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Instrumentation for Monitoring Central Chilled-Water Plant Efficiency

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NOTE

Approved addenda, errata, or interpretations for this guideline can be downloaded free of charge from the ASHRAE Web site at www.ashrae.org/technology.

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

FOREWORD

Guideline 22 was developed by ASHRAE to provide a source of information on the instrumentation and collection of data needed for monitoring the efficiency of an electric-motor-driven central chilled-water plant. A minimum level of instrumentation quality is established to ensure that the calculated results of chilled-water plant efficiency are reasonable. Several levels of instrumentation are developed so that the user of this guideline can select the level that suits the needs of each installation.

The basic purpose served by this guideline is to enable the user to continuously monitor chilled-water plant efficiency in order to aid in the operation and improvement of that particular chilled-water plant, not to establish a level of efficiency for all chilled-water plants. Therefore, the effort here is to improve individual plant efficiencies and not to establish an absolute efficiency that would serve as a minimum standard for all chilled-water plants.

It is recognized that there are different needs for monitoring the efficiency of a chilled-water plant. In most cases, the principal objective is to maintain and improve the efficiency of the chilled-water plant. There are also cases where greater accuracy is desired for monitoring chilled-water plant efficiency. The instrumentation section allows the user to determine the required accuracy for the application.

The user of this guideline should be aware that the quality of the instrumentation directly affects the results obtained and, therefore, the accuracy of the chilled-water plant efficiency. As a result, special attention should be given to the selection of instrumentation in order to ensure that the expected result is delivered.

Chilled-water plant efficiency is expressed in different terms. This guideline uses the recognized term for chilled-water plant efficiency, which is coefficient of performance *(COP). While the guideline uses COP, it is understood that in areas using inch-pound (I-P) units, kW/ton is the common term for determining chilled-water plant efficiency. Appendix B of this guideline provides the information necessary to derive chilled-water plant efficiency when using kW/ton. Also, in Appendix E, an example specification is provided for designers of chilled-water plants who wish to incorporate the monitoring of COP or kW/ton into specifications for new plants or modifications of existing plants.*

It should be pointed out that this guideline does not offer any information on the design of a chilled-water plant. It is applicable to all electric-motor-driven chilled-water plants regardless of their configuration or types of chillers, cooling towers, pumps, and other parasitic electric chilled-water plant loads. This guideline is designed to help plant managers and operators achieve and maintain a desired level of efficiency for their chilled-water plants.

This is a revision of ASHRAE Guideline 22-2008. This guideline was prepared under the auspices of ASHRAE. It may be used, in whole or in part, by an association or government agency with due credit to ASHRAE. Adherence is strictly on a voluntary basis and merely in the interests of obtaining uniform standards throughout the industry.

The changes made for the 2012 revision are as follows:

- *Updated references*
- *Minor editorial changes*

1. PURPOSE

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

2. SCOPE

2.1 This guideline includes

a. recommendations for methods and devices used to measure electrical usage, fluid flow, and temperature, and
b. procedures for acquiring the necessary data and calculating system efficiency.

2.2 These procedures are for site-specific application. They do not discuss the comparison of collected data between different sites, nor do they recommend that data obtained be applied in this manner.

2.3 The procedures also do not discuss

a. any plants except electrically driven chilled-water plants,
b. design and operation of central chilled-water plants, except for recommending the instrumentation used to determine plant efficiency, or
c. selection, application, or operation of system components.

3. DEFINITIONS

For the definitions of key terms used in this guideline, refer to *ASHRAE Terminology of Heating, Ventilation, Air Conditioning, and Refrigeration.*[1]

4. UTILIZATION

4.1 This guideline allows the user to monitor chilled-water plant efficiency and to make modifications to the setpoints of the system such that the overall efficiency of the chilled-water plant is improved. 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.

The efficiency of the chilled-water plant, which is defined in this guideline as coefficient of performance (COP), is dependent upon the energy use of a number of different pieces of equipment, including, but not limited to, the following:

- chillers,
- evaporator pumps,
- condenser pumps, and
- cooling towers.

Each piece of equipment can have a significant impact on chilled-water plant efficiency.

This guideline is entirely focused on reporting the operational efficiency of existing plants. For information relating to achieving efficiency during the initial design of a chilled-water plant, refer to recognized standards such as *ANSI/ASHRAE/IESNA 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings*,[2] as well as to the ASHRAE Handbooks.[3, 4, 5, 6]

Since the design and layout of chilled-water plants varies widely depending upon their specific applications, this guideline addresses common chilled-water plant layouts for instrumentation and collection of data. Applications that include thermal energy storage and heat recovery are more complex and may require a more sophisticated approach than this guideline provides. If some modification of the data collection and analysis method were made to include the additional equipment used in such applications, this variation on the methodology of this guideline could be used to give an overall chilled-water plant efficiency.

Chilled-water plant efficiency is not dependent upon any one device; rather, it is the overall match of system components that determine efficiency.

4.2 Informative Appendix E of this guideline provides a sample specification that can be used when management prefers to contract the determination of chilled-water plant efficiency to an outside vendor or agency. For this guideline to be cited in a specification, the following plant-specific information must be provided:

- Equipment whose power is to be included.
- Equipment whose power is not to be included (if any).
- Thermal cooling loads to be included.
- Thermal cooling loads not to be included (if any).
- The maximum allowable error tolerance in the result.
- A summary of how the gathered data should be stored and presented.

5. CHILLED-WATER PLANT TYPES AND INSTRUMENTATION

5.1 Primary/Secondary Chilled Water. Detailed in Figure 5-1 is an example primary/secondary chilled-water system. The diagram provides a set of typical points that could be measured to give an overall chilled-water plant COP. These points can be reduced or expanded upon as the user deems necessary.

5.2 Primary or Variable Primary Flow System. Detailed in Figure 5-2 is an example primary flow system. A system such as this normally utilizes variable-frequency drives on the chilled-water pumps, as is specified by some requirements of ANSI/ASHRAE/IESNA Standard 90.1.[2] The diagram provides a set of typical points that could be measured to give an overall chilled-water plant COP. These points can be reduced or expanded upon as the user deems necessary.

5.3 Instrumentation. To measure chilled-water plant efficiency, appropriate instrumentation is required to achieve the expected result of this guideline. An instrumentation table such as Table 5-1 should be used to define the instrument range, measurement range, and measurement accuracy for each piece of equipment that uses electric energy. The specific instrument and the measurement range are dependent on the capacity of equipment for the specific chilled-water plant. See Informative Appendix A, Instrument Specifications Table, for an example of the data that should be provided in the table.

Depending on the specific application, the user may decide to measure chilled-water plant efficiency with or without the pump energy required to distribute water to the loads.

Data calculation and archiving of this data should be to one order of magnitude greater than the measurement accuracy. Operator interface display resolution should be consistent with the measurement accuracy; the recommendation of this guideline is that the resolution should be the same magnitude as the midpoint of the measured value multiplied by the accuracy.

5.4 Data Quality. The quality of any measurement is dependent upon the measurement location, the capability of the measurement sensor and the data-recording instrument, and the sampling method employed. This guideline recommends that the instrumentation selected for monitoring central chilled-water plant efficiency have the capabilities described in Sections 5.4.1 and 5.4.2 below.

Note: If pre-existing instrumentation is already installed on the equipment, one may consider making use of it. To be considered, however, such instrumentation should first meet the data integrity recommendations of this guideline and be budgeted for the added costs for calibration and maintenance that this guideline recommends.

5.4.1 Data Recording Device. The selection of a data recording device is dependent upon the following factors:

- Quality of the device (accuracy, precision, drift, rate of response).
- Quantity and type of inputs required.
- Installation restrictions.
- Signal conditioning.
- Measurement range.
- Resources available to purchase and support the device.

Digital data acquisition instrumentation is now the typical hardware of choice to gather field data. This is true whether the data is gathered by a portable instrument or by a permanently installed building automation system (BAS). However, 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 (See Heinemeier et al.).[7] Building management system (BMS) control requirements are not always compatible with measurement and monitoring requirements.

Characteristics to consider for the data recording device include:

Scan Rate. It is always best to strive for an order of magnitude higher scan rate than the period of the process being measured. This is especially true with dynamic processes.

Time Measurement Characteristics. Performance measurements are directly affected by the resolution, accuracy, and precision of the data recording device internal

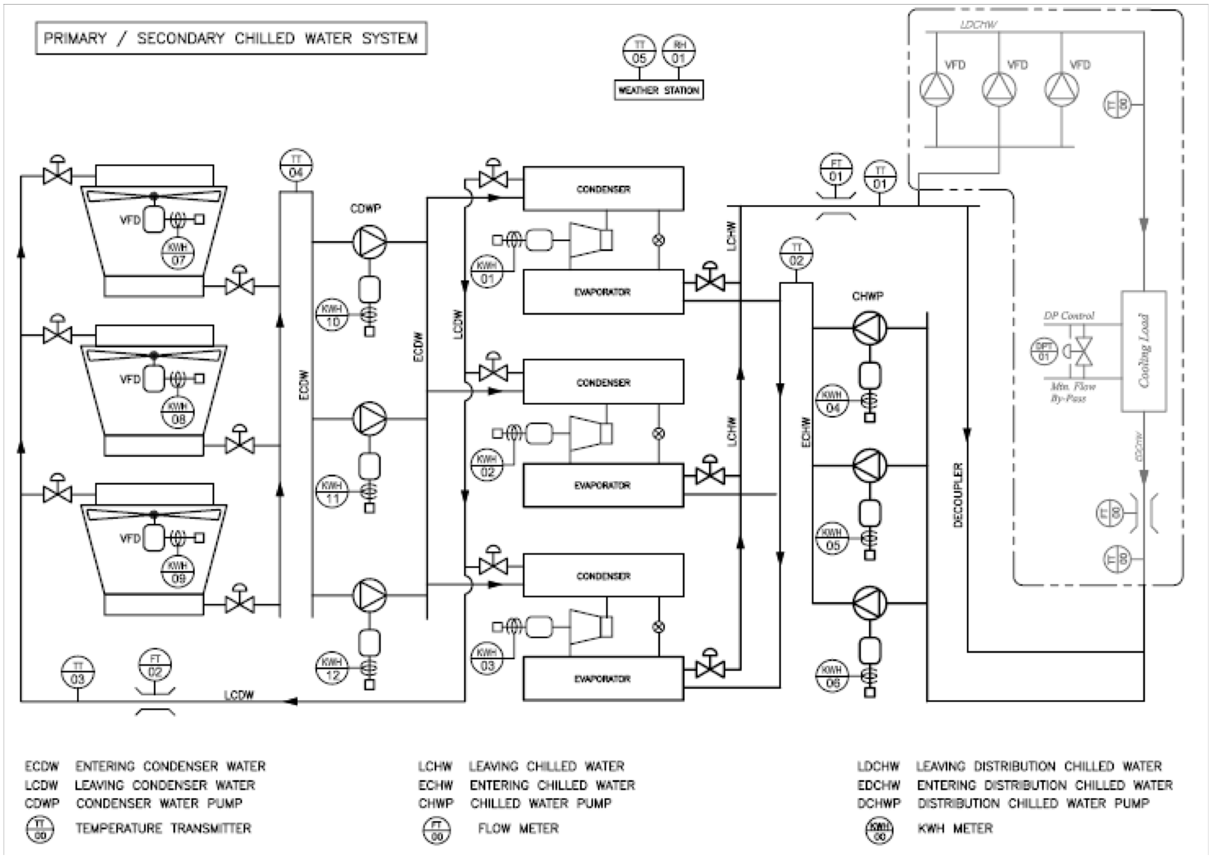

Figure 5-1 Example of primary/secondary chilled-water plant.

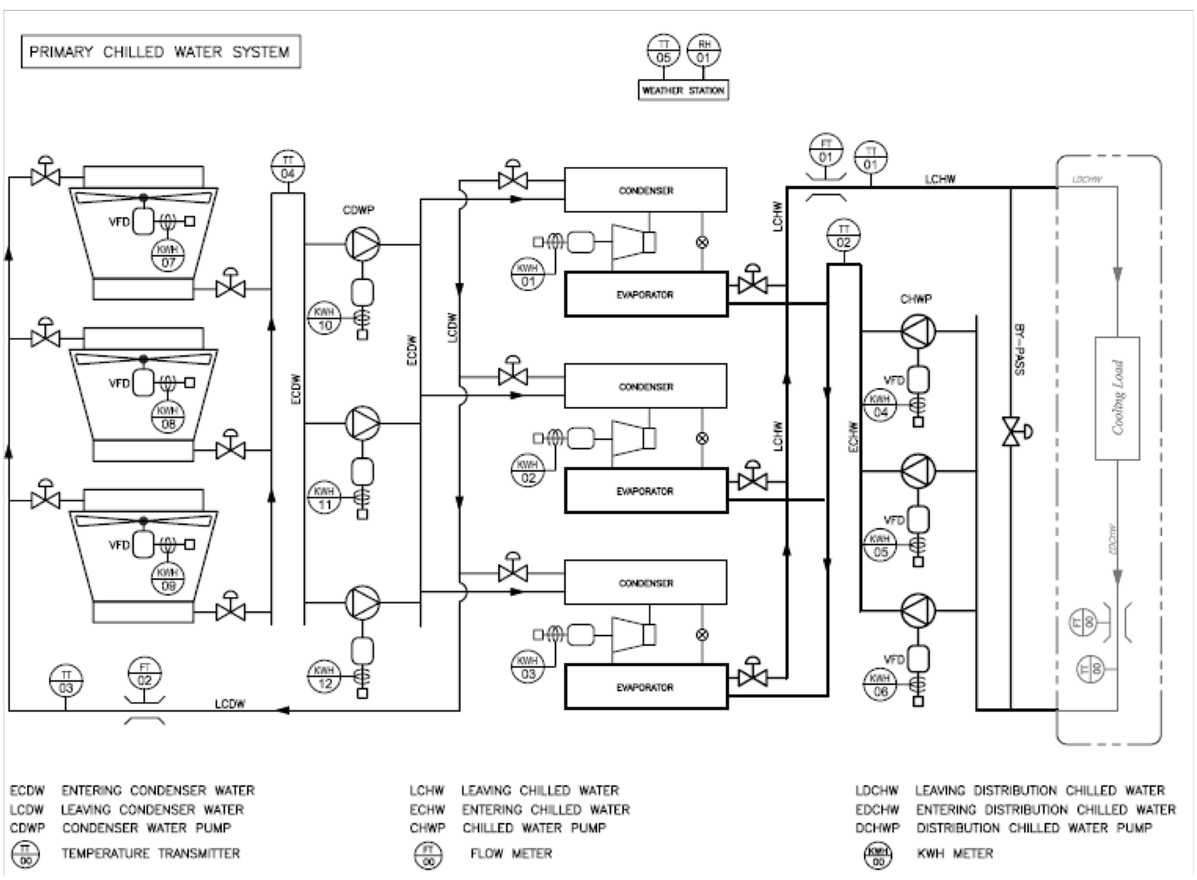

Figure 5-2 Example of primary-only chilled-water plant.

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									

clock per unit of time. Most systems provide reasonable capabilities.

Engineering-Unit Conversion Methods. Converting of sensor output to engineering units is typically provided by most equipment utilizing the linear scalar and offset method ($y = mx + b$). Advanced systems provide for polynomial curve fitting or point-to-point interpolation. Many systems offer some form of temperature conversion tables or standard equations for resistance temperature detectors (RTDs) and/or thermocouples (TCs). Engineering units are extremely helpful in performing on-line sensor calibrations, troubleshooting, and inter-channel calculations (using concurrent data from more than one channel).

Math Functions. It is desirable to have the ability to manipulate the sampled data as it is scanned. One may also need to determine individual channel interval averages, minimums, maximums, standard deviations, and samples per interval and perform inter-channel calculations, including obtaining averages and loads. BASs typically are not provided with the ability to perform time-interval-based averaging intervals; however, some newer systems can be configured to provide the required data.

Data Archival and Retrieval Format. Most limited channel data recording devices provide for archival of averaged or instantaneous measured data in a time series record format that can be directly loaded into a spreadsheet.

In general, using a BAS as the data-recording instrument should be considered only after careful review of its capabilities. Some BASs cannot record and archive data at regular intervals; however, some newer systems can be configured to provide the required data.

5.4.2 Sensors. Sensor selection is dependent upon the quality (accuracy, precision, drift, rate of response), quantity, installation restrictions, method of measurement required, signal output requirements (or signal conditioning), measurement range, turndown, the capabilities of the intended data recording device, and the resources available to purchase and/or support it.

5.5 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, and a user's calibration against the independent lab instrument (a transfer standard) is considered third order.

5.6 The Uncertainty of the Measurement. It should be understood that any measurement of chilled-water plant efficiency includes a degree of uncertainty; this is true whether or not the degree of uncertainty is specifically specified. Measurements made in the field are especially subject to potential errors. In contrast to measurements made under the controlled conditions of a laboratory setting, field measurements are typically made under less predictable circumstances and with less accurate and less expensive instrumentation. Field measurements are vulnerable to errors arising from variable measurement conditions (the method employed may not be the best choice for the conditions of the specific application), from limited instrument field calibration (typically due to the fact that field calibration is more complex and expensive), from the simplified data sampling and archiving methods employed, and from limitations in the ability to adjust instruments in the field. Table 5-2 provides a range of maximum allowable measurement error requirements of individual measurements to meet a desired overall uncertainty in the resulting efficiency.

It is recommended that the installed instrumentation be capable of calculating a resultant COP within 5% of the true value. As Table 5-2 shows, only the measurement errors listed in the first three rows of the table are capable of meeting this recommendation.

See Informative Appendix C for a discussion of how the desired uncertainty in the result impacts individual sensor selection. See also *ASHRAE Guideline 14, Measurement of Energy and Demand Savings,* Annex A: Physical Measurements,[8] for a detailed discussion of sensors, calibration techniques, laboratory standards for measurement of physical characteristics, equipment testing standards, and cost and error considerations.

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

6. DATA GATHERING AND TRENDING

6.1 Averaging Calculation Method. The measured values from instruments are unlikely to be constant; they can fluctuate to a greater or lesser extent depending on the installed conditions and the instrument employed. For calculation, display, and recording purposes, all data should be continuously averaged over a short time period to remove the fluctuations ("smoothing") and provide meaningful data to work with. For more detailed information about averaging, refer to Informative Appendix D in this guideline.

7. CALCULATIONS

7.1 Computation of the Coefficient of Performance (COP)

7.1.1 For an electric-motor-driven chilled-water plant, the term *COP* is a dimensionless ratio consisting of the work done, W_d, divided by the work applied, W_a.

7.1.2 The work done, W_d, is the standard heat transfer equation for all chilled-water solutions under steady-state conditions:

For I-P units,

$$W_d = m_w \times c_p \times \Delta T \quad \text{(Btu/h)}, \qquad \text{(1) (I-P)}$$

where

m_w = water flow rate in lb/h,

c_p = specific heat at constant pressure in Btu/(lb·°F), and

ΔT = temperature difference in °F.

For SI units,

$$W_d = m_w \times c_p \times \Delta T \quad \text{(kW)}, \qquad \text{(1) (SI)}$$

where

m_w = water flow rate in kg/s,

c_p = specific heat at constant pressure in kJ/(kg·K), and

ΔT = temperature difference in °C.

7.1.3 The work applied, W_a, is the sum of all electrical energy inputs to the chilled-water plant:

For I-P units,

$$W_a = 3413 \times \text{kW} \quad \text{(Btu/h)}, \qquad \text{(2) (I-P)}$$

where

W_a = electrical power in kW.

For SI units,

$$W_a = \text{kW} \quad \text{(kW)}, \qquad \text{(2) (SI)}$$

where

W_a = electrical power in kW.

7.1.4 The basic equation for COP for all chilled-water solutions is therefore expressed as follows:

For I-P units,

$$\text{COP} = \frac{W_d}{W_a} = \frac{m_w \times c_p \times \Delta T}{3413 \times \Sigma\text{kW}} \quad \text{(dimensionless)} \qquad \text{(3) (I-P)}$$

For SI units,

$$\text{COP} = \frac{W_d}{W_a} = \frac{m_w \times c_p \times \Delta T}{\Sigma\text{kW}} \quad \text{(dimensionless)} \qquad \text{(3) (SI)}$$

7.2 Determination of COP for Chilled-Water Plants Utilizing Standard Water

7.2.1 Chilled-water plants in US locations measure the flow rate, ω, in gallons per minute (gpm).

For I-P units, therefore,

$$\omega = \frac{m_w}{8.34\ \text{lb/gal} \times 60\ \text{min/h}} = \frac{m_w}{500}\ ;\ \text{or}\ m_w = 500\omega\ , \qquad \text{(4) (I-P)}$$

where ω is flow in gpm.

For S-I units,

$$\text{L/s} = \omega = m_w\ , \qquad \text{(4) (SI)}$$

where ω is flow in L/s.

7.2.2 For I-P units, although the specific heat, c_p, for pure water at temperatures from 40°F to 60°F ranges from 1.006 to 1.002, it is generally accepted as 1.0 for standard water at these temperatures. For SI units, although the specific heat, c_p, for pure water at temperatures from 4.44°C to 15.55°C ranges from 4.203 to 4.185 kJ/(kg·K), it is generally accepted as 4.19 kJ/(kg·K) for standard water at these temperatures.

7.2.3 The differential temperature, Δ*T*, for chilled-water plants is the difference between the temperature of the water returning to the plant from the distribution system, T_2, and the water supplied by the chilled-water plant to the distribution system, T_1.

7.2.4 The equation for COP_w for a chilled-water plant utilizing standard water is therefore expressed as follows:

For I-P units,

$$\text{COP}_w = \frac{500 \times \omega \times 1 \times (T_2 - T_1)}{3413 \times \Sigma\text{kW}} = \frac{\omega \times (T_2 - T_1)}{6.826 \times \Sigma\text{kW}} \quad \text{(dimensionless)} \qquad \text{(5) (I-P)}$$

For SI units,

$$\text{COP}_w = \frac{\omega \times 4.19 \times (T_2 - T_1)}{\Sigma\text{kW}} \quad \text{(dimensionless)} \qquad \text{(5) (SI)}$$

7.3 Determination of COP for Chilled-Water Plants Utilizing Other Solutions of Water

7.3.1 Solutions of water and chemicals are used in chilled-water plants to alter the freezing point. For I-P units, typical solutions are the glycols that have specific gravities greater than 1 and specific heats less than 1. Equation 5 (I-P) can be altered for glycols (or other solutions) since all specific gravities used herein are related to that for water.

For I-P units, therefore,

$$\text{COP}_g = \frac{\omega_s \times s_g \times c_{pg} \times (T_2 - T_1)}{6.826 \times \Sigma\text{kW}}, \qquad (6)\ (\text{I-P})$$

where

ω_s = flow of the glycol solution in gpm,

s_g = specific gravity of the glycol solution (dimensionless), and

c_{pg} = specific heat of the glycol solution in Btu/(lb·°F).

For SI units, specific gravities are greater than 1 and specific heats less than 4.19 kJ/kg. Equation 5 (SI) can be altered for glycols since all specific gravities used herein are related to that for water.

For SI units, therefore,

$$\text{COP}_g = \frac{\omega_s \times \rho \times c_{pg} \times (T_2 - T_1)}{1000 \times \Sigma\text{kW}}, \qquad (6)\ (\text{SI})$$

where

ω_s = flow of the glycol solution in L/s,

ρ = density of the glycol solution in kg/m^3, and

c_{pg} = specific heat of the glycol solution in kJ/(kg·K).

Note: See Informative Appendix B of this guideline for the determination of kW/ton for electric-motor-driven chilled-water plants.

8. REFERENCES

[1] *ASHRAE Terminology of Heating, Ventilation, Air Conditioning, and Refrigeration*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1991.

[2] *ANSI/ASHRAE/IESNA Standard 90.1-2007, Energy Standard for Buildings Except Low-Rise Residential Buildings,* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 2007.

[3] *2009 ASHRAE Handbook—Fundamentals*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 2009.

[4] *2008 ASHRAE Handbook—HVAC Systems and Equipment*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 2008.

[5] *2007 ASHRAE Handbook—HVAC Applications*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 2007.

[6] *2010 ASHRAE Handbook—Refrigeration*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 2010.

[7] Heinemeier, K.E., H. Akbari, and S. Kromer, Monitoring savings in energy savings performance contracts using energy management and control systems, *ASHRAE Transactions* 102(2), 1996.

[8] *ASHRAE Guideline 14-2002, Measurement of Energy and Demand Savings*, Annex A, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 2002.

(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.