BS EN 328:2014

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Heat exchangers — Forced convection unit air coolers for refrigeration — Test procedures for establishing the performance

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The UK participation in its preparation was entrusted to Technical Committee RHE/30, Heat exchangers.

A list of organizations represented on this committee can be obtained on request to its secretary.

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ISBN 978 0 580 80318 5

ICS 23.120; 27.060.30

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 August 2014.

Amendments issued since publication

Date	Text affected

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 328

August 2014

ICS 23.120; 27.060.30

Supersedes EN 328:1999

English Version

Heat exchangers - Forced convection unit air coolers for refrigeration - Test procedures for establishing the performance

Echangeurs thermiques - Aérofrigorifères à convection forcée pour la réfrigération - Procédures d'essai pour la détermination de la performance

Wärmeübertrager - Ventilatorluftkühler - Prüfverfahren zur Leistungsfeststellung

This European Standard was approved by CEN on 22 May 2014.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 328:2014 E

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Foreword

This document (EN 328:2014) has been prepared by Technical Committee CEN/TC 110 “Heat exchangers”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2015, and conflicting national standards shall be withdrawn at the latest by February 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 328:1999 and EN 328:1999/A1:2002.

The main changes with respect to the previous edition are listed below:

a) Clause 3 “Terms and definitions” is modified;

b) The revised standard takes into account the application of CO_2.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

This European Standard is one of a series of European Standards dedicated to heat exchangers.

1 Scope

This European Standard is applicable to non-ducted unit air coolers for refrigeration operating:

a) with direct dry expansion of a refrigerant;

b) with liquid overfeed by pump circulation of a refrigerant;

c) with a liquid.

This standard specifies uniform methods of performance assessment to test and ascertain the following:

— product identification;

— standard capacity;

— standard liquid pressure drop;

— standard refrigerant pressure drop (for operation with liquid overfeed by pump circulation only);

— nominal air flow rate;

— nominal fan power.

It does not cover evaluation of conformity.

It is not applicable to air coolers for duct mounting or with natural air convection.

This standard does not cover technical safety aspects.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories (ISO/IEC 17025)*

EN 60034-1, *Rotating electrical machines - Part 1: Rating and performance (IEC 60034-1)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply:

3.1
physical definitions
3.1.1
forced convection unit air cooler
refrigeration system component transferring heat from air to a refrigerant or liquid. The air is mechanically circulated over the heat transfer surface by integral fan(s) and fan drive(s)

Note 1 to entry: The heat transfer coil includes refrigerant distributing and collecting headers.

Note 2 to entry: In the following “forced convection unit air cooler” is referred to as “unit cooler”.

3.1.2
heat transfer surface (air side)
external surface of the cooling coil which is in contact with the air flow passing the cooling coil

3.1.3
internal volume
volume of the refrigerant containing parts of the unit cooler between its two connections

3.1.4
fouling resistance
thermal resistance of a layer of unwanted deposit on the heat exchanger surface reducing its heat transfer performance

Note 1 to entry: The fouling resistance for a clean surface is zero. Clean, in this context, means that all production residues have been removed from the heat transfer surface and the fan(s) by the factory's cleaning process.

3.2
refrigerant
working fluid in a cooling system, which absorbs heat at low pressure / temperature by evaporation and rejects heat at a higher pressure / temperature by condensation

3.3
liquid
working fluid remaining liquid during the absorption of heat

3.4
capacities
3.4.1
sensible air cooling capacity
heat flow rejected by the air resulting from a dry bulb temperature drop

3.4.2
latent cooling capacity
heat flow rejected by the air resulting from condensation of water vapour or frost formation including subcooling on the unit cooler surface

3.4.3
total cooling capacity
sum of the sensible and the latent capacities measured at the same time

3.4.4
gross cooling capacity
total heat flow absorbed by the refrigerant or liquid

3.4.5
net cooling capacity
cooling capacity available for cooling the air equal to the gross cooling capacity minus the fan power

3.4.6
standard capacity
gross cooling capacity at standard conditions and normal atmospheric pressure of 1013,25 hPa of a unit cooler with clean internal and external surfaces

3.4.7
fan power
electric power, absorbed by the fan motors at the electrical terminals of the motor(s)

3.4.8
nominal fan power
fan power measured during the air flow test and corrected to the normal atmospheric pressure of 1013,25 hPa

Note 1 to entry: The fan power will also differ with the temperature at which the fan runs. As the fan power is only a small proportion of the total cooling load, the deviations are considered to be negligible.

3.5
rotational speed of the fans
average rotational speeds of fans

3.6
pressures and pressure differences
for the purposes of this standard all pressures are average values ascertained over the test duration

3.6.1
evaporating pressure
absolute pressure of the refrigerant, at the outlet connection of the unit cooler

3.6.2
liquid inlet pressure
static pressure of the liquid at the inlet connection of the unit cooler

3.6.3
liquid outlet pressure
static pressure of the liquid at the outlet connection of the unit cooler

3.6.4
liquid pressure difference
difference between the liquid inlet pressure and the liquid outlet pressure

3.6.5
refrigerant inlet pressure
absolute pressure of the refrigerant, at the inlet connection of the unit cooler (see Annex F)

3.6.6
critical pressure
pressure at the critical point where the liquid and gaseous phases of the refrigerant have the same physical properties

3.7
temperatures
for the purposes of this standard all temperatures are average values ascertained over the test duration

3.7.1
air temperatures
3.7.1.1
air inlet temperature
average dry bulb temperature of the air at the unit cooler inlet, taking into consideration the local air velocities

3.7.1.2
air dew point temperature
dew point temperature of the air within the calorimeter room

3.7.1.3
inside temperature
air temperature inside the calorimeter room responsible for the heat exchange with the ambient

3.7.1.4
ambient temperature
temperature around the calorimeter room responsible for the heat exchange with the inside

3.7.2
refrigerant temperatures
3.7.2.1
evaporating temperature
dew point temperature of the refrigerant, corresponding to the evaporating pressure

3.7.2.2
superheating temperature
temperature of the refrigerant vapour at the outlet connection of the unit cooler, measured on the wall of the tube at the location recommended by the manufacturer for fixing the expansion valve sensing element or downstream of the liquid-suction heat exchanger where this is an integral part of the unit cooler

3.7.2.3
subcooled refrigerant temperature
temperature of the liquid refrigerant at the inlet connection to the expansion device (not necessarily part of the unit cooler)

3.7.2.4
bubble point temperature for cooler measurement
temperature calculated from the enthalpy based on the temperature and pressure at the inlet of the expansion valve

3.7.3
liquid temperatures
3.7.3.1
liquid inlet temperature
average temperature of the liquid at the inlet connection of the unit cooler taking into consideration the local liquid velocities

3.7.3.2
liquid outlet temperature
average temperature of the liquid at the outlet connection of the unit cooler taking into consideration the local liquid velocities

3.7.4
water temperatures
(applicable only where the balancing heat is supplied by water)

3.7.4.1
water inlet temperature
temperature of the water as it enters the calorimeter

3.7.4.2
water outlet temperature
temperature of the water as it leaves the calorimeter

3.7.5
vapour outlet temperature
temperature of the refrigerant vapour at the vapour outlet connection of the separator

3.8
temperature differences
3.8.1
temperature differences for refrigerants
3.8.1.1
inlet temperature difference
difference between the air inlet temperature and the evaporating temperature

3.8.1.2
superheating
difference between the superheating temperature and the evaporating temperature

3.8.1.3
degree of superheating
ratio of the superheating to the inlet temperature difference

3.8.1.4
subcooling
difference between the bubble point temperature corresponding to the absolute pressure of the refrigerant at the inlet connection to the expansion device and the subcooled refrigerant temperature

3.8.2
temperature differences for liquids
3.8.2.1
inlet temperature difference
difference between the air inlet temperature and the liquid inlet temperature

3.8.2.2
liquid temperature difference
difference between the liquid inlet and outlet temperatures

3.9
high glide
refrigerant where the difference between the condensing and bubble point temperatures at a condensing temperature of 40 °C is greater than 3K

3.10
operation with refrigerants
3.10.1
direct expansion operation
evaporation process in which the refrigerant enters the unit cooler via a direct expansion device as a liquid-vapour mixture and leaves it in superheated state (see system boundaries in Annex A)

3.10.2
operation with liquid overfeed by pump circulation
evaporation process in which the refrigerant leaves the unit cooler in partially evaporated state, the process being operated by a mechanical liquid pump and a separator being parts of a refrigerating machine

Note 1 to entry: The refrigerant is transported from the separator to the unit cooler by the mechanical pump (see Annex F).

3.10.3
supercritical operation
thermodynamic cycle in which the outlet pressure at the compressor is higher than the critical pressure of the refrigerant with a gas cooler being part of the refrigerator

3.11
refrigerant enthalpies
3.11.1
refrigerant inlet specific enthalpy
specific enthalpy of the refrigerant at the inlet connection of the unit cooler system. For capacity calculation it is defined as the specific enthalpy of the saturated liquid refrigerant at the inlet to the expansion device corresponding to the subcooled refrigerant temperature and for transcritical operation it is defined as the enthalpy corresponding to temperature and pressure

Note 1 to entry: For liquid overfeed by pump circulation the refrigerant inlet enthalpy cannot be defined by temperature and pressure measurement at the unit cooler's connections (see Annex E).

3.11.2
refrigerant outlet specific enthalpy
specific enthalpy of the refrigerant at the outlet connection of the unit cooler system. For capacity calculation it is defined as the specific enthalpy of the refrigerant corresponding to the evaporating pressure and the superheating temperature

Note 1 to entry: For liquid overfeed by pump circulation the refrigerant outlet enthalpy cannot be defined by temperature and pressure measurement at the unit cooler's connections (see Annex E).

3.11.3
specific vaporization enthalpy
enthalpy at the evaporating pressure without regard to the pressure drop across the unit cooler (see Annex F)

3.12
nominal air flow
air volume flow rate flowing through the unit cooler, when its air side is dry and clean

3.13
oil content
proportion of oil by mass in the refrigerant related to the pure refrigerant

3.14
refrigerant recirculation rate
ratio between the actual mass flow rate through the unit cooler and the mass flow rate necessary for the total evaporation of the refrigerant (see Annex F)

4 Symbols

For the purposes of this document, Table 1 applies:

Table 1 — Symbols

E_{el}	electrical energy input into the calorimeter	kJ
F	correction factor for the deviation from standard atmospheric pressure	Pa
h_{L1}	liquid inlet specific enthalpy	kJ/kg
h_{L2}	liquid outlet specific enthalpy	kJ/kg
h_{R1}	refrigerant inlet specific enthalpy	kJ/kg
h_{R2}	refrigerant outlet specific enthalpy	kJ/kg
h_{R3}	refrigerant specific enthalpy at the outlet connection of the unit cooler (see Annex E)	kJ/kg
h_{W1}	water inlet specific enthalpy (balancing air heater)	kJ/kg
h_{W2}	water outlet specific enthalpy (balancing air heater)	kJ/kg
HL	heat flow from the calorimeter inside to its ambient	kW
n	rotational speed of fans	1/min
p_{atm}	atmospheric pressure	Pa
p_e	evaporating pressure	bar
p_{e1}	refrigerant pressure at the inlet connection of the unit cooler (see Annex E)	bar
p_{e2}	refrigerant pressure at the vapour outlet connection of the separator (see Annex E)	bar
p_{L1}	liquid pressure at unit cooler inlet	bar
p_{L2}	liquid pressure at unit cooler outlet	bar
p_{R1}	refrigerant pressure at expansion device inlet	bar
P_1	capacity (primary method)	kW
P_2	capacity (confirming method)	kW
P_M	measured capacity	kW
q_m	mass flow rate	kg/s
q_{mRPu}	refrigerant mass flow rate on the low pressure side through the pump	kg/s
q_V	volume flow rate	m^3/s
rd	relative deviation	-
ρ	density	kg/m3
$r\,r$	recirculation rate	-
t_{LM}	temperature of liquid at the flow measuring point	°C
t_{RM}	temperature of refrigerant at the flow measuring point (liquid line)	°C
t_{WM}	temperature of water at the flow measuring point (balancing air heater)	°C
t_{A1}	air inlet temperature (dry bulb)	°C
t_{bp}	temperature of refrigerant at boiling curve	°C
t_{dp}	air dew point temperature within the calorimeter room	°C
t_e	evaporating temperature	°C
t_i	individual air temperature inside the calorimeter	°C
$t_{(pR1)}$	saturation temperature corresponding to p_{R1}	°C

t_{L1}	liquid inlet temperature	°C
t_{L2}	liquid outlet temperature	°C
t_{R1}	refrigerant temperature at the inlet to the expansion device	°C
t_{R2}	vapour outlet temperature at the vapour outlet connection of the separator (see Annex E)	°C
t_{R3}	actual temperature at unit cooler outlet connection (see Annex E)	°C
t_{W1}	water inlet temperature	°C
t_{W2}	water outlet temperature	°C
t_{sup}	superheating temperature	°C
Δp	pressure drop	bar
Dt_1	inlet temperature difference	K
Δh_e	refrigerant specific enthalpy change in the unit cooler at p_e (see Annex E)	kJ/kg
Δh_O	specific vaporization enthalpy at p_e (see Annex E)	kJ/kg
Δh_R	difference between refrigerant outlet and inlet specific enthalpies	kJ/kg
Δt_{sub}	subcooling = $t_{(pR1)}$ - t_{R1}	K
Δt_{sup}	superheating	K
Δt_L	temperature difference between liquid inlet and outlet	K
τ	test duration	S
U	voltage	V

Subscripts

m mass;

v volume;

L liquid;

M flow meter;

R refrigerant;

W water.

Numbers indicate positions defined on the circuit diagrams.

Superscripts

(a/b) refers to the test sequence, (a) above and (b) below the standard conditions.

(st) refers to standard conditions.

5 Standard capacity

5.1 Basis of standard capacity data

The cooling capacity of a given unit cooler, or its overall coefficient of heat transfer depends on the following:

a) the inlet temperature and the humidity content of the entering air;

b) the mass flows of air, refrigerant or liquid;

c) the evaporating temperature or the inlet temperature of the liquid;

d) the degree of refrigerant superheating;

e) further conditions e.g.

— the degree of refrigerant subcooling;

— pressure and temperature at the inlet of the expansion device in supercritical operation;

— oil content;

f) the state of frosting.

Because of the related dependence of the overall coefficient of heat transfer on both the mass flow and the temperature difference, it is not permissible to specify cooling capacities per unit of temperature difference, as the coefficient of heat transfer can only be taken as a constant value in a very limited range of operating conditions.

Therefore cooling capacities are given for specific operating conditions.

The influence of frosting on the unit cooler surfaces (latent cooling capacity) can only be measured with great difficulty because of the changing processes. Therefore this standard only considers cooling capacities under non frosting conditions, as these can be measured and tested under steady-state conditions.

5.2 Standard conditions for the cooling capacity

5.2.1 General

The standard capacity shall be based on tests performed on a clean unit cooler at nominal voltage and frequency under one or more of the conditions specified in 5.2.2 and 5.2.3.

5.2.2 Refrigerants

The standard conditions for refrigerants are given in Table 2 and Table 3:

Table 2 — Standard conditions for refrigerants

Standard condition	t_{A1} °C	t_{dp} °C	t_e °C	$\Delta t_{sup} / Dt_1$ –	t_{R1} °C
SC 1	+10	< −2	0	0,65	30
SC 2	0	< −10	- 8	0,65	30
SC 3	- 18	< - 27	- 25	0,65	20
SC 4	- 25	< - 33	- 31	0,65	20
SC 5	- 34	< - 42	- 40	0,65	20
NOTE It is essential that the oil content be below 1 % of mass.					

The standard rating conditions for the operation with R744 (CO_2) is given in Table 3:

Table 3 — Standard conditions for operation with R744 (CO_2)

Standard Condition	t_{A1} °C	t_{dp} °C	t_e °C	Δt_{sup} / Dt_1	t_{bp} °C
SC 1	+10	< −2	0	0,65	20
SC 2	0	< −10	- 8	0,65	20
SC 3	- 18	< - 27	- 25	0,65	10
SC 4	- 25	< - 33	- 31	0,65	10
SC 5	- 34	< - 42	- 40	0,65	10

The enthalpy of t_{bp} applies.

For standard conditions for operation with liquid overfeed by pump circulation see Annex E.

5.2.3 Liquids

The standard conditions for liquids are given in Table 4:

Table 4 — Standard conditions for liquids

Standard condition	t_{A1} °C	t_{dp} °C	t_{L1} °C	t_{L2} °C	Intended for	Comments
SC 10	+ 16	< + 2	+ 4	+ 8	Water	The flow direction shall be given
SC 11	0	< - 12	- 10	- 7	Specified liquid	
NOTE The quality of the liquid needs to be such that it does not cause measurable fouling during the entire operation for establishing the test.						

5.3 Conditions for the nominal air flow rate

The nominal air volume flow rate shall be referred to an air temperature of + 20°C.

NOTE The air volume flow rate is not influenced by atmospheric pressure and air temperature when the fan speed is constant.

5.4 Conditions for nominal fan power

The nominal fan power shall be referred to an air temperature of + 20°C and to an atmospheric pressure of 1013,25 hPa.

6 Manufacturer's data

To identify the unit cooler and allow traceability, the manufacturer or supplier shall supply the test house with the following minimum information for each unit cooler to be tested:

a) model designation of unit;

b) model designation of fan;

c) rating of the fan motor(s) according to EN 60034-1;

d) standard capacity for the standard conditions in the range of application, stating the refrigerants used;

e) nominal air flow;

f) nominal fan power;

g) nominal voltage and frequency;

h) total heat transfer surface (air side);

i) fin pitch and thickness;

j) tube nominal bore;

k) tube geometry;

l) circuiting arrangement;

m) internal volume including distributors and headers;

n) installation instructions;

o) maximum permissible operating pressure *PS*.

7 Measurements

7.1 Uncertainty of measurements

The permissible uncertainty of significant measurements is given in Table 5.

Table 5 — Uncertainty of measurements

Measured quantity	Unit	Uncertainty of measurement
Air		
— inlet temperature	°C	±0,2 K
— dew point temperature	°C	±2 K
— all other temperatures	°C	±0,5 K
Refrigerant	°C	±0,2 K
— temperature		
— pressure	kPa	shall ensure that the evaporating temperature to be obtained within ± 0,2 K
— volume flow rate[a]	kg/s m^3/s	±0,2 %
Liquid		
— temperature	°C	±0,2 K
— temperature difference.	K	±0,1 K
— pressure drop	kPa	±5 % or 1 kPa (larger value applies)
— liquid refrigerant volume flow rate[a]	m^3/s	±1 %
Electrical quantities (fans)		
— electrical power input	W	±1 % or at least 1 W
— current	A	±0,5 %
— voltage	V	±0,5 %
— frequency	Hz	±0,5 %
Oil content in the refrigerant	kg	±20 % of the measured value
Atmospheric pressure	hPa	±5 hPa
Fan speed	min^{-1}	±1 %
[a] also mass flow rate with equivalent uncertainty can be used.		

7.2 Measurement criteria

7.2.1 Pipe side temperature measurement

One of two methods of measurement shall be used as follows:

a) Method A

When the temperature is measured on the outside of the connecting pipe it shall be measured at two opposite points of the same cross-section and, if the pipe is horizontal, there shall be one point above and one below. The pipe shall be insulated on each side of the temperature measuring point for a length of at least 10 times of its outside diameter. It shall be ensured, that good thermal contact exists between the sensor and the pipe at the measuring point.

The measured value is the arithmetic mean of both individual values.

b) Method B

When the temperature is measured by a sensor immersed in the pipe, care shall be taken that temperature stratifications and flow patterns do not influence the accuracy of the measurements.

7.2.2 Superheating temperature

The superheating temperature shall be measured as near as possible to the outlet connection provided by the manufacturer.

This location shall be within a distance of 500 mm from the unit cooler outlet connection and within the calorimeter room.

Where a liquid to suction heat exchanger is an integral part of the unit cooler the measuring point for the superheating temperature shall be at the outlet connection of the heat exchanger.

Method A shall be used.

7.2.3 Temperature at expansion device inlet

The subcooled liquid refrigerant temperature shall be measured as near as possible to the expansion device inlet.

NOTE At low evaporating temperatures and small capacities the temperature measurement can be influenced by conductivity.

Where a liquid to suction heat exchanger is an integral part of the unit cooler the measuring point for the subcooled liquid refrigerant temperature shall be at the inlet connection of the expansion device.

Both methods A or B may be used. When method B is applied, care shall be taken that the sensor does not cause the generation of flash gas.

7.2.4 Liquid temperatures

The liquid temperatures shall be measured as near as possible to the connections, provided by the manufacturer.

Method A or B may be used.

7.2.5 Water temperatures (balancing air heater)

Water temperatures shall be measured as the water enters or leaves the calorimeter. Method B is preferred.

7.2.6 Air temperature measurement

7.2.6.1 Air inlet temperatures

The air inlet dry bulb temperatures shall be measured in the centre of equal sections of the face area of the coil. These sections shall not be larger than 0,2 m^2 and be square if possible. There shall be at least 6 sections. Temperature sensing elements shall be shielded against radiation and any other form of heat transfer affecting the accuracy of the measurement.

The dew point shall be measured at one point within the calorimeter room.

7.2.6.2 Inside and ambient air temperatures

Inside and ambient air temperatures shall be measured 0,15 m perpendicular to the surface of the calorimeter. Only dry bulb temperatures are significant.

If the calorimeter is in direct contact with the floor, the temperature shall be measured on the outer surface of the insulation.

NOTE The quantity and location of temperature measuring points will be dependent on the calorimeter design and the variation in inside and ambient temperatures.

There shall be at least one inside and ambient temperature measuring point on each of the six surrounding surfaces.

7.2.7 Pressure measuring points

The pressure measuring points shall be located in the middle of a straight part of pipe of constant diameter, equal to that of the cooler connections, having a length of not less than 10 times its diameter ensuring that there is no restriction involved. They shall be positioned between the temperature measuring points and the connections of the unit cooler.

7.2.8 Flow rates

7.2.8.1 General

The flow rates of refrigerants, liquids and water shall be measured according to the recommendations of the installation instructions for the flow measuring devices.

7.2.8.2 Refrigerant flow rate

When measuring the refrigerant flow rate, the refrigerant shall be sufficiently subcooled to prevent the generation of flashgas which causes inaccurate measurements. In order to check that there is no flashgas, a sight glass shall be placed immediately after the flow measuring section.

NOTE 1 When measuring refrigerant flow rate, it is practical to locate the measuring device on the liquid side of the circuit, and for transcritical operation between gas cooler and expansion device.

NOTE 2 Refrigerant flow rates usually fluctuate over any length of time. Therefore to measure these, integrating devices are more suitable than momentary indicators.

7.2.8.3 Liquid and water flow rate

NOTE As with refrigerants, integrating devices are more suitable than momentary indicators.

7.2.9 Oil content

The oil content shall be measured unless it can be guaranteed that is below 1 % by mass. For a recommended measurement procedure see Annex F (informative).

7.2.10 Non azeotropic refrigerant

For high-glide refrigerants the refrigerant mixture shall be measured unless it can be guaranteed that the mass fraction varies by less than ± 2 % from the manufacturer's data.

8 Testing methods and equipment

8.1 Testing methods

8.1.1 Capacity

8.1.1.1 General

In order to fulfil the requirements of this standard, two methods of determining the cooling capacity shall be used simultaneously. The primary method shall determine the capacity on the air side. The confirming method shall determine the capacity on the refrigerant / liquid side. The result of the confirming method shall agree with that of the primary method within ± 4 %.The testing methods and arrangements are shown in Annexes B to E. If the deviation between the two methods is greater than ± 4 %, it can be assumed that there is an error either in the testing arrangement or in the execution of the tests.

These test methods are not suitable for high glide refrigerants used with liquid feed by gravity or liquid overfeed by pump circulation. The method in Annex F shall be used as a confirmation method.

8.1.1.2 Primary test method

The following primary test method shall be used to determine the gross cooling capacity on the air side in a calorimeter. The principle of this method is to measure the total heat flow into a calorimeter room in order to balance the cooling capacity of the unit cooler under test. This heat input is equal to the cooling capacity of the unit cooler, taking into consideration the heat flow exchanged between the calorimeter and the ambient as well as the connecting pipes for the unit cooler within the calorimeter.

8.1.1.3 Confirming test method

The following confirming test method shall be used to determine the gross cooling capacity on the refrigerant / liquid cycle side. The principle of this method is to measure the refrigerant / liquid flow rate and to multiply this flow rate by the difference between the specific enthalpies at the outlet and inlet connections of the unit cooler. The specific enthalpy difference of the refrigerant / liquid shall be determined from the temperature and pressure measurements and physical properties of the refrigerant.

8.1.1.4 Air flow method

For the purposes of this standard the air flow method for determining the capacity is considered to be inaccurate and therefore its use is not permitted.

8.1.2 Air flow

The method used shall be to measure the overall air flow rate at free inlet and discharge conditions.

NOTE Forced convection unit coolers create very turbulent air flows. Therefore measurements of air speeds at individual points cannot be used.

8.1.3 Heat exchange with the ambient

The heat exchange with the ambient is measured via the electric heat inducement into the calorimeter room.

8.2 Equipment

8.2.1 Calorimeter room

8.2.1.1 General

The unit cooler shall be installed in a well insulated calorimeter room together with a balancing air heater.

The test installation shall be capable of maintaining steady-state conditions as required by this standard.

The testing arrangement shall be designed in such a way that the unit cooler can be tested reproducibly under conditions as in practical operation, particular attention being paid to the following:

The air flow through the unit cooler being tested shall not be modified,

The air flow around the unit cooler shall not be influenced; recirculation of air shall neither be created nor prevented if it is a normal feature,

Care shall be taken with non-azeotropic refrigerants, such that there are no liquid refrigerant accumulations in the refrigerant cycle (i.e. in big sized liquid vessels with low liquid level). While testing non-azeotropic refrigerants, the concentration of the individual refrigerants within the mixture circulating through the unit cooler shall remain identical to the concentration with which it was originally filled.

NOTE Non-azeotropic refrigerants are mixtures of more than one refrigerant with different individual boiling temperatures. If the mixture is separated at a two phase state e.g. in a vessel, one of the two phases can accumulate effecting the concentration of each refrigerant within the rest of the system.

The total heat content of the calorimeter room is calculated from the mass and specific heat of the objects in the room, the interior covering of the walls and floor and half the insulation thickness.

8.2.1.2 Inside arrangement

The unit cooler shall be installed so that,

a) no obstacle is positioned within a distance of 1,5 x $\sqrt{A \times B}$ away from the discharge of the unit cooler;

b) no obstacle is positioned within a distance of 0,75 x $\sqrt{A \times B}$ parallel to the sides of the unit cooler;

c) all distances correspond to the minimum requirements of the installation instructions provided by the manufacturer, particularly the distance of the air inlet from the back wall and the ceiling;

d) the volume in m^3 of the compartment, housing the unit cooler under test, shall be between 1/30 and 1/600 of the air flow rate in m^3/h produced by the unit cooler under test together with all auxiliary air moving devices.

Where A and B are the air inlet dimensions of the unit cooler.

The total heat content of the calorimeter shall be chosen such that it does not vary by more than ± 0,5 % of the capacity measured during the test duration.

8.2.1.3 Ambient arrangement

All equipment in the refrigerant cycle, except for the measuring points at the unit cooler and the expansion device shall be placed outside the calorimeter room.

The calorimeter room shall be designed and arranged in its ambient such, that verification of the heat exchange with the ambient according to the requirements of this standard is possible.

The calorimeter room shall be located in an ambient the average temperature of which can be held constant. There shall be no significant heat radiation to the test room. The clearance between the calorimeter room and the walls of the enclosing space shall be sufficient to allow the reproducible measurement of the ambient temperature.

Ambient conditions of the calorimeter room shall be such that the same air conditions, particularly air movements, prevail during the calibration test as during the capacity test.

8.2.1.4 Heat exchange with the ambient

The calorimeter shall be designed such, that the heat exchange with the ambient does not influence the accuracy of the test result by more than ± 1 %.

In practice this means for example that the heat loss should be known with an uncertainty of less than ± 10 % if it amounts to 10 % of the measured capacity.

The heat exchange of the calorimeter with the ambient shall not exceed 20 % of the measured capacity.

8.2.1.5 Heat inducement

The balancing air heater shall be designed and installed such, that the general requirements, specified above, are met. It shall be constructed in such a way that heat is not radiated directly on to the unit cooler or on to the temperature measuring points or the walls and the floor.

For a water heated air heater the water inlet and outlet temperature measuring points shall be positioned immediately outside the calorimeter wall.

All power input into the calorimeter shall be measured.

8.2.2 Refrigerant / liquid pipes

The refrigerant / liquid pipes, especially the liquid line for refrigerants, within the calorimeter room, shall be insulated sufficiently well for the heat emission in the calorimeter room to be less than 0,5 % of the cooling capacity to be measured.

8.2.3 Expansion device

In order to obtain the specific enthalpy of the refrigerant (primary) at the unit cooler inlet, the expansion point shall be placed as close to the unit cooler inlet connection as possible.

8.2.4 Flashgas

A sight glass shall be placed before the expansion device in order to check that no flashgas is present.

8.2.5 Air flow measurement

It is recommended that the air flow rate is measured according to EN ISO 5801 using an inlet or outlet chamber arrangement. An auxiliary fan shall be used which provides ambient pressure in the chamber at the pressure measuring points adjacent to the connection of the unit cooler.

Other methods are acceptable provided that the required accuracy is achieved.

For the measurement of the air temperature one point at the inlet or outlet is sufficient.

8.2.6 Liquid receiver

For high glide refrigerants the internal volume of the liquid receiver shall be less than 4 % of the total system volume.

9 Test procedures

9.1 General

The unit cooler shall be installed in accordance with the manufacturer's specification.

All components supplied by the manufacturer as part of the unit cooler shall be included in the test setup and used in accordance with the manufacturer's instructions.

9.2 Calibration of the calorimeter room

The difference between the inside and ambient temperatures shall be as high as possible but not exceed 40 K.

When selecting the temperatures, the effect they may have on the insulation material shall be taken into account.

The test duration shall be chosen such that any deviation from steady-state conditions cannot influence the uncertainty of the test result by more than ± 0,5 %.

The test duration shall continue for at least 6 h after steady-state conditions have been reached. The temperatures and temperature differences shall not change by more than ± 2,5 % of the measured temperature difference during the test duration.

Measurements shall be taken at regular intervals small enough to monitor all significant fluctuations. At least 7 sets of measurements are required.

With the water / refrigerant flow to the balancing air heater / unit cooler off, the calorimeter room is heated electrically. The electrical power input, including fan motors, under steady-state conditions, is the heat loss.

The heat flow through the calorimeter room walls shall be measured when the air circulation in the calorimeter room is at the maximum achievable value and another value approximately 50 % lower. If fitted, fans on the balancing heater shall be on to correspond to test conditions as closely as possible.

When the calorimeter room floor is in contact with the floor of the site, additionally the heat inducement into the calorimeter room shall be varied such, that the higher value lies at least 50 % above the lower.

NOTE It is desirable that the ambient air temperature is varied additionally as this will give an indication of the relative proportions of the heat flow through the floor and the other surrounding surfaces.

A theoretical evaluation of the heat transfer shall be established and compared to the measured results.

Individual inside air temperatures or ambient air temperatures shall not differ from each other by more than 10 % of the difference between the inside and ambient temperature.

The following data shall be recorded:

Individual inside and ambient temperatures;

Air flow rates of the unit cooler and balancing air heater fans;

Test duration [τ];

Electrical energy input into the calorimeter [E_{el}].

9.3 Measurement of the cooling capacity

9.3.1 Air humidity

The standard conditions require dry surfaces; no frost or condensate on the unit cooler is allowed.

9.3.2 Subcooled refrigerant temperature

The condensing temperature shall be sufficiently far above the subcooled refrigerant temperature to prevent the generation of flash gas.

9.3.3 Steady-state conditions

Measurement of the cooling capacity can only be carried out at steady-state conditions which shall be reached at least half an hour before starting the test.

Steady-state conditions are assumed to be reached and maintained if during the period of one hour all alterations and periodic fluctuations remain within the following ranges:

a)	air inlet temperature	±0,2 K
b)	evaporating temperature	±0,5 K
c)	inlet temperature difference	±0,3 K
d)	superheating temperature	±1,0 K
e)	fan speed	±2 %
f)	electric power input	±1,0 %
g)	ambient temperature	±1 K
h)	liquid flow rate (where applicable)	±0,5 %

For measurements with liquids, the liquid inlet and outlet temperatures are used instead of the evaporating temperature.

In order to ensure that steady-state conditions are maintained, the data shall be continuously monitored at intervals small enough to identify all significant fluctuations.

9.3.4 Test duration

The test duration shall be chosen such that any deviation of temperatures will not influence the uncertainty of the test result by more than ± 0,5 %. The test duration shall be a minimum of one hour. At least five sets of measurements shall be taken at regular intervals during the test period.

The heat capacity (water equivalent) of the calorimeter room and the apparatus therein has considerable influence on the accuracy of the measurements when the temperatures are not completely constant and as the uncertainty caused in this way shall not be more than 0,5 % when constant conditions are not maintained exactly, the test duration depends on the heat capacity and on the relative deviation from constant conditions. The following formula gives an estimation of the testing time:

$$\tau \geq \left(200 \times \Delta t_{\mathrm{i}} \times \mathrm{C}\right) / \mathrm{P} \tag{1}$$

where

τ is the test duration required for an uncertainty < 0,5 % in s;

Δt_{i} is the temperature difference between the highest and the lowest inside air temperature during the test period in K;

C is the heat capacity of the calorimeter room in kJ/K;

P is the measured cooling capacity in kW.

The heat capacity of the calorimeter room is calculated from the mass and specific heat of the objects in the room, the interior covering of the walls and half the insulation thickness of the walls.

9.3.5 Conducting the test

9.3.5.1 Refrigerants - direct expansion operation

In order to retain sufficient accuracy when converting the measured capacity to the standard conditions, the average values shall be within the following deviations from the standard conditions:

Table 6 — Deviation of test conditions

Test	Unit	Deviation
All tests	t_e	±1 K
	t_{dp}	±2 K
	D_{t1}	±0,5 K
	t_{R1}	±1 K (only for subcritical operation)
	t_{bp}	±1 K (only for transcritical operation)
	p_{R1}	±2,5 bar (only for transcritical operation)
	supply voltage	±2 %
	frequency	±1 %
Single test	$\Delta t_{sup} / Dt_1$	±0,02
Duplicate test	$\Delta t_{sup} / Dt_1$	±0,10

NOTE A superheat ratio of ± 0,02 equals a capacity shift of about ± 1 %. When the uncertainty of the measuring equipment of about 3 % is added, the limit of 5 % is almost reached.

9.3.5.2 Refrigerants - operation with liquid overfeed by pump circulation

Operation with liquid overfeed by pump circulation is covered in Annex F.

9.3.5.3 Liquids

In order to retain sufficient accuracy when converting the measured capacity and pressure drop to the standard conditions, the average values shall be within the following deviation from the standard condition:

Table 7 — Deviation of test conditions

Test	Unit	Deviation
All tests	t_{L1}	±2 K
	t_{dp}	±2 K
Single test	Dt_1 and Δt_L	±0,2 K

Duplicate test	Dt_1	±2 K
	Δt_L	±1,0 K

Duplicate tests shall be conducted with $(\Delta t_L / Dt_1)^{(a,b)}$ above and below $(\Delta t_L / Dt_1)^{(st)}$

9.3.6 Air inlet temperature

The dry bulb temperatures at the individual measuring points shall not differ from each other by more than (0,1 x Dt_1). If necessary, temperature build-ups shall be prevented by a suitable arrangement, but care shall be taken, that air circulation around and air flow through the unit cooler are not influenced thereby.

9.3.7 Data to be recorded

9.3.7.1 General

With air side temperatures the values at individual measuring points shall be recorded.

If the difference between any individual air inlet temperatures exceeds (0,1 x Dt_1) this fact, and the reason for it, shall be mentioned in the test report.

NOTE The unit cooler itself may generate recirculation of air and thus cause a greater deviation.

The following data shall be recorded for each test condition:

t_{A1}, t_{dp}, t_{amb}, t_i

E_{el}, τ, P_{atm}, P_{fan}, n and U

when applicable: q_{mW} or q_{vW}, t_{W1}, t_{W2}, t_{WM}

9.3.7.2 Refrigerants - direct expansion operation

The following additional data shall be recorded: p_e, t_{R1}, p_{R1}, t_{sup}, q_{mR} or q_{vR} and t_{RM}, p_{R1}

9.3.7.3 Refrigerants - operation with liquid overfeed by pump circulation

Operation with liquid overfeed by pump circulation is covered in Annex E.

9.3.7.4 Liquids

The following additional data shall be recorded: t_{L1}, t_{L2}, q_{mL} or q_{vL} and t_{LM}, p_{L1}, p_{L2}.

9.4 Measuring the fan performance

The unit cooler shall be tested without influencing the air resistance at air inlet and outlet.

The air temperature shall be (20 ± 5) °C.

The air flow rate and fan power shall be measured under steady-state conditions, which are assumed to exist when the fan speed does not change by more than 0,5 % within 15 min.

The following data shall be recorded: P_{fan}, n, t_{air}, p_{atm} and supply voltage. For measuring the air flow rate, all data required by the test method shall be recorded.

10 Calculating the cooling capacity

10.1 Heat loss factor

The heat loss / gain shall be calculated by use of a calculation model considering the air flow inside the calorimeter and verified using the different calibration test results.

10.2 Cooling capacity

10.2.1 From the air side energy input

10.2.1.1 General

The air side energy input includes the total energy introduced into the calorimeter room, including that for the fans. The capacity obtained from this is corrected by the heat flow exchanged with the ambient under capacity test conditions.

10.2.1.2 Electrical power input

The capacity calculated using the electrical power input is given by

$$P_1 = E_{el} \; / \; \tau + HL \tag{2}$$

where

HL is the heat flow from the ambient into the calorimeter under capacity test conditions.

10.2.1.3 Water heated balancing air heater

The capacity calculated using a water heated balancing air heater is given by

$$P_1 = q_{\text{mW}} \times \left(h_{W1} - h_{W2}\right) + E_{el} \; / \; \tau + HL \tag{3}$$

where

HL is the heat flow from the ambient into the calorimeter under capacity test conditions.

10.2.2 From flow rate of refrigerant

Calculating the capacity from the refrigerant flow is carried out according to one of the following formulae:

For volume flow measurements:

$$P_2 = q_{\text{vR}} \times \rho_{\text{RM}} \times \Delta h_{\text{R}} \tag{4}$$

For mass flow measurements:

$$P_2 = q_{\text{MR}} \times \Delta h_{\text{R}} \tag{5}$$

10.2.3 From the flow rate of liquid

Calculating the capacity from the liquid flow is carried out according to the following formula:

$$P_2 = q_{\text{vL}} \times p_{\text{LM}} \times \left(h_{\text{L2}} - h_{\text{L1}}\right) \tag{6}$$

For mass flow measurements

$$P_2 = q_{\mathrm{MLX}} \left(h_{\mathrm{L2}} - h_{\mathrm{L1}} \right)$$

10.2.4 Measured capacity

The measured capacity is the average of the capacities obtained from the primary and confirming method.

$$P_{\mathrm{M}} = \left(P_1 + P_2 \right) \ / \ 2 \quad (7)$$

11 Conversion to standard conditions

11.1 Cooling capacity

11.1.1 General correction for atmospheric pressure

For each test a correction factor for the deviation from standard atmospheric pressure (1013,25 hPa) shall be determined according to:

$$F^{(a,b)} = 1 + \left(1013{,}25 - p_{atm}{}^{(a,b)} \right) \times 6{,}5 \times 10^{-4} \quad (8)$$

This formula should allow for the influence of air atmospheric pressure on the capacity of a unit cooler. It is assumed, that the capacity increases approx. 0,065 % per hPa of higher air pressure and decreases approx. 0,065 % per hPa of lower air pressure compared to 1013,25,25 hPa.

11.1.2 Refrigerants with direct expansion operation

11.1.2.1 Single test

No correction for the superheating is required. The standard capacity is given as follows:

$$P^{(\mathrm{st})} = \left(\frac{P_m}{\Delta t_1} \right)^{(a)} \times \Delta t_1{}^{(st)} \times F^{(a)} \quad (9)$$

11.1.2.2 Duplicate tests

The standard capacity is obtained by linear interpolation of *(P / Dt₁)* between its two measured values against the degree of superheating.

The following formulae shall be applied:

$$\left(\frac{P}{Dt_1} \right)^{(st)} = X^{(b)} + \frac{\left(X^{(a)} - X^{(b)} \right)}{\left(Z^{(a)} - Z^{(b)} \right)} \times \left(0{,}65 - Z^{(b)} \right) \quad (10)$$

where

$X^{(a,b)} = [P_{\mathrm{M}} / Dt_1]^{(a,b)} \times F^{(a,b)}$

$Z^{(a,b)} = [\Delta t_{sup} / Dt_1])^{(a,b)}$; and $0{,}65 = [\Delta t_{sup} / Dt_1]^{(st)}$

(a,b) identifies the two individual tests for one standard condition.

$$P^{(st)} = \left(\frac{P}{Dt_1}\right)^{(st)} \times Dt_1^{(st)} \tag{11}$$

11.1.3 Refrigerants - operation with liquid overfeed by pump circulation

For additional requirements where operation is with liquid overfeed by pump circulation see Annex E.

11.1.4 Liquids

11.1.4.1 Single test

Within the permissible deviations the following relationship shall apply:

$$P^{(st)} = \left(\frac{P_M}{Dt_1}\right)^{(a)} \times Dt_1^{(st)} \times F^{(a)} \tag{12}$$

11.1.4.2 Duplicate tests

Within the permissible deviations the following relationship shall apply:

a) Determine:

$$B^{(st)} = \left(\frac{\Delta t_L}{Dt_1}\right)^{(st)} \tag{13}$$

b) Determine for each test:

$$A^{(a,b)} = \left(\frac{P_M}{Dt_1}\right)^{(a,b)} \times F^{(a,b)} \tag{14}$$

$$B^{(a,b)} = \left(\frac{\Delta t_L}{Dt_1}\right)^{(a,b)} \tag{15}$$

where

Δt_L is the measured value

$$\left(\frac{P}{Dt_1}\right)^{(st)} = A^{(b)} + \frac{A^{(a)} - A^{(b)}}{B^{(a)} - B^{(b)}} \times (B^{(st)} - B^{(b)}) \tag{16}$$

The standard capacity is calculated according to the following formula:

$$P^{(st)} = \left(\frac{P}{Dt_1}\right)^{(st)} \times Dt_1^{(st)} \tag{17}$$

11.2 Calculating the standard liquid side pressure drop

11.2.1 General

For liquids the standard pressure drop is calculated in accordance with 11.2.2 and 11.2.3.

11.2.2 Single Test

a) Determine $\Delta p_L^{(a)} = [p_{L1} - p_{L2}]^{(a)}$ (18)

and $q_{\mathrm{mL}}^{(\mathrm{a})} = \dfrac{P_{\mathrm{M}}^{(a)}}{c_{\mathrm{pL}} \times \Delta t_{\mathrm{L}}^{(\mathrm{a})}}$ (19)

where

Δt_L is the measured value.

$$q_{\mathrm{mL}}^{(\mathrm{st})} = \frac{P^{(\mathrm{st})}}{c_{\mathrm{pL}} \times \Delta t_{\mathrm{L}}^{(st)}} \quad (20)$$

b) Standard liquid side pressure drop is determined according to:

$$\Delta p_L^{(st)} = \Delta p_L^{(a)} \, x \left(\frac{q_{mL}^{(\mathrm{st})}}{q_{mL}^{(\mathrm{st})}} \right)^{1,8} \quad (21)$$

NOTE 1,8 is an empirical value, considering that the exponent normally lies between 1,5 and 2. Therefore for a single test the accuracy is sufficient.

11.2.3 Duplicate Tests

a) Determine:

$$q_{\mathrm{mL}}^{(\mathrm{st})} = \frac{P^{(\mathrm{st})}}{c_{\mathrm{pL}} \times \Delta t_{\mathrm{L}}^{(st)}} \quad (22)$$

b) For each test determine:

$$\Delta p_L^{(\mathrm{a,b})} = \left(p_{\mathrm{pL1}} - p_{\mathrm{pL2}} \right)^{(\mathrm{a,b})} \quad (23)$$

$$q_{\mathrm{mL}}^{(\mathrm{a,b})} = \frac{P_{\mathrm{M}}^{(a,b)}}{c_{\mathrm{pL}} \times \Delta t_{\mathrm{L}}^{(a,b)}} \quad (24)$$

where

Δt_L is the measured value.

c) Standard liquid side pressure drop is determined according to:

$$\log\left(\Delta p_{\mathrm{L}}^{(st)}\right) = \log\left(\Delta p_{\mathrm{L}}^{(\mathrm{b})}\right) + \frac{\log\left(\Delta p_{\mathrm{L}}^{(\mathrm{a})}\right) - \log\left(\Delta p_{\mathrm{L}}^{(\mathrm{b})}\right)}{\log\left(q_{\mathrm{mL}}^{(\mathrm{a})}\right) - \log\left(q_{\mathrm{mL}}^{(\mathrm{b})}\right)} \times \left\{ \log\left(q_{\mathrm{mL}}^{(\mathrm{st})}\right) - \log\left(q_{\mathrm{mL}}^{(\mathrm{b})}\right) \right\} \quad (25)$$

11.3 Nominal air flow

The measured air flow rate shall be assumed to be the nominal air flow rate. No correction to nominal conditions is necessary.

11.4 Nominal fan power

The fan power is dependent on the density of the air. Therefore the fan power at standard conditions shall be calculated as follows:

$$P_{fan}^{(st)} = P_{fan} \times \frac{1013,25}{p_{atm}} \qquad (26)$$

where

P_{fan} and p_{atm} are the values measured during the air flow rate test.

NOTE For the purposes of this standard a correction for air temperature within the permissible deviations is considered not to be necessary. The atmospheric pressure cannot be influenced and therefore a correction is regarded to be necessary because of the strong influence of air density on the fan power.

12 Test report

The test report shall be in accordance with EN ISO/IEC 17025. The test report shall at least contain:

a) date;

b) test institute;

c) test location;

d) test method;

e) test supervisor;

f) test object designation:

  1) type;

  2) serial number;

  3) name of the manufacturer;

g) the reference of the refrigerant properties including version number;

h) type of liquid and concentration;

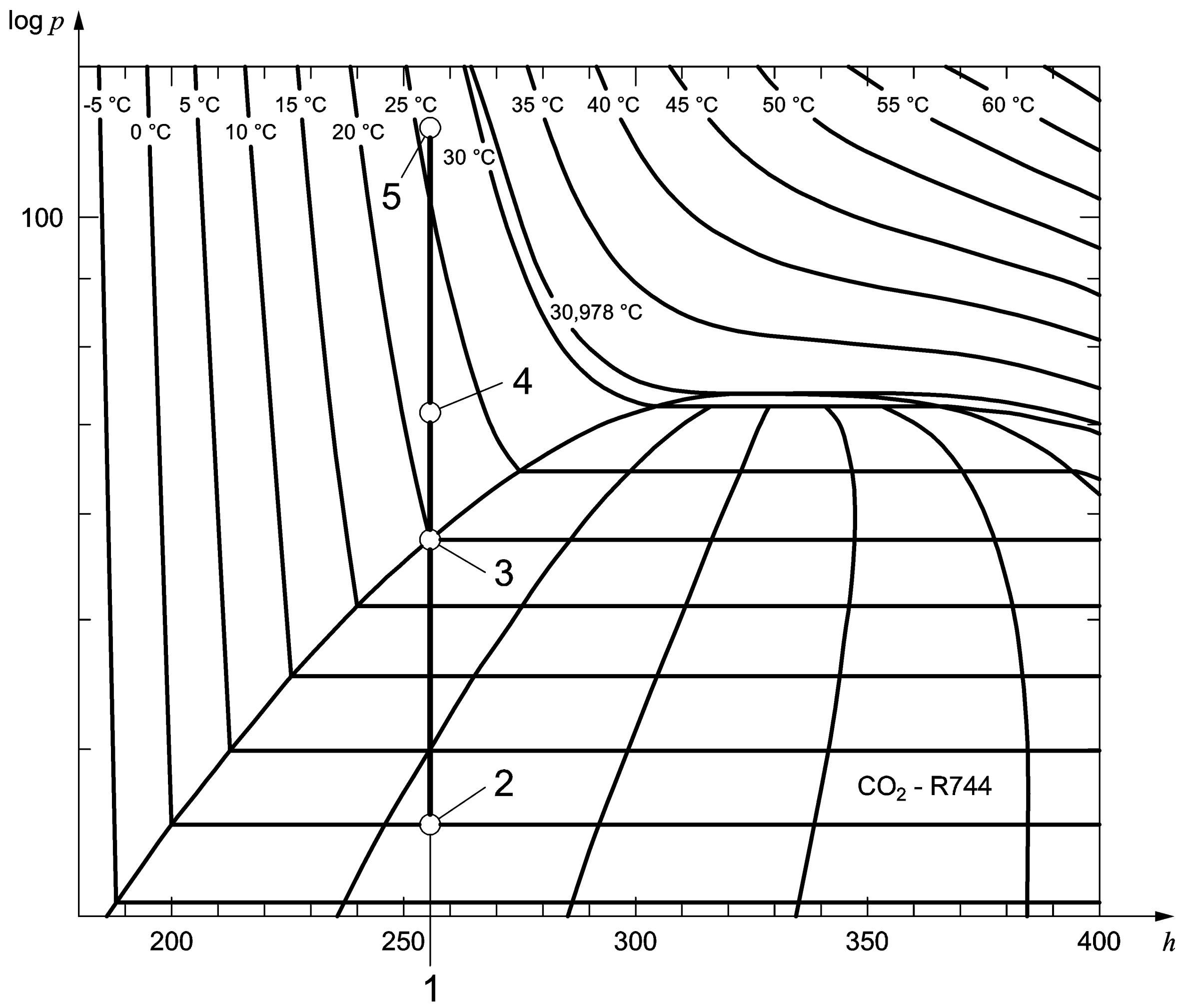
i) the reference of the liquid properties including version number;

j) reference to this European Standard;

k) relevant measured values, see 9.3.7 and 9.4.

Annex A
(informative)
Bubble point temperature

A.1 Diagram bubble point temperature



Key

1 enthalpy h_{bp} at t_{bp}

2 outlet EXV

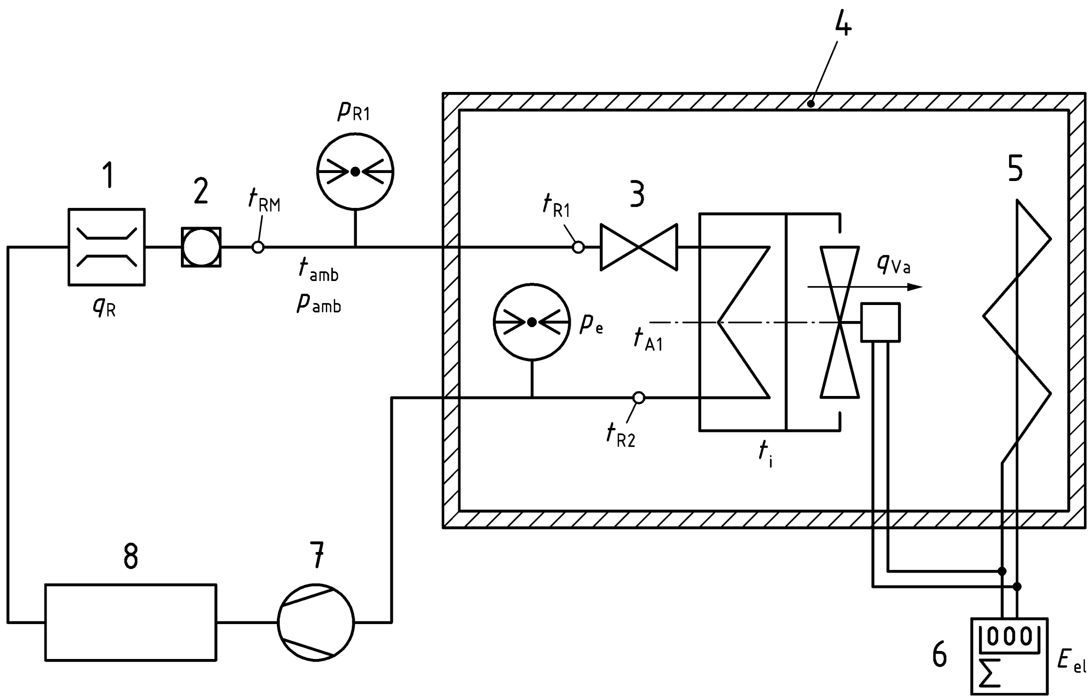
3 bubble point temperature t_{bp}

4 inlet EXV subcritical

5 inlet EXV supercritical

Figure A.1 — Bubble point temperature

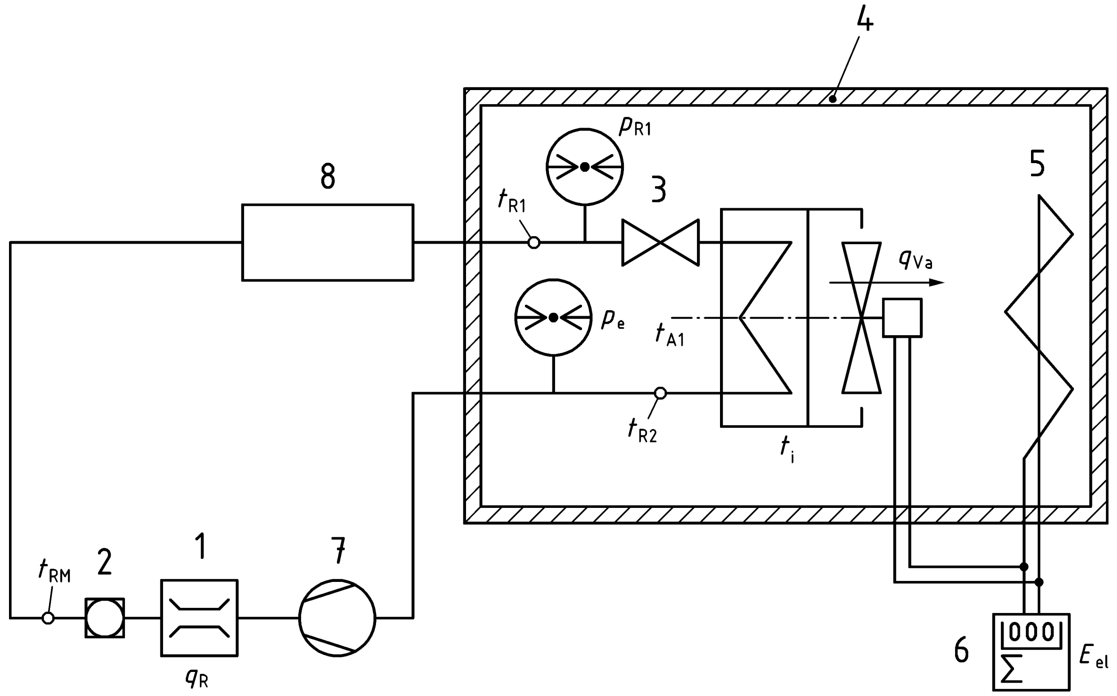
Annex B
(normative)
Test installation for direct expansion operation



Key

1 refrigerant flow meter
2 sight glass
3 expansion device
4 calorimeter room enclosure
5 heater
6 electric supply meter
7 compressor
8 condensing unit

Figure B.1 — Test installation for direct expansion operation

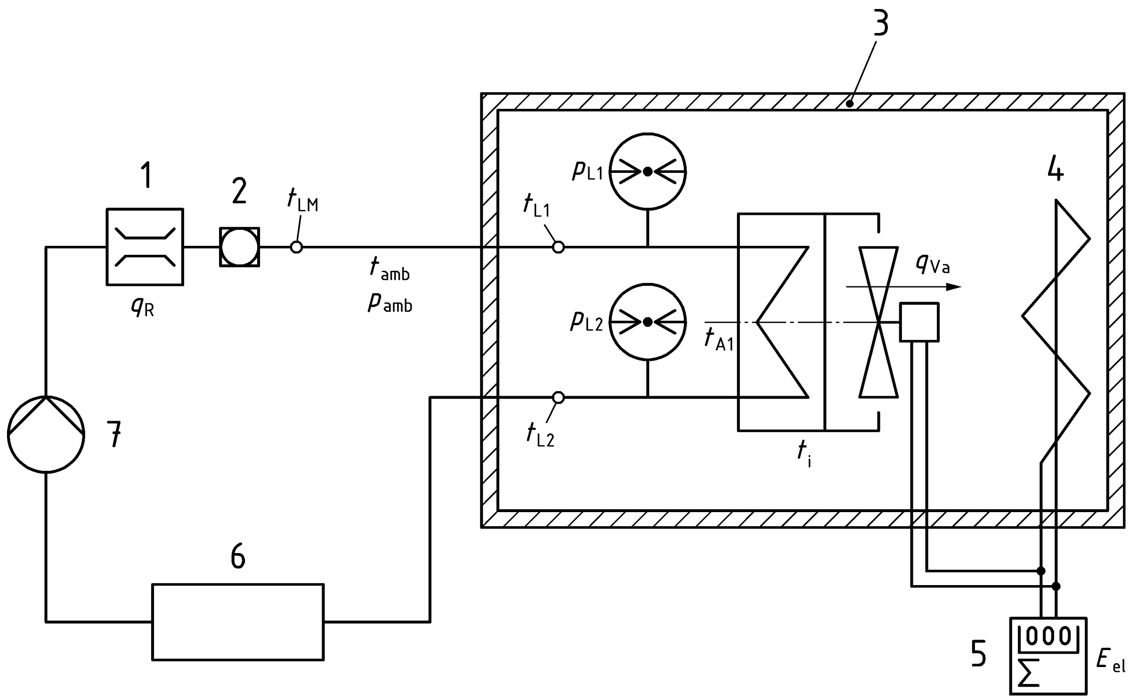


Key

1	refrigerant flow meter
2	sight glass
3	expansion device
4	calorimeter room enclosure
5	heater
6	electric supply meter
7	compressor
8	gas cooler

Figure B.2 — Test installation for supercritical direct expansion operation

Annex C
(normative)
Test installation for liquids

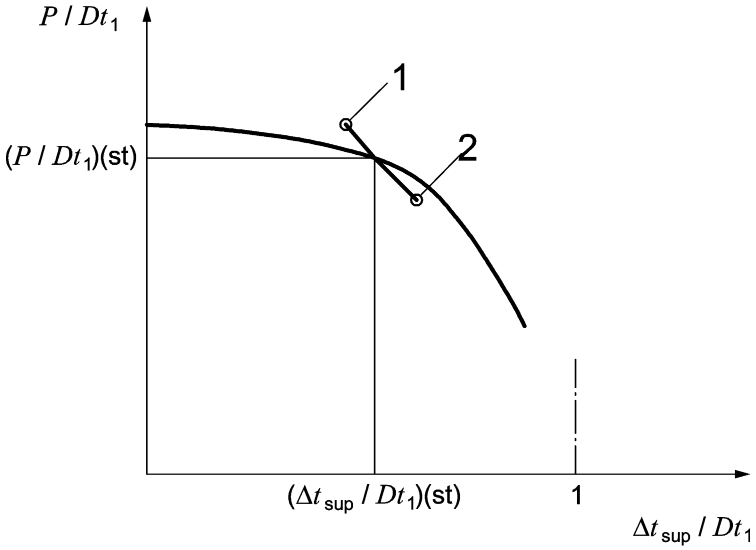


Key

1 liquid flowmeter
2 sight glass
3 calorimeter room enclosure
4 heater
5 electric supply meter
6 liquid cooler
7 pump

Figure C.1 — Test installation for liquids

Annex D
(informative)
Superheating and capacity



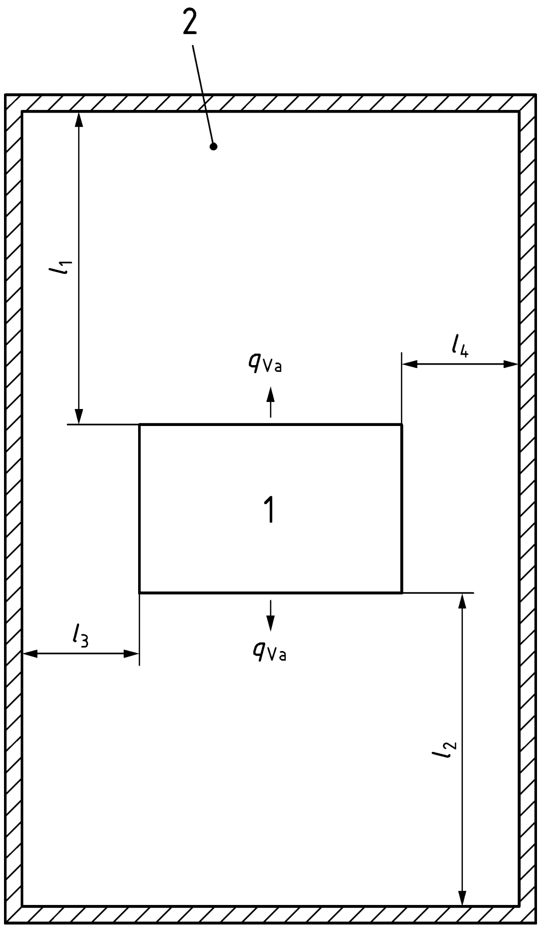
Key

1 measuring point a

2 measuring point b

Figure D.1 — Superheating and capacity

Annex E
(normative)
Test arrangement

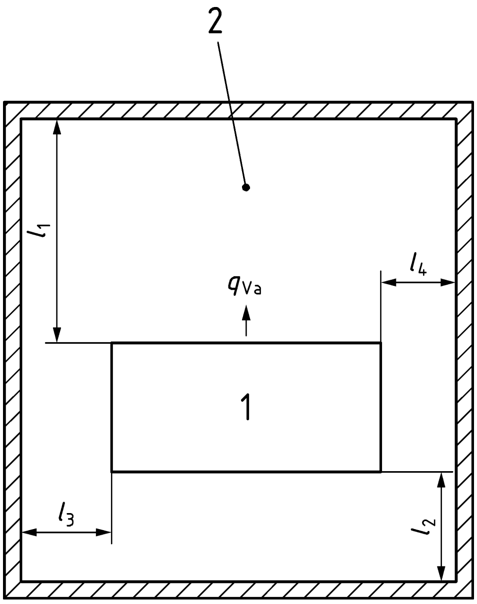


$$l_1, l_2 \geq 1,5 \times \sqrt{A \times B}$$
$$l_3, l_4 \geq 0,75 \times \sqrt{A \times B}$$

Key

1 unit cooler
2 calorimeter room
l_1 distance 1 unit cooler wall
l_2 distance 2 unit cooler wall
l_3 distance 3 unit cooler wall
l_4 distance 4 unit cooler wall

Figure E.1 — Minimum distances for dual discharge



$$l_1 \geq 1,5 \times \sqrt{A \times B}$$
$$l_3, l_4 \geq 0,75 \times \sqrt{A \times B}$$
l_2 according to manufacturer's specification

Key

1 unit cooler
2 calorimeter room
l_1 distance 1 unit cooler wall
l_2 distance 2 unit cooler wall
l_3 distance 3 unit cooler wall
l_4 distance 4 unit cooler wall

Figure E.2 — Minimum distances for single discharge

Annex F
(normative)
Operation with liquid overfeed by pump circulation

F.1 Scope

This annex applies to unit air coolers for refrigeration, operating with liquid overfeed by pump circulation of a refrigerant. It deals mainly with the confirming method for the assessment of the capacity. Unless otherwise specified in this annex, reference should be made to the main body of this standard.

F.2 Standard conditions

The standard conditions for operation with liquid overfeed by pump circulation are given in Table F.1 and Table F.2

Table F.1 — Standard conditions for operation with liquid overfeed by pump circulation

Standard condition	t_{A1} °C	t_{dp} °C	t_e °C	*rr*	t_{R1} °C
SC1	+10	< - 2	0	2	30
SC2	0	< −10	- 8	2	30
SC3	- 18	< - 27	- 25	2	20
SC4	- 25	< - 33	- 31	2	20
SC5	- 34	< - 42	- 40	2	20
NOTE It is essential that the oil content be below 1 % of mass.					

Table F.2 — Standard condition for operation with CO_2 with liquid pump circulation

Standard condition	t_{A1} °C	t_{dp} °C	t_e °C	*rr*	t_{bp} °C
SC1	+10	< - 2	0	2	20
SC2	0	< −10	- 8	2	20
SC3	- 18	< - 27	- 25	2	10
SC4	- 25	< - 33	- 31	2	10
SC5	- 34	< - 42	- 40	2	10
NOTE It is essential that the oil content be below 1 % of mass.					

NOTE The superheating at the vapour outlet of the separator, which will be close to zero, and the subcooled liquid refrigerant temperature are only used for capacity calculation. Therefore, a fixed value on principle is not necessary. So for the subcooled liquid refrigerant temperature a convenient value was chosen.

F.3 Measurements

F.3.1 Uncertainty of measurements

The uncertainty of measurement for the recirculated refrigerant flow rate shall be not more than ± 15 % of the measured value.

F.3.2 Measurement criteria

The recirculated refrigerant flow rate shall be measured by a mass flow metre which does not cause significant pressure drop in order to prevent generation of flash gas.

The oil content shall be determined from a probe taken at the unit cooler inlet.

Care shall be taken with non azeotropic refrigerants, that concentration differences in the refrigerant cycle do not influence the repeatability of test results.

The ambient temperature around the refrigerant installation shall be measured such that it is representative for the calculation of the heat exchange with the ambient.

F.4 Testing methods and equipment

F.4.1 Testing methods

F.4.1.1 General

The testing method and the measuring points are shown in Figure F.1.

F.4.1.2 Primary test method

For the primary test method see main body of this standard.

F.4.1.3 Confirming test method

The principle of this method is to measure the refrigerant flow rate through the expansion device and to multiply it by the difference between the specific enthalpies at the inlet to the expansion device and at the outlet connection to the compressor of the liquid separator.

The specific enthalpy difference of the refrigerant shall be determined from the temperature and pressure measurements and physical properties of the refrigerant.

NOTE For a well insulated installation it can be assumed that the capacity thus determined is sufficiently equal to the unit air cooler's real capacity. At the cooler's connections it is impossible to determine the enthalpies and moreover, the measurement of the recirculated refrigerant flow rate is too uncertain.

F.4.2 Testing equipment

F.4.2.1 The pipes connecting the unit cooler to the measuring installation, as well as the installation itself, particularly the liquid separator, shall be insulated thoroughly. The heat flow absorbed shall be below 0,5 % of the measured capacity. No moisture shall condense on the test installation.

F.4.2.2 The flow metre in the low pressure circuit shall be placed between two sight glasses in order to check the presence of flash gas.

F.4.2.3 Expansion device

In order to obtain the specific enthalpy of the refrigerant (primary) at the unit cooler inlet, the expansion point shall be placed as close to the inlet of the separator as possible. Any expansion device is accepted.

F.4.2.4 Liquid traps

For non-azeotropic refrigerants care shall be taken that liquid accumulations, necessary for the operation, do not influence measurably the concentration in the cooler.

F.5Test procedures

F.5.1 Calibration of the refrigerant side of the installation

A calculation model shall be established in accordance with the state of the art, as a calibration of the refrigerant cycle between the points for determining the enthalpies for the capacity calculation is considered to be too uncertain.

F.5.2 Capacity measurements

F.5.2.1 Steady-state conditions

The measurement of the cooling capacity shall be carried out in steady-state conditions which shall be reached at least half an hour before the test commences.

Steady-state conditions are assumed to have been reached and maintained when all changes and periodic fluctuations during test duration remain within the following ranges:

a) Refrigerant temperature at the inlet of expansion device;	t_{R1};	±3,0 K;
b) Refrigerant temperature at the inlet of the expansion device in transcritical operation;	t_{R1};	±0,1 K;
c) Refrigerant pressure at the inlet of the expansion device in transcritical operation;	p_{R1};	±0,5 bar;
d) Vapour outlet temperature;	t_{R2};	±0,5 K;
e) Refrigerant flow rates.	q_{mR}, q_{mRPu};	±3,0 %.

In order to ensure that steady-state conditions are maintained, all important data shall be continuously monitored at intervals small enough to identify all significant fluctuations.

F.5.2.2 Permissible deviations

In order to retain sufficient accuracy when converting the measured capacity to the standard conditions, the mean test conditions shall be within the following deviations from the standard conditions:

rr	±10 %	
Δt_{sub}	≥ 5 K	for subcritical operation
t_{R1}	±5 K	
t_{R1}	±1 K	for transcritical operation
p_{R1}	±2,5 bar	for transcritical operation

F.5.2.3 Conducting the test

When the recirculation rate deviates by not more than ± 10 % from the standard value, only a single test is required.

For larger deviations up to ± 30 %, duplicate tests (a) and (b) shall be run, one above and one below the standard value.

The following data shall be recorded for each of the tests:

- t_{A1}, t_{dp}, t_{amb}, t_i, (values at individual measuring points)
- t_{R1}, t_{R2}, t_{R3};
- p_{atm}, p_e, p_{e1}, p_{e2}, p_{R1};
- q_{vR} and t_{RM} or q_{mR}, q_{mRPu};
- ambient temperature around the refrigerant side installation
- liquid refrigerant level in the separator
- oil content in the unit cooler
- E_{el}, τ
- when applicable: q_{mR} or q_{vW}, t_{W1}, t_{W2}

F.6 Capacity calculations

For each individual test the following calculations apply:

F.6.1 Confirming method

The cooling capacity is calculated by the following formula:

$$P_2 = q_{\mathrm{mR}} \times (h_{\mathrm{R2}} - h_{\mathrm{R1}}) \tag{F.1}$$

F.6.2 Recirculation rate for pump circulation

$$rr = \frac{q_{mRPu}}{(P_2 \ / \ \Delta h_o)} \tag{F.2}$$

F.7 Conversion to standard conditions

F.7.1 Cooling capacity

The standard capacity is obtained by linear interpolation of the test results over the recirculation rate according to the following procedure:

$$P^{(a)} = \left[P_M{}^{(a)} \ / \ Dt_1^{(b)} \right] \times Dt_1^{(st)} \times F^{(a)} \tag{F.3}$$

$$P^{(b)} = \left[P_M{}^{(b)} \ / \ Dt_1^{(b)} \right] \times Dt_1^{(st)} \times F^{(b)} \tag{F.4}$$

$$P^{(st)} = p^{(b)} + \frac{\left[p^{(a)} - p^{(b)} \right]}{\left[rr^{(a)} - rr^{(b)} \right]} \times \left[rr^{(st)} - rr^{(b)} \right] \tag{F.5}$$

When the recirculation rate deviates by not more than ± 10 % from the standard value, the standard capacity is $P^{(a)}$.

F.7.2 Refrigerant side pressure drop

NOTE Contrary to direct expansion operation where the refrigerant side pressure drop is a design criterion for pump circulation operation, it is an application data for the selection of the pump.

F.7.2.1 Single test

a) Determine:

$$\Delta p_R{}^{(a)} = \left[p_{R1} - p_{R2} \right]^{(a)} \tag{F.6}$$

$$q_{mRPu}{}^{(st)} = \frac{P^{(st)} \times rr^{(st)}}{\Delta h_o{}^{(st)}} \tag{F.7}$$

b) Standard liquid side pressure drop is determined according to:

$$\Delta p_R{}^{(st)} = \Delta p_R{}^{(a)} \times \left\{ \frac{q_{mRPu}{}^{(st)}}{q_{mRPu}{}^{(a)}} \right\}^{1,8} \tag{F.8}$$

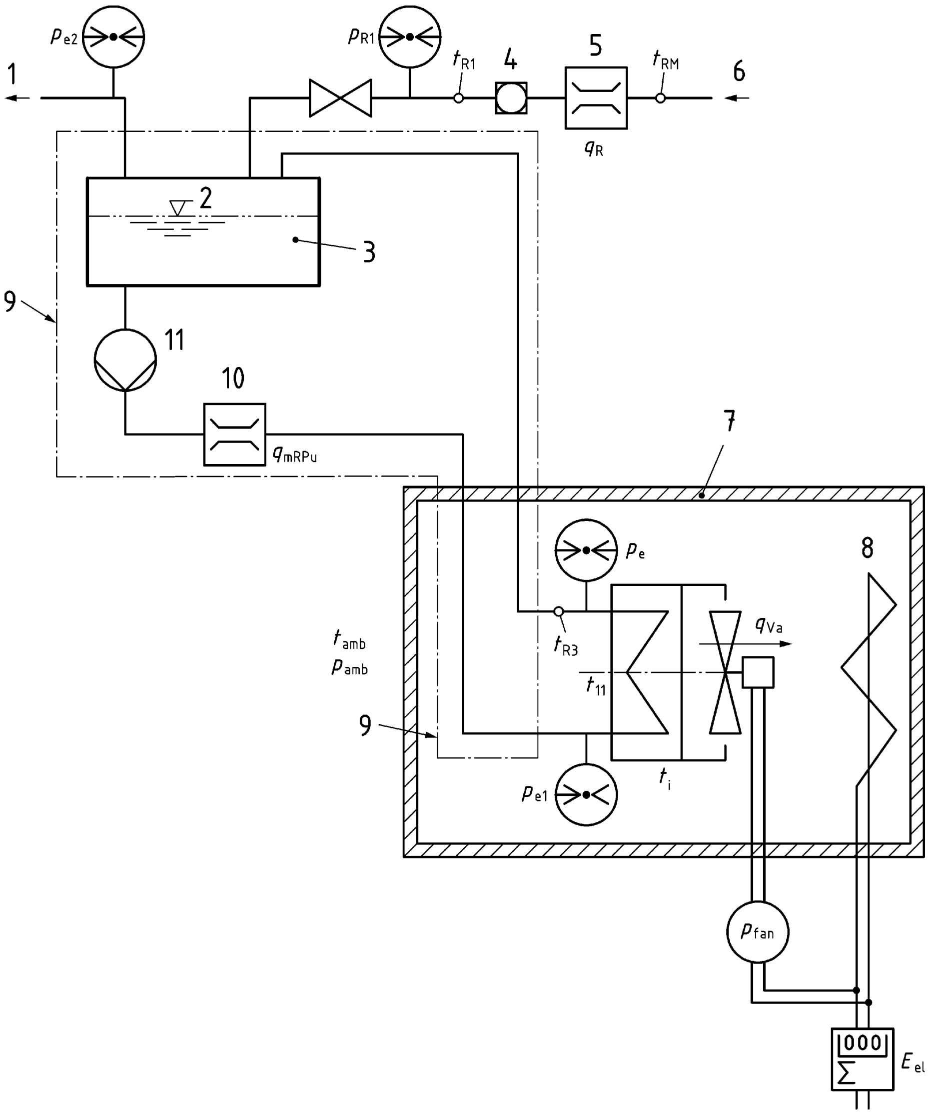
where

$q_{mRPu}{}^{(a)}$ is the measured value

NOTE 1,8 is an empirical value, considering that the exponent normally lies between 1,5 and 2. Therefore for a single test the accuracy is sufficient. Within the specified deviations, the influence of the recirculation rate is considered to be negligible.

F.7.2.2 Duplicate tests

As a simple linear interpolation method is not applicable, a conversion to standard conditions shall be executed by use of a calculation model in accordance with the state of the art and verified by the measured results.



Key

1 to compressor

2 refrigerant level

3 separator

4 sight glass

5 flowmeter refrigerant

6 from condenser

7 calorimeter room enclosure

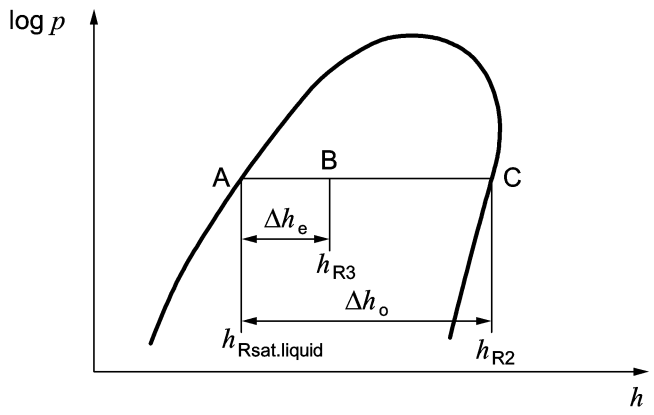
8 heater

9 insulation

10 mass flowmeter refrigerant

11 pump

Figure F.1 — Circuit diagram for pump circulation



Key

A saturated liquid refrigerant at unit cooler inlet

B refrigerant at unit cooler outlet connection

C saturated refrigerant vapour at unit cooler outlet connection

Figure F.2 — Definition of recirculation rate

The recirculation rate *r r* is defined as follows:

$r\,r = \Delta h_o / \Delta h_e$

Annex G
(informative)
Procedure to measure the oil content

The oil content should be measured under steady-state conditions, immediately after the capacity test has been finished. The probe should be extracted from the liquid line directly before the expansion device.

The following procedure for measuring the oil content is recommended. Other methods are acceptable, provided that the required accuracy is achieved.

a) Evacuate the pressure vessel for the oil/refrigerant mixture sample, having a volume of 100 cm^3 to 200 cm^3;

b) Weigh the empty vessel with an accuracy of ± 0,1 g;

c) Connect this vessel to the liquid cooler at the appropriate position;

d) Weigh the vessel filled with the test sample with an accuracy of ± 0,1 g;

e) Evaporate the refrigerant carefully in order to prevent any escape of oil with the refrigerant and evacuate the vessel. The refrigerant is to be recovered;

f) Add a solvent to the remaining oil (e.g.methylchloroform) in the vessel. Shake the mixture carefully and put it into an evaporating pan which has been weighed accurately to ± 1 mg. Following this, rinse the vessel twice with the solvent and put this mixture into the pan also;

g) Evaporate the solvent by means of a boiling water bath;

h) Weigh the evaporation pan with the oil accurately to ± 1 mg;

i) The oil content is obtained by dividing the difference of the weights of the evaporating pan with and without the remaining oil by the difference of the weights of the pressure vessel with and without the refrigerant/oil test sample.

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