FAQs on Instrumentation for

Permanent Measurement and Verification

for Water-cooled Chilled Water Plant System

Q1. Why is it important to measure accurately the temperature difference between the supply and return of the chilled or condenser water?

The temperature difference between the chilled/condenser water supply and return temperature (°C) is used to compute the net cooling load delivered to the building, or amount of energy consumed by AHUs/FCUs (air handling units/ fan coil units). As an illustration, for a chilled water plant operating with a chilled water supply and return temperature difference of 5°C, a seemingly acceptable error of ±0.5°C can in fact lead to a 20% error in the final computation of the system cooling load.

In addition, many energy audits conducted on existing buildings have shown that a large number of existing chiller plants experience a low delta T syndrome (i.e. temperature difference of about 2 °C to 3 °C), especially when they operate at part load conditions. In such circumstances, the error in the cooling load computation is even greater.

A maximum uncertainty of ± 0.05°C end-to-end for each temperature measurement is thus required, to allow for optimisation of the plant operation. Since the lifetime of a typical chiller plant is 15 to 20 years, it is important to install highly accurate temperature sensors for long-term accurate trending of the operational efficiency of the plant.

Q2. What are the possible sources of error that may affect the end-to-end temperature uncertainty of ± 0.05 °C?

The end-to-end uncertainty encompasses the entire chain of the temperature measurement process, i.e. the temperature sensor, transmitter, wiring, data acquisition system, etc. Typical sources that introduce errors in the measurement chain include:

i. *Thermowell type*
Temperature sensors installed in thermowells are not in direct contact with the water (ie Closed-end thermowell) and this might have an impact on the accuracy. In addition, the conductive thermal compound within the thermowells tends to dry out over time, which will affect thermal conductivity.

ii. *Location of temperature sensors*
Care should be taken if sensors for the chilled water supply are installed in locations exposed to direct sunlight. The metal parts of the sensor could easily reach 50°C due to direct solar radiation and this gives rise to inaccurate readings.

Installation of temperature sensors near pipe joints from 2 different sources might cause unstable measurements due to mixing of water temperatures.

iii. *Use of transmitters*
Some systems use transmitters to convert the sensor resistance from ohms to 4~20 milliamps (mA) DC signal to allow for transmission over a long distance. There is a tendency for the transmitters to drift over time, and be affected by ambient temperature fluctuations.

iv. *A/D conversion in Data Logger*
An additional source of error is introduced when an A/D convertor is used to convert the analogue signal of ohms or mA from the sensor or transmitter into digital signals for processing by a computer.

v. *Affected by electromagnetic field*
Most of the sensors are installed in environments with high Electromagnetic field, where a typical chiller plant room houses the chillers, pumps, fans, inverters, and

sometimes, even high voltage transformers. The interference from the electromagnetic field due to these equipment may affect wireless or even improperly-shielded wired communication.

Q3. Why do we need a separate set of temperature sensors for measurement when there are sensors built within the chillers?

Most chillers in the market are factory-tested to rigorous standards in accordance to ANSI/AHRI Standard 550/590 which specifies an allowable tolerance of 5% for capacity, efficiency and heat balance. Separate meters are used during the factory test rather than the built-in sensors in order to achieve the required uncertainty level. Other measurement standards such as ASHRAE guideline 14 and ASHRAE Guideline 22 have also stated the use of independent sensors rather than the chiller's built-in sensors.

Q4. My building has an extensive and expensive Building Automation System (BAS), why can't I use it to comply with GM V4.1 or ENRB V.3?

The majority of BAS in the market address issues of comfort, safety, convenience, manpower savings, etc. However, they do not specifically target accurate measurements to attain long-term chiller plant efficiency within ±5% at the moment. Moreover, the existing BAS may not have the excess capacity to add I/O points for measurements and the capability to use the meter's data output protocol. In hot and humid climates such as Singapore, the majority of commercial buildings have cooling needs year-round, and the cooling system of a building can sometimes account for 30% to 50% of the total energy usage. Hence, it is necessary to install accurate M&V instrumentation to ensure that chiller plants operate efficiently over its life cycle.

Q5. Does BCA Green Mark require temperature sensor for each chiller? Is it costly to install accurate temperature sensors to comply with GM NRB V4.1 and ENRB V3.0?

Temperature sensors are not required for individual chillers. For GM NRB V4.1 and ENRB V3.0, temperature sensors are to be provided for chilled water and condenser water loop at the main headers, i.e. two (2) for measuring the supply and return temperature at the chilled water header and two (2) at condenser water header, a total of four (4) temperature sensors.

Although these temperature sensors are more expensive than standard BAS sensors, each calibrated sensor can be procured at about S$500.

Q6. Is there a list of suppliers/vendors who can offer market solution to meet accurate M&V requirement?

Highly accurate M&V instrumentation was introduced in public sector retrofit projects through the Guaranteed Energy Savings Performance (GESP) programme about 5 years ago. To date, the public sector has awarded over a dozen contracts with stringent M&V requirements. Many vendors are involved, and more of such contracts are in the pipeline. The M&V standard in public sector retrofits is set even higher at ±0.03°C end-to-end measurement uncertainty.

A list of accredited ESCOs (Energy Services Companies) is available on the e2singapore.gov website, which features MNCs and local SMEs. Some of the ESCOs maintain their own calibration labs; and some also offer performance guarantee through energy performance contracts with financing.

Since 2013, BCA has also started registering competent persons familiar with the M&V standards and practices under the BCA Energy Auditors Scheme. The list of Energy

Auditors registered with BCA can be found in the following website http://www.bca.gov.sg/EnvSusLegislation/Registered_Energy_Auditors.html. The BCA Academy also conducts a regular course on Measurement and Verification of Central Chilled Water Plant Performance, more information is available on the website http://www.bcaa.edu.sg/.

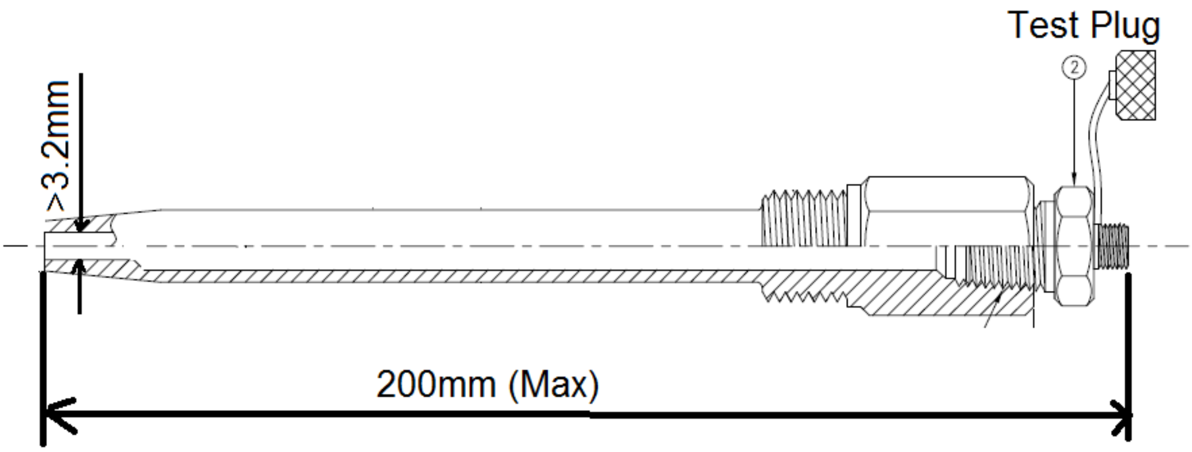
Q7. Platinum RTDs (resistance temperature detectors) have been commonly used for temperature measurements for a long time in the building industry. In fact, most of the BAS companies use PT100 sensors. Why do the authorities have a preference for thermistors?

The Green Mark standard is performance-based and technology-neutral. BCA accepts any measurement system that can provide a long term end-to-end temperature measurement uncertainty of ± 0.05°C. In a typical chiller plant, temperature ranges from 0°C to 40°C, 10KΩ thermistors have been shown to offers good sensitivity to changes in temperature; whereas a relative change in resistance (temperature coefficient of resistance) in PT100 varies only slightly for the above temperature range.

Q8. What is the spare thermowell specification?

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

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



Q9. What is the requirement for Heat Balance?

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 ±5% over the audit period (1 week).
The computation formula is as follows:

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

where $q_{condenser}$ = heat rejected

$q_{evaporator}$ = cooling load

W_{input} = measured electrical power input to compressor

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

Input power (measured)	= 100kW
Motor rated efficiency (η)	= 90%
Adjusted W_{input}	= 100kW x90%
	= 90kW

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 as follows:

Motor input power (measured)	= 30kW	(A)
Motor rated efficiency (η)	= 90%	(B)
Pump rated efficiency (η)	= 80%	(C)
Hydraulic losses	= (A) x (B) x (100%- (C))	
	= 30kW x90% x(100%-80%)	
	= 5.4kW	
Adjusted W_{input}	= kW_i(chillers) + 5.4kW	

Q10. Is yearly calibration required for temperature sensors?

Yearly calibration is not required if the heat balance meet the requirement of within ±5% for 80% of normal operating hours. However, if the heat balance fails, it is an indication that some of the sensors have drifted. The project team has to investigate the possible cause, and may need to send the sensors for calibration.

POWER

Q11. What is the measurement accuracy of power meters required by Green Mark?

There is no specific level set for power measurement in Green Mark, but the overall measurement uncertainty for the entire chilled water system (kW/RT) has to be within ±5%. It is recommended to have at least a minimum accuracy class of 1 for the power meters and an accuracy class of 0.5 for the current transformers. These are common specifications for power meter and current transformer in the market.

Q12. How many power meters are required to be installed under the Green Mark pre-requisite for permanent M&V instrumentation?

A minimum of four (4) power meters are required for each of the following groups of equipment:

- Chiller(s),
- Chilled water pump(s),
- Cooling Tower(s), and
- Condenser water pump(s).

Q13. Why is it important to specify the minimum accuracy of Current Transformers (CTs) for power measurement?

The Current Transformer is the main component affecting power measurement(s). The accuracy class of the CT has to be better than that of the power meter in order to achieve the required measurement accuracy. Power Meter suppliers will usually specify the minimum CT accuracy class required to achieve the meter measurement accuracy.

Q14. What is the calibration requirement for power meter, metering current transformer?

Presently, type test reports from manufacturers are acceptable. Nevertheless, we strongly encourage the use of verified power meters, with individual test certificate prior to the installation of any power meter(s) and current transformer(s) in order to achieve the overall chilled water plant measurement accuracy.

Q15. Why is it necessary to have true RMS power meters?

The simple averaging of meter readings only works for pure sine-waves. However, such pure sine-waves do not exist in the real world of an electrical installation.

A true RMS meter works by taking the square of the instantaneous value of the input current, averaging over the time and then displaying the square root of this average. This is accurate and applicable for all waveforms. True RMS power measurement is essential in any installation where there are non-linear loads (e.g. computers, electronic ballasts, compact fluorescent lamps, etc).
The power meter should capable of measuring the following:

a) Active energy (kWh) for 1 min per interval
b) Reactive energy (kVarh) for 1 min per interval
c) Active power (kW) for 1 min per interval
d) Reactive power (kVar) for 1 min per interval
e) Power factor for each phase

Q16. Is it difficult to achieve enough clearance of 5 pipe diameters upstream and 3 pipe diameters downstream to install the magnetic flow meter?

With proper planning of chilled water system, there is usually enough straight-length pipe clearance in the header or riser for proper installation of the flow meters.

Q17. Why does Green Mark recommend the use of full bore magnetic flow meter?

Full bore magnetic flow meter is recommended as it offers better long term accuracy, repeatability and reliability of the water flow measurement. It has no moving parts which contribute to its long term reliability and it does not impose any additional pressure loss to the system. The requirement for straight-length pipe clearance is also the least.

The ease of installation and commissioning from a full bore magnetic flow meter further enhances its desirability; however a shutdown of the chiller plant is required
In the event that a magnetic flow meter installation is not feasible, a clamp-on ultrasonic flow meter (UFM) is the next best technology to achieve long term accuracy, repeatability and reliability of the water flow measurement. However, do note that scaling of the condenser water pipe over time may affect the accuracy of UFMs.

Q18. Can I install the ultrasonic flow meters at any point so long as the straight pipe length requirement is fulfilled?

No. In ultrasonic flow meter measurement, the mounting points should also be observed to avoid locations where air bubbles are likely to occur or bubbles are likely to trap. Please see illustrations below.