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BSI Standards Publication

Chimneys — Thermal and fluid dynamic calculation methods

Part 1: Chimneys serving one heating appliance

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National foreword

This British Standard is the UK implementation of EN 13384-1:2015. It supersedes BS EN 13384-1:2002+A2:2008 which is withdrawn.

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

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Foreword

This document (EN 13384-1:2015) 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of an identical text or by endorsement, at the latest by October 2015, and conflicting national standards shall be withdrawn at the latest by October 2015.

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

This document supersedes EN 13384-1:2002+A2:2008.

According to EN 13384-1:2002+A2:2008 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;

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

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

— Part 1: Chimneys serving one heating appliance

— Part 2: Chimneys serving more than one heating 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, 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 heating 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 heating 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 heating appliance.

2 Normative references

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

EN 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.

3.1
heat output
Q
amount of heat produced by a heating appliance per unit of time

3.1.1
nominal heat output
Q_N
continuous heat output specified by the manufacturer of the heating 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 heating appliance by the fuel based on its net caloric value H_u

3.3
efficiency of the heating 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 heating 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 heating appliance and the axis of the flue gas inlet into the chimney

Note 1 to entry 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 heating appliance
P_W
difference between the static air pressure of the room of installation of the heating 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 heating appliance

3.14
maximum draught for the heating appliance
P_{Wmax}
difference between the static air pressure of the room of installation of the heating 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 heating 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 heating 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 heating 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 heating 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_{ZOmin}
difference of the minimum pressure resistance and the maximum theoretical draught of the chimney

3.21
maximum differential pressure of the heating 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 heating appliance specified for its correct operation

3.22
minimum differential pressure of the heating appliance
P_{WOmin}
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 heating 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 heating 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 heating 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 heating appliance

3.28
draught diverter
device, placed in the combustion products passage of the heating 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 heating 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 heating 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	J/(kg · K)
c_p	specific heat capacity of flue gas	J/(kg · 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	$W/(m^2 \cdot K)$
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 heating 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
P_W	minimum draught for the heating appliance	Pa
P_{Wmax}	maximum draught for the heating appliance	Pa
P_{WO}	maximum differential pressure of the heating appliance	Pa

P_{WOmin}	minimum differential pressure of the heating 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_{ZO}	maximum positive pressure at the flue gas inlet into the chimney	Pa
P_{ZOmin}	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
QN	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
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	$W/(m^2 \cdot K)$
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	$N \cdot s/m^2$
η_W	efficiency of the heating appliance	–
η_{WN}	efficiency of the heating appliance at nominal heat output	–
λ	coefficient of thermal conductivity	$W/(m \cdot K)$
ρ	density	kg/m^3
ρ_L	density of the external air	kg/m^3
ρ_m	mean density of flue gas averaged over a defined length and over the cross section	kg/m^3
$\sigma (CO_2)$	volume-concentration of CO_2	%
$\sigma (H_2O)$	volume-concentration of H_2O (vapour)	%
σ_{Rad}	black body radiation number	$W/(m^2 \cdot K^4)$
ψ	coefficient of flow resistance due to friction of the flue	–
$\left(\frac{1}{\Lambda}\right)$	thermal resistance	$m^2 \cdot K/W$

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	heating 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 heating appliance or a minimum differential pressure of the positive pressure heating 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:

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

$$P_Z \geq P_B, \text{ in Pa} \tag{2}$$

and if appropriate

$$P_{Zmax} = P_H - P_R \leq P_{Wmax} + P_{FV} + P_B = P_{Ze\,max}, \text{ in Pa} \tag{2a}$$

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 heating appliance, in Pa;

P_{Wmax} is the maximum draught for the heating appliance, in Pa;

P_Z is the minimum draught at the flue gas inlet into the chimney (see 5.10), in Pa;

P_{Zmax} 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_{Zemax} 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:

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

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

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

and if appropiate

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

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_{WO} is the maximum differential pressure of the heating appliance, in Pa;

P_{WOmin} is the minimum differential pressure of the heating appliance, in Pa;

P_{ZO} is the maximum positive pressure at the flue gas inlet into the chimney, in Pa;

P_{ZOmin} 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

$T_{i_{ob}}$ 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:

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

where

T_{iirb} 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_{iirb} 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 $(m^2 \cdot K)/W$. 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 heating appliance;

— or for the nominal heat output and for the lowest value of the heat output range declared by the manufacturer of the heating 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 heating appliance is replaced by an appliance that has an output of < 30 kW, and

— that the flue gas loss of the heating appliance is at least 8 %, and

— that the heating 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 heating appliance output.

5.5 Flue gas data characterising the heating appliance

5.5.1 General

For the calculation of temperatures and pressure values the relevant flue gas data which characterises the heating appliance, consisting of flue gas mass flow, flue gas temperature and the minimum draught required for the heating appliance or the maximum differential pressure of the heating appliance shall be obtained. Additionally the kind of the fuel supplied the volume concentration of CO_2 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 heating appliances are given in Tables B.2 and B.3.

5.5.2 Flue gas mass flow

5.5.2.1 Flue gas mass flow at nominal heat output of the heating appliance

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

If the data is not available the flue gas mass flow and the volume concentration of CO_2 can be determined from the formulas in Tables B.1, B.2 or B.3.

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

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

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

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

where

f_{mf} is the mass flow factor of an open fire place, in $kg/(s \cdot m^2)$;

A_F is the cross section of the opening of the open fire place, in m^2;

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

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

The CO_2-content of the flue gas for open fire places may be taken as $\sigma(CO_2)$ = 1 %.

5.5.2.2 Flue gas mass flow at the lowest permissible heat output

If the heating 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 at the lowest possible and permissible heat output of the heating appliance. If the manufacturer does not provide flue gas data for the lowest heat output use a mass flow of one third of the flue gas mass flow at nominal heat output.

5.5.2.3 Flue gas mass flow at the maximum draught or minimum differential pressure of the heating appliances

For the calculation of maximum draught or minimum positive pressure in a chimney the flue gas mass flow at maximum draught or minimum differential pressure of the heating appliance shall be obtained from the manufacturer of the heating 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 heating appliance and the chimney or connecting flue pipe.

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 heating appliance manufacturer. In the case of heating 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 °C (T_{WN} = 353,15 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 heating 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 heating 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 heating appliance shall be obtained from the manufacturer of the heating appliance if appropriate.

5.5.4 Minimum draught for the heating appliance (P_W) for negative pressure chimney

For the calculation of a negative pressure chimney the value of the minimum draught for the heating appliance P_W shall be obtained from the manufacturer of the heating appliance.

If no values are available, the relevant values of the minimum draught for the heating appliance should be selected from relevant product standards for heating 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 B_1 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/m^3;

A_W is the cross section of the chimney outlet of the open fire place, in m^2.

5.5.5 Maximum draught for the heating appliance (P_{Wmax}) for negative pressure chimney

For the calculation of a negative pressure chimney the value of the maximum draught for the heating appliance P_{Wmax} shall be obtained from the manufacturer of the heating appliance if appropriate.

5.5.6 Maximum differential pressure of the heating appliance (P_{WO}) for positive pressure chimney

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

5.5.7 Minimum differential pressure of the heating appliance (P_{WOmin}) for positive pressure chimney

For the calculation of a positive pressure chimney the value of the minimum differential pressure of the heating appliance P_{WOmin} shall be obtained from the manufacturer of the heating 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/Λ)

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

The thermal resistance 1/Λ 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:

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

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 K (t_L = 15 °C) for the calculation of minimum draught or maximum positive pressure at the flue gas inlet into the chimney;

T_L = 258,15 K (t_L = –15 °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 K (t_{uo} = –15 °C) for chimneys operating under wet conditions

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

T_{ub} = 288,15 K (t_{ub} = 15 °C)

T_{uh} = 293,15 K (t_{uh} = 20 °C)

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

T_{uu} = 273,15 K (t_{uu} = 0 °C)

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

T_{uo} = 258,15 K (t_{uo} = –15 °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 K (t_{uo} = 0 °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 K (t_{ub} = 15 °C)

T_{uh} = 293,15 K (t_{uh} = 20 °C)

T_{ul} = 288,15 K (t_{ul} = 15 °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 K (t_{uu} = 15 °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 K (t_{uu} = 0 °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 ¼ of the total outer surface of the chimney, the ambient air temperature T_u may be taken as 288,15 K ($t_u = 15$ °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 ($t_u = 15$ °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 ($t_u = 0$ °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/s^2;

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 $\sigma(H_2O)$ 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:

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

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:

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

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

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

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

$$T_{mV} = T_u + \frac{T_W - T_u}{K_V} \cdot \left(1 - e^{-K_V}\right), \text{ in K} \tag{18}$$

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

$$T_e = T_u + (T_W - T_u) \cdot e^{-K_V}, \text{ in K} \tag{19}$$

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 heating 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:

$$K = \frac{U \cdot k \cdot L}{\dot{m} \cdot c_p} \tag{20}$$

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/(m^2 · 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/(m^2 · K);

α_i is the internal coefficient of heat transfer (see 5.8.3.2), in W/(m^2 · K);

$\left(\frac{1}{\Lambda}\right)$ is the thermal resistance (see 5.6.3), in m^2 · 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:

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

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 ($L_{tot\,V}$ is similarly valid for the connecting flue pipe: total effective length from flue gas connection of the heating 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:

$$Pr = \frac{\eta_{\text{A}} \cdot c_{\text{p}}}{\lambda_{\text{A}}} \qquad (25)$$

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

$$Re = \frac{w_{\text{m}} \cdot D_{\text{h}} \cdot \rho_{\text{m}}}{\eta_{\text{A}}} \qquad (26)$$

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/m^2;

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/m^3.

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/(m^2 · K) for connecting flue pipes and chimneys, internal to the building, for connecting flue pipes and chimneys external to the building using 23 W/(m^2 · 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/(m^2 · K).

For a chimney (including relined chimneys) with a ventilated air gap 8 W/(m^2 · K) shall be used. For non-ventilated parts of such a chimney if the non-ventilated length external to the building is ≤ 3 D_h then 8 W/(m^2 · K) shall be used, otherwise 23 W/(m^2 · 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:

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

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 formua:

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

where

A is the internal cross section of the chimney, in m^2;

$\dot{m}$ 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/m^3.

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:

$$P_Z = P_H - P_R - P_L, \text{ in Pa} \tag{29}$$

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

where

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_Z is the minimum draught at the flue gas inlet, in Pa;

P_{Zmax} is the maximum draught at the flue gas inlet, in Pa.

NOTE The values of P_H and P_R in Formulas (29) and (29a) are normally different because the conditions are different.

5.10.1.2 Positive pressure at the flue gas inlet into the positive pressure chimney (P_{ZO} and P_{ZOmin})

The maximum and minimum positive pressure at the flue gas inlet into the positive pressure chimney P_{ZO} and P_{ZOmin} 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 maximum and minimum positive pressure at the flue gas inlet into the chimney P_{ZO} and P_{ZOmin} shall be calculated using the following formulas:

$$P_{ZO} = P_R - P_H + P_L, \text{ in Pa} \tag{30}$$

$$P_{ZOmin} = P_R - P_H, \text{ in Pa} \tag{30a}$$

where

P_H is the theoretical draught of the chimney, in Pa;

P_L is the wind velocity pressure, in Pa;

P_R is the pressure resistance of the chimney, in Pa;

P_{ZO} is the maximum differential pressure at the flue gas inlet, in Pa;

P_{ZOmin} is the minimum differential pressure at the flue gas inlet, in Pa.

NOTE The values of P_R and P_H in Formulas (30) and (30a) are normally different because the conditions are different.

5.10.2 Theoretical draught available due to chimney effect (P_H)

The theoretical draught available due to chimney effect P_H shall be calculated using the following formula:

$$P_H = H \cdot g \cdot (\rho_L - \rho_m), \text{ in Pa} \tag{31}$$

where

H is the effective height of the chimney, in m;

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

ρ_L is the density of the external air (see 5.7.4), in kg/m³;

ρ_m is the mean density of the flue gas (see 5.9.1), in kg/m³.

5.10.3 Pressure resistance of the chimney (P_R)

5.10.3.1 General

The pressure resistance of the chimney P_R shall be calculated using the following formula:

$$P_R = S_E \cdot P_E + S_{EG} \cdot P_G, \text{ in Pa} \tag{32}$$

$$P_R = S_E \cdot \left(\psi \cdot \frac{L}{D_h} + \sum_n \zeta_n \right) \frac{\rho_m}{2} \cdot w_m^2 + S_{EG} \cdot P_G, \text{ in Pa} \tag{33}$$

For $P_G \geq 0$ $S_{EG} = S_E$

For $P_G < 0$ $S_{EG} = 1{,}0$

where

D_h is the internal hydraulic diameter, in m;

L is the length of chimney, in m;

P_E is the pressure resistance due to friction and form resistance of the chimney, in Pa;

P_G is the difference in pressure caused by change of velocity of the flue gas in the chimney, in Pa;

S_E is the flow safety coefficient (see 5.7.8);

S_{EG} is the flow safety coefficient for difference in pressure through velocity change;

w_m is the mean flue gas velocity (see 5.9.2), in m/s;

ρ_m is the mean density of the flue gas (see 5.9.1), in kg/m³;

ψ is the coefficient of flow resistance due to the friction of the flue;

$\sum_n \zeta n$ sum of the coefficients of flow resistance due to directional and/or cross sectional and/or mass flow changes in the flue.

5.10.3.2 Difference in pressure caused by change of velocity of the flue gas in the chimney (P_G)

The difference in pressure caused by the change of velocity of the flue gas in the chimney P_G shall be calculated using the following formula:

$$P_G = \frac{\rho_2}{2} \cdot w_2^2 - \frac{\rho_1}{2} \cdot w_1^2, \text{ in Pa} \tag{34}$$

where

w_1 is the flue gas velocity before velocity change, in m/s;

w_2 is the flue gas velocity after velocity change, in m/s;

ρ_1 is the density of the flue gas before velocity change, in kg/m^3;

ρ_2 is the density of the flue gas after velocity change, in kg/m^3.

For w_1 and w_2 as well ρ_1 and ρ_2 the mean values of section before and after the change of the velocity may be used.

5.10.3.3 Coefficient of flow resistance due to friction of the flue (ψ)

The coefficient of flow resistance due to friction of the flue ψ for different roughness shall be calculated using the following formula:

$$\frac{1}{\sqrt{\psi}} = -2 \cdot \lg\left(\frac{2{,}51}{\mathrm{Re}\cdot\sqrt{\psi}} + \frac{r}{3{,}71\cdot D_\mathrm{h}}\right) \quad (35)$$

where

D_h is the hydraulic diameter, in m;

r is the mean value for roughness of the inner wall, in m;

Re is the Reynolds number (see 5.8.2);

ψ is the coefficient of flow resistance due to friction of the flue.

For Reynold numbers below 2 300 take the coefficient appropriate to the Reynolds number equal to 2 300.

The values for mean values for roughness shall be given by the manufacturer. In the absence of values from the manufacturer typical mean roughness values for various materials are given in Table B.4.

5.10.3.4 Coefficients of flow resistance (ζ) due to a directional and/or cross sectional change and/or mass flow change in the flue

The values of the flow resistance due to a directional and/or cross section and/or mass flow change in the flue shall be taken from the manufacturer. In the absence of values from the manufacturer, typical values of flow resistance are given in Table B.8.

The coefficient of flow resistance for the enlargement of the cross-section at the chimney outlet should not apply if the pressure change through velocity change is not taken into account at this point.

5.10.4 Wind velocity pressure (P_L)

The wind velocity pressure P_L shall be 25 Pa for inland regions (more than 20 km from the coast) and 40 Pa for coastal regions if the chimney outlet is in an adverse pressure. The chimney outlet is considered to be in an adverse pressure zone if the chimney outlet position is less than 0,4 m above the ridge and the distance of a horizontal line from the intersection with the roof, or the projection of the ridge above the roof, to the chimney outlet is less than 2,3 m, and the chimney outlet is situated:

— on a roof with a slope of more than 40° or

— on a roof with a slope of more than 25° if the opening for combustion air and the top of the chimney are on different sides of the ridge and horizontal distance from the top to the ridge is more than 1,0 m.

NOTE A chimney may also be considered to be adversely affected by the proximity of adjacent obstructions e.g. buildings, trees, mountains. A chimney outlet within 15 m from adjacent structures which extends over a horizontal angle of 30° and their upper boundary raises more than 10° above the horizon as seen from the terminal outlet may be affected by wind turbulence (see Annex C). This may be overcome by an aerodynamic terminal.

The value P_L shall be amended if the chimney has a terminal with specified aerodynamic performance. In all other cases P_L shall be 0 Pa.

5.11 Minimum draught required at the flue gas inlet into the chimney and maximum allowed draught (P_{Ze} and P_{Zemax}) and maximum and minimum differential pressure at the flue gas inlet into the chimney (P_{ZOe} and P_{ZOemin})

5.11.1 General

The minimum draught required at the flue gas inlet into the negative pressure chimney P_{Ze} and the maximum allowed draught P_{Zemax} shall be calculated with the following formulas:

$$P_{Ze} = P_W + P_{FV} + P_B, \text{ in Pa} \tag{36}$$

$$P_{Zemax} = P_{Wmax} + P_{FV} + P_B, \text{ in Pa} \tag{36a}$$

where

P_{Ze} is the minimum draught required at the flue gas inlet into the chimney, in Pa;

P_{Zemax} maximum allowed draught at the flue gas inlet into the chimney, in Pa;

P_W is the minimum draught for the heating appliance, in Pa;

P_{Wmax} maximum draught for the heating appliance, in Pa;

P_{FV} is the effective pressure resistance of the connecting flue pipe, in Pa;

P_B is the effective pressure resistance of the air supply, in Pa.

NOTE The values of P_{FV} and P_B in Formulas (36) and (36a) may be different because the conditions are different.

The maximum and minimum differential pressure at the flue gas inlet into the positive pressure chimney P_{ZOe} and P_{ZOemin} shall be calculated with the following formulas:

$$P_{ZOe} = P_{WO} - P_B - P_{FV}, \text{ in Pa} \tag{37}$$

$$P_{ZOemin} = P_{WOmin} - P_B - P_{FV}, \text{ in Pa} \tag{37a}$$

where

P_{ZOe} is the maximum differential pressure at the flue gas inlet into the chimney, in Pa;

P_{ZOemin} minimum differential pressure at the flue gas inlet into the chimney, in Pa;

P_{WO} is the maximum differential pressure at the outlet of the heating appliance, in Pa;

P_{WOmin} minimum differential pressure at the outlet of the heating appliance, in Pa;

P_{FV} is the effective pressure resistance of the connecting flue pipe, in Pa;

P_B is the effective pressure resistance of the air supply, in Pa.

NOTE The values of P_{FV} and P_B in Formulas (37) and (37a) may be different because the conditions are different.

5.11.2 Minimum and maximum draught for the heating appliance (P_W and P_{Wmax}) and maximum and minimum differential pressure of the heating appliance (P_{WO} and P_{WOmin})

The minimum and maximum draught for the heating appliance (P_W and P_{Wmax}) or the maximum and minimum differential pressure of the heating appliance (P_{WO} and P_{WOmin}) shall be obtained in accordance with 5.5.4, 5.5.5, 5.5.6 or 5.5.7.

5.11.3 Effective pressure resistance of the connecting flue pipe (P_{FV})

5.11.3.1 General

The effective pressure resistance of the connecting flue pipe P_{FV} shall be calculated using the following formula:

$$P_{FV} = P_{RV} - P_{HV}, \text{ in Pa} \quad (38)$$

where

P_{HV} is the theoretical draught available of the connecting flue pipe, in Pa;

P_{RV} is the pressure resistance of the connecting flue pipe, in Pa.

If the connecting flue pipe consists of several different sections of different design, the calculation shall be carried out for each section. The pressure resistance and the theoretical draught of the individual sections shall be totalled.

5.11.3.2 Theoretical draught available due to the chimney effect of the connecting flue pipe (P_{HV})

The theoretical draught available due to the chimney effect of the connecting flue pipe P_{HV} shall be calculated using the following formula:

$$P_{HV} = H_V \cdot g \cdot (\rho_L - \rho_{mV}), \text{ in Pa} \quad (39)$$

where

g is the acceleration due to gravity = 9,81 m/s^2;

H_V is the effective height of the connecting flue pipe, in m;

ρ_L is the density of the external air (see 5.7.4), in kg/m^3;

ρ_{mV} is the mean density of the flue gas in the connecting flue pipe, in kg/m^3.

If the flue gas inlet into the chimney is lower than the flue gas connection of the heating appliance, P_{HV} becomes negative.

5.11.3.3 Pressure resistance of the connecting flue pipe (P_{RV})

The pressure resistance of the connecting flue pipe P_{RV} shall be calculated from:

$$P_{RV} = S_E \cdot P_{EV} + S_{EG} \cdot P_{GV}, \text{ in Pa} \quad (40)$$

$$P_{RV} = S_E \cdot \left(\psi_V \cdot \frac{L_V}{D_{hV}} + \sum_n \zeta_{Vn} \right) \frac{\rho_{mV}}{2} \cdot w_{mV}^2 + S_{EGV} \cdot P_{GV}, \text{ in Pa} \quad (41)$$

For $P_{GV} \geq 0$ $S_{EGV} = S_E$

For $P_{GV} < 0$ $S_{EGV} = 1{,}0$

where

D_{hV}	is the internal hydraulic diameter of the connecting flue pipe, in m;
L_V	is the length of the connecting flue pipe, in m;
P_{EV}	is the pressure resistance due to friction and form resistance in the connecting flue pipe in Pa;
P_{GV}	is the difference in pressure caused by change of velocity of the flue gas in the connecting flue pipe, in Pa;
S_E	is the flow safety coefficient;
S_{EGV}	is the flow safety coefficient for differences in pressure through velocity change in the connecting flue pipe;
w_{mV}	is the mean velocity of the flue gas in the connecting flue pipe, in m/s;
ρ_{mV}	is the mean density of the flue gas in the connecting flue pipe, in kg/m^3;
ψ_V	is the coefficient of friction of the flue of the connecting flue pipe (see 5.10.3.3);
$\sum_n \zeta_{Vn}$	is the sum of the coefficient of flow resistance of directional and cross sectional changes of the connecting flue pipe, in m.

The mean velocity w_{mV} of the flue gas in the connecting flue pipe shall be calculated using Formula (28) with the corresponding values for the connecting flue pipe.

The coefficient of flow resistance due to friction of the flue for the connecting flue pipe shall be calculated using Formula (35) with the corresponding values for the connecting flue pipe.

NOTE The sum of the individual coefficients of resistance $\sum_n \zeta_{Vn}$ for the connecting flue pipe is dependent on the cross-sectional and directional changes between the flue gas connection of the heating appliance and chimney.ζ values are quoted in Table B.8 for the typical cross-sectional and directional changes.

The difference in pressure caused by the change of velocity of the flue gas in the connecting flue pipe P_{GV} shall be calculated using Formula (34) with the corresponding values for the connecting flue pipe.

5.11.4 Pressure resistance of the air supply (P_B)

The pressure resistance of the air supply P_B shall be determined according to the nature of the installation area (size, type and number of windows and doors, equipment with ventilation systems and additional heating appliances, etc.).

For areas without ventilation openings P_B shall be 4 Pa.

If the air for combustion is conveyed to the installation room through ventilation openings or combustion air pipes with constant cross-section over the length, P_B shall be derived using the following formula:

$$P_B = S_{EB} \cdot \left(\psi_B \cdot \frac{L_B}{D_{hB}} + \sum_n \zeta_{B,n} \right) \frac{\rho_B}{2} \cdot w_B^2 \text{ , in Pa} \tag{42}$$

where

D_{hB}	is the internal hydraulic diameter of the ventilation openings or combustion air pipe, in m;
L_B	is the length of the ventilation openings or combustion air pipe, in m;

S_{EB} is the flow safety coefficient for air supply (S_{EB} usually is 1,2);

w_B is the velocity in the ventilation openings or combustion air pipe, in m/s;

ρ_B is the density of the combustion air, in kg/m^3;

ψ_B is the coefficient of the flow resistance due to friction of the ventilation openings or combustion air pipe;

$\sum_n \zeta_{B,n}$ is the sum of the coefficients of flow resistance due to a directional and/or cross sectional and/or mass flow change in the ventilation openings or combustion air pipe.

NOTE In order to simplify calculation depending on local regulations P_B may be assumed to have a constant value of 3 Pa.

The coefficient of flow resistance due to friction of the ventilation openings or combustion air pipe ψ_B shall be calculated by using Formula (35).

The sum of the coefficients of flow resistance due to a directional and/or cross sectional and/or mass flow changes in the ventilation openings or combustion air pipes $\sum_n \zeta_{B,n}$ for the inlet, the outlet and directional changes in the pipe shall be totalled over the entire length of ventilation opening or of the pipe.

In the absence of manufactures data the values may be taken from Table B.8.

The velocity in the combustion air pipe w_B shall be derived using the following formula:

$$w_B = \frac{\beta \cdot \dot{m}}{A_B \cdot \rho_B}, \text{ in m/s} \tag{43}$$

where

A_B is the cross-section of the combustion air pipe, in m^2;

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

β is the ratio of the combustion air mass flow to the flue gas mass flow;

ρ_B is the density of the combustion air, in kg/m^3.

NOTE As an approximation β = 0,9 can be assumed.

The density of the combustion air shall be determined using Formula (13) with the corresponding values for air temperature and pressure.

5.12 Calculation of the inner wall temperature at the chimney outlet (T_{iob})

The inner wall temperature at the chimney outlet at temperature equilibrium T_{iob} shall be determined using the following formula:

$$T_{iob} = T_{ob} - \frac{k_{ob}}{\alpha_i} \left(T_{ob} - T_{uo}\right) \text{ , in K} \tag{44}$$

where

k_{ob} is the coefficient of heat transmission at the chimney outlet at temperature equilibrium, in W/(m^2·K);

T_{ob} is the flue gas temperature at the chimney outlet at temperature equilibrium, in K;

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

α_i is the internal coefficient of heat transfer, in W/(m^2 · K).

The coefficient of heat transmission at the chimney outlet k_{ob} at temperature equilibrium shall be determined from the following formula:

$$k_{ob} = \frac{1}{\frac{1}{\alpha_i} + \left(\frac{1}{\Lambda}\right) + \left(\frac{1}{\Lambda}\right)_o + \frac{D_h}{D_{hao} \cdot \alpha_{ao}}} \text{, in W/(m}^2 \cdot \text{K)} \quad (45)$$

where

D_h is the internal hydraulic diameter, in m;

D_{hao} is the external hydraulic diameter at the chimney outlet, in m;

α_i is the internal coefficient of heat transfer at the chimney outlet, in W/(m^2 · K);

α_{ao} is the external coefficient of heat transfer at the chimney outlet, in W/(m^2 · K):

$\left(\frac{1}{\Lambda}\right)$ is the thermal resistance, in m^2 · K/W;

$\left(\frac{1}{\Lambda}\right)_o$ is the thermal resistance of any additional insulation for the chimney part above the roof related to the internal hydraulic diameter to the chimney, in m^2 · K/W.

For non-insulated termination parts of a chimney if the non-insulated length external to the building is ≤ 3 D_h, a separated calculation of the inner wall temperature with the reduced thermal resistance is not necessary.

If the chimney part above the roof has additional insulation, the inner wall temperature shall be calculated for the part immediately before the additional insulation. The inner wall temperature T_{irb} immediately before the additional insulation shall be determined using the following formula:

$$T_{irb} = T_{rb} - \frac{k_b}{\alpha_i}\left(T_{rb} - T_{ur}\right) \text{, in K} \quad (46)$$

where

T_{rb} is the flue gas temperature immediately before the additional insulation at temperature equilibrium, in K;

k_b is the coefficient of heat transmission of the chimney at temperature equilibrium, in W/(m^2 · K);

T_{ur} is the ambient air temperature immediately before the additional insulation, in K;

Additional thermal resistance at the chimney outlet $(1/\Lambda)_0$ shall be calculated as specified in 5.6.3 for additional layers of insulation applied on all sides. Layers of air of a thickness of less than 1 cm shall not be deemed to provide additional thermal resistance $(1/\Lambda)_0$. In the case of ventilated cladding $(1/\Lambda)_0$ = 0 (m^2 · K)/W shall apply generally to all layers on the outside of the ventilated gap.

NOTE A value of $(1/\Lambda)_0$ = 0,1 (m^2 · K)/W may be used without any further proof if the chimney section above the roof is encased by masonry (coefficient of thermal conductivity λ ≤ 0,85 W/(m · K)) of a minimum thickness of 11,5 cm or has a minimum of 3 cm additional insulation on all sides (coefficient of thermal conductivity λ ≤ 0,1 W/(m · K)).

6 Secondary air for negative pressure chimneys

6.1 General

If the temperature requirement in 5.3 is not satisfied when the inner wall temperature is calculated according to Formula (44) or (46) without the introduction of secondary air into the chimney, it can be possible to meet the requirement by the introduction of secondary air. In this the case further calculation shall be undertaken to establish whether the temperature requirement can be satisfied when secondary air is introduced into the chimney.

If the pressure requirement of 5.2 for maximum draught (2a) is not satisfied when pressures are calculated according to Formula (29a) and (36a) without the introduction of secondary air into the chimney, it may be possible to meet the requirement by the introduction of a secondary air. In this case further calculation shall be undertaken to establish whether the pressure requirement for maximum draught can be satisfied when secondary air is introduced into the chimney.

It is a condition that the pressure requirements of 5.2 for minimum draught (1 and 2) are satisfied when calculated without secondary air.

6.2 Calculation method

The calculation shall be carried out in sections from the flue gas connection of the appliance to the place of installation of the secondary air device and from there, with changed values for the flue gas mass flow, the flue gas temperature and the flue gas composition, to the chimney outlet.

For consideration of the secondary air, a secondary air mass flow shall be added to the flue gas mass flow. The mixed temperature and the composition of the secondary air/flue gas mixture behind the secondary air inlet shall be calculated from the temperature and composition of the flue gas and of the secondary air. For the additional calculation, the physical properties (c_p, R, η_A, T_p, λ_A) dependent on the composition of the flue gas-secondary air mixture shall be calculated.

The calculation, assuming a chosen secondary air flow, shall be carried out repeatedly until the operational requirements are fulfilled or until the surplus draught is exhausted ($P_Z = P_{Ze}$ or $P_{Zmax} = P_{Zemax}$).

In the case of gas fire heating appliances with a draught diverter, only the secondary air in addition to the scheduled flue gas mass flow shall be considered.

6.3 Basic values for the calculation of secondary air

6.3.1 General

The temperature of the secondary air T_{NL} shall be taken as the ambient temperature of the air of the space from which the air is taken.

For the check of the temperature requirements the external air temperature shall be calculated using $T_L = T_{uo}$ (see 5.7.1.3). In order to calculate the secondary air mass flow the ambient temperature values of 5.7.1.3 for validating the temperature requirement shall be used.

6.3.2 Mixing calculations

The mass flow after admixture of secondary air $\dot{m}_M$ shall be derived from the following formula:

$$\dot{m}_M = \dot{m} + \dot{m}_{NL} \text{, in kg/s} \tag{47}$$

The flue gas temperature after admixture of secondary air T_M shall be derived from the following formula:

$$T_M = \frac{\dot{m} \cdot c_{pA} \cdot T_A + \dot{m}_{NL} \cdot c_{pNL} \cdot T_{NL}}{\dot{m} \cdot c_{pA} + \dot{m}_{NL} \cdot c_{pNL}} \text{, in K} \quad (48)$$

The concentration by volume of CO_2 and H_2O after admixture of secondary air shall be derived from the following formula:

$$\sigma(CO_2)_M = \frac{\dot{m} \cdot R \cdot [100 - \sigma(H_2O)] \cdot \sigma(CO_2)}{\dot{m} \cdot R \cdot [100 - \sigma(H_2O)] + \dot{m}_{NL} \cdot R_L \cdot [100 - \sigma(H_2O)_{NL}]} \text{, in \%} \quad (49)$$

$$\sigma(H_2O)_M = \frac{\dot{m} \cdot R \cdot \sigma(H_2O) + \dot{m}_{NL} \cdot R_L \cdot \sigma(H_2O)_{NL}}{\dot{m} \cdot R + \dot{m}_{NL} \cdot R_L} \text{, in \%} \quad (50)$$

The water vapour content of the secondary air may be taken as 1,1 %. This value corresponds to 60 % relative humidity at 15 °C.

where

c_{pA}	is the specific heat capacity of the flue gas before admixture of secondary air, in J/(kg · K);
c_{pNL}	is the specific heat capacity of the secondary air, in J/(kg · K);
$\dot{m}$	is the flue gas mass flow before admixture of secondary air, in kg/s;
$\dot{m}_M$	is the flue gas mass flow after admixture of secondary air, in kg/s;
$\dot{m}_{NL}$	is the secondary air mass flow, in kg/s;
R	is the gas constant of the flue gas before admixture of secondary air, in J/(kg · K);
R_L	is the gas constant of the air, in J/(kg · K);
T_A	is the temperature of the flue gas before admixture of secondary air, in K;
T_M	is the temperature of the flue gas after admixture of secondary air, in K;
T_{NL}	is the temperature of the secondary air, in K;
$\sigma(CO_2)$	is the concentration by volume of CO_2 of the flue gas before admixture of secondary air, in %;
$\sigma(CO_2)_M$	is the concentration by volume of CO_2 of the flue gas after admixture of secondary air, in %;
$\sigma(H_2O)$	is the concentration by volume of H_2O (water vapour) of the flue gas before admixture of secondary air, in %;
$\sigma(H_2O)_M$	is the concentration by volume of H_2O (water vapour) of the flue gas after admixture of secondary air, in %;
$\sigma(H_2O)_{NL}$	is the concentration by volume of H_2O (water vapour) of secondary air, in %.

6.4 Pressures

6.4.1 Pressure resistance for the air supply with secondary air (P_{BNL})

For areas without ventilation openings the effective pressure resistance for the air supply P_{BNL} with secondary air and nominal heat output shall be derived from the following formula:

$$P_{BNL} = P_B \cdot \left(1 + \frac{\dot{m}_{NL}}{\beta \cdot \dot{m}}\right)^{1,5} \text{, in Pa} \quad (51)$$

where

$\dot{m}_{NL}$	is the secondary air mass flow, in kg/s;
$\dot{m}$	is the flue gas mass flow before admixture of secondary air, in kg/s;
P_B	is the effective pressure resistance of the air supply without secondary air (see 5.11.4);
β	is the ratio of the combustion air mass flow to the flue gas mass flow (see 5.11.4).

If the air for combustion is conveyed through ventilation openings or pipes with constant cross-section over the length, P_{BNL} shall be derived from the following formula:

$$P_{BNL} = S_{EB} \cdot \left(\psi_{BNL} \cdot \frac{L_B}{D_{hB}} + \sum_n \zeta_{B,n} \right) \frac{\rho_B}{2} \; w_{BNL}^2 \text{, in Pa} \qquad (52)$$

where

D_{hB}	is the internal hydraulic diameter of the ventilation openings or combustion air pipe (see 5.11.4), in m;
L_B	is the length of the ventilation openings or combustion air pipe (see 5.11.4), in m;
S_{EB}	is the flow safety coefficient for air supply (see 5.11.4);
w_{BNL}	is the velocity in the ventilation openings or combustion air pipes taking in account the secondary air, in m/s
ρ_B	is the density of the combustion and the secondary air (see 5.11.4), in kg/m^3;
ψ_{BNL}	is the coefficient of friction of the pipe of the ventilation openings or combustion air pipe taking in account the secondary air;
$\sum_n \zeta_{B,n}$	sum of the coefficients of local resistance of the ventilation openings or combustion air supply (see 5.11.4).

5.10.3.3 shall be used for the determination of the coefficient of friction of the pipe of the ventilation openings or combustion air pipe taking in account the secondary air ψ_{BNL}.

The velocity in the ventilation openings or combustion air pipe taking in account the secondary air w_{BNL} shall be derived from the following formula:

$$w_{BNL} = \frac{\beta \cdot \dot{m} + \dot{m}_{NL}}{A_B \cdot \rho_B} \text{, in m/s} \qquad (53)$$

where

A_B	is the cross-section of the ventilation openings or combustion air pipe (see 5.11.4);
$\dot{m}$	is the flue gas mass flow before admixture of secondary air, in kg/s;
$\dot{m}_{NL}$	is the secondary air mass flow, in kg/s;
β	is the ratio of combustion air mass flow to the flue gas mass flow (see 5.11.4);
ρ_B	is the density of the combustion and the secondary air (see 5.11.4), in kg/m^3.

6.4.2 Draught required for the secondary air devices (P_{NL})

The draught required for the draught regulator P_{NL} shall be derived from the following formula:

$$P_{NL} = a_0 + a_1 \cdot \dot{m}_{NL} + a_2 \cdot \dot{m}_{NL}^2 + S_E \cdot \left(1 + \zeta_{2-3}\right) \cdot \frac{\rho_M}{2} w_M^2 \text{, in Pa} \quad (54)$$

The draught required for the draught diverter P_{NL} shall be derived from the following formula:

$$P_{NL} = P_W \left(\frac{\dot{m}_{NL} + \dot{m}}{\dot{m}}\right)^2 \text{, in Pa} \quad (55)$$

where

a_0	is the reference input value of the draught regulator, in Pa;
a_1	is the characteristic value for secondary air devices (draught regulator) (see Table B.7), in Pa/(kg/s)
a_2	is the characteristic value for secondary air devices (draught regulator) (see Table B.7), in Pa/(kg/s)^2;
$\dot{m}$	is the flue gas mass flow, in kg/s;
$\dot{m}_{NL}$	is the secondary air mass flow, in kg/s;
P_W	is the minimum draught for the heating appliance, in Pa;
S_E	is the flow safety coefficient;
w_M	is the velocity of the flue gas mixture after admixture of secondary air, in m/s;
ρ_M	is the density of the flue gas mixture after admixture of secondary air, in kg/m^3;
ζ_{2-3}	is the individual coefficient of resistance for secondary air inlet (see in Table B.8, No. 5).

The reference input value of the secondary air device a_0 shall be derived from the sum of the minimum or maximum draught for the heating appliance P_W or P_{Wmax} and for the flue gas route to the secondary air device.

For the check of the temperature requirements the following formula is valid:

— for $P_W + P_{FV1} < 10\,a_0 = 10$, in Pa (56)

and

— for $P_W + P_{FV1} \geq 10\,a_0 = P_W + P_{FV1}$, in Pa (57)

For the check of the pressure requirement for maximum draught the following formula is valid:

$a_0 = P_{Wmax} + P_{FV1}$, in Pa (57a)

where

P_{FV1}	is the effective pressure resistance for that part of the connecting flue pipe before the draught regulator, in Pa;
P_W	is the minimum draught for the heating appliance, in Pa;
P_{Wmax}	is the maximum draught for the heating appliance, in Pa.

6.4.3 Pressure resistance for that part of the connecting flue pipe before the secondary air device (P_{FV1})

The effective pressure resistance for that part of the connecting flue pipe before the draught regulator P_{FV1} shall be determined in accordance with 5.11.2.

If the draught regulator is arranged in the chimney, the chimney section up to the draught regulator can be treated as a separate part using the data appropriate to the chimney. P_{FV1} shall be taken as 0 for a draught diverter.

6.4.4 Pressure requirement with secondary air

For each secondary air mass flow, the minimum draught required or the maximum allowed draught at the flue gas inlet into the chimney P_{Ze} or P_{Zemax} shall be determined and compared with the draught at this point P_Z or P_{Zmax}.

For the check of the temperature requirements the following formula shall be fulfilled:

$$P_Z = P_H - P_R - P_L \geq P_{BNL} + P_{NL} + P_{FV2} = P_{Ze}, \text{ in Pa} \tag{58}$$

For the check of the pressure requirement for maximum draught the following formula shall be fulfilled:

$$P_{Zmax} = P_H - P_R \leq P_{BNL} + P_{NL} + P_{FV2} = P_{Zemax}, \text{ in Pa} \tag{58a}$$

where

P_{BNL} is the draught required for air supply with secondary air, in Pa;

P_{FV2} is the effective pressure resistance for that part of the connecting flue pipe after the draught regulator or after the draught diverter, 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_{NL} is the draught required for the draught regulator or the draught diverter, in Pa;

P_R is the pressure resistance of the chimney, in Pa.

NOTE The values of P_H and P_R in Formulas (58) and (58a) may be different because the conditions may be different.

For a draught regulator which is located in the chimney above the flue gas inlet, the pressure requirement after the draught regulator shall be proven.

6.5 Temperature requirement with secondary air

The temperature requirement at the chimney outlet shall be proven in accordance with 5.8 and 5.12 with the physical properties of the flue gas-secondary air mixture.

7 Calculation method for balanced flue chimneys

7.1 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 at the outlet of the air supply duct;

- 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 difference between the excess pressure for which both are designated and the pressure of the surrounding supply air;

— 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 outlet of the chimney shall be equal or 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 heating appliance or a minimum differential pressure of the positive pressure heating 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).

For the calculation, a balanced flue chimney and its air supply duct shall be divided into *Nseg* chimney segments of equal lengths each with a maximum length of 0,5 m. When the thermal resistance between the chimney (flue duct) and the air supply duct is higher than 0,65 m^2K/W then they need not to be divided into segments (*Nseg* = 1).

The connecting flue pipe and the connecting air supply pipe shall be divided into *NsegV* connecting flue pipe segments of equal lengths each with a maximum length of 0,5 m. When the thermal resistance between the connecting flue pipe and the connecting air supply pipe is higher than 0,65 $m^2 \cdot$ K/W then the configuration need not to be divided into segments (*NsegV* = 1).

7.2 Pressure requirements

The relationships (1), (2a) and (59), for negative pressure chimneys or (3), (5a), (60) and (61) for positive pressure chimneys shall be verified for all relevant operating conditions.

$$P_{\mathrm{Z}} \geq P_{\mathrm{RB}} + P_{\mathrm{HB}} \text{, in Pa} \tag{59}$$

$$P_{\mathrm{ZO}} \leq P_{\mathrm{Zexcess}} - \left(P_{\mathrm{RB}} + P_{\mathrm{HB}}\right) \text{, in Pa} \tag{60}$$

$$P_{\mathrm{ZO}} + P_{\mathrm{FV}} \leq P_{\mathrm{ZVexcess}} - P_{\mathrm{B}} \text{, in Pa} \tag{61}$$

where

P_{Z} is the draught at the flue gas inlet into the chimney, in Pa;

P_{ZO} is the positive pressure at the flue gas inlet into the chimney, in Pa;

P_{RB} is the pressure resistance of the air supply duct, in Pa;

P_{HB} is the theoretical draught available due to chimney effect of the air supply duct, in Pa;

P_{FV} is the effective pressure resistance of the connecting flue pipe, in Pa;

$P_{Zexcess}$ 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.

The pressure resistance for the air supply P_B shall be calculated using the following formula:

$$P_B = P_{RB} + P_{HB} + P_{RBV} + P_{HBV} \text{, in Pa} \quad (62)$$

where

P_B is the effective pressure resistance of air supply, in Pa;

P_{RB} is the pressure resistance of the air supply duct, in Pa;

P_{HB} is the theoretical draught available due to chimney effect of the air supply duct, in Pa;

P_{RBV} is the pressure resistance of the connecting air supply pipe, in Pa;

P_{HBV} is the theoretical draught available due to chimney effect of the connecting air supply pipe, in Pa.

7.3 Temperature requirements

The relationships (6) and (7) shall be verified.

7.4 Calculation procedure

For the calculation of the pressure and temperature values for the relationships of Formulas (1), (2a), (3), (5a), (6), (59), (60), and (61) the values of the flue gas data, characterised according to 5.5, shall be obtained for the appliance. The data specified in 7.6 shall be obtained for the chimney, the connecting flue pipe, the air supply duct and the connecting air supply pipe. For new built chimneys a pre-estimated value for the flue size should be used.

7.7 to 7.11 provide calculations needed to finalise the chimney thermal and fluid dynamic calculations. In 7.7 the formulas provide the calculation of the basic data which are needed for further calculation.

The formulas for the calculations of the relevant temperatures are compiled in 5.5.3 and 7.8. The formulas for the density of the flue gas and its velocity are compiled in 7.9.

The procedure in 7.10 and 7.11 shall be used to validate the pressure requirement. The procedure in 7.12 shall be used to validate the temperature requirement.

The validation for pressure and temperature requirement shall be conducted twice:

— for the nominal heat output of the heating appliance and

— for the lowest value of the heat output range which is indicated by the manufacturer of the heating appliance.

7.5 Flue gas data characterizing the heating appliance

The flue gas data characterizing the heating appliance shall be calculated in accordance with 5.5.

7.6 Characteristic data for the calculation

The characteristic data shall be calculated in accordance with 5.6.

The mean value for roughness of the air supply duct r_B and the connecting air supply pipe r_{BV} should be obtained from the product manufacturer. The mean values for roughness of materials normally used are listed in Table B.4.

The thermal resistance of the air supply duct $(1/\Lambda)_B$ and the connecting air supply pipe $(1/\Lambda)_{BV}$ can be determined as described in 5.6.3 for chimneys. In Formula (10) D_h is the hydraulic diameter of the inside of the air supply duct D_{hiB} or of the connecting air supply pipe D_{hiBV}.

7.7 Basic values for the calculation

7.7.1 Air temperatures

7.7.1.1 General

A differentiation shall be made between the external air temperature and the ambient air temperatures for chimneys which pass through heated areas.

7.7.1.2 External air temperature (T_L)

To check that the pressure requirement has been met the external air temperature T_L for heating systems is normally calculated using:

T_L = 288,15 K (t_L = 15 °C)	for the calculation of minimum draught or maximum positive pressure at the flue gas inlet into the chimney.
T_L = 258,15 K (t_L = -15 °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.

7.7.1.3 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:

$$T_{uo} = T_L \qquad (t_{uo} = t_L)$$

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

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

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

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

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

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.

7.7.2 Other basic values

Other basic values shall be calculated in accordance with 5.7.2 to 5.7.6 and 5.7.8.

7.8 Determination of the temperatures

7.8.1 Non-concentric (separate) ducts

When the thermal resistance between the flue duct and the air supply duct is equal to or higher than 0,65 $m^2 \cdot K/W$ the determination of the temperatures of the flue gas for separate ducts shall be calculated according to Clause 5. The temperature of the supply air within the air ducts shall be taken equal to the external air temperature.

When the thermal resistance between the flue duct and the air supply duct is less than 0,65 $m^2 \cdot K/W$ but equal to or higher than the thermal resistance of the outer duct walls the determination of the temperatures of the flue gas for separate ducts shall be calculated according to Clause 5. The mean temperature of the supply air in the air supply duct T_{mB} shall be calculated using the following formula:

$$T_{mB} = \frac{1}{\frac{0,7}{T_L} + \frac{0,3}{T_m}} \text{, in K} \qquad (63)$$

where

T_L is the external air temperature, in K

T_m is the mean temperature of the flue gas, in K

Otherwise the determination of the temperatures shall be undertaken in a similar way as described in 7.8.2 or 7.8.3.

7.8.2 Concentric ducts – calculation based on a correction factor for heat radiation

7.8.2.1 General

For concentric ducts, also the values to satisfy the pressure requirements shall be used for calculating for temperature equilibrium.

For the calculation of the temperature values in a concentric duct an iterative procedure is necessary. It is recommended to start the calculation at the first connecting flue pipe segment *j* = 1 using a pre-estimated value for the temperature of the supply air at the outlet of the concentric connecting air supply pipe $T_{oBV,1}$. Then $T_{oBV,1}$ shall be searched iteratively using the formulas in 7.8.2 until the following conditions are fulfilled:

$$\left| T_{eB,Nseg} - T_L \right| \leq 1 \text{, in K} \qquad (64)$$

where

$T_{oBV,1}$ is the temperature of the supply air at the outlet of the connecting air supply pipe segment 1, in K;

$T_{eB,Nseg}$ is the temperature of the supply air at the inlet of the chimney segment $Nseg$, in K;

T_L is the temperature of the external air, in K;

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

$Nseg$ is the number of chimney segments used in the calculation.

7.8.2.2 Temperatures in the connecting flue pipe and connecting air supply pipe segments

When the thermal resistance between the connecting flue pipe and the connecting air supply pipe is higher than 0,65 $m^2 \cdot K/W$ then the temperatures in the connecting flue pipe and the connecting air supply pipe shall be calculated in accordance to Clause 5. Then the temperature of the supply air at the beginning of the connecting air supply pipe segment $j = NsegV$ $T_{eB,NsegV}$ has to be pre-estimated instead of the temperature at the end of the connecting air supply pipe segment $j = 1$ $T_{oB,1}$ (see 7.8.2.1).

Otherwise the determination of the temperatures in the connecting flue pipe and in the connecting air supply pipe shall be undertaken as follows:

The flue gas temperature at the connecting flue pipe inlet, that means the beginning of the first connecting flue pipe segment $j = 1$ $T_{eV,1}$ is:

$$T_{eV,1} = T_w \text{, in K} \tag{65}$$

The flue gas temperature at the beginning of the connecting flue pipe segments $j > 1$ $T_{e,j}$ is:

$$T_{eV,j} = T_{oV,j-1} \text{, in K} \tag{66}$$

where

$T_{eV,j}$ is the temperature of the flue gas at the beginning of the connecting flue pipe segment j, in K;

T_W is the temperature of the flue gas at the outlet of the appliance, in K;

$T_{oV,j}$ is the temperature of the flue gas at the end of the connecting flue pipe segment j, in K.

The temperature of the supply air at the end of the connecting air supply segment $j = 1$ $T_{oB,1}$ has to be pre-estimated (see 7.8.2.1).

NOTE 1 In addition to checking the temperature requirement of the chimney, a check of the supply air temperature at the end of the connecting air supply pipe segment j = 1 $T_{oBV,1}$ may also be undertaken if there exists a maximum air inlet temperature for the heating appliance given by the manufacturer.

The temperature of the supply air at the end of connecting air supply pipe segments $j > 1$ $T_{oB,j}$ is:

$$T_{oBV,j} = T_{eBV,j-1} \text{, in K} \tag{67}$$

where

$T_{oBV,j}$ is the temperature of the supply air at the end of connecting pipe segment j, in K;

$T_{eBV,j}$ is the temperature of the supply air at the beginning of connecting pipe segment j, in K.

The flue gas temperature at the end of the concentric connecting flue pipe segment j $T_{oV,j}$ shall be calculated using the following formula:

$$T_{\mathrm{oV},j} = \frac{\left(2-K_{\mathrm{V},j}\right)\cdot\left(2-K_{\mathrm{BV},j}\right)\cdot T_{\mathrm{eV},j} - 2\cdot K_{V,j}\cdot\left(E_{\mathrm{V},j}\cdot T_{\mathrm{eV},j} - 2\cdot T_{\mathrm{oBV},j} + K_{BV\,j}\cdot T_{\mathrm{uV},j}\right)}{\left(2+K_{\mathrm{V},j}\right)\cdot\left(2-K_{\mathrm{BV},j}\right) - 2\cdot K_{\mathrm{V},j}\cdot E_{V,j}}\text{, in K} \quad (68)$$

with

$$E_{\mathrm{V},j} = \frac{\dot{m}\cdot c_{\mathrm{pV},j}}{\dot{m}_{\mathrm{B}}\cdot c_{\mathrm{pBV},j}} \quad (69)$$

where

$T_{\mathrm{oV},j}$ is the temperature of the flue gas at the end of connection flue pipe segment *j*, in K;

$T_{\mathrm{eV,j}}$ is the temperature of the flue gas at the beginning of connecting flue pipe segment *j*, in K;

$T_{\mathrm{oBV},j}$ is the temperature of the supply air at the end of the connecting air supply pipe segment *j*, in K;

$T_{\mathrm{uV},j}$ is the temperature of the ambient air of the connecting flue pipe segment *j*, in K;

$K_{\mathrm{V,j}}$ is the coefficient of cooling of connecting flue pipe segment *j*;

$K_{\mathrm{BV},j}$ is the coefficient of cooling of the connecting air supply pipe segment *j*;

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

$c_{\mathrm{pV,j}}$ is the specific heat capacity of the flue gas in connecting flue pipe segment *j*, in J/(kg·K);

$\dot{m}_{\mathrm{B}}$ is the mass flow of the supply air, in kg/s;

$c_{\mathrm{pBV},j}$ is the specific heat capacity of the supply air in connecting air supply pipe segment *j*, in J/(kg·K);

$E_{\mathrm{V,j}}$ is the heat flux ratio between the flue gas and the combustion air in the connecting flue pipe segment *j*

The supply air temperature at the beginning of the concentric connecting air supply pipe segment *j* $T_{\mathrm{eBV},j}$ shall be calculated using following formula:

$$T_{\mathrm{eBV},j} = T_{\mathrm{eV},j} + T_{\mathrm{oV},j} - T_{\mathrm{oBV},j} - \frac{2}{K_{\mathrm{V},j}}\left(T_{\mathrm{eV},j} - T_{\mathrm{oV},j}\right)\text{, in K} \quad (70)$$

where

$T_{\mathrm{eBV},j}$ is the temperature of the supply air at the beginning of connecting air supply pipe segment *j*, in K;

$T_{\mathrm{eV},j}$ is the temperature of the flue gas at the beginning of connecting flue pipe segment *j*, in K;

$T_{\mathrm{oV},j}$ is the temperature of the flue gas at the end of the flue of the connecting flue pipe segment *j*, in K;

$T_{\mathrm{oBV},j}$ is the temperature of the supply air at the end of connecting air supply pipe segment *j*, in K;

$K_{\mathrm{V,j}}$ is the coefficient of cooling of the flue of connecting flue pipe segment *j*;

NOTE 2 The formulas above are derived assuming that the heat exchange can be approximately calculated from the difference in mean temperatures.

The temperature of the flue gas averaged over the length of the concentric connecting flue pipe segment *j* $T_{\mathrm{mV},j}$ shall be calculated using the following formula:

$$T_{\mathrm{mV},j} = \frac{T_{\mathrm{eV},j} + T_{\mathrm{oV},j}}{2}\text{, in K} \quad (71)$$

where

$T_{mV,j}$ is the temperature of the flue gas averaged over the length of the connecting flue pipe segment *j*, in K;

$T_{eV,j}$ is the temperature of the flue gas at the beginning of the connecting flue pipe segment *j*, in K;

$T_{oV,j}$ is the temperature of the flue gas at the end of the connecting flue pipe segment *j*, in K;

The temperature of the supply air averaged over the length of the concentric connecting air supply pipe segment *j* $T_{mBV,j}$ shall be calculated using the following formula:

$$T_{mBV,j} = \frac{T_{eBV,j} + T_{oBV,j}}{2} \text{, in K} \tag{72}$$

where

$T_{mBV,j}$ is the temperature of the supply air averaged over the length of the connecting air supply pipe segment *j*, in K;

$T_{eBV,j}$ is the temperature of the supply air at the beginning of connecting air supply pipe segment *j*, in K;

$T_{oBV,j}$ is the temperature of the supply air at the end of connecting air supply pipe segment *j*, in K.

7.8.2.3 Temperatures in the chimney and air supply duct segments

The flue gas temperature at the chimney inlet, that means the beginning of the first chimney segment *j* = 1 $T_{e,1}$ is:

$$T_{e,1} = T_{oV,NsegV} \text{, in K} \tag{73}$$

The flue gas temperature at the beginning of the chimney segments *j* > 1 $T_{e,j}$ is:

$$T_{e,j} = T_{o,j-1} \text{, in K} \tag{74}$$

where

$T_{e,j}$ is the temperature of the flue gas at the beginning of the chimney segment *j*, in K;

$T_{oV,NsegV}$ is the temperature of the flue gas at the end of the connecting flue pipe segment $NsegV$, in K;

$T_{o,j}$ is the temperature of the flue gas at the end of the chimney segment *j*, in K.

The temperature of the supply air at the end of the air supply duct segment *j* = 1 $T_{oB,1}$ is:

$$T_{oB,1} = T_{eBV,NsegV} \text{, in K} \tag{75}$$

The temperature of the supply air at the end of air supply duct segments *j* > 1 $T_{oB,j}$ is:

$$T_{oB,j} = T_{eB,j-1} \text{, in K} \tag{76}$$

where

$T_{oB,j}$ is the temperature of the supply air at the end of the air supply duct segment *j*, in K;

$T_{eBV,NsegV}$ is the temperature of the supply air at the beginning of the connecting air supply pipe segment $NsegV$, in K;

$T_{eB,j}$ is the temperature of the supply air at the beginning of the air supply segment *j*, in K

The flue gas temperature at the end of the concentric chimney segment *j* $T_{o,j}$ shall be calculated using the following formula:

$$T_{o,j} = \frac{\left(2 - K_{,j}\right) \cdot \left(2 - K_{B,j}\right) \cdot T_{e,j} - 2 \cdot K_{,j} \cdot \left(E_{,j} \cdot T_{e,j} - 2 \cdot T_{oB,j} + K_{B,j} \cdot T_{u,j}\right)}{\left(2 + K_{,j}\right) \cdot \left(2 - K_{B,j}\right) - 2 \cdot K_{,j} \cdot E_{,j}} \text{, in K} \tag{77}$$

with

$$E_{,j} = \frac{\dot{m} \cdot c_{p,j}}{\dot{m}_B \cdot c_{pB,j}} \tag{78}$$

where

- $T_{o,j}$ is the temperature of the flue gas at the end of the chimney segment *j*, in K;
- $T_{e,j}$ is the temperature of the flue gas at the beginning of the chimney segment *j*, in K;
- $T_{oB,j}$ is the temperature of the supply air at the end of air supply duct segment *j*, in K;
- $T_{u,j}$ is the ambient air temperature of the chimney segment *j*, in K;
- K_j is the coefficient of cooling of the flue duct of the chimney segment *j* ;
- $K_{B,j}$ is the coefficient of cooling of the air supply duct of the air supply duct segment *j* ;
- $\dot{m}$ is the mass flow of the flue gas, in kg/s
- $c_{p,j}$ is the specific heat capacity of the flue gas in the chimney segment *j*, in J/(kg · K);
- $\dot{m}_B$ is the mass flow of the supply air, in kg/s;
- $c_{pB,j}$ is the specific heat capacity of the supply air in the air supply duct segment *j*, in J/(kg · K);
- E_j is the heat flux ratio between the flue gas and the supply air in the chimney segment *j*.

The supply air temperature at the beginning of the concentric air supply duct segment *j* $T_{eB,j}$ shall be calculated using the following formula:

$$T_{eB,j} = T_{e,j} + T_{o,j} - T_{oB,j} - \frac{2}{K_{,j}}\left(T_{e,j} - T_{o,j}\right) \text{, in K} \tag{79}$$

where

- $T_{eB,j}$ is the temperature of the supply air at the beginning of air supply duct segment *j*, in K;
- $T_{e,j}$ is the temperature of the flue gas at the beginning of chimney segment *j*, in K;
- $T_{o,j}$ is the temperature of the flue gas at the end of chimney segment *j*, in K;
- $T_{oB,j}$ is the temperature of the supply air at the end of air supply duct segment *j*, in K;
- $K_{,j}$ is the coefficient of cooling of the flue duct of chimney segment *j*;

NOTE The formulas above are derived assuming that the heat exchange can be approximately calculated from the difference in mean temperatures.

The temperature of the flue gas averaged over the length of the concentric chimney segment *j* $T_{m,j}$ shall be calculated using the following formula:

$$T_{m,j} = \frac{T_{e,j} + T_{o,j}}{2} \text{, in K} \tag{80}$$

where

$T_{m,j}$ is the temperature of the flue gas averaged over the length of the chimney segment *j*, in K;

$T_{e,j}$ is the temperature of the flue gas at the beginning of the chimney segment *j*, in K;

$T_{o,j}$ is the temperature of the flue gas at the end of chimney segment *j*, in K.

The temperature of the supply air averaged over the length of the concentric air supply duct segment *j* $T_{mB,j}$ shall be calculated using the following formula:

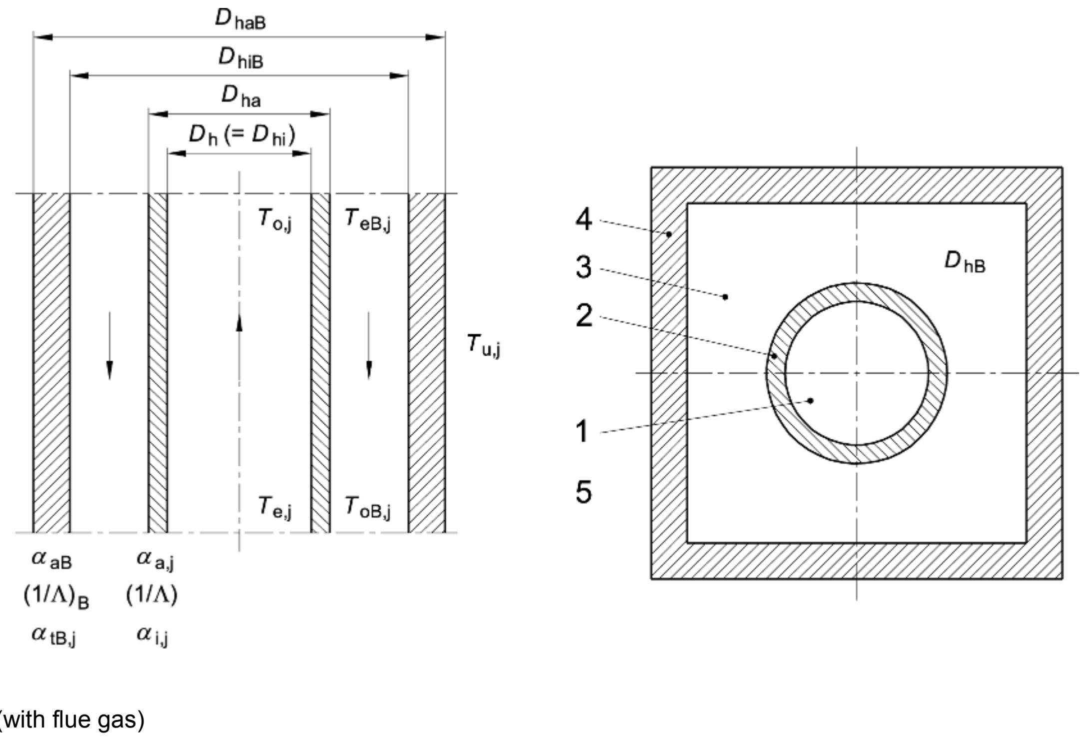
$$T_{mB,j} = \frac{T_{eB,j} + T_{oB,j}}{2} \text{, in K} \tag{81}$$

where

$T_{mB,j}$ is the temperature of the supply air averaged over the length of air supply duct segment j, in K;

$T_{eB,j}$ is the temperature of the supply air at the beginning of air supply duct segment j, in K;

$T_{oB,j}$ is the temperature of the supply air at the end of air supply duct segment j, in K.



Key

1 flue (with flue gas)

2 flue duct

3 air supply passage (with supply air)

4 air supply duct

5 ambient air

Figure 1 — Definition of the symbols used for the calculation of concentric balanced flue systems

7.8.2.4 Calculation of coefficient of cooling

The coefficient of cooling of the flue duct of the connecting flue pipe segment *j* $K_{V,j}$ shall be calculated using the following formula:

$$K_{V,j} = \frac{k_{V,j} \cdot U_V \cdot L_V}{\dot{m} \cdot c_{pV,j} \cdot NsegV} \quad (82)$$

where

$K_{V,j}$	is the coefficient of cooling of the connecting flue pipe segment *j* ;
$k_{V,j}$	is the coefficient of heat transmission between flue and the air supply passage of connecting flue pipe segment *j*, in W/(m²·K);
U_V	is the circumference of the flue of the connecting flue pipe *j*, in m;
L_V	is the length of connecting flue pipe, in m;
$\dot{m}$	is the flue gas mass flow, in kg/s;
$c_{pV,j}$	is the specific heat capacity of the flue gas in the connecting flue pipe segment *j*, in J/(kg · K);
$NsegV$	is the number of connecting flue pipe segments.

The coefficient of cooling of the air supply duct of the connecting air supply pipe K_{BV} shall be calculated using the following formula:

$$K_{BV,j} = \frac{k_{BV,j} \cdot U_{iBV} \cdot L_{BV}}{\dot{m}_B \cdot c_{pBV,j} \cdot NsegV} \quad (83)$$

where

$K_{BV,j}$	is the coefficient of cooling of connecting air supply pipe segment *j* ;
$k_{BV,j}$	is the coefficient of heat transmission between the supply air and the ambient air for the connecting air supply pipe segment *j,* in W/(m²·K);
U_{iBV}	is the circumference of the inside of the air supply duct of the connecting air supply pipe, in m;
L_{BV}	is the length of the connecting air supply pipe, in m;
$\dot{m}_B$	is the mass flow of the supply air, in kg/s;
$c_{pBV,j}$	is the specific heat capacity of the supply air in the connecting air supply pipe segment *j*, in J/(kg · K);
$NsegV$	is the number of connecting flue pipe segments.

The coefficient of cooling of the flue duct segment *j* $K_{,j}$ shall be calculated using the following formula:

$$K_{j} = \frac{k_{,j} \cdot U \cdot L}{\dot{m} \cdot c_{p,j} \cdot Nseg} \quad (84)$$

where

K_j	is the coefficient of cooling of the flue duct of the chimney segment *j*;
k_j	is the coefficient of heat transmission between flue and the air supply passage of the chimney segment *j*, in W/(m²·K);

U is the circumference of the flue, in m;

L is the length of the chimney segment, in m;

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

$c_{p,j}$ is the specific heat capacity of the flue gas in the chimney segment *j,* in J/(kg · K);

$Nseg$ is the number of chimney segments.

The coefficient of cooling of the air supply duct segment j $K_{B,j}$ shall be calculated using the following formula:

$$K_{B,j} = \frac{k_{B,j} \cdot U_{iB} \cdot L_B}{\dot{m}_B \cdot c_{pB,j} \cdot Nseg} \quad (85)$$

where

$K_{B,j}$ is the coefficient of cooling of the supply air duct of the chimney segment *j*;

$k_{B,j}$ is the coefficient of heat transmission between the supply air and the ambient air of the chimney segment *j,* in W/(m^2·K);

U_{iB} is the circumference of the inside of the air supply duct, in m;

L_B is the length of the air supply duct, in m;

$\dot{m}_B$ is the mass flow of the supply air, in g/s;

$c_{pB,j}$ is the specific heat capacity of the supply air in the chimney segment *j,* in J/(kg · K);

$Nseg$ is the number of chimney segments.

7.8.2.5 Coefficient of heat transmissions

7.8.2.5.1 Coefficient of heat transmissions between the flue gas and the supply air of the concentric connection pipe ($k_{V,j}$)

The coefficient of heat transmission between the flue gas and the supply air of the connecting pipe segment j $k_{V,j}$ shall be calculated using the following formula:

$$k_{V,j} = \frac{1}{\frac{1}{\alpha_{iV,j}} + \left(\frac{1}{\Lambda}\right)_V + \frac{D_{hV}}{D_{haV} \cdot \alpha_{aV,j} \cdot S_{rad}}}, \text{ in W/(m}^2 \cdot \text{K)} \quad (86)$$

where

$k_{V,j}$ is the coefficient of heat transmission between the flue gas and the supply air of the connecting flue pipe segment *j,* in W/(m^2 · K);

$\left(\frac{1}{\Lambda}\right)_V$ is the thermal resistance of the flue duct of the connecting flue pipe, in (m^2 · K)/W;

D_{hV} is the hydraulic diameter of the flue of connecting flue pipe, in m;

D_{haV} is the hydraulic diameter of the outside of the flue duct of the connecting flue pipe, in m;

$\alpha_{iV,j}$ is the coefficient of heat transfer between the flue gas and the inner surface of the flue duct of the connecting flue pipe segment *j,* in W/(m² · K);

$\alpha_{aV,j}$ is the coefficient of heat transfer between the supply air and the outer surface of the flue duct of the connecting flue pipe segment *j,* in W/(m² · K);

S_{rad} is the correction factor for the heat transfer by radiation.

In order to account for the effects of radiation from the outer surface of the flue duct to the inner surface of the air supply duct of the concentric connection pipes the calculation of k_V includes a correction factor for radiation S_{rad}, for which the value 2 shall be taken.

For concentric connection pipes in which the inner wall temperature of the flue duct is always lower than the condensing temperature of the flue gas the value S_{rad} = 1 should be taken.

The coefficient of heat transfer in the connection pipe $\alpha_{iV,j}$ shall be calculated using the following formula:

$$\alpha_{iV,j} = \frac{\lambda_{AV,j} \cdot Nu_{V,j}}{D_{hV}} \text{, in W/(m}^2 \cdot \text{K)} \tag{87}$$

where

D_{hV} is the internal hydraulic diameter of the connecting flue pipe, in m;

$Nu_{V,j}$ is the Nusselt number in the connecting flue pipe segment *j*;

$\lambda_{AV,j}$ is the coefficient of thermal conductivity of the flue gas in the connecting flue pipe segment *j*, in W/(m · K).

The coefficient of thermal conductivity of the flue gas λ_{AV} shall be calculated depending on the mean flue gas temperature in the connecting flue pipe segment *j* using in Tables B.1 and B.8.

The mean Nusselt number $Nu_{V,j}$ over the length of the concentric connecting flue pipe segment *j* shall be calculated using the following formula:

$$Nu_{V,j} = \left(\frac{\psi_{V,j}}{\psi_{smoothV,j}}\right)^{0,67} \cdot 0,0214 \cdot (Re_{V,j}^{0,8} - 100) \cdot Pr_{V,j}^{0,4} \cdot \left[1 + \left(\frac{D_{hV}}{L_{totV}}\right)^{0,67}\right] \tag{88}$$

where

D_{hV} is the internal hydraulic diameter of the connecting flue pipe, in m;

L_{totV} is the total length of the connecting flue pipe from the flue gas outlet of the heating appliance to the flue gas inlet into the chimney, in m;

$Pr_{V,j}$ is the Prandtl number;

$Re_{V,j}$ is the Reynolds number;

$\psi_{V,j}$ is the coefficient of the flow resistance due to friction for hydraulically rough flow (see 5.10.3.3);

$\psi_{smoothV,j}$ is the is the coefficient of the flow resistance due to friction for hydraulically smooth flow (5.10.3.3 for r = 0).

The formula can be used for 2 300 < $Re_{V,j}$ < 10 000 000 $\left(\frac{\psi_{V,j}}{\psi_{smoothV,j}}\right) < 3$ and 0,6 < $Pr_{V,j}$ < 1,5.

For mean flue gas velocity $w_{mV,j}$ < 0,5 m/s, take Nusselt number appropriate to $w_{mV,j}$ = 0,5 m/s.

For Reynolds numbers below 2 300, take Nusselt number appropriate to $Re_{V,j}$ = 2 300.

The Prandtl number $Pr_{V,j}$ shall be calculated using the following formula:

$$Pr_{V,j} = \frac{\eta_{AV,j} \cdot c_{pV,j}}{\lambda_{AV,j}} \tag{89}$$

The Reynolds number $Re_{V,j}$ shall be calculated using the following formula:

$$Re_{V,j} = \frac{w_{mV,j} \cdot D_{hV} \cdot \rho_{mV,j}}{\eta_{AV,j}} \tag{90}$$

where

$c_{pV,j}$ is the specific heat capacity of the flue gas, in J/(kg · K);

D_{hV} is the internal hydraulic diameter of the connecting flue pipe, in m;

$w_{mV,j}$ is the mean flue gas velocity (see 7.9.1), in m/s;

$\eta_{AV,j}$ is the dynamic viscosity of the flue gas, in N · s/m^2;

$\lambda_{AV,j}$ is the coefficient of thermal conductivity of the, in W/(m · K);

$\rho_{mV,j}$ is the mean density of the flue gas (see 7.9.1), in kg/m^3.

The dynamic viscosity $\eta_{AV,j}$ shall be calculated dependent on the flue gas temperature using Formula (B.10) in Table B.1.

The internal coefficient of heat transfer $\alpha_{iV,j}$ can also be calculated on wet designated chimneys as indicated, if the heat of condensation is not taken into account.

For $\alpha_{aV,j}$ the following formula shall be used:

$$\alpha_{aV,j} = \frac{\lambda_{BV,j} \cdot Nu_{aV,j}}{D_{hBV}}\text{, in W/(m}^2 \cdot \text{K)} \tag{91}$$

with

$$D_{hBV} = \frac{4 \cdot A_{BV}}{U_{aV} + U_{iBV}}\text{, in m} \tag{92}$$

$$Nu_{aV,j} = 0{,}86 \cdot \left(\frac{D_{hBV}}{D_{haV}}\right)^{0{,}16} \cdot Nu_{BV,j} \tag{93}$$

and

$$Nu_{BV,j} = \left[\frac{\psi_{BV,j}}{\psi_{smoothBV,j}}\right]^{0{,}67} \cdot 0{,}0214 \cdot \left(Re_{BV,j}^{0{,}8} - 100\right) \cdot Pr_{BV,j}^{0{,}4} \cdot \left(1 + \frac{D_{hBV}}{L_{totBV}}\right)^{0{,}67} \tag{94}$$

$$Re_{BV,j} = \frac{w_{mBV,j} \cdot D_{hBV} \cdot \rho_{mBV,j}}{\eta_{BV,j}} \tag{95}$$

where

$\lambda_{BV,j}$	is the thermal conductivity of the supply air in the concentric connecting air supply pipe segment *j*, in W/(m² · K);
$Nu_{aV,j}$	is the Nusselt number for the outside of the flue duct of the connecting air supply pipe;
D_{hBV}	is the hydraulic diameter of connecting air supply pipe, in m;
A_{BV}	is the cross-sectional area of connecting air supply pipe, in m²;
D_{haV}	is the hydraulic diameter of the outside of the flue duct of the connecting flue pipe, in m;
U_{iBV}	is the circumference of the inside of connecting air supply pipe, in m;
U_{aV}	is the circumference of the outside of the flue duct of the connecting flue pipe, in m;
$Nu_{BV,j}$	is the Nusselt number for a connecting air supply pipe segment *j*;
$\psi_{BV,j}$	is the higher of the value of the coefficient of friction of the inside of the air supply duct and the outside of the flue duct of the connecting flue pipe segment *j*;
$\psi_{smoothBV,j}$	is the coefficient of friction of the connecting air supply pipe segment *j* for hydraulically smooth flow;
$Re_{BV,j}$	is the Reynolds number of the air supply in connecting air supply pipe segment *j*;
$Pr_{BV,j}$	is the Prandtl number of the supply air in connecting air supply pipe segment *j*;
L_{totBV}	is the total length of the connecting air supply pipe from the supply air outlet of the air supply duct to the supply air inlet into the heating appliance, in m;
$w_{mBV,j}$	is the mean velocity of the supply air in the connecting air supply pipe segment *j* (see 7.9.2), in m/s;
$\rho_{mBV,j}$	is the mean density of the supply air in the connecting air supply pipe segment *j*, in kg/m³;
$\eta_{BV,j}$	is the dynamic viscosity of the supply air in the connecting air supply pipe segment *j*, N·s/m².

7.8.2.5.2 Coefficient of heat transmissions between the supply air and the ambient air for concentric connection pipes ($k_{BV,j}$)

The coefficient of heat transmission between the supply air and the ambient air for concentric connection pipes $k_{BV,j}$ shall be calculated using the following formula:

$$k_{BV,j} = \frac{1}{\dfrac{1}{\alpha_{iBV,j}} + \left(\dfrac{1}{\Lambda}\right)_{BV} + \dfrac{D_{hiBV}}{D_{haBV} \cdot \alpha_{aBV,j}}} \text{, in W/(m}^2 \cdot \text{K)} \quad (96)$$

where

$k_{BV,j}$	is the coefficient of heat transmission between the supply air and the ambient air for the connecting flue pipe segment *j*, in W/(m²·K);
$\alpha_{iBV,j}$	is the coefficient of heat transfer between the supply air and the inner surface of the air supply duct of the connecting flue pipe segment *j*, in W/(m² · K);
$\left(\dfrac{1}{\Lambda}\right)_{BV}$	is the thermal resistance of the connecting air supply pipe, in (m² · K)/W;
D_{hiBV}	is the hydraulic diameter of the inside of the connecting air supply pipe, in m;
D_{haBV}	is the hydraulic diameter of the outside of the connecting air supply pipe, in m;

$\alpha_{aBV,j}$ is the coefficient of heat transfer between the outside of the connecting air supply pipe segment *j* and the ambient air, in W/(m² · K).

For the calculation of $\alpha_{iVB,j}$ the following formulas shall be used:

$$\alpha_{iBV,j} = \frac{\lambda_{BV,j} \cdot Nu_{iBV,j}}{D_{hBV}} \text{, in W/(m}^2 \cdot \text{K)} \tag{97}$$

with

$$Nu_{iBV,j} = \left[1 - 0{,}14 \cdot \left(\frac{D_{haV}}{D_{hiBV}}\right)^{0,6}\right] \cdot Nu_{BV,j} \tag{98}$$

D_{hBV} according to Formula (92) and $Nu_{BV,j}$ according to Formula (94).

where

$\lambda_{BV,j}$ is the thermal conductivity of the supply air in the connecting air supply pipe segment *j*, in W/(m² · K);

$Nu_{BV,j}$ is the Nusselt number for a reference pipe flow for connecting air supply pipe segment *j*;

$Nu_{iBV,j}$ is the Nusselt number of the inside of the connecting air supply pipe segment *j*;

D_{hBV} is the hydraulic diameter of the connecting air supply pipe, in m;

D_{hiBV} is the hydraulic diameter of the inside of the connecting air supply pipe, in m;

D_{haV} is the hydraulic diameter of the outside of the flue duct of the connecting flue pipe, in m.

7.8.2.5.3 Coefficient of heat transmissions between the flue and the air supply passage for concentric ducts ($k_{,j}$)

For the calculation of the coefficient of heat transmission between the flue and the air supply passage for concentric ducts $k_{,j}$ (see Figure 1) the following formula shall be used:

$$k_{,j} = \frac{1}{\frac{1}{\alpha_{i,j}} + \left(\frac{1}{\Lambda}\right) + \frac{D_h}{D_{ha} \cdot \alpha_{a,j} \cdot S_{rad}}} \text{, in W/(m}^2 \cdot \text{K)} \tag{99}$$

where

$k_{,j}$ is the coefficient of heat transmission between the flue and the air supply passage of the chimney segment *j*, in W/(m² · K);

$\alpha_{i,j}$ is the coefficient of heat transfer between the flue gas and the inner surface of the flue duct of the chimney segment *j*, in W/(m² · K);

$\alpha_{a,j}$ is the coefficient of heat transfer between the supply air and the outer surface of the flue duct of the chimney segment *j*, in W/(m² · K);

D_h is the hydraulic diameter of the flue, in m;

D_{ha} is the hydraulic diameter of the outside of the flue duct, in m;

$\left(\frac{1}{\Lambda}\right)$ is the thermal resistance of the flue duct, in W/(m² · K);

S_{rad} is the correction factor for radiation from the outer surface of the flue duct to the inner surface of the air supply duct.

In order to account for the effects of radiation from the outer surface of the flue duct to the inner surface of the air supply duct the calculation of the coefficient of heat transmission k_j includes a correction factor for radiation S_{rad}, for which the value 2 shall be taken.

For chimney segments in which the inner wall temperature of the flue duct is always lower than the condensing temperature of the flue gas the value S_{rad} = 1 should be taken.

The coefficient of heat transfer in the chimney segment $\alpha_{i,j}$ shall be calculated using the following formula:

$$\alpha_{i,j} = \frac{\lambda_{A,j} \cdot Nu_{,j}}{D_h}, \text{ in W/(m}^2 \cdot \text{K)} \tag{100}$$

where

D_h is the internal hydraulic diameter of the flue, in m;

$Nu_{,j}$ is the Nusselt number of the flue in the chimney segment *j*;

$\lambda_{A,j}$ is the coefficient of thermal conductivity of the flue gas in the chimney segment *j*, in W/(m · K).

The coefficient of thermal conductivity of the flue gas $\lambda_{A,j}$ shall be calculated depending on the mean flue gas temperature using the formula in Tables B.1 and B.8.

The mean Nusselt number $Nu_{,j}$ over the height of the chimney shall be calculated using the following formula:

$$Nu_{,j} = \left(\frac{\psi_{,j}}{\psi_{smooth,j}}\right)^{0,67} \cdot 0,0214 \cdot (Re_{,j}^{0,8} - 100) \cdot Pr_{,j}^{0,4} \cdot \left[1 + \left(\frac{D_h}{L_{tot}}\right)^{0,67}\right] \tag{101}$$

where

D_h is the internal hydraulic diameter of the flue, in m;

L_{tot} is the total length from flue gas inlet into the chimney to the chimney outlet, in m;

$Pr_{,j}$ is the Prandtl number of the flue gas in chimney segment *j*;

$Re_{,j}$ is the Reynolds number of the flue gas in chimney segment *j*;

$\psi_{,j}$ is the coefficient of the flow resistance due to friction for hydraulically rough flow of the chimney segment *j* (see 5.10.3.3);

$\psi_{smooth,j}$ is the coefficient of the flow resistance due to friction for hydraulically smooth flow of the chimney segment *j* (see 5.10.3.3 for r = 0).

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

For mean flue gas velocity $w_{m,j}$ < 0,5 m/s, take Nusselt number appropriate to $w_{m,j}$ = 0,5 m/s

For Reynolds numbers below 2 300, take Nusselt number appropriate to $Re_{,j}$ = 2 300.

The Prandtl number $Pr_{,j}$ shall be calculated using the following formula:

$$Pr_{,j} = \frac{\eta_{A,j} \cdot c_{p,j}}{\lambda_{A,j}} \tag{102}$$

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

$$Re_{,j} = \frac{w_{m,j} \cdot D_h \cdot \rho_{m,j}}{\eta_{A,j}} \tag{103}$$

where

$c_{p,j}$ is the specific heat capacity of the flue gas in the chimney segment *j*, in J/(kg · K);

D_h is the internal hydraulic diameter of the flue, in m;

$w_{m,j}$ is the mean flue gas velocity in the chimney segment *j* (see 5.9), in m/s;

$\eta_{A,j}$ is the dynamic viscosity of the flue gas in the chimney segment *j*, in N·s/m^2;

$\lambda_{A,j}$ is the coefficient of thermal conductivity of the flue gas in the chimney segment *j*, in W/(m · K);

$\rho_{m,j}$ is the mean density of the flue gas in the chimney segment *j* (see 5.9), in kg/m^3.

The dynamic viscosity $\eta_{A,j}$ shall be calculated dependent on the flue gas temperature using Formula (B.10) in Table B.1.

The internal coefficient of heat transfer $\alpha_{i,j}$ can also be calculated on wet designated chimneys as indicated, if the heat of condensation is not taken into account.

For the calculation of the coefficient of heat transfer between the supply air and the outer surface of the flue duct of the chimney segment *j* $\alpha_{a,j}$ the following formula shall be used:

$$\alpha_{a,j} = \frac{\lambda_{B,j} \cdot Nu_{a,j}}{D_{hB}}, \text{ in W/(m}^2 \cdot \text{K)} \tag{104}$$

with

$$D_{hB} = \frac{4 \cdot A_B}{U_a + U_{iB}}, \text{ in m} \tag{105}$$

$$Nu_{a,j} = 0,86 \cdot \left(\frac{D_{hB}}{D_{ha}}\right)^{0,16} \cdot Nu_{B,j}, \tag{106}$$

and

$$Nu_{B,j} = \left(\frac{\psi_{B,j}}{\psi_{smoothB,j}}\right)^{0,67} \cdot 0,0214 \cdot \left(Re_{B,j}^{\ 0,8} - 100\right) \cdot Pr_{B,j}^{\ 0,4} \cdot \left(1 + \frac{D_{hB}}{L_{Btot}}\right)^{0,67} \tag{107}$$

with

$$Re_{B,j} = \frac{w_{mB,j} \cdot D_{hB} \cdot \rho_{mB,j}}{\eta_{B,j}} \tag{108}$$

where

$\alpha_{a,j}$	is the coefficient of heat transfer between the supply air and the outer surface of the flue duct of the chimney segment *j*, W/(m^2 · K);
$\lambda_{B,j}$	is the thermal conductivity of the supply air in the chimney segment *j,* W/(m · K);
$Nu_{a,j}$	is the Nusselt number for the outside of the flue duct of the chimney segment *j*;
D_{hB}	is the hydraulic diameter of the air supply passage, in m;
A_B	is the cross-sectional area of the air supply duct, in m^2;
U_{iB}	is the circumference of the inside of the air supply duct, in m;
U_a	is the circumference of the outside of the flue duct, in m;
D_{ha}	is the hydraulic diameter of the outside of the flue duct, in m;
$Nu_{B,j}$	is the Nusselt number for a reference pipe flow;
$\psi_{B,j}$	is the higher of the value of the coefficient of friction of the inside of the air supply duct and the outside of the flue duct segment *j*;
$\psi_{smoothB,j}$	is the coefficient of friction of the air supply for hydraulically smooth flow of the air supply duct segment *j*;
$Re_{B,j}$	is the Reynolds number of the air supply in air supply duct segment *j*;
$Pr_{B,j}$	is the Prandtl number of the supply air in air supply duct segment *j*;
L_{Btot}	is the total length of the air supply duct from the supply air inlet at the outside atmosphere to the supply air inlet of the connecting air supply pipe, in m;
$w_{mB,j}$	is the average velocity of the supply air in air supply duct segment *j,* in m/s;
$\rho_{mB,j}$	is the density of the supply air averaged over the length of the air supply duct segment *j,* in kg/m^3;
$\eta_{B,j}$	is the dynamic viscosity of the supply air in air supply duct segment *j*, in m^2 · s.

For mean flue gas velocity $w_{mB,j}$ < 0,5 m/s, take Nusselt number appropriate to $w_{mB,j}$ = 0,5 m/s.

For Reynolds numbers below 2 300, take Nusselt number appropriate to $Re_{B,j}$ = 2 300.

7.8.2.5.4 Coefficient of heat transmissions between the supply air and the ambient air for concentric ducts ($k_{B,j}$)

The coefficient of heat transmission between the supply air and the ambient air $k_{B,j}$ shall be calculated using the following formula in case of concentric ducts:

$$k_{B,j} = \frac{1}{\frac{1}{\alpha_{iB,j}} + \left(\frac{1}{\Lambda}\right)_B + \frac{D_{hiB}}{D_{haB} \cdot \alpha_{aB,j}}}, \text{ in W/(m}^2 \cdot \text{K)} \qquad (109)$$

where

$k_{B,j}$	is the coefficient of heat transmission between the supply air and the ambient air of chimney segment j, in W/(m^2·K);
$\alpha_{iB,j}$	is the coefficient of heat transfer between the supply air and the inner surface of the air supply duct of chimney segment j, in W/(m^2·K);
$\left(\frac{1}{\Lambda}\right)_B$	is the thermal resistance of the air supply duct, in W/(m^2 · K);

D_{haB} is the hydraulic diameter of the outside of the air supply duct, in m;

D_{hiB} is the hydraulic diameter of the inside of the air supply duct, in m;

$\alpha_{aB,j}$ is the coefficient of heat transfer between the outside of the air supply duct and the ambient air in W/(m²·K).

For the calculation of $\alpha_{iB,j}$ the following formula shall be used:

$$\alpha_{iB,j} = \frac{\lambda_{B,j} \cdot Nu_{iB,j}}{D_{hB}} \text{, in W/(m}^2 \cdot \text{K)} \tag{110}$$

with

$$Nu_{iB,j} = \left[1 - 0{,}14 \cdot \left(\frac{D_{ha}}{D_{hiB}}\right)^{0{,}6}\right] \cdot Nu_{B,j}\text{,} \tag{111}$$

and D_{hB} according to Formula (105) and $Nu_{B,j}$ according to Formula (107).

where

$\lambda_{B,j}$ is the thermal conductivity of the supply air in of the chimney segment *j*, in W/(m · K);

$Nu_{iB,j}$ is the Nusselt number for the inside of the air supply duct segment *j* ;

$Nu_{B,j}$ is the Nusselt number for a reference pipe flow;

D_{hB} is the hydraulic diameter of the air supply passage, in m;

D_{hiB} is the hydraulic diameter of the inside of the air supply duct, in m;

D_{ha} is the hydraulic diameter of the outside of the flue duct of the chimney, in m.

7.8.3 Concentric ducts – calculation based on calculated heat radiation

7.8.3.1 General

The calculation of the heat transfer based on a standardised correction factor for the radiation between the outer surface of the flue liner and the inner surface of the air supply duct can only consider the radiation for a limited temperature range and also for a limited range of flue gas velocities. Especially when the calculation is to be done not only for the determination of the cross section of the chimney but also for the determination of the heat transfer to the supply air or to adjacent rooms, it is necessary to do the calculation with a higher degree of accuracy. In this case it is necessary to calculate the temperatures in the chimney and in the air supply duct with a calculation method which considers the heat transfer by radiation in a more precise way.

The following clause gives a method for this calculation. In principle it is possible to solve the system of formulas, which describe the heat transfer process in the chimney with consideration of the radiation in the same way as it is given in 7.8.2 with solutions for the flue gas temperature at the end of a chimney segment $T_{o,j}$ and at the end of the air supply duct segment $T_{oB,j}$. Because the system of formulas in this case is far more complex than in the case of a calculation based on a standardised correction factor for the radiation, the results are far more complex than in 7.8.2. It is considered not practicable to give the solution of the system of formulas in this document, but only to give the system of formulas and to allow the user to solve this system of formulas with commonly used mathematical methods. Normally the system of formulas will be solved to get the temperatures of the flue gas and of the supply air as in 7.8.2. It is also possible to get the solutions for the different heat transfer processes, especially for the heat transfer from the chimney to the supply air and also from the air supply duct to the surrounding rooms.

7.8.3.2 System of formulas

For the calculation of the flue gas temperatures of the chimney segments and of the segments of the connecting flue pipe and for the corresponding supply air temperatures solve the following system of 15 formulas, with the unknown values $q_{C,j}$, $q_{a,j}$, $q_{iB,j}$, $q_{B,j}$, $q_{u,j}$, $q_{rad,j}$, $T_{m,j}$, $T_{o,j,}$ $T_{ma,j}$, $T_{mB,j}$, $T_{eB,j}$ (or $T_{oB,j}$ dependent on the kind of iteration), $T_{miB,j}$, $k^{*}_{,j}$, $k^{*}_{iB,j}$, $\alpha_{Rad,j}$

The heat transfer from the flue to the outer surface of the chimney $q_{C,j}$ shall be calculated using to the following formula:

$$q_{C,j} = \frac{U \cdot L}{\left[\frac{1}{\alpha_{i,j}} + \left(\frac{1}{\Lambda}\right)\right] \cdot Nseg} \cdot \left(T_{m,j} - T_{ma,j}\right), \text{ in W} \tag{112}$$

where

U is the internal circumference of the chimney, in m;

L is the length of the chimney, in m;

$T_{m,j}$ is the mean temperature of the flue gas in segment *j*, in K;

$T_{ma,j}$ is the mean temperature at the outer wall of the chimney segment *j*, in K;

$\alpha_{i,j}$ is the internal coefficient of heat transfer of the flue of segment *j* (see Formula (100)), in W/(m^2 · K);

$\left(\frac{1}{\Lambda}\right)$ is the thermal resistance of the chimney, in m^2·K/W;

$Nseg$ is the number of chimney segments used in the calculation.

$$q_{C,j} = \dot{m} \cdot c_{p,j} \cdot \left(T_{e,j} - T_{o,j}\right), \text{ in W} \tag{113}$$

where

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

$c_{p,j}$ is the specific heat capacity of the flue gas in segment *j*, in J/(kg · K);

$T_{e,j}$ is the flue gas temperature at the inlet of chimney segment *j*, in K;

$T_{o,j}$ is the flue gas temperature at the outlet of chimney segment *j*, in K.

The heat transfer from the outer wall of the chimney to the supply air $q_{a,j}$ shall be calculated using to the following formula:

$$q_{a,j} = \frac{U_a \cdot L \cdot \alpha_{a,j}}{Nseg} \cdot \left(T_{ma,j} - T_{mB,j}\right), \text{ in W} \tag{114}$$

where

U_a is the outside circumference of the chimney, in m;

L is the length of the chimney, in m;

$\alpha_{a,j}$ is the internal coefficient of heat transfer of the supply air of segment *j* (on the chimney side), in W/(m^2 · K);

$T_{ma,j}$ is the mean temperature of the outer wall of the chimney in segment *j*, in K;

$T_{mB,j}$ is the mean temperature of the supply air in segment *j*, in K;

$Nseg$ is the number of chimney segments used in the calculation.

The heat transfer from the supply air to the inner wall of the air supply duct $q_{iB,j}$ shall be calculated using to the following formula:

$$q_{iB,j} = \frac{U_{iB} \cdot L \cdot \alpha_{iB,j}}{Nseg} \cdot \left(T_{mB,j} - T_{miB,j}\right) \text{ in W} \tag{115}$$

where

U_{iB} is the inner circumference of the air supply duct, in m;

L is the length of the chimney, in m;

$\alpha_{iB,j}$ is the internal coefficient of heat transfer of the supply air of segment *j* (on the air supply duct side), in W/(m²·K);

$T_{mB,j}$ is the mean temperature of the supply air of segment *j*, in K;

$T_{miB,j}$ is the mean temperature of the inner wall of the air supply duct segment *j*, in K;

$Nseg$ is the number of chimney segments used in the calculation.

The heat transfer to the supply air in segment *j* $q_{B,j}$ shall be calculated using to the following formula:

$$q_{B,j} = \dot{m}_B \cdot c_{pB,j} \cdot \left(T_{oB,j} - T_{eB,j}\right), \text{ in W} \tag{116}$$

where

$\dot{m}_B$ is the supply air mass flow, in kg/s;

$c_{pB,j}$ is the specific heat capacity of the supply air in segment *j*, in J/(kg · K);

$T_{oB,j}$ is the temperature at the outlet of segment j of the supply air, in K;

$T_{eB,j}$ is the temperature at the inlet of segment j of the supply air, in K.

The heat transfer from the inner wall of the air supply duct to the ambient air $q_{u,j}$ shall be calculated using to the following formula:

$$q_{u,j} = \frac{U_{iB} \cdot L}{\left[\left(\frac{1}{\Lambda}\right)_B + \frac{D_{hiB}}{D_{haB} \cdot \alpha_{aB,j}}\right] \cdot Nseg} \cdot \left(T_{miB,j} - T_{u,j}\right), \text{ in W} \tag{117}$$

where

U_{iB} is the inner circumference of the air supply duct, in m;

L is the length of the chimney, in m;

$T_{miB,j}$ is the mean temperature of the inner wall of the air supply duct segment j, in K;

$T_{u,j}$ is the ambient air temperature at segment *j*, in K;

$\left(\frac{1}{\Lambda}\right)_B$	is the thermal resistance of the air supply duct, in (m^2 · K)/W;
D_{hiB}	is the hydraulic diameter of the inner wall of the air supply duct, in m;
D_{haB}	is the hydraulic diameter of the outer wall of the air supply duct, in m;
$\alpha_{aB,j}$	is the outer coefficient of heat transfer of the air supply duct segment *j*, in W/(m^2 · K);
$Nseg$	is the number of chimney segments used in the calculation.

The heat transfer based on radiation q_{rad} shall be calculated using to the following formula:

$$q_{Rad,j} = \frac{U_a \cdot L \cdot \sigma_{Rad,j}}{\left[\frac{1}{\varepsilon_a} + \frac{D_{ha}}{D_{hiB}} \cdot \left(\frac{1}{\varepsilon_{iB}} - 1\right)\right] \cdot Nseg} \cdot \left(T_{ma,j}^4 - T_{miB,j}^4\right) \text{, in W} \quad (118)$$

where

U_a	is the outside circumference of the chimney, in m;
L	is the length of the chimney, in m;
$T_{ma,j}$	is the mean temperature at the outer wall of the chimney of segment *j*, in K;
$T_{miB,j}$	is the mean temperature of the inner wall of the air supply duct of segment *j*, in K;
σ_{Rad}	is the black body radiation number σ_{Rad} = 5,67·10^{-8}, in W/(m^2·K^4);
ε_a	is the proportion of black body radiation emitted by the outer surface of the chimney, values – see Table B.5;
ε_{iB}	is the proportion of black body radiation emitted by the inner surface of the air supply duct, values – see Table B.5;
D_{ha}	is the hydraulic diameter of the outer wall of the chimney, in m;
D_{hiB}	is the hydraulic diameter of the inner wall of the air supply duct, in m;
$Nseg$	is the number of chimney segments used in the calculation.

The heat balance shall be calculated using to the following formulas:

Heat balance between the flue, the supply air and the ambient air

$$q_{C,j} = q_{u,j} + q_{B,j} \text{, in W} \quad (119)$$

Heat balance at the outer wall of the chimney

$$q_{C,j} = q_{a,j} + q_{Rad,j} \text{, in W} \quad (120)$$

Heat balance at the inner wall of the air supply duct

$$q_{u,j} = q_{iB,j} + q_{Rad,j} \text{, in W} \quad (121)$$

For segments with short length the following relations for the mean temperatures can be used:

$$T_{m,j} = \frac{T_{e,j} + T_{o,j}}{2} \text{, in K} \quad (122)$$

$$T_{\mathrm{mB},j} = \frac{T_{\mathrm{eB},j} + T_{\mathrm{oB},j}}{2} \text{, in K} \tag{123}$$

7.8.3.3 Coefficient of cooling

For the calculation of the coefficient of cooling see 7.8.2.4.

7.8.3.4 Coefficient of heat transmission

For the calculation of the coefficient of heat transmission see 7.8.2.5.

7.8.4 Mean temperatures for pressure calculation

The mean temperature of the flue gas averaged over the length of the chimney T_{m} shall be calculated using the following formula:

$$T_{\mathrm{m}} = \frac{Nseg}{\sum_{j=1}^{Nseg} \frac{1}{T_{\mathrm{m},j}}} \text{, in K} \tag{124}$$

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

$$T_{\mathrm{mV}} = \frac{NsegV}{\sum_{j=1}^{NsegV} \frac{1}{T_{\mathrm{mV},j}}} \text{, in K} \tag{125}$$

The mean temperature of the supply air averaged over the length of the air supply duct T_{mB} shall be calculated using the following formula:

$$T_{\mathrm{mB}} = \frac{Nseg}{\sum_{j=1}^{Nseg} \frac{1}{T_{\mathrm{mB},j}}} \text{, in K} \tag{126}$$

The mean temperature of the supply air averaged over the length of the connecting air supply pipe T_{mBV} shall be calculated using the following formula:

$$T_{\mathrm{mBV}} = \frac{NsegV}{\sum_{j=1}^{NsegV} \frac{1}{T_{\mathrm{mBV},j}}} \text{, in K} \tag{127}$$

where

T_{m} is the mean temperature of the flue gas averaged over the length of the chimney, in K;

$T_{\mathrm{m},j}$ is the mean temperature of the flue gas averaged over the length of the chimney segment *j*, in K;

T_{mV} is the mean temperature of the flue gas averaged over the length of the connecting flue pipe, in K;

$T_{\mathrm{mV},j}$ is the mean temperature of the flue gas averaged over the length of the connecting flue pipe segment *j*, in K;

T_{mB} is the mean temperature of the supply air averaged over the length of the air supply duct, in K;

$T_{mB,j}$ is the mean temperature of the supply air averaged over the length of the air supply duct segment *j*, in K;

T_{mBV} is the mean temperature of the supply air averaged over the length of the connecting air supply pipe, in K;

$T_{mBV,j}$ is the mean temperature of the supply air averaged over the length of the connecting air supply pipe segment *j*, in K;

$Nseg$ is the number of chimney segments;

$NsegV$ is the number of connecting flue pipe segments.

7.9 Determination of densities and velocities

7.9.1 Density and velocity of the flue gas

The density and velocity of the flue gas averaged over the length of the chimney ρ_m and w_m and of the connecting flue pipe ρ_{mV} and w_{mV} shall be calculated according to 5.9.

7.9.2 Density and velocity of the supply air

The density of the supply air averaged over the length of the connection pipe ρ_{mBV} shall be calculated with the following formula:

$$\rho_{mBV} = \frac{p_L}{R_L \cdot T_{mBV}} \text{, in kg/m}^3 \qquad (128)$$

where

ρ_{mBV} is the density of the supply air averaged over the length of the connecting air supply pipe, in kg/m³;

p_L is the pressure of the external air, in Pa;

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

T_{mBV} is the mean temperature of the supply air averaged over the length of the connecting air supply pipe, in K.

The velocity of the supply air averaged over the length of the connecting air supply pipe w_{mBV} shall be calculated using the following formula:

$$w_{mBV} = \frac{\dot{m}_B}{A_{BV} \cdot \rho_{mBV}} \text{, in m/s} \qquad (129)$$

where

w_{mBV} is the velocity of the supply air averaged over the length of the connecting air supply pipe, in m/s;

$\dot{m}_B$ is the mass flow of the supply air, in kg/s;

A_{BV} is the cross-sectional area of the connecting air supply pipe, in m²;

ρ_{mBV} is the density of the supply air averaged over the length of the connecting air supply pipe, in kg/m³.

The density of the supply air averaged over the length of the air supply duct ρ_{mB} shall be calculated with the following formula:

$$\rho_{mB} = \frac{p_L}{R_L \cdot T_{mB}}, \text{ in kg/m}^3 \qquad (130)$$

where

ρ_{mB} is the density of the supply air averaged over the length of the air supply duct, in kg/m³;

p_L is the pressure of the external air, in Pa;

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

T_{mB} is the mean temperature of the supply air averaged over the length of the air supply duct, in K.

The velocity of the supply air averaged over the length of the air supply duct w_{mB} shall be calculated using the following formula:

$$w_{mB} = \frac{\dot{m}_B}{A_B \cdot \rho_{mB}}, \text{ in m/s} \qquad (131)$$

where

w_{mB} is the velocity of the supply air averaged over the length of the air supply duct, in m/s;

$\dot{m}_B$ is the mass flow of the supply air, in kg/s;

A_B is the cross-sectional area of the air supply duct, in m²;

ρ_{mB} is the density of the supply air averaged over the length of the air supply duct, in kg/m³.

7.10 Determination of pressures

7.10.1 Pressure at the flue gas inlet into the chimney

For the calculation of the pressure at the flue gas inlet into the chimney see 5.10.1 and 7.2.

7.10.2 Theoretical draught due to chimney effect in the chimney segment (P_H)

For the calculation of the theoretical draught due to chimney effect in the chimney segment (P_H) see 5.10.2.

7.10.3 Pressure resistance in the chimney segment (P_R)

For the calculation of the pressure resistance in the chimney segment (P_R) see 5.10.3.

7.10.4 Wind velocity pressure (P_L)

The inlet/outlet construction is assumed to be designed such that wind effects are minimized. Consequently $P_L = 0$.

7.11 Minimum draught required at the flue gas inlet into the chimney and maximum allowed draught (P_{Ze} and P_{Zemax}) and maximum and minimum differential pressure at the flue gas inlet into the chimney (P_{ZOe} and P_{ZOemin})

7.11.1 General

For the general purpose see the text in 5.11.1.

7.11.2 Minimum and maximum draught for the heating appliance (P_W and P_{Wmax}) and maximum and minimum differential pressure of the heating appliance (P_{WO} and P_{WOmin})

The minimum and maximum draught for the heating appliance (P_W and P_{Wmax}) or the maximum and minimum differential pressure of the heating appliance (P_{WO} and P_{WOmin}) shall be obtained in accordance with 5.5.4, 5.5.5 or 5.5.6.

7.11.3 Effective pressure resistance of the connection pipe (P_{FV})

For the calculation of the effective pressure resistance of the connection pipe (P_{FV}) see 5.11.3.

7.11.4 Pressure resistance of the air supply

7.11.4.1 Draught due to chimney effect of the supply air duct (P_{HB})

The draught due to the chimney effect of the air supply duct shall be calculated using the following formula:

$$P_{HB} = H_B \cdot g \cdot (\rho_L - \rho_{mB}) \text{, in Pa} \tag{132}$$

where

P_{HB} is the draught due to chimney effect in the air supply duct, in Pa;

H_B is the height of the air supply duct, in m;

g is the acceleration due to gravity, shall be taken as 9,81, in m/s^2;

ρ_L is the density of ambient air, in kg/m^3;

ρ_{mB} is the density of supply air averaged over the length of the air supply duct, in kg/m^3.

NOTE Experience shows that a limit should be applied to the minimum cross sectional area of the air supply duct of concentric air flue systems. A factor of 1,5 times the flue cross sectional area is advised.

7.11.4.2 Draught due to chimney effect of the connecting air supply pipe (P_{HBV})

The draught due to chimney effect of the connecting air supply pipe shall be calculated using the following formula:

$$P_{HBV} = H_{BV} \cdot g \cdot (\rho_L - \rho_{mBV}) \text{, in Pa} \tag{133}$$

where

P_{HBV} is the draught due to chimney effect in the connecting air supply pipe, in Pa;

H_{BV} is the height of the connecting air supply pipe, in m;

g is the acceleration due to gravity, shall be taken as 9,81, in m/s^2;

ρ_L is the density of the ambient air, in kg/m^3;

ρ_{mBV} is the density of supply air averaged over the length of the connecting air supply pipe, in kg/m^3.

7.11.4.3 Pressure resistance of the air supply duct (P_{RB})

The pressure resistance of the air supply duct P_{RB} shall be calculated using the following formula:

$$P_{RB} = S_{EB} \cdot \left(\psi_B \cdot \frac{L}{D_{hB}} + \sum \zeta_B \right) \cdot \frac{\rho_{mB}}{2} \cdot w_{mB}^2 + S_{EGB} \cdot P_{GB} \text{ , in Pa} \quad (134)$$

where

P_{RB} is the pressure resistance of the air supply duct of the chimney, in Pa;

P_{GB} is the pressure change due to change in velocity of the flow in the air supply duct of the chimney, in Pa;

ψ_B is the coefficient of friction of the air supply duct of the chimney;

L is the length of the chimney, in m;

D_{hB} is the hydraulic diameter of the air supply duct of the chimney, in m;

$\Sigma\zeta_B$ is the sum of coefficients of flow resistance in the air supply duct of the chimney;

ρ_{mB} is the density of the supply air averaged over the length of the chimney, in kg/m^3;

w_{mB} velocity of the supply air averaged over the length of in the air supply duct, in m/s;

S_{EB} is the flow safety coefficient for the air supply duct;

S_{EGB} is the flow safety coefficient for the pressure resistance due to change of flow velocity in the air supply duct ($S_{EGB} = S_{EB}$ for $P_{GB} \geq 0$ and S_{EGB} = 1,0 for $P_{GB} < 0$).

The coefficient of flow resistance due to friction of the air supply duct ψ_B for different roughness shall be calculated using the following formula:

$$\frac{1}{\sqrt{\psi_B}} = -2 \cdot \lg \left(\frac{2{,}51}{Re_B \cdot \sqrt{\psi_B}} + \frac{r_B}{3{,}71 \cdot D_{hB}} \right) \quad (135)$$

where

D_{hB} is the hydraulic diameter of the air supply duct, in m;

r_B is the mean value for roughness of the inner wall of the air supply duct, in m;

Re_B is the Reynolds number in the air supply duct (see 7.8.2.5.3);

ψ_B is the coefficient of flow resistance due to friction of the air supply duct.

For Reynolds numbers below 2 300 take the coefficient appropriate to the Reynolds number equal to 2 300.

The mean values for roughness shall be given by the manufacturer. In the absence of values from the manufacturer typical mean roughness values for various materials are given in Table B.4.

The pressure change due to change of velocity of the flow P_{GB} in the air supply duct shall be calculated with the following formula:

$$P_{GB} = \frac{\rho_{mB}}{2} \cdot w_{mB}^2 \text{, in Pa} \quad (136)$$

where

ρ_{mB} is the density of the supply air averaged over the length of the air supply duct, in kg/m^3;

P_{GB} is the pressure change due to change in velocity of the flow in the air supply duct, in Pa;

w_{mB} is the velocity of the supply air averaged over the length of in the air supply duct, in m/s.

7.11.4.4 Pressure resistance of the connecting air supply pipe (P_{RBV})

The pressure resistance of the connecting air supply pipe P_{RBV} shall be calculated with the following formula:

$$P_{RBV} = S_{EB} \cdot \left(\psi_{BV} \cdot \frac{L_{BV}}{D_{hBV}} + \sum \zeta_{BV} \right) \cdot \frac{\rho_{mBV}}{2} \cdot w_{mBV}^2 + S_{EGBV} \cdot P_{GBV} \text{, in Pa} \quad (137)$$

where

P_{RBV} is the pressure resistance of the connecting air supply pipe, in Pa;

P_{GBV} is the pressure change due to change in velocity of the flow in the air supply connecting air supply pipe, in Pa;

ψ_{BV} is the coefficient of friction of the connecting air supply pipe;

L_{BV} is the length of the connecting air supply pipe, in m;

D_{hBV} is the hydraulic diameter of the air supply of the connecting air supply pipe, in m;

$\Sigma\zeta_{BV}$ is the sum of coefficients of flow resistance in the connecting air supply pipe;

ρ_{mBV} is the density of the supply air averaged over the length of the connecting air supply pipe, in kg/m^3;

w_{mBV} is the velocity of the supply air averaged over the length of in the connecting air supply pipe, in m/s;

S_{EB} is the flow safety coefficient for the connecting air supply pipe;

S_{EGBV} is the flow safety coefficient for the pressure resistance due to change of flow velocity in the connecting air supply pipe ($S_{EGBV} = S_{EB}$ for $P_{GBV} \geq 0$ and $S_{EGBV} = 1{,}0$ for $P_{GBV} < 0$).

The coefficient of flow resistance due to friction of the flue ψ_{BV} for different roughness shall be calculated using the following formula:

$$\frac{1}{\sqrt{\psi_{BV}}} = -2 \cdot \lg \left(\frac{2{,}51}{Re_{BV} \cdot \sqrt{\psi_{BV}}} + \frac{r_{BV}}{3{,}71 \cdot D_{hBV}} \right) \quad (138)$$

where

D_{hBV} is the hydraulic diameter of the connecting air supply pipe, in m;

r_{BV} is the mean value for roughness of the inner wall of the connecting air supply pipe, in m;

Re_{BV} is the Reynolds number in the connecting air supply pipe (see 7.8.2.5.3);

ψ_{BV} is the coefficient of flow resistance due to friction of the connecting air supply pipe.

For Reynolds numbers below 2 300 take the coefficient appropriate to the Reynolds number equal to 2 300.

The mean values for roughness shall be given by the manufacturer. In the absence of values from the manufacturer typical mean roughness values for various materials are given in Table B.4.

The change of pressure due to change of the flow velocity in the air supply duct of the connecting air supply pipe P_{GBV} shall be calculated with the following formula:

$$P_{GBV} = \frac{\rho_{mBV}}{2} \cdot w_{mBV}^2 - \frac{\rho_{mB}}{2} \cdot w_{mB}^2 \text{, in Pa} \quad (139)$$

where

P_{GBV} is the pressure change due to change in velocity of the flow in the connecting air supply pipe, in Pa;

ρ_{mBV} is the density of the supply air averaged over the length of the connecting air supply pipe, in kg/m^3;

ρ_{mB} is the density of the supply air averaged over the length of the air supply duct, in kg/m^3;

w_{mBV} is the velocity of the supply air averaged over the length of in the connecting air supply pipe, in m/s;

w_{mB} is the velocity of the supply air averaged over the length of in the air supply duct, in m/s.

7.12 Calculation of the inner wall temperature at the chimney outlet (T_{iob})

The inner wall temperature at the chimney outlet at temperature equilibrium T_{iob} shall be determined using the following formula:

$$T_{iob} = T_{o,Nseg} - \frac{k_{,Nseg}}{\alpha_{i,Nseg}} \cdot \left(T_{o,Nseg} - T_{uo}\right), \text{ in K} \tag{140}$$

where

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

$T_{o,Nseg}$ is the temperature of the flue gas at the end of the last chimney segment $Nseg$, in K;

$k_{,Nseg}$ is the coefficient of heat transmission between the flue and the air supply passage of the last chimney segment $Nseg$, in W/(m^2 · K);

$\alpha_{I,Nseg}$ is the coefficient of heat transfer between the flue gas and the inner surface of the flue duct of the last chimney segment $Nseg$, in W/(m^2 · K);

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

8 Consideration of the condensation heat of the flue gas water vapour

8.1 General

The preceding clause enables calculation of the parameters for a chimney operating under wet conditions without taking account of the available heat from the condensing water vapour in the flue gas. This clause describes the calculation of the available heat from condensing water vapour (latent heat of liquefaction), and the effect on the temperatures in the chimney. It is recommended to be used when the temperature requirement, see 5.3, is not fulfilled.

The effect on the pressure requirement is not dealt with in this clause.

NOTE The gas constant R considering the condensation may be determined using Annex E.

The condensation heat, which can be considered in the calculation, is very complex because the heat and mass transfer will be mostly 3-dimensional. As an example, the condensate may flow down at the inner wall of the chimney and evaporate at an area with higher temperature. The calculation method given in this document only considers the effect of the condensation of water vapour at the inner wall of the chimney, when the inner wall temperature is lower or equal to the dew point temperature of the flue gas, but allows to reduce the maximum amount of condensate by a factor f_K < 100 % in accordance with practical experience.

For the calculation with condensation a chimney shall be divided into $Nseg$ chimney segments of equal length each with a maximum length of 0,5 m. The connecting flue pipe shall also be divided into $NsegV$ connecting flue pipe segments of equal length each with a maximum length of 0,5 m, if the inner wall temperature at the outlet of the connecting flue pipe is lower than the water dew point of the flue gas.

8.2 Onset of condensation

To find the segment *NsegK* and/or *NsegKV* where condensation begins, calculate the inner wall temperature at the end of each segment *j* $T_{iob,j}$ starting with the first segment of the connecting flue pipe or chimney where condensation can occur in accordance to Clause 5 or Clause 7 until the following relationship is fulfilled:

$$T_{\text{iob},j} - T_{\text{pe},1} < 0 \text{, in K} \tag{141}$$

with

$$T_{\text{iob},j} = T_{\text{ob},j} - \frac{k_{\text{b},j}}{\alpha_{\text{i},j}} \cdot \left(T_{\text{ob},j} - T_{\text{u},j} \right) \text{, in K} \tag{142}$$

where

$T_{iob,j}$ is the inner wall temperature at the outlet of segment *j* at temperature equilibrium, in K;

$T_{pe,1}$ is the water dew point at the inlet of the first segment, in K;

$k_{b,j}$ is the coefficient of heat transmission of segment *j* at temperature equilibrium (see Clause 5 or Clause 7), in W/(m^2 · K);

$\alpha_{i,j}$ is the coefficient of heat transfer for convection of segment *j* (see Clause 5 or Clause 7), in W/(m^2 · K);

$T_{ob,j}$ is the flue gas temperature at the outlet of segment *j* at temperature equilibrium (see Clause 5 or Clause 7), in K;

$T_{u,j}$ is the ambient temperature for the area of segment *j*, in K.

NOTE It is necessary to check that the condition in Formula (141) is fulfilled, especially if there are changes in the dimensions of the flue or in the value of the thermal resistance of the connecting flue pipe and/or the chimney, in particular at the entry to the chimney.

The water dew point at the inlet of the first segment of the connecting flue pipe $T_{peV,1}$ depends on the water vapour content of the flue gas at the outlet of the appliance. For non-condensing boilers $T_{peV,1} = T_p$. For condensing boilers the value for the water vapour content of the flue gas $\sigma(H_2O)_W$ should be obtained from the appliance manufacturer. With this value the water vapour-partial pressure at the heating appliance outlet p_{DW} and the water dew point $T_{peV,1}$ can be determined using Formulas (B.6) and (B.7).

If no value is known the normal return water temperature to the boiler T_{bf} should be taken as water dew point $T_{peV,1} = T_{bf}$. The corresponding water vapour partial pressure p_{DW} can be determined with Formula (B.13).

If the flue gas mass flow at the outlet of a condensing boiler $\dot{m}_W$ has not taken account the condensation occurring in the heating appliance the flue gas mass flow can be determined with the following formula:

$$\dot{m}_{\text{W}} = \dot{m} - \Delta \dot{m}_{\text{DW}} \text{, in kg/s} \tag{143}$$

with

$$\Delta \dot{m}_{\text{DW}} = \dot{m} \cdot \frac{R}{R_{\text{D}}} \cdot \left(1 - \frac{p_{\text{D}}}{p_{\text{L}}} \right) \cdot \left(\frac{p_{\text{D}}}{p_{\text{L}} - p_{\text{D}}} - \frac{p_{\text{DW}}}{p_{\text{L}} - p_{\text{DW}}} \right) \text{, in kg/s} \tag{144}$$

where

$\dot{m}_W$ is the flue gas mass flow at the outlet of the heating appliance taking into account the change of mass flow by condensation in the appliance, in kg/s;

$\Delta\dot{m}_{DW}$	is the condensate mass flow of the heating appliance, in kg/s;
$\dot{m}$	is the flue gas mass flow before condensation, in kg/s;
R	is the gas constant of the flue gas before condensation, in J/(kg · K);
R_D	is the gas constant of water vapour and shall be taken as 496, in J/(kg · K);
p_L	is the external air pressure, in Pa;
p_D	is the water vapour partial pressure before condensation, in Pa;
p_{DW}	is the water vapour partial pressure at the heating appliance outlet, in Pa.

If $NsegKV$ = 1 the following formulas apply:

$$\dot{m}_{oV,0} = \dot{m}_W \text{, in kg/s} \tag{145}$$

$$T_{obV,0} = T_W \text{, in K} \tag{146}$$

$$T_{iobV,0} = T_W - \frac{k_{bV,1}}{\alpha_{iV,1}} \cdot \left(T_W - T_{uV,1}\right) \text{, in K} \tag{147}$$

where

$\dot{m}_{oV,0}$	is the flue gas mass flow at the inlet in the first segment, in kg/s;
$T_{obV,0}$	is the flue gas temperature at the inlet in the first segment at temperature equilibrium, in K;
$T_{iobV,0}$	is the inner wall temperature at the inlet in the first segment at temperature equilibrium, in K;
T_W	is the flue gas temperature at the outlet of the heating appliance at temperature equilibrium, in K;
$k_{bV,1}$	is the coefficient of heat transmission of the first segment at temperature equilibrium, in W/(m² · K);
$\alpha_{iV,1}$	is the coefficient of heat transfer of the first segment, in W/(m² · K);
$T_{uV,1}$	is the ambient air temperature at the first segment, in K.

The water dew point at the inlet of the first segment of the chimney $T_{pe,1}$ depends on the water vapour content of the flue gas at the outlet of the connecting flue pipe. If no condensation occurs in the connecting flue pipe $T_{pe,1} = T_{pV,1}$ can be used. Otherwise the following formula can be used:

$$\sigma(H_2O)_{V,N_{seg}V} = \frac{\frac{R}{R_D} \cdot \frac{p_D}{p_L} - \frac{\Delta\dot{m}_{DW} + \Delta\dot{m}_{DV}}{\dot{m}}}{\frac{R}{R_D} - \frac{\Delta\dot{m}_{DW} + \Delta\dot{m}_{DV}}{\dot{m}}} \cdot 100 \text{, in kg/s} \tag{148}$$

with

$$\Delta\dot{m}_{DV} = \sum_{j=NsegKV}^{NsegV} \Delta\dot{m}_{D,j} \text{, in kg/s} \tag{149}$$

where

$\sigma(H_2O)_{V,NsegV}$	is the water vapour content of the flue gas at the outlet of the connecting flue pipe, in %;
R	is the gas constant of the flue gas before condensation, in J/(kg · K);
R_D	is the gas constant of water vapour and shall be taken as 496, in J/(kg · K);
p_L	is the external air pressure, in Pa;
p_D	is the water vapour partial pressure before condensation, in Pa;
$\Delta\dot{m}_{DW}$	is the condensate mass flow of the heating appliance, in kg/s;
$\Delta\dot{m}_{DV}$	is the condensate mass flow of the connecting flue pipe, in kg/s;
$\dot{m}$	is the flue gas mass flow before condensation, in kg/s;
$NsegV$	is number of segments of the connecting flue pipe;
$NsegKV$	is number of the segment of the connecting flue pipe where the condensation begins.

With the value of the water vapour content of the flue gas at the outlet of the connecting flue pipe $\sigma(H_2O)_{V,NsegV}$ the corresponding water vapour partial pressure $p_{DV,NsegV}$ and the water dew point $T_{pe,1}$ can be determined using Formulas (B.6) and (B.7).

If $NsegK$ = 1 the following formulas apply:

$$\dot{m}_{o,0} = \dot{m}_W - \Delta\dot{m}_{DV} \text{, in kg/s} \quad (150)$$

$$T_{ob,0} = T_{eb} \text{, in K} \quad (151)$$

$$T_{iob,0} = T_{eb} - \frac{k_{b,1}}{\alpha_{i,1}} \cdot \left(T_{eb} - T_{u,1}\right) \text{, in K} \quad (152)$$

where

$\dot{m}_{o,0}$	is the flue gas mass flow at the inlet in the first segment, in kg/s;
$\Delta\dot{m}_{DV}$	is the condensate mass flow of the connecting flue pipe, in kg/s;
$T_{ob,0}$	is the flue gas temperature at the inlet in the first segment at temperature equilibrium, in K;
$T_{iob,0}$	is the inner wall temperature at the inlet in the first segment at temperature equilibrium, in K;
T_{eb}	is the flue gas temperature at the inlet in the chimney at temperature equilibrium, in K;
$k_{b,1}$	is the coefficient of heat transmission of the first segment at temperature equilibrium, in W/(m^2 · K);
$\alpha_{i,1}$	is the coefficient of heat transfer of the first segment, in W/(m^2 · K);
$T_{u,1}$	is the ambient air temperature at the first segment, in K.

8.3 Calculation of the flue gas temperature at the outlet of a chimney segment with condensation ($j \geq NsegK$)

The following formulas allow the flue gas temperature at the outlet of a chimney segment j $T_{ob,j}$ to be calculated in an iterative way.

NOTE 1 It is advised to start the iteration with a value for $T_{ob,j}$ calculated without condensation.

NOTE 2 The formulas for the chimney segment also apply for the connecting flue pipe using the appropriate values.

For the inner wall temperature at the outlet of the segment j $T_{\text{iob},j}$ the following formula applies:

$$T_{\text{iob},j} = T_{\text{ob},j} - \frac{k_{\text{obtot},j}}{\alpha_{\text{iotot},j}} \cdot \left(T_{\text{ob},j} - T_{\text{u},j}\right) \text{, in K} \tag{153}$$

where

$T_{\text{iob},j}$ is the inner wall temperature at the outlet of segment j at temperature equilibrium, in K;

$T_{\text{ob},j}$ is the flue gas temperature at the outlet of segment j at temperature equilibrium, in K;

$T_{\text{u},j}$ is the ambient temperature for the area of segment j, in K;

$k_{\text{obtot},j}$ is the total coefficient of heat transmission at the outlet of segment j at temperature equilibrium, in W/(m^2 · K);

$\alpha_{\text{iotot},j}$ is the total coefficient of heat transfer for convection and condensation at the outlet of segment j, in W/(m^2 · K).

For the total coefficient of heat transfer for convection and condensation of the segment $\alpha_{\text{itot},j}$ and the total coefficient of heat transmission $k_{\text{btot},j}$ the following formulas apply:

$$\alpha_{\text{iotot},j} = \alpha_{\text{io},j} + \alpha_{\text{ioK},j} \text{, in W/(m}^2 \cdot \text{K)} \tag{154}$$

$$k_{\text{obtot},j} = \frac{1}{\frac{1}{\alpha_{\text{iotot},j}} + \left(\frac{1}{\Lambda}\right) + \frac{D_\text{h}}{D_\text{ha} \cdot \alpha_\text{a}}} \text{, in W/(m}^2 \cdot \text{K)} \tag{155}$$

where

$\alpha_{\text{iotot},j}$ is the total coefficient of heat transfer for convection and condensation at the outlet of segment j, in W/(m^2·K);

$\alpha_{\text{io},j}$ is the coefficient of heat transfer for convection of segment j (see Clause 5 or Clause 7, calculated for $T_{\text{ob},j}$), in W/(m^2 · K);

$\alpha_{\text{ioK},j}$ is the coefficient of heat transfer by condensation at the outlet of segment j in W/(m^2 · K);

$k_{\text{obtot},j}$ is the total coefficient of heat transmission at the outlet of segment j at temperature equilibrium, in W/(m^2 · K);

$\left(\frac{1}{\Lambda}\right)$ is the thermal resistance, in m^2 · K/W;

D_h is the internal hydraulic diameter, in m;

D_ha is the external hydraulic diameter, in m;

α_a is the external coefficient of heat transfer, in W/(m^2 · K).

For the coefficient of heat transfer by condensation $\alpha_{\text{iK},j}$ the following formula applies:

$$\alpha_{\text{ioK},j} = \frac{q_{\text{K},j} \cdot Nseg}{l_{\text{c},j} \cdot U \cdot L \cdot \left(T_{\text{ob},j} - T_{\text{iob},j}\right)} \text{, in W/(m}^2 \cdot \text{K)} \tag{156}$$

with

$l_{\text{c},j}$ = 1 for j > $NsegK$ or

$NsegK$=1 and $Ti_{\text{ob},0} \leq T_{\text{pe},1}$ (157)

and

$$l_{c,j} = \frac{T_{pe,1} - T_{iob,j}}{T_{iob,j-1} - T_{iob,j}}$$, for $j = NsegK$ and $NsegK > 1$ (158)

or

$NsegK = 1$ and $T_{iob,0} > T_{pe,1}$

where

$\alpha_{iK,j}$	is the heat transfer by condensation from the flue gas to the inner wall of segment *j,* in W/(m² · K);
$q_{K,j}$	is the condensation heat of segment *j*, in W;
$Nseg$	is the number of segments;
$l_{c,j}$	is the proportion of condensation surface of segment *j* ;
U	is the internal circumference, in m;
L	is the length of the chimney, in m;
$T_{pe,1}$	is the water dew point at the inlet of the first segment, in K;
$T_{iob,NsegK}$	is the inner wall temperature at the outlet of segment $NsegK$ at temperature equilibrium, in K.

For the condensation heat $q_{K,j}$ the following formula applies:

$$q_{K,j} = \Delta\dot{m}_{D,j} \cdot r_D$$, in W (159)

where

$q_{K,j}$	is the condensation heat for segment *j*, in W;
$\Delta\dot{m}_{D,j}$	is the condensate mass flow of segment *j*, in kg/s;
r_D	is the enthalpy of evaporated water and shall be taken as 2 400 000, in J/kg.

For the mass flow of condensate the following formula applies:

$$\Delta\dot{m}_{D,j} = \dot{m} \cdot \frac{R}{R_D} \cdot \left(1 - \frac{p_D}{p_L}\right) \cdot \left(\frac{p_{Do,j-1}}{p_L - p_{Do,j-1}} - \frac{p_{Do,j}}{p_L - p_{Do,j}}\right) \cdot \frac{f_K}{100}$$, in kg/s (160)

with

$$p_{Do,j} = e^{\left(23,6448 - \frac{4077,9}{T_{iob,j} - 36,48}\right)}$$, in Pa (161)

where

$\Delta\dot{m}_{D,j}$	is the condensate mass flow of segment *j* in kg/s;
$\dot{m}$	is the flue gas mass flow before condensation, in kg/s;
R	is the gas constant of the flue gas before condensation, in J/(kg · K);
R_D	is the gas constant of water vapour and shall be taken as 496, in J/(kg · K);
p_D	is the water vapour-partial pressure before condensation, in Pa;

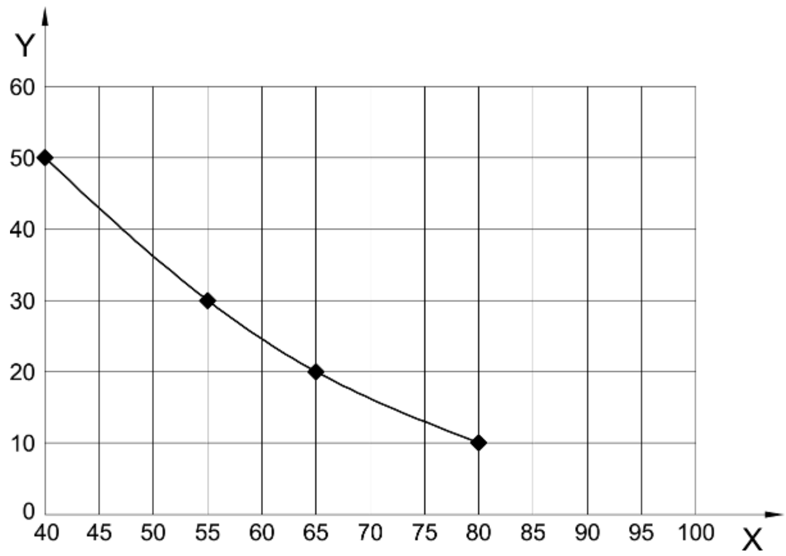
$p_{Do,j}$ is the water vapour-partial pressure due to the inner wall temperature at the outlet of segment j at temperature equilibrium, in Pa;

p_L is the external air pressure, in Pa;

f_K is the useful part of the condensation, in %;

$T_{iob,j}$ is the inner wall temperature at the outlet of segment j at temperature equilibrium, in K.

For f_K see Formulas (162) and (163) and Figure 2. For f_K the flue gas temperature at the inlet into the chimney T_e shall be used. If there is already condensation in the connecting flue pipe, for this part of f_{KV} the flue gas temperature of the appliance T_W shall be used.



Key

X t_e or t_W in °C

Y f_K or f_{Kv} in %

Figure 2 — Condensation factor f_K based on the flue gas entry temperature t_e or t_W

$$f_{KV} = 132,7 - 2,6 \cdot t_W + 0,0133 \cdot t_W^2 \text{, in \%} \quad (162)$$

and

$$f_K = 132,7 - 2,6 \cdot t_e + 0,0133 \cdot t_e^2 \text{, in \%} \quad (163)$$

where

t_W is the flue gas temperature of the appliance, in °C;

t_e is the flue gas temperature at the chimney inlet, in °C.

The formula can be used for 40 °C ≤ t_W ≤ 80 °C and 40 °C ≤ t_e ≤ 80 °C. For t_W < 40 °C is f_{kV} = 50 % and for t_e < 40 °C is f_K = 50 %.

For the flue gas mass flow at the outlet of the segment $\dot{m}_{o,j}$ the following formula applies:

$$\dot{m}_{o,j} = \dot{m}_{o,j-1} - \Delta\dot{m}_{D,j} \text{, in W} \quad (164)$$

where

$\dot{m}_{o,j}$	is the flue gas mass flow at the outlet of segment *j*, in kg/s;
$\Delta\dot{m}_{D,j}$	is the condensate mass flow of segment *j* in kg/s.

For the new calculated flue gas temperature at the outlet of the segment $T_{ob,j}$ the following formulas apply:

$$T_{ob,j} = \frac{\left(\frac{\dot{m}_{o,j-1} \cdot c_{po,j-1}}{\dot{m}_{o,j} \cdot c_{po,j}} - \frac{K_{b,j}}{2}\right) \cdot T_{ob,j-1} + \frac{q_{K,j}}{\dot{m}_{o,j} \cdot c_{po,j}} + K_{b,j} \cdot T_{u,j}}{1 + \frac{K_{b,j}}{2}} \text{, in K} \quad (165)$$

with

$$K_{b,j} = \frac{U \cdot k_{btot,j} \cdot L}{\dot{m}_{o,j} \cdot c_{po,j} \cdot Nseg} \quad (166)$$

with

$$k_{btot,j} = \left(1 - l_{c,j}\right) \cdot k_{b,j-1} + l_{c,j} \cdot k_{botot,j} \text{, for } j = NsegK \text{, in W/(m}^2 \cdot \text{K)} \quad (167)$$

and

$$k_{btot,j} = \frac{k_{botot,j\text{-}1} + k_{botot,j}}{2} \text{, for } j > NsegK \text{, in W/(m}^2 \cdot \text{K)} \quad (168)$$

where

$T_{ob,j}$	is the new calculated flue gas temperature at the outlet of segment *j*, in K;
$\dot{m}_{o,j}$	is the flue gas mass flow at the outlet of segment *j*, in kg/s;
$c_{po,j}$	is the specific heat capacity of the flue gas at the outlet of segment *j*, in J/(kg · K);
$K_{b,j}$	is the coefficient of cooling of segment *j* at temperature equilibrium;
$T_{ob,j-1}$	is the flue gas temperature at the outlet of segment *j*-1 at temperature equilibrium, in K;
$q_{K,j}$	is the condensation heat of segment *j*, in W;
$T_{u,j}$	is the ambient temperature for the area of segment *j*, in K;
U	is the internal circumference, in m;
$k_{btot,j}$	is the coefficient of heat transmission of segment *j* at temperature equilibrium, in W/(m² · K);
L	is the length, in m;
$Nseg$	is the number of segments;
$l_{c,j}$	is the proportion of condensation surface of segment *j*;
$k_{b,j-1}$	is the coefficient of heat transmission of segment *j*-1 at temperature equilibrium, in W/(m² · K);
$k_{obtot,j}$	is the total coefficient of heat transmission at the outlet of segment *j* at temperature equilibrium, in W/(m² · K).

For the exactness of the iteration the following formulas apply:

$$\left|q_{\mathrm{A},j} - q_{\mathrm{C},j}\right| \le 0,2 \cdot q_{\mathrm{A},j} \text{, in W} \tag{169}$$

with

$$q_{\mathrm{A},j} = \dot{m}_{\mathrm{o},j-1} \cdot c_{\mathrm{po},j-1} \cdot T_{\mathrm{ob},j-1} - \dot{m}_{\mathrm{o},j} \cdot c_{\mathrm{po},j} \cdot T_{\mathrm{ob},j} + q_{\mathrm{K},j} \text{, in W} \tag{170}$$

$$q_{\mathrm{C},j} = \frac{\alpha_{\mathrm{itot},j} \cdot U \cdot L}{Nseg} \cdot \frac{T_{\mathrm{ob},j-1} - T_{\mathrm{iob},j-1} + T_{\mathrm{ob},j} - T_{\mathrm{iob},j}}{2} \text{, in W} \tag{171}$$

where

- $q_{\mathrm{A},j}$ is the enthalpy difference of the flue gas between the inlet and the outlet of segment *j*, in W;
- $q_{\mathrm{C},j}$ is the total heat flow from the flue gas to the inner wall of segment *j*, in W;
- $\dot{m}_{\mathrm{o},j}$ is the flue gas mass flow at the outlet of segment *j*, in kg/s;
- $c_{\mathrm{po},j}$ is the specific heat capacity of the flue gas at the outlet of segment *j*, in J/(kg · K);
- $T_{\mathrm{ob,j}}$ is the flue gas temperature at the outlet of segment *j* at temperature equilibrium, in K;
- $q_{\mathrm{K,j}}$ is the condensation heat of segment *j*, in W;
- $\alpha_{\mathrm{iotot,},j}$ is the total coefficient of heat transfer for convection and condensation at the outlet of segment *j*, in W/(m^2 · K);
- U is the internal circumference, in m;
- L is the length of the chimney, in m;
- $Nseg$ is the number of segments;
- $T_{\mathrm{iob},j}$ is the inner wall temperature at the outlet of segment *j* at temperature equilibrium, in K.

For balanced flue chimneys with concentric ducts the Formulas (141) to (171) can be used with the following changes:

— Instead of $T_{\mathrm{u},j}$ use $T_{\mathrm{mbB},j}$

— Instead of $T_{\mathrm{uV},j}$ use $T_{\mathrm{mbBV},j}$

— Instead of α_{a} use $\alpha_{\mathrm{a},j}$

$T_{\mathrm{mB},j}$, $T_{\mathrm{mBV},j}$ and $\alpha_{\mathrm{a},j}$ can be calculated with the appropriate formulas of Clause 7.

9 Consideration of chimney fans

9.1 General

Chimney fans can be taken into account for calculation of chimneys only if

— the fan operation is controlled by safety device which cuts off the heating appliance in case of fan operation failure or

— there is sufficient proof that there is still a safe operation of the heating appliance in case of fan operation failure.

The pressure gain created by the chimney fan P_{Fan} can be calculated with the following formula:

$$P_{\text{Fan}} = \left[c_0 + c_1 \cdot \dot{V}_{\text{Fan}} + c_2 \cdot \dot{V}_{\text{Fan}}^2 + c_3 \cdot \dot{V}_{\text{Fan}}^3 + c_4 \cdot \dot{V}_{\text{Fan}}^4 \right] \cdot \frac{\rho_{\text{Fan}}}{1,2} \text{, in Pa} \quad (172)$$

$$\dot{V}_{\text{Fan}} = \frac{\dot{m}}{\rho_{\text{Fan}}} \text{, in m}^3\text{/s} \quad (173)$$

$$\rho_{\text{Fan}} = \frac{p_{\text{L}}}{R \cdot T_{\text{Fan}}} \text{, in kg/m}^3 \quad (174)$$

where

c_0	is the characteristic value of the chimney fan according to prEN 16475-2, in Pa
c_1	is the characteristic value of the chimney fan according to prEN 16475-2, in Pa/(m³/s)
c_2	is the characteristic value of the chimney fan according to prEN 16475-2, in Pa/(m³/s)^2
c_3	is the characteristic value of the chimney fan according to prEN 16475-2, in Pa/(m³/s)^3
c_4	is the characteristic value of the chimney fan according to prEN 16475-2, in Pa/(m³/s)^4
$\dot{V}_{\text{Fan}}$	is the flue gas volume flow at the chimney fan, in m³/s;
ρ_{Fan}	is the flue gas density at the chimney fan, in kg/m³;
$\dot{m}$	is the flue gas mass flow, in kg/s;
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_{Fan}	is the flue gas temperature at the chimney fan, in K.

The characteristic values of the chimney fan c_0 to c_4 have to be given by the fan manufactures or by the literature.

For a non-permanent used chimney fan the calculation has to be done without taking into account the pressure gain created by the chimney fan but its flow resistance.

9.2 Inline fans

Divergent to Formula (38) the theoretical draught available due to the chimney effect of the connecting flue pipe P_{HV} with an inline fan shall be calculated using the following formula:

$$P_{\text{HV}} = H_{\text{V}} \cdot g \cdot (\rho_{\text{L}} - \rho_{\text{mV}}) + P_{\text{Fan}} \text{, in Pa} \quad (175)$$

where

g	is the acceleration due to gravity = 9,81 m/s²;
H_{V}	is the effective height of the connecting flue pipe, in m;
ρ_{L}	is the density of the external air, in kg/m^3;
ρ_{mV}	is the mean density of the flue gas in the connecting flue pipe, in kg/m^3.

P_{Fan} is the pressure gain created by the inline fan, in Pa;

For negative pressure chimneys the requirements of 5.2.1 and the following relationship shall be verified:

$$P_{Ze} \geq P_B \text{, in Pa} \tag{176}$$

where

P_{Ze} is the minimum draught required at the flue gas inlet into the chimney, in Pa;

P_B is the effective pressure resistance of the air supply, in Pa.

NOTE 1 If necessary, the capacity of the inline fan needs to be appropriately reduced.

For positive pressure chimneys the requirements of 5.2.1 and the following relationship shall be verified:

$$P_{ZOe} + P_{FV} \leq P_{Z\ excess} \text{, in Pa} \tag{177}$$

where

P_{ZOe} is the maximum differential pressure at the flue gas inlet into the chimney, in Pa;

P_{FV} is the pressure resistance of the connecting flue pipe, in Pa;

$P_{Z\ excess}$ is the maximum allowed pressure from the designation of the chimney, in Pa.

NOTE 2 If necessary, the capacity of the inline fan needs to be appropriately reduced.

For the calculation of the pressure gain created by the inline fan P_{Fan} according Formula (172) normally the following formula can be used:

$$T_{Fan} = T_W \text{, in K} \tag{178}$$

where

T_{Fan} is the flue gas temperature at the chimney fan, in K;

T_W is the flue gas temperature of the appliance, in K.

9.3 Exhaust fans

Divergent to Formula (31) the theoretical draught available due to the chimney effect P_H with an exhaust fan shall be calculated using the following formula:

$$P_H = H \cdot g \cdot (\rho_L - \rho_m) + P_{Fan} \text{, in Pa} \tag{179}$$

where

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

H is the effective height of the chimney, in m;

ρ_L is the density of the external air, in kg/m³;

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

P_{Fan} is the pressure gain created by the exhaust fan, in Pa.

For the calculation of the pressure gain created by the exhaust fan P_{Fan} according Formula (172) normally the following formula can be used:

$$T_{Fan} = T_o \text{, in K} \tag{180}$$

where

T_{Fan} is the flue gas temperature at the chimney fan, in K;

T_o is the flue gas temperature at the chimney outlet, in K.

Annex A
(informative)

Calculation of thermal resistance

The thermal resistance of a chimney $\left(\frac{1}{\Lambda}\right)$ may be determined with knowledge of the coefficients of thermal conductivity of the materials of construction and should be determined using the following formula:

$$\left(\frac{1}{\Lambda}\right) = y \cdot \sum_{n} \left[\frac{D_h}{2 \cdot \lambda_n} \cdot \ln\left(\frac{D_{h,n+1}}{D_{h,n}}\right)\right], \text{ in m}^2 \cdot \text{K/W} \quad \text{(A.1)}$$

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;
$D_{h,n+1}$	is the hydraulic diameter of the outside of each layer, in m;
y	is the coefficient of form
	= 1,0 for round and oval cross-sections;
	= 1,10 for square and rectangular cross-sections up to a ratio of a side of 1:1,5;
λ_n	is the coefficient of thermal conductivity of the material of the layer at the operating temperature (see Table B.5), in W/(m·K).

The influence of the thermal bridges for metal system chimneys should be taken into account by a factor described in EN 1859.

NOTE A method for calculation of the thermal conductivity as a function of the temperature is described in EN 15287-1: 2007+A1:2010, Annex A.

Annex B
(informative)

Tables

Table B.1 — Values for determination of the flue gas mass flow $\dot{m}$, the specific gas constant R, the specific heat capacity c_p, the water dew point t_p, the rise in the dew point ΔT_{sp}, the coefficient of thermal conductivity λ_A and dynamic viscosity η_A of flue gas (c_p, λ_A and η_A to 400 °C)

	Characteristic fuel data						Coefficients for calculation of flue gas data												
kind of fuel	H_u	V_{Atr} min	V_L min	V_{H_2O}	$\sigma(CO_2)$ max	$\sigma(SO_2)$ max	f_{m1}	f_{m2}	f_R without cond.	f_R with cond.	f_{R1}	f_{R2}	f_{c0}	f_{c1}	f_{c2}	f_{c3}	f_w	f_{s1}	f_{s2}
	kWh/kg kWh/m^3	m^3/kg or m^3/m^3	m^3/kg or m^3/m^3	m^3/kg or m^3/m^3	%	%	g %/(kWs)	g/(kWs)	1/%	1/%	1/%	1/%	J/(kgK %)	J/(kgK^2%)	J/(kgK^3%)	1/%	%	K	K
coke	8,06	7,64	7,66	0,13	20,60	0,09	7,06	0,033	-0,0036	-0,0038	0,0036	-0,004 0	3,4	0,014	-0,000014	0,0046	1 235	99	7
stone coal (anthracite)	9,24	8,37	8,55	0,44	19,05	0,10	6,23	0,036	-0,0028	-0,0033	0,003 6	-0,003 9	5,6	0,014	-0,000013	0,0057	370	93	7
brown coal	5,42	5,09	5,17	0,68	19,48	0,04	6,61	0,055	-0,0014	-0,0026	0,003 7	-0,004 0	10,3	0,015	-0,000012	0,0083	149	80	7
RFO < 4 % S	9,43	9,91	10,48	1,15	16,17	0,28	6,14	0,052	-0,0012	-0,0024	0,003 7	-0,003 9	10,7	0,014	-0,000012	0,0082	142	94	7
RFO < 2 % S	9,61	10,06	10,67	1,21	16,15	0,14	6,11	0,052	-0,001	-0,0023	0,003 7	-0,003 8	11,0	0,014	-0,000011	0,0083	137	89	7
RFO < 1 % S	9,74	10,17	10,79	1,25	16,09	0,07	6,07	0,052	-0,0009	-0,0022	0,003 7	-0,003 8	11,2	0,014	-0,000011	0,0084	134	85	7
domestic heating oil	11,86	10,52	11,26	1,49	15,40	0,00	4,94	0,046	-0,0002	-0,0018	0,003 8	-0,003 7	13,0	0,014	-0,000011	0,0093	111	0	0
kerosene	12,09	11,36	12,14	1,57	15,00	0,00	5,09	0,047	-0,0002	-0,0018	0,003 8	-0,003 6	13,0	0,014	-0,000011	0,0093	111	0	0

natural gas H	10,03	8,67	9,57	1,86	12,00	0,00	3,75	0,053	0,0032	0,0002	0,003 9	-0,003 2	23,0	0,015	-0,000007	0,0142	57	0	0
natural gas L	9,03	7,87	8,63	1,70	11,80	0,00	3,72	0,054	0,0033	0,0003	0,003 9	-0,003 2	23,5	0,015	-0,000007	0,0144	56	0	0
liquid gas	26,67	22,46	24,51	4,10	13,80	0,00	4,20	0,049	0,0013	-0,0009	0,003 8	-0,003 5	17,6	0,015	-0,000009	0,0116	77	0	0
wood (30 % moisture)	3,70	3,44	3,45	0,80	20,50	0,00	6,89	0,076	0,0001	-0,0018	0,003 8	-0,004 1	15,4	0,016	-0,000011	0,0111	90	0	0
wood (50 % moisture)	3,12	2,98	2,99	0,86	20,50	0,00	7,08	0,090	0,001	-0,0013	0,003 8	-0,004 2	18,5	0,016	-0,000010	0,0128	72	0	0
wood pellets	5,27	4,78	4,81	0,78	20,31	0,00	6,66	0,060	-0,001	-0,0024	0,003 7	-0,004 1	11,6	0,015	-0,000012	0,0091	127	0	0

Key

f_{m1} is the coefficient for calculation of flue gas mass flow, in g·%/(kW · s);

f_{m2} is the coefficient for calculation of flue gas mass flow, in g/(kW · s);

f_R is the coefficient for calculation of gas constant of the flue gas, in 1/%;

f_{c0} is the coefficient for calculation of specific heat capacity of the flue gas, in J/(kg · K·%);

f_{c1}, is the coefficient for calculation of specific heat capacity of the flue gas, in J/(kg · K^2·%);

f_{c2}, is the coefficient for calculation of specific heat capacity of the flue gas, in J/(kg · K^3·%);

f_{c3} is the coefficient for calculation of specific heat capacity of the flue gas, in 1/%;

f_{R1} is the coefficient for calculation of gas constant of the flue gas where the water vapour content of the flue gas is known, in 1/%;

f_{R2} is the coefficient for calculation of gas constant of the flue gas where the water vapour content of the flue gas is known, in 1/%;

f_w is the coefficient for calculation of water vapour content of the flue gas, in %;

f_{s1} is the coefficient for calculation of rise in dew point, in K;

f_{s2} is the coefficient for calculation of rise in dew point, in K;

H_u is the energy content of the fuel, in kWh/kg or kWh/m^3;

$V_{Atr\,\min}$ is the relation of minimum dry flue gas volume and fuel mass or flue volume under normal condition (273,15 K, 101325 Pa), in m^3/kg or m^3/m^3;

$V_{L\,\min}$ is the relation of minimum combustion air volume and fuel mass or flue volume under normal condition (273,15 K, 101325 Pa), in m^3/kg or m^3/m^3;

V_{H_2O} is the relation of water vapour volume in the flue gas and fuel mass or flue volume under normal condition (273,15 K, 101325 Pa), in m^3/kg or m^3/m^3;

$\sigma(CO_2)_{\max}$ is the maximum carbon dioxide content of dry flue gas, in %;

$\sigma(SO_2)_{\max}$ is the maximum sulphur dioxide content of dry flue gas, in %.

Approximations:			where
$\dot{m} = \left(\frac{f_{m1}}{\sigma(CO_2)} + f_{m2} \right) \cdot Q_F$	in g/s	(B.1)	$\dot{m}$ is the flue gas mass flow, in g/s;
			$\sigma(CO_2)$ is the carbon dioxide content of dry flue gas, in %;
$Q_F = \frac{100}{\eta_W} \cdot Q$	in kW	(B.2)	Q_F is the heat input of heating appliance, in kW;
			Q is the heat output of heating appliance, in kW;
$R = R_L \cdot \left[1 + f_R \cdot \sigma(CO_2) \right]$	in J/(kg · K)	(B.3)	η_W is the efficiency of heating appliance, in %;
$c_p = \frac{1011 + 0{,}05 \cdot t_m + 0{,}0003 \cdot t_m^2 + \left(f_{c0} + f_{c1} \cdot t_m + f_{c2} \cdot t_m^2 \right) \cdot \sigma(CO_2)}{1 + f_{c3} \cdot \sigma(CO_2)}$	in J/(kg · K)	(B.4)	R is the gas constant of the flue gas, in J/(kg · K);
			R_L is the gas content of the air = 288 J/(kg · K);
$\sigma(H_2O) = \frac{100}{1 + \frac{f_w}{\sigma(CO_2)}} + 1{,}1$	in %	(B.5)	c_p is the specific heat capacity of the flue gas, in J/(kg · K);
			t_m is the mean flue gas temperature, in °C;
$p_D = \frac{\sigma(H_2O)}{100} \cdot p_L$	in Pa	(B.6)	$\sigma(H_2O)$ is the water vapour content of the flue gas, in %;
			p_D is the water vapour-partial pressure, in Pa;
$t_p = \frac{4077{,}9}{23{,}6448 - \ln(p_D)} - 236{,}67$	in °C	(B.7)	p_L is the external air pressure, in Pa;
$\Delta T_{sp} = f_{s1} + f_{s2} \cdot \ln(K_f)$	in K	(B.7)	t_p is the dew point temperature, in °C;
$\lambda_A = 0{,}0223 + 0{,}000065 \cdot t_m$	in W/(m · K)	(B.9)	

$\eta_A = 15 \cdot 10^{-6} + 47 \cdot 10^{-9} \cdot t_m - 20 \cdot 10^{-12} \cdot t_m^2$	in N · s/m²	(B.10)	ΔT_{sp} is the rise in dew point, in K; K_f is the conversion factor SO_2 in SO_3, in %; λ_A is the coefficient of thermal conductivity of the flue gas, in W/(m · K); η_A is the dynamic viscosity of the flue gas, in N · s/m².
$R = R_L \cdot \left\{ 0{,}996 + f_{R1} \cdot \sigma(H_2O) + f_{R2} \cdot \left[1 - \frac{\sigma(H_2O)}{100} \right] \cdot \sigma(CO_2) \right\}$	in J/(kg · K)	(B.11)	
$\sigma(H_2O) = \frac{p_D}{p_L} \cdot 100$	in %	(B.12)	
$p_D = e^{\left(23{,}6448 - \frac{4077{,}9}{T_p - 36{,}48}\right)}$	in Pa	(B.13)	
NOTE It is advised to use f_R without condensation" for chimneys operating under dry conditions. It is advised to use f_R with condensation" for chimneys operating under wet conditions.			

Table B.2 — Values for heating boilers

Fuel	Formula for P_W, η_W and $\sigma(CO_2)$						
coke, mineral coal, brown coal, briquettes	P_W	= {	$15 \cdot \lg Q_N$	in Pa for	100 kW <	$Q_N \leq$	100 kW
			$-70 + 50 \cdot \lg Q_N$	in Pa for		$Q_N \leq$	1 000 kW
			80 Pa	for		$Q_N >$	1 000 kW
	η_W	=	$68{,}65 + 4{,}35 \cdot \lg Q_N$	in % for		$Q_N \leq$	2 000 kW
	$\sigma(CO_2)$	= {	9,5 %	for	100 kW <	$Q_N \leq$	100 kW
			$4{,}1 + 2{,}7 \cdot \lg Q_N$	in % for		$Q_N \leq$	2 000 kW
wood	P_W	= {	$15 \cdot \lg Q_N$	in Pa for	10 kW <	$Q_N \leq$	50 kW
			$27 + 13 \cdot \lg Q_N$	in Pa for	special boilers	$Q_N \leq$	350 kW
	η_W	=	$67 + 6 \cdot \lg Q_N$	in % for		$Q_N \leq$	1 000 kW
	$\sigma(CO_2)$	= {	8,0 %	for	10 kW <	$Q_N \leq$	10 kW
			$6{,}0 + 2{,}0 \cdot \lg Q_N$	in % for		$Q_N \leq$	1 000 kW
oil and gas (with and without forced draught burner)	P_W	= {	$15 \cdot \lg Q_N$	in Pa for		$Q_N \leq$	100 kW
			$-47 + 38{,}5 \cdot \lg Q_N$	in Pa for		$Q_N >$	100 kW
	η_W	= {	$85{,}0 + 1{,}0 \cdot \lg Q_N$	in % for		$Q_N \leq$	1 000 kW
			88,0 %	for		$Q_N >$	1 000 kW
	$\sigma(CO_2)$	= {	$\frac{f_{x1}}{1 - f_{x2} \cdot \lg Q_N}$	in % for		$Q_N \leq$	100 kW
				in % for		$Q_N >$	100 kW
			f_{x3}				

Table B.3 — Values for the determination of σ (CO_2) according to Table B.2 using oil- and gas burners

Fuel	forced draught burner			natural draught burner[a]		
	f_{x1}	f_{x2}	f_{x3}	f_{x1}	f_{x2}	f_{x3}
oil	11,2	0,076	13,2	–	–	–
natural gas	8,6	0,078	10,2	5,1	0,075	6,0
liquid gas	10,0	0,080	11,9	5,9	0,079	7,0
[a] values after the draught diverter.						

Table B.4 — Typical mean values for roughness *r* of some liner materials/constructions

Materials of the liner	Typical mean values for roughness *r* m
welded steel	0,001
glass	0,001
plastic	0,001
aluminium	0,001
clay ceramic flue liners	0,0015
bricks	0,005
soldered metal	0,002
concrete	0,003
fibre cement	0,003
masonry	0,005
corrugated metal	0,005

Table B.5 — Coefficient of thermal conductivity *λ*, density *ρ*, specific heat capacity *c* and radiant coefficient *ε* of some chimney materials

Material	ρ kg/m^3	λ in W/(m · K) for t =				ε –
		20 °C	100 °C	200 °C	300 °C	
aluminium	2 800	160	160	160		0,3
steel	7 800	50	50	50	50	0,6
stainless steels	7 900	17	17	17	17	0,1
masonry						
bricks with full structure, vertically perforated bricks with closed structure,	1 200	0,60	0,63	0,66		0,9
bricks for filling purposes	1 600	0,82	0,86	0,90		
	2 000	1,15	1,20	1,26		
vertically perforated bricks with perforation degree A and B	600	0,40	0,44	0,50		0,9
	800	0,47	0,52	0,59		
	1 000	0,54	0,59	0,67		
calcium silicate units	1 000	0,30	0,33	0,36		0,7
light weight concrete with closed structure	800	0,47	0,51	0,55		0,9
	1 200	0,74	0,81	0,87		
	1 600	1,20	1,32	1,42		
	2 000	1,92	2,11	2,26		
light weight concrete with open structure	800	0,34	0,37	0,40		0,9
	1 200	0,55	0,60	0,65		
	1 600	0,90	0,97	1,06		
	2 000	1,44	1,55	1,70		
light weight concrete with open structure (natural basis)	600	0,22	0,24	0,27		0,9
	900	0,34	0,38	0,42		
	1 200	0,49	0,56	0,61		
light weight concrete with open structure, only expanded concrete	600	0,23	0,26	0,28		0,9
	900	0,36	0,40	0,45		
	1 200	0,53	0,58	0,66		
	1 500	0,72	0,80	0,89		
clay ceramic flue liner / block	2 000	1,00	1,05	1,10	1,15	0,9
mineral wool, open		0,043	0,080	0,109	0,150	0,9
mineral wool, ventilated		0,049	0,080	0,109	0,170	0,9
mineral wool, plates		0,037	0,053	0,073	0,100	0,9
mineral wool, shell		0,042	0,049	0,070	0,102	0,9
vermiculite		0,062	0,076	0,096	0,126	0,9
glass	2 200	1,07	1,20	1,37		0,9
PVDF (Polyvinyliden fluoride)	1 800	0,19	0,19			0,9
PP (Polypropylene)	900	0,22	0,22			0,9

NOTE These default values include a safety factor of 1,2 to take account of manufacturing tolerances.

Table B.6 — Thermal resistance of closed air gaps, dependent on the air gap width d_n and the surface temperature of the heat emitting wall (concentric annular clearance, vertically arranged)

Surface temperature °C	Thermal resistance $(1/\Lambda)_n$ in $m^2 \cdot K/W$				
	air gap width d_n (m)				
	0,01	0,02	0,03	0,04	0,05
40	0,123	0,147	0,153	0,152	0,150
100	0,087	0,101	0,101	0,100	0,099
150	0,065	0,075	0,075	0,074	0,074
200	0,050	0,055	0,055	0,055	0,054

NOTE 1 The effective coefficient of heat conductivity λ_n of closed air gaps can be calculated using the following formula:

$$\lambda_n = y \frac{D_{h,n}}{2\left(\frac{1}{\Lambda}\right)_n} \cdot \ln\left(\frac{D_{h,n} + 2d_n}{D_{h,n}}\right), \text{ in W/(m} \cdot \text{K)}$$

where

y is the coefficient of form (see Annex A);

$D_{h,n}$ is the external hydraulic diameter of the inner wall bounding the air gap, in m;

$\left(\frac{1}{\Lambda}\right)_n$ is the thermal resistance of the air gap, in $m^2 \cdot K/W$;

d_n is the air gap width, in m.

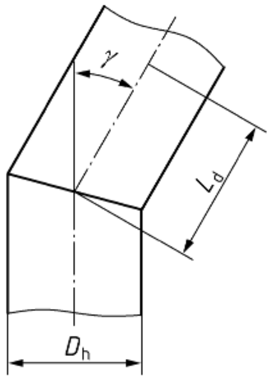
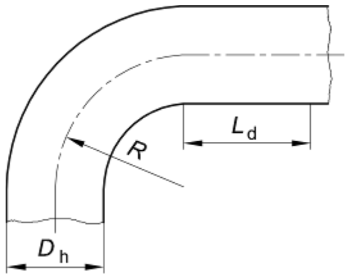
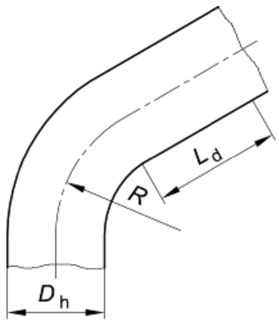
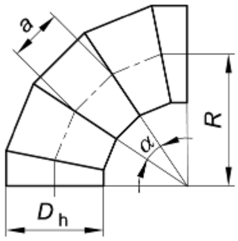
NOTE 2 For closed air gaps greater than 50 mm and/or temperatures higher than 200 °C a value of 0 is recommended in the absence of confirmed alternative data.

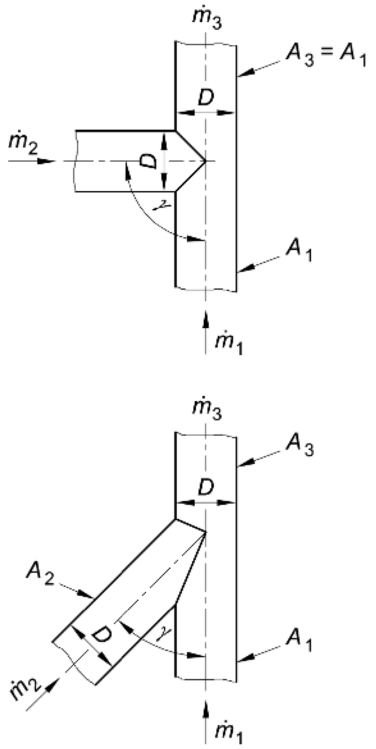
Table B.7 — Characteristic values for draught regulators

draught regulator group	a_1 Pa · s/kg	a_2 Pa · (s/kg)^2
1	400	120 000
2	200	30 000
3	140	11 400
4	97	5 000
5	74	2 800
6	48	1 260

NOTE Data for the characteristic values a_1 and a_2 are selected by categorising the draught regulator into one of six groups in accordance with prEN 16475-3.

Table B.8 — Individual coefficients of resistance for some shapes

No	Shapes	Geometric dimensions	ζ-values		
1		angle γ in °	$L_d/D_h \geq 30$	$30 > L_d/D_h \geq 2$	
		10	0,1	0,1	
		30	0,2	0,3	
		45	0,3	0,4	
		60	0,5	0,7	
		90	1,2	1,6	
2			90°-bend		
		R/D_h	$L_d/D_h \geq 30$	$30 > L_d/D_h \geq 2$	
		0,5	1,0	1,2	
		0,75	0,4	0,5	
		1,0	0,25	0,3	
		1,5	0,2	0,2	
		2,0	0,2	0,2	
3			60°-bend		
		R/D_h	$L_d/D_h \geq 30$	$30 > L_d/D_h \geq 2$	
		0,5	0,6	1,0	
		0,75	0,3	0,4	
		1,0	0,2	0,3	
		1,5	0,2	0,2	
		2,0	0,1	0,1	
4		$a = 2 \cdot R \cdot \tan\left(\frac{\alpha}{2}\right)$	90°-bend No. of segments		
		a/D_h	2 × 45°	3 × 30°	4 × 22,5°
		1,0	0,4	0,25	0,17
		1,5	0,3	0,18	0,13
		2,0	0,3	0,17	0,12
		3,0	0,35	0,19	0,13

No	Shapes		Geometric dimensions		ζ-values	
			5,0	0,4	0,20	0,15
Interpolations between the cited parameters are admissible.						
5		 condition: W_3	angle γ = 90°			
				$\dot{m}_2 / \dot{m}_3$	ζ_{2-3}	ζ_{1-3}
			A_3/A_2 = 1,0	0,0	– 0,92	0,03
				0,2	– 0,38	0,20
				0,4	0,10	0,35
				0,6	0,53	0,47
				0,8	0,89	0,56
				1,0	1,20	0,62
			angle γ = 45°			
				$\dot{m}_2 / \dot{m}_3$	ζ_{2-3}	ζ_{1-3}
			A_3/A_2 = 1,6	0,0	– 0,92	0,03
				0,2	– 0,42	0,16
				0,4	0,04	0,17
				0,6	0,22	0,06
				0,8	0,35	– 0,18
				1,0	0,35	– 0,53

No	Shapes	Geometric dimensions	ζ-values

Formula to calculate the individual coefficients of resistance on compositions[a]:

$$\zeta_{2-3} = -0{,}92\left(1-\frac{\dot m_2}{\dot m_3}\right)^2 - \left(\frac{\dot m_2}{\dot m_3}\right)^2\left[1{,}2\left(\frac{A_3}{A_2}\cos\gamma - 1\right) + 0{,}8\left(1-\left(\frac{A_3}{A_2}\right)^2\right) - \left(1-\left(\frac{A_3}{A_2}\right)^{-1}\right)\cdot\frac{A_3}{A_2}\cos\gamma\right]$$

$$+\left(2-\left(\frac{A_3}{A_2}\right)^{-1}\right)\cdot\frac{\dot m_2}{\dot m_3}\left(1-\frac{\dot m_2}{\dot m_3}\right)$$

$$\zeta_{1-3} = 0{,}03\left(1-\frac{\dot m_2}{\dot m_3}\right)^2 - \left(\frac{\dot m_2}{\dot m_3}\right)^2\left[1+1{,}62\left(\frac{A_3}{A_2}\cos\gamma - 1\right) - 0{,}38\left(1-\left(\frac{A_3}{A_2}\right)^{-1}\right)\right]$$

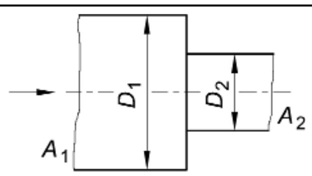
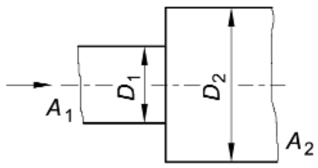
$$+\left(2-\left(\frac{A_3}{A_2}\right)^{-1}\right)\cdot\frac{\dot m_2}{\dot m_3}\left(1-\frac{\dot m_2}{\dot m_3}\right)$$

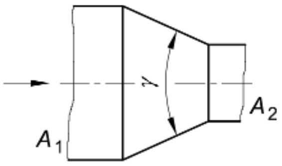
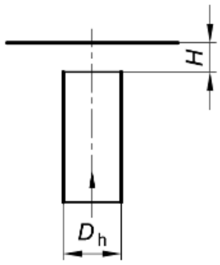
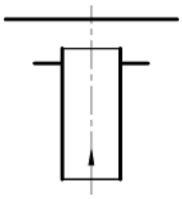
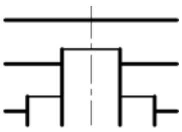
with $\frac{A_3}{A_2} \geq 1;\ 0 \leq \frac{\dot m_2}{\dot m_3} \leq 1{,}0;\ 0° < \gamma \leq 90°$

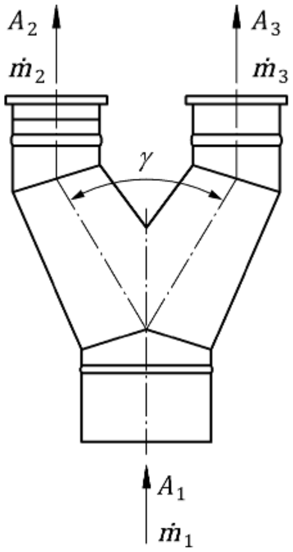
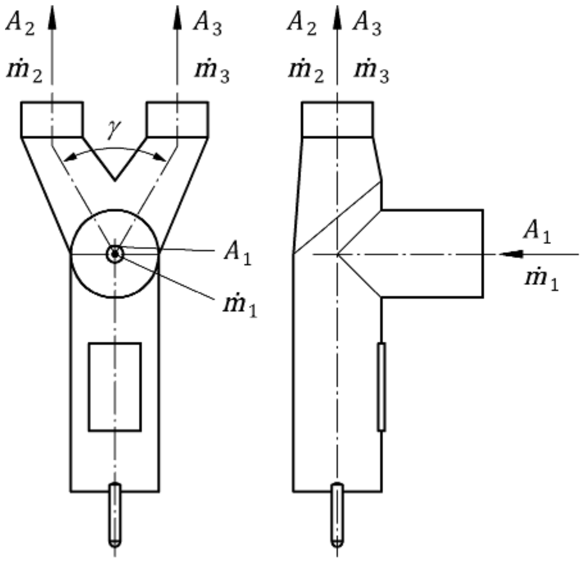
For $\frac{A_3}{A_2}$ < 1 the individual resistance of the composition can be determined as sum of the individual resistance of a cross-sectional constriction (see No. 6 respectively No. 8) and a composition $\frac{A_3}{A_2}$ = 1.

[a] according to Gardel.

Interpolations between the cited parameters are admissible.

No		Shapes	Geometric dimensions	ζ-values
6	transitional parts	 condition: W_2	A_2/A_1 0,4 0,6 0,8	 0,33 0,25 0,15 on rounded inlet edge ζ = 0
7		 condition: W_1	A_1/A_2 0 0,2 0,4 0,6 0,8 1,0	 1,0 0,7 0,4 0,2 0,1 0

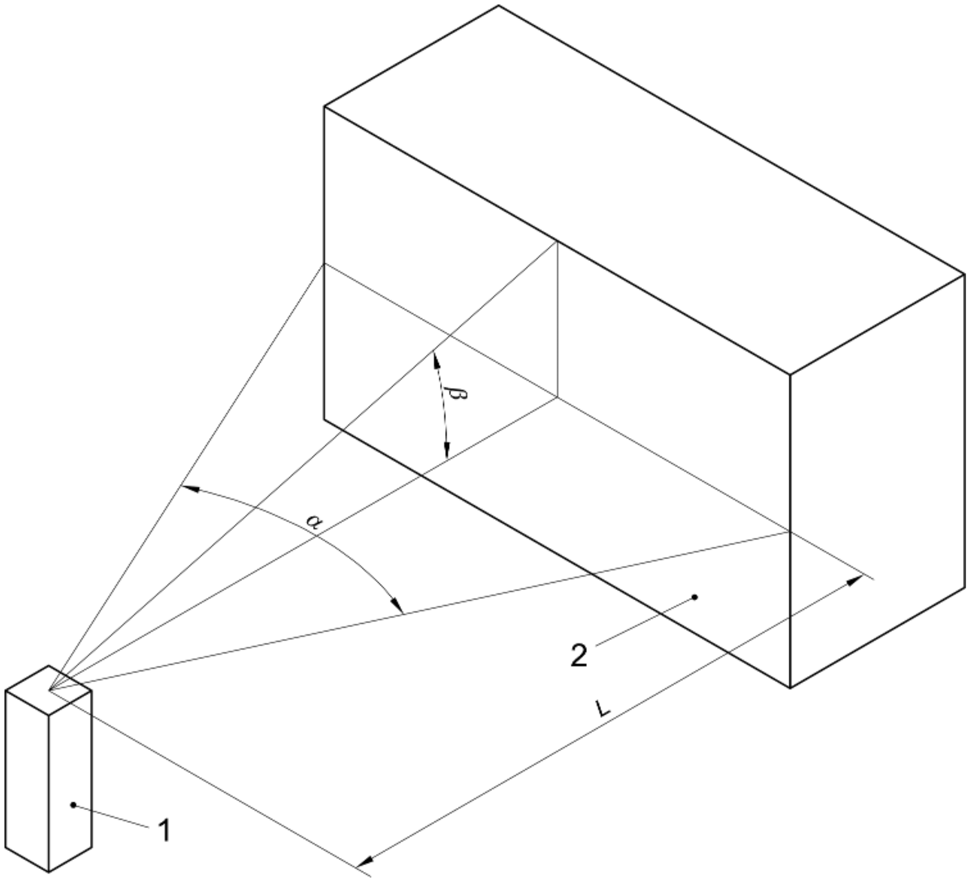
No		Shapes	Geometric dimensions	ζ-values		
8		 condition: $W2$	A_1/A_2	γ = 30°	γ = 60°	γ = 90°
			0,10	0,05	0,08	0,19
			0,25	0,04	0,07	0,17
			0,45	0,05	0,07	0,14
			1,0	0,0	0,0	0,0
9	rain caps		H/D_h			
			0,5	1,5		
			1,0	1,0		
10	Terminals	 flue terminal (P_L=0) according to EN 1856-1		1,6		
11		 Aerodynamic air flue terminal for positive pressure chimney and room sealed appliance (P_L = 0) according to EN 1856-1		5,2 (ζ_{inlet} = 3,2) (ζ_{outlet} = 2,0)		

No	Shapes		Geometric dimensions	ζ-values
12	branches	 condition: W_2 or W_3	$\gamma \approx 60°$ $\frac{A_3}{A_2} = 1$ $\frac{A_3}{A_1} = 0,5$ $\frac{\dot{m}_3}{\dot{m}_2} = 1$ $\frac{\dot{m}_3}{\dot{m}_1} = 0,5$	0,5
13		 condition: W_2 or W_3	$\gamma \approx 60°$ $\frac{A_3}{A_2} = 1$ $\frac{A_3}{A_1} = 0,5$ $\frac{\dot{m}_3}{\dot{m}_2} = 1$ $\frac{\dot{m}_3}{\dot{m}_1} = 0,5$	2,6

NOTE This table covers only non-concentric fittings due to the available data. Values for gaps in concentric fittings have to be given by the manufactures or by the literature. In the first-order approximation the values for the non-concentric fittings can be taken also for gaps in concentric fittings

Annex C
(informative)

Chimney outlet with regard to adjacent buildings



Key

1 chimney

2 building

Figure C.1 — Chimney outlet position (see text)

A chimney outlet is deemed within the influence of an adjacent building when:

— the horizontal distance L between the outlet and the building is less than 15 m; and

— the building as seen from the chimney outlet extends over a horizontal angle *α* of more than 30°; and

the upper boundary of the building as seen from the chimney outlet rises more than 10° above the horizon (angle *β*).

Annex D
(informative)

Determination of the gas constant R considering the condensation

Table B.1 gives in Formula (B.3) a normal method for the calculation of the gas constant of the flue gas R using a coefficient f_R depending on the kind of fuel once for a value without condensation and once for a value with condensation. The method for condensation does not differ between the influences of the intensity of the condensation and therefore gives a value for f_R assuming a relative high amount of condensate. This results in a low value for the gas constant R and for the theoretical draught P_H.

In the following a method calculating the gas constant R considering the intensity of condensation is given. The method follows the calculation given in Clause 8 for the calculation of the condensation heat. For the determination of the gas constant of the flue gas it is necessary to do this calculation using the external air temperature for the pressure condition. In deviation to Clause 8 under safety aspects it is necessary to calculate with a high amount of condensation. Therefore for the part of condensation heat used in calculation f_K a value of 100 % is to be used. Because this method gives values for the flue gas temperature that are higher than in reality this method cannot be used for the determination of the flue gas temperature in the chimney or in the connecting flue pipe. For this calculation the method given in Clause 5 or in Clause 8 can be used.

Using Formula (B.11) in Table B.1 for the mean gas constant of the flue gas R the following formula applies:

$$R = \frac{\frac{R_{o,0}}{2} + \sum_{j=1}^{Nseg-1} R_{o,j} + \frac{R_{o,N\mathrm{seg}}}{2}}{N_{seg}}, \text{ in J/(kg} \cdot \text{K)} \qquad \text{(D.1)}$$

where

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

$R_{o,0}$ is the gas constant of the flue gas at the inlet of the first segment, in J/(kg · K);

$R_{o,j}$ is the gas constant of the flue gas at the outlet of segment j, in J/(kg · K);

$R_{o,Nseg}$ is the gas constant of the flue gas at the outlet of the last segment, in J/(kg · K);

$Nseg$ is the number of segments.

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