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Methods of test and characterization of performance for energy recovery components

Méthode d'essai et caractérisation des performances des composants récupérateurs d'énergie

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 86, *Refrigeration and air-conditioning*, Subcommittee SC 6, *Testing and rating of air-conditioners and heat pumps*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Methods of test and characterization of performance for energy recovery components

1 Scope

This document specifies methods for testing and characterizing the performance of air-to-air heat/energy exchangers when used as devices to transfer heat or heat and water vapor between two airstreams used in ventilation systems. It also specifies methods to characterize the performance of exchangers for use in calculation of the energy performance of buildings. This document is applicable to:

— fixed-plate exchangers (also known as recuperators),

— rotary exchangers, including heat wheels and total energy wheels (also known as regenerators),

— heat pipe exchangers using a heat transfer medium, excluding those using mechanical pumping.

This document does not provide a method for measuring the response of exchangers to the formation of frost.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3966, *Measurement of fluid flow in closed conduits — Velocity area method using Pitot static tubes*

ISO 5167-1, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements*

ISO 5801, *Fans — Performance testing using standardized airways*

ISO 13253, *Ducted air-conditioners and air-to-air heat pumps — Testing and rating for performance*

ISO/IEC 17025:2017, *General requirements for the competence of testing and calibration laboratories*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
effectiveness
actual energy transfer rate (sensible, latent, or total) divided by the maximum possible energy transfer rate

Note 1 to entry: The formula for effectiveness is given in 5.2.

3.2
exhaust air transfer ratio
EATR
tracer gas concentration difference between the *leaving supply air* (3.12) and the *entering supply air* (3.11), divided by the tracer gas concentration difference between the *entering exhaust air* (3.13) and the entering *supply air* (3.11), which quantifies the air quantity transferred from the exhaust to the supply

Note 1 to entry: The formula for EATR is given in 5.6.

Note 2 to entry: It can be expressed as a percentage for rating purposes, but is used as a ratio in the calculation of RER (3.6).

3.3
fixed-plate exchanger
exchanger with multiple alternate airflow channels, separated by a heat or heat and water vapor transfer plate(s) and connected to supply and exhaust airstreams

3.4
heat pipe exchanger
exchanger with an array of finned and sealed tubes that are placed in side-by-side supply and exhaust airstreams, which may include an internal wick structure in each tube, and filled with a heat transfer medium

Note 1 to entry: Thermosiphon exchangers are a subset (or type) of heat pipe exchanger in which the heat transfer medium moves by gravitational forces only.

3.5
outside air correction factor
OACF
factor defined as the *entering supply air* (3.11) divided by the *leaving supply air* (3.12)

Note 1 to entry: The formula for OACF is given in 5.5.

3.6
recovery efficiency ratio
RER
ratio of the recovered energy rate divided by the sum of the calculated combined fan power and the auxiliary power

Note 1 to entry: The formula for RER is given in 5.4.

Note 2 to entry: RER can be characterized as gross, or as net in which case EATR (3.2) is accounted for.

3.7
rotary exchanger
exchanger with porous discs, fabricated from materials with heat or heat and water vapor retention capacity, that are regenerated by collocated supply and exhaust airstreams

3.8
standard air
dry air with a density of 1,204 3 kg/m^3 and a dynamic viscosity of 1,824 7 x 10^{-5} kg/(m·s)

Note 1 to entry: These conditions approximate dry air at 20 °C and 101,325 kPa absolute.

3.9
station
location in the test apparatus at which conditions such a temperature, humidity, pressure or airflows are measured

Note 1 to entry: indicated in Figure 1 as 1, 2, 3 and 4.

3.10
static pressure differential
static pressure at supply outlet minus the static pressure at exhaust inlet

Note 1 to entry: A positive pressure differential occurs when the static pressure at *station* (3.9) 2 is higher than the static pressure at station 3. A negative pressure differential occurs when the static pressure at station 2 is lower than the static pressure at station 3.

3.11
entering supply air
supply air inlet
outdoor airflow
OA
outside air entering the exchanger

Note 1 to entry: Indicated in Figure 1 as 1.

3.12
leaving supply air
supply air outlet
supply airflow
SA
outside air after passing through the exchanger

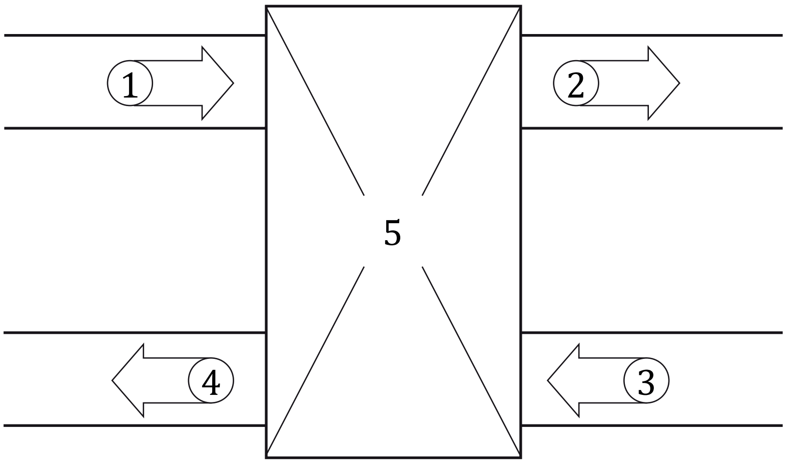
Note 1 to entry: Indicated in Figure 1 as 2.

3.13
entering exhaust air
exhaust air inlet
return airflow
RA
indoor air entering the exchanger

Note 1 to entry: Indicated in Figure 1 as 3.

3.14
leaving exhaust air
exhaust air outlet
exhaust airflow
EA
indoor air after passing through the exchanger

Note 1 to entry: Indicated in Figure 1 as 4.



Key

1 entering supply air
2 leaving supply air
3 entering exhaust air
4 leaving exhaust air
5 exchanger

Figure 1 — Schematic diagram of airflows for heat and energy recovery exchangers

4 Symbols and abbreviated terms

Symbol	Term	Units
C_i	Tracer gas concentration at station *i* (*i* = 1, 2, 3, 4)	10^{-6}
c_p	Specific heat of condensate at its measured temperature	kJ/(kg·°C)
$c_{p,i}$	Specific heat of dry air at station *i* (*i* = 1, 2, 3, 4)	J/(kg·°C)
δT_i	Maximum deviation of any temperature reading of T_i from $T_{AVE,i}$	K
δW_i	Maximum deviation of any humidity ratio reading of W_i in from $W_{AVE,i}$	kg water / kg dry air
ΔP_e	Pressure drop through the exchanger, exhaust air stream, measured	Pa
$\Delta P_{e,ref}$	Pressure drop through the exchanger, exhaust air stream, at reference conditions	Pa
ΔP_s	Pressure drop through the exchanger, supply air stream, measured	Pa
$\Delta P_{s,ref}$	Pressure drop through the exchanger, supply air stream, at reference conditions	Pa
$\Delta ps_{2,3}$	Static pressure differential	Pa
$\Delta T_{1\text{-}2}$	Temperature change in the supply airstream	°C or K
$\Delta W_{1\text{-}2}$	Humidity change in the supply airstream	kg water / kg dry air
ε	Effectiveness	%
$\varepsilon_{sensible}$	Sensible effectiveness	%
ε_{latent}	Latent effectiveness	%
ε_{total}	Total effectiveness	%
F_{oac}	Outside air correction factor (OACF)	1 [a]
h_i	Enthalpy of air at station *i* (*i* = 1, 2, 3, 4)	kJ/kg dry air

[a] Some quantities of dimension 1 are defined as ratios of two quantities of the same kind. The coherent derived unit is the number 1 (ISO 80000-1:2009, 3.8).

[b] T_e and W_e are defined and discussed in Annex E.

Symbol	Term	Units
h_{fg}	Heat of vaporization of water	J/kg
$\dot{m}_{condensate}$	Measured condensate flow rate	kg/s
$\dot{m}_i$	Mass flow rate of dry air at station *i* (*i* = 1, 2, 3, 4)	kg/s
m_s/m_e	Ratio of supply air outlet mass flow rate to exhaust air inlet mass flow rate	1 [a]
$\eta_{fs,fe}$	Combined efficiencies of the supply and exhaust air fan and drive	1 [a]
ps_i	Static pressure at station *i* (*i* = 1, 2, 3, 4)	Pa
q_{aux}	Auxiliary power input to the exchanger (e.g. to rotate a wheel)	kW
Q_{latent}	Humidity transfer rate	kg water/(kg dry air · s)
$Q_{sensible}$	Sensible energy transfer rate	W
Q_{total}	Total energy transfer rate	W
Q_2	Leaving supply volume flow rates	m^3/s
Q_3	Entering exhaust volume flow rates	m^3/s
ρ_i	Dry air density at station *i* (*i* = 1, 2, 3, 4)	kg/m^3
R_{eat}	Exhaust air transfer ratio (EATR)	1 [a]
$R_{rer,gross}$	Gross recovery efficiency ratio (gross RER)	W/W
$R_{rer,net}$	Net recovery efficiency ratio (net RER)	W/W
Θ	Purge angle	°
$T_{AVE,i}$	Average value of temperature readings taken at station *i* (*i* = 1, 2, 3, 4) during a measurement period	°C
$T_{condensate}$	Measured temperature of the condensate	°C
T_e	Temperature efficiency	% [b]
T_i	Dry-bulb temperature at station *i* (*i* = 1, 2, 3, 4)	°C
$T_{WB,i}$	Wet-bulb temperature at station *i* (*i* = 1, 2, 3, 4)	°C
U	Expanded relative uncertainty	1 [a]
$W_{AVE,i}$	Average value of humidity readings taken at station *i* (*i* = 1, 2, 3, 4) during a measurement period	kg water/kg dry air
W_e	Humidity efficiency	% [b]
W_i	Humidity at station *i* (*i* = 1, 2, 3, 4)	kg water/kg dry air
μ_i	Dynamic viscosity at station *i* (*i* = 1, 2 3 or 4)	kg/(m·s)
μ_s	Dynamic viscosity of standard air = 1,824 7 x 10^{-5}	kg/(m·s)

[a] Some quantities of dimension 1 are defined as ratios of two quantities of the same kind. The coherent derived unit is the number 1 (ISO 80000-1:2009, 3.8).

[b] T_e and W_e are defined and discussed in Annex E.

5 Metrics

5.1 General

The performance of an air-to-air heat/energy exchanger is primarily characterized by its sensible, latent, and total effectiveness [see Formulae (1), (2) and (3)] its pressure drops [see Formulae (4), (5), (6) and (7)], its recovery efficiency ratio [see Formulae (8) and (9)], the outside air correction factor [see Formula (10)], and its exhaust air transfer ratio [see Formula (11)]. Formulae (1) to (3) reproduced with permission from ANSI/ASHRAE 84:2020. Formulae (4) through (11) are based on formulae in ANSI/ASHRAE 84-2020 with permission from ANSI/ASHRAE. Annex E provides guidance on equivalence between the metrics provided in this document and related metrics in use in certain other standards.

Derived metrics that are needed for use in calculating the performance of complete systems include sensible energy transfer rate (see Formula (12)), humidity transfer rate (see Formula (13) and enthalpy transfer rate (see Formula (14)).

See Clause 4 for the units of different quantities.

5.2 Effectiveness

The sensible, latent, and total effectiveness ($\varepsilon_{\text{sensible}}$, $\varepsilon_{\text{latent}}$ and $\varepsilon_{\text{total}}$) are defined by Formulae (1), (2) and (3):

$$\varepsilon_{\text{sensible}} = \frac{\dot{m}_2 \left(c_{p,1} T_1 - c_{p,2} T_2\right)}{\dot{m}_{\text{min}} \left(c_{p,1} T_1 - c_{p,3} T_3\right)} \quad (1)$$

$$\varepsilon_{\text{latent}} = \frac{\dot{m}_2 \left(h_{\text{fg},1} W_1 - h_{\text{fg},2} W_2\right)}{\dot{m}_{\text{min}} \left(h_{\text{fg},1} W_1 - h_{\text{fg},3} W_3\right)} \quad (2)$$

$$\varepsilon_{\text{total}} = \frac{\dot{m}_2 \left(h_1 - h_2\right)}{\dot{m}_{\text{min}} \left(h_1 - h_3\right)} \quad (3)$$

where

$\dot{m}_i$ is the mass flow rate at station i (i = 1, 2 or 3)

$\dot{m}_{\text{min}}$ is the lesser of $\dot{m}_2$ and $\dot{m}_3$

$c_{p,i}$ is the specific heat of dry air at station i (i = 1, 2 or 3)

$h_{\text{fg},i}$ is the heat of vaporization of water at station i (i = 1, 2 or 3)

T_i is the dry-bulb temperature at station i (i = 1, 2 or 3)

W_i is the humidity at station i (i = 1, 2 or 3)

h_i is the enthalpy at station i (i = 1, 2 or 3)

5.3 Pressure drop

5.3.1 Measured pressure drop

The air friction pressure drops (ΔP_{s} and ΔP_{e}) at specific conditions and air mass flow rate through the exchanger are defined by Formulae (4) and (5):

$$\Delta P_{\text{s}} = ps_1 - ps_2 \quad (4)$$

$$\Delta P_{\text{e}} = ps_3 - ps_4 \quad (5)$$

where ps_{i} is the static pressure at station i (i = 1, 2, 3 or 4).

5.3.2 Standardized pressure drop

Air friction pressure drops at reference conditions ($\Delta P_{s,ref}$ and $\Delta P_{e,ref}$)can be determined by Formulae (6 and (7):

$$\Delta P_{s,ref} = \left| ps_1 \left(\frac{\rho_1}{\rho_s}\right)\left(\frac{\mu_s}{\mu_1}\right) - ps_2 \left(\frac{\rho_2}{\rho_s}\right)\left(\frac{\mu_s}{\mu_2}\right) \right| \quad (6)$$

$$\Delta P_{e,ref} = \left| ps_3 \left(\frac{\rho_3}{\rho_s}\right)\left(\frac{\mu_s}{\mu_3}\right) - ps_4 \left(\frac{\rho_4}{\rho_s}\right)\left(\frac{\mu_s}{\mu_4}\right) \right| \quad (7)$$

where

ρ_i is the density at station i (i = 1, 2, 3 or 4) kg/m^3

ρ_s is the standard density of air = 1,2043 kg/m^3

μ_i is the dynamic viscosity at station i (i = 1, 2 3 or 4) kg/(m·s)

μ_s is the dynamic viscosity of standard air = 1,8247 x 10^{-5} kg/(m·s)

5.4 Recovery efficiency ratio

a) The gross recovery efficiency ratio ($R_{rer,gross}$) of a heat/energy exchanger is defined by Formula (8):

$$R_{rer,gross} = \frac{\dot{m}_2 \left| h_1 - h_2 \right|}{\dfrac{\Delta P_s Q_2}{1000 \cdot \eta_{fan,s}} + \dfrac{\Delta P_e Q_3}{1000 \cdot \eta_{fan,e}} + q_{aux}} \quad (8)$$

b) The net recovery efficiency ratio ($R_{rer,net}$) of a heat/energy exchanger is defined by Formula (9):

$$R_{rer,net} = \frac{\dot{m}_2 \left| h_1 - \dfrac{h_2 - (R_{eat})\, h_3}{(1 - R_{eat})} \right|}{\dfrac{\Delta P_s Q_2}{1000 \cdot \eta_{fan,s}} + \dfrac{\Delta P_e Q_3}{1000 \cdot \eta_{fan,e}} + q_{aux}} \quad (9)$$

where

ΔP_s and ΔP_e are the measured pressure drops across the supply and exhaust sides of the exchanger, respectively

Q_2 and Q_3 are the leaving supply and entering exhaust volume flow rates

η_{fs} and η_{fe} is the supply and exhaust air fan and drive combined efficiencies

$q_{aux.}$ is the total auxiliary power input to the exchanger (e.g. to rotate a regenerative wheel, a pump, and to operate controls)

R_{eat} is the exhaust air transfer ratio (EATR) expressed as a ratio

In laboratory testing of heat/energy exchangers it is not usually possible to measure the power required to move air through the exchanger directly, as the blowers in the test system also are required to overcome friction pressure of the conditioning equipment, flow measurement equipment, etc. Therefore, the power required to move air through the exchanger shall be calculated, based on a reference fan and drive total efficiency which is selected for the purposes of comparison of one exchanger to another. For example, a performance rating agency could elect to use a reference fan and drive total efficiency of 0,50 in the calculation of RER for all the exchangers for which it provides ratings.

5.5 Outside air correction factor

The outside air correction factor (F_{oac}) of a heat/energy exchanger at a specific operating condition is defined by Formula (10):

$$F_{oac} = \frac{\dot{m}_1}{\dot{m}_2} \tag{10}$$

where $\dot{m}_{1,2}$ are the mass flow rates at stations 1 and 2

5.6 Exhaust air transfer ratio

The exhaust air transfer ratio (R_{eat}) of a heat/energy exchanger at a specific operating condition is defined by Formula (11):

$$R_{eat} = \frac{C_2 - C_1}{C_3 - C_1} \tag{11}$$

where C_i are the concentration of tracer gas at stations i (i = 1, 2, 3 or 4) during the test described in 9.3.

NOTE To express exhaust air transfer ratio as a percentage, multiply by 100.

5.7 Sensible energy transfer rate for the supply airstream

Sensible energy transfer rate ($Q_{sensible}$) into or out of the supply airstream for an exchanger at a specific operating condition is defined by Formula (12):

$$Q_{sensible} = \dot{m}_2 \cdot \left(T_1 c_{p,1} - T_2 c_{p,2}\right) \tag{12}$$

where

T_{1-2} are the temperatures at stations 1 and 2

$c_{p1,2}$ are the specific heats of dry air at stations 1 and 2

5.8 Humidity transfer rate for the supply airstream

Humidity transfer rate (Q_{latent}) into or out of the supply airstream for an exchanger at a specific operating condition is defined by Formula (13):

$$Q_{latent} = \dot{m}_2 \cdot \Delta W_{1-2} \tag{13}$$

where ΔW_{1-2} is the humidity change for the supply airstream.

5.9 Total energy transfer rate for the supply airstream

Total energy transfer rate (Q_{total}) into or out of the supply airstream for an exchanger at a specific operating condition is defined by Formula (14):

$$Q_{total} = \dot{m}_2 \cdot \Delta h_{1-2} \tag{14}$$

where Δh_{1-2} is the enthalpy change for the supply airstream.

6 General test requirements

6.1 Test apparatus

The test apparatus shall consist of four measurement stations. Measurements shall be taken at each station of temperature, humidity, dry air mass flow rate, tracer gas concentration, and static pressure.

6.2 Installation

The equipment to be tested shall be installed in accordance with the manufacturer's instructions. See Figures 2 and 3.

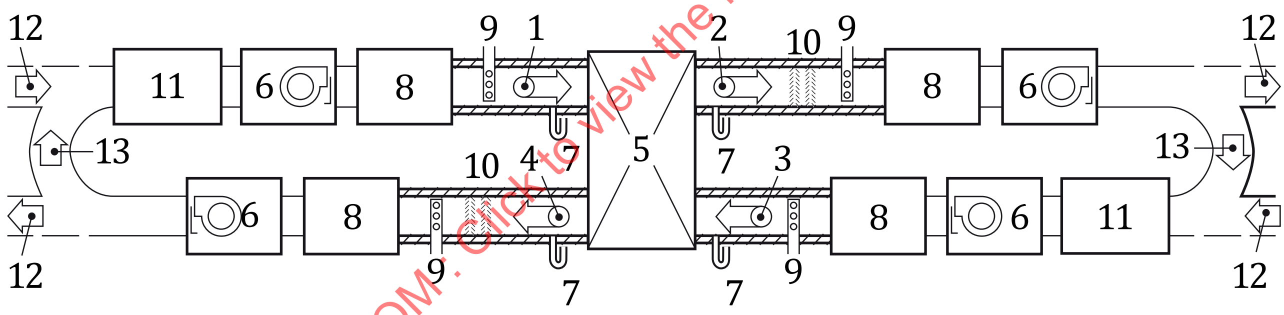
NOTE See Annex B for best practices of connecting an exchanger to test system.

6.3 Static pressures

Static pressures shall be measured according to ISO 3966, ISO 5167-1, ISO 5801 or ISO 13253.

6.4 Instrument calibration

All measurement instruments shall be calibrated using sensors, transfer standards, and primary instruments that are traceable. Calibration shall be consistent with ISO/IEC 17025:2017, 6.4 and 7.4, in order to minimize the bias of the instrument. The calibration curves associated with each instrument shall be available as a permanent record.

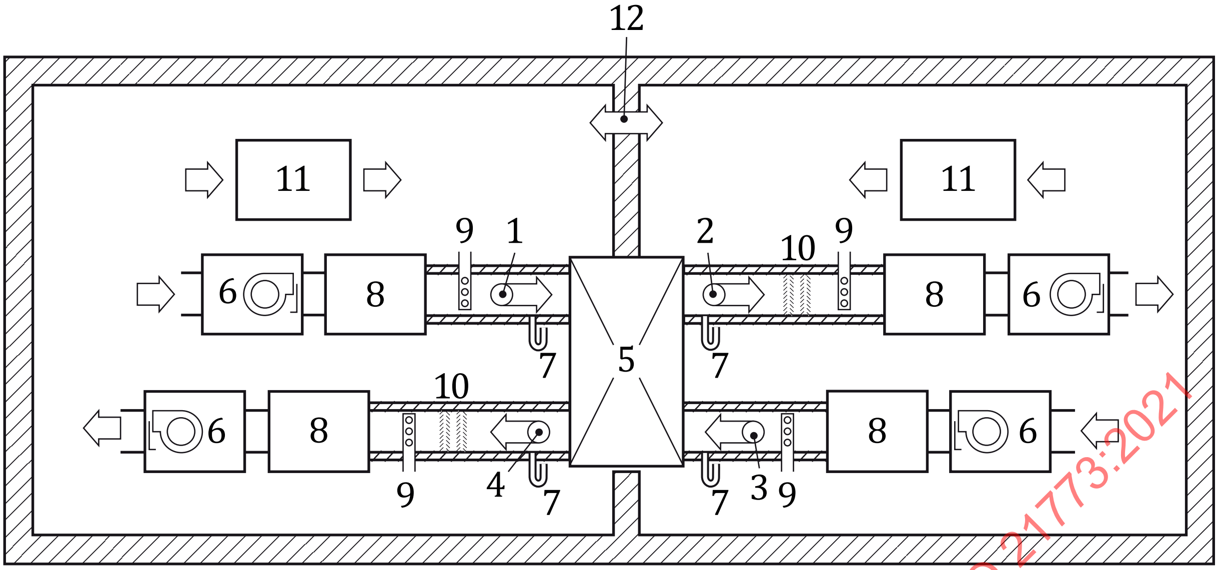


Key

1 entering supply air
2 leaving supply air
3 entering exhaust air
4 leaving exhaust air
5 exchanger
6 static pressure control apparatus
7 static pressure measuring apparatus
8 airflow measuring apparatus
9 temperature, humidity and tracer gas measuring instruments
10 air mixer
11 air conditioning apparatus
12 relief inlet/outlet
13 optional recycling duct

NOTE Refer to ISO 13253:2017, Annex C.

Figure 2 — Basic schematic for ducted measurement setup



Key

1 entering supply air
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6 static pressure control apparatus
7 static pressure measuring apparatus
8 airflow measuring apparatus
9 temperature, humidity and tracer gas measuring instruments
10 air mixer
11 air conditioning apparatus
12 pressure relief

NOTE Refer to ISO 13253:2017, Annex C.

Figure 3 — Basic schematic for 2-room measurement setup

7 Effectiveness tests

7.1 Test requirements

The test duct, measuring equipment, and the equipment under test shall be operated until steady-state equilibrium conditions are attained but for not less than 30 min. The equipment under test shall be operated until steady-state conditions are attained before applicable test data are recorded.

For rotary wheel exchangers, the wheel speed shall be checked before and after each series of test runs.

The air volume flow rates for the test shall be specified by the test requestor for the leaving supply air (station 2) and entering exhaust air (station 3).

Thermal effectiveness tests shall be performed with manufactured-specified static pressure differential between the leaving supply air (station 2) and entering exhaust air (station 3).

7.2 Stability limits when testing effectiveness

When testing effectiveness, the following requirements shall be observed.

During effectiveness tests the inlet dry-bulb temperatures shall remain within limits such that δT_1 and δT_3 shall not exceed the larger of 0,5 K or the value defined in Formulae (15) and (16).

$$\delta T_1 < 0,04 \times \left| T_{AVE,1} - T_{AVE,3} \right| \tag{15}$$

$$\delta T_3 < 0,04 \times \left| T_{AVE,1} - T_{AVE,3} \right| \tag{16}$$

where

δT_1 is the maximum deviation of any temperature reading of T_1 in K from $T_{\text{AVE},1}$

δT_3 is the maximum deviation of any temperature reading of T_3 in K from $T_{\text{AVE},3}$

$T_{\text{AVE},1}$ is the time-averaged mean value of all temperature readings T_1 in K taken at station 1 during the measurement period

$T_{\text{AVE},3}$ is the time-averaged mean value of all temperature readings T_3 in K taken at station 3 during the measurement period

During effectiveness tests the inlet humidity ratios shall remain within limits such that δW_1 and δW_3 shall not exceed the larger of 0,000 4 $\text{kg}_\text{W}/\text{kg}_\text{DA}$ or the value defined in Formulae (17) and (18).

$$\delta W_1 < 0,10 \times \left| W_{AVE,1} - W_{AVE,3} \right| \tag{17}$$

$$\delta W_3 < 0,04 \times \left| W_{AVE,1} - W_{AVE,3} \right| \tag{18}$$

where

δW_1 is the maximum deviation of any humidity ratio reading of W_1 in $\text{kg}_\text{W}/\text{kg}_\text{DA}$ from $W_{AVE,1}$

δW_3 is the maximum deviation of any humidity ratio reading of W_3 in $\text{kg}_\text{W}/\text{kg}_\text{DA}$ from $W_{AVE,3}$

$W_{\text{AVE},1}$ is the time-averaged mean value of all humidity ratio readings W_1 in $\text{kg}_\text{W}/\text{kg}_\text{DA}$ taken at station 1 during the measurement period

$W_{\text{AVE},3}$ is the time-averaged mean value of all humidity ratio readings W_3 in $\text{kg}_\text{W}/\text{kg}_\text{DA}$ taken at station 3 during the measurement period

7.3 Data collection period

For all measurements of thermal performance or leakage, data shall be collected for a period of not less than 30 min, during which the steady-state requirements in 7.2 shall be met.

For measurements of pressure drop through the exchanger, data shall be collected for a period of not less than 5 minutes.

7.4 Data sampling rates

For all tests, sets of data shall be recorded at equal intervals of 1 min or less.

For all tests, at least 30 sets of data shall be collected.

For all measurements of thermal performance or pressure drop, each complete set of data shall be obtained during a period of 10 s or less.

NOTE When testing leakage with tracer gases, it may not be possible to collect a complete set of data within 10 s or less. However, the requirement to collect at least 30 sets of data and to collect data over a period of 30 min still applies.

7.5 Temperature and humidity conditions: inlets to exchanger

Tests at cooling conditions shall be carried out under the conditions given in one or more of the columns T1 through T4 in Table 1. Tests at heating conditions shall be carried out under the conditions given in one or more of the columns T5 through T8 in Table 2.

Table 1 — Conditions of test for thermal tests (cooling)

Parameter		Standard test conditions			
		T1	T2	T3	T4
Temperature of entering supply air (°C)	dry-bulb	35,0			
	wet-bulb	23,0	24,0	31,0	24,0
Temperature of entering exhaust air (°C)	dry-bulb	21,0	24,0	27,0	27,0
	wet-bulb	15,0	17,0	20,0	19,0

Table 2 — Conditions of test for thermal tests (heating)

Parameter		Standard test conditions			
		T5	T6	T7	T8
Temperature of entering supply air (°C)	dry-bulb	2,0	5,0	7,0	5,0
	wet-bulb	1,0	3,0	6,0	3,0
Temperature of entering exhaust air (°C)	dry-bulb	21,0	20,0	20,0	25,0
	wet-bulb	14,0	15,0	12,0	18,0

7.6 Test temperature limits

For all tests, the arithmetic mean of the temperatures and mass flows at each of the inlets shall not be different from the specified temperatures and mass flows for each test by more than the allowances in Table 3.

Table 3 — Variation allowed during test

Readings	Variation of arithmetical mean values from specified test conditions
Temperature of air entering	
dry-bulb	± 0,3 K
wet-bulb	± 0,2 K
Mass flow	± 2,5 %

8 Pressure drop tests

Measured pressure drop across the heat/energy exchanger from stations 1 to 2 and stations 3 to 4 shall be determined for every thermal test.

9 Leakage tests

9.1 General test requirements

For rotary regenerative wheels, the leakage tests shall be performed with the wheel rotating at the same speed as for the effectiveness test.

Tracer gas, sampling equipment, and gas concentration levels shall be selected so as to be capable of accurately measuring the exchanger internal leakages. The injection concentration of the tracer gas shall be sufficient that an exhaust air transfer ratio of 0,002 5 can be measured by the device being used.

The tracer gas generation equipment shall be designed to provide a stable concentration of tracer gas that is uniform in the duct to which the tracer gas is introduced. The tracer gas shall be nontoxic, identifiable, measurable and inert.

Measurement equipment such as a gas chromatograph analyser, photoacoustic infrared spectroscopy analyser, or an alternative instrument with uncertainty no greater than 5 % shall be provided. If the analyser will be sequentially measuring the tracer gas concentration in samples from more than one of the stations, then either the data or the sample from the beginning of each sample measurement period shall be purged until the concentration readings have stabilized.

Ducts and other components of the test equipment shall not be permeable to or absorbent of the tracer gas and shall not allow air leakage.

9.2 Outside air correction factor

Outside air correction factor (OACF) shall be determined by measurement of mass air flows.

OACF shall be determined at positive, negative, and zero values for static pressure differential between the station 2 supply outlet and the station 3 exhaust inlet, at a specified airflow. The static pressure differential values and airflows shall be chosen to represent the range of conditions for intended use of the exchanger. OACF may be determined during thermal test or at lab ambient conditions. If OACF is determined at lab ambient conditions, the air mass flow rates and pressure differential shall be identical to the thermal tests from which RER is determined.

9.3 Exhaust air transfer ratio

Exhaust air transfer ratio (EATR) shall be determined by measurement of tracer gases.

EATR shall be determined at positive, negative, and zero values for static pressure differential between the leaving supply (station 2) and the entering exhaust (station 3). The static pressure differential values and airflows shall be identical to those in 9.2.

10 Uncertainty limits

10.1 General

A testing laboratory meeting the requirements of ISO/IEC 17025 can achieve the uncertainty limits of this clause. If necessary, a laboratory and its customer can agree on different uncertainty limits to meet their needs.

Formulae (19) through (25) are based on ANSI/ASHRAE 84:2020 with permission from ANSI/ASHRAE.

10.2 Uncertainty limits for effectiveness tests

For testing of effectiveness, the expanded relative uncertainties $U(\varepsilon_s)$ and $U(\varepsilon_l)$ shall satisfy Formulae (19) and (20):

$$\frac{U(\varepsilon_s)}{\varepsilon_s} < 0,05 \tag{19}$$

$$\frac{U(\varepsilon_l)}{\varepsilon_l} < 0,07 \tag{20}$$

10.3 Uncertainty limits for RER

For RER testing, the expanded relative uncertainties $U(R_{rer,gross})$ for the gross RER and $U(R_{rer,net})$ for the net RER shall satisfy Formula (21):

$$\frac{U(R_{rer})}{R_{rer}} < 0,10 \tag{21}$$

where R_{rer} is the recovery efficiency ratio, either gross or net.

10.4 Uncertainty limits for measured pressure drop tests

For measured pressure drop testing, the expanded relative uncertainties $U(\Delta P_s)$ and $U(\Delta P_e)$ shall satisfy Formulae (22) and (23):

$$\frac{U(\Delta P_s)}{\Delta P_s} < 0,10 \tag{22}$$

and

$$\frac{U(\Delta P_e)}{\Delta P_e} < 0,10 \tag{23}$$

10.5 Uncertainty limits for leakage tests

For OACF testing, the expanded relative uncertainty $U(F_{oac})$ shall satisfy Formula (24):

$$\frac{U(F_{oac})}{F_{oac}} < 0,02 \tag{24}$$

where F_{oac} is the outside air correction factor.

For EATR testing, the expanded relative uncertainty $U(R_{eat})$ shall satisfy Formula (25):

$$\frac{U(R_{eat})}{R_{eat}} < 0,03 \tag{25}$$

where R_{eat} is the exhaust air transfer ratio.

11 Inequality limits

11.1 General

Formulae (26) through (31) are reproduced with permission from ANSI/ASHRAE 84:2020.

11.2 Inequality limits for thermal tests

For all tests, the measured dry airflow mass flow rates shall satisfy Formula (26):

$$\frac{\left|\dot{m}_1 - \dot{m}_2 + \dot{m}_3 - \dot{m}_4\right|}{\dot{m}_{\text{minimum}(1,3)}} < 0,05 \tag{26}$$

For all thermal performance tests, the water vapor mass measured flow rates shall satisfy Formula (27):

$$\frac{\left|\dot{m}_1 W_1 - \dot{m}_2 W_2 + \dot{m}_3 W_3 - \dot{m}_4 W_4\right|}{\dot{m}_{\text{minimum}(1,3)} \left|W_1 - W_3\right|} < 0,20 \tag{27}$$

NOTE For thermal performance tests in which condensation occurs and the steady-state condensate flow rate is measured, the Formula (D.1), found in Annex D, may optionally be substituted for Formula (27).

For all thermal performance tests, the measured energy flow rates shall satisfy Formula (28):

$$\frac{\left|\dot{m}_1 h_1 - \dot{m}_2 h_2 + \dot{m}_3 h_3 - \dot{m}_4 h_4\right|}{\dot{m}_{\text{minimum}(1,3)} \left|h_1 - h_3\right|} < 0,20 \tag{28}$$

For all thermal performance tests, the measured sensible energy flow rates shall satisfy Formula (29):

$$\frac{\left|\dot{m}_1 c_{\text{p},1} t_1 - \dot{m}_2 c_{\text{p},2} t_2 + \dot{m}_3 c_{\text{p},3} t_3 - \dot{m}_4 c_{\text{p},4} t_4\right|}{\left(\dot{m} c_{\text{p}}\right)_{\text{minimum}(1,3)} \left|t_1 - t_3\right|} < 0,20 \tag{29}$$

where $\dot{m}c_{\text{p,minimum}(1,3)}$ is the lesser of $\dot{m}_1 c_{\text{p},1}$ and $\dot{m}_3 c_{\text{p},3}$

NOTE For thermal performance tests in which condensation occurs and the steady-state condensate flow rate is measured, the Formula (D.2), found in Annex D, can optionally be substituted for Formulae (28) and (29).

11.3 Inequality limits for leakage tests

During testing to determine OACF, the measured airflow mass flow rates shall satisfy Formula (30):

$$\frac{\left|\dot{m}_1 - \dot{m}_2 + \dot{m}_3 - \dot{m}_4\right|}{\dot{m}_{\text{minimum}(1,3)}} < 0,05 \tag{30}$$

During testing to determine EATR, the measured tracer gas flow rates shall satisfy Formula (31):

$$\frac{\left|\dot{m}_1 C_1 - \dot{m}_2 C_2 + \dot{m}_3 C_3 - \dot{m}_4 C_4\right|}{\dot{m}_{\text{minimum}(1,3)} \left|C_1 - C_3\right|} < 0,15 \tag{31}$$

12 Reporting of test results

Reporting of test results shall include all of the items in this Clause.

Measurements made in accordance with this document need to be reported in context in order to accurately characterize exchanger performance.

Annex A provides an example of acceptable reporting format (see Tables A.1 to A.7).

12.1 Pressure drop test results

Any report of pressure drop shall include the leaving supply and entering exhaust mass airflows or airflow volumes at standard air conditions and the static pressure differential.

12.2 Leakage test results

EATR and OACF measurements shall be reported together and at the same test conditions, and shall include:

the leaving supply and entering exhaust mass airflow or airflow volumes at standard air conditions;

the static pressure differential;

the barometric pressure.

12.3 Thermal test results

Any report of:

— effectiveness,

— temperature, humidity or enthalpy change ratio in the supply airstream, or

— sensible, humidity or total energy transfer rate

shall include:

— the leaving supply and entering exhaust mass airflow or airflow volumes at standard air conditions;

— the barometric pressure, dry-bulb temperature, a humidity metric for the leaving supply and entering exhaust airstreams, and static pressure differential.

12.4 Uncertainties

Each reported test result shall include its expanded uncertainty with its coverage factor and level of confidence.

Annex A
(informative)

Example of test data collection and calculation of metrics

Table A.1 — Information supplied by manufacturer

Manufacturer information	
Manufacturer:	
Address:	
Model information	
Model number:	
Serial number:	
Type of exchanger:	Fixed-plate / Rotary / Heat-Pipe
Air Flow:	
Specified static pressure differential:	
Rotational speed of wheel [a]	
Voltage [a]	
Phase and frequency [a]	

[a] Applies to rotary exchangers only

Table A.2 — Information about test facility

Thermal and pressure drop test record	
Test facilities information	
Date:	
Examiner:	
Address:	
Test facility name:	

Table A.3 — Thermal and pressure drop test data

Thermal and pressure drop test				**Data collected**			
			Unit	Test 1	Test 2	Test 3	Test 4
Specified static pressure differential		-	Pa				
Rotational speed of wheel		-	r/min				
Air volume or mass flow rate leaving supply air		Q_2 or $\dot{m}_2$	kg/s or m^3/s				
Air volume or mass flow rate entering exhaust air		Q_3 or $\dot{m}_3$	kg/s or m^3/s				
Entering supply air (station 1)	Temperature	T_1	C				
	Wet-bulb temperature	$T_{WB,1}$	C				
	Humidity	W_1	$kg_{(W)}/kg_{(DA)}$				
	Enthalpy	h_1	kJ/kg				
	Static pressure	ps_1	Pa				

Table A.3 *(continued)*

Thermal and pressure drop test				**Data collected**			
			Unit	Test 1	Test 2	Test 3	Test 4
Entering supply air (station 2)	Temperature	T_2	C				
	Wet-bulb temperature	$T_{\text{WB,2}}$	C				
	Humidity	W_2	$kg_{(W)}/kg_{(DA)}$				
	Enthalpy	h_2	kJ/kg				
	Static pressure	ps_2	Pa				
Entering supply air (station 3)	Temperature	T_3	C				
	Wet-bulb temperature	$T_{\text{WB,3}}$	C				
	Humidity	W_3	$kg_{(W)}/kg_{(DA)}$				
	Enthalpy	h_3	kJ/kg				
	Static pressure	ps_3	Pa				
Entering supply air (station 4)	Temperature	T_4	C				
	Wet-bulb temperature	$T_{\text{WB,4}}$	C				
	Humidity	W_4	$kg_{(W)}/kg_{(DA)}$				
	Enthalpy	h_4	kJ/kg				
	Static pressure	ps_4	Pa				
Thermal and pressure drop test				Calculated results			
Performance calculations			Unit	Test 1	Test 2	Test 3	Test 4
Static pressure differential		-	Pa				
Sensible effectiveness		$\varepsilon_{\text{sensible}}$	%				
Latent effectiveness		$\varepsilon_{\text{latent}}$	%				
Total effectiveness		$\varepsilon_{\text{total}}$	%				
Measured pressure drop in supply air		ΔP_s	Pa				
Measured pressure drop in exhaust air		ΔP_e	Pa				
Standardized pressure drop in supply air		$\Delta P_{s,ref}$	Pa				
Standardized pressure drop in exhaust air		$\Delta P_{e,ref}$	Pa				

Table A.4 — Information about test facility

Leakage test record	
Test facilities information	
Date:	
Examiner:	
Address:	
Test facility name:	

Table A.5 — Leakage test data

Leakage test				**Data collected**			
			Unit	Test 1	Test 2	Test 3	Test 4
Specified static pressure differential		-	Pa				
Rotational speed of wheel		-	r/min				
Air mass flow rate leaving supply air		$\dot{m}_2$	kg/s				
Air mass flow rate entering exhaust air		$\dot{m}_3$	kg/s				
Entering supply air (station 1)	Temperature	T_1	C				
	Wet-bulb temperature	$T_{WB,1}$	C				
	Static pressure	ps_1	Pa				
	Tracer gas concentration	C_1	(ppm or 10^{-6})				
Entering supply air (station 2)	Dry-bulb temperature	T_2	C				
	Wet-bulb temperature	$T_{WB,2}$	C				
	Static pressure	ps_2	Pa				
	Tracer gas concentration	C_2	(ppm or 10^{-6})				
Entering supply air (station 3)	Dry-bulb temperature	T_3	C				
	Wet-bulb temperature	$T_{WB,3}$	C				
	Static Pressure	ps_3	Pa				
	Tracer gas concentration	C_3	(ppm or 10^{-6})				
Entering supply air (station 4)	Dry-bulb temperature	T_4	C				
	Wet-bulb temperature	$T_{WB,4}$	C				
	Static pressure	ps_4	Pa				
	Tracer gas concentration	C_4	(ppm or 10^{-6})				
Leakage test results				**Calculated results**			
Performance calculations			Unit	Test 1	Test 2	Test 3	Test 4
static pressure differential		-	Pa				
Exhaust air transfer ratio		R_{eat}	1				
Outside air correction factor		F_{oac}	1				

Table A.6 — Performance calculation

Performance calculation			**Data collected**			
		Unit	Test 1	Test 2	Test 3	Test 4
Static pressure differential	-	Pa				
Rotational speed of wheel	-	r/min				
Air mass flow rate leaving supply air	$\dot{m}_2$	kg/s				

Table A.6 *(continued)*

Performance calculation			Data collected			
		Unit	Test 1	Test 2	Test 3	Test 4
Air mass flow rate entering exhaust air	$\dot{m}_3$	kg/s				
Sensible effectiveness	$\varepsilon_{sensible}$	%				
Latent effectiveness	ε_{latent}	%				
Total effectiveness	ε_{total}	%				
Measured pressure drop in supply air	ΔP_s	Pa				
Measured pressure drop in exhaust air	ΔP_e	Pa				
Exhaust air transfer ratio	R_{eat}	1				
Outside air correction factor	F_{oac}	1				
Supply fan and drive combined efficiency	η_{fs}	1				
Exhaust fan and drive combined efficiency	η_{fe}	1				
Auxiliary power input	q_{aux}	kW				
Gross recovery efficiency ratio	$R_{rer,gross}$					
Net recovery efficiency ratio	$R_{rer,net}$					

Table A.7 — Uncertainty calculation

Uncertainties (expanded relative uncertainties)			Calculated results			
Coverage factor [a]		Unit	Test 1	Test 2	Test 3	Test 4
Uncertainty of $\dot{m}_1$	$U(\dot{m}_1)$	kg/s				
Uncertainty of $\dot{m}_2$	$U(\dot{m}_2)$	kg/s				
Uncertainty of $\varepsilon_{sensible}$	$U(\varepsilon_{sensible})$	%				
Uncertainty of ε_{latent}	$U(\varepsilon_{latent})$	%				
Uncertainty of ε_{total}	$U(\varepsilon_{total})$	%				
Uncertainty of pressure drop in supply air	$U(\Delta P_s)$	%				
Uncertainty of pressure drop in exhaust air	$U(\Delta P_e)$	%				
Uncertainty of OACF	$U(F_{oac})$	%				
Uncertainty of EATR	$U(R_{eat})$	%				
Uncertainty of gross RER	$U(R_{rer,gross})$	%				
Uncertainty of net RER	$U(R_{rer,net})$	%				
[a] The coverage factor selected shall be indicated.						

Annex B
(informative)

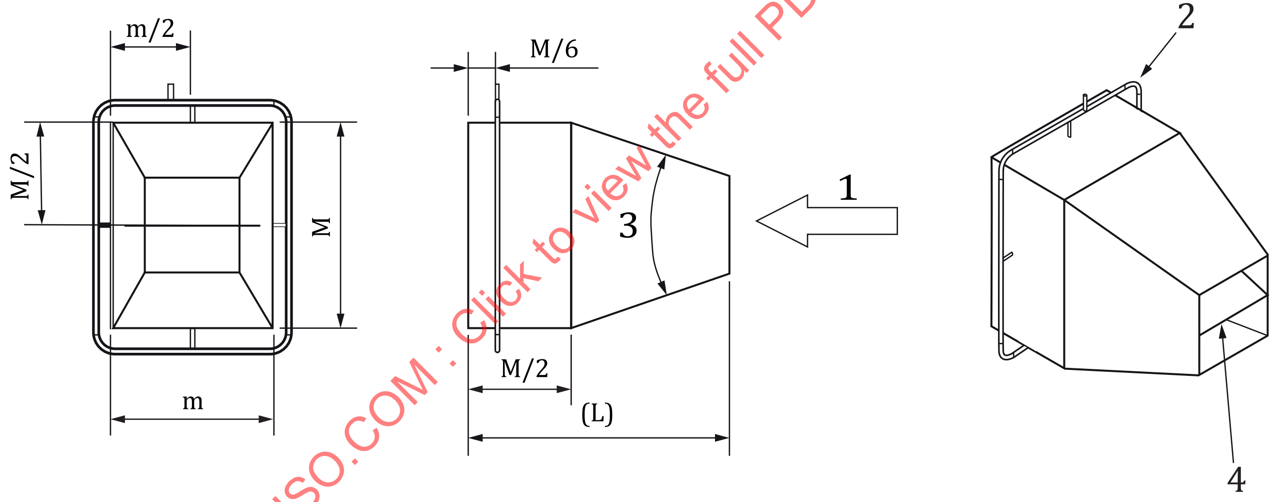
Best practices

B.1 Measure test system duct leakage

Prior to the performance tests, the ducts or casings across the test section shall be tested under the maximum negative pressure and flow rate that will be encountered under test or operating conditions. Flow rates shall be determined and shall satisfy the inequality limits in Clause 11.

B.2 Transitions between test system ducts and exchanger

Transitions between the test system ducts or casings and the exchanger shall be designed to provide good distribution of airflow at the exchanger inlets and outlets. Figures B.1 through B.10 illustrate commonly used arrangements.



Key

1 direction of air flow
2 piezometer ring
3 included angle
4 splitter plate
M major dimension of exchanger inlet
m minor dimension of exchanger inlet
L minimum dimension of transition piece in direction of air flow

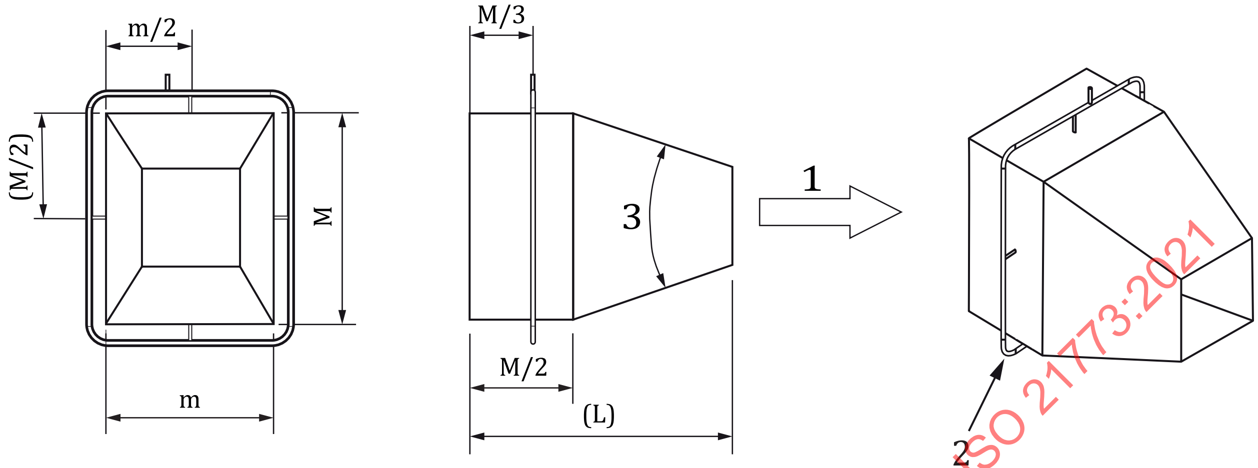
The included angle shall not exceed 40°. If the included angle > 20°, add a splitter plate at duct end, with a length equal to L/2.

Splitter plates required of included angle > 20°.

NOTE 1 Major and minor dimensions of the exchanger inlet establish the length of straight plenum section and static tap locations as shown.

NOTE 2 Piezometer ring connects four static pressure taps.

Figure B.1 — Transitions from test ducts to exchanger inlets



Key

1 direction of air flow

2 piezometer ring

3 included angle

M major dimension of exchanger inlet

m minor dimension of exchanger inlet

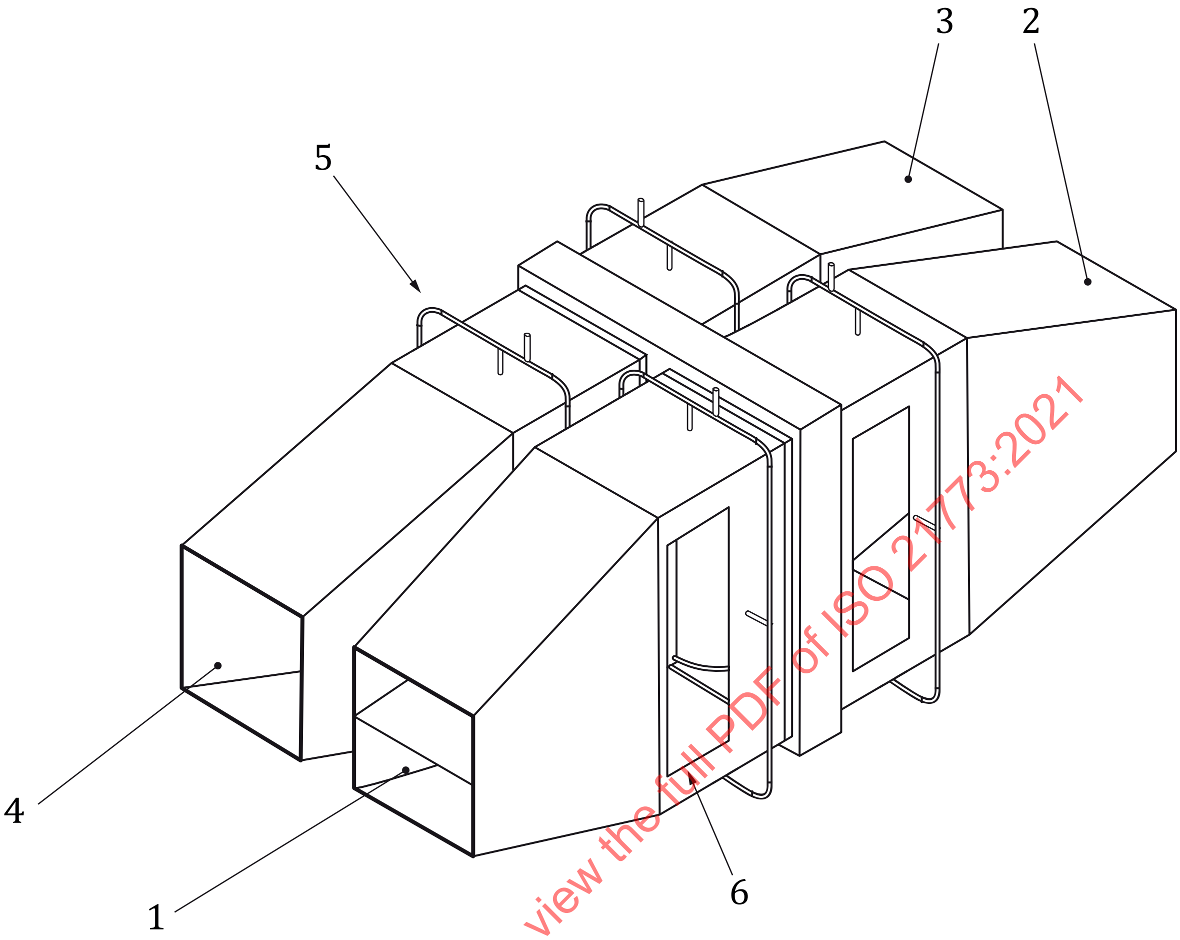
L minimum dimension of transition piece in direction of air flow

The included angle shall not exceed 40°.

NOTE 1 Major and minor dimensions of the exchanger inlet establish the length of straight plenum section and static tap locations as shown.

NOTE 2 Piezometer ring connects four static pressure taps.

Figure B.2 — Transitions from exchanger outlets to test ducts

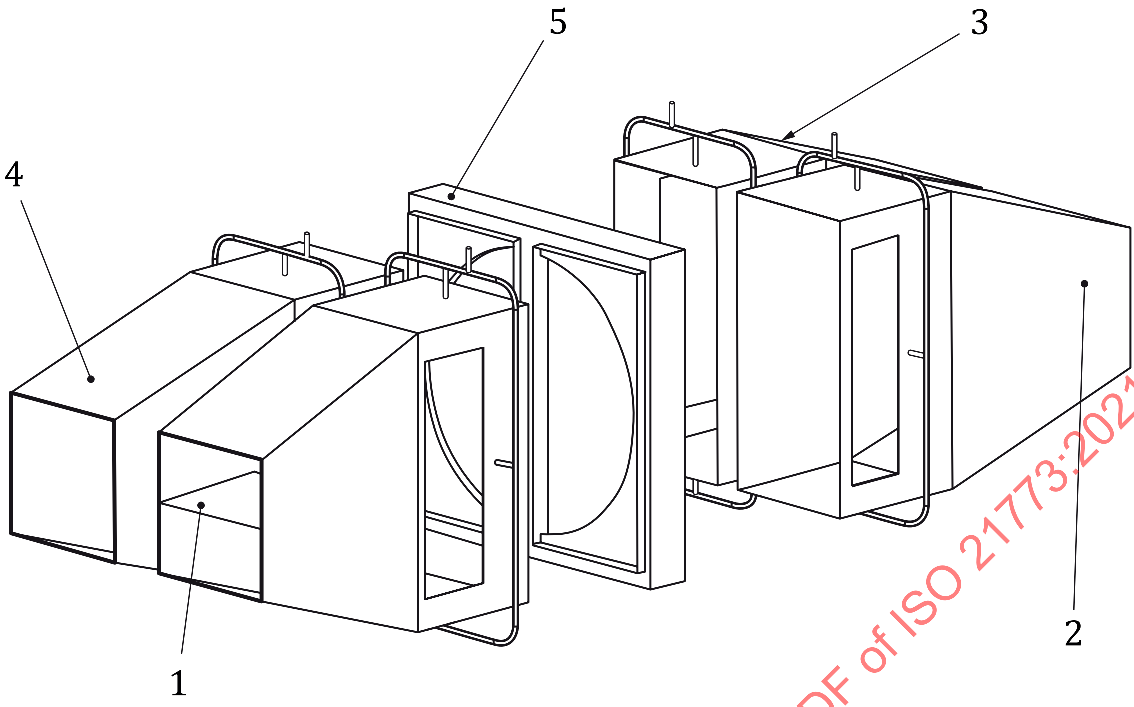


Key

1 entering supply air connection
2 leaving supply air connection
3 entering exhaust air connection
4 leaving exhaust air connection
5 piezometer ring
6 access panel

Each transition shall be equipped with a piezometer ring connecting four static taps.
Each transition shall be equipped with an access panel to allow sealing of transition to exchanger inlets and outlets.

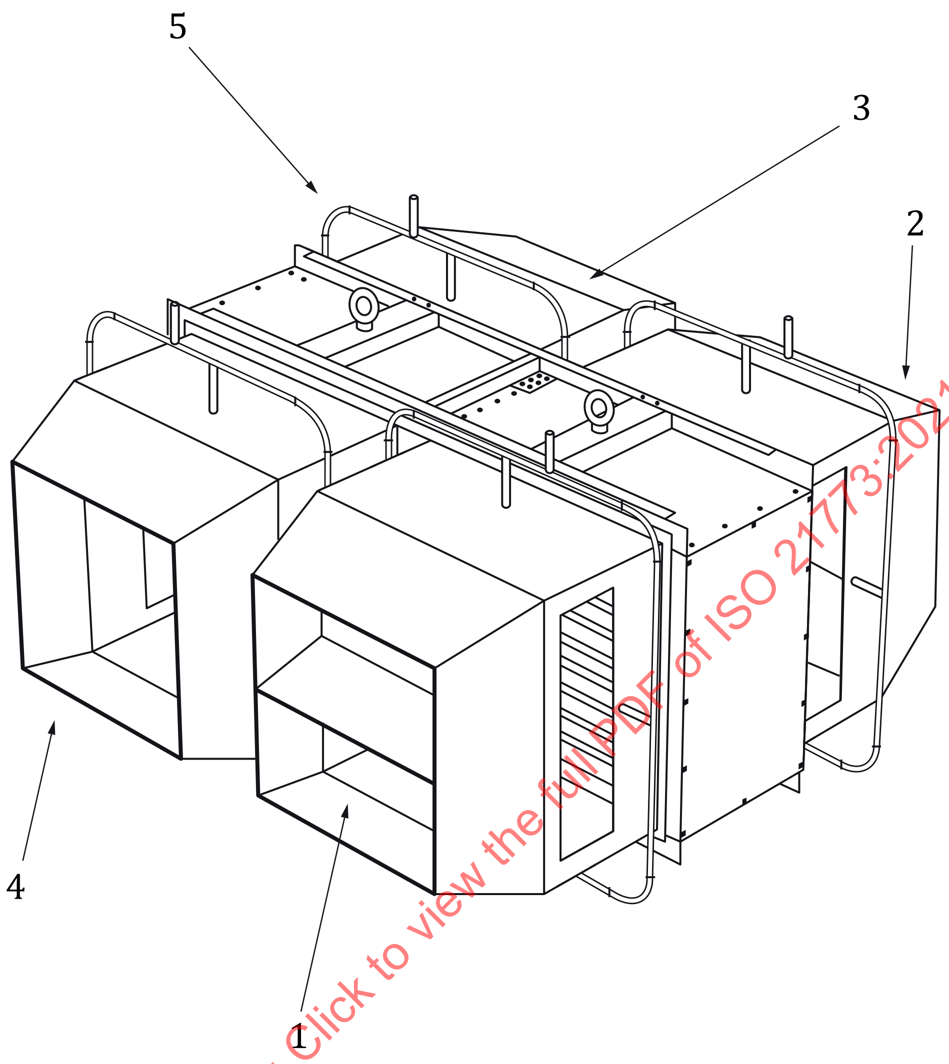
Figure B.3 — Transitions arrangement for rotary exchanger



Key

1 entering supply air transition piece
2 leaving supply air transition piece
3 entering exhaust air transition piece
4 leaving exhaust air transition piece
5 rotary exchanger

Figure B.4 — Transitions arrangement for rotary exchanger (exploded)

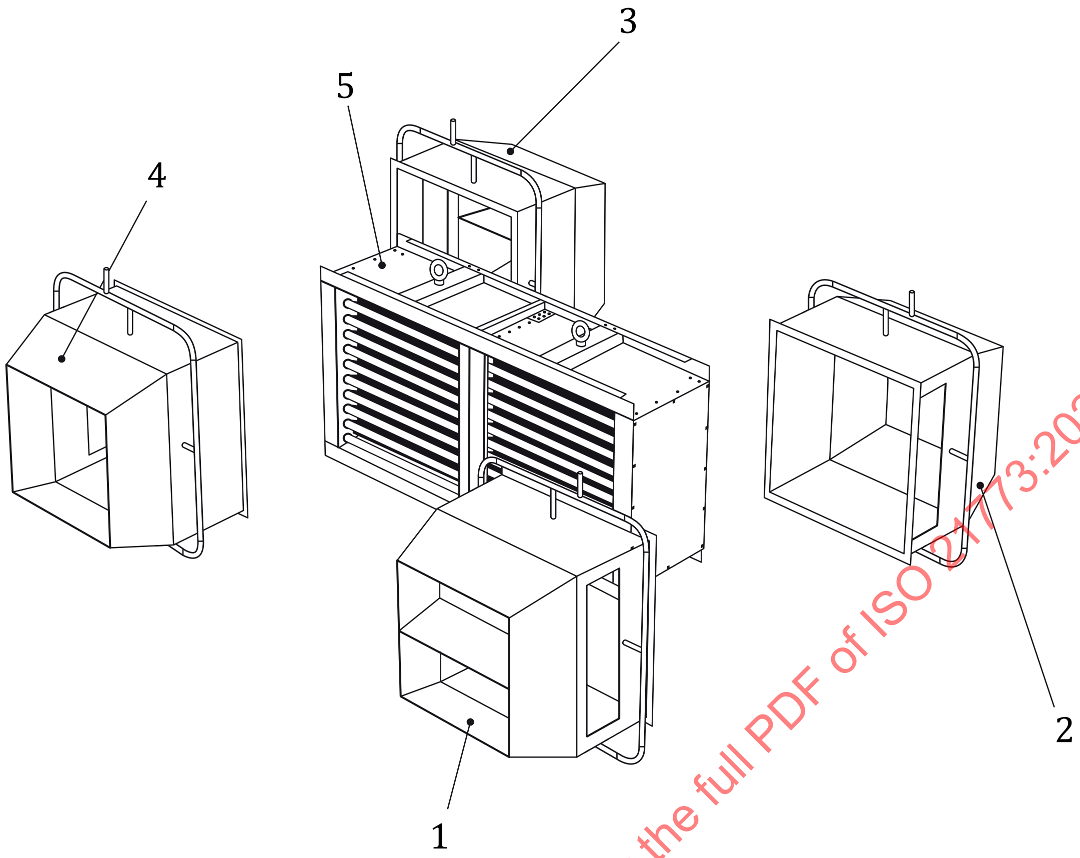


Key

1 entering supply air connection
2 leaving supply air connection
3 entering exhaust air connection
4 leaving exhaust air connection
5 piezometer ring
6 access panel

Each transition shall be equipped with a piezometer ring connecting four static taps.
Each transition shall be equipped with an access panel to allow sealing of transition to exchanger inlets and outlets.

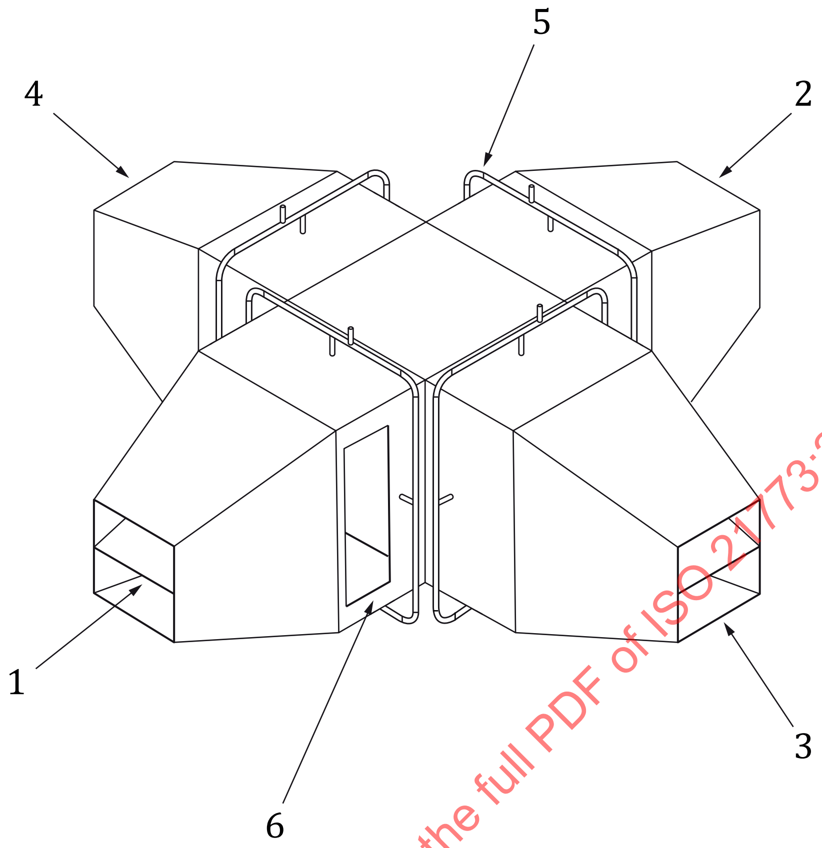
Figure B.5 — Transitions arrangement for heat pipe exchanger



Key

1 entering supply air transition piece
2 leaving supply air transition piece
3 entering exhaust air transition piece
4 leaving exhaust air transition piece
5 heat pipe exchanger

Figure B.6 — Transitions arrangement for heat pipe exchanger (exploded)

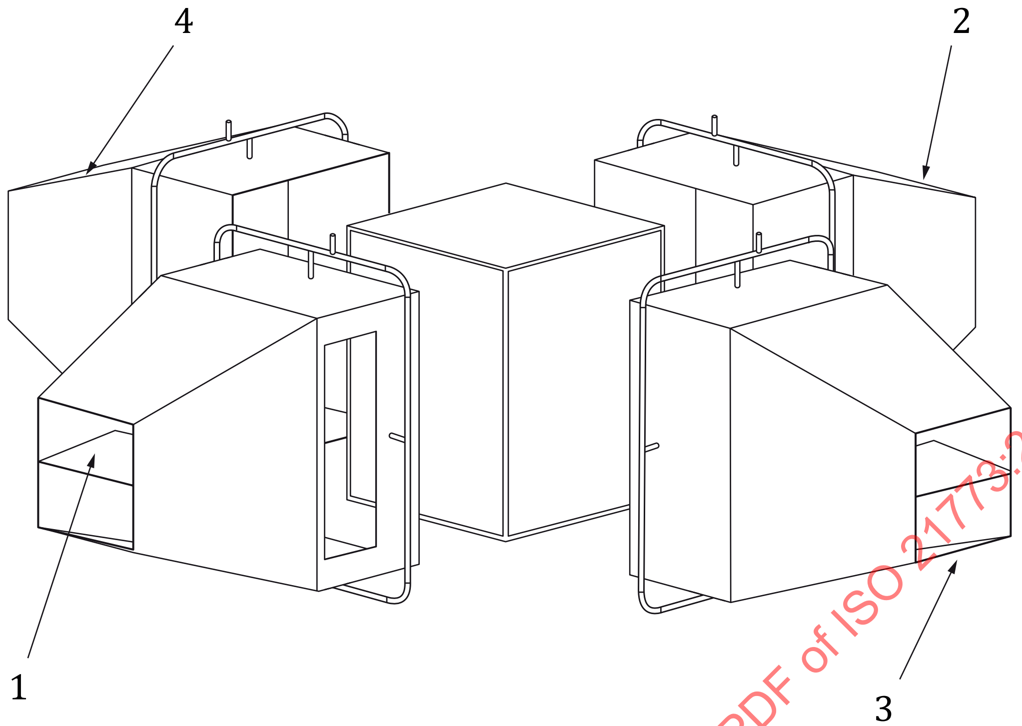


Key

1 entering supply air connection
2 leaving supply air connection
3 entering exhaust air connection
4 leaving exhaust air connection
5 piezometer ring
6 access panel

Each transition shall be equipped with a piezometer ring connecting four static taps.
Each transition shall be equipped with an access panel to allow sealing of transition to exchanger inlets and outlets.

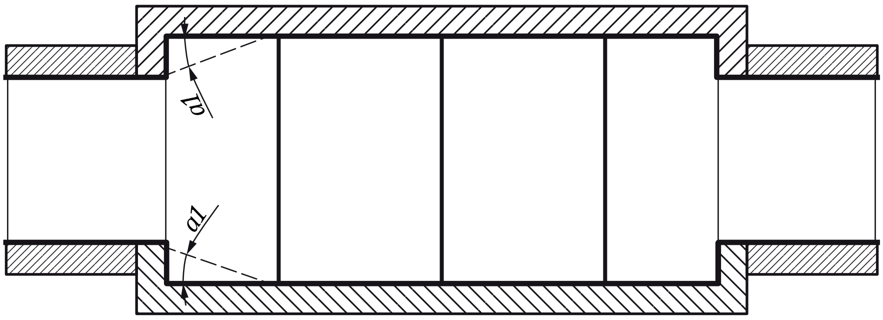
Figure B.7 — Transitions arrangement for plate exchanger



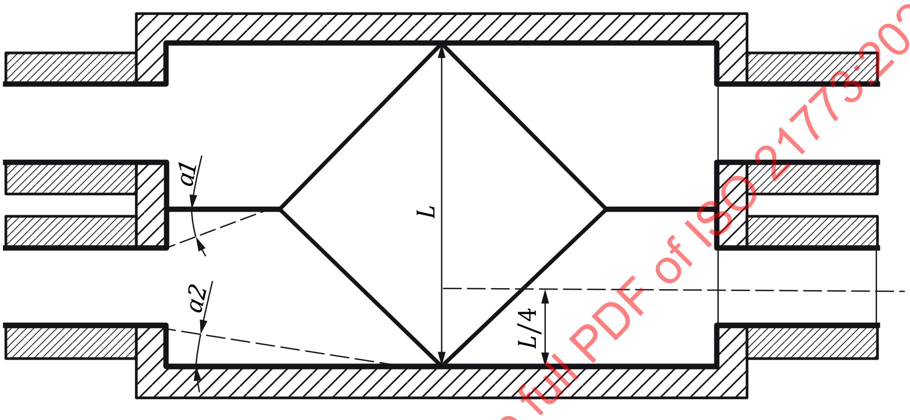
Key

1 entering supply air transition piece
2 leaving supply air transition piece
3 entering exhaust air transition piece
4 leaving exhaust air transition piece
5 plate exchanger

Figure B.8 — Transitions arrangement for plate exchanger (exploded)



a) view from above test casing



b) view from side of test casing

Key

*a*1 angle between duct outlet or inlet and nearest extreme edge of the exchanger face

*a*2 angle between duct outlet or inlet and farthest extreme edge of the exchanger face

L longest distance between edges of two adjacent faces

The test casing should be symmetrical.

Center lines of the inlet and outlet ducts shall be coincident with the centerpoint of the exchanger inlet and outlet faces, as indicated by dimension L/4.

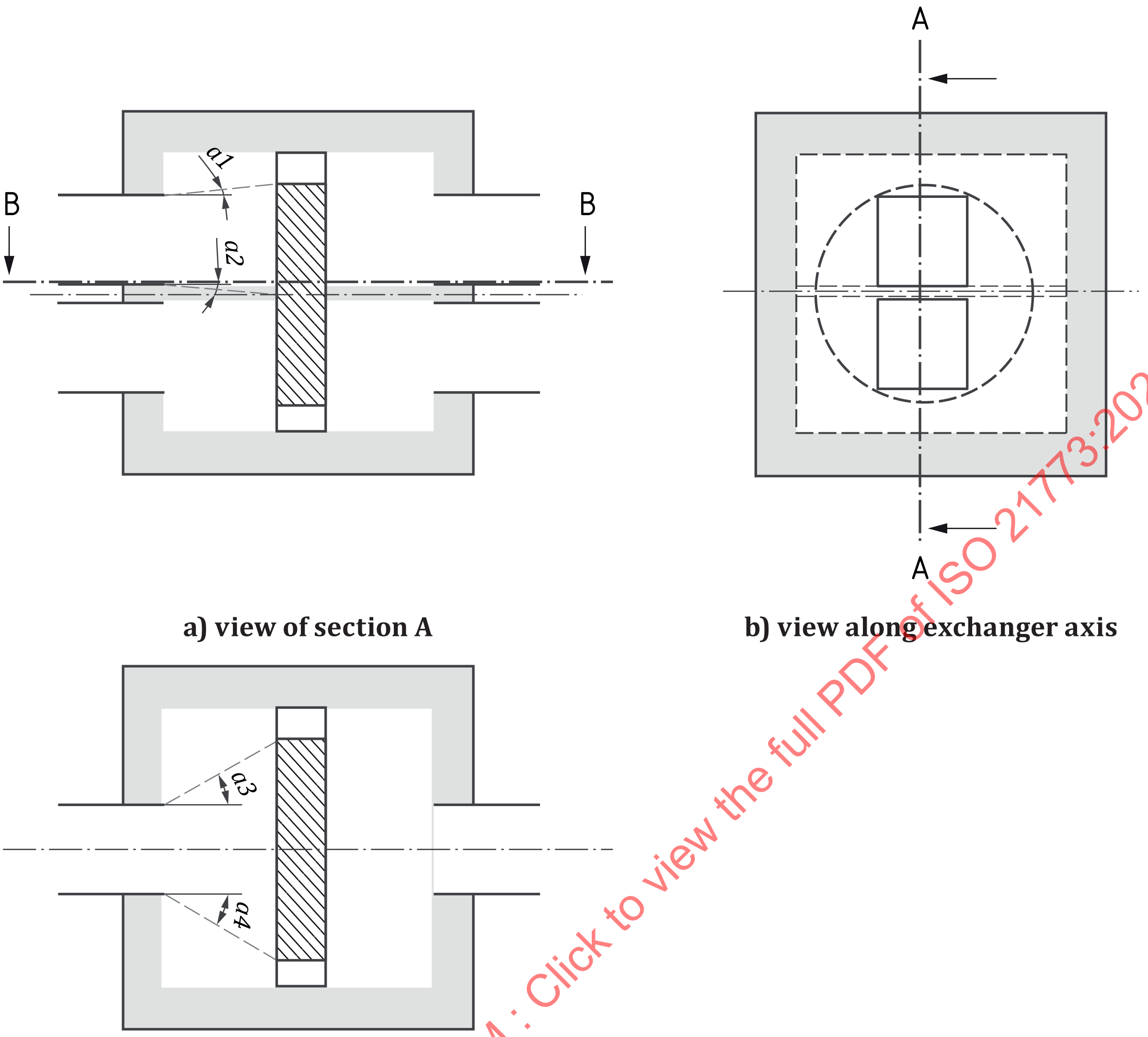
The angles $a1$ and $a2$ shall not exceed the following limits:

$a1 \leq 20°$;

$a2 \leq 15°$

If the test casing is connected to the supply and exhaust ducts by cones, then the inlet cone shall be symmetrical and feature an angle of ≤ 30°.

Figure B.9 — Schematic arrangement of a test casing for a plate exchanger



a) view of section A

b) view along exchanger axis

c) view of section B

Key

*a*1 angle, in the vertical plane, between duct outlet or inlet and intersection of exchanger's vertical axis and its circumference

*a*2 angle, in the vertical plane, between duct outlet or inlet and exchanger's centerpoint

*a*3. *a*4 angle, in the horizontal plane, between duct outlet or inlet and intersection of exchanger's horizontal axis and its circumference

L longest distance between the edges of two adjacent faces

The test casing should be symmetrical.

Centerlines of the inlet and outlet ducts shall be coincident with the centerpoint of the exchanger inlet and outlet faces, as indicated by dimension L/4.

The angles *a*1 and *a*2 shall not exceed the following limits:

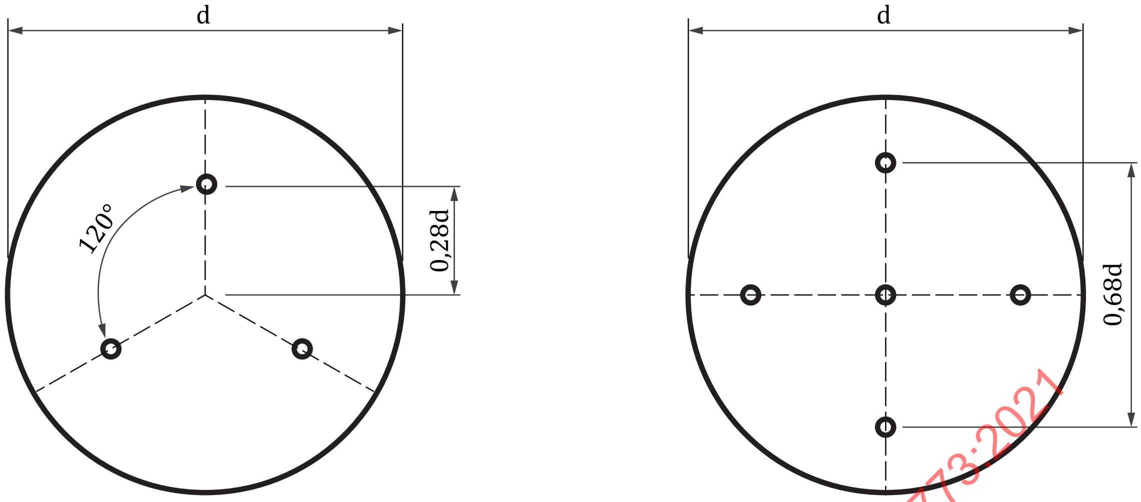
$a1 \leq 20°$;

$a2 \leq 15°$

$a3 = a4 \leq 30°$

If the test casing is connected to the supply and exhaust ducts by cones, then the inlet cone shall be symmetrical and feature an angle of ≤ 30°.

Figure B.10 — Schematic arrangement of a test casing for a rotary exchanger



a) Position of 3 probes in a circular duct **b) Position of 5 probes in a circular duct**

Key

d inside diameter of duct

The temperature probes shall be placed so that each of them is centered in areas of equal size.

Figure B.11 — Positions of 3 or 5 probes in a circular duct

B.3 Insulation of test system ducts and transitions

All ducts containing temperature and humidity measurement instruments and connected to the exchanger, if exposed to air at a measurably different temperature, should be insulated. The thermal resistance of the insulation should be not less than 2,6 m^2 K/W. If this is not possible, it should be demonstrated that the difference in temperature between the measurement location and the inlet or outlet of the exchanger would not be expected to be greater than the measurement uncertainty.

B.4 Mixing of outlet airstream

Verify that the difference between the highest and the lowest temperatures inside the duct at the temperature measurement location will not be more than 0,3 K. Provide a mixing device upstream of the temperature measurement location, if necessary, to meet this requirement.

Annex C
(informative)

Expression of performance metrics for use in calculation of system performance

C.1 General

This Annex is intended to align with the holistic approach to building energy use assessment outlined in the ISO 52000 series.

Given sufficient measurement and knowledge of a specific energy recovery ventilation (ERV) exchanger, its performance metrics as defined in Clause 5, may be expressed by empirically derived formulae, as functions of its operating conditions. These operating conditions may be described as inputs. This Annex indicates the inputs that at a minimum shall be included in such formulae. In some cases, additional inputs may be needed to generate accurate models.

With these inputs, an exchanger can be modelled properly as a portion of the system independent of where it is in the system design. The inputs, the exchanger model, and this document's performance metrics as outputs, can then be assembled as a sub-system and inserted into the set of models or spreadsheets required to comply with any jurisdiction that adopts the ISO 52000 series for the Energy Performance of Buildings. The overarching standards are now required in the EU and any jurisdiction may adopt any or all of the entire set of standards. The template for these standards requires 2 Annexes both of which are normative: Annex A is the minimum set of metrics required for compliance with these standards, and Annex B is either a recommended set of values or is for a jurisdiction to supply their regional set of values for insertion into the information needed for its building label or other building documentation. The exchanger model can be used with any regions climate or overall building data in terms of 8 760 h or some subset therein.

Since methods to determine operating conditions in which frosting may occur are not presented in this document, no attempt has been made to provide guidance on modelling thereof.

C.2 Heat transfer effectiveness

Formulae characterizing the heat transfer effectiveness of a specific exchanger at a specific operating condition, but without condensation, shall use the following inputs:

Formula (C.1) for fixed-plate exchangers:

$$\varepsilon_{\text{sensible}} = f\left(\dot{m}_2, \dot{m}_3\right) \tag{C.1}$$

where $\dot{m}_n$ is the mass flow rate at station n

Formula (C.2) for rotary exchangers:

$$\varepsilon_{\text{sensible}} = f\left(\dot{m}_2, \dot{m}_3, n\right) \tag{C.2}$$

where n is the wheel rotation speed

Formula (C.3) for heat pipe exchangers:

$$\varepsilon_{\text{sensible}} = f\left(\dot{m}_2, \dot{m}_3, \tau\right) \tag{C.3}$$

where τ is the tilt angle.

C.3 Latent transfer effectiveness

Formulae characterizing the latent transfer effectiveness of an exchanger at a specific operating condition shall use the following inputs:

Formula (C.4) for fixed-plate exchangers:

$$\varepsilon_{\text{latent}} = f(\dot{m}_2, \dot{m}_3, W_1, W_3) \tag{C.4}$$

where W_n is the humidity at station n

Formula (C.5) for rotary exchangers:

$$\varepsilon_{\text{latent}} = f(\dot{m}_2, \dot{m}_3, W_1, W_3, n) \tag{C.5}$$

C.4 measured pressure drop

Formulae characterizing the measured pressure drop of an exchanger at a specific operating condition shall use the following inputs:

Formulae (C.6) and (C.7) for fixed-plate exchangers:

$$\Delta P_s = f\left(\dot{m}_2, \dot{m}_3, \Delta ps_{2,3}\right) \tag{C.6}$$

and

$$\Delta P_e = f\left(\dot{m}_2, \dot{m}_3, \Delta ps_{2,3}\right) \tag{C.7}$$

where $\Delta ps_{2,3}$ is the static pressure differential (this factor may be negligible for exchangers with sufficiently rigid plates).

Formulae (C.8) and (C.9) for rotary exchangers, the purge setting may by an additional factor:

$$\Delta P_s = f\left(\dot{m}_2, \dot{m}_3, \Delta ps_{2,3}, \theta\right) \tag{C.8}$$

and

$$\Delta P_e = f\left(\dot{m}_2, \dot{m}_3, \Delta ps_{2,3}, \theta\right) \tag{C.9}$$

where θ is the purge angle.

Formulae (C.10) and (C.11) for heat pipe exchangers:

$$\Delta P_s = f\left(\dot{m}_2, \dot{m}_3\right) \quad \text{(C.10)}$$

and

$$\Delta P_e = f\left(\dot{m}_2, \dot{m}_3\right) \quad \text{(C.11)}$$

C.5 Recovery efficiency ratio

Formulae characterizing the recovery efficiency ratio of an exchanger at a specific operating condition shall use the following inputs in Formula (C.12):

$$R_{rer} = f\left(Q_2, Q_3, q_{aux}, \Delta P_s, \Delta P_e, \eta_{fs}, \eta_{fe}, \dot{m}_s, \dot{m}_e\right) \quad \text{(C.12)}$$

where Q_2 and Q_3 [in Formulae (C.13) and (C.14)] are the supply and exhaust sides volume flow rates,

$$Q_2 = \dot{m}_2 / \bar{\rho}_2 \quad \text{(C.13)}$$

and

$$Q_3 = \dot{m}_3 / \bar{\rho}_3 \quad \text{(C.14)}$$

$\bar{\rho}_2$ and $\bar{\rho}_3$ are the average supply and average exhaust air dry air density,

q_{aux} is the auxiliary total power input to the exchanger (e.g. to rotate a regenerative wheel and to operate controls)

η_{fs} and η_{fe} are the supply and exhaust air fan and drive total efficiencies.

C.6 Outside air correction factor and exhaust air transfer ratio

Formulae characterizing the outside air correction factor and the exhaust air transfer ratio of an exchanger at a specific operating condition shall use the following inputs:

Formulae (C.15) and (C.16) for fixed-plate exchangers:

$$F_{\text{oac}} = f\left(\dot{m}_2, \dot{m}_3, \Delta sp_{2,3}, \Delta P_{\text{s}}, \Delta P_{\text{e}}\right) \tag{C.15}$$

or

$$F_{\text{oac}} = f\left(\dot{m}_2, \dot{m}_3, sp_1, sp_2, sp_3, sp_4\right) \tag{C.16}$$

Formulae (C.17) and (C.18) for rotary exchangers, the purge setting may by an additional factor:

$$F_{\text{oac}} = f\left(\dot{m}_2, \dot{m}_3, \Delta sp_{2,3}, \Delta P_{\text{s}}, \Delta P_{\text{e}}, \theta\right) \tag{C.17}$$

or

$$F_{\text{oac}} = f\left(\dot{m}_2, \dot{m}_3, sp_1, sp_2, sp_3, sp_4, \theta\right) \tag{C.18}$$

For heat pipe exchangers the outside air correction factor and exhaust air transfer ratio are generally equal to unity, but if not, inputs shown in Formula (C.12) may be used.

C.7 Sensible energy transfer rate

Formulae characterizing the sensible energy transfer rate of an exchanger at a specific operating condition shall use the following inputs in Formula (C.19):

$$Q_{\text{sensible}} = f\left(\varepsilon_{\text{sensible}}, T_1, T_3, \dot{m}_2, c_{p,2}\right) \tag{C.19}$$

where $c_{p,2}$ is the specific heat of dry air at station 2.

C.8 Humidity transfer rate

Formulae characterizing the humidity transfer rate of an exchanger at a specific operating condition shall use the following inputs in Formula (C.20):

$$Q_{\text{latent}} = f\left(\varepsilon_{\text{latent}}, W_1, W_3, \dot{m}_2\right) \tag{C.20}$$

C.9 Energy transfer rate

Formulae characterizing the energy transfer rate of an exchanger at a specific operating condition shall use the following inputs in Formula (C.21):

$$Q_{\text{total}} = f\left(\varepsilon_{\text{total}}, \text{h}_1, \text{h}_3, \dot{m}_2\right) \tag{C.21}$$