AHRI Standard 410-2023 (SI/I-P)

2023 Standard for

Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

AIR-CONDITIONING, HEATING, & REFRIGERATION INSTITUTE

we make life better®

2311 Wilson Boulevard, Suite 400
Arlington, VA 22201, USA
www.ahrinet.org
PH 703.524.8800
FX 703.562.1942

Documents
Document Sharing Hub

Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

©Copyright 2023, by Air-Conditioning, Heating, and Refrigeration Institute
Registered United States Patent and Trademark Office
Printed in U.S.A.

IMPORTANT

SAFETY DISCLAIMER

AHRI does not set safety standards and does not certify or guarantee the safety of any products, components or systems designed, tested, rated, installed or operated in accordance with this standard/guideline. It is strongly recommended that products be designed, constructed, assembled, installed and operated in accordance with nationally recognized safety standards and code requirements appropriate for products covered by this standard/guideline.

AHRI uses its best efforts to develop standards/guidelines employing state-of-the-art and accepted industry practices. AHRI does not certify or guarantee that any tests conducted under its standards/guidelines will be non-hazardous or free from risk.

ICS Code: 27.200

Note:

This standard supersedes AHRI Standard 410-2001 with Addenda 1, 2, and 3.

AHRI CERTIFICATION PROGRAM DISCLAIMER

AHRI Standards are developed independently of AHRI Certification activities and can have scopes that include products that are not part of the AHRI Certification Program. The scope of the applicable AHRI Certification Program can be found on AHRI's website at http://www.ahrinet.org.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

Intent

This standard is intended for the guidance of the industry, including manufacturers, engineers, installers, contractors, and users.

Review and Amendment

This standard is subject to review and amendment as technology advances.

2023 Edition

This edition of AHRI Standard 410 (SI/I-P), *Performance Rating of Forced-circulation Air-cooling and Air-heating Coils*, was prepared by Air Cooling and Air Heating Coils (ACHC) Standards Technical Committee (STC). The standard was approved by the Applied Standards Subcommittee in May 2023.

Origin and Development of AHRI Standard 410

The initial publications were ARI Standard 410-1956, *Forced Circulation Air-Cooling Coils* and ARI Standard 411-1956, *Methods of Testing and Rating Forced Circulation Air-Cooling and Air-Heating Coils*. Subsequent revisions were:

ARI Standard 410-1958, *Forced Circulation Air-Cooling Coils*

ARI Standard 410-1964, *Forced Circulation Air-Cooling Coils*

ARI Standard 410-1972, *Standard for Forced Circulation Air-Cooling and Air-Heating Coils*

ARI Standard 410-1981, *Standard for Forced Circulation Air-Cooling and Air-Heating Coils*

ARI Standard 410-1987, *Standard for Forced Circulation Air-Cooling and Air-Heating Coils*

ARI Standard 410-1991, *Standard for Forced Circulation Air-Cooling and Air-Heating Coils*

AHRI Standard 410-2001, *Forced-circulation Air-cooling and Air-heating Coils*

AHRI Standard 410-2001 (with Addendum 1), *Forced-circulation Air-cooling and Air-heating Coils*

AHRI Standard 410-2001 (with Addenda 1 and 2), *Forced-circulation Air-cooling and Air-heating Coils*

AHRI Standard 410-2001 (SI/I-P) (with Addenda 1, 2 and 3) *Forced-circulation Air-cooling and Air-heating Coils*

Summary of Changes

AHRI Standard 410-2023 (SI/I-P) contains the following update(s) to the previous edition:

- Convert to a joint unit (SI/I-P) standard
- Update schematic figures to include joint units
- Enhance 100+ equations, including those used to determine coil performance

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

Committee Personnel

Air Cooling and Air Heating Coils Standards Technical Committee

Participant	Interest Category Classification	Voting Role	State / Province / Country
James Bogart Johnson Controls, Inc.	Product Manufacturer	Chair	PA, USA
Todd Michael Trane U.S. Inc.	Product Manufacturer	Chair Emeritus	WI, USA
Kyle Bowling RAE Corporation	Product Manufacturer	Primary	OK, USA
Scott Creamer Rheem Manufacturing Company	Product Manufacturer	Primary	AR, USA
Clark Hibbard Nortek Air Solutions, LLC	Product Manufacturer	Primary	OK, USA
Pete Hoch Carrier Corporation	Product Manufacturer	Primary	NY, USA
Brent Pearce Daikin Applied Americas Inc.	Product Manufacturer	Primary	MN, USA
Pedro Perez Paez Aaon, Inc.	Product Manufacturer	Primary	OK, USA
Sam Vanden Hogen Trane Technologies	Product Manufacturer	Primary	WI, USA
Kishan Padakannaya Johnson Controls, Inc.	Product Manufacturer	Alternate to James Bogart	OK, USA
Sarp Hamamcioglu	AHRI Staff Liaison		

Air Cooling and Air Heating Coils Standards Technical Committee Scope:

The Air-Cooling and Air-Heating Coils (ACHC) Standards Technical Committee is responsible for the development and maintenance of AHRI standards and guidelines pertaining to Forced-circulation Air-cooling and Air-heating Coils.

This STC applies to Forced-Circulation Air-Cooling Coils under non-frosting conditions and Forced-Circulation Air-Cooling and Air-Heating Coils only intended for:

- Field installation (built-up systems and duct-mounted coils); and
- Use in central station air-handling units.

Coils in other applications and products are out of scope.

Product definitions are as defined within AHRI Standard 410.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

Applied Standards Subcommittee

Participant	Interest Category Classification	Voting Role	State / Province / Country
Patrick Marks Johnson Controls, Inc.	Product Manufacturer	Chair	PA, USA
Darcy Lee Trane Technologies	Product Manufacturer	Vice-chair	GA, USA
Brandon Bates Energistics Laboratory	Testing Laboratory	Primary	TX, USA
Craig Burg Desert Aire Corp.	Product Manufacturer	Primary	WI, USA
Jennifer Butsch Emerson Commercial and Residential Solutions	Product Manufacturer	Primary	OH, USA
Jeff deRoos Carrier Corporation	Product Manufacturer	Primary	FL, USA
Henry Ernst Daikin Applied Americas Inc.	Product Manufacturer	Primary	MN, USA
Dana Fischer Mitsubishi Electric Cooling & Heating	Product Manufacturer	Primary	GA, USA
Armin Hauer ebm-papst Inc.	Product Manufacturer	Primary	CT, USA
Jeffrey Kellow GE Appliances, a Haier Company	Product Manufacturer	Primary	KY, USA
Tom McDermott Swegon North America Inc.	Product Manufacturer	Primary	ON, Canada
Karl Best	AHRI Staff Liaison		

Applied Standards Subcommittee Scope:

The scope of the Applied Standards Subcommittee is standards and guidelines related to the end products that are part of the AHRI Applied Industry Sector. (The definition of and list of products associated with each sector are found on the AHRI website at http://www.ahrinet.org.)

This list represents the membership at the time the Standards Technical Committee and Standards Subcommittee were balloted on the final text of this edition. Since that time, changes in the membership may have occurred. Membership on these committees shall not in and of itself constitute an endorsement by the committee members or their employers of any document developed by the committee on which the member serves.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

TABLE OF CONTENTS

PAGE

SECTIONS

Section 1. Purpose 1
Section 2. Scope 1
2.1 Scope 1
2.2 Exclusions 1
Section 3. Definitions 1
3.1 Expression of Provisions 1
3.2 Standard Specific Definitions 2
Section 4. Assumptions 8
4.1 Appendix D Reference 8
Section 5. Test Requirements 8
5.1 Method for Laboratory Tests of Testing for Rating 8
5.2 Test Coils and Test Parameters 11
5.3 Rating Variables to be Determined by Laboratory Tests for Coils with Smooth Tubes 13
5.4 Minimum Requirements for Laboratory Tests for Coils with Smooth Tubes 14
5.5 Minimum Requirements for Laboratory Tests for Coils with Turbulators or Internally Grooved Tubes 18
5.6 Requirements for Optional Laboratory Tests 19
5.7 Changes to Established Coil Line Ratings 20
Section 6. Rating Requirements 20
6.1 Ratings 20
6.2 Heat Transfer Equations for Laboratory Test Reduction and for Ratings 20
6.3 Reduction of Laboratory Test Data to Determine Parameters for Ratings 41
6.4 Standard Ratings 50
6.5 Airside Effectiveness 52
Section 7. Minimum Data Requirements for Published Ratings 58
7.1 Minimum Data Requirements for Published Ratings 58
7.2 Single-phase Liquid Coil Ratings 59
7.3 Steam Coil Ratings 59
7.4 Refrigerant Evaporator Coil Ratings 60
Section 8. Marking and Nameplate Data 60
Section 9. Conformance Conditions 60
Section 10. Symbols and Units 60
10.1 Letter Symbols 60
10.2 Subscripts 63
10.3 Superscripts 65
Section 11. Reference Information 65
11.1 Reference Properties 65

Documents
Document Sharing Hub

Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

11.2 Conversion Factors....65
11.3 Significant Figures....66

FIGURES

Figure 1 Distributing Tube Steam Coil with Inner Steam Distributing Tubes....4
Figure 2 Single Tube Steam Coil....5
Figure 3. Colburn-*j* Heat Transfer Factor and Darcy-Weisbach Friction Factor Inside Smooth Tubes for Single-phase Liquid Coils....25
Figure 4 Thermal Diagram of Counterflow Cold Single-phase Liquid Sensible Only Air-cooling Coils....26
Figure 5 Thermal Diagram of Counterflow Hot Single-phase Liquid Air-heating Coils....27
Figure 6 Thermal Diagram of Counterflow (Physical Parallelflow) Refrigerant Evaporator Sensible Only Air-cooling Coils....28
Figure 7 Thermal Diagram of Parallelflow (Physical Counterflow) Refrigerant Evaporator Sensible Only Air-cooling Coils....29
Figure 8 Thermal Diagram of Single Tube Steam Coils....30
Figure 9 Thermal Diagram of Distributing Tube Steam Coils....30
Figure 10 Thermal Diagram of Counterflow Cold Single-phase Liquid Air-cooling and Dehumidifying Coils....35
Figure 11 Thermal Diagram of Counterflow (Physical Parallelflow) Refrigerant Evaporator Air-cooling and Dehumidifying Coils....36
Figure 12 Thermal Diagram of Parallelflow (Physical Counterflow) Refrigerant Evaporator Air-cooling and Dehumidifying Coils....37
Figure 13 Combined Air Film and Metal Thermal Resistance for Dry Surface versus Air Film Thermal Resistance for Dry Surface (IP)....43
Figure 14 Total Metal Thermal Resistance of Fin and Tube Assembly Based on Total External Surface Effectiveness (IP)....44
Figure 15 Rating Data for Steam Coils (I-P)....45
Figure 16 Rating Data for Cold Single-phase Liquid Sensible Only Air-cooling Coils and Hot Single-phase Liquid Air-heating Coils (IP)....46
Figure 17 Rating Data for Cold Single-phase Liquid Air-cooling and Dehumidifying Coils (IP)....48
Figure 18 Rating Data for Refrigerant Evaporator Air-cooling and Dehumidifying Coils (IP)....50
Figure 19 Crossflow Airside Effectiveness....55
Figure 20 Thermal Two-pass Cross-counterflow Airside Effectiveness....56
Figure 21 Thermal Counterflow Airside Effectiveness....57
Figure 22 Thermal Parallelflow Airside Effectiveness....58
Figure 23 Staggered Tubes and Parallel (In-line) Tubes with Continuous Flat Plate Fins or Continuous Configurated Plate Fins....71
Figure 24 Staggered Tubes with Smooth Spiral Fins or Crimped Spiral Fins or with Flat Plate Fins or Configurated Plate Fins on Individually-finned Tube....72
Figure 25 Parallel (In-line) Tubes with Smooth Spiral Fins or Crimped Spiral Fins or with Flat Plate Fins or Configurated Plate Fins on Individually-finned Tube....72
Figure 26 Plate Fins with Collars Touching Adjacent Fins....73
Figure 27 Plate Fins with Collars not Touching Adjacent Fins....74
Figure 28 Plate Fins without Collars....75

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

Figure 29 Efficiency of Annular Fins of Constant Thickness (Plate Fins) 77
Figure 30 Smooth Spiral Fins 78
Figure 31 Crimped Spiral Fins 78
Figure 32 Efficiency of Annular Fins of Constant Cross-Sectional Area for Heat Flow (Spiral Fins) 80

TABLES

Table 1 Range of Standard Rating Conditions (SI/IP) 9
Table 2 Required Laboratory Tests 12
Table 3 Colburn-j Heat Transfer Factor Curve Fit Coefficients Inside Smooth Tubes for Single-phase Liquid Coils 23
Table 4 Darcy-Weisbach Friction Factor Curve Fit Coefficients Inside Smooth Tubes for Single-phase Liquid Coils 33
Table 5 Metal Thermal Conductivities 42
Table 6 Conversion Factors 66

APPENDICES

Appendix A. References – Normative 67
Appendix B. References – Informative 68
Appendix C. Volumetric Flow Rates of Air and Single-phase Liquid – Normative 69
Appendix D. Assumptions, Classifications, Dimensions, Fin Geometry, Fin Efficiency, and Coil Geometry – Normative 70
Appendix E. Mass and Volumetric Flow Rates of Air – Informative 83
Appendix F. Rationale and Details for Allowing the Changes in a Coil Line – Informative 84

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

PERFORMANCE RATING OF FORCED-CIRCULATION AIR-COOLING AND AIR-HEATING COILS

Section 1. Purpose

This standard establishes definitions, classifications, test requirements, rating requirements, minimum data requirements for *published ratings*, operating requirements, marking and nameplate data, and conformance conditions for *forced-circulation air-cooling and air-heating coils*.

Section 2. Scope

2.1 Scope

This standard applies to *forced-circulation air-cooling and air-heating coils* as defined in Section 3.

2.2 Exclusions

This standard does not apply to:

- *Forced-circulation air-cooling coils* under frosting conditions
- *Microchannel coils*
- *Bare tube coils*
- Air-cooling *refrigerant evaporator coils* for direct-expansion *refrigerant* systems with *refrigerant* liquid flow controlled by:
  - Capillary tube assemblies
  - Restrictor orifices
- Air-cooling *refrigerant evaporator coils* for flooded *refrigerant* systems
- Air-heating *refrigerant* condenser coils for *refrigerant* systems
- Indoor or outdoor *refrigerant* coils for heat pump *refrigerant* systems
- *Forced-circulation air-cooling and air-heating coils* for airside fluids other than air
- Non-round tube coils

Section 3. Definitions

All terms in this document shall follow the standard industry definitions in the ASHRAE Terminology website unless otherwise defined in this section.

3.1 Expression of Provisions

Terms that provide clear distinctions between requirements, recommendations, permissions, options, and capabilities.

3.1.1 "Can" or "cannot"

Express an option or capability.

3.1.2 "May"

Signifies a permission expressed by the document.

3.1.3 "Must"

Indication of unavoidable situations and does not mean that an external constraint referred to is a requirement of the document.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

3.1.4 "Shall" or "shall not"

Indication of mandatory requirements to strictly conform to the standard and where deviation is not permitted.

3.1.5 "Should" or "should not"

Indication of recommendations rather than requirements. In the negative form, a recommendation is the expression of potential choices or courses of action that is not preferred but not prohibited.

3.2 Standard Specific Definitions

3.2.1 Aqueous Glycol

Refers only to aqueous ethylene glycol and aqueous propylene glycol solutions. The thermodynamic and thermophysical properties of *aqueous glycol* are found in the latest edition of the *ASHRAE Handbook – Fundamentals* or from the glycol's manufacturer.

3.2.2 Azeotropic

A *blend* containing two or more *refrigerants* whose equilibrium vapor and liquid-phase compositions are the same at a given pressure.

3.2.3 U.S. Standard Atmosphere at Sea Level

Atmospheric air pressure at sea level (altitude, Z, equal to 0 m (0 ft)), $P_{b\ STD}$, is 101.325 kPa (29.921 in Hg) abs.

3.2.4 Job Conditions

The barometric pressure expressed as $P_{b\ JOB}$, as function of altitude, Z, that is calculated using Equation 1 for SI units and Equation 2 for IP units. This equation is accurate for altitude, Z, from -305 m (-1000 ft) to 9150 m (30000 ft).

$$P_{b\ JOB} = 101.325(1 - 2.2558 \text{ x } 10^{-6}\ Z)^{5.2559} \quad (1)$$

$$P_{b\ JOB} = 29.921(1 - 6.8754 \text{ x } 10^{-6}\ Z)^{5.2559} \quad (2)$$

3.2.5 Blend

A *refrigerant* consisting of a mixture of two or more different chemical compounds that can be used individually as *refrigerants* for other applications. *Refrigerant* mixtures of two or more different chemical compounds are *azeotropic*, *near azeotropic*, or *zeotropic*.

3.2.6 Bubble Point

The liquid saturation temperature of a *refrigerant* at the specified pressure and is the temperature where a liquid *refrigerant* first begins to boil.

3.2.7 Circuiting

The individual *tube passes* in a coil that can be interconnected by return bends to form the serpentine arrangement of multi-pass tube circuits. Coils can be used with different circuit arrangements and combinations.

3.2.8 Forced-circulation Air-cooling and Air-heating Coil

A heat exchanger, with or without extended surfaces, where tubeside fluid is circulated for the purpose of total cooling (sensible cooling plus latent cooling) or heating of a forced-circulation air stream.

3.2.8.1 Bare Tube Coil

A coil without *fins*.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

3.2.8.2 Coil Line

A product offering of coils with the following in common:

- Tubeside fluid (*single-phase liquid*, steam, or *refrigerant*)
- Tube size, spacing, and arrangement (parallel or staggered)
- Tube internal construction
- *Fin* configuration (not spacing)

3.2.8.3 Forced-circulation Air-cooling Coil

A heat exchanger, with or without extended surfaces, where either cold *single-phase liquid* or *refrigerant* is circulated, for the purpose of total cooling (sensible cooling plus latent cooling) of a forced-circulation air stream.

Note: This can be referred to as an air-cooling coil.

3.2.8.4 Forced-circulation Air-heating Coil (Air-heating Coil)

A heat exchanger, with or without extended surfaces, where either hot *single-phase liquid* or steam is circulated for the purpose of heating of a forced-circulation air stream.

3.2.8.5 Integral Face-and-bypass Coil

A coil (can be with steam as the tubeside fluid) that has damper(s) built in that controls the amount of airflow that bypasses the heat transfer surface.

3.2.8.6 Microchannel Coil

A coil (can be aluminum) with multiple flat tubes containing small channels (microchannels) where a tubeside fluid (that can be *refrigerant*) flows. Angled and louvered *fins* are located in between the flat tubes. Coil *circuiting* is accomplished by placing baffles in the distribution manifolds to feed the *refrigerant* through the flat tubes.

3.2.8.7 Refrigerant Evaporator Coil

An air-cooling coil using *refrigerant* as the tubeside fluid for direct-expansion *refrigerant* systems with *refrigerant* liquid flow controlled by an expansion valve. This coil can be described as a DX evaporator coil (direct-expansion evaporator coil).

3.2.8.8 Single-phase Liquid Coil

An air-cooling coil or *air-heating coil* using *single-phase liquid* as the tubeside fluid.

3.2.8.9 Steam Coil

An *air-heating coil* using steam as the tubeside fluid.

3.2.8.9.1 Distributing Tube

A *steam coil* with double tube (steam distributing inner tube-in-steam condensing outer tube) design as shown in Figure 1. The outer tubes can have *fins* on the airside. Each outer tube has a smaller inner tube with perforations that distribute steam evenly through the entire length of the outer tube.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

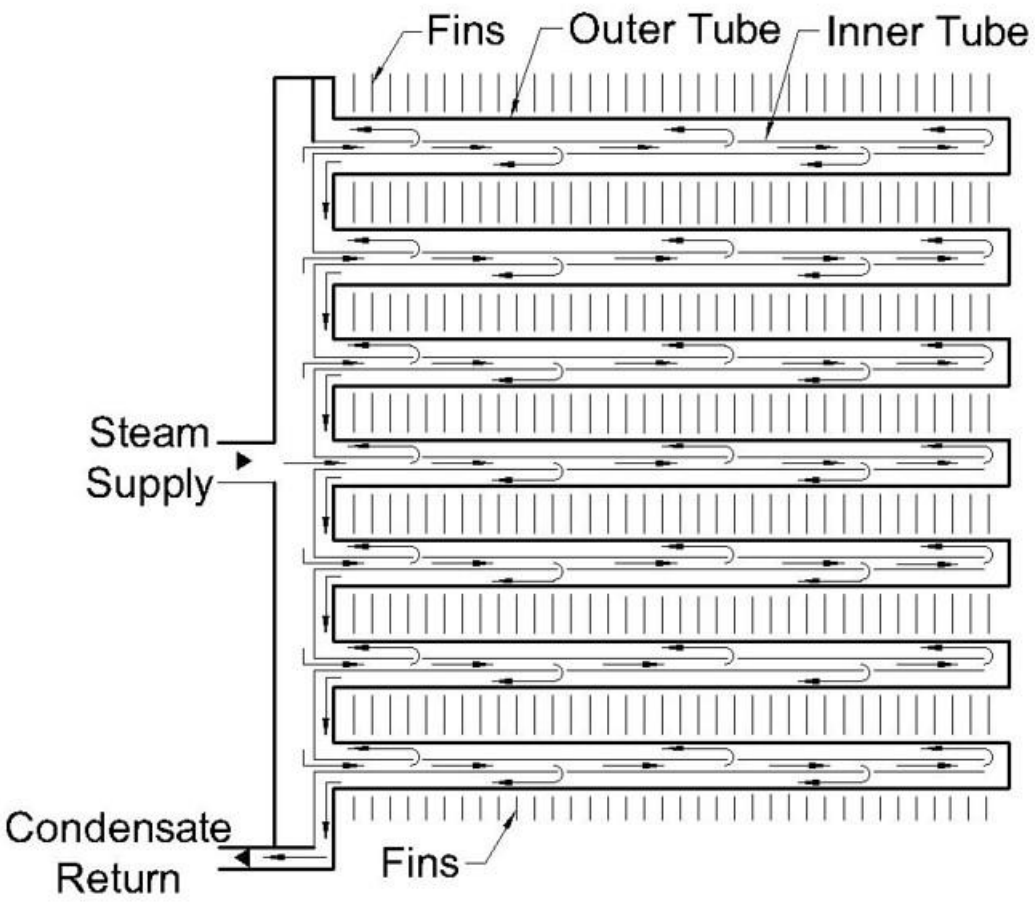


Figure 1 Distributing Tube Steam Coil with Inner Steam Distributing Tubes

3.2.8.9.2 Single Tube

Refer to Figure 2. The tubes can have *fins* on the airside. For multiple circuit one-pass coils, the steam supply header and condensate return header are at opposite ends of the coil.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

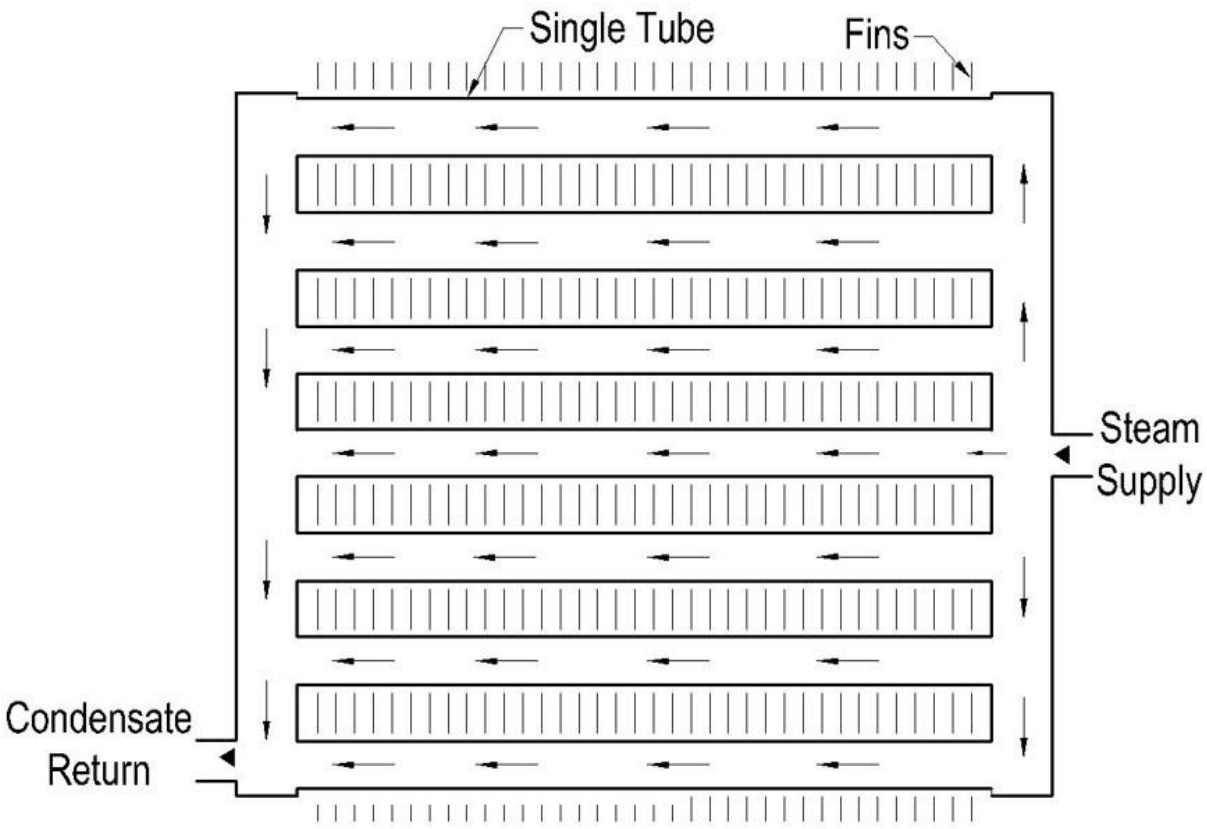


Figure 2 Single Tube Steam Coil

3.2.8.10 Test Coil

A coil that has *laboratory tests* performed on it.

3.2.9 Cooling Capacity

The total capacity associated with the change in air enthalpy that includes both the *latent capacity* and *sensible capacity* expressed in kW (Btu/h).

3.2.9.1 Latent Capacity

Capacity associated with a change in humidity ratio.

3.2.9.2 Sensible Capacity

Capacity associated with a change in dry-bulb temperature.

3.2.10 Dew Point

The vapor saturation temperature of a *refrigerant* at the specified pressure which is the temperature where the last drop of liquid *refrigerant* boils.

3.2.11 Equivalent Annular Fin

Representation of a non-circular fin with a surface area of same heat transfer effectiveness, such as fins between staggered tube arrangement (hexagonal fin surface) or fins between parallel tube arrangement (rectangular fin surface).

3.2.12 Equivalent Length

Total length of straight tubes and return bends in a single circuit in the coil.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

3.2.13 Fin

Thin piece of material (can be metal) mechanically or metallurgically bonded to a pipe, tube, or other surface to increase the heat transfer area.

3.2.14 Fin Configuration

3.2.14.1 Spiral Fin

Continuous strip of metal helically wound and attached to a tube.

3.2.14.2 Crimped Spiral Fin

Spiral fin of constant thickness whose *fin* surface adjacent to tube is radially crimped. The crimped geometry results in an annular *fin* of constant cross-sectional area for heat flow that is defined by Equation 129.

3.2.14.3 Smooth Spiral Fin

Spiral fin with a smooth *fin* surface whose *fin* geometry results in an annular *fin* of constant cross-sectional area for heat flow that is defined by Equation 126.

3.2.14.4 Plate Fin on Individually-finned Tube

Square or rectangular *fin* with one hole or one *fin* collar on an individually-finned tube

3.2.14.5 Continuous Plate Fin

Square or rectangular *fin* with holes or *fin* collars to receive multiple tubes arranged in a staggered or parallel tube arrangement.

3.2.14.6 Configurated Plate Fin

Plate *fin* with non-flat *fin* surfaces (corrugated, wavy, louvered, lanced).

3.2.14.7 Flat Plate Fin

Plate *fin* with flat *fin* surfaces.

3.2.15 Fin Pitch

Number of transverse *fins* per unit length of tube that can be used for coils rated with I-P units. An example is 12 *fins*/in (fpi).

3.2.16 Fin Spacing

Distance between two successive transverse *fins* on a tube and can be used for coils rated with SI units. An example is 2.0 mm/*fin*.

3.2.17 Headers

A manifold extending from the coil that distributes fluid entering the tubes or collects fluid leaving the tubes or both.

3.2.18 Heating Capacity

The capacity associated with the change in dry-bulb temperature expressed in kW (Btu/h).

3.2.19 Internally Grooved Tubes

Tubes with internally enhanced tube surface used to increase turbulence of tubeside fluids, and a smooth external tube surface.

3.2.20 Laboratory Tests

Tests conducted per ANSI/ASHRAE Standard 33-2016 on representative coils to determine basic heat transfer and pressure drop characteristics that are used in developing *published ratings.*

3.2.21 Maximum Temperature Glide

The difference between the saturated liquid temperature (*bubble point*) and the saturated vapor temperature (*dew point*) for the as-formulated *blend* composition at constant pressure.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

3.2.22 Near Azeotropic

A *zeotropic blend* with a small *temperature glide* that can be disregarded without consequential error in analysis for a specific application.

3.2.23 Published Ratings

A statement of the assigned values of those performance characteristics, under stated *rating conditions*, where a unit can be chosen to fit the application. These values apply to all units of the same nominal size and type (identification) produced by the same manufacturer. This includes the rating of all performance characteristics shown on the unit or published in specifications, advertising or other literature controlled by the manufacturer, at stated *rating conditions*.

3.2.23.1 Application Ratings

A rating based on tests performed at *rating conditions* other than *standard rating conditions*.

3.2.23.1 Rating Conditions

Any set of operating conditions where a single level of performance results and causes only that level of performance to occur.

3.2.23.2 Standard Rating

A rating based on tests performed at *standard rating conditions*.

3.2.23.3 Standard Rating Conditions

Rating conditions used as the basis of comparison for performance characteristics. Refer to Table 1 in Section 5.

3.2.24 Refrigerant

A two-phase working fluid for the vapor compression cycle that enters the expansion device as a liquid, enters the air-cooling coil as a two-phase fluid, absorbs heat from the airstream by the process of evaporation, and leaves the coil as a superheated gas.

3.2.25 Single-phase Liquid

Aqueous glycol or water in the liquid phase.

3.2.26 Smooth Tubes

Tubes with smooth internal and external tube surfaces.

3.2.27 Standard Air

Air weighing 1.2 kg dry air/m^3 (0.075 lbm dry air/ft^3) that approximates dry air at 21.1°C (70.0°F) and at a standard barometric pressure of 101.325 kPa (29.921 in Hg) abs.

3.2.28 Standard Coil Orientation

The standard coil position is that of horizontal tubes and vertical coil face with horizontal airflow.

3.2.29 Standard Water

Water weighing 998.9 kg/m^3 (62.361 lbm/ft^3) that approximates water density at 15.6°C (60.0°F) and at a standard barometric pressure of 101.325 kPa (29.921 in Hg) abs.

3.2.30 Temperature Glide

The absolute value of the difference between the starting and ending temperatures of a phase change process by a *refrigerant* within a component of a refrigerating system, exclusive of any subcooling or superheating. This term can describe condensation or evaporation of a *zeotropic blend*.

3.2.31 Test Series

Multiple individual tests performed on the same *test coil*.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

3.2.32 Tube Pass

A *single tube* that runs the length of the coil and crosses the airflow.

3.2.33 Turbulators

Mechanical devices (inserts) inside tubes used to increase turbulence of fluids. Turbulated tube external tube surface is smooth.

3.2.34 Zeotropic

Blends comprising multiple components of different volatilities that, when used in refrigeration cycles, change volumetric composition and saturation temperatures as *blends* evaporate (boil) or condense at constant pressure.

Section 4. Assumptions

4.1 Appendix D Reference

Please refer to Appendix D to locate information about assumptions, classifications, dimensions, fin/coil geometry, and fin efficiency.

Section 5. Test Requirements

5.1 Method for Laboratory Tests of Testing for Rating

Forced-circulation air-cooling and air-heating coils shall be tested in accordance with ANSI/ASHRAE Standard 33-2016 and within the bounds of Table 1, except as outlined in Section 5.1.1 and Section 5.1.2.

5.1.1 Redundant Measurements

Duplicate instrumentation can be utilized to verify the accuracy of the *single-phase liquid* measurements. For *integral face-and-bypass coils* that utilize a *single-phase liquid*, duplicate instrumentation shall be used. For any test performed using duplicate instrumentation, the following shall apply.

1) Instrumentation shall meet the accuracy and location requirements as spelled out in ANSI/ASHRAE Standard 33-2016.
2) Temperature measurements between instruments shall be within ±0.11°C (±0.2°F) for the same *single-phase liquid* temperature measurement (such as an outlet).
3) Mass flow rate measurements between instruments shall be within ±1.0%.
4) If this method is used and the tolerance requirements have been met, the average of the two *single-phase liquid* measurements shall be used for reporting purposes.

5.1.2 Refrigerant Temperature Measuring Instruments

The temperature of *refrigerants* shall be measured by inserting the temperature measuring instrument into a liquid-filled well inserted in the conduit. the temperature measuring instrument shall not be inserted directly into the *refrigerant*.

Refer to Table 1 to see the range of standard rating conditions.

P_b, barometric pressure shall be between 30.139 and 104.979 kPa (8.9 and 31.0 in Hg) abs for all coils.

Maximum P_s, average air absolute static pressure at coil shall be 110.316 kPa (16.0 psia) for all coils.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

Table 1 Range of Standard Rating Conditions (SI/IP)

Item		Air-cooling Coils			*Air-heating Coils*		
		Refrigerant	**Cold Water**	**Cold *Aqueous Glycol***	**Steam**	**Hot Water**	**Hot *Aqueous Glycol***
Standard Dry Air Face Velocity for Dry Surface Coils (Sensible Only)	Standard m/s	0.51 to 7.62	0.51 to 7.62	0.51 to 7.62	0.51 to 7.62	0.51 to 7.62	0.51 to 7.62
	Standard ft/min	100 to 1500	100 to 1500	100 to 1500	100 to 1500	100 to 1500	100 to 1500
Standard Dry Air Face Velocity for Wet Surface Coils (Air-cooling and Dehumidifying)	Standard m/s	0.51 to 4.06	0.51 to 4.06	0.51 to 4.06	—	—	—
	Standard ft/min	100 to 800	100 to 800	100 to 800	—	—	—
Entering Air Dry-bulb Temperature	°C	18.3 to 48.9	18.3 to 48.9	18.3 to 48.9	-28.9 to 37.8	-17.8 to 37.8	-28.9 to 37.8
	°F	65.0 to 120.0	65.0 to 120.0	65.0 to 120.0	-20.0 to 100.0	0.0 to 100.0	-20.0 to 100.0
Maximum Entering Air Wet-bulb Temperature	°C	29.4	29.4	29.4	—	—	—
	°F	85.0	85.0	85.0	—	—	—
Mean *Single-phase Liquid* Velocity Inside Tubes[1,2]	mean m/s	—	0.15 to 2.44	0.15 to 2.44	—	0.15 to 2.44	0.15 to 2.44
	mean ft/min	—	0.5 to 8.0	0.5 to 8.0	—	0.5 to 8.0	0.5 to 8.0
Entering *Single-phase Liquid* Temperature	°C	—	1.7 to 32.2	-17.8 to 32.2	—	37.8 to 121.1	37.8 to 121.1
	°F	—	35.0 to 90.0	0.0 to 90.0	—	100.0 to 250.0	100.0 to 250.0
Saturated *Refrigerant* Vapor Temperature Leaving Coil Suction Header	°C	-1.1 to 12.8	—	—	—	—	—
	°F	30.0 to 55.0	—	—	—	—	—
Minimum *Refrigerant* Vapor Superheat Leaving Coil Suction Header	°C	3.3	—	—	—	—	—
	°F	6.0	—	—	—	—	—
Steam Pressure at Coil Inlet	kPag	—	—	—	13.79 to 1723.69	—	—
	psig	—	—	—	2.0 to 250.0	—	—

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

Item		Air-cooling Coils			*Air-heating Coils*		
		Refrigerant	**Cold Water**	**Cold *Aqueous Glycol***	**Steam**	**Hot Water**	**Hot *Aqueous Glycol***
Maximum Steam Superheat at Coil Inlet	°C	—	—	—	27.8	—	—
	°F	—	—	—	50.0	—	—
Aqueous Glycol Concentration by Mass	%	—	—	10 to 60	—	—	10 to 60
Minimum *Fin* Surface Temperature	°C	> 0.0	> 0.0	> 0.0	—	—	—
	°F	> 32.0	> 32.0	> 32.0	—	—	—
Minimum Internal Tube Wall Surface Temperature	°C	—	> 0.0	> *Aqueous Glycol* freezing point	> 0.0	> 0.0	> *Aqueous Glycol* freezing point
	°F	—	> 32.0	> *Aqueous Glycol* freezing point	> 32.0	> 32.0	> *Aqueous Glycol* freezing point
Tubeside Fouling Factor Allowance	$m^2 \cdot K/W$	0.00000	0.00000 to 0.00018	0.00000 to 0.00018	0.00000	0.00000 to 0.00018	0.00000 to 0.00018
	$h \cdot ft^2 \cdot °F/Btu$	0.00000	0.00000 to 0.00100	0.00000 to 0.00100	0.00000	0.00000 to 0.00100	0.00000 to 0.00100

Notes:

1) Predicted performance and actual performance of water coils operating at mean *single-phase liquid* velocities inside tubes below the minimum listed is expected to show variations exceeding currently accepted tolerances for the following reasons:
   a. Application of coils at low mean *single-phase liquid* velocity inside tubes can lead to fouling and can lead to air entrapment.
   b. Differences in coil design/type affect the variation in low Re_L heat transfer coefficient.
2) On lower limit, Re_L shall exceed 700 at t_{Lm}.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

5.2 Test Coils and Test Parameters

Each *coil line* rated in accordance with this Standard shall have separate *laboratory tests* conducted using representative *test coils*.

5.2.1 Required Laboratory Tests

Refer to Table 2 to see the required laboratory tests.

5.2.1.1 Thermal Resistance (*R*)

The overall thermal resistance, *R*, can be determined by test or either of the following procedures:

1) For coils with *smooth tubes* R_{aD} is determined from *steam coil* tests, assuming a steam-side heat transfer coefficient, fv, of 11356 W/(m^2·K) (2000 Btu/(h·ft^2·°F)). One-row *steam coil* tests shall be used to determine R_{aD} for one-row hot water coils. One-row or two-row *steam coil* tests shall be used to determine R_{aD} for two-row hot water coils. For coils with *turbulators* or *internally grooved tubes*, R_{aD} cannot be determined from *steam coil* tests.

2) R_{aD} is determined from cold water sensible only air-cooling coil tests. One-row cold water sensible only air-cooling coil tests shall be used to determine R_{aD} for one-row hot water coils. One-row or two-row cold water sensible only air-cooling coil tests shall be used to determine R_{aD} for two-row hot water coils. Three or more-row cold water sensible only air-cooling coil tests shall be used to determine R_{aD} for three or more-row hot water coils.

For procedures in Section 5.2.1.1(1) and Section 5.2.1.1(2) isothermal water pressure drop tests shall be conducted per Section 5.6.2.

5.2.1.2 Hot Water Two-row Laboratory Tests

The dry surface air film thermal resistance, R_{aD}, can be determined as in Section 5.2.1.1 except that two-row coils shall be used.

5.2.1.3 All Cooling Test Series Requirement

A complete *test series* shall be run with each *refrigerant* with tests required per Section 5.4.5.

5.2.1.4 All Cooling Tests with Four or More Rows

If a *coil line* has four or more rows, a test shall be performed on a coil with at least four rows. If the *coil line* only has up to three rows, the three-row coil shall be tested.

5.2.1.5 Aqueous Glycol Tests

These coils shall have separate *laboratory tests* using the same coil as used for water dry surface coil tests unless a water coil with *smooth tubes* of identical tube spacing and *fin* configuration has already been tested to determine the air film thermal resistance, R_a, and air pressure drop as functions of standard dry air face velocity and *fin spacing*.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

Table 2 Required Laboratory Tests

Coil Type	One-row	Two-row		Three-row or More
		In-Line Tubes or *Flat Plate Fins*	All Other Configurations	
Distributing Tube Steam	Test	Test	No Test[1]	No Test[1]
Single Tube Steam	Test[2]	Test[2]	No Test[1]	No Test[1]
Hot Water	Test	Test	Test	Test
All Cooling	Test[3]	Test	Test[3]	Test
Aqueous Glycol	Test	Test	Test	Test

Notes:

- Where "No Test" is indicated, the manufacturer can perform tests to establish performance factors, in which case the requirements in Section 5.2.1 and notes from Table 2 do not apply.

1. Steam ratings can be calculated using data from one-row tests of the same coil type.
2. If ratings are determined for *distributing tube steam coil* of the same surface geometry, the same ratings can be used for *single tube steam coil* and additional tests are not required.
3. A complete set of tests is not required, provided that the air film heat transfer coefficient, f_a, as determined from a cold water sensible only air-cooling coil *test series*, is not greater than 102.5% of those tested in accordance with Section 5.2.1.4. If this agreement exists for a one-row coil, a test is not required for a two-row coil.

5.2.2 Physical Coil Requirements

The manufacturer shall confirm that the *test coils* used for *laboratory tests* are representative of current production materials and manufacturing methods. The *test coils* shall comply with the following requirements:

5.2.2.1 Coil Face Area

0.186 m^2 to 1.86 m^2 (2 ft^2 to 20 ft^2).

5.2.2.2 Rows

In accordance with Table 2.

5.2.2.3 Fin Spacings

The maximum and minimum *fin spacings* or *fin pitch* shall be tested. If the difference between the maximum and minimum *fin spacing* exceeds 3 mm/*fin* or 8 *fins*/in, an intermediate spacing shall be tested.

5.2.2.4 Fin Thickness and Material

The *test coil* shall be constructed with aluminum *fins* at the minimum *fin* thickness if aluminum *fins* are offered. If aluminum *fins* are not offered, test each material type at the minimum *fin* thickness. For changes from *test coil*, see Section 5.7.1 and Section 5.7.2.

5.2.3 Coil Circuiting Guidance

Circuiting guidance for *test coils* is as follows:

5.2.3.1 Steam Coils

Circuiting shall provide representative tube loadings and distribution.

5.2.3.2 Single-phase Liquid Coils

Circuiting shall be designed to match the intended flow arrangement, such as crossflow or thermal cross-counterflow for one-row and two-row coils and thermal counterflow for three or more row coils.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

Note: When determining airside ratings, the *test coil* should be designed with the smallest number of circuits that use up as much tubeside pressure drop in the *test coil*) within flow capabilities of the test facility (system pressure drop versus flow curve). This results in a higher *single-phase liquid* tubeside velocity that has a lower tubeside resistance, and minimizes uncertainty of the tubeside resistance on the air film thermal resistance.

Note: When determining tubeside ratings, the *test coil* should be designed with the number of circuits that allows the coil to be tested over the required *single-phase liquid* tubeside fluid velocity range with resulting tubeside fluid pressure drop values that are within flow capabilities of the test facility (system pressure drop versus flow capability).

5.2.3.3 Refrigerant Evaporator Coils

Circuiting for each of the two required circuit lengths shall estimate the intended flow arrangement, such as thermal parallel flow or thermal counterflow for three or more row coils.

5.3 Rating Variables to be Determined by Laboratory Tests for Coils with Smooth Tubes

Information contained in this section is for testing coils with *smooth tubes*. Refer to Section 5.5 for testing requirements of coils with *turbulators* or *internally grooved tubes*.

5.3.1 Rating Variables

Laboratory tests are designed such that heat transfer and pressure drop variables The variables to be determined for coils with *smooth tubes*, as further described in Section 5.4, include the following:

5.3.1.1 Steam Coils

Overall thermal resistance, air pressure drop, and steam pressure drop.

5.3.1.2 Single-phase Liquid Coils

Air film thermal resistance for dry and wet surface conditions, air pressure drop for dry and wet surface conditions, and *single-phase liquid* pressure drop.

5.3.1.3 Refrigerant Evaporator Coils

Refrigerant film thermal resistance and *refrigerant* pressure drop for each *refrigerant* to be rated.

5.3.2 Range of Heat Transfer Variables

The range of heat transfer variables that can have ratings applied shall be limited strictly to the range included in the *laboratory tests* as described under Section 5.4. Values shall not be extrapolated outside the range covered in the *laboratory tests* as described under Section 5.4 except for the following:

1) Initial air-to-tubeside fluid temperature difference, *ITD*, for all coils.
2) Inlet steam pressure, p_{v1}, for *steam coils*.
3) Saturated *refrigerant* vapor temperature leaving coil suction header, t_{r2g}, for *refrigerant evaporator coil*s.
4) *Single-phase liquid* velocity inside tubes, V_L, for *single-phase liquid coils*.
5) *Single-phase liquid* temperatures, t_L, for *single-phase liquid coils*.
6) *Single-phase liquid* concentrations, x_L, for *aqueous glycol* coils.

5.3.3 Range of Heat Transfer Variables

The heat transfer variables for the coil applications covered by this standard shall be evaluated for their effect on thermal performance by conducting *laboratory tests* and are described in Section 5.4.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

5.4 Minimum Requirements for Laboratory Tests for Coils with Smooth Tubes

Information contained in this section is for testing coils with *smooth tubes*. Refer to Section 5.5 for testing requirements of coils with *turbulators* or *internally grooved tubes*.

5.4.1 Air Velocity

All of the following *test series* for specific coil applications, except under Section 5.5.2.3, Section 5.4.5.3, Section 5.5.3, Section 5.5.2.4, and Section 5.6.2 shall be made with at least four different standard dry air face velocities, covering the complete rating range in equally spaced velocity increments on a logarithmic scale.

5.4.2 Air Pressure Drop

The coil air pressure drop for all dry and wet surface tests shall be recorded per ANSI/ASHRAE Standard 33-2016.

5.4.3 Steam Coils

The *steam coils test series* determines the variation in the overall thermal resistance, R, with the standard dry air face velocity, V_a, and to determine the steam pressure drop through the coil, Δp_v.

5.4.3.1 Steam Pressure

For any test, the inlet steam pressure shall be 13.8 to 69.0 kPag (2 to 10 psig) with an inlet steam superheat as specified in ANSI/ASHRAE Standard 33-2016.

5.4.3.2 Air Temperature

The entering air dry-bulb temperature shall not exceed 37.8°C (100°F).

Note: The conditions for determining ratings of *steam coils* should be:

t_{1db} = Entering air dry-bulb temperature = 15.6°C (60°F).

p_{v1} = Entering steam pressure = 34.5 kPag (5 psig).

5.4.4 Single-phase Liquid Coils

5.4.4.1 Tubeside Fluid

Water shall be used, if obtainable, as the tubeside fluid for all *single-phase liquid* tests in order to simplify the testing and data reduction procedure. If water is not obtainable an *aqueous glycol* shall be used.

5.4.4.2 Tubeside Fluid Velocity

For any test with *single-phase liquid coils* except under Section 5.5.2.3, Section 5.5.2.4, and Section 5.6.2, one *single-phase liquid* velocity inside tubes shall be used in the range from 0.91 to 1.83 m/s (3 to 6 ft/s).

5.4.4.3 Air-heating Coils

Hot *single-phase liquid air-heating coils* shall be subjected to a single *test series* for the purpose of determining the variation in the dry surface air film heat transfer coefficient, f_a, and air pressure drop, Δp_{sD}, with standard dry air face velocity, V_a (see Section 5.4.1, Section 5.4.2, and Section 5.4.4.1.). Alternatively, airside performance data from *steam coils* or sensible only air-cooling coils shall be used (see Table 2). If any hot *single-phase liquid air-heating coils* are tested, the temperature limitations in Section 5.6.1 apply and the tests shall be the same as those required in Section 5.5.2.2.

Note: The conditions for determining airside ratings of hot *single-phase liquid air-heating coils* should be:

t_{1db} = Entering air dry-bulb temperature = 15.6°C (60°F).

t_{L1} = Entering *single-phase liquid* temperature = 82.2°C (180°F).

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

Re_L = *Single-phase liquid* Reynolds Number ≥ 10000 (turbulent flow regime).

$t_{L1} - t_{L2}$ = *Single-phase liquid* temperature rise ≥ 2.8°C (≥ 5°F) at minimum air velocity.

5.4.4.4 Sensible Only Air-cooling Coils

For coils with *smooth tubes*, the *single-phase liquid* film heat transfer coefficient, f_L, is initially known and shall be calculated using equations in Section 6.2.3.3.1.2. For coils with *smooth tubes*, the *single-phase liquid* Darcy-Weisbach friction factor, f'_{DWL}, is initially known and shall be calculated using equations in Section 6.2.3.3.1.2. Therefore, only a single *test series* is required for the purpose of determining the variation in the dry surface air film heat transfer coefficient, f_a, and air pressure drop, Δp_{sD}, with standard dry air face velocity, V_a (see Section 5.4.1, Section 5.4.2, and Section 5.4.4.1.).

To assure completely dry airside surface, the entering *single-phase liquid* temperature, t_{L1}, for all tests shall be at least 1.7°C (3°F) greater than the entering air *dew point* temperature, t_{1dp}.

Note: The conditions for determining airside ratings of dry surface *single-phase liquid* sensible only air-cooling coils should be:

t_{1db} = Entering air dry-bulb temperature = 35°C (95°F).

t_{1wb} = Entering air wet-bulb temperature = 17.8°C (64°F).

t_{L1} = Entering *single-phase liquid* temperature = 7.2°C (45°F) (1.7°C [3°F]) above entering air *dew point* temperature).

Re_L = *Single-phase liquid* Reynolds Number ≥ 10000 (turbulent flow regime).

$t_{L2} - t_{L1}$ = *Single-phase liquid* temperature rise ≥ 2.8°C (≥ 5°F) at minimum air velocity.

5.4.4.5 Air-cooling and Dehumidifying Coils

Two *test series* shall be conducted.

5.4.4.5.1 Dry Surface Tests

If the *test coil* has not been previously tested per the requirements of Section 5.4.4.4, then those tests shall comprise the first *test series*. If the exact *test coil* has been tested per Section 5.4.4.4, then additional dry surface tests are not required.

5.4.4.5.2 Wet Surface Tests

The second *test series* shall be conducted on the exact coil used for the procedures in Section 5.4.4.5.1. The wet surface *test series* determines the completely wet surface air film heat transfer coefficients and air pressure drop.

5.4.4.5.2.1 Surface Condition

To determine air film heat transfer coefficients, f_a, and air pressure drop under completely wet surface conditions, each test shall be conducted with the entire airside surface actively condensing moisture. This operating condition exists when the airside surface temperature at all locations throughout the coil is below the entering air *dew point* temperature ($t_{s1} < t_{1dp}$).

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

5.4.4.5.2.2 Range of Variables

For each wet surface test, the range in each of the following design variables shall fall within the limits listed below:

t_{L1} = Entering *single-phase liquid* temperature: 1.7° to 12.8°C (35.0° to 55.0°F).

$t_{1db} - t_{1wb}$ = Entering wet-bulb depression ≥ 3.3°C (≥ 6.0°F).

q_s / q_t = Air sensible heat ratio ≤ 0.75.

$t_{2wb} - t_{L1} \geq 2.8$°C (≥ 5.0°F).

Note: The conditions for determining airside ratings of wet surface *single-phase liquid* air-cooling and dehumidifying coils should be:

t_{1db} = Entering air dry-bulb temperature = 26.7°C (80°F).

t_{1wb} = Entering air wet-bulb temperature = 21.7°C (71°F).

t_{L1} = Entering *single-phase liquid* temperature = 5.6°C (42°F) (13.9°C (25°F) below entering air *dew point* temperature).

Re_L = *Single-phase liquid* Reynolds Number ≥ 10000 (turbulent flow regime).

$t_{L2} - t_{L1}$ = *Single-phase liquid* temperature rise ≥ 2.8°C (≥ 5°F) at minimum air velocity.

5.4.5 Refrigerant Evaporator Coils

Complete testing, as outlined below, shall be conducted to establish ratings for each *refrigerant* and tube diameter. Three series of tests shall be run on the exact same prototype coil or coils.

5.4.5.1 Dry Surface Tests

If the *test coil* has not been previously tested per the requirements of Section 5.4.4.4, then those tests shall comprise the first *test series*. If the exact *test coil* has been tested per Section 5.4.4.4, then additional dry surface tests are not required.

5.4.5.2 Wet Surface Tests

If the *test coil* has not been previously tested per the requirements of Section 0, then those tests shall comprise the second *test series*. If the exact *test coil* has been tested per Section 5.4.4.5.2, then additional wet surface tests are not required.

5.4.5.3 Refrigerant Evaporator Coil Tests

The third *refrigerant evaporator coil test series* determines the *refrigerant* evaporating film heat transfer coefficients, f_r, as a function of *refrigerant* loading rate per tube circuit, q_t/N_c, and the *refrigerant* pressure drops through the coil tube circuits, Δp_{rc}, as a function of *refrigerant* mass flow rate per tube circuit, w_r/N_c. Using *refrigerant*, the third *test series* shall be conducted with at least two different lengths of *refrigerant* circuits for a given coil with the following *circuiting* arrangements:

5.4.5.3.1 Circuiting 1

A circuit whose length is not less than 50% of the maximum equivalent length used in the line of rated coils.

5.4.5.3.2 Circuiting 2

A circuit whose length is not greater than 33% of the length of *circuiting* 1 (Section 5.4.5.3.1).

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

5.4.5.3.3 Minimum Number of Tests Per Circuiting Arrangement

For each of the two *refrigerant* circuit lengths, a minimum of four tests are required. These four tests are to cover the complete range of *refrigerant* loading per circuit, q_t/N_c, in equal increments of capacity on a logarithmic scale, and shall be conducted with a constant liquid temperature in the range of 42.2° to 44.4°C (108°F to 112°F) entering the control device and with a maximum of 12.8°C (55°F) saturated *refrigerant* vapor temperature leaving coil suction header.

5.4.5.3.4 Evaluation

The above eight tests shall serve to evaluate the effects of *refrigerant* loading per circuit on both the coil circuit saturated *refrigerant* pressure drop and the *refrigerant* evaporating film heat transfer coefficient.

5.4.5.3.5 Air Velocity

For any test, the standard dry air face velocity, V_a, shall be between 0.51 to 4.06 standard m/s (100 to 800 standard ft/min).

5.4.5.3.6 Surface Condition

The surface shall be operated either completely dry ($t_{r2g} > t_{1dp}$ + 1.7°C (3°F)) or completely wet ($t_{s1} < t_{1dp}$) to simplify the data reduction procedure.

5.4.5.3.7 Range of Variables

For each wet surface test, the range in each of the following design variables shall fall within the limits listed below:

t_{r2g} = Saturated *refrigerant* vapor temperature leaving coil suction Header: 1.7° to 12.8°C (35.0° to 55.0°F).

$t_{1db} - t_{1wb}$ = Entering wet-bulb depression ≥ 3.3°C (≥ 6.0°F).

q_s/q_t = Air sensible heat ratio ≤ 0.75.

$t_{2wb} - t_{r1} \geq 2.8$°C (≥ 5.0°F) for counterflow coils.

$t_{2wb} - t_{r2g} \geq 2.8$°C (≥ 5.0°F) for parallel flow coils.

$t_{1db} - t_{r2g} - \Delta t_{r2g} \geq 2.8$°C (≥ 5.0°F).

5.4.5.3.8 Refrigerant Vapor Superheat Leaving Coil Suction Header

Refrigerant vapor superheat leaving coil suction header, for any test, shall be maintained per ANSI/ASHRAE Standard 33-2016 and shall not be less than 3.3°C (6°F).

Note: The conditions for determining tubeside ratings of dry surface *refrigerant* evaporator sensible only air-cooling coils should be:

t_{1db} = Entering air dry-bulb temperature = 35°C (95°F).

t_{1wb} = Entering air wet-bulb temperature = 17.8°C (64°F).

t_{r0} = Subcooled *refrigerant* liquid temperature entering liquid control device = 43.3°C (110°F).

t_{r2g} = Saturated *refrigerant* vapor temperature leaving coil suction header = 7.2° to 12.8°C (45° to 55°F) (minimum 1.7°C (3°F) above entering air *dew point* temperature).

Δt_{r2g} = *Refrigerant* vapor superheat leaving coil suction header = 5.6°C (10°F).

Note: The conditions for determining tubeside ratings of wet surface *refrigerant* evaporator air-cooling and dehumidifying coils should be:

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

t_{1db} = Entering air dry-bulb temperature = 26.7°C (80°F).

t_{1wb} = Entering air wet-bulb temperature = 21.7°C (71°F).

t_{r0} = Subcooled *refrigerant* liquid temperature entering liquid control device = 43.3°C (110°F).

t_{r2g} = Saturated *refrigerant* vapor temperature leaving coil suction header = 1.7° to 12.8°C (35° to 55°F).

Δt_{r2g} = *Refrigerant* vapor superheat leaving coil suction header = 5.6°C (10°F).

5.5 Minimum Requirements for Laboratory Tests for Coils with Turbulators or Internally Grooved Tubes

Information contained in this section is for *testing coils* with *turbulators* or *internally grooved tubes*. These tests determine the heat transfer and pressure drop characteristics of the non-smooth tubes since the information shown in Figure 3 is not valid for non-smooth tubes. Except for the use of non-smooth tubes, the *test coils* used in these *test series* shall be identical in design and arrangement to the *test coils* in Section 5.4.3 through Section 5.4.5.

5.5.1 Steam Coils

Tests shall be conducted as described in Section 5.4.3. The overall thermal resistance, R, and steam pressure drop through the coil, Δp_v, determined from this *test series* shall be used for rating coils with non-smooth tubes.

5.5.2 Single-phase Liquid Coils

Tests shall be conducted as described in Section 5.5.2.1.

5.5.2.1 Air-heating Coils, Sensible Only Air-cooling Coils, and Air-cooling and Dehumidifying Coils

In these individual tests, both the tubeside fluid and air film heat transfer coefficients, as a function of the respective fluid mass flow rate, are unknown. Two *test series* are required for this coil design. An *air-heating coil* or sensible only air-cooling coil shall be used for the testing. The temperature limitations in Section 5.6.1 apply for *air-heating coils*.

To assure completely dry airside surface, the entering *single-phase liquid* temperature, t_{L1}, for all tests shall be at least 1.7°C (3°F) greater than the entering air *dew point* temperature, t_{1dp}.

5.5.2.2 Test Series Number 1

A single *test series*, as described in Section 5.4.4.4 shall first be conducted on a coil whose design and arrangement are the same in all respects to the non-smooth design except that *smooth tubes* are used. This *test series* determines the variation in the dry surface air film heat transfer coefficient, f_{aD}, with standard dry air face velocity, V_a (see Sections 5.4.1, Section 5.4.2, and Section 5.4.4.1).

5.5.2.3 Test Series Number 2

A single *test series* shall be conducted on a coil whose design and arrangement are the same as the rated design including internal tube geometry. This *test series* determines the tubeside *single-phase liquid* heat transfer and pressure drop performance data.

A minimum of eleven tests shall be conducted to define the Colburn-*j* heat transfer factor, j_L and Darcy-Weisbach friction factor, f'_{DWL}, similar to that shown in Figure 3. Four test points shall be at Re_L below 2100, three test points shall be at Re_L between 2100 and 7000, and four test points shall be at Re_L above 7000. All tests shall be conducted at one standard dry air face velocity between 1.02 to 4.06 standard m/s (200 and 800 standard ft/min).

Note: A high standard dry air face velocity and close *fin spacing* should be used for accuracy reasons.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

These tests shall be conducted using a base coil with L_s/D_i ratio between 30 and 90. Ratings for the range of Re_L between 700 and 7000 shall be based upon the L_s/D_i ratio to the -0.33333 power in the laminar flow region.

For each of the test points above, the *single-phase liquid* pressure drop shall be recorded to verify the Darcy-Weisbach friction factor f'_{DWL} determined from the isothermal pressure drop test (see Section 5.5.2.4).

A second *test series* may be conducted on a non-smooth tube coil whose design and arrangement are the same as the first coil tested in *test series* Number 2, but with a different straight tube length per pass, L_s. This *test series* enable the determination of the L_s/D_i exponent in the laminar region ($Re_L < 2100$). A minimum of seven tests shall be conducted to define the Colburn-*j* heat transfer factor, j_L, and Darcy-Weisbach friction factor, f'_{DWL}, to that shown in Figure 3. Four test points shall be at Re_L below 2100 and three test points shall be at Re_L between 2100 and 7000. The L_s/D_i exponent determined from the two *test coils* in the laminar region ($Re_L < 2100$) may then be used for rating purposes. The last three points ($2100 \leq Re_L < 7000$) are used to define the transition region.

5.5.2.4 Isothermal Pressure Drop for Single-phase Liquid Coils

For each *test coil* tested in Section 5.5.2.3, the *single-phase liquid* pressure drop through the coil shall be determined under isothermal operating conditions. Conduct at least four tests at Re_L below 1000, at least four tests at Re_L between 1000 and 4000, and at least four tests at Re_L above 4000. Testing shall be conducted to cover the complete rating range of Re_L in equally spaced increments on a logarithmic scale for each of the three ranges described above. For each of the test points above, the *single-phase liquid* pressure drop shall be recorded to enable determination of the Darcy-Weisbach friction factor, f'_{DWL}.

5.5.3 Refrigerant Evaporator Coils

Tests requirements are identical to those in Section 5.4.5.1 and Section 5.4.5.2 except that the *test coil* for Section 5.4.5.3 shall use non-smooth tubes, but otherwise have the same design and arrangement as the coil used in Section 5.4.5.1 and Section 5.4.5.2.

5.6 Requirements for Optional Laboratory Tests

If a manufacturer performs optional *laboratory tests*, beyond those required in Table 2, testing shall be conducted in accordance with the provisions of this section.

5.6.1 Single-phase Liquid Air-heating Coils

The difference between the entering *single-phase liquid* temperature, t_{L1}, and the entering air dry-bulb temperature, t_{1db}, shall be at least 26.7°C (80°F), and the *single-phase liquid* and airside conditions shall be within the range of Table 1.

5.6.2 Isothermal Single-phase Liquid Pressure Drop

For each *single-phase liquid coil* tested, the *single-phase liquid* pressure drop through the coil shall be determined under isothermal operating conditions. Testing shall be conducted with at least four different *single-phase liquid* velocities, covering the complete rating range of *single-phase liquid* velocity inside tubes in equally spaced increments on a logarithmic scale. The results of this test shall be used with the Darcy-Weisbach friction factor for the tube in the *test coils* to verify manufacturer established *single-phase liquid* pressure drop of tubeside coil attachments, $\Delta p_{L\,ATT}$.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils

5.7 Changes to Established Coil Line Ratings

5.7.1 Changes Requiring Calculated Verification of Ratings (No Additional Laboratory Tests)

After establishing the original *standard ratings*, one or more of the following changes can be made or offered as an option in a *coil line* without changing *published ratings*, provided that the calculated influence of any or all of these changes does not reduce the capacity to less than 97.5% of the corresponding *standard ratings* and does not increase the calculated pressure drop to more than 105.0% of the corresponding *standard ratings*. The next version of *published ratings* shall reflect the calculated influence of these changes.

1) Copper *fin* thickness can be decreased up to 30% below aluminum *fin* thickness for dry surface coils.
2) *Fin* thickness increase.
3) Tube wall thickness.
4) Tube material, limited to materials listed in Table 5.

If the calculated capacity is less than 97.5% or the calculated pressure drop is greater than 105.0%, new ratings shall be published.

5.7.2 Changes Requiring Additional Laboratory Tests

After establishing the original *standard ratings*, one or more of the following changes can be made or offered as an option in a *coil line* provided a sensible only air-cooling coil or *air-heating coil test series* of four standard dry air face velocities is run and the test capacities are not less than 97.5% of the corresponding *standard ratings*:

1) *Fin* material other than copper or aluminum
2) Method of *fin*-to-tube bonding
3) Tube material other than as provided in Table 5
4) *Fin* thickness decrease

If the test capacities are less than 97.5% of *standard ratings*, or if other changes such as tube outside diameter, tube spacing, *fin* configuration, tube internal surface, or tube arrangement are made, a complete set of *laboratory tests* shall be run, and *published ratings* shall be changed accordingly. If the air pressure drops are greater than 105% of *standard ratings*, a series of air pressure drop tests shall be run and ratings shall be published accordingly.

Section 6. Rating Requirements

6.1 Ratings

Ratings for *forced-circulation air-cooling and air-heating coils* consist of *standard ratings* used in the selection or application of coils. Ratings can be given for a range of conditions encountered, so that the rating at any selected condition can be selected directly or by interpolation.

1) Ratings shall include performance characteristics produced under specified conditions or means for calculating specific coil requirements.
2) Ratings shall be presented in the form of curves, tables, charts, or automated rating/selection computer procedures.
3) Ratings shall be developed using basic performance characteristics obtained from *laboratory tests* in accordance with this standard.

6.2 Heat Transfer Equations for Laboratory Test Reduction and for Ratings

6.2.1 Initial Test Data Reduction Procedure

The initial test data reduction procedure and calculations for the determination of the parameters listed below are given in ANSI/ASHRAE Standard 33-2016 for *air-heating coils*, sensible only air-cooling coils, and air-cooling and dehumidifying coils.

Documents
Document Sharing Hub
Full document details: AHRI Standard 410-2023 - Performance Rating of Forced-circulation Air-cooling and Air-heating Coils