BSR/ASHRAE Standard 212P

Public Review Draft

Method of Test for Determining Energy Performance and Water-Use Efficiency of Add-On Evaporative Pre-Coolers for Unitary Air Conditioning Equipment

Second Public Review (November 2018)
(Draft Shows Proposed Independent Substantive Changes to Previous Public Review Draft)

This draft has been recommended for public review by the responsible project committee. To submit a comment on this proposed standard, go to the ASHRAE website at www.ashrae.org/standards-research--technology/public-review-drafts and access the online comment database. The draft is subject to modification until it is approved for publication by the Board of Directors and ANSI. Until this time, the current edition of the standard (as modified by any published addenda on the ASHRAE website) remains in effect. The current edition of any standard may be purchased from the ASHRAE Online Store at www.ashrae.org/bookstore or by calling 404-636-8400 or 1-800-727-4723 (for orders in the U.S. or Canada).

The appearance of any technical data or editorial material in this public review document does not constitute endorsement, warranty, or guaranty by ASHRAE of any product, service, process, procedure, or design, and ASHARE expressly disclaims such.

© 2018 ASHRAE. This draft is covered under ASHRAE copyright. Permission to reproduce or redistribute all or any part of this document must be obtained from the ASHRAE Manager of Standards, 1791 Tullie Circle, NE, Atlanta, GA 30329. Phone: 404-636-8400, Ext. 1125. Fax: 404-321-5478. E-mail: standards.section@ashrae.org.

ASHRAE, 1791 Tullie Circle, NE, Atlanta GA 30329-2305

TABLE OF CONTENTS

This is a review of Independent Substantive Changes that were made since the last public review. Areas where substantive changes have been made are highlighted in gray. In these areas, text that was removed from the previous public review is provided for reference but is shown in ~~strikeout~~ and text that has been added is shown with underline.

Only the changes highlighted in gray are open to comment at this time. All other material in this publication public review draft is provided for context only and is not open for public review comment except as it relates to the proposed changes.

(This foreword is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

FOREWORD

The objective of this method of test is to provide estimates of the performance of evaporative pre-coolers used to reduce the temperature of the air entering the condensers of unitary vapor compression air conditioners. The standard includes a laboratory test procedure that measures the temperature and airflow dependence of the coefficient of performance (COP) of a specific unitary conditioner at three different face velocities, then measures that performance a second time with the evaporator pre-cooler installed. The change in COP at the same outdoor air temperature is used to estimate the effective temperature of the air leaving the evaporative pre-cooler. Measuring the wet-bulb temperature of the incoming outdoor air allows the evaporative effectiveness of the evaporative pre-cooler to be calculated. This is the primary measured output of this method of test. In addition, this method of test provides a calculation procedure for estimating the impact of the measured evaporative effectiveness on the Capacity, Power Draw, and COP of a generic air-conditioner, as well as a calculation procedure for estimating water consumption of the tested evaporative pre-cooler.

1. PURPOSE

To provide test methods for gathering performance data for use in calculating the energy savings potential and water-use performance of add-on evaporative pre-coolers for condenser inlet air of air-cooled, direct expansion unitary air conditioning equipment.

2. SCOPE

This standard applies to add-on evaporative pre-cooling accessories applied to the condenser inlet air of air-cooled unitary direct-expansion cooling equipment with less than or equal to 240,000 Btu/h (70 kW) cooling capacity.

3. DEFINITIONS

adiabatic saturation: evaporating water into air without external gain or loss of heat. Sensible heat in both air and water becomes latent heat in entrained vapor, and temperatures fall and equalize.

air, standard: dry air having a mass density of 0.075 lbm/ft^3 (1.204 kg/m^3), a specific heat of 0.24 Btu/lbm-°F [1.006 kJ/kg-°C], a specific heat ratio of 1.4, and a viscosity of 1.22E-5 lbm/ft-s ~~s[s~~ [1.82E-5 kg/m-s]. Dry air at 68°F [20°C] and 29.92 in. Hg [101.325 kPa] has these properties, approximately.

apparatus: testing facility or laboratory, and instrumentation.

bleed:_a device or system that allows for a controlled continuous or intermittent release of part of the circulated water of an evaporative system in order to control the concentration of dissolved solids.

capacity: the rate, expressed in Btu/h [watts], at which the equipment removes heat from the air passing through it under specified conditions of operation. ~~Total capacity consists of the combination of sensible capacity (associated with a change in dry-bulb temperature) and latent capacity (associated with a change in humidity ratio).~~

efficiency: ~~a~~ ratio of the net total cooling capacity ~~of the unitary equipment~~ to the effective power input at any given set of rating conditions, in watts per watt. This ~~The~~ efficiency is expressed ~~by a dimensionless~~ as the Coefficient of Performance (COP).

equilibrium: a steady-state condition during which the fluctuations of variables being measured remain within the specified test tolerances.

equipment, unitary: a direct-expansion air conditioning system employing compressor(s), indoor air coil(s), and outdoor coil(s) in one or more assemblies. For the purposes of this standard, the scope is limited to equipment that employs air-cooled condensers.

evaporative effectiveness: a measure of the cooling performance of an evaporative cooling system, determined as the dry-bulb temperature reduction achieved divided by the entering wet-bulb depression [%]. Similar to “direct saturation efficiency” in ASHRAE HVAC Systems and Equipment Handbook.

evaporative pre-cooler: a device that cools air by the evaporation of water, which is subsequently used for cooling the condenser of a unitary air conditioner.

pressure, standard barometric: the absolute pressure exerted by the atmosphere at mean sea level, defined as 29.92 in. Hg or 14.696 psia [101.325 kPa].

temperature, dry-bulb: the air temperature measured by a dry temperature sensor [°F (°C)].

temperature, wet-bulb: the air temperature measured by a temperature sensor covered by a water-moistened wick and exposed to air in motion. When correctly measured, it is a close approximation of the temperature of adiabatic saturation [°F (°C)].

test: ~~the recorded readings for various points of operation taken while equilibrium is maintained and used in the computation of results.~~ the recorded group of readings of required test data taken while equilibrium is maintained and used in the computation of results.

wet-bulb depression: ~~the difference between the dry and wet-bulb temperatures of an air sample~~ the difference between the dry-bulb and wet-bulb temperatures at the same location [°F (°C)].

4. NOMENCLATURE

The definitions of terms used in this standard are provided in Table 4.1.

Table 4.1 Symbols

a_{COP} = quadratic coefficient for equation describing relationship between temperature at coefficient of performance of the baseline unit [-]

b_{COP} = linear coefficient for equation describing relationship between temperature at coefficient of performance of the baseline unit [-]

c_{COP} = quadratic coefficient for equation describing relationship between temperature at coefficient of performance of the baseline unit [-]

CAP_{TEMP}^{MODE} = total cooling capacity, Btu/h [W]
MODE = test unit operating mode:
  BASE = test unit without pre-cooler
  DRY = pre-cooler attached, water off
  WET = pre-cooler attached, water on
  EEnom = at nominal face velocity
  200 = at 200 ft/min (1.0 m/s) face velocity
  350 = at 350 ft/min (1.75 m/s) face velocity
  500 = at 500 ft/min (2.5 m/s) face velocity
  EEnomWET = at nominal face velocity (pre-cooler water on)
  200WET = at 200 ft/min (1.0 m/s) face velocity (pre-cooler water on)
  350WET = at 350 ft/min (1.75 m/s) face velocity (pre-cooler water on)
  500WET = at 500 ft/min (2.5 m/s) face velocity (pre-cooler water on)
  %inc = percentage capacity increase for generic RTU
TEMP = outside air dry-bulb temperature, °F [°C], and outside air wet-bulb temperature, °F [°C]

$\mathrm{COP}_{\mathrm{TEMP}}^{\mathrm{MODE}}$ = coefficient of performance [-]
Ratio of total cooling capacity to total unit input power:
MODE = test unit operating mode:
- BASE = test unit without pre-cooler
- DRY = pre-cooler attached, water off
- WET = pre-cooler attached, water on
- EEnom = at nominal face velocity
- 200 = at 200 ft/min (1.0 m/s) face velocity
- 350 = at 350 ft/min (1.75 m/s) face velocity
- 500 = at 500 ft/min (2.5 m/s) face velocity
- EEnomWET = at nominal face velocity (pre-cooler water on)
- 200WET = at 200 ft/min (1.0 m/s) face velocity (pre-cooler water on)
- 350WET = at 350 ft/min (1.75 m/s) face velocity (pre-cooler water on)
- 500WET = at 500 ft/min (2.5 m/s) face velocity (pre-cooler water on)
- %inc = percentage COP increase for generic RTU

TEMP = outside air dry-bulb temperature, °F [°C], with or without outside air wet-bulb temperature, °F [°C]

$c_{p,l}$ = specific heat of the liquid (e.g., water), Btu/lbm·°F [J/kg·°C]

$EE_{T_{DB}/T_{WB}}$ = evaporative effectiveness, %, determined at the measured outside air dry-bulb and wet-bulb temperature combination.

K = flow coefficient of system curve SCFM/(in. wc)^n [(sl/s/Pa^n)]

$\dot{m}_{water,evap}$ = the rate at which water is evaporated into air, as determined from condenser air-side measurements, gal/h [kg/h]

$\dot{\mathrm{m}}_{\mathrm{TEMP}}^{\mathrm{water}}$ = water consumption of pre-cooler, gal/h [kg/h]
TEMP = outside air dry-bulb temperature, °F [°C], and outside air wet-bulb temperature, °F [°C]

$\dot{\mathrm{m}}_{\mathrm{MODE}}^{\mathrm{water}}$ = water consumption of pre-cooler, gal/h [kg/h]
MODE = test unit operating mode:
- EEnom = at nominal face velocity
- 200 = at 200 ft/min (1.0 m/s) face velocity
- 350 = at 350 ft/min (1.75 m/s) face velocity
- 500 = at 500 ft/min (2.5 m/s) face velocity

$\dot{m}_{heating\ liquid}$ = mass flow rate of liquid if used for evaporator load, lbm/h [kg/s]

n = flow exponent of system curve [-]

$\mathrm{P}_{\mathrm{TEMP}}^{\mathrm{MODE}}$ = input power, total test unit (unitary equipment only), W [watts]
MODE = test unit operating mode:
- BASE = test unit without pre-cooler
- DRY = pre-cooler attached, water off
- WET = pre-cooler attached, water on

EEnom = at nominal face velocity
200 = at 200 ft/min (1.0 m/s) face velocity
350 = at 350 ft/min (1.75 m/s) face velocity
500 = at 500 ft/min (2.5 m/s) face velocity
EEnomWET = at nominal face velocity (pre-cooler water on)
200WET = at 200 ft/min (1.0 m/s) face velocity (pre-cooler water on)
350WET = at 350 ft/min (1.75 m/s) face velocity (pre-cooler water on)
500WET = at 500 ft/min (2.5 m/s) face velocity (pre-cooler water on)
%red = percentage power draw decrease for generic RTU
TEMP = outside air dry-bulb temperature, °F [°C], with or without outside air wet-bulb temperature, °F [°C]

$P_{\text{TEMP}}^{\text{pre-cooler}}$ = input power, pre-cooler, W [watts]
TEMP = outside air dry-bulb temperature, °F [°C], and outside air wet-bulb temperature, °F [°C]

p_b = barometric pressure, in. Hg [kPa]

Δp_{coil} = pressure differential across the condenser coil, in. wc [Pa]

$\Delta p_{coil+cooler}$ = pressure differential across the condenser coil plus the pre-cooler, in. wc [Pa]

$\Delta p_{coil+cooler,dry}$ = pressure differential across the condenser coil + pre-cooler (Dry), in. wc [Pa]

$\Delta p_{coil+cooler,wet}$ = pressure differential across the condenser coil + pre-cooler (Wet), in. wc [Pa]

Q_{cond} = ~~Air~~ airflow through the condenser with or without the pre-cooler, referenced to the inlet density, CFM [l/s]

Q_{SCFM} = airflow through condenser, adjusted ~~to~~ to standard air density (0.075 lbm/ft³ [1.204 kg/m³]), SCFM [sl/s]

$R_{pre\text{-}cool}$ = relative velocity of the air passing through the pre-cooler compared to air passing through the condenser

~~q_{tci} = total cooling capacity, indoor side data, Btu/h [W]~~

T_{DB} = dry-bulb temperature for target outdoor air condition, °F [°C]

$T_{DB,\ eq}$ = equivalent dry-bulb temperature leaving the pre-cooler, °F [°C]

$T_{DB,\ in}$ = measured dry-bulb temperature entering the condenser, °F [°C]

$t_{l,in}$ = temperature of heated liquid entering evaporator (if used), °F [°C]

$t_{l,out}$ = temperature of liquid leaving evaporator (if used), °F [°C]

T_{WB} = wet-bulb temperature for target outdoor air condition, °F [°C]

$T_{WB,\ in}$ = measured wet-bulb temperature entering the condenser, °F [°C]

$V_{pre\text{-}cool}$ = ~~Face~~ face velocity at the pre-cooler inlet, ft/s [m/s]

v_{cond} = specific volume of dry air at the condenser airflow measurement apparatus, ft³/lbm [m³/kg]

ρ_{INLET} = air density at pre-cooler intake calculated from measured temperature, humidity and barometric pressure as per ASHRAE 2013 Fundamentals IP [1], Chapter 1, lbm/ft³ (kg/m³)

ρ_{STANDARD} = standard air density, 0.075 lbm/ft³ (1.204 kg/m³)

W_{in} = humidity ratio of air entering condenser pre-cooler, dimensionless [mass water vapor / mass dry air]

W_{out} = humidity ratio of air leaving condenser, dimensionless [mass water vapor / mass dry air]

$WUE_{T_{DB}/T_{WB}}$ = water use effectiveness, %, determined at specified outside air dry-bulb and wet-bulb temperature combination.

5. MEASUREMENT PROTOCOL

5.1 Input Data Requirements

5.1.1 Test Description:

Date:

Location: (Facility name, city, state)

Person Performing Test: (Name, email, telephone)

5.1.2 Evaporative Pre-Cooler Specifications

The manufacturer's specifications for the pre-cooler shall be reported, including all the characteristics listed herein:

Table 5.1 - Pre-cooler Description

Data Required	Description
Manufacturer:	
Model Number:	
Media	Manufacturer-specified media, and media used for testing, media manufacturer and condition of media (hours of operation, expected lifetime)

Water distribution method	Example: Water distributor, spray nozzles
Manufacturer recommended range of cooling-equipment capacity	Btu/h (kW)
Manufacturer recommended pre-cooler face velocity requirement	Maximum pre-cooler face velocity recommended by the manufacturer [ft/min (m/s)]
Water Pressure	Manufacturer specified ~~operating~~ inlet (i.e., supply) water pressure, gauge [psi (kPa)]
Power Requirement	Voltage, amperage
Water Maintenance	Example: single-pass, sump with bleed (timed, adjustable, conductivity controlled), sump with purge (timed, adjustable, conductivity controlled)
Pre-cooler control method	Example: cycling with condensing unit, time-delayed start, outdoor air temperature control
Water flow control method	Example: constant, ambient-temperature modulated, wet-bulb-depression modulated
Expected media life	Seasons, years
Pre-Cooler Air-Flow Surface Area	Reported in units of ft^2 ~~[~~(m^2)~~]~~
Pre-cooler Picture	Picture of the test unit with pre-cooler installed

5.1.3 Cooling Equipment Used for Testing (Equipment-Manufacturer Data)

The cooling equipment used for testing shall be capable of being operated with a single compressor operated at a constant speed and a constant condenser fan speed for all tests. The cooling equipment used for testing the evaporative pre-cooler shall be reported, including all the characteristics listed herein:

Table 5.2 – Test unit description

Data Required	Description
Manufacturer:	
Model Number:	
Serial Number	
Refrigerant	Example: R-22 or R-410A
Capacity	AHRI Rated Cooling Capacity in Btu/h (kW)

Efficiency	AHRI Rated Energy Efficiency Ratio [COP]
Number of Compressors	Total and number used during testing
Number of Condenser Fans	Total and number used during testing
Condenser Coil Airflow Surface Area	Reported in units of ft^2 [m^2]
Test Unit Picture	Picture of the test unit

5.2 Methods of Testing

5.2.1 Description of Test Apparatus

Recommended configurations for the test apparatus are provided in ASHRAE Standard 37-2009[4], Section 6. An example configuration is shown in Figure 5.1. An airflow measuring device is attached to the equipment air discharge (evaporator and condenser, as applicable) and then, in turn, connected to reconditioning equipment. The discharge from the reconditioning apparatus provides air to the test room at the specified dry-bulb temperature and water vapor content.

The arrangement shown along with the others in Standard 37 are intended to illustrate the various possibilities available and should not be construed as applying specifically and solely to the types of equipment shown. Other means of handling the air leaving the airflow measuring apparatus and supplying air at the proper conditions to the equipment may be employed provided that they do not interfere with the prescribed means of measuring airflow rate, temperature, and external resistance, and provided that they do not create unstable conditions surrounding the equipment. The outdoor test room shall be configured to capture and manage the humidified air leaving the condenser such that it does not adversely affect the water vapor content of the air entering the condenser.

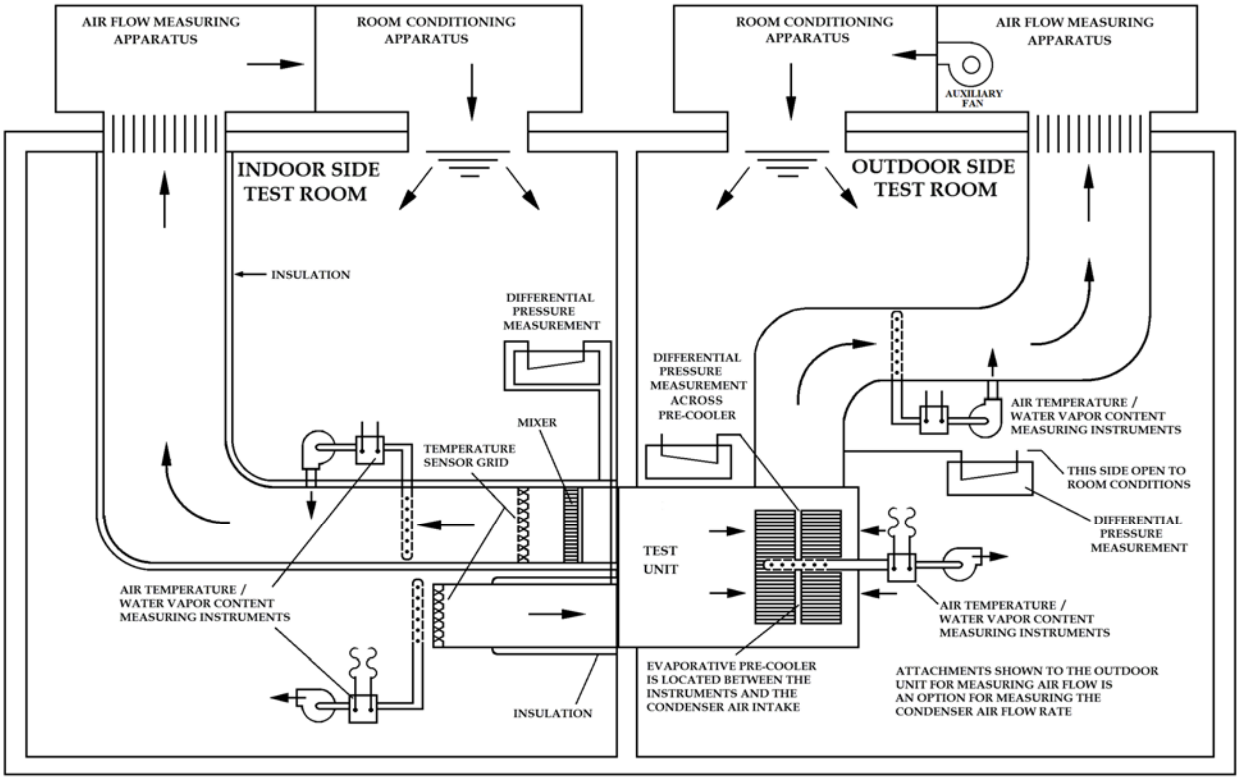


Figure 5.1 - Room air enthalpy test method arrangement.

Testing shall be performed at three different equipment configurations over a range of environmental conditions. The equipment configurations are:

5.2.1.1 Configuration 1: Cooling equipment baseline (at as-found flow, and four constant mass-flow conditions (i.e., face velocities))
5.2.1.2 Configuration 2: Dry-cooler: The pre-cooler is installed with water turned off
5.2.1.3 Configuration 3: Wet cooler: The pre-cooler is installed and operational with water turned on (at as-found flow, and four constant mass-flow conditions (i.e., face velocities))

5.2.2 Measurement Accuracies, Test Conditions, and Test Tolerances

The required measurements, accuracies, and test conditions are summarized in Table 5.3. Measurements shall be taken every 10 seconds or faster and averaged, and ~~the~~ those averages shall be recorded at a frequency of every minute or faster. All measured data shall be recorded to at least 4 significant figures, unless otherwise specified.

Table 5.3 - Measurement Accuracies, Test Conditions, and Test Tolerances

Measurement		Units	Test Condition	Instrument Accuracy	Test Operating Tolerance[1]	Test Condition Tolerance[2]
Outdoor air dry-bulb temperature		°F (°C)	Table 5.4 Table 5.6 Table 5.7	± 0.5 (0.3)	±2.0 (1.1)	±0.5 (0.3)
Outdoor air wet-bulb temperature		°F (°C)	Table 5.4 Table 5.6 Table 5.7	± 0.5 (0.3)	±1.0 (0.6)	±0.3 (0.2)
Indoor air dry-bulb temperature	Entering	°F (°C)	80 (26.7)	±0.5 (0.3)	±2.0 (1.1)	±0.5 (0.3)
	Leaving		-	±0.5 (0.3)	-	-
Indoor air wet-bulb temperature	Entering	°F (°C)	67 (19.4)	±0.5 (0.3)	±1.0 (0.6)	±0.3 (0.2)
	Leaving		-	±0.5 (0.3)	-	-
Indoor airflow rate		% of reading ~~cfm (l/s)~~	Per Section 5.2.4.1	±1	±2	±1
Outdoor air mass flow rate		% of reading	Per Section 5.2.3	±1	±2	±1
~~Nozzle pressure differential~~		~~% of reading~~	-	~~±1~~	~~±2~~	-
Condenser-coil static pressure differential		in. wc (Pa)	Per Section 5.2.3	±0.002 (0.5)	±0.02 (5.0)	
Differential pressure across condenser		% of reading	Per Section 5.2.3	±1	±2	-
Indoor load water temperature[3]	Entering	°F (°C)	80 (26.7)	±0.5 (0.3)	±1.0 (0.6)	±0.5 (0.3)
	Leaving		-	±0.5 (0.3)	-	-
Indoor load water flow rate[3]		% of reading	Per Section 5.2.4.2	±1	±2	
Refrigerant pressure[4]		% of reading	-	±2.5	-	-
Refrigerant temperature[4]		% of reading	-	±2.5	-	-

---

[1] The difference between the maximum and minimum measurement over the test duration for any operating condition.

[2] The difference between the nominal test condition and the average value over the test duration for any operating condition.

[3] Only required when the indoor load is provided by a water-to-refrigerant heat exchanger.

[4] Only required when cooling capacity is measured on the refrigerant side

Measurement	**Units**	**Test Condition**	**Instrument Accuracy**	**Test Operating Tolerance[1]**	**Test Condition Tolerance[2]**
Refrigerant mass flow[4]	% of reading	-	±1	-	-
System Voltage	% of reading	Manufacturer specified	±1	±2	-
System Power[5]	% of reading	-	±2	-	-
Pre-cooler Power[6]	% of reading	-	±2	-	-
Pre-cooler inlet water temperature	°F (°C)	90 (32.2)	±0.5 (0.3)	±10.0 (5.6)	±5 (3)
Pre-cooler water flow rate	% of reading		±2.5		
Barometric pressure	% of reading	-	±2.5	-	-

---

[5] This measurement must include Compressor plus Condenser-Fan Power at a minimum, or the total power consumption of the unit. The system power does not include pre-cooler power.

[6] This includes total power to the pre-cooler including any pumps, solenoid valves, and control electronics. Because of the intermittent operation of some systems, the measurement shall be made with an integrating energy (watt-hour) meter. The average power consumption is then determined as the totalized energy divided by the integration period. If necessary, the integration period shall be extended beyond the normal test period to capture complete cycles (e.g., start to start).

5.2.3 Outdoor-Airflow Measurement, Characterization, and Control

The outdoor condenser fan airflow shall be measured under all configurations using a nozzle-based airflow measuring apparatus according to ASHRAE Standard 37-2009 [4]. The accuracy of the pressure transducer used in the nozzle airflow measuring apparatus shall meet the requirements of Table 5.3.

5.2.3.1 Baseline Equipment Characterization and Control

To accommodate any impact of the test apparatus (i.e., exhaust ductwork) on the performance of the equipment being tested, the equipment shall be operated first in free-air with no exhaust ducting attached, the compressor off, and the outdoor temperature at 105ºF (40.6ºC). During this test, the differential pressure across the condenser coil (and screen if present) of the test unit (Δp_{coil}) shall be measured by means of a static pressure measurement between the room (from which the outdoor air is entering the condenser) and the condenser-coil outlet plenum (permanently located upstream of the fan, in a location sheltered from high velocities and turbulence). The pressure measurement points within the condenser coil outlet plenum (i.e., between the condenser coil and the condenser fan) and outside the coil (i.e., in the test room), shall be the same for all tests. The differential pressure shall be measured with the accuracy specified in Table 5.3.

During all nominal (as-found) baseline-equipment performance tests, the auxiliary fan shall be controlled so as to maintain the same pressure differential across the condenser coil (Δp_{coil}). The pressure matching shall be accomplished by changing the speed of an auxiliary fan connected to the exhaust ductwork leaving the condenser fan.

For the four constant mass-flow baseline characterization tests, 1) at as-found mass flow at 105ºF (40.6ºC), 2) at ~~300~~ 200 ft/min (~~1.5~~ 1.0 m/s) face velocity at 105ºF (40.6ºC), 3) at ~~400~~ 350 ft/min (~~2.0~~ 1.75 m/s) face velocity at 105ºF (40.6ºC), and 4) at 500 ft/min (2.5 m/s) face velocity at 105ºF (40.6ºC), the auxiliary fan shall be adjusted to maintain a constant mass-flow rate at all outdoor-air conditions.

5.2.3.2 Condenser-Coil Resistance

To be able to estimate the impact of the pre-cooler on condenser flow, the pressure drop across the condenser coil shall be measured at different face velocities, so as to produce a “system-curve” for the condenser coil. This shall be accomplished by measuring Δp_{coil} at a series of flows measured by the nozzle airflow measurement apparatus. These flows shall be created by changing the speed of the auxiliary fan connected to the exhaust ductwork leaving the condenser fan (or adding resistance in that exhaust ductwork). The flows to be measured shall be chosen to produce condenser-coil face velocities of ~~300~~ 200 ft/min (~~1.5~~ 1.0 m/s), ~~400~~ 350 ft/min (~~2.0~~ 1.75 m/s), and 500 ft/min (2.5 m/s). Δp_{coil} shall be recorded at each face velocity (Record results in Table 5.4).

~~**Table 5.4 – Flow Resistance Data 105ºF (40.6ºC)**~~

	~~Condenser Coil (Δp_{coil})~~		~~Condenser Coil plus Dry Pre-Cooler ($\Delta p_{coil+cooler}$)~~		~~Condenser Coil plus Wet Pre-Cooler ($\Delta p_{coil+cooler}$)~~	
~~Face Velocity [fpm (m/s)]~~	~~Flow [SCFM (sl/s)]~~	~~Pressure Difference [in. wc (Pa)]~~	~~Flow [SCFM (sl/s)]~~	~~Pressure Difference [in. wc (Pa)]~~	~~Flow [SCFM (sl/s)]~~	~~Pressure Difference [in. wc (Pa)]~~
~~Nominal[1]~~						
~~300 (1.5)~~						
~~400 (2)~~						
~~500 (2.5)~~						

~~[1] Nominal face velocity is defined as the measured volumetric flowrate through the condenser at 105ºF (40.6ºC) divided by the surface area of the condenser.~~

5.2.3.3 Pre-Cooler Resistance (Dry)

To determine how to control the auxiliary fan during performance testing with a dry pre-cooler (Table 5.7), the equipment shall be operated first in free-air with the dry pre-cooler attached, but with no exhaust ducting attached, the compressor off, and the outdoor temperature at 105ºF (40.6ºC). During this test, the differential pressure across the condenser coil of the test unit ($\Delta p_{coil+cooler}$) shall be measured by means of a static pressure measurement between the room (from which the outdoor air is entering the condenser) and the condenser-coil outlet plenum (permanently located upstream of the fan, in a location sheltered from high velocities and turbulence). The differential pressure shall be measured with the accuracy specified in Table 5.3.

To directly characterize the flow resistance of a dry pre-cooler at different face velocities, the differential pressure across the condenser coil plus the pre-cooler ($\Delta p_{coil+cooler}$) shall be measured by means of a static pressure measurement between the room and the condenser-coil outlet plenum (same location upstream of the fan) at different face velocities, so as to produce a "system-curve" for the combination of the condenser coil and pre-cooler. This shall be accomplished by measuring $\Delta p_{coil+cooler}$ at a series of flows measured by the nozzle airflow measuring apparatus. These flows shall be created by changing the speed of the auxiliary fan connected to the exhaust ductwork leaving the condenser fan (or adding resistance in that exhaust ductwork). The flows to be measured shall be chosen to produce condenser-coil face velocities of 200 ft/min (1.0 m/s), 350 ft/min (1.75 m/s), ~~300 ft/min (1.5 m/s), 400 ft/min (2.0 m/s),~~ and 500 ft/min (2.5 m/s). $\Delta p_{coil+cooler}$ shall be recorded at each face velocity. Record results in Table 5.4.

5.2.3.4 Pre-Cooler Resistance (Wet)

To determine how to control the auxiliary fan during performance testing with a wet pre-cooler (Table 5.8), the equipment shall be operated first in free-air with the dry pre-cooler attached, but with no exhaust ducting attached, the compressor off, and the outdoor temperature at 105ºF (40.6ºC). During this test, the differential pressure across the condenser coil of the test unit ($\Delta p_{coil+cooler}$) shall be measured by means of a static pressure measurement between the room (from which the outdoor air is entering the condenser) and the condenser-coil outlet plenum (permanently located upstream of the fan, in a location sheltered from high velocities and turbulence). The differential pressure shall be measured with the accuracy specified in Table 5.3.

To directly characterize the flow resistance of a wet pre-cooler at different face velocities, the differential pressure across the condenser coil plus the pre-cooler ($\Delta p_{coil+cooler}$) shall be measured by means of a static pressure measurement between the room and the condenser-coil outlet plenum (same location upstream of the fan) at different face velocities, so as to produce a "system-curve" for the combination of the condenser coil and wet pre-cooler. This shall be accomplished by measuring $\Delta p_{coil+cooler}$ at a series of flows measured by the nozzle airflow measuring apparatus. These flows shall be created by changing the speed of the auxiliary fan connected to the exhaust ductwork leaving the condenser fan (or adding resistance in that exhaust ductwork). The flows to be measured shall be chosen to produce condenser-coil face velocities of 200 ft/min (1.0 m/s), 350 ft/min (1.75 m/s), ~~300 ft/min (1.5 m/s), 400 ft/min (2.0 m/s),~~ and 500 ft/min (2.5 m/s). $\Delta p_{coil+cooler}$ shall be recorded at each face velocity. Record results in Table 5.4.

Table 5.5 - Flow Resistance Data 105°F (40.6°C)

	Condenser Coil (Δp_{coil})		Condenser Coil plus Dry Pre-Cooler ($\Delta p_{coil+cooler,dry}$)		Condenser Coil plus Wet Pre-Cooler ($\Delta p_{coil+cooler,wet}$)	
Face Velocity [fpm (m/s)]	Flow (Q_{cond}) [SCFM (sl/s)]	Pressure Difference [in. wc (Pa)]	Flow (Q_{cond}) [SCFM (sl/s)]	Pressure Difference [in. wc (Pa)]	Flow (Q_{cond}) [SCFM (sl/s)]	Pressure Difference [in. wc (Pa)]
Nominal[1]						
200 (1.0)						
350 (1.75)						
500 (2.5)						

[1] Nominal face velocity is defined as the measured volumetric flowrate through the condenser at 105°F (40.6°C) divided by the surface area of the condenser. All values shall be reported to at least 4 significant figures.

5.2.3.5 System Curves

The data in Table 5.4 shall be used to produce system curves for each of the three configurations in Table 5.4: condenser coil, condenser coil plus dry pre-cooler, and condenser coil plus wet pre-cooler. The system curves shall be power-law fits of the form:

$$Q_{SCFM}\,\cancel{Flow} = K * \Delta p^{n}$$

The results shall be reported in Table 5.5.

Table 5.5 - Flow Resistance Characterization 105ºF (40.6ºC)

	Flow Coefficient, K [SCFM/(in. wc)^n]	Flow Exponent, n [-]
Condenser Coil (Δp_{coil})		
Condenser Coil plus Dry Pre-Cooler ($\Delta p_{coil+cooler,\ dry,}$)		
Condenser Coil plus Wet Pre-Cooler ($\Delta p_{coil+cooler,\ wet}$)		

~~**Table 5.5 – Flow Resistance Characterization 105ºF (40.6ºC)**~~

~~Condenser Coil (Δp_{coil})~~		~~Condenser Coil plus Dry Pre-Cooler ($\Delta p_{coil+cooler}$)~~		~~Condenser Coil plus Wet Pre-Cooler ($\Delta p_{coil+cooler}$)~~	
~~Flow Coefficient, K [SCFM/(in. wc)^n(sl/s/Pa^n)]~~	~~Flow Exponent, n [-]~~	~~Flow Coefficient, K [SCFM/(in. wc)^n(sl/s/Pa^n)]~~	~~Flow Exponent, n [-]~~	~~Flow Coefficient, K [SCFM/(in. wc)^n(sl/s/Pa^n)]~~	~~Flow Exponent, n [-]~~

5.2.4 Capacity Measurement

The cooling capacity shall be measured on the evaporator side using one of the three techniques in this section. In all cases, the external conditions (temperatures, flows, pressures) seen by the evaporator and blower (if present) shall be the same with and without the pre-cooler installed. All measurements shall be made with instrument accuracies and operating conditions specified in Table 5.3.

5.2.4.1 The first option is a ~~fin-coil~~ refrigerant-to-air evaporator with controlled inlet temperature, humidity, and airflow, using the change in air enthalpy and airflow rate to measure capacity, CAP_{TEMP}^{MODE}. For this option, the capacity shall be measured according the procedures in ASHRAE Standard 37-2009 [4], Section 7.3.3.1.

The indoor airflow shall be held constant at a fixed value within ~~350-450 cfm per rated ton of capacity~~ manufacturer specifications. ~~where the rated capacity is the value cited by the manufacturer in published literature for the unit's rated cooling capacity when operated at Test Condition A as described by ANSI/AHRI 210/240 [2] or the standard rating condition for cooling as described by ANSI/AHRI 340/360 [3].~~ The indoor airflow and any external static pressure shall be held constant for all baseline and pre-cooler tests within the test operating and test condition tolerances in Table 5.3.

5.2.4.2 The second option is a refrigerant to water heat exchanger with controlled inlet water temperature and water flow, using water flow and the temperature differential across the heat exchanger to measure capacity. In this option, the water to refrigerant evaporator is used to simulate the same load that a refrigerant-to-air ~~fin-coil~~ evaporator would provide.

The cooling capacity of the water is calculated from:

$$\underline{CAP^{MODE}_{TEMP}}\ \sout{q_{tci}} = \dot{m}_{heating\ liquid} * c_{p,l} * \left(t_{l,in} - t_{l,out}\right)$$

In this method, the protocol described in this section shall be followed to set the water flow rate at the 95°F outdoor air temperature, and the water flow rate shall be held at this value for the remainder of the tests. To set the water flow rate at 95°F, the water entering the evaporator shall meet the conditions specified in Table 5.3. Then, the water flow rate shall be controlled such that the delivered capacity to the evaporator matches manufacturer-reported cooling capacity plus 500 Btu/h (0.15 kW) per rated ton. The rated capacity is the value cited by the manufacturer in published literature for the unit's rated cooling capacity when operated at test condition A in ANSI/AHRI 210/240 [2] or the standard rating condition for cooling as described by ANSI/AHRI 340/360 [3].

5.2.4.3 The third option is a refrigerant-to-air ~~fin-coil~~ evaporator with controlled inlet temperature, humidity, and airflow, using the change in refrigerant enthalpy and the refrigerant flow rate to measure capacity, $\underline{CAP^{MODE}_{TEMP}}$. For this option, the capacity shall be measured according the procedures described in Section 7.5 of ASHRAE Standard 37-2009 [4].

5.2.5 Performance-Data Measurement Protocol

For all tests performance-test data, including all power and capacity tests in Tables 5.6 through 5.9, each measurement shall be based upon averaging the results over the 30 minutes, following a 30-minute stabilization period at each environmental condition.

5.3 Performance-Test Data

5.3.1 Baseline Performance (Configuration 1)

For the first equipment configuration (baseline), the cooling equipment power draw and cooling capacity shall be reported for the baseline cooling equipment with no pre-cooler installed at ~~four~~ five different outdoor-air temperature conditions at ~~five~~ four different condenser-fan face velocities as specified in Table 5.6.

If the cooling equipment is removed from the test chamber, tests 5.6a and 5.6e shall be repeated. If the new coefficient of performance (COP) test results are within ±3% of the prior results, the prior results in Table 5.6 can be used for the fits in Table 6.1. If either of the test results vary by more than ±3%, all of the tests in Table 5.6 shall be performed.

Table 5.6 - Equipment Configuration 1A: Baseline Cooling Equipment Data without Pre-Cooler

Test	Date	Target OA Condition T_{DB} [°F (°C)]	Condenser Inlet Flow [ACFM (l/s)]	Condenser Inlet Flow[SCFM (sl/s)]	Cooling Equipment Capacity [Btu/h (kW)]	Cooling Equipment Power [kW]	COP* [-]
Pressure Differential (Δp_{coil}) held constant (from 5.2.3.1) at Nominal Condenser-Coil Face Velocity:							
5.6 a	yy/mm/dd	105(40.6)			CAP_{105}^{BASE}	P_{105}^{BASE}	COP_{105}^{BASE}
5.6 b	yy/mm/dd	95 (35)			CAP_{95}^{BASE}	P_{95}^{BASE}	COP_{95}^{BASE}
5.6 c	yy/mm/dd	85(29.4)			CAP_{85}^{BASE}	P_{85}^{BASE}	COP_{85}^{BASE}
5.6 d	yy/mm/dd	75(23.9)			CAP_{75}^{BASE}	P_{75}^{BASE}	COP_{75}^{BASE}
5.6 e	yy/mm/dd	65(18.3)			CAP_{65}^{BASE}	P_{65}^{BASE}	COP_{65}^{BASE}
Mass flow held constant at AS-FOUND mass flow at 105ºF (40.6ºC) (from 5.2.3.1)							
5.6 f	yy/mm/dd	105(40.6)			CAP_{105}^{EEnom}	P_{105}^{EEnom}	COP_{105}^{EEnom}
5.6 g	yy/mm/dd	95 (35)			CAP_{95}^{EEnom}	P_{95}^{EEnom}	COP_{95}^{EEnom}
5.6 h	yy/mm/dd	85(29.4)			CAP_{85}^{EEnom}	P_{85}^{EEnom}	COP_{85}^{EEnom}
5.6 i	yy/mm/dd	75(23.9)			CAP_{75}^{EEnom}	P_{75}^{EEnom}	COP_{75}^{EEnom}
5.6 j	yy/mm/dd	65(18.3)			CAP_{65}^{EEnom}	P_{65}^{EEnom}	COP_{65}^{EEnom}
Mass flow held constant at mass flow at ~~300~~ 200 ft/min (1.0 m/s) at 105ºF (40.6ºC) (from 5.2.3.1)							
5.6 k	yy/mm/dd	105(40.6)			$CAP_{105}^{2\cancel{3}00}$	$P_{105}^{2\cancel{3}00}$	$COP_{105}^{2\cancel{3}00}$
5.6 l	yy/mm/dd	95 (35)			$CAP_{95}^{2\cancel{3}00}$	$P_{95}^{\cancel{3}200}$	$COP_{95}^{2\cancel{3}00}$
5.6 m	yy/mm/dd	85(29.4)			$CAP_{85}^{2\cancel{3}00}$	$P_{85}^{2\cancel{3}00}$	$COP_{85}^{2\cancel{3}00}$
5.6 n	yy/mm/dd	75(23.9)			$CAP_{75}^{2\cancel{3}00}$	$P_{75}^{2\cancel{3}00}$	$COP_{75}^{2\cancel{3}00}$
5.6 o	yy/mm/dd	65(18.3)			$CAP_{65}^{2\cancel{3}00}$	$P_{65}^{2\cancel{3}00}$	$COP_{65}^{2\cancel{3}00}$
Mass flow held constant at mass flow at ~~400~~ 350 ft/min (1.75 m/s) at 105ºF (40.6ºC) (from 5.2.3.1)							
5.6p	yy/mm/dd	105(40.6)			$CAP_{105}^{\cancel{40}350}$	$P_{105}^{\cancel{40}350}$	$COP_{105}^{\cancel{40}350}$
5.6q	yy/mm/dd	95 (35)			$CAP_{95}^{\cancel{40}350}$	$P_{95}^{\cancel{40}350}$	$COP_{95}^{\cancel{40}350}$
5.6r	yy/mm/dd	85(29.4)			$CAP_{85}^{\cancel{40}350}$	$P_{85}^{\cancel{40}350}$	$COP_{85}^{\cancel{40}350}$
5.6s	yy/mm/dd	75(23.9)			$CAP_{75}^{\cancel{40}350}$	$P_{75}^{\cancel{40}350}$	$COP_{75}^{\cancel{40}350}$
5.6t	yy/mm/dd	65(18.3)			$CAP_{65}^{\cancel{40}350}$	$P_{65}^{\cancel{40}350}$	$COP_{65}^{\cancel{40}350}$
Mass flow held constant at mass flow at 500 ft/min (2.5 m/s) at 105ºF (40.6ºC) (from 5.2.3.1)							
5.6 u	yy/mm/dd	105(40.6)			CAP_{105}^{500}	P_{105}^{500}	COP_{105}^{500}
5.6v	yy/mm/dd	95 (35)			CAP_{95}^{500}	P_{95}^{500}	COP_{95}^{500}
5.6w	yy/mm/dd	85(29.4)			CAP_{85}^{500}	P_{85}^{500}	COP_{85}^{500}
5.6x	yy/mm/dd	75(23.9)			CAP_{75}^{500}	P_{75}^{500}	COP_{75}^{500}
5.6y	yy/mm/dd	65(18.3)			CAP_{65}^{500}	P_{65}^{500}	COP_{65}^{500}

*Derived Quantity $COP^{BASE} = CAP^{BASE}/P^{BASE}$ at corresponding outdoor air temperature

5.3.2 Dry Pre-Cooler Performance (Configuration 2)

For the Equipment Configuration 2 (Cooling Equipment with Dry Pre-Cooler Installed), the cooling equipment power and cooling capacity shall be reported for the cooling equipment with the pre-cooler installed and the water supply turned off at one outdoor-air temperature condition, as specified in Table 5.7. The condenser-coil pressure differential ($\Delta p_{coil+cooler}$) obtained in Section 5.2.3.3 shall be maintained during this test to incorporate the effect of the added flow resistance from the dry pre-cooler.

Table 5.7 - Equipment Configuration 2: Cooling Equipment Data with Dry Evaporative Pre-Cooler Installed

Test	Date	Target Outdoor Air Condition T_{DB} [°F (°C)]	Actual Outdoor Air Condition T_{DB} [°F (°C)]	Pre-Cooler Inlet Airflow [ACFM (l/s)]	Pre-Cooler Inlet Airflow [SCFM (sl/s)]	Capacity [Btu/h (kW)]	Cooling Equipment Power [kW]	COP* [-]
5.7 a	yy/mm/dd	75 (23.9)				CAP_{75}^{DRY}	P_{75}^{DRY}	COP_{75}^{DRY}

*Derived Quantity $COP^{DRY} = CAP^{DRY}/P^{DRY}$ at corresponding outdoor air temperature

5.3.3 Wet Pre-Cooler Performance (Configuration 3)

For Equipment Configuration 3A, the cooling equipment power and cooling capacity shall be reported for the cooling equipment with the pre-cooler installed and operating at the four outdoor-air conditions, as specified and reported in Table 5.8. The condenser-coil pressure differential ($\Delta p_{coil+cooler}$) obtained in Section 5.2.3.4 shall be maintained during all tests. The average inlet water pressure (i.e., water pressure provided to the pre-cooler) shall be measured during the tests in Table 5.8 and Table 5.9, and shall be recorded in Table 7.1.

For the 105°F (40.6ºC) outdoor air condition (Equipment Configuration 3B), the testing shall be performed at mass flowrates from Table 5.6 for the nominal face velocity and the three specified face velocity conditions. For these constant mass-flow tests, the condenser mass flows obtained in Table 5.6 for the constant-mass-flow baseline tests shall be maintained, while $\Delta p_{coil+cooler}$ shall be recorded for each test. The airflow shall be adjusted by varying the speed of the auxiliary fan on the airflow measurement apparatus in conjunction with adjusting the resistance of the exhaust duct downstream from the external static pressure measurement point, either by the selection of nozzles in the airflow measurement apparatus or by an adjustable damper in the duct. These results shall be recorded in Table 5.9. (Note that test 5.9a is the same as test 5.8b, which does not need to be repeated.)

Table 5.8 - Equipment Configuration 3A: Cooling Equipment Data with Wet Evaporative Pre-Cooler Installed

Test	Date	Target Outdoor Air Condition T_{DB}/T_{WB} [°F/°F(°C/°C)]	Actual Outdoor Air Condition T_{DB}/T_{WB} [°F/°F(°C/°C)]	Pre-Cooler Inlet Airflow [SCFM (sl/s)]	Capacity [Btu/h (kW)]	Cooling Equipment Power [kW]	Pre-Cooler Power [kW]	COP* [-]	Water Use [gal/h (kg/h)]
5.8 a	yy/mm/dd	115/76 (46.1/24.4)			$CAP^{WET}_{115/76}$	$P^{WET}_{115/76}$		$COP^{WET}_{115/76}$	$\dot{m}^{water}_{115/76}$
5.8 b	yy/mm/dd	105/73 (40.6/22.8)			$CAP^{WET}_{105/73}$	$P^{WET}_{105/73}$		$COP^{WET}_{105/73}$	$\dot{m}^{water}_{105/73}$
5.8 c	yy/mm/dd	95/70 (35/21.1)			$CAP^{WET}_{95/70}$	$P^{WET}_{95/70}$		$COP^{WET}_{95/70}$	$\dot{m}^{water}_{95/70}$
5.8 d	yy/mm/dd	85/67 (29.4/19.4)			$CAP^{WET}_{85/67}$	$P^{WET}_{85/67}$		$COP^{WET}_{85/67}$	$\dot{m}^{water}_{85/67}$

*Derived Quantity $COP^{WET} = \frac{CAP^{WET}}{(P^{WET} + P^{pre-cooler})}$ at corresponding outdoor air temperature

Table 5.9 - Equipment Configuration 3B: Cooling Equipment Data with Wet Evaporative Pre-Cooler Installed and Operated at Table 5.6 Mass Flowrates at 105/73°F (40.6/22.8°C)

Test	Date	$\Delta p_{coil+cooler}$ [in. wc (Pa)]	Pre-Cooler Inlet Airflow [SCFM (sl/s)]	Capacity [Btu/h (kW)]	Cooling Equipment Power [kW]	Pre-Cooler Power [kW]	COP* [-]	Water Use [gal/h (kg/h)]
5.9 a	yy/mm/dd			$CAP^{EEnomWET}_{105/73}$	$P^{EEnomWET}_{105/73}$		$COP^{EEnomWET}_{105/73}$	$\dot{m}^{water}_{EEnom}$
5.9 b	yy/mm/dd			$CAP^{\cancel{3}200WET}_{105/73}$	$P^{\cancel{3}200WET}_{105/73}$		$COP^{\cancel{3}200WET}_{105/73}$	$\dot{m}^{water}_{\cancel{3}200}$
5.9 c	yy/mm/dd			$CAP^{\cancel{40}350WET}_{105/73}$	$P^{\cancel{40}350WET}_{105/73}$		$COP^{\cancel{40}350WET}_{105/73}$	$\dot{m}^{water}_{\cancel{40}350}$
5.9 d	yy/mm/dd			$CAP^{500WET}_{105/73}$	$P^{500WET}_{105/73}$		$COP^{500WET}_{105/73}$	$\dot{m}^{water}_{500}$

*Derived Quantity $COP^{WET} = \frac{CAP^{WET}}{(P^{WET} + P^{pre-cooler})}$ at corresponding outdoor air temperature

6. CALCULATION PROCEDURES

The tests performed within this standard shall be used to produce the following outputs from the values measured and reported in Section 5.3:

1) Evaporative Effectiveness for all Wet Configuration tests
2) Power, Capacity, and coefficient of performance (COP) impacts of Pre-Cooler in Dry Configuration
3) Water Use Efficiency for all Wet Configuration tests.

6.1 Performance Curves for Baseline Cooling Equipment

The COP of the base unit as a function of condenser-air dry-bulb temperature under steady state evaporator conditions shall be characterized using a quadratic relationship between condenser-air inlet temperature and equipment COP. A least-squares fit to the data points from Table 5.6 shall be used to calculate the coefficients a_{COP}, b_{COP}, and c_{COP} in the following equations:

$$COP = a_{COP} \cdot {T_{DB}}^2 + b_{COP} \cdot T_{DB} + c_{COP}$$

Five curves (sets of coefficients) shall be developed, one curve for each of the five data sets in Table 5.6. The baseline cooling equipment shall be operated for all tests using a single compressor operated at a constant speed and a constant condenser fan speed.

6.2 Evaporative Effectiveness

The equivalent average dry-bulb temperature leaving the pre-cooler, $T_{DB,out}$ for each wet-media test point is calculated by solving for the temperature point on the appropriate baseline COP curve calculated in Section 6.1 that corresponds to the COP measured during that wet-media test (See Figure 6.1). The appropriate curve to be used for each wet-cooler test is summarized in Table 6.1.

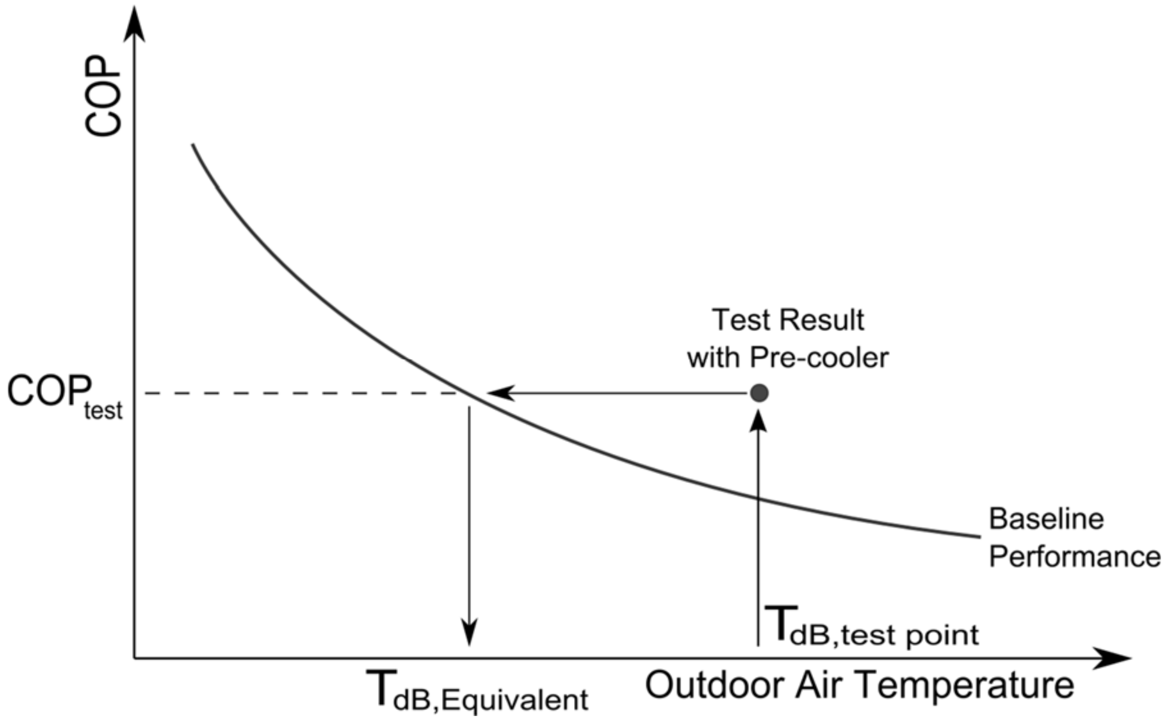


Figure 6.1 - Diagram of equivalent dry-bulb temperature calculation from baseline quadratic fit

Table 6.1 - Baseline Data-Fit Coefficient Summary

Wet Cooler Data	Baseline Data Set Used for Fit	Coefficients		
		a_{COP}	b_{COP}	c_{COP}
5.8a – 5.8d	5.6a – 5.6e			
5.9a	5.6f – 5.6j			
5.9b	5.6k – 5.6o			
5.9c	5.6p – 5.6t			
5.9d	5.6u – 5.6y			

All calculated coefficients shall be reported to at least 5 significant figures.

The process illustrated in Figure 6.1 shall be implemented using the following equation:

$$T_{DB,eq} = \frac{-b_{COP} - \cancel{+}\sqrt{{b_{COP}}^2 - 4a_{COP}(c_{COP} - COP^{\mathrm{WET}}_{\mathrm{T_{DB}/T_{WB}}})}}{2a_{COP}}$$

Constants a_{COP}, b_{COP}, and c_{COP} are from Section 6.1, $\mathrm{COP}^{\mathrm{WET}}_{\mathrm{T_{DB}/T_{WB}}}$ is the COP of the test unit measured during a pre-cooler test, and $T_{DB,eq}$ is the calculated equivalent dry-bulb temperature for that test. Using the equivalent dry-bulb temperature, the evaporative effectiveness shall be calculated at each test point using the following equation:

$$EE_{T_{DB}/T_{WB}} = \frac{T_{DB,in} - T_{DB,eq}}{T_{DB,in} - T_{WB,in}}$$

where

$T_{DB,in}$ and $T_{\cancel{D}WB,in}$ are the measured dry-bulb and wet-bulb temperatures of the air entering the pre-cooler (recorded in Table 7.1), and
$T_{DB,eq}$ is the equivalent dry-bulb temperature calculated for those same inlet conditions.

6.3 Water Use Effectiveness

Water use effectiveness is the percentage of water that is used for pre-cooling divided by the total water supplied to the pre-cooler during testing. This effectiveness does not include any maintenance water use for recirculating systems and may not accurately represent total water use for single pass systems under all conditions. Water use effectiveness shall be calculated using the following equation:

$$WUE_{T_{DB}/T_{WB}} = \frac{\dot{\mathrm{m}}^{water,evap}_{T_{DB}/T_{WB}}}{\dot{\mathrm{m}}^{water}_{T_{DB}/T_{WB}}}$$

where

$\dot{\mathrm{m}}^{water,evap}_{\mathrm{T_{DB}/T_{WB}}}$	is the rate at which water evaporates into the air, and
$\dot{\mathrm{m}}^{water}_{\mathrm{T_{DB}/T_{WB}}}$	is the amount of water supplied to pre-cooler as reported in Table 5.8.

The rate at which water is evaporated into the air shall be calculated using the following equation:

$$\dot{m}^{water,evap} = \frac{(W_{out} - W_{in}) \times Q_{cond}}{v_{cond}}$$

where

W_{out} and W_{in} are the humidity ratio exiting and entering the pre-cooler apparatus [-]
Q_{cond} is the volumetric flow rate across the condenser and pre-cooler [ft^3/min [(m^3/s)] as described by ANSI/ASHRAE Standard 41.2-1987 [5], and
v_{cond} is the specific volume of the dry air at the point where the volumetric flow is calculated [ft^3/lbm (m^3/kg)].

W_{out} is calculated based upon standard psychometric calculations (ASHRAE 2013 Fundamentals IP [1], Chapter 1) using the equivalent pre-cooler outlet dry-bulb temperature $T_{DB,\mathrm{eq}}$ and the pre-cooler inlet wet-bulb temperature$T_{WB,in}$ (pre-cooler assumed to be adiabatic), to determine the humidity ratio.

6.4 Equipment Performance Indicators

The impact of the pre-cooler on equipment performance shall be reported based upon the measured evaporative effectiveness at each test condition, combined with a "generic" equipment performance characterization at 67°F (19.4°C) indoor wet-bulb temperature, represented by the following equations, noting that this performance curve does not represent any actual RTU, but rather describes a generic single-speed, single-compressor RTU with constant condenser fan speed:

$$CAP_g = 8.22321\ x\ 10^{-6} \cdot {T_{DB}}^2 - \cancel{0.00}807456\ \underline{x\ 10^{-3}} \cdot T_{DB} + 1.692868$$
$$P_g = 3.82155 \text{ x } 10^{-5} \cdot {T_{DB}}^2 + \cancel{0.00}172041\ \underline{x\ 10^{-3}} \cdot T_{DB} + \cancel{0.}4.91096\ \underline{x\ 10^{-1}}$$
$$COP_g = 1.09187 \text{ x } 10^{-4} \cdot {T_{DB}}^2 - \cancel{0.0}3637492\ \underline{x\ 10^{-2}} \cdot T_{DB} + 3.470951$$

The impacts of the pre-cooler at each target test condition shall be calculated at each outdoor air test condition using the generic equations above, the measured evaporative effectiveness at each condition ~~(corrected to sea level),~~ and the following equations:

$$CAP^{\%inc}_{T_{DB}/T_{WB}} = \frac{CAP_{g,T_{DB,eq}} - CAP_{g,T_{DB}}}{CAP_{g,T_{DB}}} \times 100$$
$$P^{\%red}_{T_{DB}/T_{WB}} = \frac{P_{g,T_{DB}} - P_{g,T_{DB,eq}}}{P_{g,T_{DB}}} \times 100$$
$$COP^{\%inc}_{T_{DB}/T_{WB}} = \frac{COP_{g,T_{DB,eq}} - COP_{g,T_{DB}}}{COP_{g,T_{DB}}} \times 100$$

where $T_{DB,eq}$ shall be calculated using the following equation:

$$\mathrm{T_{DB,eq}} = \mathrm{T_{DB}} - (\mathrm{T_{DB}} - \mathrm{T_{WB}}) \times EE_{T_{DB}/T_{WB}}$$

6.5 Impacts of Dry Equipment Configuration on Performance

The impacts of the dry pre-cooler equipment on power draw, capacity, and COP of the cooling equipment shall be calculated for the actual cooling equipment being tested using the following equations:

$$CAP_{75}^{\%inc} = \frac{CAP_{75}^{DRY} - CAP_{75}^{BASE}}{CAP_{75}^{BASE}} \times 100$$

$$P_{75}^{\%red} = \frac{P_{75}^{BASE} - P_{75}^{DRY}}{P_{75}^{BASE}} \times 100$$

$$COP_{75}^{\%inc} = \frac{COP_{75}^{DRY} - COP_{75}^{BASE}}{COP_{75}^{BASE}} \times 100\mathbf{6.6}$$

6.6 Pre-cooler Face Velocity

The velocity of the air passing through the pre-cooler shall be calculated based upon the following equation:

$$V_{pre-cool} = \frac{Q_{cond}}{A_{pre-cooler}}$$

The relative velocity of the air passing through the pre-cooler compared to air passing through the condenser shall be calculated based upon the following equation:

$$R_{pre-cool} = \frac{A_{condenser}}{A_{pre-cooler}}$$

6.7 Standard Air Flow Rate

The inlet airflow is adjusted to standard conditions by a ratio of the inlet density to standard air density (0.075 lbm/ft^3 [1.204 kg/m^3]):

$$Q_{SCFM} = Q_{cond} \times \frac{\rho_{inlet}}{\rho_{standard}}$$

7. TEST REPORT

The test report shall include completed Tables 5.1, 5.2, 5.4, 5.5, 5.6, 5.7, 5.8, and 5.9, as well as a completed version of Table 7.1.

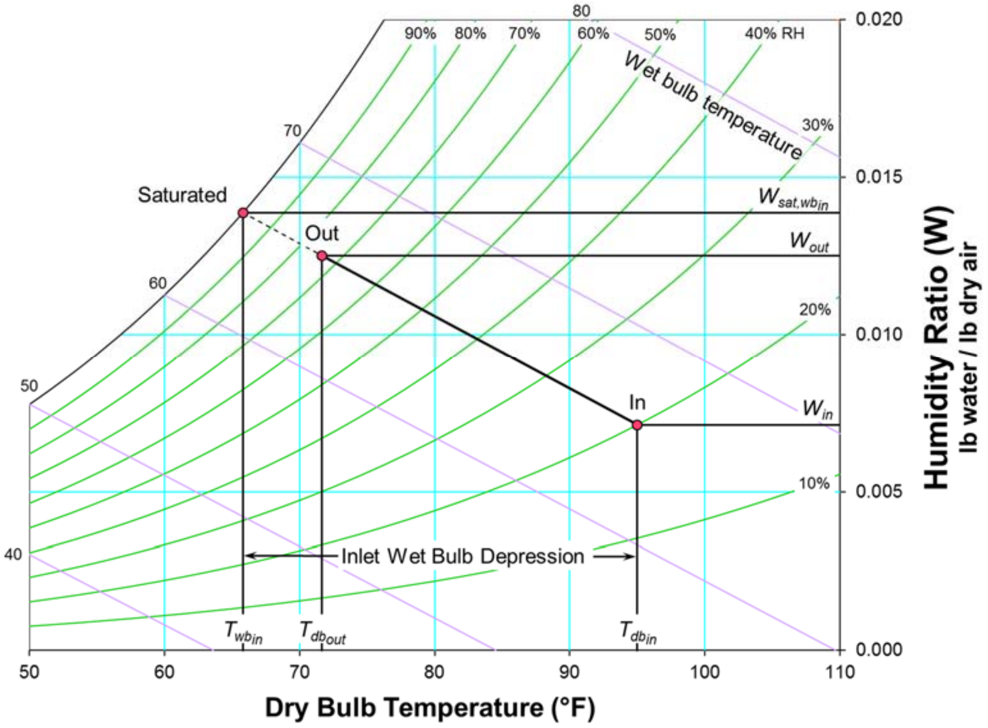
8. REFERENCES

1. *2013 ASHRAE Handbook – Fundamentals,* Inch-Pound Edition
2. ANSI/AHRI 210/240-2008, *Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment*
3. ANSI/AHRI 340/360-2007, *Performance Rating of Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment*
4. ANSI/ASHRAE 37-2009, *Methods of Testing for Rating Electrically Driven Unitary Air Conditioning and Heat-Pump Equipment*
5. ANSI/ASHRAE 41.2-1987 (RA 1992), *Standard Methods for Air Velocity and Airflow Measurement*
6. ANSI/ASHRAE 133-2008, *Method of Testing Direct Evaporative Air Coolers*

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

Informative Appendix A: Water Use Effectiveness

The figure below illustrates the assumptions behind the process used to calculate the water use effectiveness.



(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

Informative Appendix B: Additional Water Use

The calculations in Standard 212 are based upon evaporated water only and thus do not include any water use associated with eliminating (or managing) scale formation on or around evaporative pre-coolers. This water use varies between manufacturers and technologies and generally depends upon local water quality. Maintenance water use generally ranges from 0% to 50% of evaporated water use.

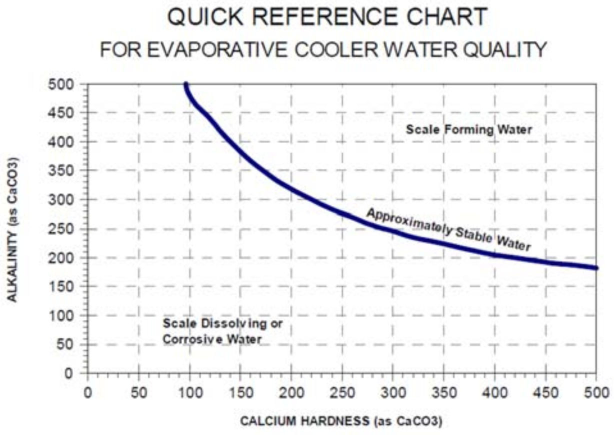
Although a comprehensive treatment of maintenance water issues is beyond the scope of this standard, some key considerations are presented below. Proper attention to maintenance items for Add-on

Evaporative Pre-coolers can prevent problems with scale build-up, corrosion, and biological growth. Consult the manufacturer of the equipment for specific maintenance schedules. For corrosion and biological growth prevention, industry standards can be applied. (*Note: For rigid media, oxidizing biocides are discouraged.) (**Note: If dosing the supply or recirculating water with biocides is necessary, the water must be able to completely flush the rigid media.)

Scale Build-up:
Add-on Evaporative Pre-coolers often use very porous rigid media. Every time the water pump is turned off, the contaminants and treatment chemicals dry on the rigid media. In the case of spray systems or other technologies, the surrounding equipment and other surfaces may be affected by the water quality. Most applications turn the equipment on and off multiple times each day, which can compound the problem. Therefore, the water supply to the Evaporative Pre-coolers requires suitable attention to limit scale, corrosion, and microbial growth. It is important to be aware of the local water supply water quality in all cases. For the most part, chemical treatment may not be necessary. Controlling water chemistry by maintaining the cycles of concentration (COC) of recirculating systems is a preferred method. Water can be scale-forming or scale dissolving as shown in the Chart below. Stable water quality serves to continually maintain a microscopic calcium layer which acts as a protective barrier. Without this precisely formed barrier, the media will wear away faster than media that is properly maintained and protected.

Once-through systems are subject solely to the local water supply quality.

Common scale-forming minerals include: Calcium Carbonate, Calcium Sulphate, Calcium Phosphate, Iron Oxide, Silica (SiO2).



(***Note: For example, paper and glass fiber based rigid media can be destroyed by both high and low pH. The organic binder in most rigid media requires a pH of 7 to 9.) The required pH range is fairly easy to achieve using natural water sources. The evaporative process itself will cause naturally occurring minerals to become more concentrated and this will have an effect on pH. The minerals concentrate because they do not evaporate with the water. Meanwhile the addition of makeup water into the system contributes a steady load of additional minerals. This phenomenon of concentrating minerals through evaporation results is the concept known as COC. For example, three (3) cycles of concentration means that the system water contains three times the mineral content per unit volume than that of the makeup water. Anionic mineral compounds such as bicarbonates (HCO_3) and carbonates (CO_3) are defined as forms of alkalinity. As these compounds increase in concentration, pH rises due to an increase in alkalinity.

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

Informative Appendix C: Water Carry-Over

No tests were conducted under this standard to determine whether the installation and operation of the device in accordance with manufacturer's instructions does or does not result in liquid water being deposited on the condensing coil, or other portions of the condensing unit.

Water deposition on the coil or other portions of the condensing unit, often as a result of carryover, have been reported historically. The potential issues associated with water deposition on coils have included scale formation on heat exchanger surfaces from the deposition of dissolved solids contained in the liquid water, and accelerated corrosion of both the condensing coil and other elements of the system. Concerns regarding these liquid water deposition issues have resulted in equipment manufacturers placing restrictions or prohibitions on the use of evaporative pre-coolers as a condition of maintaining warranty coverage.

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

Informative Appendix D: Condenser Geometry Effects

In evaluating the performance of an evaporative pre-cooler, Standard 212 measures the impact of the evaporative pre-cooler on the performance of a particular packaged air conditioner and generalizes those measurements by applying the measured evaporative effectiveness to a generic air conditioner via a "generic" relationship between performance and outdoor air temperature. However, this normalization does not account for variations in condenser geometry. The results of this method of test assume that all of the air entering the condenser coil has been pre-cooled evaporatively. If some of the air entering the condenser coil has not passed through the evaporative pre-cooler, the impact of the pre-cooler would be reduced. Roughly speaking, that reduction would scale with the ratio of condenser air not passing through the pre-cooler, to the total condenser air flow. One example of a configuration that significantly impacts the use of results obtained with this standard is a V-coil condenser, where the inside part of "V" does not receive air that has gone through the pre-cooler, and where the use of the inside part of the "V" depends on the number of compressors in operation. In this case, the performance of the evaporative pre-cooler depends on the number of compressors in operation.

Add new Appendix E.

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

Informative Appendix E: Condenser Example Calculation

This example calculation appendix includes example data tables and demonstrates the required calculation procedure for estimating the impact of the measured evaporative effectiveness on the Capacity, Power Draw, and COP of a generic air-conditioner, as well as a calculation procedure for estimating water consumption of the tested evaporative pre-cooler. The data included is a realistic example but does not represent performance of an actual pre-cooler.

5. MEASUREMENT PROTOCOL

5.1 Input Data Requirements

5.1.1 Test Description

An example test description is shown below.

Date: July 21st, 2016

Location: Western Cooling Efficiency Center, Davis, CA

Person Performing Test: John Doe, jdoe@ucdavis.edu, 530-752-1234

5.1.2 Evaporative Pre-Cooler Specifications

Examples of the pre-cooler description and test unit description are shown in Tables 5.1 and 5.2.

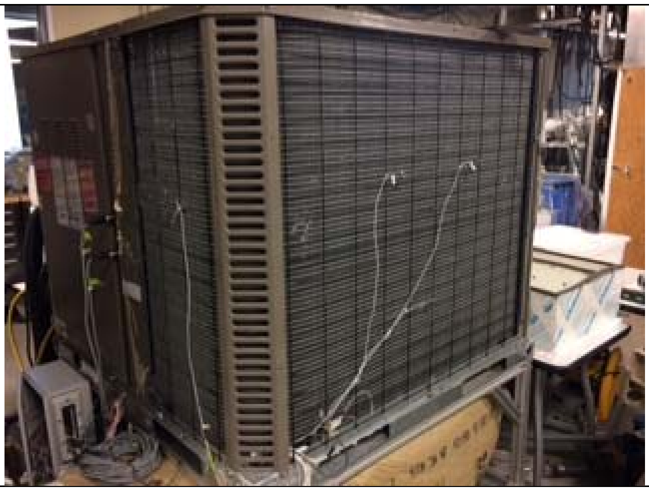
Table 5.6 - Pre-cooler Description

Data Required	Description
Manufacturer:	Evaporative Cooler Company
Model Number:	ABC123
Media	8” deep cellulose media with 0.28” flute height
Water distribution method	Recirculated from sump with water distribution over media
Manufacturer recommended range of cooling-equipment capacity	120,000 – 600,000 Btu/h (35.2 – 175.8 kW)
Manufacturer recommended pre-cooler face velocity requirement	600 ft/min (3 m/s)
Water Pressure	20-60 psi (138-414 kPa)
Power Requirement	120V, 8A
Water Maintenance	Sump with bleed (adjustable)
Pre-cooler control method	Outdoor air temperature control, condensing unit must be on
Water flow control method	Constant flow when condensing unit is on
Expected media life	5 Years

Pre-Cooler Air-Flow Surface Area	16 ft² (1.5 m²)
Pre-cooler Picture	

5.1.3 Cooling Equipment Used for Testing (Equipment-Manufacturer Data)

Table 5.7 – Test unit description

Data Required	Description
Manufacturer:	Air Conditioner Company
Model Number:	ABC123
Serial Number	XYZ456
Refrigerant	R-410A
Capacity	46,000 Btu/h (13.5 kW)
Efficiency at AHRI Rating condition	COP = 3.21
Number of Compressors	1
Number of Condenser Fans	1
Condenser Coil Airflow Surface Area	16 ft² (1.5 m²)
Test Unit Picture	

5.2 Methods of Testing

5.2.3.2 Condenser-Coil Resistance

An example data set for the condenser coil resistance for the condenser coil, condenser coil plus dry pre-cooler, and condenser coil plus wet pre-cooler is shown in Table 5.4.

Table 5.4 – Flow Resistance Data 105°F (40.6°C)

	Condenser Coil (Δp_{coil})		Condenser Coil plus Dry Pre-Cooler ($\Delta p_{coil+cooler}$)		Condenser Coil plus Wet Pre-Cooler ($\Delta p_{coil+cooler}$)	
Face Velocity [fpm]	Flow (Q_{cond}) [SCFM]	Pressure Difference [in. wc]	Flow (Q_{cond}) [SCFM]	Pressure Difference [in. wc]	Flow (Q_{cond}) [SCFM]	Pressure Difference [in. wc]
Nominal[1]	3404	0.0730	3404	0.0970	3404	0.1160
200	2984	0.0620	2984	0.0800	2984	0.0970
350	5222	0.1340	5222	0.1820	5222	0.2100
500	7460	0.2220	7460	0.3070	7460	0.3500

[1] Nominal face velocity is defined as the measured volumetric flowrate through the condenser at 105°F (40.6°C) divided by the surface area of the condenser.

5.2.3.5 System Curves

The data in Table 5.4 are plotted and a power-law least-squares fit is performed to produce system curves in the form of $Q_{SCFM} = K * \Delta p^n$ for each of the three configurations in Table 5.4: condenser coil, condenser coil plus dry pre-cooler, and condenser coil plus wet pre-cooler (Figure 1). The results are reported in Table 5.5.

Table 5.5 – Flow Resistance Characterization 105°F (40.6°C)

	Flow Coefficient, K [SCFM/(in. wc)^n]	Flow Exponent, n [-]
Condenser Coil (Δp_{coil})	21900	0.7140
Condenser Coil plus Dry Pre-Cooler ($\Delta p_{coil+cooler,\ dry}$)	16670	0.6810
Condenser Coil plus Wet Pre-Cooler ($\Delta p_{coil+cooler,\ wet}$)	15840	0.7140

5.3 Performance-Test Data

5.3.1 Baseline Performance (Configuration 1)

The cooling equipment power draw and cooling capacity are reported for the baseline cooling equipment with no pre-cooler installed at five different outdoor-air temperature conditions at four different condenser-fan face velocities as specified (Table 5.6).

5.3.2: Dry Pre-Cooler Performance (Configuration 2)

For the Equipment Configuration 2 (Cooling Equipment with Dry Pre-Cooler Installed), the cooling equipment power and cooling capacity are reported for the cooling equipment with the pre-cooler installed and the water supply turned off at the specified outdoor-air temperature condition (Table 5.7).

5.3.3: Wet Pre-Cooler Performance (Configuration 3)

For Equipment Configuration 3A, the cooling equipment power, cooling capacity, and water use are reported for the cooling equipment with the pre-cooler installed and operating at the four specified outdoor-air conditions (Table 5.8). The average inlet water pressure (i.e., water pressure provided to the pre-cooler) shall be measured during the tests in Table 5.8 and Table 5.9, and shall be recorded in Table 7.1.

For the 105°F (40.6°C) outdoor air condition (Equipment Configuration 3B), the cooling equipment power, cooling capacity, and water use are reported for the cooling equipment with the pre-cooler installed and operating at the mass flowrates from Table 5.6 for the nominal face velocity and the three specified face velocity conditions (Table 5.9).

Table 5.6 – Equipment Configuration 1A: Baseline Cooling Equipment Data without Pre-Cooler

Test	Date	Target OA Condition T_{DB} [°F]	Condenser Inlet Flow [ACFM]	Condenser Inlet Flow [SCFM]	Cooling Equip. Capacity [Btu/h]		Cooling Equip. Power [kW]		COP* [-]	
Pressure Differential (Δp_{coil}) held constant (from 5.2.3.1) at Nominal Condenser-Coil Face Velocity:										
5.6 a	07/24/17	105	3665	3413	CAP_{105}^{BASE}	43204	P_{105}^{BASE}	4.522	COP_{105}^{BASE}	2.800
5.6 b	07/24/17	95	3668	3478	CAP_{95}^{BASE}	46423	P_{95}^{BASE}	4.101	COP_{95}^{BASE}	3.317
5.6 c	07/24/17	85	3677	3550	CAP_{85}^{BASE}	49729	P_{85}^{BASE}	3.763	COP_{85}^{BASE}	3.873
5.6 d	07/24/17	75	3675	3615	CAP_{75}^{BASE}	52942	P_{75}^{BASE}	3.464	COP_{75}^{BASE}	4.479
5.6 e	07/24/17	65	3658	3666	CAP_{65}^{BASE}	55160	P_{65}^{BASE}	3.222	COP_{65}^{BASE}	5.017
Mass flow held constant at AS-FOUND mass flow at 105°F (40.6°C) (from 5.2.3.1)										
5.6 f	07/24/17	105	3654	3403	CAP_{105}^{EEnom}	42688	P_{105}^{EEnom}	4.551	COP_{105}^{EEnom}	2.749
5.6 g	07/24/17	95	3600	3413	CAP_{95}^{EEnom}	46083	P_{95}^{EEnom}	4.124	COP_{95}^{EEnom}	3.275
5.6 h	07/24/17	85	3507	3386	CAP_{85}^{EEnom}	49211	P_{85}^{EEnom}	3.793	COP_{85}^{EEnom}	3.802
5.6 i	07/24/17	75	3402	3346	CAP_{75}^{EEnom}	52561	P_{75}^{EEnom}	3.512	COP_{75}^{EEnom}	4.386
5.6 j	07/24/17	65	3302	3309	CAP_{65}^{EEnom}	55101	P_{65}^{EEnom}	3.250	COP_{65}^{EEnom}	4.969
Mass flow held constant at mass flow at 200 ft/min (1.0 m/s) at 105°F (40.6°C) (from 5.2.3.1)										
5.6 k	07/24/17	105	3200	2980	CAP_{105}^{200}	42560	P_{105}^{200}	4.626	COP_{105}^{200}	2.696
5.6 l	07/24/17	95	3143	2980	CAP_{95}^{200}	45814	P_{95}^{200}	4.194	COP_{95}^{200}	3.202
5.6 m	07/24/17	85	3087	2980	CAP_{85}^{200}	48756	P_{85}^{200}	3.844	COP_{85}^{200}	3.717
5.6 n	07/24/17	75	3030	2980	CAP_{75}^{200}	52201	P_{75}^{200}	3.560	COP_{75}^{200}	4.297
5.6 o	07/24/17	65	2973	2980	CAP_{65}^{200}	55078	P_{65}^{200}	3.287	COP_{65}^{200}	4.911
Mass flow held constant at mass flow at 350 ft/min (1.75 m/s) at 105°F (40.6°C) (from 5.2.3.1)										
5.6p	07/24/17	105	5600	5215	CAP_{105}^{350}	42404	P_{105}^{350}	4.214	COP_{105}^{350}	2.949
5.6q	07/24/17	95	5501	5215	CAP_{95}^{350}	46318	P_{95}^{350}	3.830	COP_{95}^{350}	3.545
5.6r	07/24/17	85	5402	5215	CAP_{85}^{350}	50115	P_{85}^{350}	3.525	COP_{85}^{350}	4.167
5.6s	07/24/17	75	5303	5215	CAP_{75}^{350}	53088	P_{75}^{350}	3.260	COP_{75}^{350}	4.773
5.6t	07/24/17	65	5203	5215	CAP_{65}^{350}	54938	P_{65}^{350}	3.043	COP_{65}^{350}	5.291
Mass flow held constant at mass flow at 500 ft/min (2.5 m/s) at 105°F (40.6°C) (from 5.2.3.1)										
5.6u	07/24/17	105	8000	7450	CAP_{105}^{500}	40028	P_{105}^{500}	3.906	COP_{105}^{500}	3.004
5.6v	07/24/17	95	7858	7450	CAP_{95}^{500}	44161	P_{95}^{500}	3.654	COP_{95}^{500}	3.542
5.6w	07/24/17	85	7717	7450	CAP_{85}^{500}	48187	P_{85}^{500}	3.214	COP_{85}^{500}	4.394
5.6x	07/24/17	75	7575	7450	CAP_{75}^{500}	50926	P_{75}^{500}	2.960	COP_{75}^{500}	5.042
5.6y	07/24/17	65	7433	7450	CAP_{65}^{500}	54123	P_{65}^{500}	2.747	COP_{65}^{500}	5.774

*Derived Quantity $COP^{BASE} = CAP^{BASE}/P^{BASE}$ at corresponding outdoor air temperature

Table 5.7 - Equipment Configuration 2: Cooling Equipment Data with Dry Evaporative Pre-Cooler Installed

Test	Date	Target Outdoor Air Condition T_{DB} [°F]	Pre-Cooler Inlet Airflow [ACFM]	Pre-Cooler Inlet Airflow [SCFM]	Capacity [Btu/h] CAP_{75}^{DRY}	Cooling Equipment Power [kW] P_{75}^{DRY}	COP* [-] COP_{75}^{DRY}
5.7 a	07/24/17	75	3615	3555	52413	3.501	4.388

*Derived Quantity $COP^{DRY} = CAP^{DRY}/P^{DRY}$ at corresponding outdoor air temperature

Table 5.8 - Equipment Configuration 3A: Cooling Equipment Data with Wet Evaporative Pre-Cooler Installed Test 8

Test	Date	Target Outdoor Air Condition T_{DB}/T_{WB} [°F/°F]	Pre-Cooler Inlet Airflow [SCFM]	Capacity [Btu/h]		Cooling Equipment Power [kW]		Pre-Cooler Power [kW]	COP* [-]		Water Use [gal/h]	
5.8a	07/24/17	115/76	3459	$CAP_{115/76}^{WET}$	53133	$P_{115/76}^{WET}$	3.741	0.128	$COP_{115/76}^{WET}$	4.025	$\dot{m}_{115/76}^{water}$	13.01
5.8b	07/24/17	105/73	3389	$CAP_{105/73}^{WET}$	51603	$P_{105/73}^{WET}$	3.613	0.128	$COP_{105/73}^{WET}$	4.043	$\dot{m}_{105/73}^{water}$	10.68
5.8c	07/24/17	95/70	3357	$CAP_{95/70}^{WET}$	49913	$P_{95/70}^{WET}$	3.484	0.127	$COP_{95/70}^{WET}$	4.051	$\dot{m}_{95/70}^{water}$	8.36
5.8d	07/24/17	85/67	3373	$CAP_{85/67}^{WET}$	48255	$P_{85/67}^{WET}$	3.360	0.127	$COP_{85/67}^{WET}$	4.056	$\dot{m}_{85/67}^{water}$	6.67

*Derived Quantity $COP^{WET} = \frac{CAP^{WET}}{(P^{WET} + P^{pre-cooler})}$ at corresponding outdoor air temperature

Table 5.9 - Equipment Configuration 3B: Cooling Equipment Data with Wet Evaporative Pre-Cooler Installed and Operated at Table 5.6 Mass Flowrates at 105/73°F (40.6/22.8°C)

Test	Date	Pre-Cooler Inlet Airflow [SCFM]	Capacity [Btu/h]		Cooling Equipment Power [kW]		Pre-Cooler Power [kW]	COP* [-]		Water Use [gal/h]	
5.9a	07/24/17	3389	$CAP_{105/73}^{EEnomWET}$	51603	$P_{105/73}^{EEnomWET}$	3.613	0.128	$COP_{105/73}^{EEnomWET}$	4.043	$\dot{m}_{EEnom}^{water}$	10.65
5.9b	07/24/17	2974	$CAP_{105/73}^{200WET}$	52816	$P_{105/73}^{200WET}$	3.684	0.127	$COP_{105/73}^{200WET}$	4.061	$\dot{m}_{200}^{water}$	9.654
5.9c	07/24/17	5207	$CAP_{105/73}^{350WET}$	47030	$P_{105/73}^{350WET}$	3.339	0.128	$COP_{105/73}^{350WET}$	3.975	$\dot{m}_{350}^{water}$	16.52
5.9d	07/24/17	7439	$CAP_{105/73}^{500WET}$	41244	$P_{105/73}^{500WET}$	2.994	0.128	$COP_{105/73}^{500WET}$	3.872	$\dot{m}_{500}^{water}$	23.15

*Derived Quantity $COP^{WET} = \frac{CAP^{WET}}{(P^{WET} + P^{pre-cooler})}$ at corresponding outdoor air temperature

6. CALCULATION PROCEDURES

The tests performed were used to produce the following outputs from the values measured and reported in Section 5.3:

1. Evaporative Effectiveness for all Wet Configuration tests
2. Power, Capacity, and coefficient of performance (COP) impacts of Pre-Cooler in Dry Configuration
3. Water Use Efficiency for all Wet Configuration tests.

6.1 Performance Curves for Baseline Cooling Equipment

The COP of the base unit was characterized using a quadratic relationship between condenser-air inlet temperature and equipment COP. A least-squares fit to the data points from Table 5.6 was used to calculate the coefficients a_{COP}, b_{COP}, and c_{COP} in the following equations:

$$COP = a_{COP} \cdot T_{DB}{}^{2} + b_{COP} \cdot T_{DB} + c_{COP}$$

Five curves (sets of coefficients) were calculated for each of the five data sets in Table 5.6 and are shown in Table 6.1

6.2 Evaporative Effectiveness

For each wet-media test point, the equivalent average dry-bulb temperature leaving the pre-cooler was calculated by solving for the temperature point on the appropriate baseline COP curve calculated in Section 6.1 that corresponds to the COP measured during that wet-media test (See Figure 6.1). The appropriate curve used for each wet-cooler test is summarized in Table 6.1.

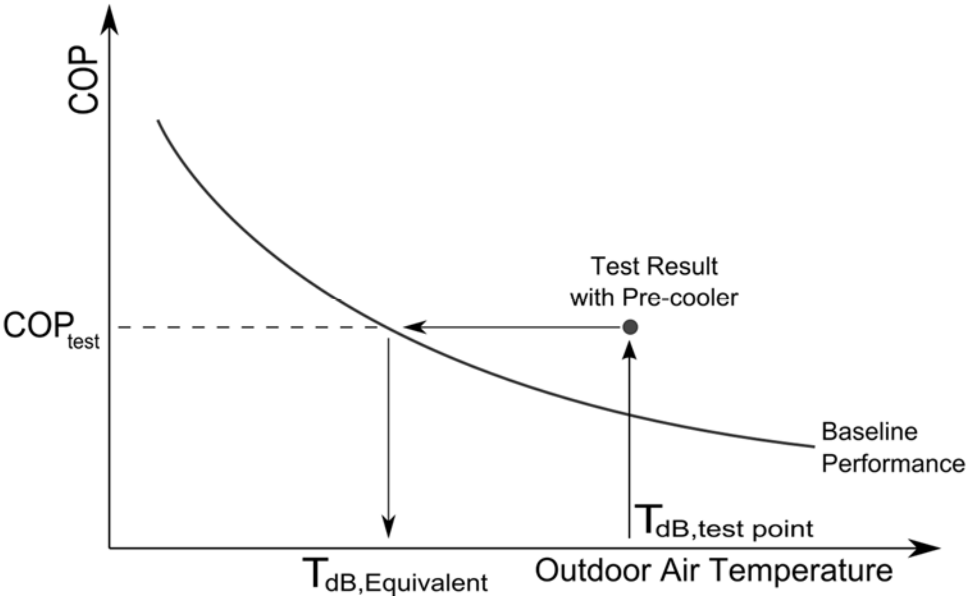


Figure 6.1: Diagram of equivalent dry-bulb temperature calculation from baseline quadratic fit

Table 6.1 - Baseline Data-Fit Coefficient Summary

Wet Cooler Data	Baseline Data Set Used for Fit	Coefficients		
		a_{COP}	b_{COP}	c_{COP}
5.8a – 5.8d	5.6a – 5.6e	$6.5714\text{x}10^{-5}$	$-6.7131\text{X}10^{-2}$	9.1154
5.9a	5.6f – 5.6j	$1.2214\text{x}10^{-4}$	$-7.6274\text{X}10^{-2}$	9.4126
5.9b	5.6k – 5.6o	$1.9429\text{x}10^{-4}$	$-8.8149\text{X}10^{-2}$	9.8129
5.9c	5.6p – 5.6t	$-1.1929\text{x}10^{-4}$	$-3.8890\text{X}10^{-2}$	8.3367
5.9d	5.6u – 5.6y	$1.1929\text{x}10^{-4}$	$-9.0450\text{X}10^{-2}$	11.1504

All calculated coefficients shall be reported to at least 5 significant figures.

The process illustrated in Figure 6.1 was implemented using the following equation for each of the eight pre-cooler tests, where the coefficients a_{cop}, b_{cop}, and c_{cop} were determined from Table 6.1 and $\mathrm{COP}^{\mathrm{WET}}_{\mathrm{T_{DB}/T_{WB}}}$ was determined from Table 5.8 and Table 5.9.

$$T_{DB,eq} = \frac{-b_{COP} - \sqrt{{b_{COP}}^{2} - 4a_{COP}(c_{COP} - COP^{\mathrm{WET}}_{\mathrm{T_{DB}/T_{WB}}})}}{2a_{COP}}$$

	Equation	$T_{DB,eq}$
5.8 a	$\frac{-(-6.7131\text{x}10^{-2}) - \sqrt{(-6.7131\text{x}10^{-2})^2 - 4(6.5714\text{x}10^{-5})(9.1154 - 4.025)}}{2(6.5714\text{x}10^{-5})}$	82.49°F
5.8 b	$\frac{-(-6.7131\text{x}10^{-2}) - \sqrt{(-6.7131\text{x}10^{-2})^2 - 4(6.5714\text{x}10^{-5})(9.1154 - 4.043)}}{2(6.571\text{x}10^{-5})}$	82.17°F
5.8 c	$\frac{-(-6.7131\text{x}10^{-2}) - \sqrt{(-6.7131\text{x}10^{-2})^2 - 4(6.5714\text{x}10^{-5})(9.1154 - 4.051)}}{2(6.5714\text{x}10^{-5})}$	82.03°F
5.8 d	$\frac{-(-6.7131\text{x}10^{-2}) - \sqrt{(-6.7131\text{x}10^{-2})^2 - 4(6.5714\text{x}10^{-5})(9.1154 - 4.056)}}{2(6.5714\text{x}10^{-5})}$	81.94°F
5.9 a	$\frac{-(-7.6274\text{x}10^{-2}) - \sqrt{(-7.6274\text{x}10^{-2})^2 - 4(1.2214\text{x}10^{-4})(9.4126 - 4.043)}}{2(1.2214\text{x}10^{-4})}$	80.87°F
5.9 b	$\frac{-(-8.8149\text{x}10^{-2}) - \sqrt{(-8.8149\text{x}10^{-2})^2 - 4(1.9429\text{x}10^{-4})(9.8129 - 4.061)}}{2(1.9429\text{x}10^{-4})}$	79.00°F
5.9 c	$\frac{-(-3.8891\text{x}10^{-2}) - \sqrt{(-3.8891\text{x}10^{-2})^2 - 4(-1.1929\ \text{x}10^{-4})(8.3367 - 3.975)}}{2(-1.1929\ \text{x}10^{-4})}$	88.25°F
5.9 d	$\frac{-(-9.0449\text{x}10^{-2}) - \sqrt{(-9.0449\text{x}10^{-2})^2 - 4(1.1929\ \text{x}10^{-4})(11.1504 - 3.872)}}{2(1.1929\ \text{x}10^{-4})}$	91.52°F

Using the equivalent dry-bulb temperature, $T_{db,eq}$, the evaporative effectiveness was then calculated for each test point using the equation:

$$EE_{T_{DB}/T_{WB}} = \frac{T_{DB,in} - T_{DB,eq}}{T_{DB,in} - T_{WB,in}}$$

where

$T_{DB,in}$ and $T_{WB,in}$ are the measured dry-bulb and wet-bulb temperatures of the air entering the pre-cooler (recorded in Table 7.1), and
$T_{DB,eq}$ is the equivalent dry-bulb temperature calculated for those same inlet conditions.

	Equation	$EE_{T_{DB}/T_{WB}}$	
5.8a	$\frac{114.82°F - 82.49°F}{114.82°F - 76.19°F}$	$EE_{115/76}$	0.84
5.8b	$\frac{105.15°F - 82.17°F}{105.15°F - 73.05°F}$	$EE_{105/73}$	0.72
5.8c	$\frac{94.98°F - 82.03°F}{94.98°F - 70.08°F}$	$EE_{95/70}$	0.52
5.8d	$\frac{85.24°F - 81.94°F}{85.24°F - 67.15°F}$	$EE_{85/67}$	0.18
5.9a	$\frac{105.09°F - 80.87°F}{105.09°F - 72.89°F}$	$EE_{105/73}$	0.75
5.9b	$\frac{105.02°F - 79.00°F}{105.02°F - 73.03°F}$	$EE_{105/73}$	0.81
5.9c	$\frac{104.89°F - 88.25°F}{104.89°F - 73.15°F}$	$EE_{105/73}$	0.52
5.9d	$\frac{104.79°F - 91.52°F}{104.79°F - 72.87°F}$	$EE_{105/73}$	0.42

6.3 Water Use Effectiveness

The rate at which water was evaporated into the air was calculated using the following equation:

$$\dot{m}^{water,evap} = \frac{(W_{out} - W_{in}) \times Q_{cond}}{v_{cond}}$$

where

W_{out} and W_{in} are the humidity ratio exiting and entering the pre-cooler apparatus [-]
Q_{cond} is the actual volumetric flow rate across the condenser and pre-cooler [ft³/min]
v_{cond} is the specific volume of the dry air at the point where the volumetric flow is calculated [ft³/lbm].

To determine the humidity ratio W_{out}, standard psychometric calculations (ASHRAE 2013 Fundamentals IP [1], Chapter 1) were made based on the equivalent pre-cooler outlet dry-bulb temperature $T_{DB,eq}$ and the pre-cooler inlet wet-bulb temperature $T_{WB,in}$ (pre-cooler assumed to be adiabatic).

	Equation	Result [lb/min]	Result [gal/h]
5.8a	$\frac{(0.0180 - 0.0105) \times 3781}{14.725}$	1.930	13.88
5.8b	$\frac{(0.0154 - 0.0101) \times 3639}{14.466}$	1.337	9.617
5.8c	$\frac{(0.0130 - 0.0100) \times 3541}{14.205}$	0.7475	5.375
5.8d	$\frac{(0.0108 - 0.0101) \times 3494}{13.956}$	0.1927	1.385
5.9a	$\frac{(0.0155 - 0.0099) \times 3639}{14.462}$	1.410	10.14
5.9b	$\frac{(0.0161 - 0.0101) \times 3226}{14.462}$	1.345	9.673
5.9c	$\frac{(0.0139 - 0.0101) \times 5647}{14.463}$	1.511	10.866
5.9d	$\frac{(0.0132 - 0.0101) \times 8069}{14.456}$	1.735	12.477

Conversions:
1 gallon of water = 8.344 lbs
1 hour = 60 min

The water use effectiveness was calculated using the following equation:

$$WUE_{T_{DB}/T_{WB}} = \frac{\dot{m}^{water,evap}_{T_{DB}/T_{WB}}}{\dot{m}^{water}_{T_{DB}/T_{WB}}}$$

where

$\dot{m}^{water,evap}_{T_{DB}/T_{WB}}$ *is the rate at which water evaporates into the air, and*
$\dot{m}^{water}_{T_{DB}/T_{WB}}$ *is the amount of water supplied to pre-cooler as reported in Table 5.8.*

	Equation	Result	
5.8a	$\frac{13.88}{14.03}$	$WUE_{115/76}$	0.99
5.8b	$\frac{9.617}{10.68}$	$WUE_{105/73}$	0.90
5.8c	$\frac{5.375}{8.362}$	$WUE_{95/70}$	0.64
5.8d	$\frac{1.385}{6.674}$	$WUE_{85/67}$	0.21
5.9a	$\frac{10.14}{10.65}$	$WUE_{105/73}$	0.95
5.9b	$\frac{9.325}{9.654}$	$WUE_{105/73}$	0.97
5.9c	$\frac{11.37}{16.52}$	$WUE_{105/73}$	0.69
5.9d	$\frac{9.877}{23.15}$	$WUE_{105/73}$	0.43

6.4 Equipment Performance Indicators

The impact of the pre-cooler on equipment performance was calculated based upon the measured evaporative effectiveness at each test condition, combined with a “generic” equipment performance characterization at 67°F (19.4°C) indoor wet-bulb temperature, represented by the following equations. Note that this performance curve does not represent any actual RTU, but rather describes a generic single-speed, single-compressor RTU with constant condenser fan speed:

$$CAP_g = 8.22321\, x\, 10^{-6} \cdot {T_{DB}}^2 - 8.07456\, x\, 10^{-3} \cdot T_{DB} + 1.692868$$

$$P_g = 3.82155 \text{ x } 10^{-5} \cdot {T_{DB}}^2 + 1.72041\, x\, 10^{-3} \cdot T_{DB} + 4.91096\, x\, 10^{-1}$$

$$COP_g = 1.09187 \text{ x } 10^{-4} \cdot {T_{DB}}^2 - 3.637492\, x\, 10^{-2} \cdot T_{DB} + 3.470951$$

The impacts of the pre-cooler at each target test condition were calculated using the generic equations above, the measured evaporative effectiveness at each condition, and the following equations:

$$CAP_{T_{DB}/T_{WB}}^{\%inc} = \frac{CAP_{g,T_{DB,eq}} - CAP_{g,T_{DB}}}{CAP_{g,T_{DB}}} \times 100$$

$$P_{T_{DB}/T_{WB}}^{\%red} = \frac{P_{g,T_{DB}} - P_{g,T_{DB,eq}}}{P_{g,T_{DB}}} \times 100$$

$$COP_{T_{DB}/T_{WB}}^{\%inc} = \frac{COP_{g,T_{DB,eq}} - COP_{g,T_{DB}}}{COP_{g,T_{DB}}} \times 100$$

where $T_{DB,eq}$ was calculated from:

$$\mathrm{T_{DB,eq}} = \mathrm{T_{DB}} - (\mathrm{T_{DB}} - \mathrm{T_{WB}}) \times EE_{T_{DB}/T_{WB}}$$

An example calculation is shown for test 5.8a, and the results are shown for all.

5.8a	Equation	Result
$\mathrm{T_{DB,eq}}$	$105 - (105 - 76) \cdot 0.84$	82.36
$CAP_{115/76}$	$8.22321\ x\ 10^{-6} \cdot 115^2 - 8.07456\ x\ 10^{-3} \cdot 115 + 1.692868$	0.873046
$CAP_{g,115/76}$	$8.22321\ x\ 10^{-6} \cdot 82.36^2 - 8.07456\ x\ 10^{-3} \cdot 82.36 + 1.692868$	1.083633
$P_{g,115/76}$	$3.82155\ \mathrm{x}\ 10^{-5} \cdot 115^2 + 1.72041\ x\ 10^{-3} \cdot 115 + 0.491096$	1.194343
$P_{g,115/76}$	$3.82155\ \mathrm{x}\ 10^{-5} \cdot 82.36^2 + 1.72041\ x\ 10^{-3} \cdot 82.36 + 0.491096$	0.892004
$COP_{g,115/76}$	$1.09187\ \mathrm{x}\ 10^{-4} \cdot 115^2 - 3.637492\ x\ 10^{-2} \cdot 115 + 3.470951$	0.731833
$COP_{g,115/76}$	$1.09187\ \mathrm{x}\ 10^{-4} \cdot 82.36^2 - 3.637492\ x\ 10^{-2} \cdot 82.36 + 3.470951$	1.215763
$CAP_{115/76}^{\%inc}$	$\frac{1.082686 - 0.873046}{0.873046} \times 100$	24.1%
$P_{115/76}^{\%red}$	$\frac{1.194343 - 0.893134}{1.194343} \times 100$	25.3%
$COP_{115/76}^{\%inc}$	$\frac{1.213174 - 0.731833}{1.213174} \times 100$	66.1%

	$CAP_{T_{DB}/T_{WB}}^{\%inc}$		$P_{T_{DB}/T_{WB}}^{\%red}$		$COP_{T_{DB}/T_{WB}}^{\%inc}$	
5.8a	$CAP_{115/76}^{\%inc}$	24.1%	$P_{115/76}^{\%red}$	25.3%	$COP_{115/76}^{\%inc}$	66.1%
5.8b	$CAP_{105/73}^{\%inc}$	16.0%	$P_{105/73}^{\%red}$	18.6%	$COP_{105/73}^{\%inc}$	42.7%
5.8c	$CAP_{95/70}^{\%inc}$	8.6%	$P_{95/70}^{\%red}$	11.0%	$COP_{95/70}^{\%inc}$	22.2%
5.8d	$CAP_{85/67}^{\%inc}$	2.1%	$P_{85/67}^{\%red}$	2.9%	$COP_{85/67}^{\%inc}$	5.1%
5.9a	$CAP_{105/73}^{\%inc}$	16.8%	$P_{105/73}^{\%red}$	19.4%	$COP_{105/73}^{\%inc}$	45.2%
5.9b	$CAP_{105/73}^{\%inc}$	18.2%	$P_{105/73}^{\%red}$	20.8%	$COP_{105/73}^{\%inc}$	49.5%
5.9c	$CAP_{105/73}^{\%inc}$	11.6%	$P_{105/73}^{\%red}$	14.0%	$COP_{105/73}^{\%inc}$	29.9%
5.9d	$CAP_{105/73}^{\%inc}$	9.3%	$P_{105/73}^{\%red}$	11.4%	$COP_{105/73}^{\%inc}$	23.5%

6.5 Impacts of Dry Equipment Configuration on Performance

The impacts of the dry pre-cooler equipment on power draw, capacity, and COP of the cooling equipment were calculated for the actual cooling equipment being tested using the following equations:

$$CAP_{75}^{\%inc} = \frac{CAP_{75}^{DRY} - CAP_{75}^{BASE}}{CAP_{75}^{BASE}} \times 100$$

$$P_{75}^{\%red} = \frac{P_{75}^{BASE} - P_{75}^{DRY}}{P_{75}^{BASE}} \times 100$$

$$COP_{75}^{\%inc} = \frac{COP_{75}^{DRY} - COP_{75}^{BASE}}{COP_{75}^{BASE}} \times 100$$

	Equation	Result
$CAP_{75}^{\%inc}$	$\frac{52413 - 52942}{52942} \times 100$	-1.0%
$P_{75}^{\%red}$	$\frac{3.464 - 3.501}{3.464} \times 100$	-1.1%
$COP_{75}^{\%inc}$	$\frac{4.388 - 4.479}{4.479} \times 100$	-2.0%

6.6 Pre-cooler Face Velocity

The velocity of the air passing through the pre-cooler was calculated based upon the following equation:

$$V_{pre-cool} = \frac{Q_{cond}}{A_{pre-cooler}}$$

The relative velocity of the air passing through the pre-cooler compared to air passing through the condenser shall be calculated based upon the following equation:

$$R_{pre-cool} = \frac{A_{condenser}}{A_{pre-cooler}}$$

6.7 Standard Airflow Rate

The inlet airflow is adjusted to standard conditions by a ratio of the inlet density to standard air density (0.075 lbm/ft^3 [1.204 kg/m^3]):

$$Q_{SCFM} = Q_{cond} \times \frac{\rho_{inlet}}{\rho_{standard}}$$

7. TEST REPORT

Table 7.1 – Test Report

<table>
<tr><th rowspan="3">Test</th><th rowspan="3">Date</th><th colspan="4">Measured Test Conditions</th><th colspan="2">Calculated</th><th colspan="3">for Generic RTU with 67°F WB at Indoor Coil</th></tr>
<tr><th colspan="2">Pre-Cooler Inlet Air</th><th colspan="2">Indoor Air</th><th rowspan="2">Evap. Eff. (%)</th><th rowspan="2">Water-Use Eff. (%)</th><th rowspan="2">Power Reduction (%)</th><th rowspan="2">Capacity Increase (%)</th><th rowspan="2">COP Increase (%)</th></tr>
<tr><th>Dry-Bulb (°F [°C])</th><th>Wet-Bulb (°F [°C])</th><th>Dry-Bulb (°F [°C])</th><th>Wet-Bulb (°F [°C])</th></tr>
<tr><td colspan="11">*Tests conducted at nominal airflow rate.*</td></tr>
<tr><td>5.8 a</td><td>16/07/21</td><td>114.82</td><td>76.19</td><td>80.15</td><td>67.12</td><td>85%</td><td>99%</td><td>25.3%</td><td>24.1%</td><td>66.1%</td></tr>
<tr><td>5.8 b</td><td>16/07/21</td><td>105.15</td><td>73.05</td><td>79.85</td><td>67.05</td><td>72%</td><td>90%</td><td>18.6%</td><td>16.0%</td><td>42.7%</td></tr>
<tr><td>5.8 c</td><td>16/07/21</td><td>94.98</td><td>70.08</td><td>80.02</td><td>66.98</td><td>52%</td><td>64%</td><td>11.0%</td><td>8.6%</td><td>22.2%</td></tr>
<tr><td>5.8 d</td><td>16/07/21</td><td>85.24</td><td>67.15</td><td>79.96</td><td>67.09</td><td>18%</td><td>21%</td><td>2.9%</td><td>2.1%</td><td>5.1%</td></tr>
<tr><td colspan="3">COP sensitivity (Table 6.1)</td><td colspan="3">$6.5714x10^{-5}$</td><td colspan="2">$-6.7131X10^{-2}$</td><td colspan="3">9.1154</td></tr>
<tr><td colspan="3">Pre-cooler face velocity (6.6)</td><td colspan="3">$V_{pre\text{-}cool}$</td><td colspan="2">Velocity Ratio (6.6)</td><td colspan="3">1.0</td></tr>
<tr><td colspan="11">*Tests conducted at nominal baseline mass flow rate at 105°F (40.6°C)*</td></tr>
<tr><td>5.9a</td><td>16/07/21</td><td>105.09</td><td>72.89</td><td>80.12</td><td>66.96</td><td>75%</td><td>95%</td><td>19.4%</td><td>16.8%</td><td>45.2%</td></tr>
<tr><td colspan="3">COP sensitivity (Table 6.1)</td><td colspan="3">1.2214x10-4</td><td colspan="2">-7.6274X10-2</td><td colspan="3">9.1154</td></tr>
<tr><td colspan="3">Pre-cooler face velocity (6.6)</td><td colspan="3">225</td><td colspan="2">Velocity Ratio (6.6)</td><td colspan="3">1.0</td></tr>
<tr><td colspan="11">*Tests conducted at 200 ft/min baseline mass flow rate at 105°F (40.6°C)*</td></tr>
<tr><td>5.9b</td><td>16/07/21</td><td>105.02</td><td>73.03</td><td>80.16</td><td>66.89</td><td>81%</td><td>97%</td><td>18.2%</td><td>20.8%</td><td>49.5%</td></tr>
<tr><td colspan="3">COP sensitivity (Table 6.1)</td><td colspan="3">1.9429x10-4</td><td colspan="2">-8.8149X10-2</td><td colspan="3">9.8129</td></tr>
<tr><td colspan="3">Pre-cooler face velocity (6.6) [ft/min]</td><td colspan="3">200</td><td colspan="2">Velocity Ratio (6.6)</td><td colspan="3">1.0</td></tr>
<tr><td colspan="11">*Tests conducted at 350 ft/min baseline mass flow rate at 105°F (40.6°C)*</td></tr>
<tr><td>5.9c</td><td>16/07/21</td><td>104.89</td><td>73.15</td><td>79.98</td><td>67.10</td><td>52%</td><td>69%</td><td>11.6%</td><td>14.0%</td><td>29.9%</td></tr>
<tr><td colspan="3">COP sensitivity (Table 6.1)</td><td colspan="3">-1.1929x10-4</td><td colspan="2">-3.8890X10-2</td><td colspan="3">8.3367</td></tr>
<tr><td colspan="3">Pre-cooler face velocity (6.6) [ft/min]</td><td colspan="3">350</td><td colspan="2">Velocity Ratio (6.6)</td><td colspan="3">1.0</td></tr>
<tr><td colspan="11">*Tests conducted at 500 ft/min baseline mass flow rate at 105°F (40.6°C)*</td></tr>
<tr><td>5.9d</td><td>16/07/21</td><td>104.79</td><td>72.87</td><td>79.95</td><td>67.03</td><td>42%</td><td>43%</td><td>9.3%</td><td>11.4%</td><td>23.5%</td></tr>
<tr><td colspan="3">COP sensitivity (Table 6.1)</td><td colspan="3">1.1929x10-4</td><td colspan="2">-9.0450X10-2</td><td colspan="3">11.1504</td></tr>
<tr><td colspan="3">Pre-cooler face velocity (6.6) [ft/min]</td><td colspan="3">500</td><td colspan="2">Velocity Ratio (6.6)</td><td colspan="3">1.0</td></tr>
<tr><td colspan="8"></td><td colspan="3">**Dry Media Restriction Impact**</td></tr>
<tr><td>5.7a</td><td>16/07/21</td><td>75.12</td><td>63.02</td><td>80.13</td><td>67.08</td><td>n/a</td><td>n/a</td><td>−1.1%</td><td>−1.0%</td><td>−2.0%</td></tr>
<tr><td colspan="3">Average Barometric Pressure [in. Hg]:</td><td colspan="8">30.08</td></tr>
<tr><td colspan="3">Inlet Water Pressure [psi]:</td><td colspan="8">60.21</td></tr>
<tr><td colspan="3">Average Pre-Cooler Power [W]:</td><td colspan="8">128.5</td></tr>
</table>