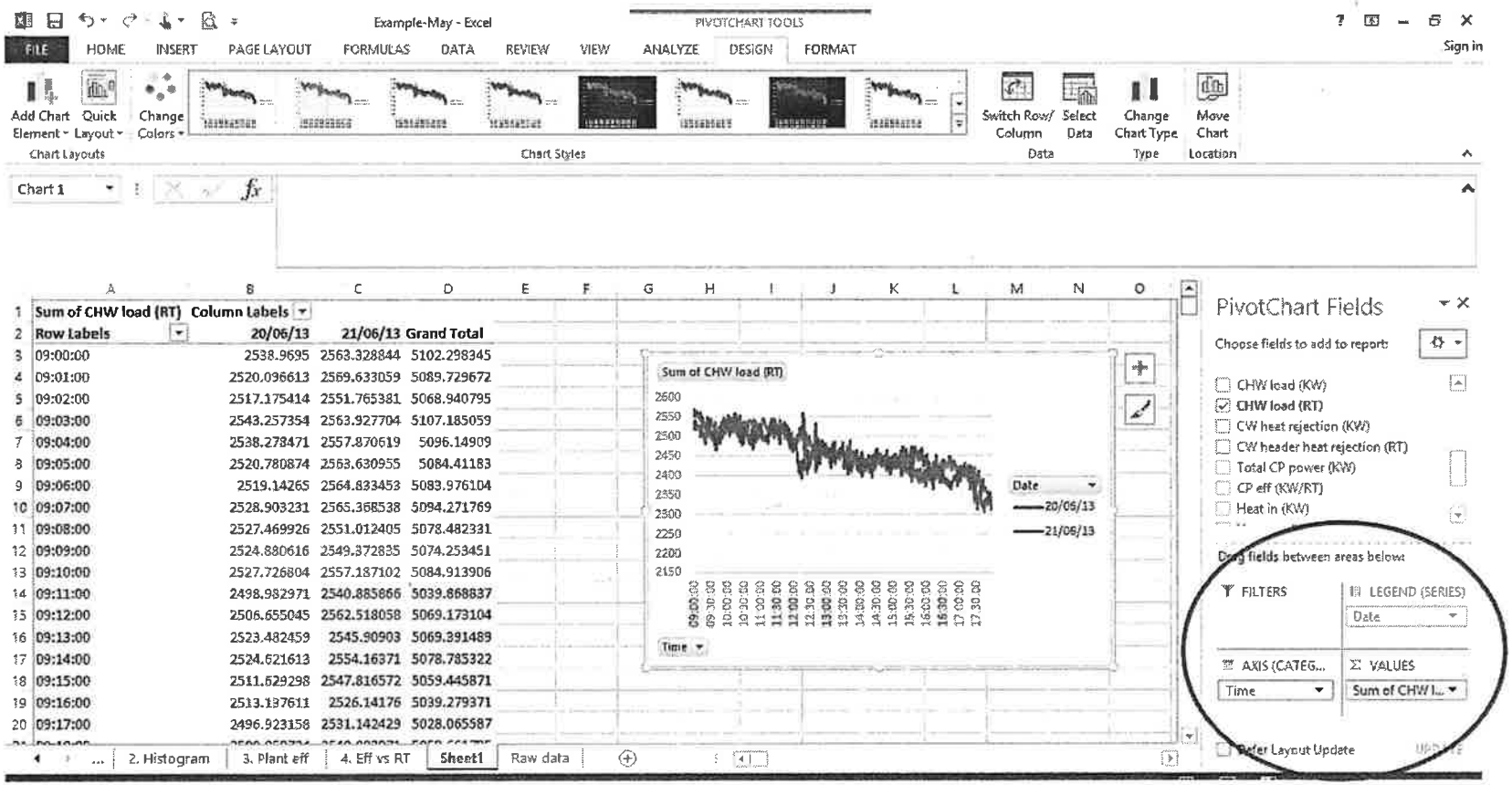
>Drag **Time** to AXIS , **Date** as LEGEND , **CHW Load RT** to VALUES



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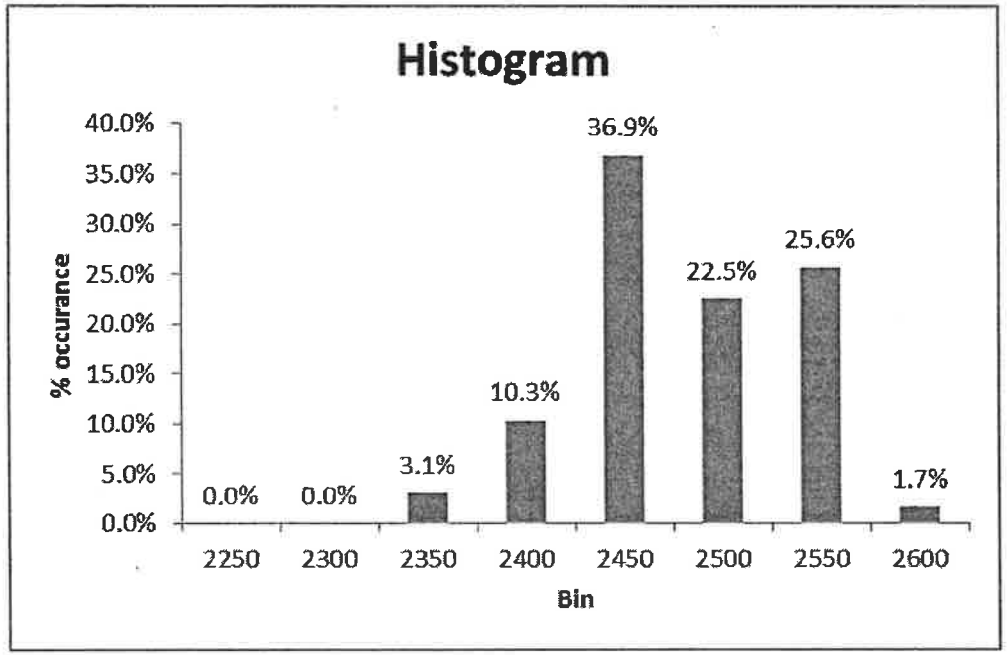
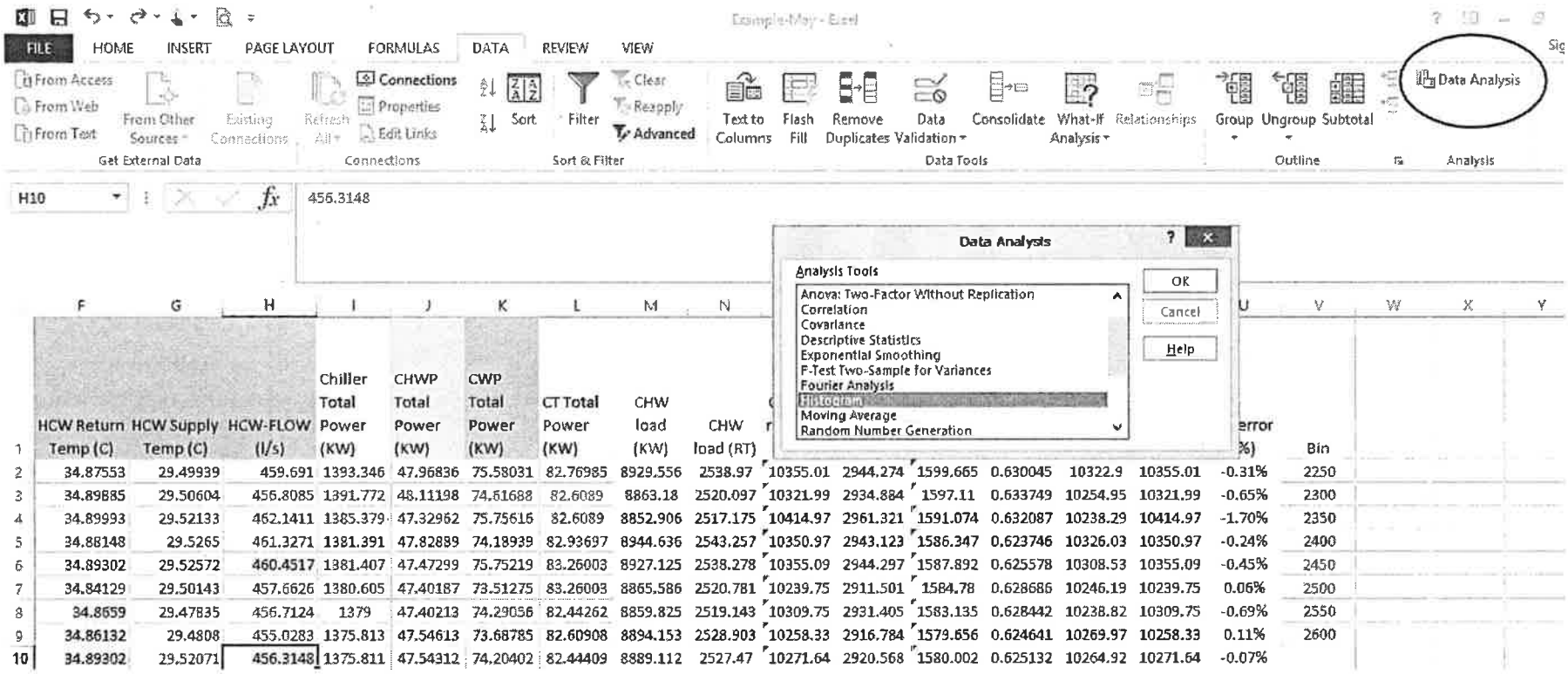
Frequency of Cooling Load Occurrence



Data Analysis > Histogram



	F	G	H	I	J	K	L	M	N	U	V	W	X	Y
1	HCW Return Temp (C)	HCW Supply Temp (C)	HCW-FLOW (l/s)	Chiller Total Power (KW)	CHWP Total Power (KW)	CWP Total Power (KW)	CT Total Power (KW)	CHW load (KW)	CHW load (RT)	error %)	Bin			
2	34.87553	29.49939	459.691	1393.346	47.96836	75.58031	82.76985	8929.556	2538.97	-0.31%	2250			
3	34.89885	29.50604	456.8085	1391.772	48.11198	74.61688	82.6089	8863.18	2520.097	-0.65%	2300			
4	34.89993	29.52133	462.1411	1385.379	47.32962	75.75616	82.6089	8852.906	2517.175	-1.70%	2350			
5	34.88148	29.5265	461.3271	1381.391	47.82889	74.18939	82.93697	8944.636	2543.257	-0.24%	2400			
6	34.89302	29.52572	460.4517	1381.407	47.47299	75.75219	83.26003	8927.125	2538.278	-0.45%	2450			
7	34.84129	29.50143	457.6626	1380.605	47.40187	73.51275	83.26003	8865.586	2520.781	0.06%	2500			
8	34.8659	29.47835	456.7124	1379	47.40213	74.29056	82.44262	8859.825	2519.143	-0.69%	2550			
9	34.86132	29.4808	455.0283	1375.813	47.54613	73.68785	82.60908	8894.153	2528.903	0.11%	2600			
10	34.89302	29.52071	456.3148	1375.811	47.54312	74.20402	82.44409	8889.112	2527.47	-0.07%				

										10355.01	2944.274	1599.665	0.630045	10322.9	10355.01
										10321.99	2934.884	1597.11	0.633749	10254.95	10321.99
										10414.97	2961.321	1591.074	0.632087	10238.29	10414.97
										10350.97	2943.123	1586.347	0.623746	10326.03	10350.97
										10355.09	2944.297	1587.892	0.625578	10308.53	10355.09
										10239.75	2911.501	1584.78	0.628686	10246.19	10239.75
										10309.75	2931.405	1583.135	0.628442	10238.82	10309.75
										10258.33	2916.784	1579.656	0.624641	10269.97	10258.33
										10271.64	2920.568	1580.002	0.625132	10264.92	10271.64

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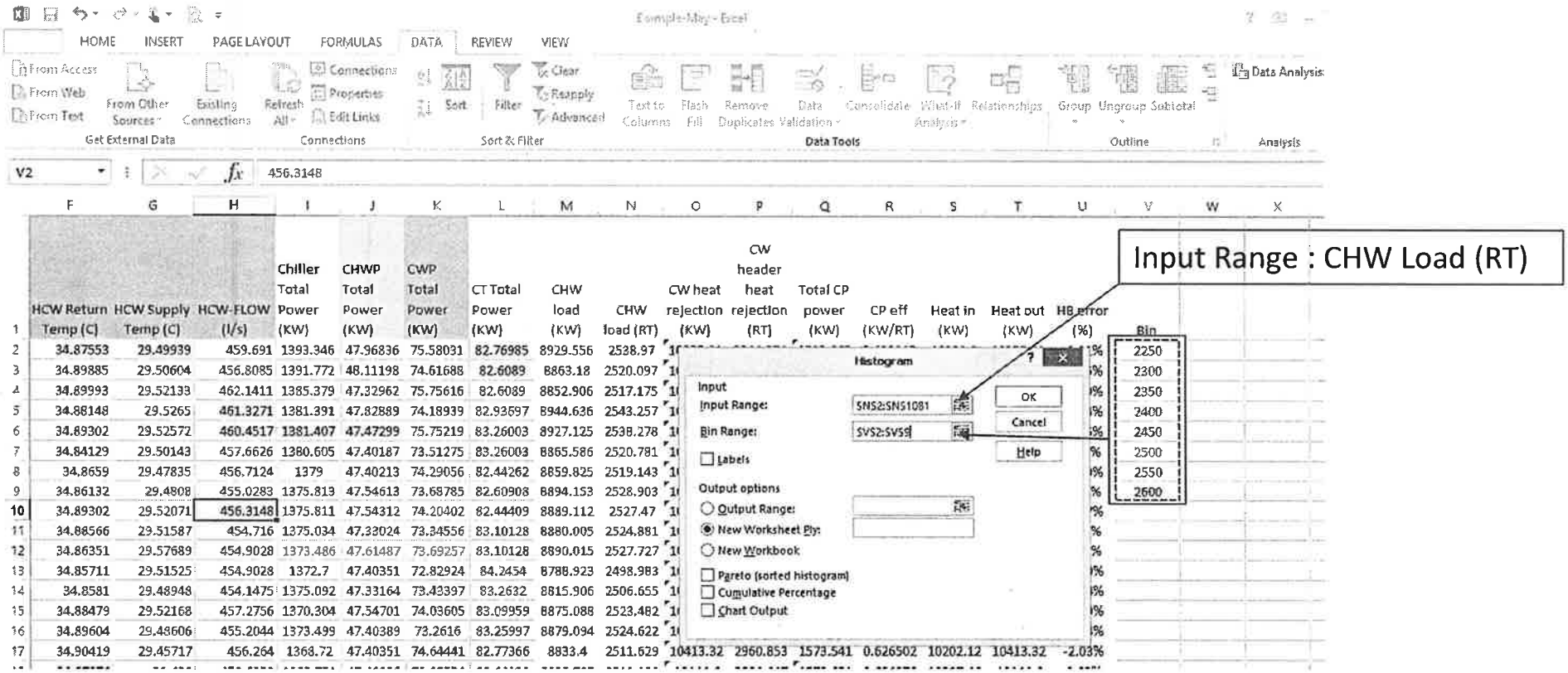
>Select the Range and save as new worksheet



	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	HCW Return Temp (C)	HCW Supply Temp (C)	HCW-FLOW (l/s)	Chiller Total Power (KW)	CHWP Total Power (KW)	CWP Total Power (KW)	CT Total Power (KW)	CHW load (KW)	CHW load (RT)	CW heat rejection (KW)	CW header heat rejection (RT)	Total CP power (KW)	CP eff (KW/RT)	Heat in (KW)	Heat out (KW)	HB error (%)	Bin
2	34.87553	29.49939	459.691	1393.346	47.96836	75.58031	82.76985	8929.556	2538.97								2250
3	34.89885	29.50604	456.8085	1391.772	48.11198	74.61688	82.6089	8863.18	2520.097								2300
4	34.89993	29.52133	462.1411	1385.379	47.32962	75.75616	82.6089	8852.906	2517.175								2350
5	34.88148	29.5265	461.3271	1381.391	47.82889	74.18939	82.93697	8944.636	2543.257								2400
6	34.89302	29.52572	460.4517	1381.407	47.47299	75.75219	83.26003	8927.125	2538.278								2450
7	34.84129	29.50143	457.6626	1380.605	47.40187	73.51275	83.26003	8865.586	2520.781								2500
8	34.8659	29.47835	456.7124	1379	47.40213	74.29056	82.44262	8859.825	2519.143								2550
9	34.86132	29.4808	455.0283	1375.813	47.54613	73.68785	82.60908	8894.153	2528.903								2600
10	34.89302	29.52071	456.3148	1375.811	47.54312	74.20402	82.44409	8889.112	2527.47								
11	34.88566	29.51587	454.716	1375.034	47.33024	73.34556	83.10128	8880.005	2524.881								
12	34.86351	29.57689	454.9028	1373.486	47.61487	73.69257	83.10128	8890.015	2527.727								
13	34.85711	29.51525	454.9028	1372.7	47.40351	72.82924	84.2454	8788.923	2498.983								
14	34.8581	29.48948	454.1475	1375.092	47.33164	73.43397	83.2632	8815.906	2506.655								
15	34.88479	29.52168	457.2756	1370.304	47.54701	74.03605	83.09959	8875.088	2523.482								
16	34.89604	29.48606	455.2044	1373.499	47.40389	73.2616	83.25997	8879.094	2524.622								
17	34.90419	29.45717	456.264	1368.72	47.40351	74.64441	82.77366	8833.4	2511.629	10413.32	2960.853	1573.541	0.626502	10202.12	10413.32	-2.03%	

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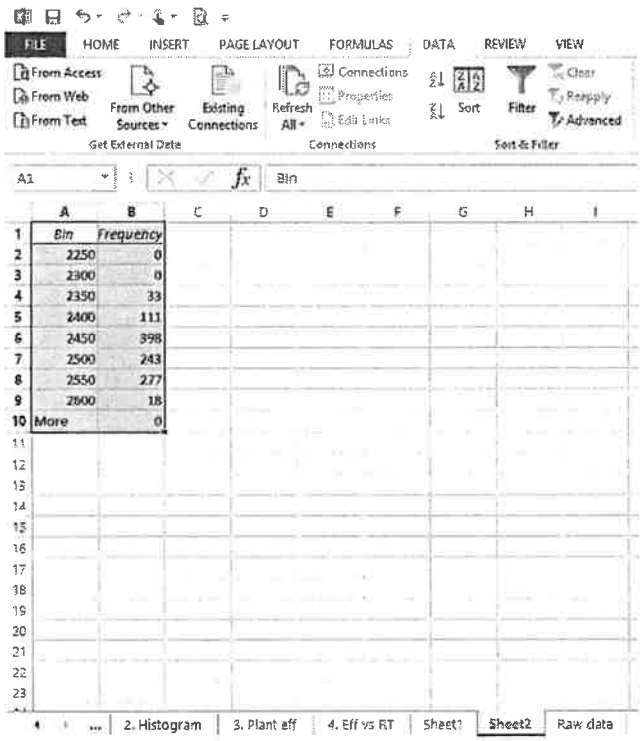
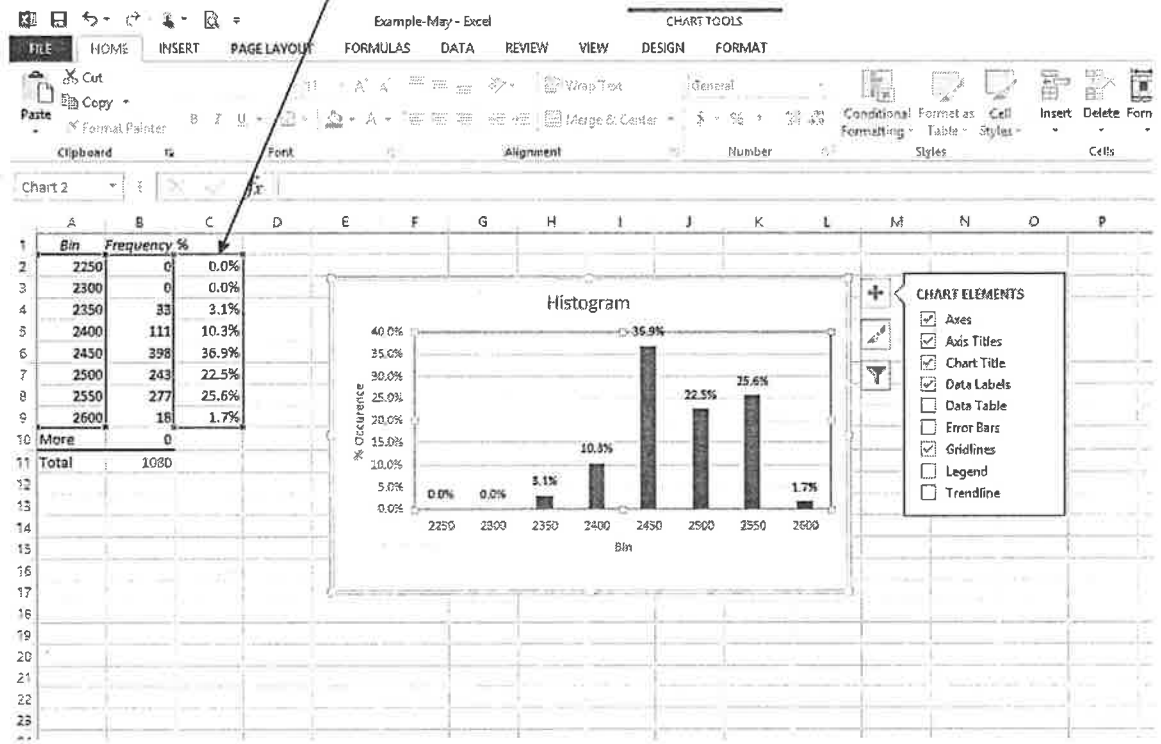
% Occurrence = Frequency/Total

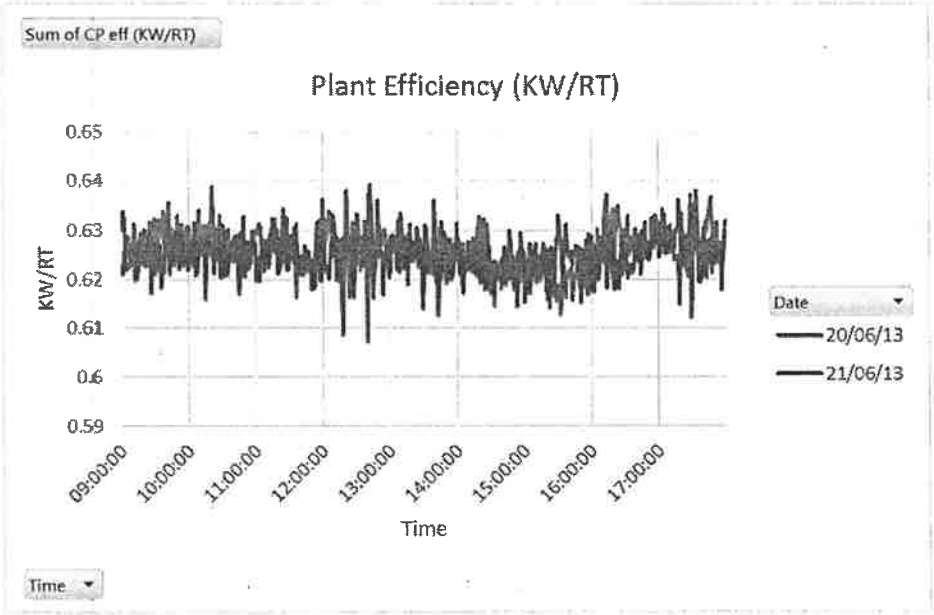


	A	B
1	Bin	Frequency
2	2250	0
3	2300	0
4	2350	33
5	2400	111
6	2450	398
7	2500	243
8	2550	277
9	2600	18
10	More	0



	A	B	C
1	Bin	Frequency	%
2	2250	0	0.0%
3	2300	0	0.0%
4	2350	33	3.1%
5	2400	111	10.3%
6	2450	398	36.9%
7	2500	243	22.5%
8	2550	277	25.6%
9	2600	18	1.7%
10	More	0	
11	Total	1080	

Plant Efficiency (KW/RT)



Measurement & Verification Pte Ltd
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Drag CP eff (KW/RT) to VALUES box

