



BSI Standards Publication

Chimneys - Thermal and fluid dynamic calculation methods

Part 1: Chimneys serving one combustion appliance

National foreword

This British Standard is the UK implementation of EN 13384-1:2015+A1:2019. It supersedes BS EN 13384-1:2015, which is withdrawn.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to CEN text carry the number of the CEN amendment. For example, text altered by CEN amendment A1 is indicated by A1 A1.

The UK participation in its preparation was entrusted to Technical Committee B/506, Chimneys.

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

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ICS 91.060.40

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 April 2015.

Amendments/corrigenda issued since publication

Date	Text affected
31 July 2019	Implementation of CEN amendment A1:2019
31 August 2019	Implementation of CEN correction notice 17 July 2019: title of document and reference in European foreword corrected

English Version

Chimneys - Thermal and fluid dynamic calculation methods - Part 1: Chimneys serving one combustion appliance

Conduits de fumée - Méthodes de calcul thermo-aérodynamique - Partie 1: Conduits de fumée ne desservant qu'un seul appareil

Abgasanlagen - Wärme- und strömungstechnische Berechnungsverfahren - Teil 1: Abgasanlagen mit einer Feuerstätte

This European Standard was approved by CEN on 24 January 2015 and includes Amendment 1 approved by CEN on 27 April 2019.

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European foreword

This document (EN 13384-1:2015+A1:2019) has been prepared by Technical Committee CEN/TC 166 “Chimneys”, the secretariat of which is held by ASI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2020, and conflicting national standards shall be withdrawn at the latest by January 2020.

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

This document supersedes A1 EN 13384-1:2015 A1.

This document includes Amendment 1 approved by CEN on 26 June 2019.

According to EN 13384-1:2002+A2:2008 and EN 13384-1:2015+A1:2019 the following fundamental changes are given:

- editorial mistakes have been corrected;
- mistakes in formulas have been corrected;
- for wood the rise of the dew point to take into account the acid condensation has been deleted;
- table for material characteristics in Table B.5 has been adapted to EN 15287-1 and supplemented by radiation coefficients;
- in Calculation of thermal resistance according to Annex A are linked to the method of EN 15287-1 for taking into account the temperature dependence has been added;
- for non-concentric ducts the calculation of the mean temperature of the air supply has been amended;
- for chimney fans a calculation procedure has been added;
- “heating appliance” replaced by “combustion appliance”;
- New calculation for combustion air mass flow introduced;
- “Supply air” replaced by “combustion air”.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

The start and finish of text introduced or altered by amendment is indicated in the text by tags A1 A1.

This European Standard “Chimneys — Thermal and fluid dynamic calculation methods” consists of three Parts:

- Part 1: Chimneys serving one combustion appliance

- Part 2: Chimneys serving more than one combustion appliance
- Part 3: Methods for the development of diagrams and tables for chimneys serving one heating appliance

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

1 Scope

This European Standard specifies methods for the calculation of the thermal and fluid dynamic characteristics of chimneys serving one A_1 combustion A_1 appliance.

The methods in this part of this European Standard are applicable to negative or positive pressure chimneys with wet or dry operating conditions. It is valid for chimneys with A_1 combustion A_1 appliances for fuels subject to the knowledge of the flue gas characteristics which are needed for the calculation.

The methods in this part of this European Standard are applicable to chimneys with one inlet connected with one appliance. The methods in Part 2 of this European Standard are applicable to chimneys with multiple inlets and one inlet with multiple appliances. Part 3 describes methods for the development of diagrams and tables for chimneys serving one A_1 combustion A_1 appliance.

2 Normative references

A_1 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. A_1

EN 1443, *Chimneys - General requirements*

EN 1856-1, *Chimneys - Requirements for metal chimneys - Part 1: System chimney products*

EN 1859, *Chimneys — Metal chimneys — Test methods*

EN 13502, *Chimneys - Requirements and test methods for clay/ceramic flue terminals*

EN 15287-1:2007+A1:2010, *Chimneys - Design, installation and commissioning of chimneys - Part 1: Chimneys for non-roomsealed heating appliances*

prEN 16475-2, *Chimneys - Accessories - Part 2: Chimney fans - Requirements and test methods*

CEN/TR 1749, *European scheme for the classification of gas appliances according to the method of evacuation of the combustion products (types)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1443 and the following apply.

A_1 ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp> A_1

3.1

heat output

Q

amount of heat produced by a A_1 combustion A_1 appliance per unit of time

3.1.1

nominal heat output

Q_N

continuous heat output specified by the manufacturer of the $\square_{A1}$ combustion $\langle A1 \rangle$ appliance related to specified fuels

3.1.2

heat output range

range of output below the nominal heat output specified by the manufacturer over which the appliance can be used

3.2

heat input

Q_F

amount of heat in unit time which is supplied to the $\square_{A1}$ combustion $\langle A1 \rangle$ appliance by the fuel based on its net calorific value H_u

3.3

efficiency of the $\square_{A1}$ combustion $\langle A1 \rangle$ appliance

η_w

ratio of the heat output (Q) from the appliance to the heat input (Q_F)

3.4

flue gas mass flow

$\dot{m}$

mass of flue gas leaving the $\square_{A1}$ combustion $\langle A1 \rangle$ appliance through the connecting flue pipe per time unit

3.5

effective height of the chimney

H

difference in height between the axis of the flue gas inlet into the chimney and the outlet of the chimney

3.6

effective height of the connecting flue pipe

H_v

difference in height between the axis of the flue gas chimney outlet of the $\square_{A1}$ combustion $\langle A1 \rangle$ appliance and the axis of the flue gas inlet into the chimney

Note 1 to entry H_v In the case of open fire chimneys, H_v is the difference in height between the height of the upper frame of the furnace and the axis of the flue gas inlet into the chimney.

3.7

draught

positive value of the negative pressure in the flue

3.8

theoretical draught available due to chimney effect

P_H

pressure difference caused by the difference in weight between the column of air equal to the effective height outside a chimney and the column of flue gas equal to the effective height inside the chimney

3.9**pressure resistance of the chimney** **P_R**

pressure which is necessary to overcome the resistance of the flue gas mass flow which exists when carrying the flue gases through the chimney

3.10**wind velocity pressure** **P_L**

pressure generated on the chimney due to wind

3.11**minimum draught at the flue gas inlet into the chimney** **P_Z**

difference between the minimum theoretical draught and the sum of the maximum pressure resistance of the chimney and the wind velocity pressure

3.12**maximum draught at the flue gas inlet into the chimney** **P_{Zmax}**

difference between the maximum theoretical draught and the minimum pressure resistance in the chimney

3.13**minimum draught for the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance** **P_W**

difference between the static air pressure of the room of installation of the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance and the static pressure of the flue gas at the chimney outlet of the appliance which is necessary to maintain the correct operation of the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance

3.14**maximum draught for the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance** **P_{Wmax}**

difference between the static air pressure of the room of installation of the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance and the static pressure of the flue gas at the outlet of the appliance which is the maximum allowed to maintain the correct operation of the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance

3.15**effective pressure resistance of the connecting flue pipe** **P_{FV}**

static pressure difference between the axis of the inlet of the connecting flue pipe and the axis of the chimney outlet due to the theoretical draught and pressure resistance

3.16**effective pressure resistance of the air supply** **P_B**

difference between the static pressure in the open air and the static air pressure in the room of installation of the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance at the same height

3.17

minimum draught required at the flue gas inlet into the chimney

P_{ze}
sum of the minimum draught required for the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance and the draught required to overcome the effective pressure resistance of the connecting flue pipe and the effective pressure resistance of the air supply

3.18

maximum allowed draught at the flue gas inlet into the chimney

P_{zemax}
sum of the maximum draught allowed for the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance and the draught required to overcome the effective pressure resistance of the connecting flue pipe and the effective pressure resistance of the air supply

3.19

maximum positive pressure at the flue gas inlet into the chimney

P_{zo}
difference of the maximum pressure resistance and the minimum theoretical draught of the chimney added by the wind velocity pressure

3.20

minimum positive pressure at the flue gas inlet into the chimney

$P_{zo\min}$
difference of the minimum pressure resistance and the maximum theoretical draught of the chimney

3.21

maximum differential pressure of the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance

P_{wo}
maximum difference between the static pressure of the flue gas at the chimney outlet of the appliance and the static pressure of the air at the inlet to the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance specified for its correct operation

3.22

minimum differential pressure of the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance

$P_{wo\min}$
minimum difference between the static pressure of the flue gas at the outlet of the appliance and the static pressure of the air at the inlet to the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance specified for its correct operation. This can be a negative value.

3.23

maximum differential pressure at the flue gas inlet into the chimney

P_{zoe}
difference between the maximum differential pressure of the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance and the sum of the effective pressure resistance of the connecting flue pipe and the effective pressure resistance of the air supply

3.24

secondary air

ambient air added to the flue gas in addition to the nominal flue gas mass flow

3.25**minimum differential pressure at the flue gas inlet into the chimney** P_{zoemin}

difference between the minimum differential pressure of the $\square_{A1}$ combustion $\diamond_{A1}$ appliance and the sum of the effective pressure resistance of the connecting flue pipe and the effective pressure resistance of the air supply

3.26**secondary air device**

draught regulator or a draught diverter

3.27**draught regulator**

component which automatically supplies ambient air to the chimney, the connecting flue pipe or the $\square_{A1}$ combustion $\diamond_{A1}$ appliance

3.28**draught diverter**

device, placed in the combustion products passage of the $\square_{A1}$ combustion $\diamond_{A1}$ appliance, that is intended to maintain the quality of combustion within certain limits and to keep the combustion stable under certain conditions of up draught and down draught

3.29**temperature limit of the inner wall** T_g

allowed minimum temperature of the inner wall of the chimney outlet

3.30**air-supply duct**

component or components parallel to the chimney (separate or concentric) that conveys combustion air from the outside atmosphere to the inlet of the connecting air supply pipe

3.31**balanced flue chimney**

chimney where the point of air entry to the air supply duct is adjacent to the point of discharge of combustion products from the flue, the inlet and outlet being so positioned that wind effects are substantially balanced

3.32**chimney segment**

calculation part of a chimney

3.33**condensate mass flow** $\Delta \dot{m}_D$

mass of water vapour of the flue gas condensed in the $\square_{A1}$ combustion $\diamond_{A1}$ appliance, connecting flue pipe or the chimney per time unit

3.34**connecting air supply pipe**

component or components connecting the air supply duct outlet with the room-sealed $\square_{A1}$ combustion $\diamond_{A1}$ appliance combustion air inlet

3.35

condensation factor

f_k

proportion of the theoretical maximum condensation mass flow usable in the calculation

3.36

chimney fan

exhaust fan or inline fan

3.36.1

exhaust fan

fan positioned on the outlet of the chimney

3.36.2

inline fan

fan positioned as a section of the connecting flue

4 Symbols and abbreviations

The symbols given in this clause can be completed by one or more indices to indicate location or materials if necessary.

Table 1 — Symbols, terminology and units

Symbol	Terminology	Unit
A	cross section area	m^2
c	specific heat capacity	$\text{J}/(\text{kg} \cdot \text{K})$
c_p	specific heat capacity of flue gas	$\text{J}/(\text{kg} \cdot \text{K})$
d	thickness of the section	m
D	diameter	m
D_h	hydraulic diameter	m
E	heat flux ratio	–
g	acceleration due to gravity	m/s^2
H	effective height of the chimney	m
k	coefficient for heat transmission	$\text{W}/(\text{m}^2 \cdot \text{K})$
K	coefficient of cooling	–
L	length	m
l_c	proportion of condensation surface	–
$\dot{m}$	flue gas mass flow	kg/s
$\dot{m}_w$	flue gas mass flow of A_1 combustion A_1 appliance reduced by condensed water	kg/s
$\dot{m}_D$	condensate mass flow	kg/s
N_u	Nusselt number	–
N_{seg}	number of segments	–
p	static pressure	Pa
p_L	external air pressure	Pa
P_B	effective pressure resistance of the air supply	Pa
P_E	pressure resistance due to friction and form resistance of the chimney	Pa
P_{FV}	effective pressure resistance of the connecting flue pipe	Pa
P_G	difference in pressure caused by change of velocity of flue gas in the chimney	Pa
P_H	theoretical draught available due to chimney effect	Pa
P_{HV}	theoretical draught available due to chimney effect of the connecting flue pipe	Pa
P_L	wind velocity pressure	Pa
P_{NL}	draught required for secondary air devices	Pa
P_R	pressure resistance of the chimney	Pa
P_{RV}	pressure resistance of the connecting flue pipe	Pa

Symbol	Terminology	Unit
P_W	minimum draught for the $\langle A_1 \rangle$ combustion $\langle A_1 \rangle$ appliance	Pa
P_{Wmax}	maximum draught for the $\langle A_1 \rangle$ combustion $\langle A_1 \rangle$ appliance	Pa
P_{W0}	maximum differential pressure of the $\langle A_1 \rangle$ combustion $\langle A_1 \rangle$ appliance	Pa
P_{W0min}	minimum differential pressure of the $\langle A_1 \rangle$ combustion $\langle A_1 \rangle$ appliance	Pa
P_Z	minimum draught at the flue gas inlet into the chimney	Pa
P_{Zmax}	maximum draught at the flue gas inlet into the chimney	Pa
P_{Ze}	minimum draught required at the flue gas inlet into the chimney	Pa
P_{Zemax}	maximum allowed draught at the flue gas inlet into the chimney	Pa
P_{Z0}	maximum positive pressure at the flue gas inlet into the chimney	Pa
P_{Z0min}	minimum positive pressure at the flue gas inlet into the chimney	Pa
P_{ZOe}	maximum differential pressure at the flue gas inlet into the chimney	Pa
P_{ZOemin}	minimum differential pressure at the flue gas inlet into the chimney	Pa
$P_{Zexcess}$	maximum allowed pressure from the designation of the chimney	Pa
$P_{ZVexcess}$	maximum allowed pressure from the designation of the connecting flue pipe	Pa
Pr	Prandtl number	–
q_C	heat transfer from the flue to the outer surface	W
q_K	condensation heat	W
Q	heat output	kW
Q_F	heat input	kW
Q_N	nominal heat output	kW
r	mean value for roughness of the inner wall	m
R	gas constant of the flue gas	J/(kg · K)
R_L	gas constant of the air	J/(kg · K)
Re	Reynolds number	–
s	cross section	m
S_E	flow safety coefficient	–
S_H	correction factor for temperature instability	–
S_{rad}	correction factor for radiation	–
t	temperature	°C
T	temperature, absolute	K
T_g	temperature limit	K
T_{io}	inner wall temperature at chimney outlet	K
T_{iob}	inner wall temperature at the chimney outlet at temperature equilibrium	K

Symbol	Terminology	Unit
T_{irb}	flue gas temperature immediately before the additional insulation	K
T_{L}	external air temperature	K
T_{m}	mean temperature of the flue gas	K
T_{p}	water dew point	K
T_{sp}	condensing temperature	K
T_{u}	ambient air temperature	K
T_{ub}	ambient air temperature of the boiler room	K
T_{uh}	ambient air temperature for heated areas	K
T_{ul}	ambient air temperature for areas external to the building	K
T_{uo}	ambient air temperature at the chimney outlet	K
T_{ur}	is the ambient air temperature immediately before the additional insulation	K
T_{uu}	ambient air temperature for unheated areas inside the house	K
T_{W}	flue gas temperature of the appliance	K
T_{WN}	flue gas temperature of the appliance at nominal heat output	K
T_{Wmin}	flue gas temperature of the appliance at the lowest possible heat output	K
U	internal chimney segment parameter	m
w	mean velocity within a cross section	m/s
w_{m}	mean velocity over a defined length	m/s
y	form value	–
z	height above sea level	m
α	coefficient of heat transfer	W/(m ² · K)
β	ratio of the combustion air mass flow to the flue gas mass flow	–
γ	angle between flow directions	°
δ	wall thickness	m
ε	proportion of black body radiation emitted by a surface	–
ζ	coefficient of flow resistance due to a directional and/or cross sectional and/or mass flow change in the flue	–
η	dynamic viscosity	N · s/m ²
η_{W}	efficiency of the $\langle A_1 \rangle$ combustion $\langle A_1 \rangle$ appliance	–
η_{WN}	efficiency of the $\langle A_1 \rangle$ combustion $\langle A_1 \rangle$ appliance at nominal heat output	–
λ	coefficient of thermal conductivity	W/(m · K)
ρ	density	kg/m ³
ρ_{L}	density of the external air	kg/m ³

Symbol	Terminology	Unit
ρ_m	mean density of flue gas averaged over a defined length and over the cross section	kg/m ³
σ (CO ₂)	volume-concentration of CO ₂	%
σ (H ₂ O)	volume-concentration of H ₂ O (vapour)	%
σ_{Rad}	black body radiation number	W/(m ² · K ⁴)
ψ	coefficient of flow resistance due to friction of the flue	–
$\left(\frac{1}{\Lambda}\right)$	thermal resistance	m ² · K/W

Table 2 — Additional subscripts

Subscript	Terminology	Unit
a	outside	–
A	flue gas	–
b	equilibrium temperature condition	–
B	combustion air	–
D	water vapour	–
e	entrance	–
F	open fire place	–
G	change in velocity	–
i	inside	–
K	condensation	–
L	open air (outside)	–
m	mean value	–
M	mixture	–
n	counting index	–
N	nominal value	–
NL	secondary air	–
o	chimney outlet	–
O	positive pressure	–
tot	totalized over all sections (segments)	–
u	ambient air	–
V	connecting flue pipe	–
W	$\langle A_1 \rangle$ combustion $\langle A_1 \rangle$ appliance	–

5 Calculation method for non-balanced flue chimneys

5.1 General principles

The calculation of inside dimensions (cross section) of negative pressure chimneys is based on the following four criteria:

- the minimum draught at the flue gas inlet into the chimney shall be equal to or greater than the minimum draught required at the flue gas inlet into the chimney;
- the minimum draught at the flue gas inlet to the chimney shall be equal to or greater than the effective pressure resistance of the air supply;
- the maximum draught at the flue gas inlet into the chimney shall be equal to or less than the maximum allowed draught at the flue gas inlet into the chimney;
- the temperature of the inner wall at the outlet of the chimney shall be equal to or greater than the temperature limit.

The calculation of inside dimensions (cross section) of positive pressure is based on the following four criteria:

- the maximum positive pressure at the flue gas inlet into the chimney shall be equal or less than the maximum differential pressure at the flue gas inlet into the chimney;
- the maximum positive pressure in the connecting flue pipe and in the chimney shall not be higher than the excess pressure for which both are designated;
- the minimum positive pressure at the flue gas inlet into the chimney shall be equal or greater than the minimum differential pressure at the flue gas inlet into the chimney;
- the temperature of the inner wall at the chimney outlet of the chimney shall be equal to greater than the temperature limit.

NOTE The pressure requirements for maximum draught or minimum positive pressure are only required if there is a limit for the maximum draught for the negative pressure $\langle A_1 \rangle$ combustion $\langle A_1 \rangle$ appliance or a minimum differential pressure of the positive pressure $\langle A_1 \rangle$ combustion $\langle A_1 \rangle$ appliance.

In order to verify the criteria two sets of external conditions are used:

- the calculation of the minimum draught and maximum positive pressure is made with conditions for which the capacity of the chimney is minimal (i.e. high outside temperature); and also
- the calculation of the maximum draught and minimum positive pressure and of the inner wall temperature with conditions for which the inside temperature of the chimney is minimal (i.e. low outside temperature).

5.2 Pressure requirements

5.2.1 Negative pressure chimneys

The following relationships shall be verified:

$$P_Z = P_H - P_R - P_L \geq P_W + P_{FV} + P_B = P_{Ze}, \text{ in Pa} \quad (1)$$

$$P_Z \geq P_B, \text{ in Pa} \quad (2)$$

and if appropriate

$$P_{Z\max} = P_H - P_R \leq P_{W\max} + P_{FV} + P_B = P_{Z\max}, \text{ in Pa} \quad (2a)$$

where

- P_B is the effective pressure resistance of air supply (see 5.11.3), in Pa;
- P_{FV} is the effective pressure resistance of the connecting flue pipe, in Pa;
- P_H is the theoretical draught available due to chimney effect, in Pa;
- P_L is the wind velocity pressure, in Pa;
- P_R is the pressure resistance of the chimney, in Pa;
- P_W is the minimum draught for the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance, in Pa;
- $P_{W\max}$ is the maximum draught for the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance, in Pa;
- P_Z is the minimum draught at the flue gas inlet into the chimney (see 5.10), in Pa;
- $P_{Z\max}$ is the maximum draught at the flue gas inlet into the chimney (see 5.11), in Pa;
- P_{Ze} is the minimum draught required at the flue gas inlet into the chimney, in Pa;
- $P_{Z\max}$ is the maximum allowed draught at the flue gas inlet into the chimney, in Pa.

NOTE The values of P_H and P_H in Formulas (1) and (2a) are normally different because the conditions are different.

5.2.2 Positive pressure chimneys

The following relationships shall be verified:

$$P_{ZO} = P_R - P_H + P_L \leq P_{W0} - P_B - P_{FV} = P_{Zoe}, \text{ in Pa} \quad (3)$$

$$P_{ZO} \leq P_{Z\text{ excess}}, \text{ in Pa} \quad (4)$$

$$P_{ZO} + P_{FV} \leq P_{ZV\text{ excess}}, \text{ in Pa} \quad (5)$$

and if appropriate

$$P_{ZO\min} = P_R - P_H \geq P_{W0\min} - P_B - P_{FV} = P_{Zoemin}, \text{ in Pa} \quad (5a)$$

where

- P_B is the effective pressure resistance of air supply, in Pa;
- P_{FV} is the effective pressure resistance of the connecting flue pipe, in Pa;
- P_H is the theoretical draught available due to chimney effect, in Pa;
- P_L is the wind velocity pressure, in Pa;
- P_R is the pressure resistance of the chimney, in Pa;
- P_{W0} is the maximum differential pressure of the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance, in Pa;
- $P_{W0\min}$ is the minimum differential pressure of the $\boxed{A_1}$ combustion $\langle A_1 \rangle$ appliance, in Pa;
- P_{ZO} is the maximum positive pressure at the flue gas inlet into the chimney, in Pa;
- $P_{ZO\min}$ is the minimum positive pressure at the flue gas inlet into the chimney, in Pa;

P_{ZOe}	is the maximum differential pressure at the flue gas inlet into the chimney, in Pa;
P_{ZOemin}	is the minimum differential pressure at the flue gas inlet into the chimney, in Pa;
$P_{Z\ excess}$	is the maximum allowed pressure from the designation of the chimney, in Pa;
$P_{ZVexcess}$	is the maximum allowed pressure from the designation of the connecting flue pipe, in Pa.

NOTE The values of P_H and P_R in Formulas (3) and (5a) are normally different because the conditions are different

5.3 Temperature requirement

The following relationship shall be verified:

$$T_{iob} \geq T_g, \text{ in K} \quad (6)$$

where

T_{iob} is the inner wall temperature at the chimney outlet at temperature equilibrium, in K;

T_{ig} is the temperature limit, in K.

If the chimney above the roof has additional insulation the following relationship shall also be verified:

$$T_{irb} \geq T_g, \text{ in K} \quad (7)$$

where

T_{irb} is the inner wall temperature immediately before the additional insulation, in K.

The temperature limit T_{ig} of chimneys with dry operating conditions shall be taken as the condensing temperature T_{isp} of the flue gas (see 5.7.6).

The temperature limits T_{ig} of chimneys with wet operating conditions shall be taken as 273,15 K which prevents the formation of ice at the chimney outlet.

NOTE The comparison of the inner wall temperature before the additional insulation T_{irb} with the admissible limit temperature of the flue gas T_{ig} is not necessary, if the value of the thermal resistance of the additional insulation is not more than 0,1 (m² · K)/W. For chimneys operating under wet conditions the comparison is not necessary, if the value of the ambient air temperature immediately before the additional insulation is ≥ 0 °C.

5.4 Calculation procedure

For the calculation of the pressure and temperature values for the relationships of Formulas (1), (2), (2a), (3), (4), (5), (5a) and (6) the values of the flue gas data characterising according to 5.5 shall be obtained for the appliance. The data specified in 5.6 shall be obtained for the chimney and its connecting flue pipe. For new built chimneys, a pre-estimated value for the flue size should be used.

5.7 to 5.11 provide calculations needed to finalise the chimney thermal and fluid dynamic calculations. In 5.7 the formulas provide the calculation of the basic data which are needed for further calculation.

In 5.5.3 and 5.8 the formulas for the calculations of the relevant temperatures are compiled. The formulas for the density of the flue gas and its velocity are compiled in 5.9.

The procedure in 5.10 and 5.11 shall be used to validate the pressure requirement. The procedure in 5.12 shall be used to validate the temperature requirement.

The validation for pressure and temperature requirement shall be conducted:

- either for the nominal heat output declared by the manufacturer of the A_1 combustion A_1 appliance;
- or for the nominal heat output and for the lowest value of the heat output range declared by the manufacturer of the A_1 combustion A_1 appliance

If the pressure requirement for maximum draught (2a) or the temperature requirements (6) and (7) of negative pressure chimneys are not fulfilled the validation of the pressure condition or temperature condition can occasionally be achieved by taking additional secondary air to the flue gas into account according to Clause 6.

NOTE The temperature requirement need not be met for the following conditions provided that it is accepted that in case the requirement for temperature is not fulfilled no guarantee can be given that no moisture appears.

The conditions are:

- where the A_1 combustion A_1 appliance is replaced by an appliance that has an output of < 30 kW, and
- that the flue gas loss of the A_1 combustion A_1 appliance is at least 8 %, and
- that the A_1 combustion A_1 appliance has a draught diverter which provides adequate ventilation in the chimney during standby periods or periods of low output. This may be achieved by over-sizing the A_1 combustion A_1 appliance output.

5.5 Flue gas data characterising the A_1 combustion A_1 appliance

5.5.1 General

For the calculation of temperatures and pressure values the relevant flue gas data which characterises the A_1 combustion A_1 appliance, consisting of flue gas mass flow, flue gas temperature and the minimum draught required for the A_1 combustion A_1 appliance or the maximum differential pressure of the A_1 combustion A_1 appliance shall be obtained. Additionally the kind of the fuel supplied the volume concentration of CO₂ of the flue gas and the geometry of the connecting flue pipe shall be specified.

Typical data for some fuels are given in Table B.1.

Typical data for some A_1 combustion A_1 appliances are given in Tables B.2 and B.3.

5.5.2 A_1 Flue gas mass flow and combustion air mass flow

5.5.2.1 Flue gas mass flow and combustion air mass flow at nominal heat output of the combustion appliance

For the calculation of pressure and temperature values according to relationships of formulae (1), (2), (2a), (3), (4), (5), (5a) and (6) the flue gas mass flow and combustion air mass flow at nominal heat output conditions for the combustion appliance shall be obtained.

If the data are not available the flue gas mass flow, combustion air mass flow and the volume concentration of CO₂ can be determined from the formulas in Tables B.1, B.2 or B.3.

If the chimney is connected to a multi-fuel combustion appliance, the calculation and dimensioning should be carried out by considering all the fuels suited to the appliance.

In the case of combustion appliances with a draught diverter the flue gas mass flow downstream of the draught diverter shall be used.

The flue gas mass flow $\dot{m}$ and combustion air mass flow $\dot{m}_B$ of an open fire place depends on its opening. For the calculation use the following formulae:

$$\dot{m} = f_{mf} \cdot A_F, \text{ in kg/s} \quad (8)$$

$$\dot{m}_B = \dot{m}, \text{ in kg/s} \quad (8a)$$

where

f_{mf} is the mass flow factor of an open fire place, in kg/(s·m²);

A_F is the cross section of the opening of the open fire place, in m²;

For open fire places with an opening height less than or equal its width $f_{mf} = 0,139 \text{ kg/(s·m}^2\text{)}$.

For open fire places with an opening height greater than its width $f_{mf} = 0,167 \text{ kg/(s·m}^2\text{)}$.

The CO₂-content of the flue gas for open fire places may be taken as $\sigma(\text{CO}_2) = 1 \%$.

5.5.2.2 Flue gas mass flow and combustion air mass flow at the lowest permissible heat output

If the combustion appliance is designed to operate under modulating conditions an additional check shall be conducted for the pressure and temperature requirement of the flue gas mass flow and combustion air mass flow at the lowest possible and permissible heat output of the combustion appliance. If the manufacturer does not provide flue gas data and combustion air mass data for the lowest heat output use a mass flow of one third of the flue gas mass flow and combustion air mass flow at nominal heat output.

5.5.2.3 Flue gas mass flow and combustion air mass flow at the maximum draught or minimum differential pressure of the combustion appliances

For the calculation of maximum draught or minimum positive pressure in a chimney, the flue gas mass flow and combustion air mass flow at maximum draught or minimum differential pressure of the combustion appliance shall be obtained from the manufacturer of the combustion appliance, if appropriate.

5.5.2.4 Flue gas mass flow with secondary air

If secondary air is supplied by a draught regulator or draught diverter the air flow shall be calculated according to 6.3 depending on the actual difference of the pressure in the room of installation of the combustion appliance and the chimney or connecting flue pipe. $\langle A_1 \rangle$

5.5.3 Flue gas temperature

5.5.3.1 Flue gas temperature at nominal heat output (T_{WN})

The flue gas temperature at nominal heat output T_{WN} shall be obtained from the $\langle A_1 \rangle$ combustion $\langle A_1 \rangle$ appliance manufacturer. In the case of $\langle A_1 \rangle$ combustion $\langle A_1 \rangle$ appliances with a draught diverter, the flue gas temperature downstream of the draught diverter shall be used.

If the manufacturer provides data showing flue gas temperature downstream of the draught diverter in relation to draught, such data shall be used for the calculation.

If the flue gas temperature T_{WN} of open fire places is not known a value of $t_{WN} = 80\text{ °C}$ ($T_{WN} = 353,15\text{ K}$) should be used.

5.5.3.2 Flue gas temperature at the lowest possible heat output (T_{Wmin})

The lowest designated flue gas temperature T_{Wmin} shall be obtained from the A1 combustion A1 appliance manufacturer. If this data is not available, use as flue gas temperature 2/3 of the value of the flue gas temperature in °C at nominal heat output.

5.5.3.3 Flue gas temperature at the maximum draught or minimum differential pressure of the A1 combustion A1 appliances

For the calculation of maximum draught or minimum positive pressure in a chimney the flue gas temperature at maximum draught or minimum differential pressure of the A1 combustion A1 appliance shall be obtained from the manufacturer of the A1 combustion A1 appliance if appropriate.

5.5.4 Minimum draught for the A1 combustion A1 appliance (P_w) for negative pressure chimney

For the calculation of a negative pressure chimney the value of the minimum draught for the A1 combustion A1 appliance P_w shall be obtained from the manufacturer of the A1 combustion A1 appliance.

If no values are available, the relevant values of the minimum draught for the A1 combustion A1 appliance should be selected from relevant product standards for A1 combustion A1 appliances. If no values for boilers are available see Table B.2.

If the available value of the minimum draught is a negative number (implying a positive pressure operation) a value of $P_w = 0$ shall be used in the calculations.

If no valid data for the draught diverter from the manufacturer is available, for gas fired appliances designated as B₁ according to CEN/TR 1749 use a value of 3 Pa for the minimum draught and use the value of 10 Pa for all other gas fired appliances equipped with a draught diverter.

The minimum draught P_w for the operation of fire places should be calculated with the flue gas mass flow and the cross section of the chimney outlet of the open fire place. The theoretical draught available due to chimney effect in the open fire place and the flue gas collector should be neglected. The local resistance in the flue gas collector (gather) is taken into account by using a flow safety coefficient $S_E = 1,5$.

$$P_w = \frac{\dot{m}^2}{2 \cdot \rho_w \cdot A_w^2} \cdot S_E, \text{ in Pa} \quad (9)$$

where

$\dot{m}$ is the flue gas mass flow, in kg/s;

S_E is the flow safety coefficient;

ρ_w is the density of flue gas in the chimney outlet of the open fire place, in kg/m³;

A_w is the cross section of the chimney outlet of the open fire place, in m².

5.5.5 Maximum draught for the A_1 combustion A_1 appliance ($P_{W\max}$) for negative pressure chimney

For the calculation of a negative pressure chimney the value of the maximum draught for the A_1 combustion A_1 appliance $P_{W\max}$ shall be obtained from the manufacturer of the A_1 combustion A_1 appliance if appropriate.

5.5.6 Maximum differential pressure of the A_1 combustion A_1 appliance (P_{W0}) for positive pressure chimney

For the calculation of a positive pressure chimney the value of the maximum differential pressure for the A_1 combustion A_1 appliance P_{W0} shall be obtained from the manufacturer of the A_1 combustion A_1 appliance.

5.5.7 Minimum differential pressure of the A_1 combustion A_1 appliance ($P_{W0\min}$) for positive pressure chimney

For the calculation of a positive pressure chimney the value of the minimum differential pressure of the A_1 combustion A_1 appliance $P_{W0\min}$ shall be obtained from the manufacturer of the A_1 combustion A_1 appliance if appropriate.

5.6 Characteristic data for the calculation

5.6.1 General

In order to calculate the relevant pressure and temperature values the roughness of the inner wall and the thermal resistance of the connecting flue pipe and the chimney shall be determined.

5.6.2 Mean value for roughness (r)

The mean value for roughness of the inner liner shall be obtained from the product manufacturer. The mean values for roughness of inner liners of materials normally used are listed in Table B.4.

5.6.3 Thermal resistance ($1/\Lambda$)

The thermal resistance $1/\Lambda$ of the system chimney shall be obtained from the product manufacturer.

The thermal resistance $1/\Lambda$ of the components shall be obtained from the product manufacturer and should include the effects of thermal bridges (e.g. joints).

Calculations involving thermal resistance for system chimneys and/or components should normally be undertaken using values obtained at the mean operating temperature. The thermal resistance value obtained at the designation temperature may be used.

For multiwall custom built chimneys the thermal resistance shall be determined using the following formula:

$$\left(\frac{1}{\Lambda}\right) = D_h \cdot \sum_n \left[\left(\frac{1}{\Lambda}\right)_n \cdot \frac{1}{D_{h,n}} \right], \text{ in } m^2 \cdot K/W \quad (10)$$

where

D_h is the internal hydraulic diameter, in m;

$D_{h,n}$ is the hydraulic diameter of the inside of each layer, in m;

$\left(\frac{1}{\Lambda}\right)_n$ is the thermal resistance of a pipe shell, referring to its internal surface, in $m^2 \cdot K/W$.

Where the specific data for individual components is not known the thermal resistance can be determined in accordance with Annex A. The thermal resistance of closed air gaps is given in Table B.6.

5.7 Basic values for the calculation

5.7.1 Air temperatures

5.7.1.1 General

On chimneys which pass through heated areas, a differentiation shall be made between the external air temperature and the ambient air temperatures.

5.7.1.2 External air temperature (T_L)

The external air temperature T_L shall be taken as the maximum temperature of external air at which the chimney is intended to be used.

The external air temperature T_L for heating systems is normally calculated using

$T_L = 288,15 \text{ K}$ ($t_L = 15 \text{ °C}$) for the calculation of minimum draught or maximum positive pressure at the flue gas inlet into the chimney;

$T_L = 258,15 \text{ K}$ ($t_L = -15 \text{ °C}$) for the calculation of maximum draught or minimum positive pressure at the flue gas inlet into the chimney.

Other values for T_L may be used based on national accepted data.

5.7.1.3 Ambient air temperature (T_u)

To check that the pressure requirement for the minimum draught or maximum positive pressure has been met the ambient air temperature $T_u = T_L$ shall be used. To check that the pressure requirement for the maximum draught or minimum positive pressure and the temperature requirement have been met the following values for ambient air temperatures T_u shall be used:

— for chimneys without ventilated air gaps:

$T_{uo} = 258,15 \text{ K}$ ($t_{uo} = -15 \text{ °C}$) for chimneys operating under wet conditions

$T_{uo} = 273,15 \text{ K}$ ($t_{uo} = 0 \text{ °C}$) for chimneys operating under dry conditions

$T_{ub} = 288,15 \text{ K}$ ($t_{ub} = 15 \text{ °C}$)

$T_{uh} = 293,15 \text{ K}$ ($t_{uh} = 20 \text{ °C}$)

$T_{ul} = T_{uo}$ ($t_{ul} = t_{uo}$)

$T_{uu} = 273,15 \text{ K}$ ($t_{uu} = 0 \text{ °C}$)

— for chimneys with ventilated air gaps ventilated in the same direction as the flue gas:

$T_{uo} = 258,15 \text{ K}$ ($t_{uo} = -15 \text{ °C}$) for chimneys operating under wet conditions if the height of the unheated area inside the building and external to the building does exceed 5 m

$T_{uo} = 273,15 \text{ K}$ ($t_{uo} = 0 \text{ °C}$) for chimneys operating under dry conditions and for chimneys operating under wet conditions if the height of the unheated area inside the building and external to the building does not exceed 5 m

$T_{ub} = 288,15 \text{ K}$ ($t_{ub} = 15 \text{ °C}$)

$T_{uh} = 293,15 \text{ K}$ ($t_{uh} = 20 \text{ °C}$)

$T_{ul} = 288,15 \text{ K}$ ($t_{ul} = 15 \text{ °C}$) if the height of the unheated area inside the building and external to the building does not exceed 5 m

$T_{ul} = T_{uo}$ ($t_{ul} = t_{uo}$) if the height of the unheated area inside the building and external to the building does exceed 5 m

$T_{uu} = 288,15 \text{ K}$ ($t_{uu} = 15 \text{ °C}$) if the height of the unheated area inside the building and external to the building does not exceed 5 m

$T_{uu} = 273,15 \text{ K}$ ($t_{uu} = 0 \text{ °C}$) if the height of the unheated area inside the building and external to the building does exceed 5 m

Other values for T_{uo} may be used based on national accepted data.

Parts of the chimney which are in areas with different ambient air temperature should either be calculated in sections with the same ambient temperature or the ambient air temperature corresponding to the parts of the outer surface be determined for the calculation using the following formula:

$$T_u = \frac{(T_{ub} \cdot A_{ub}) + (T_{uh} \cdot A_{uh}) + (T_{uu} \cdot A_{uu}) + (T_{ul} \cdot A_{ul})}{A_{ub} + A_{uh} + A_{uu} + A_{ul}}, \text{ in K} \quad (11)$$

where

T_{uo} is the ambient air temperature at the chimney outlet, in K;

T_{ub} is the ambient air temperature for boiler room, in K;

T_{uh} is the ambient air temperature for heated areas, in K;

T_{ul} is the ambient air temperature for areas external to the building, in K;

T_{uu} is the ambient air temperature for unheated areas inside the building, in K;

A_{ub} is the outer surface area of the chimney in the boiler room, in m^2 ;

A_{uh} is the outer surface area of the chimney in heated areas, in m^2 ;

A_{ul} is the outer surface area of the chimney external to the building, in m^2 ;

A_{uu} is the outer surface area of the chimney in unheated areas inside the building, in m^2 .

NOTE 1 If parts of the outer surface of chimneys without back ventilation in areas external to the building and unheated areas do not exceed $\frac{1}{4}$ of the total outer surface of the chimney, the ambient air temperature T_u may be taken as 288,15 K ($t_u = 15^\circ\text{C}$).

NOTE 2 If the height of chimneys with air gaps ventilated in the same direction as the flue gas in areas external to the building and unheated areas do not exceed 5 m, the ambient air temperature T_u may be taken as 288,15 K ($t_u = 15^\circ\text{C}$).

NOTE 3 If the height of chimneys with air gaps ventilated in the opposite direction as the flue gas in areas external to the building and unheated areas do not exceed 5 m, the ambient air temperature T_u may be taken as 273,15 K ($t_u = 0^\circ\text{C}$).

5.7.2 External air pressure (p_L)

The external air pressure p_L shall be determined as follows dependent on the height above sea level using the following formula:

$$p_L = 97000 \cdot e^{(-g \cdot z)/(R_L T_L)}, \text{ in Pa} \quad (12)$$

where

g is the acceleration due to gravity = 9,81 m/s²;

R_L is the gas constant of the air, in J/(kg · K);

T_L is the external air temperature, in K;

z is the height above sea level, in m;

97000 is the external air pressure at sea level corrected for weather influence, in Pa.

5.7.3 Gas constant

5.7.3.1 Gas constant of the air (R_L)

The gas constant of the air R_L shall be taken as 288 J/(kg · K) (water content $\sigma(\text{H}_2\text{O})$ as a volume fraction of 1,1 %).

5.7.3.2 Gas constant of the flue gas (R)

The gas constant of the flue gas R shall be determined using the formula in Tables B.1 and B.3.

5.7.4 Density of the external air (ρ_L)

The density of the external air ρ_L shall be calculated using the following formula:

$$\rho_L = \frac{p_L}{R_L \cdot T_L}, \text{ in kg/m}^3 \quad (13)$$

where

p_L is the external air pressure, in Pa;

R_L is the gas constant of the air, in J/(kg · K);

T_L is the external air temperature, in K.

5.7.5 Specific heat capacity of the flue gas (c_p)

The specific heat capacity c_p of the flue gas shall be calculated using the formula in Table B.1 and Table B.4.

5.7.6 Condensing temperature (T_{sp})

For gas, domestic heating oil and chemically untreated wood, the condensing temperature T_{sp} of the flue gas shall be identified by the water dew point T_p . In these the cases:

$$T_{sp} = T_p \quad (14)$$

The water dew point T_p of the flue gas for different fuels and concentrations by volume of CO_2 in the flue gas shall be calculated using the Formulas (B.5), (B.6) and (B.7).

For coal and residual fuel oil, the condensing temperature of the flue gas is the acid dew point T_{sp} . In these the cases:

$$T_{sp} = T_p + \Delta T_{sp} \quad (15)$$

The rise in the dew point through sulphur trioxide in the flue gas (ΔT_{sp}) can be calculated using formula in Table B.1. For the exact determination of the acid dew point, knowledge of the conversion from sulphur dioxide into sulphur trioxide (conversion factor K_f) is required. As an approximate value, it can be assumed that the concentration by volume of sulphur trioxide (SO_3) is approximately 2 % of that of the sulphur dioxide (SO_2).

5.7.7 Correction factor for temperature instability (S_H)

For the calculation of minimum draught or maximum positive pressure the correction factor S_H for temperature instability shall be 0,5.

For the calculation of maximum draught or minimum positive pressure the correction factor S_H for temperature instability shall be 1.

5.7.8 Flow safety coefficient (S_E)

For the calculation of minimum draught of negative pressure chimneys the safety coefficient $S_E = 1,5$ shall be used, except a value of 1,2 shall be used for strictly controlled appliance and chimney installations (e.g. industrial installation with permanent supervision), and for room sealed appliances with forced draught burners.

For the calculation of maximum positive pressure of positive pressure chimneys the safety coefficient S_E shall be a minimum value of 1,2.

For the calculation of maximum draught or minimum positive pressure the safety coefficient S_E shall be 1.

5.8 Determination of the temperatures

5.8.1 General

For the validation of pressure and temperature requirements, the mean flue gas temperature and the flue gas temperature at the chimney outlet shall be determined.

The mean temperature of the flue gas T_m shall be calculated using the following formula:

$$T_m = T_u + \frac{T_e - T_u}{K} \cdot (1 - e^{-K}), \text{ in K} \quad (16)$$

The flue gas temperature at the chimney outlet T_o shall be calculated using the following formula:

$$T_o = T_u + (T_e - T_u) \cdot e^{-K}, \text{ in K} \quad (17)$$

The mean temperature of the flue gas in the connecting flue pipe T_{mV} shall be calculated in accordance using the following formula:

$$T_{mV} = T_u + \frac{T_w - T_u}{K_v} \cdot (1 - e^{-K_v}), \text{ in K} \quad (18)$$

The flue gas temperature at the chimney inlet T_e shall be calculated using the following formula:

$$T_e = T_u + (T_w - T_u) \cdot e^{-K_v}, \text{ in K} \quad (19)$$

where

K is the coefficient of cooling (see 5.8.2);

K_v is the coefficient of cooling of the connecting flue pipe (see 5.8.2);

T_e is the flue gas temperature at the chimney inlet, in K;

T_u is the ambient air temperature (see 5.7.1.3), in K;

T_w is the flue gas temperature of the A_1 combustion A_1 appliance, in K.

5.8.2 Calculation of the coefficient of cooling (K)

The coefficient of cooling K shall be calculated using the following formula:

$$K = \frac{U \cdot k \cdot L}{\dot{m} \cdot c_p} \quad (20)$$

where

c_p is the specific heat capacity of the flue gas (see 5.7.5), in J/(kg · K);

k is the coefficient of heat transmission (see 5.8.3), in W/(m² · K);

L is the length of the chimney, in m;

$\dot{m}$ is the flue gas mass flow (see 5.5.2), in kg/s;

U is the internal chimney circumference, in m.

For the coefficient of cooling K_v of the connecting flue pipe, the corresponding parameters for the connecting flue pipe shall be used.

5.8.3 Coefficient of heat transmission (k_b)

5.8.3.1 General

The coefficient of heat transmission of the chimney at temperature equilibrium k_b shall be calculated using the following formula:

$$k_b = \frac{1}{\frac{1}{\alpha_i} + \left(\frac{1}{\Lambda}\right) + \frac{D_h}{D_{ha} \cdot \alpha_a}}, \text{ in W/(m}^2 \cdot \text{K)} \quad (21)$$

The coefficient of heat transmission of the chimney for no temperature equilibrium k shall be calculated using the following formula:

$$k = \frac{1}{\frac{1}{\alpha_i} + S_H \cdot \left[\left(\frac{1}{\Lambda}\right) + \frac{D_h}{D_{ha} \cdot \alpha_a} \right]}, \text{ in W/(m}^2 \cdot \text{K)} \quad (22)$$

where

D_h is the internal hydraulic diameter, in m;

D_{ha} is the external hydraulic diameter, in m;

S_H is the correction factor for temperature instability (see 5.7.7);

α_a is the external coefficient of heat transfer (see 5.8.3.2, in W/(m² · K);

α_i is the internal coefficient of heat transfer (see 5.8.3.2), in W/(m² · K);

$\left(\frac{1}{\Lambda}\right)$ is the thermal resistance (see 5.6.3), in m² · K/W.

5.8.3.2 Internal coefficient of heat transfer (α_i)

The coefficient of heat transfer in the chimney α_i shall be calculated using the following formula:

$$\alpha_i = \frac{\lambda_A \cdot Nu}{D_h}, \text{ in W/(m}^2 \cdot \text{K)} \quad (23)$$

where

D_h is the internal hydraulic diameter, in m;

Nu is the Nusselt number;

λ_A is the coefficient of thermal conductivity of the flue gas, in W/(m · K).

The coefficient of thermal conductivity of the flue gas λ_A shall be calculated depending on the mean flue gas temperature using the formula in Table B.1 and B.8.

The mean Nusselt number Nu over the height of the chimney shall be calculated using the following formula:

$$Nu = \left(\frac{\psi}{\psi_{\text{smooth}}} \right)^{0,67} \cdot 0,0214 \cdot (\text{Re}^{0,8} - 100) \cdot \text{Pr}^{0,4} \cdot \left[1 + \left(\frac{D_h}{L_{\text{tot}}} \right)^{0,67} \right] \quad (24)$$

where

D_h is the internal hydraulic diameter, in m;

L_{tot} is the total length from flue gas inlet into the chimney to the chimney outlet ($L_{\text{tot}V}$ is similarly valid for the connecting flue pipe: total effective length from flue gas connection of the  combustion  appliance to the flue gas inlet into the chimney), in m;

Pr is the Prandtl number;

Re is the Reynolds number;

ψ is the coefficient of the flow resistance due to friction for hydraulically rough flow (see 5.10.3.3)

ψ_{smooth} is the coefficient of the flow resistance due to friction for hydraulically smooth flow (see 5.10.3.3 for $r = 0$)

The formula can be used for $2\,300 < Re < 10\,000\,000$, $\left(\frac{\psi}{\psi_{\text{smooth}}}\right) < 3$ and $0,6 < Pr < 1,5$.

For mean flue gas velocity $w_m < 0,5$ m/s, take Nusselt number appropriate to $w_m = 0,5$ m/s.

For Reynolds numbers below 2 300, take Nusselt number appropriate to $Re = 2\,300$.

The Prandtl number Pr shall be calculated using the following formula:

$$Pr = \frac{\eta_A \cdot c_p}{\lambda_A} \quad (25)$$

The Reynolds number Re shall be calculated using the following formula:

$$Re = \frac{w_m \cdot D_h \cdot \rho_m}{\eta_A} \quad (26)$$

where

c_p is the specific heat capacity of the flue gas, in J/(kg · K);

D_h is the internal hydraulic diameter, in m;

w_m is the mean flue gas velocity (see 5.9), in m/s;

η_A is the dynamic viscosity of the flue gas, in N · s/m²;

λ_A is the coefficient of thermal conductivity of the flue gas, in W/(m · K);

ρ_m is the mean density of the flue gas (see 5.9), in kg/m³.

The dynamic viscosity η_A shall be calculated dependent on the flue gas temperature using Formula (B.10) in Table B.1.

The internal coefficient of heat transfer α_i can also be calculated on wet designated chimneys as indicated, if the heat of condensation is not taken into account.

5.8.3.3 External coefficient of heat transfer (α_a)

The external coefficient of heat transfer α_a shall be 8 W/(m² · K) for connecting flue pipes and chimneys, internal to the building, for connecting flue pipes and chimneys external to the building using 23 W/(m² · K).

For connecting flue pipes and chimneys which lie partially external to the building, the coefficient of heat transfer α_a shall be interpolated.

Where parts of the chimneys are external to the building but are shielded with an air gap of at least 1 cm but not more than 5 cm then the external coefficient of heat transfer α_a shall be 8 W/(m² · K).

For a chimney (including relined chimneys) with a ventilated air gap 8 W/(m² · K) shall be used. For non-ventilated parts of such a chimney if the non-ventilated length external to the building is $\leq 3 D_h$ then 8 W/(m² · K) shall be used, otherwise 23 W/(m² · K) shall be used.

5.9 Determination of the density of the flue gas and the velocity of the flue gas

5.9.1 Density of the flue gas (ρ_m)

The mean density of the flue gas ρ_m shall be determined using the following formula:

$$\rho_m = \frac{p_L}{R \cdot T_m}, \text{ in kg/m}^3 \quad (27)$$

where

p_L is the external air pressure (see 5.7.2), in Pa;

R is the gas constant of the flue gas (see 5.7.3.2), in J/(kg · K);

T_m is the mean temperature of the flue gas (see 5.8.1), in K.

For the mean density of the flue gas ρ_{mV} in the connecting flue pipe, the corresponding values of the connecting flue pipe shall be used.

5.9.2 Velocity of the flue gas (w_m)

The mean flue gas velocity w_m shall be calculated using the following formula:

$$w_m = \frac{\dot{m}}{A \cdot \rho_m}, \text{ in m/s} \quad (28)$$

where

A is the internal cross section of the chimney, in m²;

$\dot{m}$ is the flue gas mass flow (see 5.5.1), in kg/s;

ρ_m is the mean density of the flue gas, in kg/m³.

For the mean flue gas velocity w_{mV} in the connecting flue pipe, the corresponding values of the connecting flue pipe shall be used.

5.10 Determination of the pressures

5.10.1 Pressure at the flue gas inlet into the chimney

5.10.1.1 Draught at the flue gas inlet into the negative pressure chimney (P_Z and P_{Zmax})

The minimum and maximum draught at the flue gas inlet into the negative pressure chimney P_Z and P_{Zmax} are primarily dependent on the flue gas mass flow and the flue gas temperature, the effective chimney height, the cross-section and the characteristic values of design (roughness and thermal resistance) of the chimney.

The minimum and maximum draught at the flue gas inlet into the chimney P_Z and P_{Zmax} shall be calculated using the following formulas:

$$P_Z = P_H - P_R - P_L, \text{ in Pa} \quad (29)$$

$$P_{Zmax} = P_H - P_R, \text{ in Pa} \quad (29a)$$

where