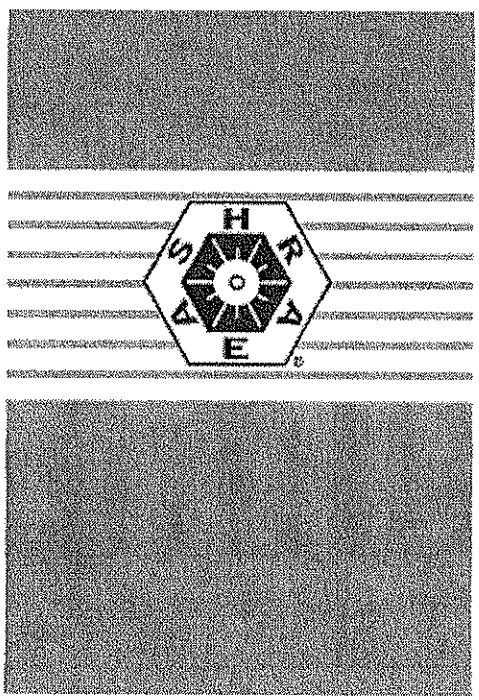
ASHRAE GUIDELINE 14-2002

Measurement of Energy and Demand Savings

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ASHARE GUIDELINE 14-2002

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Measurement of Energy and Demand Savings

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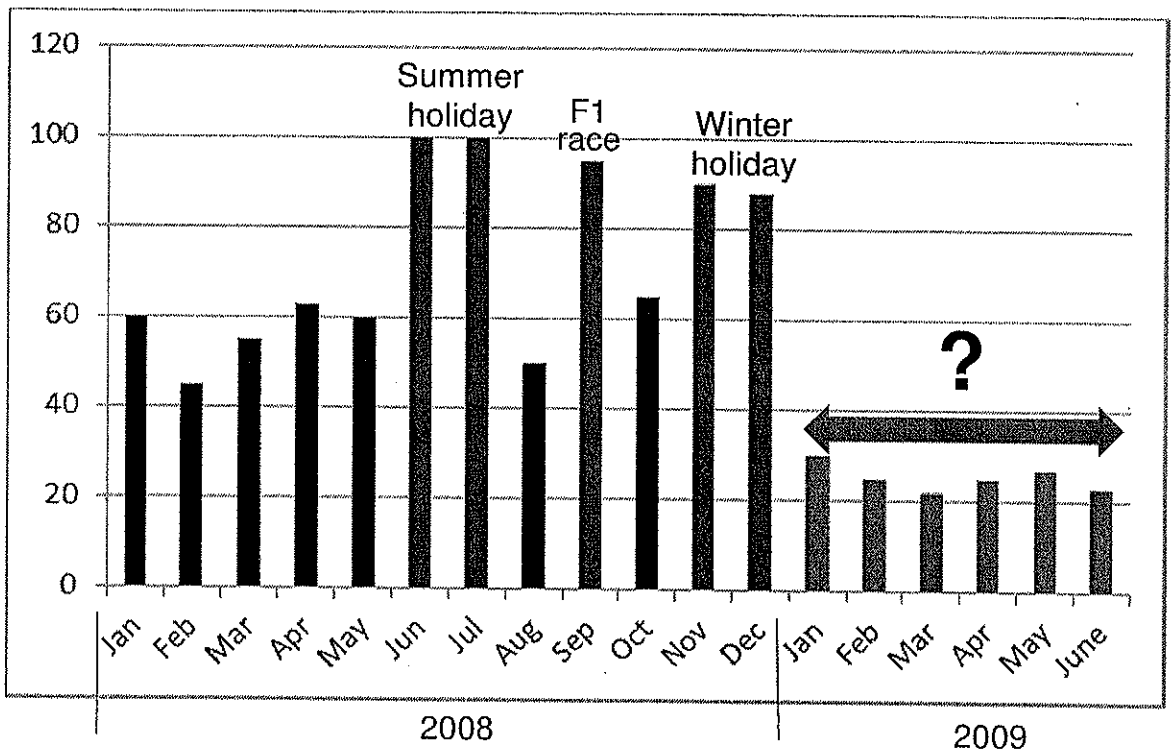
Introduction

- **Purpose**
  - Provide guidelines for reliably measuring energy and demand savings due to building energy management projects.

- **Scope**
  - Provide guidelines for using pre-retrofit and post retrofit data to quantify energy and demand savings.
  - Encompasses residential, commercial and industrial facilities.

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Factors affecting energy consumption



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Basic methodology

- Can energy use or demand savings can be calculated by comparing measurements of energy use before and after the implementation of EEMs (Energy efficiency measures) or ECMs (Energy conservation measures)?

- Simple comparison by subtraction of post-retrofit energy use from pre-retrofit energy use does not differentiate between the energy impacts of other factors such as
  - Weather changes
  - Occupancy changes
  - Production changes
  - Operating hours changes
  - Tenancy type changes

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Basic methodology

This guideline addresses determination of energy savings by comparing before and after energy use AND making adjustments for non-ECMS changes that affect energy use.

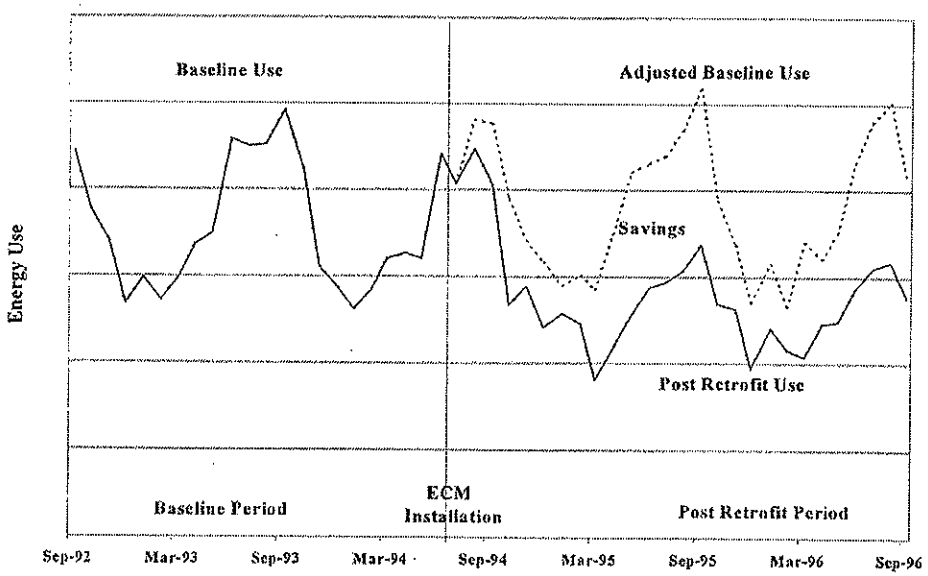


Figure 3-1 Determining savings.

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Uncertainty and costs

- 3.3 P2 "Weather, occupancy are examples of 2 factors that often change and often affect energy use. Relationship between these factors and energy use are usually determined through data analysis, not text book formulae. Since data analysis can be conducted in an infinite number of ways, there can be no absolute certainty about the relationship chosen."

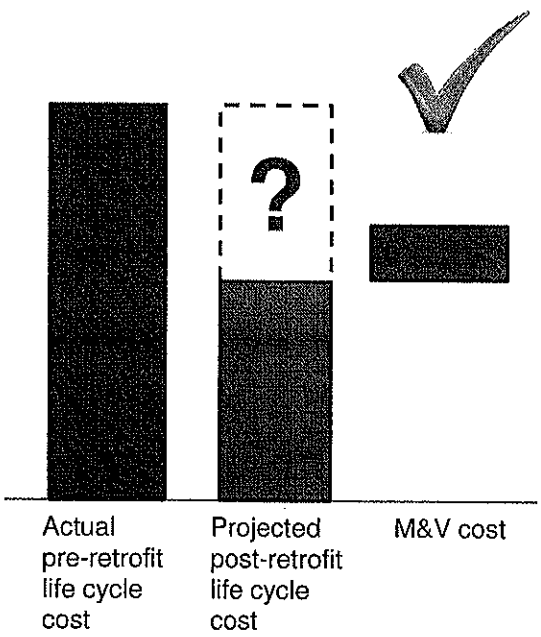
- 3.3 P4 "There are numerous sources of uncertainty including
  a. instrumentation or measurement error,
  b. normalization or model error,
  c. sampling error,
  d. errors of assumptions.

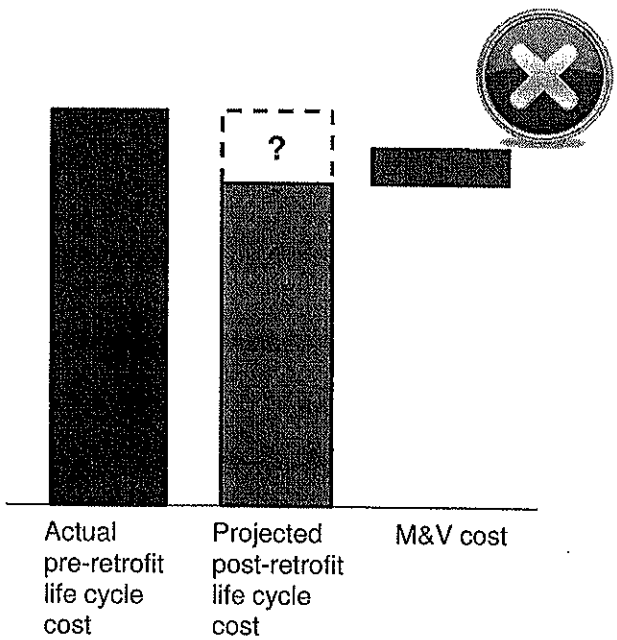


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Uncertainty and costs

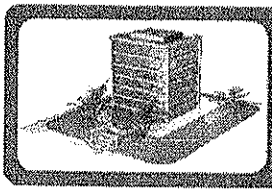
- The value of improved accuracy to ESCOs or owners depends on how they expect this improvement to affect them.





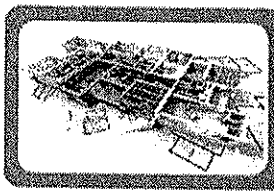
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M&V approaches



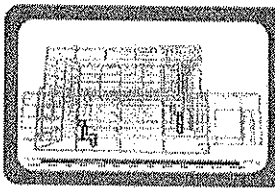
Whole Building Approach

- Uses a "main" meter to measure energy flow
- ECMs may be applied to one or more of the systems served by the meter
- Might involve the use of monthly utility bill data
- Option of two paths (prescriptive or performance)



Retrofit Isolation Approach

- Uses meters to isolate the energy use and/or demand of the subsystems affected by the ECM pre and post-retrofit



Whole Building Calibrated Simulation Approach

- Uses computer simulation software to model facility energy use and demand
- Model is calibrated against actual energy use and demand data
- Calibrated model is used to predict energy use and demand of the post-retrofit period

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M&V approaches

	Whole building approach	Retrofit isolation approach	Whole building callbrated simulation approach
Methodology	Use a main meter	Use meters to isolate energy use of sub system	Computer simulation tool
Accuracy	High	Medium to high. Depends on M&V system	Medium to low. Depends on user skill level.
Issues	Too simplistic. There are many interacting sub-systems and interacting factors that affect the main meter.	Sometimes it is not possible to isolate the sub-system. Eg lighting ECMs affect cooling/heating loads.	Time consuming and need very skilled users for reliable models. Diiferent softwares have different results.
Potential dispute in M&V	Very high	Low to medium	High
Cost	Low	Medium to high	High

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Selecting baseline period

- Generally the period just before the retrofit is preferred as the baseline period.
- The period should be long enough to include all the conditions encountered by the affected systems (eg winter, summer, max or min hotel occupancy, max or min factory production).
- Where less than 12 months of data are available, the selected period should represent the reminding periods.
- Where more than 12 months of data are available, ensure that no time period is over represented.
- Ideal for baseline to have integral number of continuous 12-month periods.

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Documenting baseline conditions

- Occupancy pattern, density, schedule, and type, for each of the typical seasons.
- Throughput or other plant loads on typical and average days in each operating mode.
- Operating schedules and key set-points of energy using systems for all operating modes.
- Spot measurements under known operating conditions, where separate circuits serve distinct types of constant loads.
- Non-routine functions of the facilities, their dates and impacts on operations.
- The nature and timing of any breakdowns of significant energy using equipment.
- Equipment nameplate data, except where changes are likely to be easily noticed and documented, eg addition of spaces or new services.

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Selecting post-retrofit period

- Encompass all operating modes of the retrofitted system.
- Span the full range of all the independent variables normally expected for the post retrofit period
- Provide the intended level of cetainty in the reported savings.

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Example of regression model

$$E = C + B_1V_1 + B_2V_2 + B_3V_3 + \ldots \qquad (6.1\text{-}1)$$

where

E = energy use or demand estimated by the equation,

C = constant term in [energy units/day] or [demand units/billing period],

B_n = coefficient of independent variable V_n in [energy units/driving variable units/day] or [demand units/driving variable units/day],

V_n = driving variable.

Eg: Weather, % occupancy, F&B customer volume

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Instrumentation & data management

- 7.3 P1: "The quality of any measurement is dependent upon the effect of the measurement location, the capability of the measurement sensor and the data recording instrument and the sampling method employed."

- 7.3 P2: "BMS hardware is typically not designed for this particular application (ie M&V) and its ability must be demonstrated before it can be used with confidence."

- 7.3 P3: "Sensor selection is dependent on
  - Quality: accuracy, precision, drift, rate of respond
  - Quantity
  - Installation restrictions
  - Method of measurement required
  - Signal output requirements
  - Measurement range & turndown
  - Capabilities of the recoding devise
  - Resources to purchase and support it."

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Calibration

- 7.5.1: Calibration recommendation "It is highly recommended that the instrumentation used in measuring the information required to evaluate energy and demand savings be calibrated with procedures developed by National Institute of Standards and Technology (NIST). Primary standards and no less than 3rd order NIST-traceable calibration should be utilized whenever possible.

- 7.8.1.2: When to recalibrate "For critical measurement points, which are part of a long term testing project, a six month to yearly calibration is highly recommended."

- 7.8.1.3: When to replace "For critical measurements, whose continued error could lead to a failed experiment, it is probably better to recalibrate once, then replace as soon as possible if the sensor continues to show signs of nonperformance.

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Measurement System Verification

- 7.6.1 "The most stringent method to verify the uncertainty of a measurement system is an in-situ, through-system calibration of each measurement system input with other instrument of know certainty or by the use of a different measurement method if certainty."

- 7.6.1 " The conservation of energy and flows is the most comprehensive."
  - Does the sum of the energy used and the energy delivered = sum of energy rejected.

- AHRI 550 requires a heat balance within +/-5% tolerance.

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b. Project summary

An office building located in San Luis Obispo, California, will retrofit 14 supply and return HVAC fans that currently have inlet guide vanes to control air flow with variable speed drives that will control the fan motor speed to control the air flow. The building typically operates seven days per week with reduced occupancy during evenings and weekend hours. In addition to offices, there are various labs, research areas, storage areas, lounge areas, and a health center that operate on different schedules. The project is being installed as part of a guaranteed savings performance contract with an ESCO.

This is not a VAV conversion. The building's HVAC system currently operates as a variable air volume system, and no chiller plant or boiler plant savings are expected from this retrofit. The VSDs will be controlled on the basis of maintaining downsteam static pressure that varies as different building zones call for more or less airflow. Project activities consist of disabling inlet vane dampers, linkages, and actuators and installing VSDs, relays, and power monitoring/communications equipment. No changes will be made to the building's HVAC system zone VAV boxes, downstream dampers, or controls.

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C2.1 Example Variable Inlet Vanes to VSD Retrofit Project Using Retrofit Isolation Approach

Pre-retrofit regression model

Fan I.D.	Equation	R^2	SE
S-1	$y = 10.4030 + 10.5248x - 18.0789x^2 + 26.9252x^3$	0.9915	0.5688
S-2	$y = 10.3957 + 10.4487x - 19.0382x^2 + 28.2856x^3$	0.9959	0.4013
S-3	$y = 10.9191 + 3.3867x + 14.9550x^3$	0.9943	0.4477
S-4	$y = 10.9291 + 3.6195x + 14.1278x^3$	0.9902	0.5689
S-5	$y = 14.4886 + 21.9351x^3$	0.9876	0.7847
S-6	$y = 10.5572 + 10.6577x - 20.4243x^2 + 29.4898x^3$	0.9929	0.5267
S-7	$y = 13.6589 + 2.9424x + 19.4597x^3$	0.9888	0.7729
R-1	$y = 5.9346 + 8.6009x^3$	0.9871	0.3141
R-2	$y = 5.1804 + 6.3106x - 13.0719x^2 + 16.6547x^3$	0.9948	0.2219
R-3	$y = 5.3273 + 4.4642x - 9.1618x^2 + 14.3863x^3$	0.9952	0.2133
R-4	$y = 4.9288 + 7.0136x - 12.5063x^2 + 15.4316x^3$	0.9916	0.2826
R-5	$y = 8.0309 + 2.2653x + 10.6592x^3$	0.9926	0.3598
R-6	$y = 5.7877 + 8.9539x^3$	0.9831	0.3745
R-7	$y = 7.887 + 6.1534x - 13.3275x^2 + 21.9334x^3$	0.9973	0.2459

where

y = Fan Motor Power (kW)

x = Percent of fan system maximum air flow rate (% CFM).



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a. Project summary

An owner of a 250,000 ft^2 office complex, located in San Jose, is participating in a guaranteed savings performance contract with an ESCO. The facility is cooled by a central chilled water plant with a 350-ton centrifugal chiller that is 10 years old. The owner of the building is planning to replace the existing chiller with a new, high efficiency, variable speed drive unit. No other changes are planned to the condenser or chilled water pumps or the cooling tower. The unit under consideration has been rated with an ARI nominal efficiency of 0.55 kW/ton. The efficiency of the existing chiller complied with ASHRAE 90.1 and has an ARI rated nominal efficiency of 0.748 kW/ton.

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- Step 1 - Calculate cooling load. The cooling load will be computed based on the flow and temperature data collected with the EMS. Equation 1 below will be used to compute the tons of cooling currently being provided by the chiller.

$$Tons_i = \frac{(CHWF)(500)(ECWT - LCWT)(1)}{12,000} \quad (1)$$

- Step 2 - Calculate post-installation capacity temperature correction. Capacity of any chiller is a function of the nominal capacity and the current chilled water and condenser water temperatures. The equation is bi-quadratic, with the coefficients defined by the CEC.

$$Capacity = Cap_{nom}(a + b(CHWT) + c(CHWT)^2 + d(CWT) + e(CWT)^2 + f(CHWT)(CWT)) \quad (2)$$

where

a = –1.7420400
b = 0.0292920
c = –0.0000670
d = 0.0480540
e = –0.0002910
f = –0.0001060

CEC: California energy commission

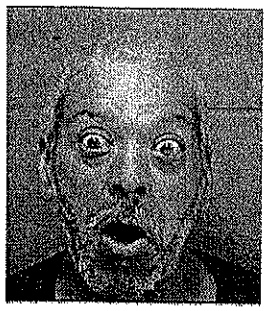
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- Step 3 - Calculate post-installation part-load ratio. The current part-load ratio is simply the ratio of current tons to current capacity.

$$PLR_t = \frac{Ton_t}{Cap_t} \quad (3)$$

- Step 4 - Calculate the part-load adjustment to the nominal chiller kW. The result of this equation is a multiplier to be used with the chiller's nominal, full-load demand to estimate use at the given part load.

$$PLR_{adj} = a + b(PLR)_t + c(PLR)_t^2 \quad (4)$$



where

a = 0.2229030
b = 0.3133870
c = 0.4637100

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- Step 5 - Calculate the ambient adjustment to the nominal chiller kW. This adjustment factor accounts for the change in nominal chiller performance as a function of condenser and supply water temperatures.

$$Temp_{Adj} = a + b(CHWT) + c(CHWT)^2 + d(CWT) + e(CWT)^2 + f(CHWT)(CWT) \quad (5)$$



where
a = 3.11750000
b = –0.10923600
c = 0.00138900
d = 0.00375000
e = 0.00015000
f = –0.00037500

- Step 6 - Calculate the current baseline chiller kW. Using the part-load and temperature adjustment factors, calculate the baseline chiller demand as the product of nominal chiller demand, PLR_{Adj} and $Temp_{Adj}$.

$$kW_t = (kW_{Nom})(PLR_{Adj})(Temp_{Adj}) \quad (6)$$

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Practical recommendations for performance M&V

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Practical audit recommendations

- Focus audit on energy intensive system such as air conditioning, lighting and hot-water.
- Identify opportunities to reduce consumption 1st.
  - Over cooling, over lighting, over ventilating.
- Identify opportunities to increase efficiency next.
  - Chiller plant: KWi/RT
  - Airside: Wi/CMH
  - Lighting: W/m^2 to achieve working level LUX
  - Hot-water: COP
- Specify for accurate & continuous monitoring especially for chiller plant.
- Specify for measurement system's accuracy validation
  - Consistency check for temp, flow & energy.

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Chiller plant example



Chiller plant electricity consumption cost $ =

Cooling load x Hrs Operation x KWi/RT x $/KWH

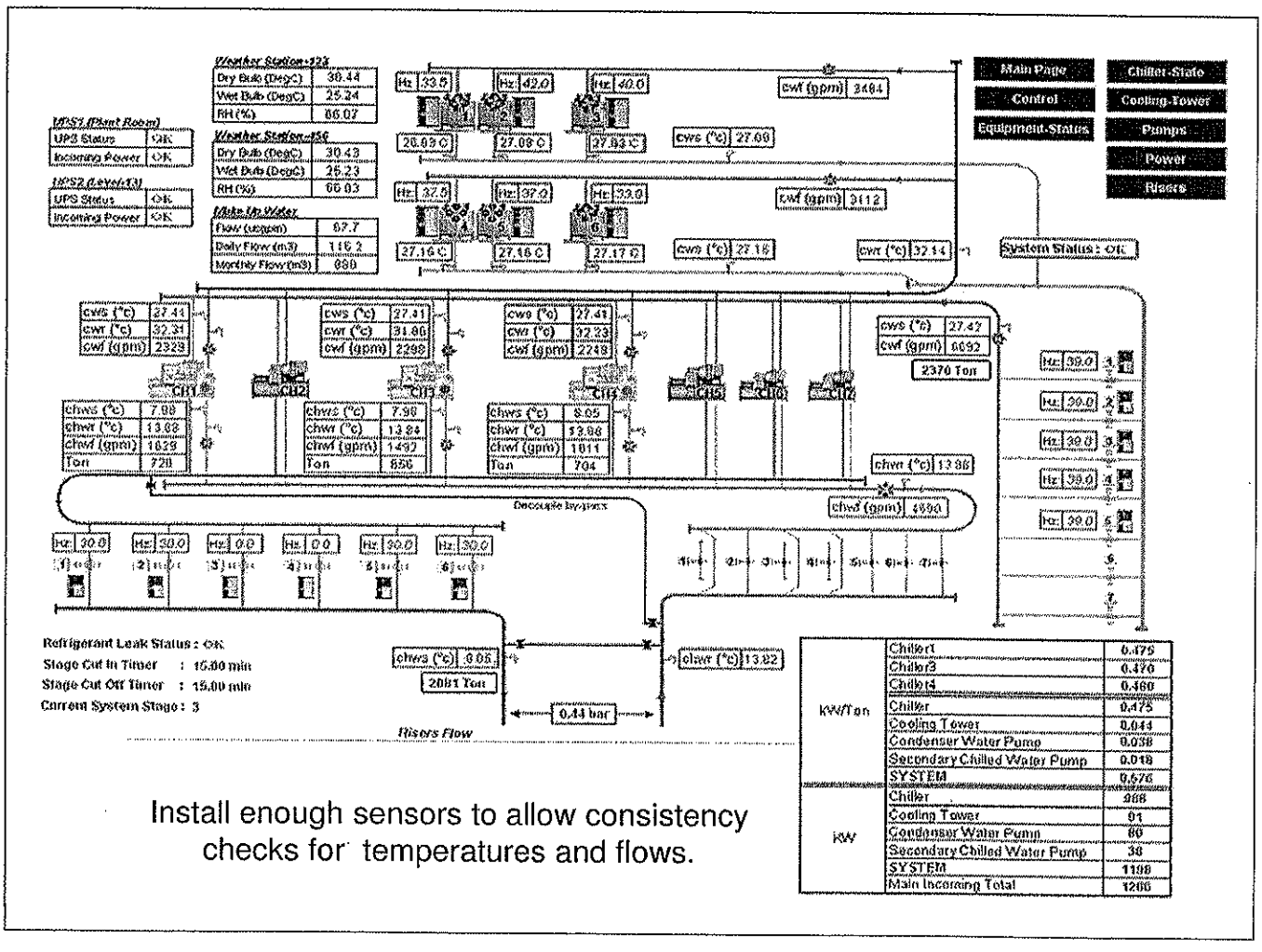
Dependents:

- Cooling load: Weather, vacancy rate, occupant type room temp, OA, infiltration etc; Business cycle, occupant type , start/stop controls etc
- KWi/RT: Design, installation, equipment, optimization, maintenance, weather etc
- $/KWH: Power provider, oil prices, govt regulations etc

Consumption factors → Try to reduce wastage

Efficiency factors → Try to reduce losses

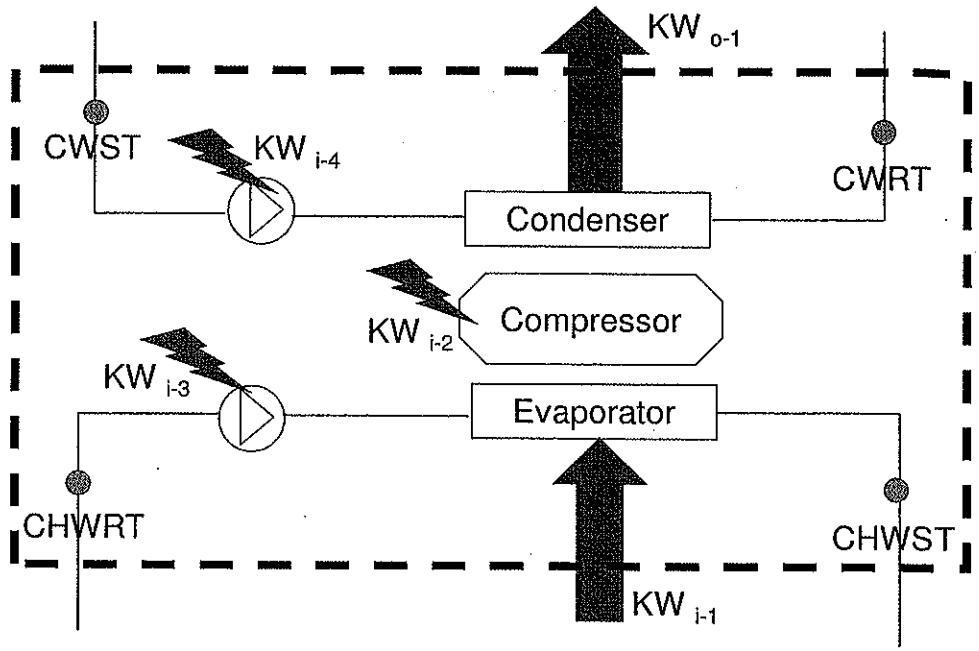
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Install enough sensors to allow consistency checks for temperatures and flows.

Heat Balance

Energy cannot be created or destroyed
Heat in = Heat out



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Heat Balance Equation

Energy IN = $KW_{i-1} + KW_{i-2} + KW_{i-3} + KW_{i-4}$

Energy OUT = KW_{o-1}

The heat balance is represented by the following equation:

$$\frac{\text{Energy IN} - \text{Energy OUT}}{\text{Energy OUT}} \times 100\% \quad <= \quad +/- 5\%$$

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Heat balance notes

- Pump KWi (KW_{i-3} & KW_{i-4}) is typically small and can usually be neglected.
- Heat rejection for non-hermetic chiller has to be properly accounted by ESCO and chiller manufacturer in the heat balance. Seek advise on motor heat dissipation to plant room from the chiller manufacturer.
- Continuous monitoring across a week to validate heat balance is recommended.



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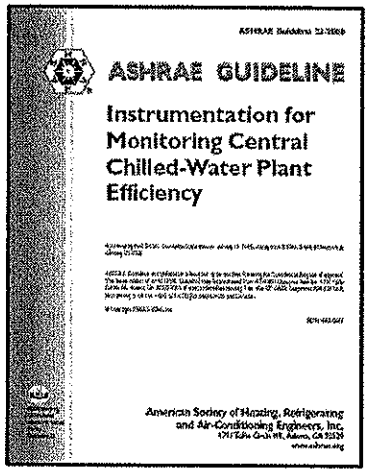
Thank you for your attention.

Questions?

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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 x Cp x DT

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

- Cp for pure water

  @ 4.44C, Cp= 4.203 kj/kg.k
  @ 15.55C, Cp = 4.185 kj/kg.k
  Common to assume Cp = 4.19 kj/kg.k

- Density for pure water

  Mass of 1L = 1kg

- Wd for pure water

$$\text{Wd (KW)} = 4.19 \times \text{flow rate (L/S)} \times \text{DT (C)}$$

Determination of COP

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

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

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

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

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

$$1\ \text{RT} = 3.517\ \text{KW}$$

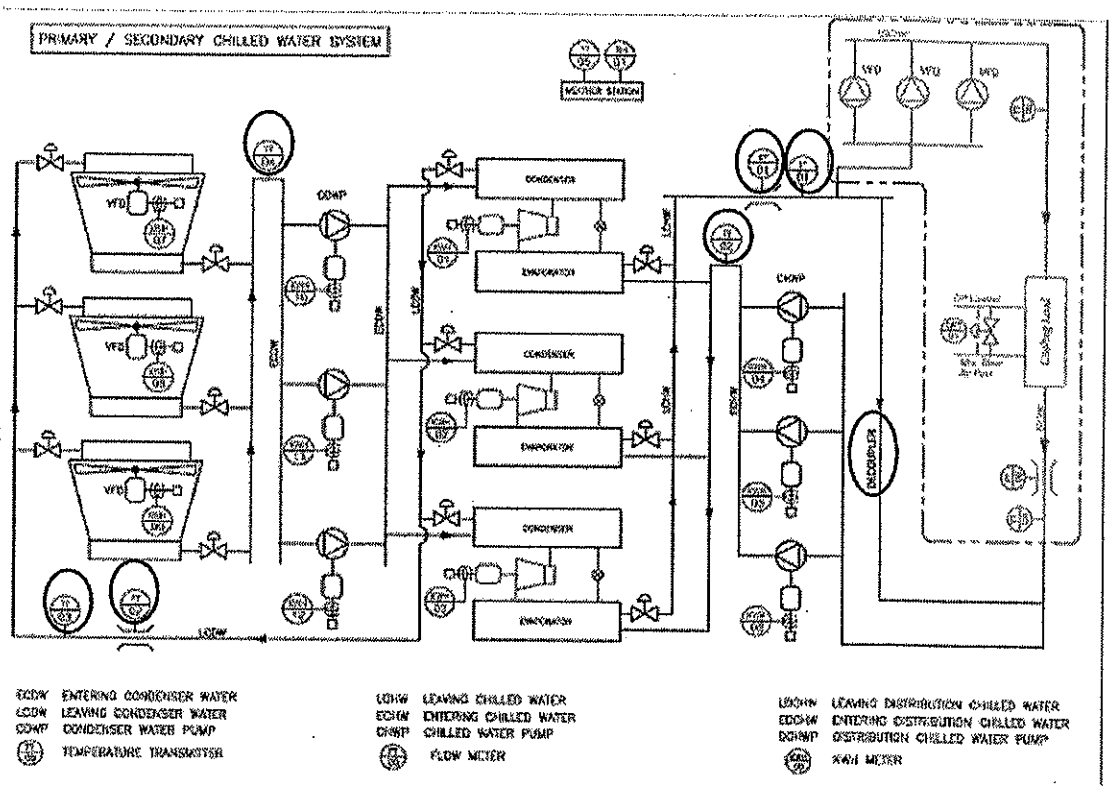


Figure 5-1 Example of primary/secondary chilled-water plant.

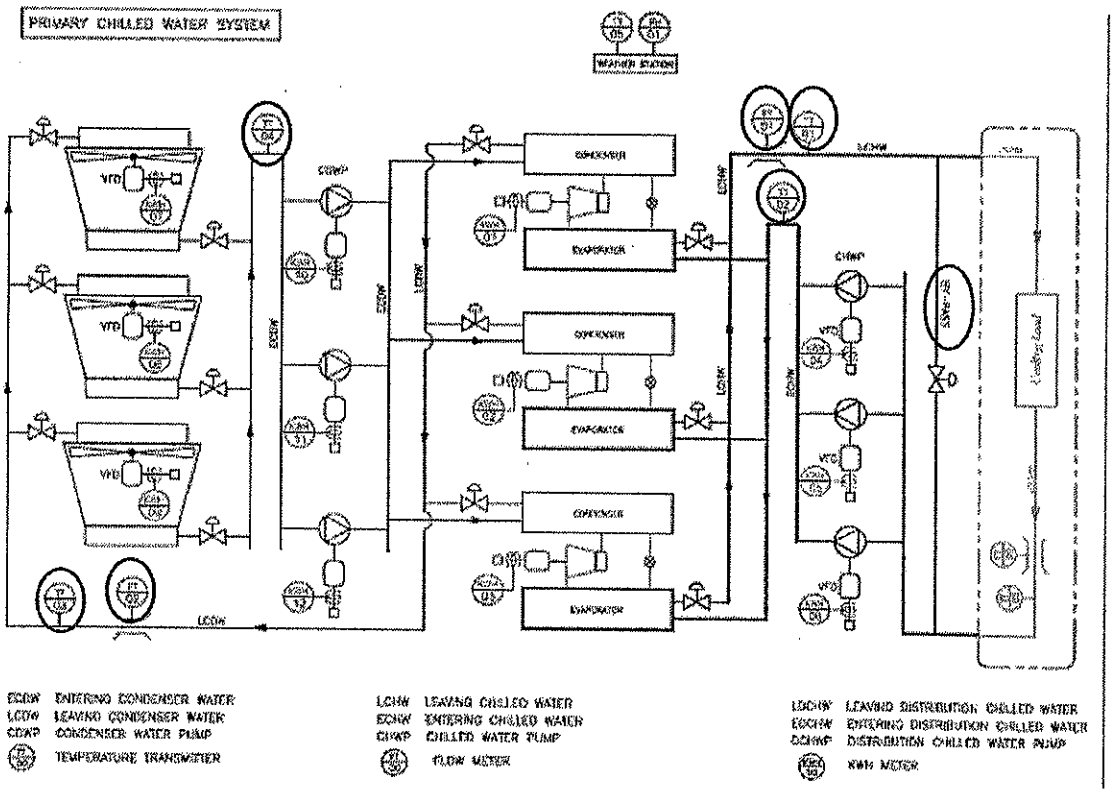


Figure 5-2 Example of primary-only chilled-water plant.

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									

9

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 0.1°C (0.18°F) 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 (0.0018°F). 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

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.

Data acquisition

- The data acquisition system, including its control network and field panels, shall be capable of collecting data at **all points at a minimum sampling interval of one minute** without measurably affecting control performance.
- **Continuous sampling** is preferred.
- Standard 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 Δ*T*. 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 Δ*T* = 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
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

5% limit

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

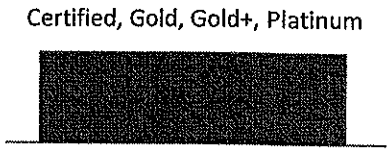
GMv4.0 compared to Ashrae guide 22

- 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; K2 = constant for converting chilled-water flow times ΔT to tons; K3 = 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

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, #49a, #49b, #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

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Save Chiller Plant Energy With Guideline 22-2008

Guideline for Instrumentation for Monitoring Central Chilled-Water Plant Efficiency

By James R. (Burt) 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 most 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 many values that would be needed for such a test. This article's goal is to assist designers and operators in using the 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 temperature and condenser water temperature. The resultant information can be a useful tool in maintenance programs; an increase in kW/ton may signal a need for maintenance or an instrument 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 on 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 improvement 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 to 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 2.29%. 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*.

$$kW/ton = \frac{\Sigma kW \times 24}{Q \times (T_2 - T_1)} \quad (1)$$

About the Author

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Thank You
for your attention

Q&A