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Specification for

Air heating and cooling coils —

Part 1: Method of testing for rating of
cooling coils

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- Manufacturers' Association of Radiators and Convectors
- Oil Appliance Manufacturers' Association
- Unit Heater Manufacturers' Association

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Foreword

This Part of this British Standard has been prepared under the authority of the Refrigeration, Heating and Air Conditioning Industry Standards Committee in response to requests from industry.

The Committee acknowledge their debt to the Heating and Ventilating Research Association for the Association's work in formulating the methods of testing that appear in this standard.

This Part is the first of a series concerned with air heating and cooling coils.

It is intended to issue further Parts which will deal with methods of testing for rating of heating coils, with air cooling coils for chilled water and for direct expansion, and with construction and safety aspects of heating and cooling coils.

Where reference is made to British Standards for which no metric version is available then the appropriate British Standard in imperial units shall be used in conjunction with BS 350 "*Conversion factors and tables*"; attention is also drawn to BS 3763 "*The International System of units (SI)*".

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 50, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

0 Introduction

The principal complexities in testing cooling coils arise from

- a) small water temperature differences;
- b) the accuracy of measurement of air wet-bulb temperature near saturation;
- c) the non-uniform air temperature and non-uniform humidity profiles off the coil.

a) and b) can be overcome either by specifying sophisticated instrumentation or by the careful use of simple instruments, e.g. thermocouple and mercury in glass thermometer; the latter alternative has been adopted in this standard, errors being assessed by an overall heat balance. The non-uniform off-coil conditions can only be overcome by adequate air mixing and suitable mixers have therefore been specified.

In this standard fairly tight tolerances have been applied to the definition of steady state conditions. The tight tolerances are to allow for the probability of small water temperature differences and for the large effect of a small air wet bulb temperature change on the air total heat and dew point. The duration of the test period has been chosen to ensure an accurate average heat transfer figure.

The wide range of cooling coils produced by any one manufacturer makes it desirable that testing is carried out only on a relatively small number of representative coils. Such a technique is already in existence for hot water air heater batteries (see BS 3208) where a representative coil is defined as one having the same water tube arrangement, number of circuits, fin type and spacing as the coils in the production range.

It is logical to apply the same principle to cooling coils. However, the effect of dehumidification cannot be ignored and consequently the method of analysis employed for cooling coils is considerably more complex than that given for heating coils in BS 3208. The method of analysis used in this standard is based upon that given in ARI¹⁾ Standard 410-64, "*Standard for forced-circulation air-cooling and air-heating coils*", as this is considered to be the most satisfactory method available at present.

Tests have to be carried out on coils with both dry and fully wet surfaces in order to obtain the air-side thermal resistances. This data is then used to obtain the heat transfer, both latent and sensible, for a wide range of entering air conditions.

1 Scope

This standard gives a method of testing for rating of duct-mounted air cooling coils, with chilled water as the cooling medium, within the following range of variables:

- Inlet air temperature: below 40 °C
- Inlet water temperature: 2 °C to 20 °C
- Inlet air wet bulb depression: greater than 4 °C
- Sensible heat ratio (Q_s/Q_T): less than 0.8 (for dehumidifying coils)
- Water flow: Reynolds number above 3 100
- Air velocity at coil face: 1 m/s to 4 m/s

2 References

The titles of the British Standards referred to in this standard are listed on the inside back cover.

3 Definitions

For the purpose of this standard, the following definitions apply:

3.1

cooling coil

a water-to-air heat exchanger of the tubular type through which air is passed by mechanical means over the external surface; such as is normally connected into a system of ventilation ductwork

in this British Standard, the heat exchanger surface considered is of the extended surface, externally finned type

¹⁾ Air Conditioning and Refrigeration Institution, Arlington, Virginia, USA.

3.2**reference air conditions**

temperature: 20 °C, absolute pressure: 1.013 bar ²⁾, relative humidity: 43 %, density: 1.200 kg/m³

3.3**rows**

the number of banks of tubes in the direction of the air flow (see Figure 1)

3.4**passes**

the number of times the water in any one circuit crosses the air flow (see Figure 2)

3.5**similar coils**

a range of similar coils is defined as coils having the same:

- a) water tube size, spacing, arrangement (in-line or staggered, see Figure 2) and internal construction;
- b) fin type, construction and spacing (see Figure 3);
- c) water flow geometry, i.e. the general method of combining rows and circuits shall be the same for all coils in the range.

3.6**turbulator**

a device inside a tube for increasing the turbulence and heat transfer

4 Nomenclature

Symbol	Description	Units
A_{dc}	Calculated dry coil external surface area	m ²
A_{De}	Surface area of ductwork between inlet sampling tube and centre of coil	m ²
A_{Do}	Surface area of ductwork between outlet sampling tube and centre of coil	m ²
A_F	Coil face area	m ²
A_i	Coil internal surface area ($N_t \pi d_i l_t 10^{-3}$)	m ²
A_o	Coil external surface area ($A_p + A_s$)	m ²
A_{oc}	Calculated coil external surface area	m ²
A_p	Area of exposed tubes	m ²
A_s	Total surface area of coil fins (both sides) ^a	m ²
A_t	Cross-sectional area of coil tube	m ²
A_{wc}	Calculated wet coil external surface area	m ²
B	Coil surface area ratio (A_o/A_i)	—
C	Thermal resistance ratio	kg K/kJ
c_{pa}	Specific heat capacity of moist air	kJ/(kg K)
c_{pw}	Specific heat capacity of water	kJ/(kg K)
c_{pam}	Specific heat capacity of air at mean air temperature	kJ/(kg K)
c_{pwm}	Specific heat capacity of water at mean water temperature	kJ/(kg K)
C_o	Heat transfer exponent	
d_i	Tube internal diameter	mm

^a For A_s , total surface area of coil fins, where fin collars are employed, the collar is taken as part of the exposed tube area.

²⁾ 1 bar = 10⁵ N/m² = 100 kPa.

Symbol	Description	Units
d_o	Tube external diameter	mm
E	Effectiveness	—
F	Factor for corrected logarithmic mean temperature	—
f_a	Air side heat transfer coefficient	W/(m ² K)
f_w	Water side heat transfer coefficient	W/(m ² K)
f_{ws}	Water side heat transfer coefficient for smooth bore tubes	W/(m ² K)
f_{wt}	Water side heat transfer coefficient for tubes fitted with turbulators	W/(m ² K)
g	Acceleration due to gravity	m/s ²
h_{ai}	Enthalpy of inlet air	kJ/kg dry air
h_{aic}	Corrected enthalpy of inlet air	kJ/kg dry air
h_{ao}	Enthalpy of outlet air	kJ/kg dry air
h_{aoc}	Corrected enthalpy of outlet air	kJ/kg dry air
h_{si}	Enthalpy of saturated air at coil surface temperature at air inlet	kJ/kg dry air
h_{so}	Enthalpy of saturated air at coil surface temperature at air outlet	kJ/kg dry air
h_{am}	Mean air enthalpy ($h_{aic} + h_{aoc}$)/2	kJ/kg dry air
h_{sm}	Enthalpy of saturated air at mean coil surface temperature	kJ/kg dry air
h_{sD}	Enthalpy of saturated air at inlet air dew point	kJ/kg dry air
h_B	Enthalpy of air at wet/dry boundary	kJ/kg dry air
h_s	Enthalpy of saturated air at apparatus dew point	kJ/kg dry air
Δh_m	Log mean enthalpy difference	kJ/kg dry air
k	Thermal conductivity of insulating material	W/(m K)
K_i	Air inlet section heat leakage coefficient	kW/K
K_o	Air outlet section heat leakage coefficient	kW/K
K_w	Hydraulic pressure drop correction factor	—
k_t	Thermal conductivity of tube wall material	W/(m K)
k_f	Thermal conductivity of fin material	W/(m K)
l_e	Length of one complete water circuit ($l_i = N_t l_t / N_c$)	m
l_t	Length of each water tube (one pass)	m
M	Air-to-water side heat capacity ratio	—
m_a	Air mass flow rate	kg/s
m_w	Water mass flow rate	kg/s
N	Number of rows in coil	—
N_c	Number of circuits	—
N_m	Number of rows in test coil	—
N_n	Number of rows in n row coil	—
N_t	Number of tubes in coil	—
P_b	Barometric pressure	bar ^a
P_F	Static pressure upstream of flow meter	Pa
ΔP_{sn}	Static pressure drop for n row coil	Pa

^a 1 bar = 10⁵ N/m² = 100 kPa.

Symbol	Description	Units
Δp_c	Coil air side pressure drop	Pa
Δp_{cr}	Coil air side pressure drop corrected to reference density	Pa
Δp_F	Air flow meter pressure drop	Pa
Δp_w	Hydraulic pressure drop (measured)	Pa
Δp_{wc}	Hydraulic pressure drop corrected for head differences between coil inlet and outlet	Pa
Δp_{wct}	Hydraulic pressure drop at reference temperature	Pa
Q	Heat transferred	kW
Q_s	Mean sensible heat transferred	kW
Q_{as}	Sensible heat transferred on air side	kW
Q_{aT}	Total heat transferred on air side	kW
Q_T	Mean total heat transferred	kW
Q_w	Heat transferred on water side	kW
R	Overall thermal resistance	m ² K/W
R_{ad}	Air film thermal resistance for a dry surface	m ² K/W
R_{aw}	Air film thermal resistance for a moist surface	m ² K/W
R_f	Fin thermal resistance	m ² K/W
R_{md}	Dry metal thermal resistance	m ² K/W
R_t	Tube wall thermal resistance	m ² K/W
R_w	Water film thermal resistance (based on A_o)	m ² K/W
t_a	Ambient temperature, (dry bulb)	°C
t_{ad}	Apparatus dew point	°C
t_{ai}	Inlet air temperature, (dry bulb)	°C
t_{ao}	Outlet air temperature, (dry bulb)	°C
t_{aic}, t_{aoc}	t_{ai} and t_{ao} corrected for heat losses	°C
t'_{ai}	Inlet air temperature, (wet bulb)	°C
t'_{ao}	Outlet air temperature, (wet bulb)	°C
t_D	Inlet air dew point	°C
t_F	Flow meter temperature, (dry bulb)	°C
t'_F	Flow meter temperature, (wet bulb)	°C
t_{si}	Coil surface temperature at inlet	°C
t_{so}	Coil surface temperature at outlet	°C
t_{sm}	Mean coil surface temperature	°C
t_{wi}	Inlet water temperature	°C
t_{wo}	Outlet water temperature	°C
t_{wm}	Mean water temperature; $(t_{wi} + t_{wo})/2$	°C
Δt_m	Corrected logarithmic mean temperature difference between air and water	°C

Symbol	Description	Units
V_r	Air volume flow rate corrected to reference air density; the reference air density is 1.2 kg/m ³	m ³ /s
v_r	Air velocity at reference conditions	m/s
v_w	Mean water velocity	m/s
ΔW	Change in moisture content across coil	kg/kg dry air
X_b	Inner radius of annular fin	mm
X_e	Outer radius of annular fin	mm
Y_f	Fin thickness	mm
Y_i	Thickness of insulating material	mm
y	Factor defined in B.2	kg K/kJ
Z	Ratio of slope of saturated air enthalpy curve to specific heat capacity of moist air	—
Greek Symbols		
β	Bypass factor	—
γ, δ	Parameters defined in 12.1.1.2	—
η	Surface effectiveness	—
ϕ	Fin efficiency	—
ρ	Density	kg/m ³
ρ_r	Reference air density (1.2 kg/m ³)	kg/m ³
Subscripts		
a	air; apparatus	
B	boundary	
b	barometric; inner radius (of fin)	
c	calculated; circuits; corrected	
D	dew point; duct	
De, Da	duct dimensions	
e	outer radius (of fin)	
F	face; flow meter	
f	fin	
i	inlet; insulating; internal	
m	mean; metal; number of rows in test coil	
n	a number	
o	external; outlet	
p	exposed tubes; pressure	
r	reference condition(s)	
s	saturated; sensible heat; smooth; surface	
t	reference temperature; tube(s); turbulator	
T	total	
w	water; wet	

5 Instrumentation

5.1 Temperature

5.1.1 The measurement of temperature shall comply with the requirements of BS 1041. If liquid in glass thermometers are used, they shall be graduated in intervals not exceeding 0.1 °C, and shall comply with the requirements of BS 593, partial immersion ranges. All temperature measuring instruments shall be calibrated, against an NPL calibrated thermometer, to a precision of 0.1 °C.

5.1.2 The entry and exit water temperature shall be measured by means of instruments inserted into oil filled pockets similar to those shown in Figure 4.

5.1.3 For water temperature differences below 5 °C it will be necessary to take special care and the differential thermocouple system shown in Figure 5 is recommended. A separate measurement of inlet water temperature will be required.

Where a differential thermocouple system is employed, then the differential in millivolts shall be divided by half the number of junctions (i.e. 3 in the case of that shown in Figure 5), and added to or subtracted from the relevant measured temperature (converted to millivolts if measured by a direct reading instrument).

5.1.4 The entry and exit air wet bulb and dry bulb measurements shall be made by means of the system given in BS 4194:1967 (Appendix D). The measurement system shall be connected to sampling tubes similar to those shown in Figure 6.

5.2 Water flow measurement. The measurement of water flow should preferably be by means of direct weighing (although one of the methods described in BS 1042 may be used). The water leaving the test rig shall be collected in vessels of known weight, and weighed to an accuracy of 0.1 % over the range of the weights used in the test. The weight of each vessel used shall not exceed 50 % of its normal contents. The net weight of each charge shall be recorded by weighing the vessel both after emptying the previous charge and after filling.

5.3 Air flow measurement

5.3.1 Air flow measurement shall be in accordance with BS 1042-1 or, alternatively, a flow meter may be calibrated in-situ by the method given in BS 1042-2.

5.3.2 Leakage flow rates may be measured by means of a calibrated variable area flow meter or integrating air volume flow meter, see Figure 7.

5.4 Pressure measurement

5.4.1 Wall static pressures shall be measured with static taps complying with the specifications laid down in BS 1042-2. A minimum of four taps shall be symmetrically disposed about the duct walls and connected to form a piezometric ring.

5.4.2 Manometers shall have scale intervals no greater than 2 % of the indicated reading, with the exception of pressure below 50 Pa, in which case the maximum intervals shall be 1 Pa.

5.4.3 An inverted U-tube manometer, similar to that shown in Figure 10, shall be employed for the measurement of hydraulic pressure drop.

5.4.4 The minimum differential pressures for flow measurement shall be a) 25 Pa for inclined U-tube manometers and micro-manometers and b) 500 Pa for vertical U-tube manometers.

6 Air flow leakage test

The heat transfer tests described in this standard are to be carried out on coils that have been sealed against air flow leakage; this will not, however, always be the case in practice and consequently it is necessary to carry out air flow leakage tests to indicate possible degradation of coil heat transfer performance.

6.1 A standard coil shall be connected to an air supply system similar to one of those shown in Figure 7.

6.2 The air supply pressure shall be increased to that desired for the test and held for a minimum period of 15 min and then reduced to zero. The supply pressure shall then be increased to the previous level and held constant for a further 15 min, at the end of which the air flow rate shall be read and recorded as the coil leakage flow rate at the test pressure.

NOTE If an integrating flow meter is employed measurement may commence 10 min after the second pressurization.

7 Test apparatus

7.1 Waterside

7.1.1 There shall be available a means for providing and controlling a continuous supply of water at any temperature and flow rate that are required for the test. Suitable arrangements of equipment are shown in Figure 8 and Figure 9.

7.1.2 The pipe work shall be arranged to give an unobstructed straight run at entry and exit from the coil under test, the pipe diameter being equal to that demanded by the unit connections and of a length equal to five pipe diameters. The thermometer pockets shall be positioned such that the water flow is towards the base of the pocket, as indicated by the arrows in Figure 4.

7.1.3 Side wall tapplings for measuring the hydraulic pressure drop shall be fitted adjacent to the connections to the coil. These tapplings shall be as specified in Figure 10 and connected to form a piezometer ring.

7.1.4 The lengths of pipe between the temperature measurement positions, the coil connections and the coil casing shall be insulated with at least 40 mm thickness of insulating material having a thermal conductivity not exceeding 0.06 W/(m K)

7.2 Air side

7.2.1 The test coil shall be connected to an air supply and measuring system similar to that shown in Figure 11, the flow metering system being located downstream of the coil under test.

7.2.2 The air velocity, temperature and humidity profiles at the sampling tubes shall be uniform (to within 5 %) and therefore, mixers similar to those shown in Figure 12 shall be employed, together with the flow straightener, gauze screens, and changes in section indicated in Figure 11.

NOTE It is recommended that the profiles at the inlet and outlet sampling tubes are checked during the assembly of the test rig as any large deviations from the mean may give rise to difficulty in obtaining a heat balance. The outlet conditions should also be checked before the flow metering system is connected.

7.2.3 The test coil and ductwork between the inlet and outlet sampling tubes shall be insulated with at least 50 mm thickness of insulating material having a thermal conductivity not exceeding 0.06 W/(m K). Ductwork between the sampling tubes shall be constructed from metal and ductwork from the inlet sampling tube to the flow meter shall be sealed against air leaks. The test coil shall be sealed against air leakage and fitted with condensate drains.

NOTE If the ductwork between the outlet sampling tube and the flow meter is of non-absorbent material then it will not be necessary to measure the wet bulb temperature at the flow meter.

8 General test instructions

8.1 The coil condensate drains shall be connected to a condensation collection system similar to that shown in Figure 13. Care shall be taken to ensure that:

- a) the tubes containing the sealing water do not rise above the level of the bottom of the coil drain tray;
- b) there is a sufficient head of water within the drain tubes to prevent air leakage.

8.2 If the test is to be on a dry coil surface then the inlet air dew point shall not be higher than the entering water temperature.

8.3 Before commencing the test

- a) bleed the water supply system to remove all air;
- b) start the air supply system and set the desired flow rate;
- c) circulate the water through the coil and regulate the flow and temperature to those desired for the test;
- d) set the required air inlet temperature and humidity.

8.4 The test shall be carried out under steady state conditions. These shall be said to exist when the following measurements do not vary by more than the specified amounts from their mean value over a period of 60 min; readings being taken at 15 min intervals, or alternatively, using a data logger.

- a) Inlet air temperature, dry bulb ± 0.1 °C
wet bulb ± 0.1 °C
- b) Inlet water temperature ± 0.1 °C
- c) Water flow rate ± 1 %
- d) Air flow rate ± 1 %

For wet coil tests, the condensate shall be seen to be flowing into the collecting vessel(s) indicated in Figure 13.

NOTE It is unlikely that the condensate will be discharged at a uniform rate. The form of discharge is likely to be periodic and if possible at least one cycle should be allowed to elapse before commencing testing.

8.5 The test shall occupy not less than 60 min, and complete sets of data shall be taken at intervals not exceeding 10 min with the exception of barometric pressure and ambient temperature which shall be recorded at start and finish. During the test, the mean values shall not vary by more than those for the steady state conditions (see 8.4). A complete set of data shall comprise:

Symbol	Description	Units
t_{wi}	is the inlet water temperature	°C
t_{wo}	is the outlet water temperature	°C
t_{ai}	is the inlet air temperature, (dry bulb)	°C
t'_{ai}	is the inlet air temperature, (wet bulb)	°C
t_{ao}	is the outlet air temperature, (dry bulb)	°C
t'_{ao}	is the outlet air temperature, (wet bulb)	°C
Δp_c	is the coil air side pressure drop	Pa
Δp_F	is the air flow meter pressure drop	Pa
p_F	is the static pressure upstream of flow meter	Pa
t_F	is the flow meter temperature, (dry bulb)	°C
t'_F	is the flow meter temperature, (wet bulb)	°C
m_w	is the water flow rate from weighing or pressure drop measurements	kg/s
Δp_w	is the hydraulic pressure drop	Pa
p_b	is the barometric pressure	bar ^a
t_s	is the ambient temperature, (dry bulb)	°C

^a 1 bar = 10⁵ N/m² = 100 kPa.

8.6 The test measurements shall be averaged and the mean values used in all computations.

9 Calculations

9.1 Water side heat transfer. The heat transferred to the water shall be computed from the equation:

$$Q_w = m_w c_{pw} (t_{wo} - t_{wi}) \text{ (kW)}$$

where

- m_w is the water mass flow rate (kg/s) obtained by direct weighing or by means of a flow meter
- c_{pw} is the specific heat capacity of water at $(t_{wo} + t_{wi})/2$ [kJ/(kg K)]
- t_{wi} is the inlet water temperature (°C)
- t_{wo} is the outlet water temperature (°C)

9.2 Air side heat leakage

9.2.1 The heat leakage, coefficients K_i , K_o , (kW/K) for the sections between the inlet air temperature measuring station and the coil centre, and the coil centre and outlet air temperature measuring station respectively shall be computed from the equations:

$$\text{Inlet section: } K_i = A_{De} k / Y_i \text{ (kW/K)}$$

$$\text{Outlet section: } K_o = A_{Do} k / Y_i \text{ (kW/K)}$$

where

- A_{De} is the surface area of ductwork between inlet sampler and centre of coil (m²)
- A_{Do} is the surface area of ductwork between outlet sampler and centre of coil (m²)
- Y_i is the thickness of insulating material (mm)
- k is the thermal conductivity of insulating material [W/(mK)]

9.2.2 The following corrections shall be made for heat losses and gains to the air passing through the test coil:

Inlet air enthalpy at coil

$$h_{aic} = h_{ai} + \frac{K_i(t_a - t_{ai})}{m_a} \text{ (kJ/kg (dry air))}$$

Inlet air temperature (dry bulb) at coil

$$t_{aic} = t_{ai} + \frac{K_i(t_a - t_{ai})}{m_a c_{pa}} \text{ (}^\circ\text{C)}$$

Outlet air enthalpy at coil

$$h_{aoc} = h_{ao} - \frac{K_o(t_a - t_{ao})}{m_a} \text{ (kJ/kg (dry air))}$$

Outlet air temperature (dry bulb) at coil

$$t_{aoc} = t_{ao} - \frac{K_o(t_a - t_{ao})}{m_a c_{pa}} \text{ (}^\circ\text{C)}$$

where

- h_{aic} is the corrected enthalpy of inlet air [kJ/kg (dry air)]
- h_{ai} is the enthalpy of inlet air [kJ/kg (dry air)]
- K_i is the air inlet section heat leakage coefficient (kW/K)
- t_a is the ambient temperature (dry bulb) ($^\circ\text{C}$)
- t_{ai} is the inlet air temperature (dry bulb) ($^\circ\text{C}$)
- m_a is the air mass flow rate (kg/s)
- t_{aic} is the inlet air temperature (dry bulb) corrected for heat losses ($^\circ\text{C}$)
- C_{pa} is the specific heat capacity of moist air [kJ/(kg K)]
- h_{aoc} is the corrected enthalpy of outlet air [kJ/kg (dry air)]
- h_{ao} is the enthalpy of outlet air [kJ/kg (dry air)]
- K_o is the air outlet section heat leakage coefficient (kW/K)
- t_{ao} is the outlet air temperature (dry bulb) ($^\circ\text{C}$)
- t_{aoc} is the outlet air temperature (dry bulb) corrected for heat losses ($^\circ\text{C}$)

9.2.3 If the total heat leakage is less than 1 % of the test coil capacity (Q_w), no correction is necessary.

NOTE Air mass flow rate. The air mass flow rate shall be calculated from the flow meter calibration with the air density obtained from the barometric pressure, upstream static pressure, the wet and dry bulb temperatures at the flow meter. If, however, the duct between the flow meter and the off-coil sampling tube is constructed from a non-water-absorbing material, the necessary moisture content may be obtained from the off-coil measurements.

9.3 Air side sensible and total heat transfer

9.3.1 Sensible heat transferred

$$Q_{as} = m_a c_{pa} (t_{aic} - t_{aoc}) \text{ (kW)}$$

9.3.2 Total heat transferred

$$Q_{aT} = m_a(h_{aic} - h_{aoc}) - m_a c_{pw} \Delta W t'_{ao} \text{ (kW)}$$

where

- Q_{as} is the sensible heat transferred on air side (kW)
- m_a is the air mass flow rate (kg/s)
- c_{pa} is the specific heat capacity of moist air [kJ/(kg K)]
- t_{aic} is the inlet air temperature (dry bulb) corrected for heat losses (°C)
- t_{aoc} is the outlet air temperature (dry bulb) corrected for heat losses (°C)
- Q_{at} is the total heat transferred on air side (kW)
- h_{aic} is the corrected enthalpy of inlet i [kJ/kg (dry air)]
- h_{aoc} is the corrected enthalpy of outlet air [kJ/kg (dry air)]
- pw is the specific heat capacity of water [kJ/(kg K)]
- ΔW is the change in moisture content across coil [kg/kg (dry air)]
- t'_{ao} is the outlet air temperature (wet bulb) (°C)

9.4 Mean heat transfer

For sensible cooling only $-(Q + Q_{as})/2$ (kW)

For sensible and latent cooling $Q_T (Q_w + Q_{aT})/2$ (kW)

where

- Q_s is the mean sensible heat transferred (kW)
- Q_w is the heat transferred on water side (kW)
- Q_{as} is the sensible heat transferred on air side (kW)
- Q_T is the mean sensible heat transferred (kW)
- Q_{aT} is the total heat transferred on air side (kW)

9.5 Heat balance

A test shall be void if the ratios:

Q_w/Q_{as} or Q_w/Q_{aT} are outside the limiting values 0.95 and 1.05

where

- Q_w is the heat transferred on water side (kW)
- Q_{as} is the sensible heat transferred on air side (kW)
- Q_{aT} is the total heat transferred on air side (kW)

9.6 Hydraulic pressure drop. The hydraulic pressure drop shall be corrected for any height (static head) difference between measuring points.

9.7 Air side pressure drop. The air mass flow rate shall be converted to the air volume flow rate (V_r) at reference conditions by the equation:

$$V_r = m_a / \rho_r = m_a / 1.2 \text{ (m}^3\text{/s)}$$

and the pressure drop converted by the equation:

$$\Delta p_{cr} = \rho_a \Delta p_c / \rho_r = \rho_a \Delta p_c / 1.2 \text{ (Pa)}$$

where

V_r is the air volume flow rate corrected to reference air density (m^3/s)

m_a is the air mass flow rate (kg/s)

ρ_r is the reference air density (1.2 kg/m^3)

Δp_{cr} is the coil air side pressure drop corrected to reference density (Pa)

ρ_a is the air density (kg/m^3)

Δp_c is the coil air side pressure drop (Pa)

10 Requirements for rating tests

10.1 To establish ratings for similar coils (see 3.5), having four or more rows, the test coil shall have a minimum of four rows.

If the ratings are required for 1, 2 or 3 row coils, then separate tests shall be carried out on similar coils (see 3.5) with the appropriate number of rows.

All test coils shall have a minimum face area of 0.5 m^2 .

10.2 The tests shall be carried out within the range of variables given in clause 1. For values of variables outside this range, further tests will be required.

11 Tests required for establishing a rating

The following tests shall be made.

11.1 Heat transfer Both sensible and latent cooling tests shall be made at one water velocity and a minimum of four air flow rates spaced approximately at equal logarithmic intervals throughout the required flow range.

Latent cooling tests shall be on a coil with a fully wet surface.

NOTE A fully wet coil condition can only be confirmed from the analysis of the test data.

11.2 Air side static pressure drop. The air side static pressure drop shall be measured during each heat transfer test.

11.3 Hydraulic pressure drop. The hydraulic pressure drop shall be measured during each heat transfer test. An additional series of measurements shall be carried out on one coil at a minimum of four water velocities covering the manufacturer's recommended range of water velocities. These measurements may be carried out without a thermal load. The water temperatures shall be recorded.

11.4 Air flow leakage. A 4 row coil shall be tested for air leakage. Tests shall be carried out at a minimum of four static pressures, spaced at equal logarithmic intervals, up to $1\,500 \text{ Pa}$ or the manufacturer's maximum recommended working pressure, whichever is the greater. The leakage flow rate per coil tube shall be plotted against static pressure on logarithmic graph paper. It will be possible to obtain the approximate leakage flow for any coil in the range from this graph.

12 Heat transfer calculations

The heat transferred from a coil surface is related to the fluid and coil properties by the equations:

$$Q_s = \frac{A_o \Delta t_m \times 10^{-3}}{R_{ad} + R_{md} + R_w}, \text{ for a dry coil surface (kW)}$$

$$Q_T = \frac{A_o \Delta h_m \times 10^{-3}}{c_{pa} R_{aw}}, \text{ for a wet coil surface (kW)}$$

where

Q_s is the mean sensible heat transferred (kW)

Q_T is the mean total heat transferred (kW)

A_o	is the coil external surface area ($A_p + A_s$) (m^2)
A_p	is the area of exposed tubes (m^2)
A_s	is the total surface area of coil fins (both sides) (m^2)
R_{ad}	is the dry air film thermal resistance (m^2 K/W)
R_{md}	is the dry metal thermal resistance (m^2 K/W)
R_w	is the water film thermal resistance (based on A_o) (m^2 K/W)
Δt_m	is the corrected logarithmic mean temperature difference between air and water (see 12.3) ($^{\circ}C$)
c_{pa}	is the specific heat capacity of moist air [kJ/(kg K)]
R_{aw}	is the air film thermal resistance for a moist surface (m^2 K/W)
Δh_m	is the logarithmic mean enthalpy difference between the inlet air and the enthalpy of saturated air at the coil surface temperature (see 12.4) [kJ/kg (dry air)]

In order to employ the two equations, it is necessary to calculate the various thermal resistances. These shall be determined from theoretical and experimental data as described in the following clauses.

12.1 Metal thermal resistance. The dry metal thermal resistance of the coil (R_{md}) may be expressed as the sum of the tube wall (R_t) and fin thermal resistances (R_f). The fin thermal resistance is a function of the air side heat transfer coefficient and will therefore depend upon the state of the coil surface which may be either dry or wet. In order to avoid duplicating equations and calculations, a general heat transfer coefficient f_a is employed

12.1.1 Basic equations

12.1.1.1 Tube wall thermal resistance:

$$R_t = \frac{B(d_o - d)}{t(1 + d_o/d_i)} \times 10^{-3} (m^2 \text{ K/W})$$

where

R_t	is the tube wall thermal resistance (m^2 K/W)
k_t	is the thermal conductivity of the tube wall material [W/(m K)]
d_o	is the tube external diameter (mm)
d_i	is the tube internal diameter (mm)
B	is the coil surface ratio (A_o/A_i)
A_o	is the coil external surface area ($A_p + A_s$) (m^2)
A_i	is the coil internal surface area ($N_t \pi d_i l_t \times 10^{-3}$) (m^2)
A_p	is the area of exposed tubes (m^2)
A_s	is the total surface area of coil fins (both sides) (m^2)
N_t	is the number of tubes in coil
l_t	is the length of coil water tube (m)

12.1.1.2 Fin thermal resistance:

$$R_f = \frac{(1 - \eta)}{\eta f_a} (m^2 \text{ K/W})$$