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Thermal insulation products — Vacuum insulation panels (VIPs) — Specification

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 document 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 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 3, *Thermal insulation products, components and systems*.

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.

Thermal insulation products — Vacuum insulation panels (VIPs) — Specification

1 Scope

This document:

- defines requirements for vacuum insulation panels (VIPs) with silica or glass fibre core, which are used for thermal insulation of buildings;
- outlines required product properties, their performance, test methods and rules for conformity evaluations, identification and labelling;
- provides a test method to determine ageing factors and the influence of the linear thermal bridges at the edges.

This document is applicable to all types of silica and glass fibre core VIPs, independent of the type of envelope. In the case of a glass fibre core VIP, it is only applicable to VIPs with desiccants whose service life is ≥ 25 years.

This document is not applicable to:

- any specific installation and application requirements;
- products intended to be used for the insulation of building equipment and industrial installations.

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 1182, *Reaction to fire tests for products — Non-combustibility test*

ISO 1716, *Reaction to fire tests for products — Determination of the gross heat of combustion (calorific value)*

ISO 3529-1, *Vacuum technology — Vocabulary — Part 1: General terms*

ISO 3529-2, *Vacuum technology — Vocabulary — Part 2: Vacuum pumps and related terms*

ISO 3529-3, *Vacuum technology — Vocabulary — Part 3: Total and partial pressure vacuum gauges*

ISO 8301, *Thermal insulation — Determination of steady-state thermal resistance and related properties — Heat flow meter apparatus*

ISO 8302, *Thermal insulation — Determination of steady-state thermal resistance and related properties — Guarded hot plate apparatus*

ISO 8990, *Thermal insulation — Determination of steady-state thermal transmission properties — Calibrated and guarded hot box*

ISO 10211, *Thermal bridges in building construction — Heat flows and surface temperatures — Detailed calculations*

ISO 10456, *Building materials and products — Hygrothermal properties — Tabulated design values and procedures for determining declared and design thermal values*

ISO 11925-2, *Reaction to fire tests — Ignitability of products subjected to direct impingement of flame — Part 2: Single-flame source test*

ISO 12136, *Reaction to fire tests — Measurement of material properties using a fire propagation apparatus*

ISO 12567-1, *Thermal performance of windows and doors — Determination of thermal transmittance by the hot-box method — Part 1: Complete windows and doors*

ISO 12576-1:2001, *Thermal insulation — Insulating materials and products for buildings — Conformity control systems — Part 1: Factory-made products*

ISO 29465, *Thermal insulating products for building applications — Determination of length and width*

ISO 29466, *Thermal insulating products for building applications — Determination of thickness*

ISO 29467, *Thermal insulating products for building applications — Determination of squareness*

ISO 29468, *Thermal insulating products for building applications — Determination of flatness*

ISO 29472, *Thermal insulating products for building applications — Determination of dimensional stability under specified temperature and humidity conditions*

EN 13501-1, *Fire classification (Euroclasses) of construction products and building elements — Classification using test data from reaction to fire tests*

EN 13823, *Reaction to fire tests for building products — Building products excluding floorings exposed to the thermal attack by a single burning item*

3 Terms, definitions, symbols and units

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

ISO and IEC maintain terminology 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/>

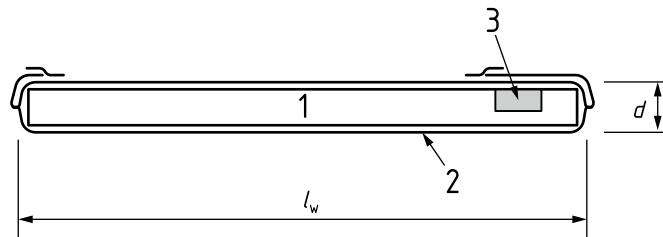
3.1 Terms and definitions

3.1.1

vacuum insulation panel VIP

insulation element containing open porous *core material* (3.1.4) and an *adsorbent* (3.1.8) within an *envelope* (3.1.5), where the *inner pressure* (3.1.10) inside the envelope is significantly lower, close to the vacuum (i.e. zero pressure), than the ambient air pressure

Note 1 to entry: A schematic view of a VIP is shown in [Figure 1](#).

**Key**

- 1 core material
- 2 envelope
- 3 adsorbent
- d thickness (3.1.17)
- l_w working length (3.1.11)

Figure 1 — Schematic view of VIP**3.1.2****silica core VIP**

vacuum insulation panel (VIP) (3.1.1) using fumed silica or other comparable silica powders as *core material* (3.1.4)

3.1.3**glass fibre core VIP**

vacuum insulation panel (VIP) (3.1.1) using glass fibre as *core material* (3.1.4), and generally containing an *adsorbent* (3.1.8)

3.1.4**core material**

open porous insulation material constituting the main component inside the *vacuum insulation panel (VIP)* (3.1.1) *envelope* (3.1.5)

3.1.5**envelope**

barrier layer(s) of the *vacuum insulation panel (VIP)* (3.1.1) resisting gas or vapour permeation into and securing the vacuum inside the VIP

3.1.6**metallized film****MF**

laminated film containing a high barrier performance metallic thin layer produced by chemical/physical deposition

3.1.7**aluminium foil laminated film****AF**

laminated film containing aluminium foil as a gas barrier layer

3.1.8**adsorbent**

material adsorbing either water vapour or dry air, or both, physically or chemically

3.1.9**desiccant**

material added inside the *envelope* (3.1.5) for the purpose of adsorbing water vapour

EXAMPLE CaO.

3.1.10

inner pressure

total gas pressure within the *vacuum insulation panel (VIP)* (3.1.1)

3.1.11

working length

l_w

longer linear dimension of the major surface of the test specimen

Note 1 to entry: See [Figure 2](#).

3.1.12

working width

w_w

shorter linear dimension of the major surface of the test specimen, measured at right angles to the *working length* (3.1.11)

Note 1 to entry: See [Figure 2](#).

3.1.13

core length

l_c

longer linear dimension of the *core material* (3.1.4) of the test specimen

Note 1 to entry: See [Figure 2](#).

3.1.14

core width

w_c

shorter linear dimension of the *core material* (3.1.4) of the test specimen, measured at right angles to the *core length* (3.1.13)

3.1.15

length of edge seal

l_2

longer linear dimension of the edge seal of the test specimen

Note 1 to entry: See [Figure 2](#).

3.1.16

width of edge seal

w_2

shorter linear dimension of the edge seal of the test specimen, measured at right angles to the *edge seal length* (3.1.19)

Note 1 to entry: See [Figure 2](#).

3.1.17

thickness

d

linear dimension measured perpendicularly to the length and width plane

3.1.18

surface area

A_{sur}

area of gas permeation plane of the test specimen

Note 1 to entry A_{sur} shall be determined by [Formulae \(1\)](#) or [\(2\)](#).

metallized film (MF) (3.1.6) on both sides:

$$A_{\text{sur}} = l_2 \times w_2 \times 2 \quad (1)$$

MF on single side:

$$A_{\text{sur}} = l_2 \times w_2 \quad (2)$$

3.1.19

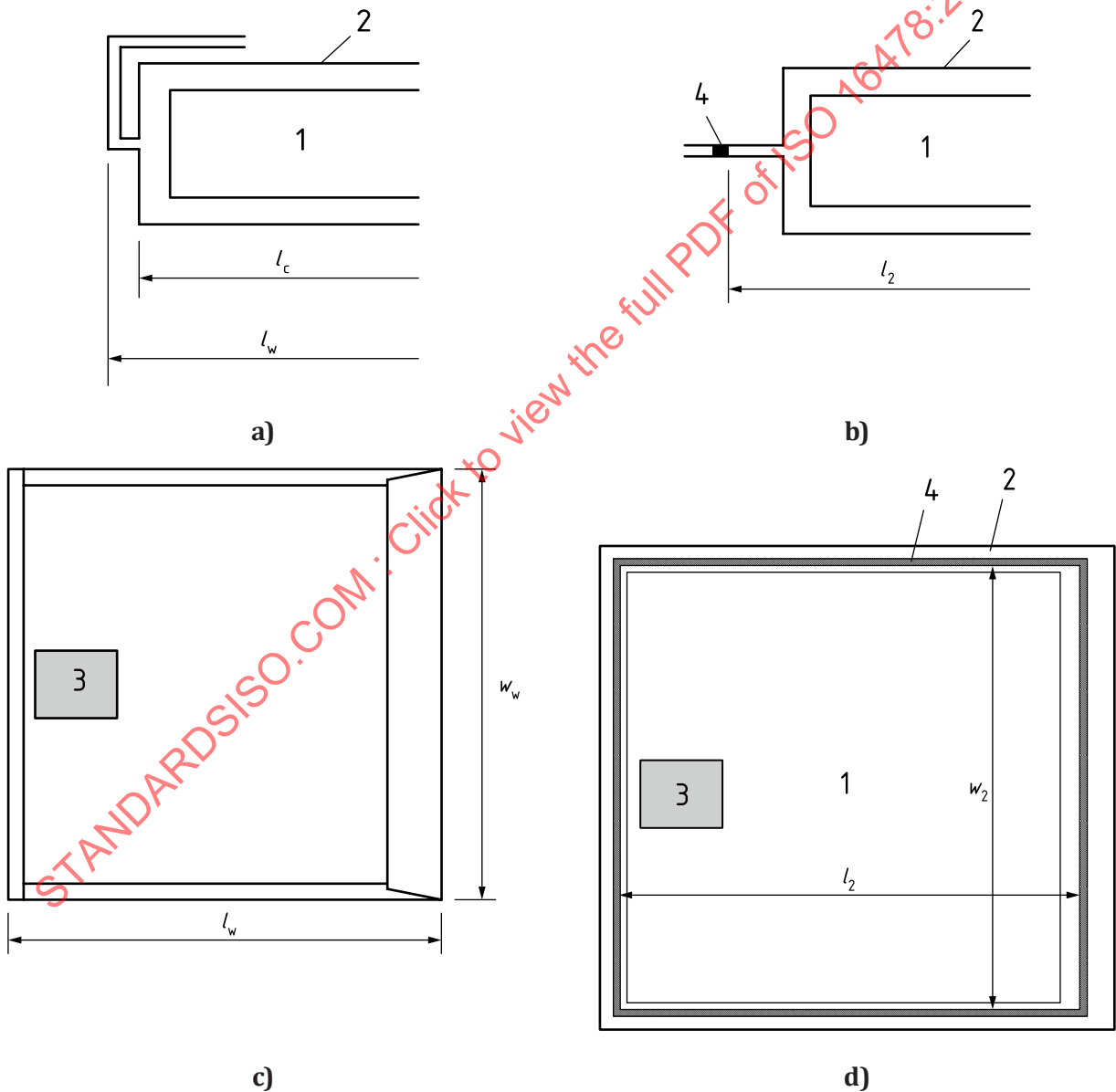
edge seal length

l_{es}

total length of the edge seal of the test specimen

Note 1 to entry: l_{es} shall be determined by [Formula \(3\)](#).

$$l_{\text{es}} = l_2 \times 2 + w_2 \times 2 \quad (3)$$



Key

- 1 core material (3.1.4)
- 2 envelope (3.1.5)
- 3 adsorbent or desiccant
- 4 edge seal
- l_c core length (3.1.13)
- l_w working length (3.1.11)
- l_2 length of edge seal (3.1.15)
- w_w working width (3.1.12)
- w_2 width of edge seal (3.1.16)

Figure 2 — Dimensions of a VIP

3.1.20

centre of panel

COP

area of the *vacuum insulation panel (VIP)* (3.1.1) not affected by the *edge effect* (3.1.21)

3.1.21

edge effect

thermal bridging along the edge due to higher thermal conductivity of the outer *envelope* (3.1.5) compared to the *core material* (3.1.4)

3.1.22

aged value

expected mean thermal conductivity value at 25 years in specified laboratory conditions

3.2 Symbols and units

A	surface area of the VIP	m^2
A_m	metering area of the GHP or HFM apparatus used for measurement	m^2
A_N	nominal surface area of the VIP	m^2
A_{sp}	area of the specimen measured by hot box method	m^2
A_{sur}	surface area of gas permeation plane of the product	m^2
$A_{sur,sp}$	surface area of gas permeation plane of the specimen	m^2
C_{des}	capacity of the desiccant	g/g
$C_{des,20\%}$	capacity of the desiccant including a safety margin of 20 %	g/g
d	thickness	m
$d_{ambient}$	thickness of the ventilated VIP	m
d_N	nominal thickness of the product	m
d_{VIP}	thickness of the VIP	m
f_{air}	acceleration factor for dry air of the envelope	-

f_v	acceleration factor for water vapour of the VIP envelope	-
k	factor related to the number of test results available	-
l	length	m
l_c	core length	m
l_2	length of edge seal	m
l_w	working length	m
l_ψ	length of the joints within the metering area	m
m_1	initial water amount of core material	g
m_2	amount of adsorbed water vapour	g
m_{25a}	water vapour amount adsorbed over 25 years	g
m_{des}	mass of desiccant	g
$m_{des,1a}$	mass of the desiccant after test	g
$m_{des,1d}$	sufficient amount of desiccant	g
$m_{des,2a}$	mass of the desiccant before acceleration test	g
$m_{des,2c}$	mass of the desiccant after acceleration test	g
$m_{des,0}$	mass of the fully dried desiccant	g
$m_{des,sat}$	mass of the saturated desiccant	g
$m'_{t,air,23/50}$	inner dry air mass increase rate at 23 °C, 50 % relative humidity (RH)	g/day
$m'_{t,v,23/50}$	water vapour mass increase rate at 23 °C, 50 % RH	g/day
N	number of test results	-
P_{air}	air permeability of the VIP envelope	$m^3 \cdot Pa / (m^2 \cdot s)$
$P_{air,total,23/50}$	air permeability of the VIP envelope of the product at 23 °C, 50 % RH	g/(day·Pa)
$P_{air,total,sp,23/50}$	air permeability of the VIP envelope of the specimen at 23 °C, 50 % RH	g/(day·Pa)
$P_{air,A,23/50}$	air permeability of the film surface at 23 °C, 50 % RH	g/($m^2 \cdot day \cdot Pa$)
$P_{air,l,23/50}$	air permeability of the edge seal at 23 °C, 50 % RH	g/($m \cdot day \cdot Pa$)
P_v	water intake rate of the VIP envelope	kg/($m^2 \cdot s$)
p_{air}	air pressure inside the VIP	Pa
$p_{air,atm}$	atmospheric pressure	Pa
p_{lim}	maximum value of the inner pressure measured at least 24 hours after production	Pa

p_v	water vapour pressure inside the VIP	Pa
$p_{v,out}$	atmospheric water vapour pressure	Pa
p_0	initial value of the inner pressure	Pa
$p_{1/2}$	inner pressure of VIP, where λ increases by 1/2 of the thermal conductivity of still air	Pa
$p'_{t,air,23/50}$	inner pressure increase rate at 23 °C, 50 % RH	Pa/day
$p'_{t,air,40}$	inner pressure increase rate at 40 °C	Pa/day
$p'_{t,air,60}$	inner pressure increase rate at 60 °C	Pa/day
$p'_{t,air,80}$	inner pressure increase rate at 80 °C	Pa/day
R_{aux}	thermal resistance of the auxiliary material	m ² ·K/W
R_D	declared thermal resistance	m ² ·K/W
R_{eq}	thermal resistance obtained by assuming the entire surface to be homogeneous calculated by the thermal transmittance	m ² ·K/W
$R_{s,t}$	total surface thermal resistance	m ² ·K/W
R_{mean}	mean thermal resistance	m ² ·K/W
R_{tot}	thermal resistance of VIP plus auxiliary material	m ² ·K/W
$R_{90/90}$	90 % fractile with a confidence level of 90 % for the thermal resistance	m ² ·K/W
S	top surface area (working length x working width) of the VIP	m ²
S_b	deviation from squareness on width or length	mm/m
S_{MAX}	deviation from flatness	mm
S_N	nominal perimeter of the product	m
s_λ	estimate of the standard deviation of the thermal conductivity	W/(m·K)
T	temperature	K
t	time	s
t_{des}	lifetime of desiccant	a
U	thermal transmittance	W/(m ² ·K)
V	core volume of the product	m ³
V_{sp}	core volume of the specimen	m ³
V_{void}	void volume of core	m ³
w	width	m
w_c	core width	m
w_2	width of edge seal	

w_w	working width	m
X	water content inside the VIP	mass-%
λ_{air}	thermal conductivity of still air	W/(m·K)
λ_{ambient}	thermal conductivity of a ventilated VIP at centre of the panel	W/(m·K)
λ_{cop}	thermal conductivity for centre of panel	W/(m·K)
$\lambda_{\text{cop,mean}}(25 \text{ years})$	average value of thermal conductivity over 25 years in use at centre of panel	W/(m·K)
$\lambda_{\text{cop,90/90,aged}}$	$\lambda_{90/90}$ at centre of panel plus ageing	W/(m·K)
λ_D	declared thermal conductivity	W/(m·K)
λ_{eq}	thermal conductivity including edge effect	W/(m·K)
$\lambda_{\text{eq,ja}}$	equivalent thermal conductivity including edge effect	W/(m·K)
λ_{mean}	mean value of thermal conductivity	W/(m·K)
λ_i	one test result of thermal conductivity	W/(m·K)
λ_0	thermal conductivity in the evacuated state	W/(m·K)
λ'_p	change of thermal conductivity with pressure	W/(m·K·Pa)
λ'_t	change of thermal conductivity with time	W/(m·K·s)
λ_{VIP}	thermal conductivity of the VIP	W/(m·K)
λ'_X	change of thermal conductivity with humidity	W/(m·K)/mass-%
$\lambda_{90/90}$	90 % fractile with a confidence level of 90 % of thermal conductivity	W/(m·K)
$\lambda'_{t,23/50}$	change of thermal conductivity with time at 23 °C 50 % RH	W/(m·K·s)
$\lambda'_{t,50/70}$	change of thermal conductivity with time at 50 °C 70 % RH	W/(m·K·s)
$\lambda_{\text{cop}}(t)$	time-dependent thermal conductivity value	W/(m·K)
$\lambda(t)_{,23/50}$	time-dependent value of thermal conductivity at 23 °C 50 % RH	W/(m·K·s)
$\lambda(t)_{,50/70}$	time-dependent value of thermal conductivity at 50 °C 70 % RH	W/(m·K·s)
$\lambda^*(t=0)$	interpolated initial thermal conductivity	W/(m·K)
σ_{mt}	tensile strength perpendicular to faces	kPa
σ_{10}	compressive stress at 10 % deformation	kPa
φ	RH inside the VIP	%
φ'_x	change of RH inside the VIP as function of water content	(rel. humidity-%) / (mass-%)
Φ_{in}	quantity of heat generated in the hot box	W

Φ_l	quantity of heat loss from the hot box	W
Φ_{sur}	quantity of heat flow through the surround panel	W
ψ	linear thermal transmittance	W/(m·K)
ψ_m	linear thermal transmittance for the joints in the metering area	W/(m·K)
$\Delta\theta_n$	environmental temperature difference between both sides of the specimen	K

4 Requirements

4.1 General

Products shall be assessed in accordance with [Clause 6](#) and meet the requirements as outlined in [Clause 4](#).

All characteristics defined in [Clause 4](#), if declared, shall be subject to product type determination (PTD) in accordance with [Annex E](#). The minimum frequencies of tests in the factory production control (FPC) shall be in accordance with [Annex E](#).

NOTE The manufacturer can choose to give information for additional properties (see [Annex F](#)).

4.2 Thermal resistance and thermal conductivity

4.2.1 General

Requirements of thermal resistance and thermal conductivity are given in [Table 1](#).

Table 1 — Thermal resistance and thermal conductivity

Property	Thermal resistance	Thermal conductivity
	R m ² ·K/W	λ W/(m·K)
Initial value of centre of panel (COP) ($\lambda_{\text{cop},90/90}$, $R_{\text{cop},90/90}$)	> 1,6	< 0,005
Initial value including thermal bridging (λ_D)	–	Declare
Aged value of COP ($\lambda_{\text{cop},90/90,\text{aged}}$, $R_{\text{cop},90/90,\text{aged}}$)	> 0,8	< 0,010
Aged value including thermal bridging ($\lambda_{90/90,\text{aged}}$)	–	Declare

4.2.2 Initial COP thermal properties

The initial value of COP, $R_{\text{cop},90/90}$ and $\lambda_{\text{cop},90/90}$ shall be determined by using [Formulae \(4\)](#) and [\(5\)](#) and shall not exceed the limits given in [Table 1](#).

$$\lambda_{\text{cop},90/90} = \lambda_{\text{mean}} + k \times s_{\lambda} \quad (4)$$

$$R_{\text{cop},90/90} = \frac{d_N}{\lambda_{\text{cop},90/90}} \quad (5)$$

4.2.3 Size dependent value

4.2.3.1 General

Edge effect and ageing effect depends on the size of VIP.

The value, including thermal bridging and aged value, shall be declared according to Method A. In addition, for better comparison between different products, the thermal resistance and thermal conductivity shall be declared according to Method B for panels when at least one of their dimensions (length or width) is smaller than 250 mm.

Method A: Respective panel size of VIP as placed on the market;

Method B: Following a set of reference dimensions (length × width × thickness) of VIP:

- a) 0,3 m × 0,3 m × 0,01 m;
- b) 1,0 m × 0,5 m × 0,01 m;
- c) 0,3 m × 0,3 m × 0,03 m;
- d) 1,0 m × 0,5 m × 0,03 m.

More details regarding initial values including thermal bridging, aged value of COP and aged value including thermal bridging are provided in [4.2.3.2](#), [4.2.3.3](#) and [4.2.3.4](#), respectively.

4.2.3.2 Initial value including thermal bridging

Thermal conductivity, including thermal bridging along edges, λ_D , shall be determined by using [Formulae \(6\)](#) and [\(7\)](#) and shall be declared.

$$\lambda_D = \lambda_{\text{cop},90/90} + \Delta\lambda_{\text{edge}} \quad (6)$$

$$\Delta\lambda_{\text{edge}} = \psi \times d_N \times \frac{S_N}{S} \quad (7)$$

4.2.3.3 Aged COP thermal properties

Aged value of COP, $\lambda_{90/90, \text{aged}}$ and $R_{\text{cop},90/90, \text{aged}}$, shall be determined by using [Formulae \(8\)](#) and [\(9\)](#) and shall not exceed the limits provided in [Table 1](#).

$$\lambda_{\text{cop},90/90, \text{aged}} = \lambda_{\text{cop},90/90} + \Delta\lambda_{\text{cop}, \text{mean}} (25 \text{ years}) \quad (8)$$

$$R_{\text{cop},90/90, \text{aged}} = \frac{d_N}{\lambda_{\text{cop},90/90, \text{aged}}} \quad (9)$$

4.2.3.4 Aged value including thermal bridging

Aged value including thermal bridging, $\lambda_{90/90, \text{aged}}$, shall be determined by using [Formula \(10\)](#) and shall be declared.

$$\lambda_{90/90, \text{aged}} = \lambda_D + \Delta\lambda_{\text{cop}, \text{mean}} (25 \text{ years}) \quad (10)$$

4.3 Length, width, squareness and flatness

The tolerance of core length, core width, squareness and flatness for silica core VIP and for glass fibre core VIP shall not exceed the limits given in [Tables 2](#) and [3](#) respectively.

Table 2 — Tolerances of length, width, squareness and flatness for silica core VIP

Tolerance				
Core length and core width			Squareness on length and width	Flatness
$(l_c, w_c) < 500$ mm	$500 \text{ mm} \leq (l_c, w_c) \leq 1\,000$ mm	$(l_c, w_c) > 1\,000$ mm	S_b	$S_{\max}$
mm			mm/m	mm
± 4	± 5	± 6	5	6

Table 3 — Tolerances of length, width, squareness and flatness for glass fibre core VIP

Tolerance				
Core length and core width			Squareness on length and width	Flatness
$(l_c, w_c) < 500$ mm	$500 \text{ mm} \leq (l_c, w_c) \leq 1\,000$ mm	$(l_c, w_c) > 1\,000$ mm	S_b	$S_{\max}$
mm			mm/m	mm
± 5	± 5	± 6	10	6

4.4 Thickness

The tolerance of thickness shall not exceed the limits given in [Table 4](#).

Table 4 — Tolerances of thickness

Thickness mm	Tolerance mm	
	Silica core VIP	Glass fibre core VIP
≤ 10	$\pm 0,5$	± 1
$10 < d_N \leq 20$	± 1	± 2
$20 < d_N \leq 30$	$\pm 1,5$	± 3
> 30	± 2	± 4

4.5 Dimensional stability

The relative changes in length and width shall not exceed 1 %, and the relative change in thickness shall not exceed 3 %.

5 Sampling

The laboratory conducting the testing shall be responsible for random sampling of VIP.

6 Test methods

6.1 General

One test result for a product property is the average of the measured values on the number of test specimens mentioned in [Table 5](#).

Unlike other insulating materials, VIPs cannot be cut to the size required by the test standards. They shall be produced in the sizes stated in [Table 5](#).

Table 5 — Test methods and test specimens

Clause number in ISO 16478 (this document)	Test method	Test specimen length and width ^a	Minimum number of measurements to get one test result
6.2.1	ISO 8301 or ISO 8302	≥ 300	10
6.2.2	Annex A	≥ 300	1
6.2.3	Annex B	≥ 300	2 per condition
	Annex C	≥ 300	3 per condition
6.3	6.3.1	Full-size	3
6.3	6.3.2	Full-size	3
6.3	6.3.3	Full-size	3
6.4	6.4	Full-size	3
6.5	ISO 29472	≥ 200	3
^a Full-size product thickness when the limits of the test methods are exceeded.			

6.2 Thermal resistance and thermal conductivity

6.2.1 General

The thermal conductivity and the thermal resistance shall be rounded upwards in steps of 0,000 5 W/(m·K) and downwards to the nearest 0,05 m²·K/W, respectively.

6.2.2 Initial COP thermal properties

Thermal resistance and thermal conductivity within 2 d to 30 d after production shall be determined in accordance with ISO 8301 or ISO 8302 under the following conditions:

- at a mean reference temperature of 10 °C or 23 °C;
- after conditioning the test specimen at (23 ± 2) °C and (50 ± 5) % relative humidity (RH) for at least 24 h.

$\lambda_{\text{cop},90/90}$ shall represent at least 90 % of the production, determined with a confidence level of 90 % in accordance with ISO 10456.

The measurement shall be carried out directly on the VIP, or, for uneven surfaces, to avoid air gaps. The measurement shall be carried out with the VIP positioned between two flexible contact sheets of another insulation material of known thermal conductivity ("auxiliary material"). The thermal conductivity λ_{VIP} can be calculated from the total thermal resistance R_{tot} of the composites, the thermal resistance of the auxiliary material R_{aux} and the measured thickness of VIP using [Formula \(11\)](#).

$$\lambda_{\text{VIP}} = \frac{d_{\text{N}}}{R_{\text{tot}} - R_{\text{aux}}} \quad (11)$$

6.2.3 Linear thermal transmittance

Linear thermal transmittance, ψ , shall be determined in accordance with [Annex A](#).

6.2.4 Aged thermal properties (25 years)

Aged $\Delta\lambda_{\text{cop,mean}}$ (25 years) for silica core VIP and for glass fibre core VIP shall be determined in accordance with [Annexes B](#) and [C](#), respectively.

6.3 Length, width, squareness and flatness

6.3.1 General

Length, l , and width, w , shall be determined in accordance with ISO 29465. The seams and folded edges or ends shall not be included in the measurement. The deviation from squareness on length and width, S_b , shall be determined in accordance with ISO 29467. The deviation from flatness, S_{max} , shall be determined in accordance with ISO 29468.

6.3.2 Length and width

ISO 29465 applies with the following recommendation:

- Considering the welding or folding of the envelope of the product, it is recommended to pinch the panel with a flat bar and measure the distance between them.

6.3.3 Squareness on length and width

- ISO 29467 is normally applicable to products with straight edges. ISO 29467 stipulates that it can be adapted accordingly for products of other shapes such as profiles edges.
- The determination of the squareness for length and width shall be done by measuring the deviation on all sides of the test specimen, the test specimen laying on a flat surface. Therefore, there are four points to be measured, one for each side. The 4 values of linearity deviation for each side shall be recorded.
- If the squareness concerns a field having a welding or folding of the envelope, the measurements shall be carried out twice by turning the test specimen upside down on the flat side. In this case, the number of measurements rises from four values to eight values.
- The test report shall include all individual values measured for deviation from squareness for length and width and from linearity, specifying if the measurements are made on the short or the long edge.
- If the summit to be measured has an angle greater than 90° , the measurement cannot be done (it will be obtained by turning the panel over on the other side), the indication "angle > 90° " shall be mentioned in the test report (different from 0).
- All of the measurements shall be recorded in the test report.

6.3.4 Flatness

ISO 29468 applies with the following recommendations:

- The panel shall be laid down on the opposite side of any welding or folding of the envelope of the products.
- The measuring points as stated in the standard shall exclude the welding or folding areas of the envelopes of the products.

6.4 Thickness

If there is neither folding nor welding of the envelope on both measured sides, ISO 29466 applies, with a load plate of 250 Pa.

If the products show welding or folding of the envelope on at least one of the areas being measured, these shall be measured while applying different load plates.

The selected load plates for this test can be either:

- dimensions (mm): 200 × 200, pressure applied to the test specimen: 1 kPa;
- dimensions (mm): 600 × 600, pressure applied to the test specimen: 1,5 kPa.

In the case of applying the 600 × 600 plate, the measuring points shall be carried out in accordance with ISO 29466, in relation to their location on the 600 × 600 plate.

The pressure to be applied should allow the folds or any irregularity of the envelope to be flattened enough (their impact being assessed elsewhere, in particular during the determination of the thermal bridges).

The seams and folded edges or ends and adsorbent shall not be included in the measurement.

6.5 Dimensional stability

Dimensional stability under specified temperature or under specified temperature and humidity conditions shall be determined in accordance with ISO 29472. The test shall be carried out at 70 °C and 90 % RH.

7 Conformity control

The manufacturer or authorised representative shall be responsible for the conformity of the product in accordance with ISO 12576-1:2001, Clause 4.

All characteristics defined in [Clause 4](#), if declared, shall be subject to PTD in accordance with [Annex E](#). The minimum frequencies of tests in the FPC shall be in accordance with [Annex E](#).

8 Marking and labelling

Products conforming to this document shall be marked clearly, either on the product or on the label or the packaging, with the following information:

- reference to this document, i.e. ISO 16478:20—;
- product name or other identifying characteristics;
- name or identifying mark and address of the manufacturer or authorised representative;
- initial value of COP ($\lambda_{\text{cop},90/90}$, $R_{\text{cop},90/90}$);
- initial value including thermal bridging (λ_{D});
- aged value of COP ($\lambda_{\text{cop},90/90,\text{aged}}$, $R_{\text{cop},90/90,\text{aged}}$);
- aged value including thermal bridging ($\lambda_{90/90,\text{aged}}$);
- thickness (d_{N});
- working length (l_{w});
- working width (w_{w});
- squareness on length and width (S_{b});
- flatness (S_{max});
- dimensional stability;
- number of pieces and area in the package, as appropriate.

Annex A (normative)

Determination of linear thermal transmittance

A.1 General

The linear thermal transmittance shall be determined by numerical simulation or by either hot plate method or hot box method.

Numerical simulation is described in [A.2](#). The hot plate method and hot box method are described in [A.3](#) and [A.4](#), respectively.

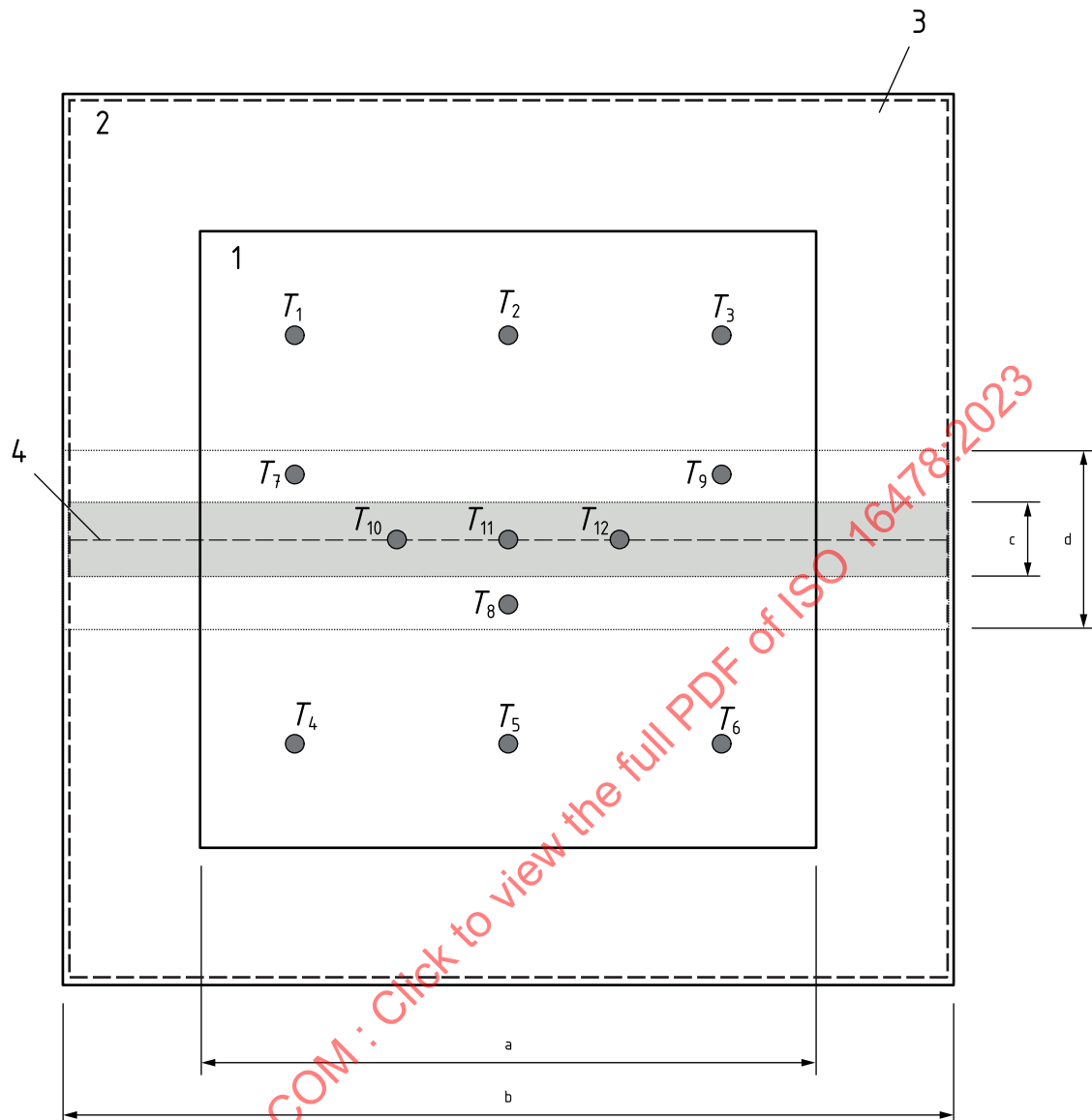
A.2 Numerical simulation

The determination of the linear thermal transmittance value shall be carried out by numerical simulations according to ISO 10211. It is recommended to use the finite difference method because of better accuracy and greater tolerance on the size and shape of numerical cells when simulating the thin component layers of the envelope material between two panels. The used details and boundary conditions shall be documented carefully.

A.3 Hot plate method

A.3.1 Procedure

The determination of the linear thermal transmittance values shall be done by measurement in the guarded hot plate (GHP) or heat-flow meter (HFM) as well, if additional measures take the non-uniform temperature distribution within the surfaces of the VIP assembly with joints into account. Therefore, two VIPs are assembled within the GHP or HFM apparatus so that their joint is within the metering area (see [Figure A.1](#)), and the ratio of specimen area to metering area should be given. The flatness and thickness of two nominally identical specimens should be within tolerances specified in [Tables 2, 3 and 4](#). Temperature sensors shall be placed directly on the joint (area strongly influenced by thermal bridge), in the area slightly influenced by the edge effect and in the undisturbed area (COP) as well.

**Key**

- 1 metering area
- 2 guarded area
- 3 test specimen
- 4 joint between two panels to be measured
- T_1 to T_6 temperature sensors for COP area
- T_7 to T_9 temperature sensors for area slightly influenced by the thermal bridging effect of the joint
- T_{10} to T_{12} temperature sensors for area strongly influenced by the thermal bridging effect of the joint
- a Size of metering area.
- b Size of apparatus.
- c Area strongly influenced by the thermal bridging effect of the joint.
- d Area slightly influenced by the thermal bridging effect of the joint.

Figure A.1 — Joint assembly configuration for GHP or HFM measurement

The width of the influenced areas depends strongly on the cross conduction within the barrier layers of the envelope and possible cover-layers on the surfaces of the VIP. The sizes of the VIP shall be selected large enough to assure a significant unaffected area (i.e. COP) within the metering area. Reasonable

values for the influenced areas and the minimum panel sizes can be determined by numerical simulations of the assembly.

The measured temperature differences on the different areas shall be area weighted and averaged before calculating the equivalent thermal conductivity result for the VIP. The measurement shall be documented carefully.

When using the HFM-method, special precautions shall be taken to avoid an over-assessment of the thermal bridging effect of the joint due to accidentally arranged thermopile sensors parallel to the joint. This can be eliminated by arranging the HFM non-parallel to the joint, e.g. at an angle of 20°.

When using the GHP-method, special precautions shall be made to avoid an over-assessment of the thermal bridging effect of the joint due to cross conduction within the heating plate and the cooling plate. This can strongly be reduced by using flexible contact layers on the specimens.

A.3.2 Calculation

The linear thermal transmittance ψ can be determined by comparison of a GHP or HFM measurement in the centre of a panel and the GHP or HFM measurement of the joint assembly on panels of identical thickness by applying [Formula \(A.1\)](#). The surface resistances can be omitted for this calculation of the GHP and HFM setups, as it is assumed that the heating and cooling plates are in perfect thermal contact with the specimens.

$$\psi_m = \frac{A}{d \times l_\psi} \times (\lambda_{eq, ja} - \lambda_{cop}) \quad (A.1)$$

Linear thermal transmittance values for joints of two panels refer to the length of the joint. Linear thermal transmittance values for panel edges refer to the perimeter length of the panel. If a linear thermal transmittance value for a joint is used to calculate the equivalent thermal conductivity of a panel, it shall be divided by 2, before the multiplication with the perimeter length of the panel.

A.4 Hot box method

A.4.1 General

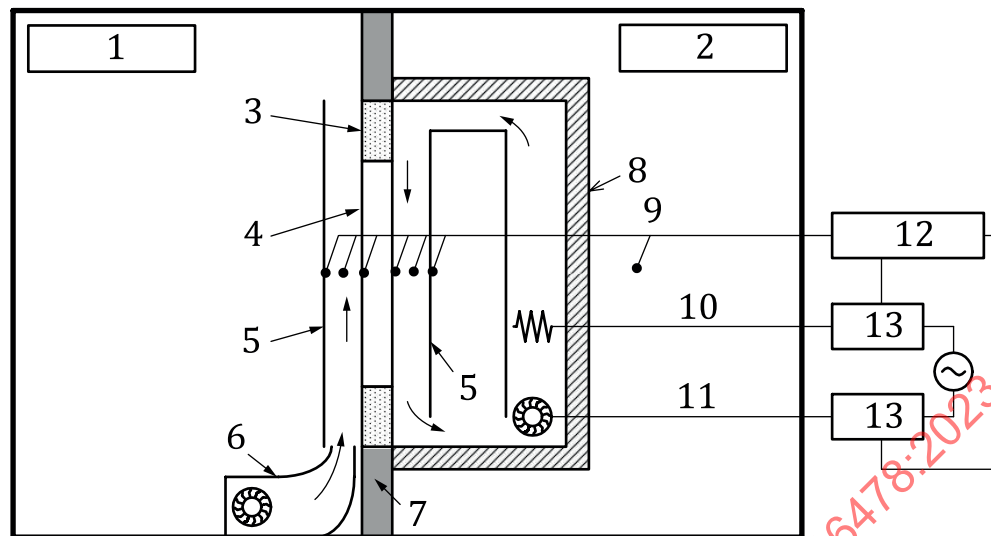
The linear thermal transmittance values shall be determined by the measurements in the hot box method, described in this subclause:

NOTE The measurement accuracy depends on the dimension of the apparatus and the specification of VIP.

A.4.2 Test apparatus

The test apparatus shall be in conformance with the calibrated hot box method. A typical configuration is shown in [Figure A.2](#). The configuration and functions of the test apparatus shall be as specified in [A.4.3](#) to [A.4.5](#) according to ISO 8990, except for containing hot box's opening with an area of 3,6 m² or more.

The location of temperature sensors and baffle shall be as specified in ISO 12567-1. An airflow blower shall be installed on the low-temperature chamber side.



Key

- | | | | |
|---|--------------------------|----|--------------|
| 1 | low-temperature chamber | 8 | hot box |
| 2 | high-temperature chamber | 9 | thermocouple |
| 3 | surround panel | 10 | heater |
| 4 | specimen | 11 | fan |
| 5 | baffle | 12 | data logger |
| 6 | airflow blower | 13 | watt meter |
| 7 | specimen mounting frame | | |

Figure A.2 — Calibrated hot box apparatus

A.4.3 Surround panel

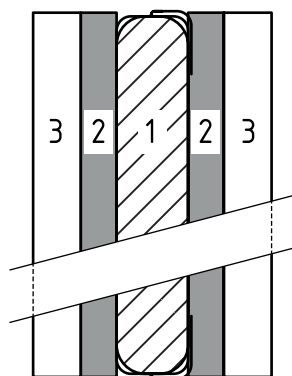
A surround panel shall be used to fill the space between a specimen mounting frame and a specimen and shall conform to the following requirements:

- The surround panel shall be almost of the same thickness as the specimen.
- The material that is used for the surround panel shall be homogeneous. The thermal conductivity of the surround panel shall be stable and similar to that of the calibration panel. The thermal resistance or thermal conductivity of the surround panel shall be measured according to ISO 8301 or ISO 8302 at the mean temperature (the mean of both air temperatures of the surround panel in the steady state).

A.4.4 Specimen

A specimen shall be composed of VIPs and auxiliary materials, which are covered on both sides of the VIPs, as shown in [Figure A.3](#). The thermal resistance of the auxiliary materials shall be measured according to ISO 8301 or ISO 8302.

The specimen shall be the same size as placed on the market (Method A in [4.2.3.1](#)) or the most suitable size for the hot box apparatus.



Key

- 1 VIP
- 2 auxiliary material: sponge rubber or silicone foam
- 3 auxiliary material: gypsum board

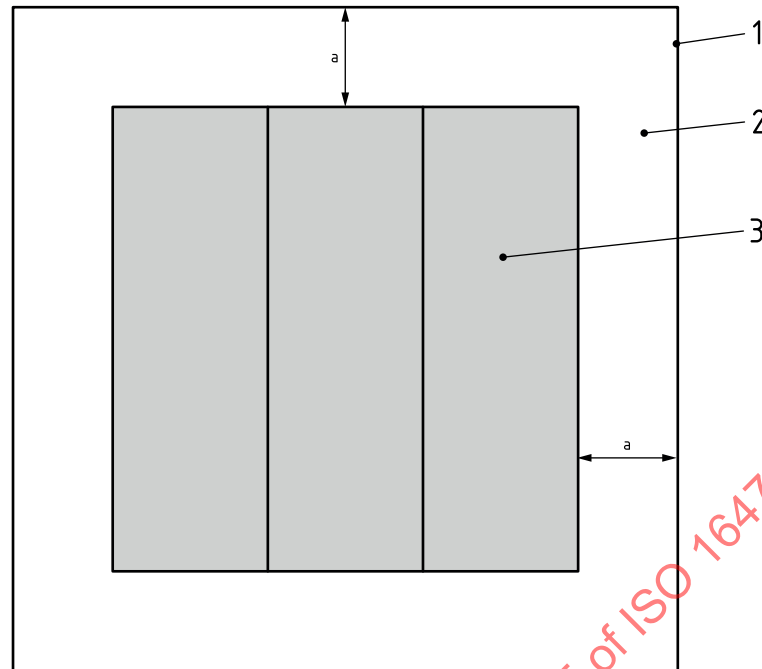
Figure A.3 — Configuration (cross-section) of specimen

A.4.5 Procedure

Measurements shall be carried out in accordance with ISO 8990.

The mounting space of the specimen shall be as wide as possible, as shown in [Figure A.4](#). Specimens shall be located at more than 150 mm from the specimen mounting frame.

The gaps formed between VIPs and between specimens and surround panels shall be sealed with tape from the frontside and backside.

**Key**

- 1 specimen mounting frame
- 2 surround panel
- 3 specimen (VIP + auxiliary material)
- a 150 mm or more.

Figure A.4 — Specimen mounting example**A.4.6 Calculation**

The thermal transmittance, U , of the specimen shall be determined by [Formula \(A.2\)](#).

$$U = \frac{\Phi_{\text{in}} - \Phi_{\text{l}} - \Phi_{\text{sur}}}{A_{\text{sp}} \times \Delta\theta_{\text{n}}} \quad (\text{A.2})$$

The equivalent thermal resistance, R_{eq} , and the equivalent thermal conductivity, λ_{eq} , shall be calculated by [Formulae \(A.3\)](#) and [\(A.4\)](#).

$$R_{\text{eq}} = U^{-1} - R_{\text{s,t}} - R_{\text{aux}} \quad (\text{A.3})$$

$$\lambda_{\text{eq}} = \frac{d}{R_{\text{eq}}} \quad (\text{A.4})$$

The linear thermal transmittance, ψ , shall be calculated by [Formula \(A.5\)](#).

$$\psi = \frac{A_{\text{sp}}}{d \times S_{\text{N}}} (\lambda_{\text{eq}} - \lambda_{\text{cop}}) \quad (\text{A.5})$$

Annex B
(normative)

Determination of aged value for silica core VIP

B.1 General

Ageing procedures shall be used for silica core VIP since the thermal conductivity increases with time during service time. This deterioration of thermal performance is due to the increase of inner gas pressure, moisture content and possible changes of the core material's structure itself. The properties of the core material (pore diameter), the permeation through the barrier film concerning air and water vapour and the size and thickness of the vacuum panel, all can have an influence on thermal conductivity change. As the change of thermal conductivity of VIP with time for a building application is relatively small, accelerated ageing at higher temperature and humidity levels (50 °C, 70 % RH) is performed. During the accelerated ageing, the increase of thermal conductivity, gas pressure and mass (moisture content) is measured. The accelerated increase of thermal conductivity then is scaled back to standard conditions (23 °C, 50 % RH). For scaling to standard conditions, the properties of the barrier films regarding the air and water permeation as a function of temperature have to be known (see B.4).

Ageing procedures are described in Figure B.1.

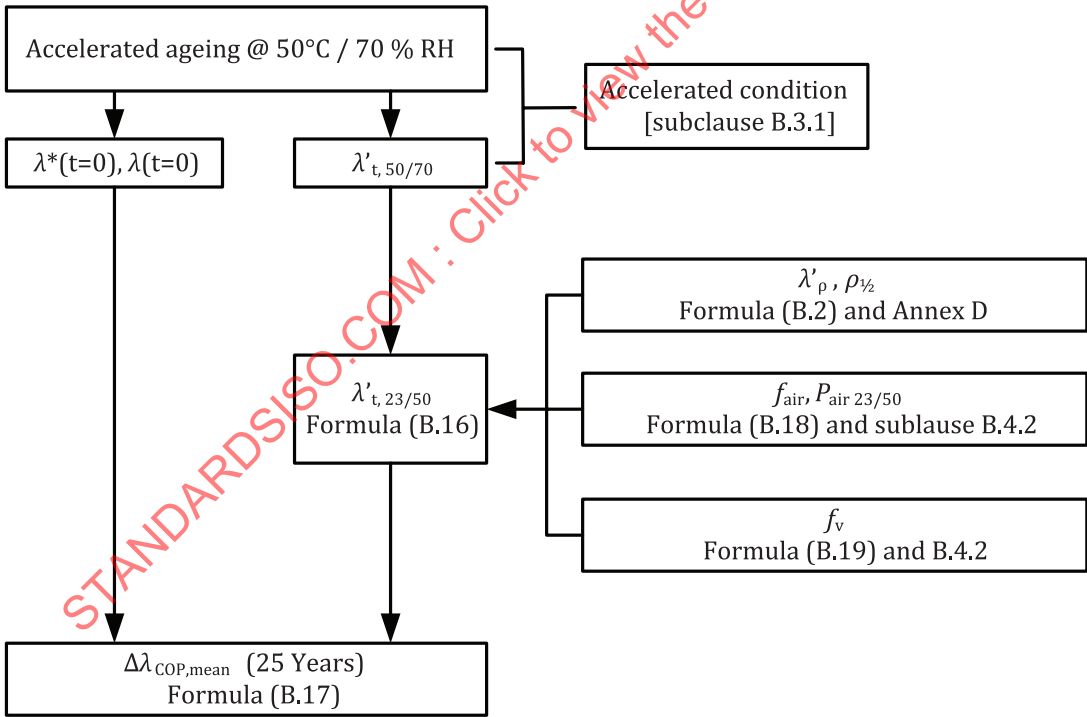


Figure B.1 — Flowchart of ageing procedure

B.2 Time dependence of thermal conductivity

B.2.1 Increase of thermal conductivity due to permeation of dry air

The thermal conductivity as a function of gas pressure can be described by [Formula \(B.1\)](#).

$$\lambda(p) = \lambda_0 + \lambda_{air} / (1 + p_{1/2} / p) \quad (B.1)$$

For $p \ll p_{1/2}$ the change of thermal conductivity with gas pressure λ'_p is constant [see [Formula \(B.2\)](#)].

$$\lambda'_p = \lambda_{air} / p_{1/2} \quad (B.2)$$

The thermal conductivity of still air λ_{air} is 0,026 W/(m·K) at room temperature and the procedures to determine $p_{1/2}$ are described in [Annex D](#).

B.2.2 Increase of thermal conductivity due to permeation of water vapour

The relation between water content X and RH ϕ and hence the water vapour pressure p_v within the VIP core is described by its adsorption isotherm. In the case of silica core materials for low RH ϕ the adsorption isotherm can be approximated by a linear relationship [see [Formula \(B.3\)](#)].

$$\phi'x = \Delta\phi / \Delta X = const. \quad (B.3)$$

EXAMPLE 1 For pyrogenic silica powder $\phi'_x \approx 14$ RH-%/mass-%.

Accordingly, the water content change ΔX is also responsible for the water vapour pressure increase [see [Formula \(B.4\)](#)].

$$\Delta p_v = \phi'_x \times \Delta X \times p_s(T) \quad (B.4)$$

EXAMPLE 2 $p_s(23\text{ °C}) = 2\,800$ Pa

where $p_s(T)$ is saturated vapour pressure at temperature T .

The total gas pressure p is given by [Formula \(B.5\)](#):

$$p = p_v + p_{air} \quad (B.5)$$

In a first approximation, [Formula \(B.2\)](#) can be applied both for water vapour and for air.

As experiments with silica core material have shown, an increase of water content ΔX here is responsible for an increase of thermal conductivity [see [Formula \(B.6\)](#)].

$$\Delta\lambda = \lambda'_x \times \Delta X \quad (B.6)$$

EXAMPLE 3 $\lambda'_x \approx 0,000\,5$ W/(m·K)/ % at room temperature for pyrogenic silica core material.

In total, in a linear approximation, the change rate of thermal conductivity λ with time t is given by [Formula \(B.7\)](#):

$$\lambda'_t = \Delta\lambda / \Delta t = \lambda'_p \times \Delta p / \Delta t + \lambda'_x \times \Delta X / \Delta t \quad (B.7)$$

The pressure increase rates of both air and water vapour $\Delta p / \Delta t$ and water content $\Delta X / \Delta t$ are dependent on temperature T and vapour pressure differences between inside and outside the panel.

Using [Formulae \(B.4\)](#) and [\(B.5\)](#), [Formula \(B.7\)](#) can be rewritten as [Formula \(B.8\)](#):

$$\lambda'_t = \lambda'_p \times \Delta p_{air} / \Delta t + (\lambda'_x + \lambda'_p \times \varphi_x \times p_s) \times \Delta X / \Delta t \quad (\text{B.8})$$

The increased rate of air pressure Δp_{air} is proportional to the air permeability P_{air} , which is defined as the amount of air in m³ [standard condition for temperature and pressure (STP)] permeating through the envelope of a 1 m² panel in a year. Δp_{air} is also inversely proportional to the thickness of the panel d of VIP as shown in [Formula \(B.9\)](#):

$$p't = \Delta p_{air} / \Delta t = P_{air} / d \quad (\text{B.9})$$

The increase of water content ΔX is proportional to the vapour permeation rate P_v through the envelope and inversely proportional to the mass per area $\rho \cdot d$ of VIP as shown in [Formula \(B.10\)](#):

$$\Delta X / \Delta t = P_v / (\rho \times d) \quad (\text{B.10})$$

In principle, there are two methods to determine the increase of thermal conductivity with time t :

- Method 1: Direct measurements: by testing the increase of thermal conductivity of samples stored under certain climate conditions (temperature T and RH φ).
- Method 2: Indirect measurements: by measuring the increase of gas pressure $p = p_v + p_{air}$ along the storage time plus measuring the increase of weight of the panel which is equal to the amount of water absorbed by the core material.

For calculating $\Delta \lambda_{cop,mean}$ (25 years), Method 1 shall be used.

B.3 Thermal conductivity increase during service time

B.3.1 General

Accelerated ageing is used to determine the average value of thermal conductivity over the first 25 years of use. Measurement of thermal conductivity for silica core VIP at accelerated conditions is described in [B.3.2](#). The estimation of thermal conductivity increase at standard conditions for silica VIP is described in [B.3.3](#). Calculation of mean thermal conductivity increase due to ageing over 25 years is described in [B.3.4](#).

B.3.2 Measurement of thermal conductivity at accelerated conditions

At standard conditions (23 °C, 50 % RH) the increase rate of thermal conductivity with time is usually rather low so accelerated ageing conditions at higher temperatures and humidity are chosen (50 °C, 70 % RH), where the permeation of air and water vapour through the envelope is enhanced considerably. According to [Formula \(B.7\)](#), the increase of thermal conductivity is also accelerated accordingly.

If Method A in [4.2.3.1](#) is used to declare the thermal conductivity, two VIP test specimens per product thickness from different production dates shall be used for the procedure in this subclause.

If Method B in [4.2.3.1](#) is used to declare the thermal conductivity, two VIP test specimens of 10 mm thickness and two VIP test specimens of 30 mm thickness from different production dates shall be used for the procedure in this subclause.

These VIP test specimens are stored at 50 °C, 70 % RH over a period of 180 days. At the start of storage, after 30 days, after 60 days, after 90 days, after 120 days and at the completion of storage after 180 days, the thermal conductivity is measured according to ISO 8301 or ISO 8302 and the average of the two samples with the same thickness is calculated

Also, the inner pressure, p ([Annex G](#)) as well as the mass m shall be measured for control purposes and cross-check.

From the average values of the thermal conductivity between 60 days and 180 days, the steady state increase rate at 50 °C, 70 % RH of $\lambda'_{t,50/70}$ shall be calculated.

From the determined values of inner pressure and weight between 60 days and 180 days, the annual increase of inner pressure of VIP p'_a and the annual increase of relative weight (= relative increase in humidity X') shall be calculated and compared to the measured increase of thermal conductivity $\lambda'_{t,50/70}$ as a countercheck.

The reason for using the measurement results from 60 days and 180 days for the calculation of the thermal conductivity increase rate is to eliminate the effect of short-term mechanisms such as outgassing and changes of the solid conductivity which become negligible after 60 days.

A typical example of measured values (average of two measurements for VIP with the same thickness) is shown in [Figure B.2](#). The increase in the first 60 days is typically higher than observed afterwards. After 60 days, the thermal conductivity is approximately a linear function with time. The slope of this linear function $\Delta\lambda/\Delta t = \lambda'_{t,50/70}$ shall be determined by least squares fit method to the measured values after 60 days, 90 days, 120 days and 180 days of accelerated ageing. Likewise the corrected thermal conductivity $\lambda^*(t=0)$ shall be determined as interpolation of this best fit to $t=0$.

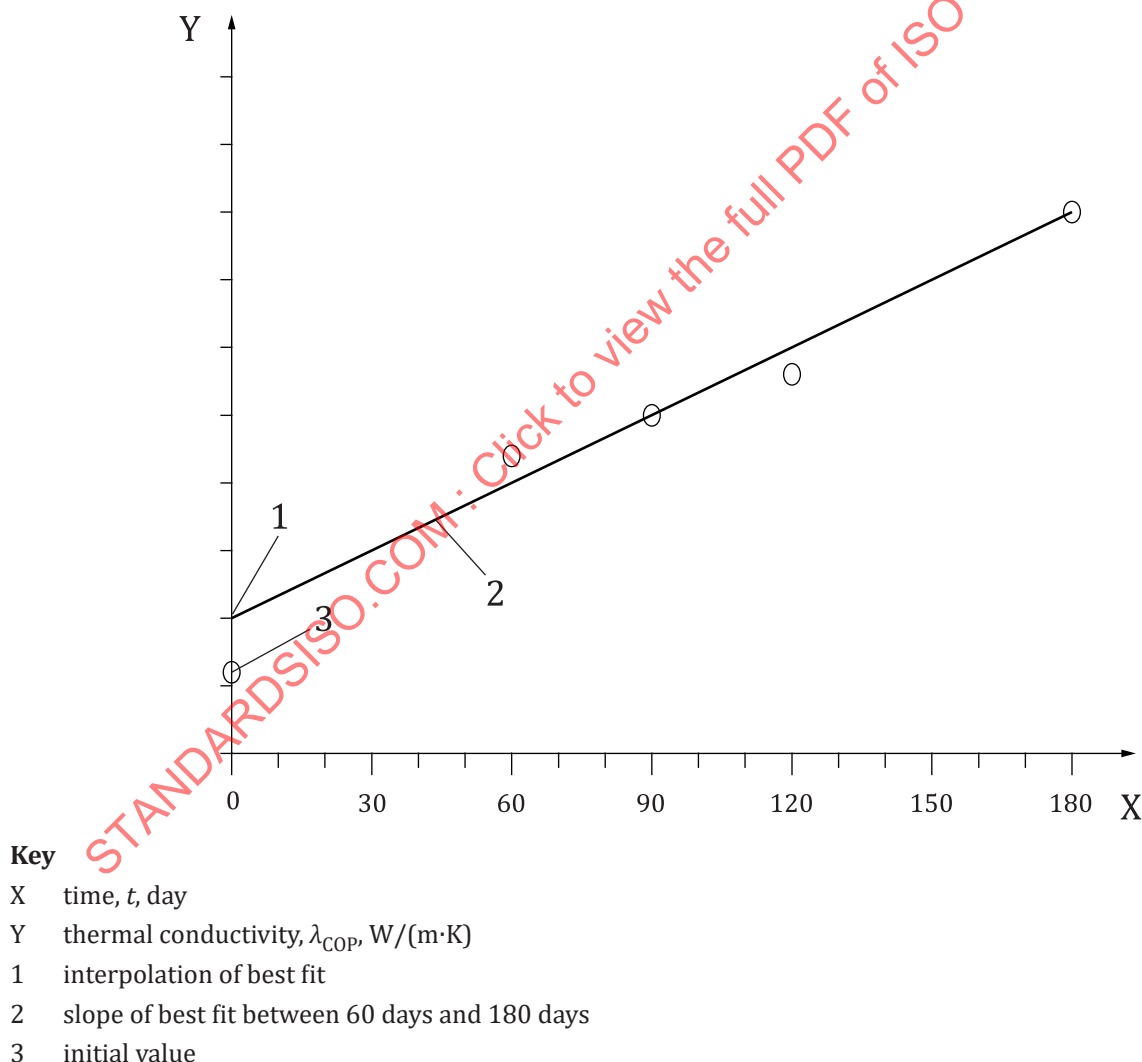


Figure B.2 — Thermal conductivity of VIP at 50 °C/70 % RH

B.3.3 Estimation of thermal conductivity increase at standard conditions

The thermal conductivity as a function of time at accelerated conditions 50 °C, 70 % RH can be approximated by [Formula \(B.11\)](#):

$$\lambda(t)_{50/70} = \lambda^*(t=0) + \lambda'_{t,50/70} \times t \quad (\text{B.11})$$

whereas the thermal conductivity as a function of time at 23 °C, 50 % RH can be approximated by [Formula \(B.12\)](#):

$$\lambda(t)_{23/50} = \lambda^*(t=0) + \lambda'_{t,23/50} \times t \quad (\text{B.12})$$

The relation between the thermal conductivity increase at 50 °C, 70 % RH and the thermal conductivity increase at the standard climate 23 °C, 50 % RH can be obtained by the following formulae using the accelerating factors f_{air} of air permeation and f_v of water vapour permeation of the envelope as defined in [B.4](#):

$$\lambda'_{t,50/70} = (\lambda'_x + \lambda'_p \times \varphi'_x \times p_s) \times X'_{t,50/70} + \lambda'_p \times f_{\text{air}} \times p'_{t,\text{air},23/50} \quad (\text{B.13})$$

$$\lambda'_{t,23/50} = (\lambda'_x + \lambda'_p \times \varphi'_x \times p_s) / f_v \times X'_{t,50/70} + \lambda'_p \times p'_{t,\text{air},23/50} \quad (\text{B.14})$$

Combining [Formulae \(B.13\)](#) and [\(B.14\)](#), the increase of thermal conductivity at standard conditions 23 °C/50 % RH is obtained by using [Formula \(B.15\)](#):

$$\lambda'_{t,23/50} = 1/f_v \times \lambda'_{t,50/70} + \lambda'_p \times p'_{t,\text{air},23/50} \times (1 - f_{\text{air}}/f_v) \quad (\text{B.15})$$

or by using [Formula \(B.16\)](#)

$$\lambda'_{t,23/50} = 1/f_v \times \lambda'_{t,50/70} + \lambda'_p \times P_{\text{air},23/50} / d \times (1 - f_{\text{air}}/f_v) \quad (\text{B.16})$$

with λ'_p from [Formula \(B.2\)](#). The air permeability of the envelope at 23 °C/50 % RH, $P_{\text{air},23/50}$, and the acceleration factors for air and water vapour of the envelope f_{air} and f_v shall be determined according to [B.4](#).

B.3.4 Calculation of mean thermal conductivity increase over 25 years

The average value of thermal conductivity change due to ageing at centre of panel over 25 years in use $\Delta\lambda_{\text{cop,mean}}(25 \text{ years})$ shall be used for each thickness of the VIP as placed on the market (Method A in [4.2.3.1](#)) or for the standard thicknesses 10 mm and 30 mm (Method B in [4.2.3.1](#)) as in [Formula \(B.17\)](#):

$$\Delta\lambda_{\text{cop,mean}}(25 \text{ years}) = \lambda^*(t=0) - \lambda(t=0) + \lambda'_{t,23/50} \times 12,5 \text{ years} \quad (\text{B.17})$$

where $\lambda^*(t=0)$ and $\lambda(t=0)$ are determined according to [B.3.3](#) and $\lambda'_{t,23/50}$ from [Formula \(B.15\)](#).

B.4 Barrier performance of the envelope

B.4.1 Acceleration factors

The supplier of the envelope shall provide the following information on the barrier properties of the VIP envelope as tested by a notified laboratory:

- permeability of air, P_{air} , at 50 °C, 70 % RH and at 23 °C, 50 % RH [$\text{cm}^3 \text{ (STP)}/(\text{m}^2 \text{ day})$];
- water intake rate, P_v , at 50 °C, 70 % RH and at 23 °C, 50 % RH ($\text{g}/\text{m}^2 \text{ day}$).

The determination of the permeability of air P_{air} shall be described in [B.4.2](#), the determination of the water intake rate in [B.4.3](#). The acceleration factors f_{air} for dry air and water vapour f_v shall be defined via [Formulae \(B.18\)](#) and [\(B.19\)](#):

$$f_{\text{air}} = P_{\text{air}} (50\text{ °C}, 70\text{ \% RH}) / P_{\text{air}} (23\text{ °C}, 50\text{ \% RH}) \quad (\text{B.18})$$

$$f_v = P_v (50\text{ °C}, 70\text{ \% RH}) / P_v (23\text{ °C}, 50\text{ \% RH}) \quad (\text{B.19})$$

Typical factors determined by using [Formulae \(B.18\)](#) and [\(B.19\)](#) for metalized PET films are $f_v = 10$ and is $f_{\text{air}} = 4$. For calculation, these values can be used for envelopes containing these kinds of films. Alternatively, and for all other envelopes, the procedures described in [B.4.2](#) and [B.4.3](#) shall be used.

B.4.2 Procedure for measuring the air permeability of an envelope

The air permeability of the VIP envelope shall be tested using a core material with $p_{1/2} < 1\,000\text{ Pa}$, e.g. a glass fibre core whose $\lambda(p)$ relation shall be measured previously by the notified body according to one of the procedures described in [Annex D](#).

Six $300\text{ mm} \times 300\text{ mm} \times 10\text{ mm}$ panels shall be produced by the notified body using this glass fibre core and the envelope under consideration. An amount of desiccant large enough to absorb the entire penetrating vapour shall be used in all six panels. Three of them shall be stored for 180 days at 50 °C , $70\text{ \% RH}$ and three shall be stored for 180 days at 23 °C , $50\text{ \% RH}$. The thermal conductivity shall be measured after $t = 120\text{ days}$, $t = 150\text{ days}$ and $t = 180\text{ days}$.

By using the already known $\lambda(p)$ relation, the inner pressure of each of the panels shall be determined along the storage time. The steady state air permeability shall be calculated by linearly fitting the slope $\Delta p / \Delta t$ from day 120 to day 180. The air permeability values for each condition set shall be the average value for the three panels tested.

B.4.3 Procedure for measuring the water intake rate of an envelope

The procedure shall start with the preparation of a small glass fibre core VIP ($\sim 150\text{ mm} \times 120\text{ mm} \times 7\text{ mm}$) with an amount of desiccant large enough to absorb the entire penetrating vapour inside using the inspected film. The panels shall be weighed using a micro-balance, and then held in a climate chamber at the relevant temperature and RH. For 60 days, the panels shall be weighed every 10 days. The mass gain during this period shall be caused by the water molecules permeating and absorbed by the desiccant. The water intake rate value shall be calculated by dividing the mass gain in the last 30 days duration by the surface area of the envelope divided by 30 days ($\text{g/m}^2 \times \text{day}$).

Three panels shall be tested at 50 °C , $70\text{ \% RH}$ and three panels at 23 °C , $50\text{ \% RH}$. The WI values for each condition set shall be the average value for the three panels tested.

Annex C
(normative)

Determination of the aged values for glass fibre core VIP

C.1 General

Ageing procedures shall be used for glass fibre core VIP since the thermal conductivity increases with time during service time. This deterioration of thermal performance is due to an increase in inner gas pressure. For glass fibre core VIP, permeated water vapour is adsorbed by desiccant. The influence of thermal conductivity due to permeation of water vapour is negligible during the desiccant lifetime. The increase in inner pressure under standard conditions 23 °C, 50 % RH, is estimated by the Arrhenius plot. The ageing procedure described in C.2 shall be used to calculate a mean thermal conductivity at COP over a period of 25 years.

The ageing procedure is described in Figure C.1.

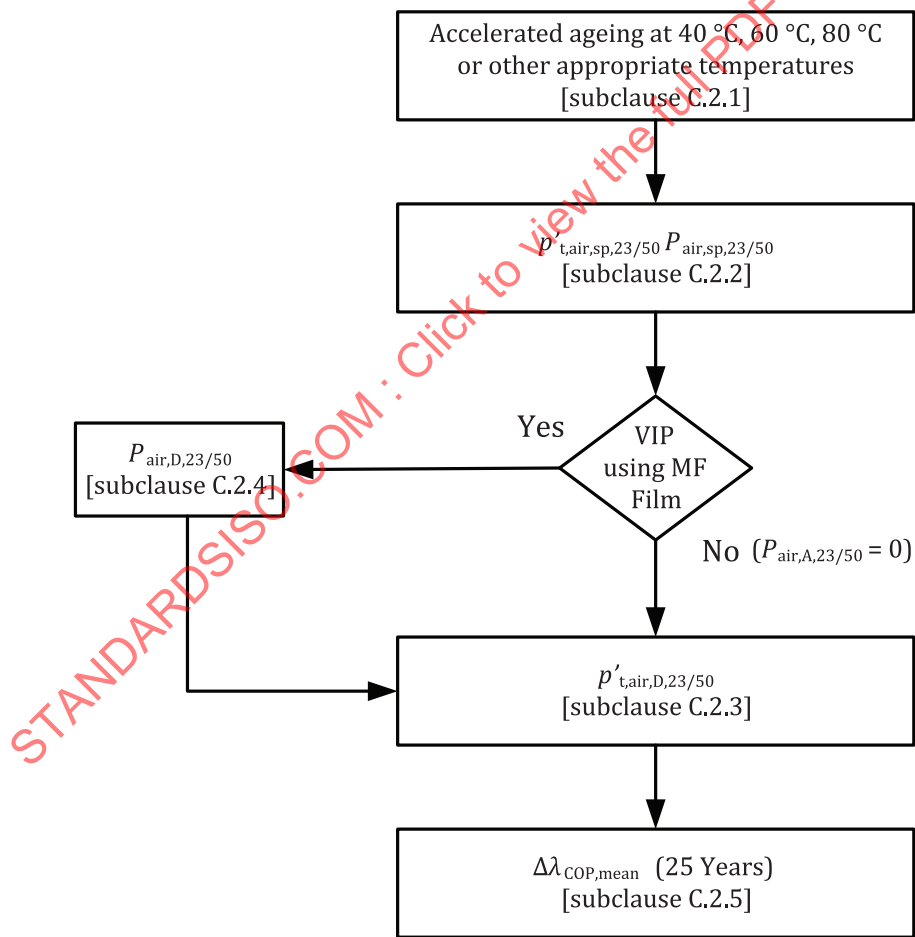


Figure C.1 — Flowchart of ageing procedure

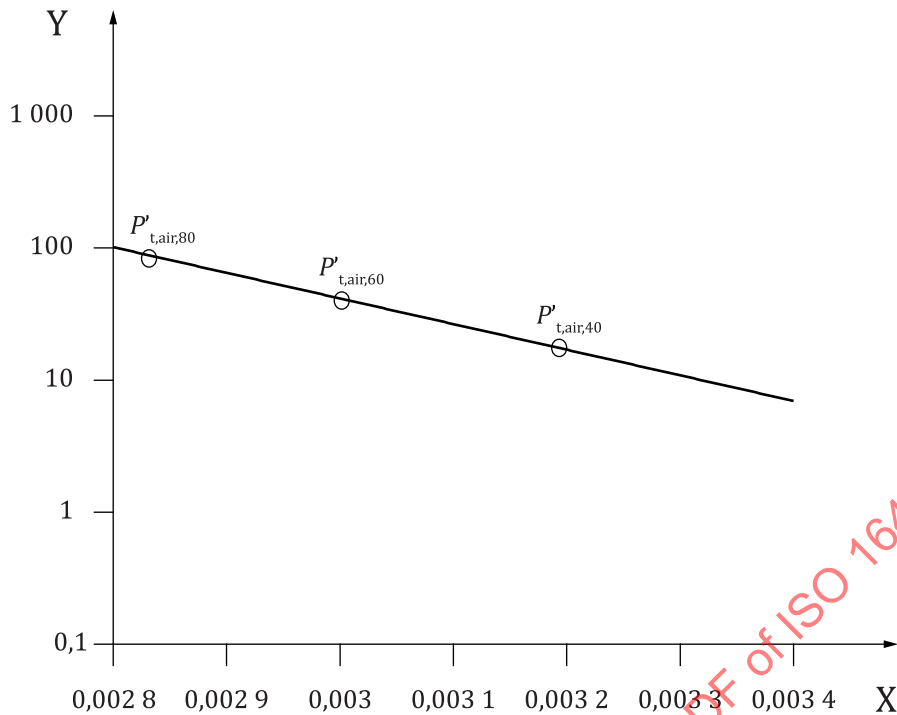
C.2 Thermal conductivity increase during service time

C.2.1 Measurement of thermal conductivity at accelerated conditions

- a) The specimens shall be 300 mm × 300 mm in size and 10 mm thick. Three specimens per test condition shall be prepared.
- b) The initial thermal conductivity of the specimens shall be measured according to ISO 8301 or ISO 8302, at a mean temperature of $(23 \pm 2) ^\circ\text{C}$ or $(10 \pm 2) ^\circ\text{C}$, and the specimens shall be stored in a climate chamber conditioned at 40 °C, 60 °C and 80 °C or other set of appropriate temperatures. Absolute humidity in the climate chamber shall be controlled at the same value as standard conditions: 23 °C, 50 % RH.
- c) The thermal conductivity at a mean temperature of $(23 \pm 2) ^\circ\text{C}$ or $(10 \pm 2) ^\circ\text{C}$ shall be measured according to ISO 8301 or ISO 8302, at 30-day intervals from 30 days to 180 days after the start of conditioning.

C.2.2 Determination of inner pressure increase rate and total air permeability under standard condition

- a) The inner pressure of each panel at accelerated conditions, for example $p_{\text{air,sp},40}$, $p_{\text{air,sp},60}$ and $p_{\text{air,sp},80}$, shall be determined along the storage time by using the relationship between $\lambda(p)$ and the inner pressure according to [Annex D](#). The inner pressure increase rate, for example $p'_{\text{t,air,sp},40}$, $p'_{\text{t,air,sp},60}$ and $p'_{\text{t,air,sp},80}$ shall be determined by least square fit method. These values for each condition set shall be average values for the three panels tested.
- b) Inner pressure increase rate, $p'_{\text{t,air,sp},23/50}$ under standard conditions: 23 °C, 50 % RH, shall be estimated by the Arrhenius plot (see [Figure C.2](#)).

**Key**

X	$1/T, K^{-1}$
Y	inner pressure increase rate, $p'_{t,air,sp}$, Pa/day
$P'_{t,air,40}$	inner pressure increase rate at 40 °C, Pa/day
$P'_{t,air,60}$	inner pressure increase rate at 60 °C, Pa/day
$P'_{t,air,80}$	inner pressure increase rate at 80 °C, Pa/day

Figure C.2 — Arrhenius plot

- c) Inner dry air mass increase rate $m'_{t,air,sp}$ (g/day) shall be converted by using the ideal gas state formula from inner dry air pressure increase rate $p'_{t,air,sp}$ (Pa/day).
- d) The total dry air permeability of the envelope at 23 °C, 50 % RH shall be determined by using [Formula \(C.1\)](#).

$$P_{air,total,sp,23/50} = \frac{m'_{t,air,sp,23/50}}{p_{air,atm}} \quad (C.1)$$

C.2.3 Determination of inner pressure increase rate of a product size VIP

[Formula \(C.2\)](#) and [Formula \(C.3\)](#) shall be used to determine the inner pressure increase rate at a product size, $p'_{t,air,23/50}$.

- a) For VIP using aluminium foil laminated film (AF):

$$p'_{t,air,23/50} = p'_{t,air,sp,23/50} \times \frac{V_{sp}}{V} \times \frac{l_{es}}{l_{es,sp}} \quad (C.2)$$

- b) For VIP using metallized film (MF), which covers VIP using MF on one side and AF on the other:

$$p'_{t,air,23/50} = p'_{t,air,sp,23/50} \times \frac{V_{sp}}{V} \times \frac{P_{air,total,23/50}}{P_{air,total,sp,23/50}} \quad (C.3)$$

The film used in both a) and b) should have the same type of seal layers, the same seal layer thickness and the same seal width and exactly the same sealing technique.

C.2.4 Determination of dry air permeability of the envelope for VIP using MF

C.2.4.1 General

For VIP using MF, dry air is penetrated through the edge seam but also through the film surface. The permeability of dry air through the envelope at an arbitrary product size shall be determined by the following steps.

C.2.4.2 Dry air permeability through film surface

The dry air permeability per surface area of gas permeation plane, $P_{\text{air,A},23/50}$ shall be determined by [Formula \(C.4\)](#)

$$P_{\text{air,A},23/50} = \frac{P_{\text{air,total,sp},23/50} - P_{\text{air,l},23/50} \times l_{\text{es,sp}}}{A_{\text{sur,sp}}} \quad (\text{C.4})$$

The dry air permeability per edge seal length shall be determined in accordance with [C.2.4.3](#).

C.2.4.3 Dry air permeability through edge seal

Dry air permeation does not occur for AF, assuming that the pinhole of the surface is negligible.

The dry air permeability through the seam edge for VIP with MF shall be estimated from the similar glass fibre core specimen using AF. The dry air permeability for VIP with AF shall be determined in accordance with [C.2.2](#). The dry air permeability per edge seal length, $P_{\text{air,l},23/50}$, shall be determined using [Formula \(C.5\)](#):

$$P_{\text{air,l},23/50} = \frac{P_{\text{air,total,sp},23/50}}{l_{\text{es,sp}}} \quad (\text{C.5})$$

C.2.4.4 Dry air permeability at a product size

The overall dry air permeability through the envelope at arbitrary product size, $P_{\text{air,total},23/50}$, shall be determined by [Formula \(C.6\)](#):

$$P_{\text{air,total},23/50} = P_{\text{air,A},23/50} \times A_{\text{sur}} + P_{\text{air,l},23/50} \times l_{\text{es}} \quad (\text{C.6})$$

C.2.5 Calculation of mean thermal conductivity increase over 25 years

Thermal conductivity as a function of time at COP shall be calculated by [Formula \(C.7\)](#).

$$\lambda_{\text{cop}}(t) = \lambda_0 + \frac{\lambda_{\text{air}}}{1 + \frac{p_{1/2}}{p_0 + p'_{\text{t,air},23/50} \times t}} \quad (\text{C.7})$$

The average value of thermal conductivity change due to ageing at COP over 25 years in use, $\Delta\lambda_{\text{cop,mean}}(25 \text{ years})$, shall be calculated by [Formula \(C.8\)](#):

$$\Delta\lambda_{\text{cop,mean}}(25 \text{ years}) = \lambda_{\text{air}} \times \left[\frac{1}{y} - \frac{\ln(1+x/y)}{x} \right] \quad (\text{C.8})$$

$$x = \frac{p'_{\text{t,air},23/50}}{p_{1/2}} \times 25 \text{ years}, \quad y = 1 + \frac{p_0}{p_{1/2}}$$

where

$p'_{t,air,23/50}$ is determined according to [C.2.3](#);

$p_{1/2}$ is determined according to [Annex D](#);

$\lambda_{air} = 0,026 \text{ W/(m}\cdot\text{K)}$;

p_0 is converted from the initial thermal conductivity by using $\lambda(p)$ relation in accordance with [Annex D](#).

C.3 Desiccant lifetime

C.3.1 Measurement of the water intake rate of an envelope

The specimens shall be stored in a climate chamber conditioned at the standard and accelerated conditions. Three panels shall be tested at 50 °C, 70 % RH and three panels at 23 °C, 50 % RH. The WI values for each condition set shall be the average value for the three panels tested. The specimens shall be 300 mm × 300 mm in size and 10 mm thick. In addition, the envelope should contain MF at least on one side.

Their masses shall be measured using an electronic force balance with a minimum weighing resolution of 1 mg or less at 10-day intervals until 60 days after the start of conditioning. If no specimen shows an increase of 0,1 g or more in mass during a 10-day measurement period, measurements shall be taken at intervals long enough for its mass to increase in increments of 0,1 g or more.

The specimen should be stored for 24 h at the same temperature and RH as the measurement room in advance before measuring the mass.

From the measurement results, the amount of water vapour transmitted per day shall be determined by the least square method, and the water vapour permeability and the acceleration factor shall be determined by [Formulae \(C.9\)](#) and [\(C.10\)](#):

$$P_{v,total,sp} = \frac{m'_{t,v,sp}}{p_{v,out}} \quad (C.9)$$

$$f_v = \frac{P_{v,total,sp,50/70}}{P_{v,total,sp,23/50}} \quad (C.10)$$

C.3.2 Desiccant lifetime

C.3.2.1 General

The lifetime of the desiccant shall be determined according to the method described in [C.3.2.2](#). If $t_{des} < 25$ years then the product contains an amount of desiccant too little to work properly for 25 years and the VIP is not covered by this document.

C.3.2.2 Method

C.3.2.2.1 Determination of the initial water amount of core material absorbed by the core material and the envelope

The initial water amount of the core material m_1 shall be determined in the following way:

- Three specimens with a sufficient amount of desiccant material $m_{des,1a}$ (e.g. 50 g of CaO) shall be produced. The specimens shall be 300 mm × 300 mm in size and 10 mm thick.
- The specimens shall be stored for 2 h at 100 °C.

- c) Before opening the VIP, the specimens shall be stored for 12 h at 23 °C.
- d) The mass of the desiccant material after this procedure $m_{\text{des},1\text{d}}$ shall be measured (e.g. 52 g of CaO). The initial water amount of the core material shall be determined by [Formula \(C.11\)](#):

$$m_1 = m_{\text{des},1\text{d}} - m_{\text{des},1\text{a}} \quad (\text{C.11})$$

C.3.2.2.2 Determination of water vapour amount adsorbed over 25 years

The water vapour amount adsorbed over 25 years, $m_{25\text{a},\text{v}}$ shall be determined in the following way:

- a) Three specimens with sufficient desiccant $m_{\text{des},2\text{a}}$ (e.g. 50 g of CaO) shall be produced. The specimens shall be 300 mm × 300 mm in size and 10 mm thick.
- b) Specimens shall be stored for 180 days at 50 °C, 70 % RH.
- c) The mass of the desiccant material after acceleration test $m_{\text{des},2\text{c}}$ shall be measured.
- d) The amount of adsorbed water vapour m_2 shall be calculated using [Formula \(C.12\)](#):

$$m_2 = m_{\text{des},2\text{c}} - m_{\text{des},2\text{a}} \quad (\text{C.12})$$

- e) The water vapour diffusion rate through the VIP envelope, $m'_{\text{t},\text{v},23/50}$ shall be determined using [Formula \(C.13\)](#):

$$m'_{\text{t},\text{v},23/50} = \frac{1}{f_{\text{v}}} \times \frac{(m_2 - m_1)}{180} \quad (\text{C.13})$$

where, f_{v} shall be determined in accordance with [C.3.1](#).

- f) The adsorbed water vapour amount adsorbed over 25 years $m_{25\text{a},\text{v}}$ shall be determined using [Formula \(C.14\)](#):

$$m_{25\text{a},\text{v}} = m'_{\text{t},\text{v},23/50} \times 25 \text{ years} \quad (\text{C.14})$$

C.3.2.2.3 Calculation of desiccant lifetime

Desiccant lifetime shall be determined in the following way:

- a) The mass of the fully dried desiccant $m_{\text{des},0}$ shall be measured.
- b) The mass of the saturated desiccant $m_{\text{des},\text{sat}}$ shall be measured. The capacity of the desiccant shall be determined using [Formula \(C.15\)](#):

$$C_{\text{des}} = \frac{m_{\text{des},\text{sat}} - m_{\text{des},0}}{m_{\text{des},0}} \quad (\text{C.15})$$

- c) The water vapour adsorption rate of the desiccant slows down near saturation. The capacity of the desiccant including a safety margin of 20 % shall be determined using [Formula \(C.16\)](#):

$$C_{\text{des},20\%} = 0,8 \times C_{\text{des}} \quad (\text{C.16})$$

- d) The lifetime of desiccant shall be determined using [Formula \(C.17\)](#):

$$t_{\text{des}} = \frac{1}{365} \times \frac{m_{\text{des}}}{m'_{\text{t},\text{v},23/50}} \times C_{\text{des},20\%} \quad (\text{C.17})$$

Annex D (normative)

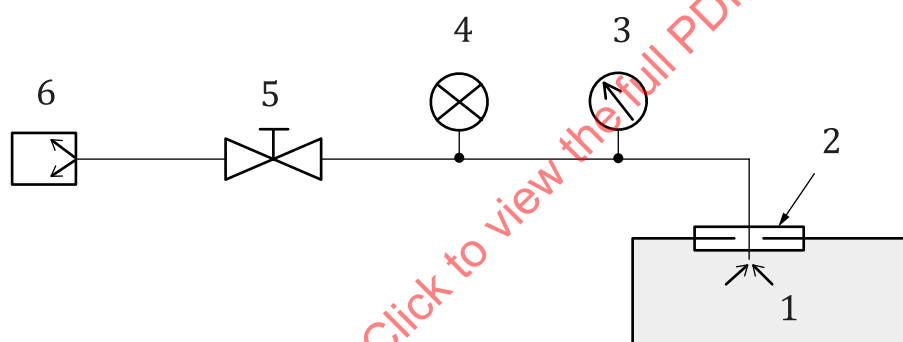
Relationship between $\lambda(p)$ and the inner pressure

D.1 General

This annex gives the method of determining the thermal conductivity as a function of gas pressure.

D.2 Apparatus

A leak-tight connector is mounted on one half of the panel while the other half of the tested panel is kept flat for hot plates thermal conductivity measurements. The connector allows a deliberate change of inner pressure by letting in a small dose of air and also accurately measures the inner pressure level while the hot plate device takes thermal conductivity readings. A typical configuration is shown in [Figure D.1](#).



Key

- 1 test specimen
- 2 leak tight connector
- 3 pressure gage
- 4 leak valve
- 5 vacuum valve
- 6 vacuum pump

Figure D.1 — Apparatus (example)

D.3 Procedure

At first, thermal conductivity is measured in accordance with ISO 8301 or ISO 8302 after evacuation of the system through the connector down to a pressure of about 0,1 Pa. Later, controlled amounts of air are injected into the envelope through the leak tight connector. The thermal conductivity is measured in accordance with ISO 8301 or ISO 8302 after each air injection together with the corresponding pressure measurement in the step of pressure as follows:

- for silica core VIP: 10, 100, 1 000, 10 000 Pa;
- for glass fibre core VIP: 0.1, 1, 10, 100, 1 000 Pa.

The parameter $p_{1/2}$ is determined from the best fit curve according to the least square method of the data points $\lambda(p)$ to the function in [Formula \(D.1\)](#).

$$\lambda(p) = \lambda_o + \lambda_{\text{air}} / (1 + p_{1/2} / p) \quad (\text{D.1})$$

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Annex E (normative)

Product type determination (PTD) and factory production control (FPC)

Table E.1 — Minimum number of tests for PTD and minimum number of product testing frequency

Clause number from ISO 16478 (this document)	PTD ^b Minimum number of tests ^c	FPC ^a Minimum testing frequency Direct testing
4.2	A minimum of 10 tests are needed statistically with a minimum of 4 tests from the PTD	Initial value 1 per day value including ageing according to Annexes A and B or Annex C per 2 years
4.3	4	1 per 24 h
4.4	4	1 per 24 h
4.5	4	—
^a In accordance with ISO 12576-1, the minimum testing frequencies expressed in test results shall be understood as the minimum for each production unit line under stable conditions. In addition to the testing frequencies given in this table, testing of relevant properties of the product shall be repeated when changes or modifications are made that are likely to affect the conformity of the product. ^b PTD, see ISO 12576-1. It is only relevant when properties are declared. ^c The minimum number of tests may be reduced according to ISO 12576-1. For initial type testing of long-term thermal and freeze-thaw properties, test results of similar products produced at different plants or lines will be recognized until testing for a new plant or line is complete.		

Annex F (informative)

Additional properties

F.1 General

The manufacturer can choose to give information on the following properties (see [Table F.1](#)).

Unlike other insulating materials, VIP cannot be cut to the size required by the test standards. They shall be produced in the sizes stated in [Table F.1](#).

F.2 Additional properties

F.2.1 Inner pressure

The inner pressure of the panel shall be measured at least 24 h after production according to [Annex G](#).

F.2.2 Deformation

Dimensions under specified compressive load and temperature conditions shall be determined according to ISO 29764. The conditioning shall be carried out at 40 kPa and 70 °C.

F.2.3 Compressive stress or strength

Compressive stress at 10 % deformation, σ_{10} , or the compressive strength, σ_m , shall be determined in accordance with ISO 29469.

F.2.4 Tensile strength perpendicular to face

Tensile strength perpendicular to faces, σ_{mt} , shall be determined in accordance with ISO 29765.

F.2.5 Compressive creep

Compressive creep, X_{ct} , and total thickness reduction, X_t , shall be determined in accordance with ISO 20392. The test shall be carried out after at least 122 days in steps of at least 1 kPa.

F.2.6 Shear strength

Shear strength, τ , shall be determined in accordance with ISO 16537.

F.2.7 Thermal conductivity of the punctured VIP

The thermal resistance and thermal conductivity of a punctured VIP shall be recorded upon measurements in accordance with ISO 8301 or ISO 8302. The value of ambient pressure should be recorded during measurements. To this extent the envelope of the VIP shall be opened at the edge. The length or diameter of the opening shall be between 10 mm and 20 mm. For VIP with evacuation valves, the valve can be opened until ambient pressure is reached.

The thermal resistance and thermal conductivity shall be determined after conditioning the test specimen at $(23 \pm 2) ^\circ\text{C}$ and $(50 \pm 5) \% \text{ RH}$ for at least 24 h. The thickness of the punctured VIP can differ from the thickness of the evacuated VIP. Therefore, the thickness of the punctured VIP d_{ambient} shall be measured according to ISO 29466.

The edge effect, $\Delta\lambda_{\text{edge}}$, measured or modelled with non-punctured VIP according to 4.2.3.2 should be used to calculate the thermal conductivity and thermal resistance of the punctured VIP according to [Formulae \(F.1\)](#) and [\(F.2\)](#).

$$\lambda_{\text{ambient, eff}} = \lambda_{\text{ambient}} + \Delta\lambda_{\text{edge}} \quad (\text{F.1})$$

$$R_{\text{ambient, eff}} = d_{\text{ambient}} / \lambda_{\text{ambient, eff}} \quad (\text{F.2})$$

F.2.8 Reaction to fire

The reaction to fire for non-EU classifications shall be determined in accordance with results of testing from ISO 12136.

The reaction to fire (for Euroclass classification) shall be determined in accordance with EN 13501-1 mounting and fixing procedure for reaction to fire tests which is given in [Annex H](#). The minimum product testing frequencies for the reaction to fire characteristics are shown in [Table F.2](#).

Table F.1 — Test methods, dimensions of specimens and conditions

Clause number in ISO 16478 (this document)	Test methods	Test specimen		Specific conditions
		Dimensions (mm)	Minimum number to get one test result	
F.2.1	Annex G	≥ 300	1	At least 24 h after production
F.2.2	ISO 29764	≥ 200	3	40 kPa and 70 °C
F.2.3	ISO 29469	≥ 200	3	10 % deformation
F.2.4	ISO 29765	≥ 200	3	—
F.2.5	ISO 20392	≥ 200	3	after at least 122 days
F.2.6	ISO 16537	200 × 100	3	—
F.2.7	ISO 8301 or ISO 8302	≥ 300	1	
F.2.8	See EN 13501-1 and see Annex H	See Annex H	See EN 13501-1	See EN 13501-1

Table F.2 — Minimum product testing frequencies for the reaction to fire characteristics

Clause in ISO 16478 (this document)		Minimum testing frequency ^a									
No	Title	Direct testing ^b			Indirect testing ^{c, d}						
	Reaction to fire ^e	Test method	Frequency	Test method	Frequency	Product		Substantial		Non-Substantial	
E.2.8	Class					Test method	Frequency	Test method	Frequency	Test method	Frequency
	A1 without testing	EN 13820	1 per 3 months or 1 per 2 years and indirect testing	-	-	-	-	Loss on ignition	1 per 4 h	Weight per area	1 per 1 h
	A1	ISO 1182 and ISO 1716 (and EN 13823)	1 per 2 years and indirect testing	-	-	-	-	Loss on ignition	1 per 4 h	Either loss on ignition or calorific potential	1 per 4 h
	A2	ISO 1182 or ISO 1716 and EN 13823	1 per 2 years and indirect testing	-	-	-	-	Apparent density	1 per 1 h	Weight per area	1 per 1 h
						Manufacturer's method	1 per month	Loss on ignition	1 per 4 h	Either loss on ignition or calorific potential	1 per 4 h
								Apparent density	1 per 1 h	Weight per area	1 per 1 h

^a The minimum testing frequencies, expressed in test results, shall be understood as the minimum for a product or a product group for each production unit/line under stable conditions. In addition to the testing frequencies given in the table, testing of relevant properties of the product shall be repeated when changes or modifications are made that are likely to affect the performance of the product.

^b Direct testing may be conducted either by a third party or by the manufacturer.

^c Indirect testing shall be either on the product or on its components.

^d Indirect testing is only possible in the case of products falling within the system 1 for reaction to fire, or by having a notified body verifying the correlation to the direct testing.

Not all reaction to fire classes apply for the products conforming to this document.

Table F.2 (continued)

Clause in ISO 16478 (this document)		Minimum testing frequency ^a									
No	Title	Direct testing ^b				Indirect testing ^{c, d}					
		Reaction to fire ^e		Product		Substantial		Non-Substantial		Frequency	
F.2.8	Class	Test method	Frequency	Test method	Frequency	Test method	Frequency	Test method	Frequency	Test method	Frequency
		EN 13823 and ISO 11925-2	1 per month or 1 per 2 years and indirect testing	-	-	-	-	-	-	-	-
	B C D			Manufacturer's method	1 per month	Loss on ignition	1 per 4 h	Either loss on ignition or calorific potential	1 per 4 h		
			1 per week or 1 per 2 years and indirect testing	-	-	Apparent density	1 per 1 h	Weight per area	1 per 1 h		
				Manufacturer's method	1 per month	-	-	-	-		
	E	ISO 11925-2	1 per week or 1 per 2 years and indirect testing	-	-	-	-	-	-		
				Manufacturer's method	1 per month	-	-	-	-		
	F	ISO 11925-2	1 per 10 years	-	-	-	-	-	-		

^a The minimum testing frequencies, expressed in test results, shall be understood as the minimum for a product or a product group for each production unit/line under stable conditions. In addition to the testing frequencies given in the table, testing of relevant properties of the product shall be repeated when changes or modifications are made that are likely to affect the performance of the product.

^b Direct testing may be conducted either by a third party or by the manufacturer.

^c Indirect testing shall be either on the product or on its components.

^d Indirect testing is only possible in the case of products falling within the system 1 for reaction to fire, or by having a notified body verifying the correlation to the direct testing.

^e Not all reaction to fire classes apply for the products conforming to this document.

Annex G (informative)

Measurement of inner pressure

G.1 General

The aim of this annex is to give a method to measure the inner pressure of a VIP product. In this context, ISO 3529-1, ISO 3529-2 and ISO 3529-3 shall be referenced for the terminologies.

Three methods are possible to determine the inner pressure:

- the pressure compensation method according to [G.4.3](#);
- the pressure sensor method according to [G.4.4](#);
- the evacuation valve method in [G.4.5](#).

For the pressure compensation method, the external pressure around the VIP is reduced in a vacuum chamber. Alternatively, the external pressure around one part of the VIP is reduced under a suction bell until it equals the inner pressure of the VIP.

For the pressure sensor method, the inner pressure is measured by a sensor placed inside the VIP^[6].

For the VIP with evacuation valve and vacuum pump the inner pressure can be determined under two different boundary conditions:

- a) as part of the production process during respectively at the end of the evacuation phase (see [Figure G.1](#));
- b) as an in situ-measurement in the building construction respectively on the building site.

Dependent on the particular boundary conditions, the measurement of the inner pressure demands an instrumentation as follows:

- VIP with an evacuation valve;
- fine vacuum pump for the pressure range $P \leq 1\,500$ Pa (fine vacuum); if necessary, in combination with a helium leakage test device;
- rotary vane pump for the pressure range $1\,500 \text{ Pa} \leq P < 101\,325$ Pa (rough vacuum);
- evacuation tube with a double junction and four connecting flanges with associated slide valves for the closing-off of the connected devices;
- pressure gauge (load cell);
- display unit of the pressure gauge.

G.2 Apparatus

G.2.1 Vacuum chamber

The internal gas pressure of VIP is identified by using the panel envelope laminate as a measurement membrane. The level of vacuum for the pressure compensation method is shown to work in the range 20 Pa to about 10 000 Pa. A pressure with a factor of 10 below the expected internal gas pressure of the

VIP shall be attainable with the vacuum pump used and shall be within the measurement range of the gas pressure sensor.

G.2.2 Laser

Device used to measure the displacement of the envelope for the compensation method with a resolution of 0,1 mm or below.

G.2.3 Suction bell

For panels above 250 mm × 250 mm the gauge head diameter of 250 mm can be used. A pressure with a factor of 10 below the expected internal gas pressure of the VIP shall be attainable with the vacuum pump used and shall be within the measurement range of the gas pressure sensor.

G.2.4 Standard pressure gauges

Usually a capacitive type pressure sensor is used.

G.3 Test specimens

In real dimension, (l, L, d) limited by the size of the vacuum chamber.

Number of specimens: one, tested five times.

Conditioning: $(23 \pm 2) ^\circ\text{C}$ and $(50 \pm 10) \% \text{ RH}$ for a minimum 24 h at ambient pressure.

G.4 Procedure

G.4.1 General

The measurement of inner pressure for VIP without evacuation valves shall be performed by means of the one of the methods described in either [G.4.3](#), [G.4.4](#) or [G.4.5](#).

G.4.2 Test conditions

The test shall be carried out at $(23 \pm 2) ^\circ\text{C}$.

G.4.3 Pressure compensation method (lift-off technique)

The test vacuum panel is placed in the centre of a vacuum chamber. One laser displacement gauge should point at the centre of the panel on one side without seal. When the chamber lid is closed, a vacuum pump evacuates the air out of the chamber. Gas pressure in the chamber and the movement (lift) of the laminate envelope that encases the VIP is measured simultaneously, therefore measuring the internal vacuum pressure of a flexible covered panel. The external pressure around the VIP is reduced in a vacuum chamber or the external pressure around one part of the VIP is reduced under a suction bell until it falls just below the inner pressure of the VIP. The flexible envelope begins to lift off the core material (see [Figure G.1](#)). This procedure is recorded by means of laser optical distance measurement in combination with the external pressure and leads to the calculation of the compensation pressure (= inner VIP pressure). The lift-off technique works well only with core materials such as fumed silica (see [Figure G.3a](#)) that have small volume expansion when inflated. The lift-off technique cannot be applied to glass fibre cores (see [Figure G.3b](#)) because the core starts expanding at external pressure much higher than the inner pressure.

For better accuracy the system should include four laser displacement units. The measurement shall be repeated five times, the first result is discarded. After each measurement, increase the pressure to ambient pressure. The inner pressure is determined by [G.5](#).