

**MEASUREMENT & VERIFICATION (M&V) GUIDELINES**  
**FOR CENTRAL AIR-CONDITIONING PLANT**

(Reference: Green Mark for Non-residential Building Version 4.0)

**(1) Instrumentation for Monitoring Central Water Cooled Chilled - Water Plant Efficiency**

The instrumentation shall have the capability to calculate resultant chilled water plant efficiency within  $\pm 5\%$  of the true value and in accordance with ASHRAE Guide 22 and AHRI 550/590. The methodology for determining the total uncertainty of measurement shall be computed using the root-sum square formula as follows:

$$\text{Error}_{\text{rms}} = \sqrt{\sum (U_N)^2}$$

where  $U_N$  = individual uncertainty of variable N (%)

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

In deriving the measurement errors contributed by flow meters, an additional 1% is to be included in the computation.

The following instrumentation and installation are also required to be complied with:-

- (a) Location and installation of the measuring devices to meet the manufacturer's recommendation.
- (b) Data Acquisition system i.e. Analog-to-digital or A/D converter used shall have a minimum resolution of 16 bit.
- (c) All data logging with capability to trend at 1 minute sampling time interval.
- (d) Flow meters for chilled-water and condenser water loop shall be ultrasonic / full bore magnetic type or equivalent.
- (e) Temperature sensors with minimum accuracy of  $\pm 0.05\text{ }^\circ\text{C}$  @  $0^\circ\text{C}$ . All thermo-wells shall be installed in a manner which ensures that the sensors can be in direct contact with fluid flow. 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 accuracy.

**(2) Verification of central chilled water plant instrumentation : Heat balance – substantiating test**

The verification of chilled water plant instrument using the heat balance - substantiating test shall be in accordance to AHRI 550/590. The heat balance shall be conducted over the entire normal operating hours with more than 80% of the computed heat balance within  $\pm 5\%$  over the audit period.

It should be carried out one-year after building operation or before statutory completion of project whichever is earlier.

The heat balance is represented by the following equation:

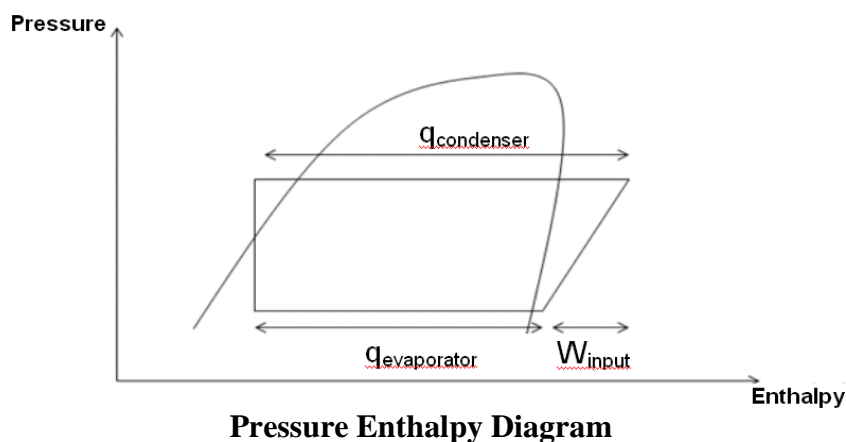
$$Q_{\text{condenser}} = Q_{\text{evaporator}} + W_{\text{input}}$$

where  $q_{\text{condenser}}$  = heat rejected

$q_{\text{evaporator}}$  = cooling load

$W_{\text{input}}$  = measured electrical power input to compressor

The pressure enthalpy diagram below shows the concept of heat balance equation in a vapour compression cycle.



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

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

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

$$\begin{aligned} \text{Input power (measured)} &= 100\text{kW} \\ \text{Motor rated efficiency } (\eta) &= 90\% \\ \text{Adjusted } W_{\text{input}} &= 100\text{kW} \times 90\% \\ &= 90\text{kW} \end{aligned}$$

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 pump efficiency values provided by the manufacturer. An example is illustrated as follows:

$$\begin{aligned}
 \text{Motor input power (measured)} &= 30\text{kW} && \text{(A)} \\
 \text{Motor rated efficiency } (\eta) &= 90\% && \text{(B)} \\
 \text{Pump rated efficiency } (\eta) &= 80\% && \text{(C)} \\
 \text{Hydraulic losses} &= (\text{A}) \times (\text{B}) \times [(100\% - (\text{C}))] \\
 &= 30\text{kW} \times 90\% \times (100\% - 80\%) \\
 &= 5.4\text{kW} \\
 \text{Adjusted } W_{\text{input}} &= kW_i (\text{chillers}) + 5.4\text{kW}
 \end{aligned}$$

**(3) Documentary evidences to be submitted with the Audit Report**

- (a) Calculation of the overall uncertainty of measurement of the resultant chiller plant efficiency in kW/RT to be within  $\pm 5\%$  of the true value based on instrumentation specifications.
- (b) Instruments' calibration certificates from accredited laboratory or batch calibration certificates from manufacturers.
- (c) Chiller plant room plan layouts showing the details of the instruments' locations and the types of instrumentation used.
- (d) Summary of instruments, standards and measurement accuracy to be presented in the following format.

Instruments	Instruments Calibration Standards	Quantity	Measurement Error (% of Reading)	Resultant Error (% kW/RT)	Type / Brand / Model
Temperature Sensors					
Flow Meters / Sensors					
Power Meter					

**(4) References**

- (a) ASHRAE Guideline 22 – Instrumentation for Monitoring Central Chilled-Water Plant Efficiency
- (b) AHRI Standard 550/590 – Performance Rating of Water- Chilling Packages Using The Vapor Compression Cycle

(c) Instrumentation Accuracy

As instrumentation accuracies stated in calibration certificates and technical specifications are based on controlled conditions in a laboratory, it is necessary to allow for onsite deviations and measurements. The following instrumentation accuracy listed can be considered for the monitoring central water-cooled chilled-water plant efficiency.

Description	Measurement Error
Temperature Sensors - 10K/30K Thermistor - Platinum Resistance Thermometers	$\pm 0.03^{\circ}\text{C} - 0.05^{\circ}\text{C} @ 0^{\circ}\text{C}$
Flow Sensor / Meter - Ultrasonic - Full bore magnetic	$\pm 0.5 - 1\%$ over entire measurement range
Power Meter	ANSI C12.1-2008, Class 1 $\pm 1\%$

(5) Worked examples - Computation of overall uncertainty in the resulting chilled-water plant efficiency

Based on the selected instrumentation and manufacturers' specification, the individual uncertainties in the measurement of mass flow rate (by flow meter), electrical power input (by power meter) and the temperature difference (by temperature sensors) are as follows:-

Item	Description	Measurement Error (% of reading)
1	Flow Meter	$1\% \text{ see note (1)} + 1\%$ (i.e. 2%)
2	Power Meter	1%
3	Temperature sensors with accuracy of $\pm 0.05^{\circ}\text{C} @ 0^{\circ}\text{C}$	$1.79\% \text{ see note (2)}$
	Temperature difference ( $\Delta T$ )	

Note:

- (1) An additional 1% to be included in the computation of measurement errors for flow meter.
- (2) The measurement error (%) for temperature sensors is calculated based on on the maximum possible difference for the design or actual delta T (i.e.  $\Delta T$ ). This maximum possible difference can be assumed to be twice the stated accuracy of the sensor. In this case,

$$\begin{aligned}
 \text{Temperature sensors with accuracy @ } 0^{\circ}\text{C} &= \pm 0.05^{\circ}\text{C} \\
 \text{Design/ Actual } \Delta T &= 5.6^{\circ}\text{C} \\
 \text{Measurement errors for } \Delta T &= (0.05^{\circ}\text{C} \times 2) / 5.6^{\circ}\text{C} \\
 &= 0.1^{\circ}\text{C} / 5.6^{\circ}\text{C} \\
 &= 1.79\%
 \end{aligned}$$

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

$$\begin{aligned}
 \text{Error}_{\text{rms}} &= \sqrt{(\sum (U_N)^2)} \\
 &= \sqrt{(2^2 + 1^2 + 1.79^2)} \\
 &= 2.86\%
 \end{aligned}$$

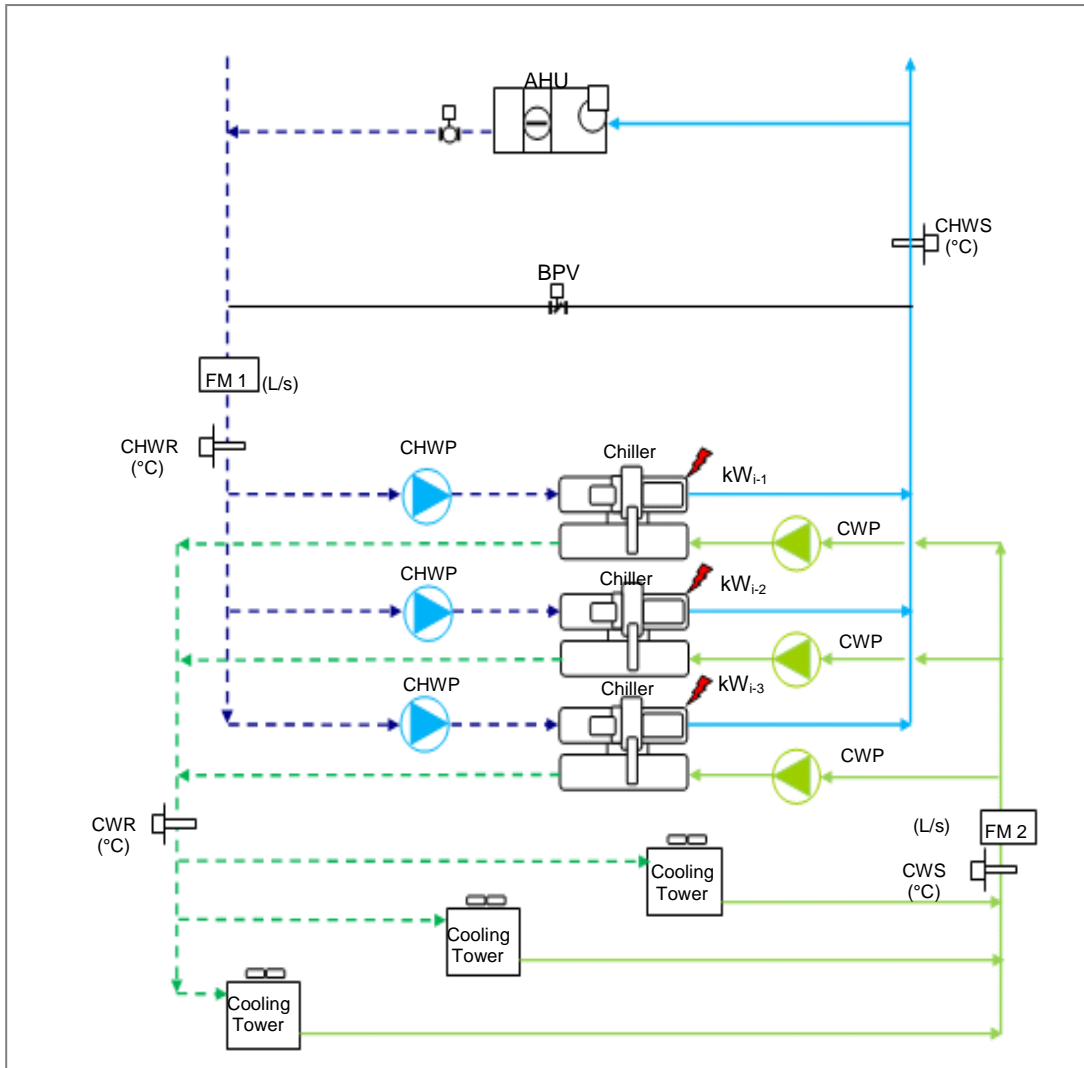
where  $U_N$  = individual uncertainty of variable N (%)

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

Therefore, the total uncertainty for the calculated chilled-water plant efficiency (kW/RT) is 2.86% which falls within the 5% of the true value.

**(6) Worked examples - Determining Heat Balance for Different Plant Configuration**

**(a) Plant A – Constant Primary Chilled-Water System**



A:  $q_{\text{evaporator}} = m \times C_p \times \Delta T = FM1 \times C_p \times (CHWR - CHWS)$

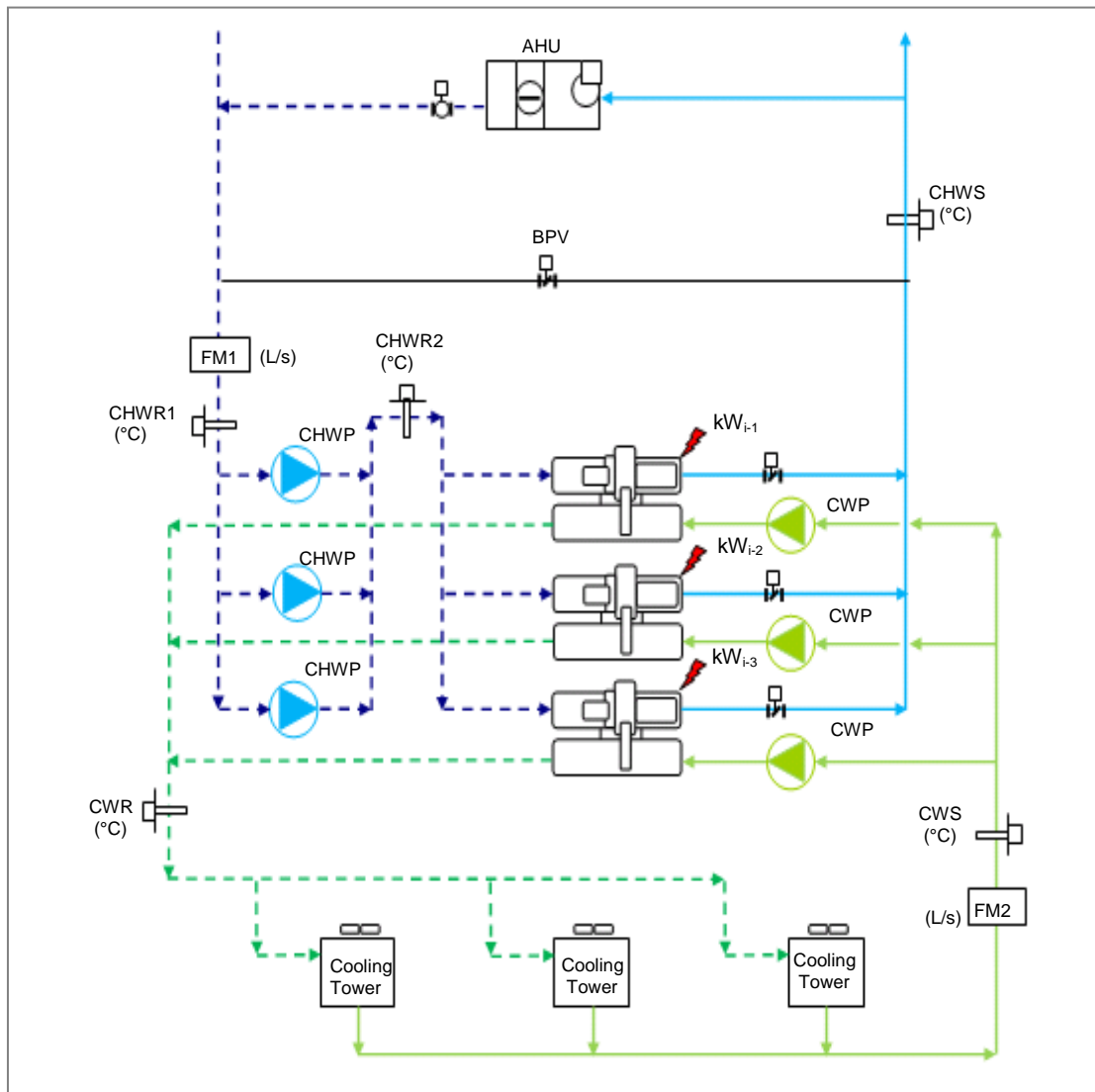
B:  $q_{\text{condenser}} = m \times C_p \times \Delta T = FM2 \times C_p \times (CWR - CWS)$

C:  $W_{\text{input}} = kW_{i-1} + kW_{i-2} + kW_{i-3}$

where  $C_p = 4.19 \text{ kJ/kg}\cdot^\circ\text{C}$  and density of chilled water is assumed to be  $1\text{ kg/l}$

Percent heat balance =  $[(A + C) - B] / B \times 100\%$

Note : 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.

**(b) Plant B – Variable Primary Chilled-Water System**

$$A: \quad q_{\text{evaporator}} = FM1 \times C_p \times (CHWR2 - CHWS)$$

$$B: \quad q_{\text{condenser}} = FM2 \times C_p \times (CWR - CWS)$$

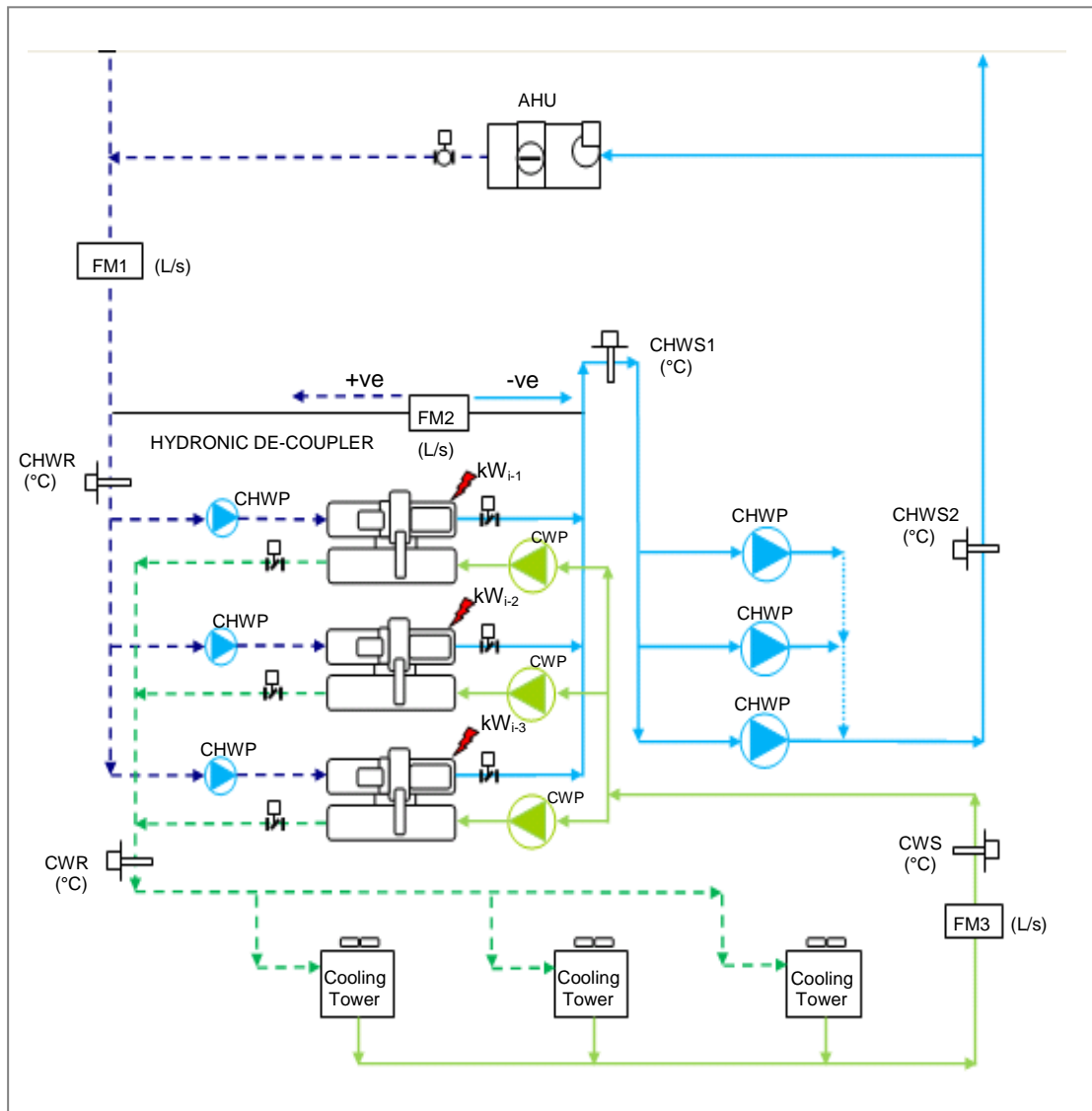
$$C: \quad W_{\text{input}} = kW_{i-1} + kW_{i-2} + kW_{i-3}$$

where  $C_p = 4.19 \text{ kJ/kg}\cdot\text{°C}$  and density of chilled water is assumed to be  $1\text{kg/l}$

$$\text{Percent heat balance} = [(A + C) - B] / B \times 100\%$$

Note: In the event where CHWR1 is used and heat balance exceeds  $\pm 5\%$ , 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.

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



A:  $q_{\text{evaporator}} = (FM1 + (+/-FM2)) \times Cp \times (CHWR - CHWS1)$

B:  $q_{\text{condenser}} = FM3 \times Cp \times (CWR - CWS)$

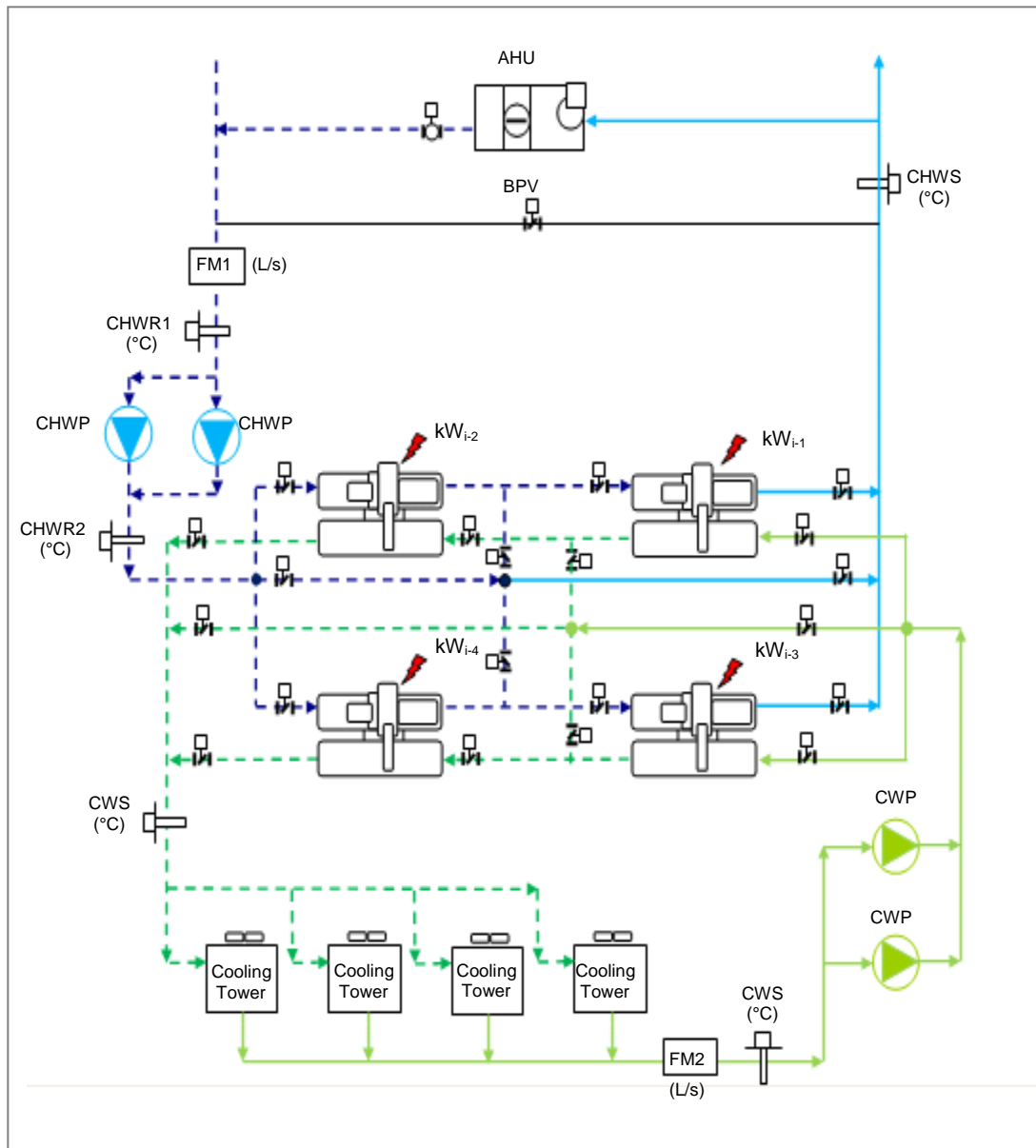
C:  $W_{\text{input}} = kW_{i-1} + kW_{i-2} + kW_{i-3}$

where  $Cp = 4.19 \text{ kJ/kg}\cdot^{\circ}\text{C}$  and density of chilled water is assumed to be  $1\text{kg/l}$

Percent heat balance =  $[(A + C) - B] / B \times 100\%$

Note: 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 certified gear losses and pump efficiency values provided by the manufacturer.

(d) Plant D – Series Counter Flow Chilled-Water System



A:  $q_{\text{evaporator}} = \text{FM1} \times C_p \times (\text{CHWR2} - \text{CHWS})$   
 B:  $q_{\text{condenser}} = \text{FM2} \times C_p \times (\text{CWR} - \text{CWS})$   
 C:  $W_{\text{input}} = kW_{i-1} + kW_{i-2} + kW_{i-3} + kW_{i-4}$

where  $C_p = 4.19 \text{ kJ/kg}\cdot^\circ\text{C}$  and density of chilled water is assumed to be  $1\text{kg/l}$

Percent heat balance =  $[(A + C) - B] / B \times 100\%$

Note: In the event where CHWR1 is used and heat balance exceeds  $\pm 5\%$ , 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.

**(7) Heat Balance Calculation**

The following example illustrates a successful heat balance where 80% of the computed heat balance falls within  $\pm 5\%$  as required.

	(a) Chilled water supply temperature	(b) Chilled water return temperature	(c) Chilled water flow rate	(d) Condenser water supply temperature	(e) Condenser water return temperature	(f) Condenser water flow rate	(g) Chiller kW	(h) Heat Gain	(i) Heat Rejected	(j) Percent Heat Balance
dd/mm/yyyy hh:mm	°C	°C	L/s	°C	°C	L/s	kW	kW	kW	%
16/06/2010 15:00	6.70	12.60	84.10	29.4	35.5	97.65	308	2,079.04	2,495.84	-4.36
16/06/2010 15:01	6.71	12.50	84.20	29.5	35.4	97.60	309	2,042.70	2,412.77	-2.53
16/06/2010 15:02	6.72	12.30	84.30	29.6	35.3	97.55	310	1,970.95	2,329.79	-2.10
16/06/2010 15:03	6.73	12.10	84.20	29.7	35.2	97.50	311	1,894.53	2,246.89	-1.84
16/06/2010 15:04	6.74	12.20	84.10	29.8	35.1	97.55	312	1,923.99	2,166.29	3.22
16/06/2010 15:05	6.75	12.00	84.00	29.9	35	97.60	311	1,847.79	2,085.61	3.51
16/06/2010 15:06	6.74	12.30	84.10	29.8	35.1	97.65	310	1,959.23	2,168.51	4.64
16/06/2010 15:07	6.73	12.10	84.20	29.7	35.2	97.60	309	1,894.53	2,249.19	-2.03
16/06/2010 15:08	6.72	12.10	84.30	29.6	35.3	97.55	308	1,900.31	2,329.79	-5.21
16/06/2010 15:09	6.71	12.20	84.20	29.5	35.4	97.50	309	1,936.86	2,410.30	-6.82
16/06/2010 15:10	6.70	12.40	84.10	29.4	35.2	97.55	310	2,008.56	2,370.66	-2.20
										<b>Percentage of heat balance within <math>\pm 5\%</math> = 82%</b>

$$(h) \text{ Heat Gain} = m \times C_p \times \Delta T = (c) \times 4.19 \text{kJ/kg} \cdot ^\circ\text{C} \times [(b) - (a)]$$

$$(i) \text{ Heat Rejected} = (f) \times 4.19 \text{kJ/kg} \cdot ^\circ\text{C} \times [(e) - (d)]$$

$$(j) \text{ Percentage heat balance} = [(g) + (h) - (i)] / (i) \times 100\%$$

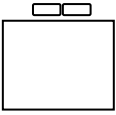


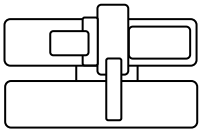







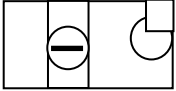

Based on the above example, 82% of the heat balance calculation falls within  $\pm 5\%$  which fulfills the criterion of 80%.

Note : Actual heat balance shall be conducted over the entire normal operating hours with more than 80% of the computed heat balance within  $\pm 5\%$  over the audit period.

**Abbreviations used in Worked Examples**

CH	Chiller	--
CHWP	Chilled Water Pump	-
CWP	Condenser Water Pump	-
CT	Cooling Tower	-
CHWS	Chilled Water Supply Temperature	°C
CHWR	Chilled Water Return Temperature	°C
CHWLR	Chilled Water Load Return Temperature	°C
CWS	Condenser Water Supply Temperature	°C
CWR	Condenser Water Return Temperature	°C
KW	Electrical Power Consumption	kW
KW/RT	Electrical Input kW per Refrigeration Tonnage	I kW/ton
$q_{\text{evaporator}}$	Cooling Load	kW or RT
$q_{\text{condenser}}$	Heat Rejection	kW or RT
$W_{\text{input}}$	Energy Balance	-
MV	Motorized Valve	-
AHU	Air Handling Unit	
BP	Bypass Line	
BPV	Bypass Valve (2-Way Modulating)	
$C_p$	Specific Heat Capacity of Water	4.19 kJ/kg.°C
CCV	Cooling Coil Valve	
°C	Degrees Celsius	
l/s	Liters per second	
kW	Kilo-Watts	
RT	Refrigeration Ton	
$\Delta T$	Temperature difference, Delta T	

**Symbols used in Worked Examples**

	<p>CT</p>
	<p>CWP</p>
	<p>CHWP</p>
	<p>CH</p>
	<p>CWS</p>
	<p>CWR</p>
	<p>CHWS</p>
	<p>CHWR</p>
	<p>MV</p>
	<p>Water Immersion Sensor</p>
	<p>Flow Meter</p>
	<p>AHU</p>
	<p>CCV (2-Way Modulating)</p>