

Chimneys — Thermal and fluid dynamic calculation methods —

Part 2: Chimneys serving more than one heating appliance

ICS 91.060.40

National foreword

This British Standard is the UK implementation of EN 13384-2:2003+A1:2009. It supersedes BS EN 13384-2:2003 which is withdrawn.

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

The UK participation in its preparation was entrusted by Technical Committee B/506, Chimneys, to Subcommittee B/506/1, Chimneys general requirements.

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

The method of sizing chimneys in the UK is given in supporting documents to building regulations appropriate to that legislative area of the UK. In England and Wales this is the Approved Document J to the Building Regulations. In Scotland this is the Building Standards (Scotland) Regulations Part F. In Northern Ireland this is the Technical Booklet L to the Building Regulations (Northern Ireland).

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 23 May 2003

© BSI 2010

ISBN 978 0 580 62243 4

Amendments/corrigenda issued since publication

Date	Comments
31 January 2010	Implementation of CEN amendment A1:2009

English Version

Chimneys - Thermal and fluid dynamic calculation methods - Part 2: Chimneys serving more than one heating appliance

Conduit de cheminée - Méthode de calcul thermo-
aéraulique - Partie 2 : Conduits de fumée desservant plus
d'un appareil de chauffage

Abgasanlagen - Wärme- und strömungstechnische
Berechnungsverfahren - Teil 2: Abgasanlagen mit
mehreren Feuerstätten

This European Standard was approved by CEN on 11 March 2003 and includes Amendment 1 approved by CEN on 23 November 2008.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.



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

Management Centre: rue de Stassart, 36 B-1050 Brussels

Contents

	page
Foreword	4
1 Scope	5
2 Normative references	5
3 Terms and definitions	6
4 Symbols, terminology, units	7
5 Calculation method	9
5.1 General principles	9
5.2 Pressure equilibrium condition	11
5.2.1 A_1 Negative pressure chimneys A_1	11
5.2.2 A_1 Positive pressure chimneys	12
5.3 Mass flow requirement.....	13
5.4 Pressure A_1 requirements A_1	13
5.4.1 A_1 Negative pressure chimneys	13
5.4.2 A_1 Positive pressure chimneys	14
5.5 Temperature requirement.....	16
5.6 Calculation procedure.....	16
6 Flue gas data characterising the heating appliance.....	18
7 Data for chimney and connecting flue pipes.....	20
8 Basic data for the calculation	20
8.1 Air temperatures.....	20
8.1.1 External air temperature (T_L)	20
8.1.2 Ambient air temperature (T_u)	20
8.2 External air pressure (p_L)	20
8.3 Gas constant.....	20
8.3.1 Gas constant of the air (R_L).....	20
8.3.2 Gas constant of flue gas (R)	21
8.4 Density of air (ρ_L)	21
8.5 Specific heat capacity of the flue gas (c_p).....	21
8.6 Water vapour content ($\sigma(\text{H}_2\text{O})_j$) and condensing temperature (T_{sp})	21
8.7 Correction factor for temperature instability (S_H).....	21
8.8 Flow safety coefficient (S_E)	21
8.9 External coefficient of heat transfer	21
9 Determination of temperatures	21
10 Mixing calculations	24
10.1 Flue gas mass flow ($\dot{m}_{j,j}$)	24
10.2 Flue gas temperature at the inlet of the chimney segment ($T_{e,j}$).....	24
10.3 CO_2 -content of the flue gas in the chimney segment ($\sigma(\text{CO}_2)_j$).....	24
10.4 H_2O -content of the flue gas ($\sigma(\text{H}_2\text{O})_j$)	24
10.5 Gas constant of the flue gas (R_j)	25
10.6 Flue gas data.....	25
10.6.1 Specific heat capacity ($c_{pV,j}$), ($c_{p,j}$).....	25
10.6.2 Thermal conductivity of the flue gas ($\lambda_{AV,j}$), ($\lambda_{A,j}$).....	25
10.6.3 Dynamic viscosity ($\eta_{AV,j}$), ($\eta_{A,j}$).....	26
11 Density and velocity of the flue gas	26
12 A_1 Determination of the pressures A_1	27
12.1 A_1 Pressures at each inlet of the chimney segments A_1	27
12.1.1 A_1 Draught	27

12.1.2	A1 Positive pressure	27
A1 12.1.3	A1 Draught due to chimney effect in the chimney segment ($P_{H,j}$).....	28
A1 12.1.4	A1 Pressure resistance in the chimney segment ($P_{R,j}$).....	28
12.2	A1 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}) A1	30
A1 12.2.1	Minimum required and maximum allowed draught.....	30
12.2.2	Maximum available and minimum allowed differential pressure	31
A1 12.2.3	A1 Calculated pressure resistance of the connecting flue pipe ($P_{V,j}$).....	31
A1 12.2.4	Calculated pressure resistance of the air supply ($P_{Bc,j}$) A1	33
13	Inner wall temperature	34
14	Cascade installations	35
14.1	Principle of the calculation method.....	35
14.2	Pressure equilibrium condition.....	35
A1 14.2.1	Negative pressure cascade installation A1	35
A1 14.2.2	Positive pressure cascade installation.....	37
14.3	Mass flow requirement.....	37
14.4	Pressure A1 requirements A1	38
A1 14.4.1	Negative pressure chimneys A1	38
14.4.2	Positive pressure chimneys	38
14.5	Temperature requirement	39
14.6	Calculation procedure.....	40
14.7	A1 Pressures A1 at the outlet of the connecting flue pipe and A1 pressures A1 at the inlet of the collector segment.....	40
14.7.1	A1 Pressure A1 at the flue gas inlet into the collector segment A1 ($P_{ZC,j,l}$ or $P_{ZOC,j,l}$) A1	40
14.7.2	A1 Pressures required or available A1 at the outlet of the connecting flue pipe A1 ($P_{ZeC,j,l}$, $P_{ZeOC,j,l}$) A1	43
14.8	Inner wall temperature ($T_{iobC,j,l}$)	45
15	Balanced flue chimney.....	45
15.1	Principle of the calculation method.....	45
15.2	Pressure equilibrium condition.....	45
15.3	Mass flow requirement.....	46
15.4	Pressure requirements	46
A1 15.4.1	Negative pressure chimneys A1	46
15.4.2	Positive pressure chimneys	47
15.5	Temperature requirements	48
15.6	Calculation procedure for balanced flue chimneys	49
15.7	Mass flow of the supply air.....	50
15.8	Determination of the temperatures in balanced flue chimneys.....	51
15.8.1	Separate ducts	51
15.8.2	Concentric ducts	51
15.8.3	Concentric connection pipes	58
15.9	A1 Pressures of the air supply ducts A1	64
15.9.1	A1 Draught due to chimney effect of the air supply duct of chimney segment j A1	64
15.9.2	Draught due to chimney effect A1 <i>deleted text</i> A1 of the air supply duct of connection pipes	64
15.9.3	Pressure resistance of the air supply duct of the chimney segment j ($P_{RB,j}$).....	65
15.10	Density and velocity of the supply air	68
15.10.1	Density and velocity of the supply air in the air supply duct averaged over the length of the chimney segment.....	68
15.10.2	Density and velocity of the supply air averaged over the length of the connection pipes	69
Annex A	(informative) Recommendations.....	70
A.1	Recommendations for the chimney and heating appliances:.....	70
A.2	Recommendations for connecting flue pipes:.....	70
Annex B	(informative) Characteristics for the heating appliance	71

Foreword

This document (EN 13384-2:2003+A1:2009) has been prepared by Technical Committee CEN /TC 166, "Chimneys", the secretariat of which is held by UNI.

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 July 2009, and conflicting national standards shall be withdrawn at the latest by July 2009.

This document includes Amendment 1 approved by CEN on 2008-11-23.

This document supersedes EN 13384-2:2003.

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

This standard is one of a series of standards prepared by CEN/TC 166 comprising product standards and execution standards for chimneys.

Annexes A and B are informative.

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

Introduction

The calculation described in this standard is complex and is intended to be solved by using a computer programme. The general principles of this calculation method of EN 13384-1 also apply to this standard.

This standard is in support of the execution standards for a chimney installation serving more than one heating appliance.

The execution standard identifies limitations and safety considerations associated with the design, installation, commissioning and maintenance of a chimney serving more than one heating appliance (not dealt within the calculation method).

1 Scope

This part of EN 13384 specifies methods for calculation of the thermal and fluid dynamic characteristics of chimneys serving more than one heating appliance.

This part of EN 13384 covers both the cases, either

- (1) where the chimney is connected with more than one connecting flue pipe from individual or several appliances in a multi-inlet arrangement or
- (2) where the chimney is connected with an individual connecting flue pipe connecting more than one appliance in a cascade arrangement.

The case of multiple inlet cascade arrangement is covered by the case (1).

A1 This part of EN 13384 deals with chimneys operating under negative pressure conditions (there can be positive pressure condition in the connecting flue pipe) and with chimneys operating under positive pressure conditions and is valid for chimneys serving heating appliances for liquid, gaseous and solid fuels. **A1**

This part of EN 13384 does not apply to:

- chimneys with different thermal resistance or different cross-section in the various chimney segments. This part does not apply to calculate energy gain.
- chimneys with open fire places, e.g. open fire chimneys or chimney inlets which are normally intended to operate open to the room
- chimneys which serve a mixture of fan assisted or forced draught burners or natural draught appliances. Fan assisted appliances with draught diverter between the fan and the chimney are considered as natural draught appliances.
- chimneys with multiple inlets from more than 5 storeys. (This does not apply to balanced flue chimney.)
- chimneys serving heating appliances with open air supply through ventilation openings or air ducts, which are not installed in the same air supply pressure region (e.g. same side of building).

A1 For positive pressure chimneys this part only applies if any heating appliance which is out of action can be positively isolated to prevent flue gas back flow. **A1**

2 Normative references

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

A1 EN 1443:2003 **A1** *Chimneys – General requirements*

A1 *deleted text* **A1**

EN 13384-1:2002 *Chimneys – Thermal and fluid dynamic calculation methods – Part 1: Chimneys serving one appliance*

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

EN 15287-2:2008, *Chimneys – Design, installation and commissioning of chimneys – Part 2: Chimneys for roomsealed appliances*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1443:2003, EN 13384-1:2002, EN 15287-1:2007, EN 15287-2:2008 and the following apply.

3.1 chimney segment

part of a chimney between two consecutive flue gas connections or between the last flue gas connection and the chimney outlet

3.2 collector segment

part of a connecting flue pipe between two consecutive flue gas connections or between the last flue gas connection and the chimney inlet

3.3 air-flue gas system

system of concentric or non concentric ducts or parallel ducts for transport of combustion air from the open air to the heating appliances and products of combustion from the heating appliances to the open air

3.4 flue gas mass flow ($\dot{m}$)

mass of the flue gas leaving the heating appliance through the connecting flue pipe per unit of time. In case of a chimney serving more than one heating appliance, the air being transported through an appliance which is out of action is also given the term flue gas mass flow.

3.4.1 declared flue gas mass flow ($\dot{m}_{W,j}$)

flue gas mass flow given by the manufacturer of the heating appliance j with respect to the heat output used in the calculation

3.4.2 calculated flue gas mass flow ($\dot{m}_{Wc,j}$)

flue gas mass flow calculated with respect to calculated draught and the working conditions of the heating appliance j

3.5 calculated flue gas temperature ($T_{Wc,j}$)

flue gas temperature at the outlet of the heating appliance j depending on the calculated flue gas mass flow

3.6 calculated draught of the flue gas of the heating appliance ($P_{Wc,j}$)

draught at the flue gas outlet of the heating appliance j depending on the calculated flue gas mass flow

3.7 flue damper

device to close or partially close the flue

3.8

balanced flue chimney

chimney where the point of air entry to the combustion air 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

3.9

cascade arrangement

arrangement where two or more appliances situated in the same space are connected by a common connecting flue pipe to the chimney

3.10

multi inlet arrangement

arrangement where two or more appliances situated in different spaces are connected to the chimney by individual connecting flue pipes

3.11

air duct

independent duct in a building or a structural part of a flue terminal conveying combustion air to a room-sealed appliance

3.12

pressure equalising opening

opening or duct that directly connects the air duct with the flue at its base

4 Symbols, terminology, units

Symbols, terminology and units are given to make the text of this standard understandable, although a part of them is already listed in part 1 of this standard series. Indices added to symbols for purposes of the calculation method for chimneys serving more than one heating appliance relate to one chimney segment and/or connection flue pipe section. An example of an indices numbering scheme is given in Figures 1 and 2. Indices numbering shall begin at the lowest, farthest appliance connection. For more than one cascade system/connection, the indices numbering scheme for the calculation formula should be adopted in a similar manner to that for a single cascade scheme. Symbols assigned to a specific section will be indicated by the number of the section after the comma (e. g. $H_{1,1}$ is the effective height of a section of a chimney segment between the outlet of the connecting flue pipe of the heating appliance in the lowest position and the outlet of the connecting flue pipe of the next heating appliance).

Table 1 - Symbols, terminology, units

Symbols	Terminology	Units
A	cross sectional area of the chimney	m^2
c_p	specific heat capacity of flue gas	$J/(kg \cdot K)$
D	diameter	m
D_h	hydraulic diameter	m
g	acceleration due to gravity = 9,81	m/s^2
H_j	effective height of the chimney segment j	m
$H_{V,j}$	effective height of the connecting flue pipe j	m
$K_{,j}$	coefficient of cooling of the chimney segment j	-
k_j	coefficient of heat transmission of the chimney segment j	$W/(m^2 \cdot K)$

$k_{ob,j}$	coefficient of heat transmission at upper end of the chimney segment j	W/(m ² ·K)
$K_{V,j}$	coefficient of cooling of the connecting flue pipe j	-
L_j	length of the chimney segment j	m
$\dot{m}_j$	flue gas mass flow in the chimney segment j	kg/s
$\dot{m}_{V,j}$	flue gas mass flow in the connecting flue pipe j	kg/s
$\dot{m}_{W,j}$	declared flue gas mass flow of the heating appliance j	kg/s
$\dot{m}_{Wc,j}$	calculated flue gas mass flow of the heating appliance j	kg/s
N	number of heating appliances serving the chimney	-
Nu	Nusselt number	-
$Q_{min,j}$	minimum heat output of the heating appliance j	kW
$Q_{N,j}$	nominal heat output of the heating appliance j	kW
$P_{B,j}$	pressure resistance of the air supply j of the heating appliance j	Pa
$P_{Bc,j}$	calculated pressure resistance of the air supply of the heating appliance j	Pa
$P_{H,j}$	theoretical draught available due to chimney effect in chimney segment j	Pa
P_L	wind velocity pressure	Pa
p_L	external air pressure	Pa
$P_{R,j}$	pressure resistance of the chimney segment j	Pa
Pr	Prandtl number	-
$P_{V,j}$	calculated pressure resistance of the connecting flue pipe j	Pa
$P_{W,j}$	minimum draught for the heating appliance j	Pa
$P_{Wc,j}$	calculated draught of the heating appliance j	Pa
$\langle A_1 \rangle P_{Wmax,j}$	maximum draught for the heating appliance j	Pa
$P_{WO,j}$	maximum differential pressure of the heating appliance j	Pa
$P_{Woc,j}$	calculated positive differential pressure of the heating appliance j	Pa
$P_{Womin,j}$	minimum differential pressure of the heating appliance j	Pa $\langle A_1 \rangle$
$P_{Z,j}$	draught at the flue gas inlet into the chimney segment j	Pa
$\langle A_1 \rangle P_{Z,min,j}$	minimum draught at the flue gas inlet into the chimney segment j	Pa
$P_{Zmax,j}$	maximum draught at the flue gas inlet into the chimney segment j	Pa
$P_{Ze,j}$	minimum draught required at the flue gas inlet into the chimney segment j	Pa
$P_{Zemax,j}$	maximum allowed draught at the flue gas inlet into the chimney segment j	Pa
$P_{ZO,j}$	maximum positive pressure at the flue gas inlet into the chimney segment j	Pa
$P_{ZOmin,j}$	minimum positive pressure at the flue gas inlet into the chimney segment j	Pa
$P_{ZOe,j}$	maximum differential pressure at the flue gas inlet into the chimney segment j	Pa
$P_{ZOemin,j}$	minimum differential pressure at the flue gas inlet into the chimney segment j	Pa $\langle A_1 \rangle$
R	gas constant of the flue gas	J/(kg·K)
r	mean value of roughness value of the inner wall	m

Re	Reynolds number	-
R_L	gas constant of the air	J/(kg·K)
S_E	flow safety coefficient	-
S_H	correction factor-of temperature instability	-
$T_{e,j}$	flue gas temperature at the inlet of the chimney segment j	K
$T_{g,j}$	temperature limit of the chimney segment j	K
$T_{lob,j}$	inner wall temperature at the outlet-of chimney segment j at temperature equilibrium	K
T_L	external air temperature	K
$T_{m,j}$	mean temperature of the flue gas in the chimney segment j	K
$T_{o,j}$	flue gas temperature at the outlet of the chimney segment j	K
$T_{u,j}$	ambient air temperature of the chimney segment j	K
$T_{W,j}$	declared flue gas temperature of the heating appliance j	K
$T_{Wc,j}$	calculated flue gas temperature of the heating appliance j	K
U	internal circumference of the chimney	m
$w_{m,j}$	mean velocity over the length and over the cross section of the chimney segment j	m/s
α_i	internal coefficient of heat transfer of the flue	W/(m ² ·K)
γ	angle between flow directions e. g. between connecting flue pipe and the chimney segment	deg
η_A	dynamic viscosity of flue gas	N·s/m ²
$\frac{1}{\Lambda}$	thermal resistance	m ² ·K/W
λ_A	coefficient of thermal conductivity of flue gas	W/(m·K)
$\rho_{m,j}$	density of flue gas averaged over the length and over the cross section of the chimney segment j	kg/m ³
ψ	coefficient of flow resistance due to friction of the flue	-
ζ	coefficient of flow resistance due to a directional and/or cross sectional and/or mass flow change in the flue	-

5 Calculation method

5.1 General principles

The calculation is based upon determining the mass flow distribution in the chimney which fulfils the pressure equilibrium condition (formula 1) at each flue gas inlet to the chimney (see Figure 1). After such a distribution has been found A_1 four A_1 requirements shall be verified:

- A_1 (1) the mass flow requirement (Equations 4 and 5)
- (2) the pressure requirement for minimum draught or maximum positive pressure (Equations 6 or 6b and 6c)
- (3) the pressure requirement for maximum draught or minimum positive pressure (Equation 6a or 6d)
- (4) the temperature requirement (Equation 7) A_1

[A1] NOTE 1 **[A1]** The calculation is affected by the specific installation design. For recommendations for the installation of appliance and connection flue pipes see Annex A.

[A1] NOTE 2 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 (draught) 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). **[A1]**

The validation of the mass flow requirement and pressure requirement shall be done at following working conditions, using the external and ambient air temperatures specified in EN 13384-1.

- All heating appliances are simultaneously operating at nominal heat output.
- All heating appliances are simultaneously operating at minimum heat output
- A single heating appliance operating at nominal heat output and all other appliances out of action (all possible cases)
- A single heating appliance operating at minimum heat output and all other appliances out of action (all possible cases)

If the control of the installation guarantees that not all appliances will be in operation simultaneously, the validation of the mass flow requirement and pressure requirement may be done with the maximum number of appliances which will be in operation under the most adverse condition.

The validation for the mass flow requirement and pressure requirement for working conditions with heating appliances at minimum heat output is not required in the following cases:

- the heating appliances do not have any heat output range
- the heating appliances have a heat output which is limited to a fixed value as specified on a label on the appliance. In this case the nominal heat output is the given heat output on the label.
- heating appliances heated with solid fuels without fan and appliances with regulated air supply.

The validation of the mass flow requirement for working conditions with appliances at nominal heat output is not required in the following case:

- the heating appliances have a flue gas mass flow at minimum heat output higher than or equal to the flue gas mass flow at nominal heat output.

The temperature requirement shall be validated for the following relevant working condition, using the ambient and external air temperatures as specified in EN 13384-1:

- heating appliances for solid fuels without fan and heating appliances with regulated air supply are in operation at nominal heat output,
- heating appliances with a draught diverter which provide domestic hot water only are out of action. These heating appliances operate with a considerable secondary air (These operate only a short time and therefore it can be assumed that condensation will not cause damage or a lack in safety);
- heating appliances with a fixed output range are in operation at this (nominal) heat output;
- all other heating appliances are in operation at minimum heat output.

When chimneys suitable for operating under wet conditions are located inside a building the check of the temperature requirement is necessary only for the top of the chimney.

The validation of the temperature requirement is not necessary when the chimney serves only domestic gas fired water heaters with instantaneous production and domestic gas fired storage water heaters.

If the chimney system includes a draught regulator, the system is handled as a cascade system.

5.2 Pressure equilibrium condition

5.2.1 A1 Negative pressure chimneys A1

The following formulae shall be fulfilled for each chimney segment j at all relevant working conditions:

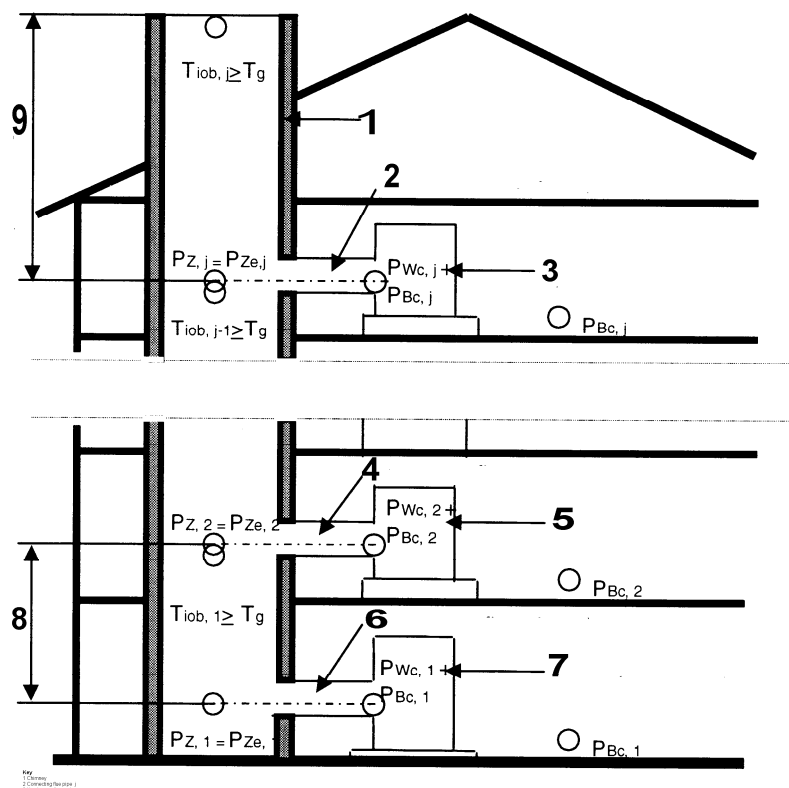
$$\left| P_{Z,j} - P_{Ze,j} \right| \leq 0,1 \quad \text{in Pa} \quad (1)$$

$$P_{Z,j} = -P_L + \sum_{k=j}^N (P_{H,k} - P_{R,k}) \quad \text{in Pa} \quad (2)$$

$$P_{Ze,j} = P_{Wc,j} + P_{V,j} + P_{Bc,j} \quad \text{in Pa} \quad (3)$$

Where:

$P_{Z,j}$	draught at the flue gas inlet to the chimney segment j	in Pa
$P_{H,k}$	theoretical draught due to chimney effect in chimney segment k	in Pa
$P_{R,k}$	pressure resistance of the chimney segment k	in Pa
$P_{Wc,j}$	calculated draught of the heating appliance	in Pa
$P_{V,j}$	calculated pressure resistance of the connecting flue pipe of chimney segment j	in Pa
$P_{Bc,j}$	calculated pressure resistance of the air supply for the heating appliance j	in Pa
$P_{Ze,j}$	required draught at the flue gas inlet to the chimney segment j	A1 in Pa A1
P_L	wind velocity pressure	A1 in Pa A1
N	number of heating appliances	



Key

- 1 Chimney
- 2 Connecting flue pipe j
- 3 Heating appliance j
- 4 Connecting flue pipe 2
- 5 Heating appliance 2
- 6 Connecting flue pipe 1
- 7 Heating appliance 1
- 8 Chimney segment 1
- 9 Chimney segment j

Figure 1 - Example of multiple inlet arrangement and numbering pressure values and temperature values of a chimney serving more than one heating appliance

5.2.2 A1 Positive pressure chimneys

The following equations shall be fulfilled for each chimney segment j at all relevant working conditions:

$$\left| P_{ZOe, j} - P_{ZO, j} \right| \leq 0,1 \quad \text{in Pa} \quad (3a)$$

$$P_{ZO, j} = P_L + \sum_{k=j}^N (P_{R, k} - P_{H, k}) \quad \text{in Pa} \quad (3b) \quad \text{A1}$$

$$\boxed{A_1} P_{ZOe,j} = P_{WOc,j} - P_{V,j} - P_{Bc,j} \quad \text{in Pa (3c)}$$

where

$P_{ZO,j}$	positive pressure at the flue gas inlet to the chimney segment j	in Pa
$P_{H,k}$	theoretical draught due to chimney effect in chimney segment k	in Pa
$P_{R,k}$	pressure resistance of the chimney segment k	in Pa
$P_{WOc,j}$	calculated positive differential pressure of the heating appliance j	in Pa
$P_{V,j}$	calculated pressure resistance of the connecting flue pipe of chimney segment j	in Pa
$P_{Bc,j}$	calculated pressure resistance of the air supply for the heating appliance j	in Pa
$P_{ZOe,j}$	maximum differential pressure at the flue gas inlet to the chimney segment j	in Pa
P_L	wind velocity pressure	in Pa
N	number of heating appliances $\boxed{A_1}$	

5.3 Mass flow requirement

$\boxed{A_1}$ Equations 4 and/or. 5 $\boxed{A_1}$ shall be verified for all relevant working conditions (see 5.6).

For each heating appliance in operation at nominal or minimum heat output :

$$\dot{m}_{Wc,j} \geq \dot{m}_{W,j} \quad \text{in kg/s (4)}$$

and for each heating appliance out of action:

$$\dot{m}_{Wc,j} \geq 0 \quad \text{in kg/s (5)}$$

Where:

$\dot{m}_{Wc,j}$	calculated mass flow of the heating appliance	in kg/s
$\dot{m}_{W,j}$	declared mass flow of the heating appliance	in kg/s

Where a damper is applied, flow resistance shall be taken as 0 unless additional data are available.

5.4 Pressure $\boxed{A_1}$ requirements

5.4.1 Negative pressure chimneys

For negative pressure chimneys it has to be additionally checked that the negative pressure (minimum draught) in the chimney ($P_{Z,j}$) is more than or equal to the negative pressure in the room where the heating appliance is placed at calculated draught conditions for air supply. The check on this pressure requirement shall be done using the same conditions as specified for the check on the mass flow requirement (see 5.3 and 5.6). The following relations shall be verified:

$$P_{Z,j} \geq P_{Bc,j} \quad \text{in Pa (6)}$$

where $\boxed{A_1}$

A1 $P_{Z,j}$ draught at the inlet to the chimney segment j in Pa

$P_{Bc,j}$ calculated pressure resistance of the air supply for the heating appliance j in Pa

If required it has to be additionally checked that the negative pressure (draught) in the chimney ($P_{Zmax,j}$) is less than or equal to the maximum allowed draught ($P_{Zemax,j}$) caused by the heating appliance. The relation (6a) shall be verified for all relevant working conditions (see 5.6).

The check of this pressure requirement shall be done with a separate calculation using the newly calculated flue mass flows that fulfil the pressure equilibrium conditions at an external air temperature of $T_L = 258,15$ K ($t_L = -15$ °C, see EN 13384-1).

$$P_{Zmax,j} = \sum_{k=j}^N (P_{H,k} - P_{R,k}) \leq P_{Wmax,j} + P_{V,j} + P_{Bc,j} = P_{Zemax,j} \quad \text{in Pa} \quad (6a)$$

where

$P_{Zmax,j}$	maximum draught at the flue gas inlet into the chimney segment j in Pa
$P_{Zemax,j}$	maximum allowed draught at the flue gas inlet into the chimney segment j in Pa
$P_{H,k}$	theoretical draught due to chimney effect in chimney segment k in Pa
$P_{R,k}$	pressure resistance of the chimney segment k in Pa
$P_{Wmax,j}$	maximum draught for the heating appliance j in Pa
$P_{V,j}$	calculated pressure resistance of the connecting flue pipe of chimney segment j in Pa
$P_{Bc,j}$	calculated pressure resistance of the air supply for the heating appliance j in Pa

NOTE The values of $P_{H,k}$ and $P_{R,k}$ in Equations (2) and (6a) are normally different because the conditions are different. **A1**

5.4.2 **A1** Positive pressure chimneys

For positive pressure chimneys it has to be additionally checked that the maximum positive pressure in the connecting flue pipe ($P_{ZO,j} + P_{V,j}$) and in the chimney ($P_{ZO,j}$) is not higher than the excess pressure for which both are designated ($P_{ZV\ excess}$ and $P_{Z\ excess}$). The check on the pressure requirement shall be done using the same conditions as specified for the check on the mass flow requirement (see 5.3 and 5.6). The following relations shall be verified:

$$P_{ZO,j} \leq P_{Z\ excess} \quad \text{in Pa} \quad (6b)$$

$$P_{ZO,j} + P_{V,j} \leq P_{ZV\ excess} \quad \text{in Pa} \quad (6c)$$

where

$P_{ZO,j}$ positive pressure at the flue gas inlet to the chimney segment j in Pa

$P_{V,j}$ calculated pressure resistance of the connecting flue pipe of chimney segment j 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 **A1**

A1 If required it has to be additionally checked that the minimum positive pressure in the chimney ($P_{ZOmin,j}$) is more than or equal to the minimum allowed positive pressure ($P_{ZOemin,j}$) caused by the heating appliance. The relation (6d) shall be verified for all relevant working conditions (see 5.6).

The check of this pressure requirement shall be done with a separate calculation using the newly calculated flue mass flows that fulfil the pressure equilibrium conditions at an external air temperature of $T_L = 258,15 \text{ K}$ ($t_L = -15 \text{ °C}$, see EN 13384-1).

$$P_{ZOmin,j} = \sum_{k=j}^N (P_{R,k} - P_{H,k}) \geq P_{WOmin,j} - P_{Bc,j} - P_{V,j} = P_{ZOemin,j} \quad \text{in Pa} \quad (6d)$$

where

$P_{ZOmin,j}$	minimum positive pressure at the flue gas inlet into the chimney segment j in Pa
$P_{ZOemin,j}$	minimum differential pressure at the flue gas inlet into the chimney segment j in Pa
$P_{H,k}$	theoretical draught due to chimney effect in chimney segment k in Pa
$P_{R,k}$	pressure resistance of the chimney segment k in Pa
$P_{WOmin,j}$	minimum differential pressure of the heating appliance j in Pa
$P_{Bc,j}$	calculated pressure resistance of the air supply for the heating appliance j in Pa
$P_{V,j}$	calculated pressure resistance of the connecting flue pipe of chimney segment j in Pa

NOTE The values of $P_{H,k}$ and $P_{R,k}$ in Equations (3b) and (6d) are normally different because the conditions are different. **A1**

5.5 Temperature requirement

The relations (7) shall be verified for all relevant working conditions (see 5.6).

The check of the temperature requirement shall be done with a separate calculation using the newly calculated flue mass flows that fulfil the pressure equilibrium conditions at an external air temperature of $T_{u0,j}$ (see EN 13384-1)

$$T_{iob,j} \geq T_{g,j} \quad \text{in K (7)}$$

Where:

$T_{iob,j}$	temperature of the inner wall of the chimney segment j at the end	in K
$T_{g,j}$	temperature limit for chimney segment j	in K

The temperature limit $T_{g,j}$ for chimneys suitable for operating under dry conditions is equal to the condensing temperature $T_{sp,j}$ of the flue gas (see 8.6). $T_{g,j} = T_{sp,j}$

The temperature limit $T_{g,j}$ for chimneys suitable for operating under wet conditions is equal to the freezing point of water: $T_{g,j} = 273,15$ K.

NOTE The following cases can be exempted from meeting the temperature requirement provided that it is accepted that in case the requirement for temperature should be not fulfilled no guarantee can be given that no moisture appears. In this cases insulation is recommended.

- heating appliances which are substituted to a usual chimney which is already in operation and
- the heat output of the heating appliances which are connected and/or substituted does not exceed 30 kW for each and
- the flue gas losses are not more or equal than 8 % and
- an effective air conditioning of the chimney during standstill periods is given by draught diverters or dampers and
- sufficient standstill periods are given (e. g. the minimum steady state heat output of the heating appliance is not less than 20 % as the required heat).

5.6 Calculation procedure

For the calculation of the pressure and temperature values in a chimney serving more than one heating appliance an iterative procedure is necessary. This calculation procedure is based on the application of mass and energy conservation formulae under quasi steady state conditions.

In each point of connection between various ducts (at the end of connecting flue pipes, the $\boxed{A_1}$ beginning $\langle A_1 \rangle$ and the end of the chimney segments), all called nodes (see Figure 2), the following procedure shall be used:

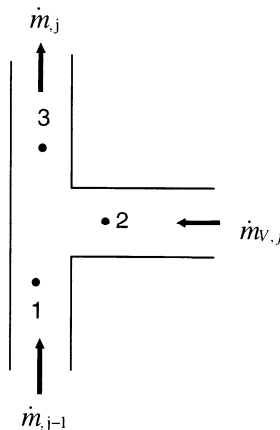


Figure 2 - Designation of flow numbering for each node j (see formulae 8 and 9)

- The mass flow and the temperature shall be calculated with formulae 8 and 9.

$$\dot{m}_{j-1} + \dot{m}_{V,j} = \dot{m}_j \quad \text{in kg/s (8)}$$

$$\dot{m}_{j-1} \cdot c_{p,j-1} \cdot T_{o,j-1} + \dot{m}_{V,j} \cdot c_{pV,j} \cdot T_{oV,j} = \dot{m}_j \cdot c_{p,j} \cdot T_{e,j} \quad \text{in J/s (9)}$$

where:

$\dot{m}_{j-1}$	flue gas mass flow in chimney segment j-1	in kg/s
$\dot{m}_{V,j}$	flue gas mass flow in connecting flue pipe	in kg/s
$\dot{m}_j$	flue gas mass flow in chimney segment j	in kg/s
$c_{p,j-1}$	specific heat capacity of flue gas in chimney segment j-1	in J/(kg·K)
$c_{pV,j}$	specific heat capacity of flue gas in connecting flue pipe j	in J/(kg·K)
$c_{p,j}$	specific heat capacity of flue gas in chimney segment j	in J/(kg·K)
$T_{o,j-1}$	temperature of the flue gas at the end of chimney segment j-1	in K
$T_{oV,j}$	temperature of the flue gas at the end of connecting flue pipe j	in K
$T_{e,j}$	temperature of the flue gas at the inlet of chimney segment j	in K

- $\overline{A_1}$ The draught or positive pressure at the beginning of the chimney segment (at point 3), is derived from the draught or positive pressure of this chimney segment and all succeeding segments according to Equation 2. $\overline{A_1}$

NOTE For certain fan assisted heating appliances according to the information of the manufacturer it can be assumed that the mass flow is independent of the draught $\overline{A_1}$ or positive pressure $\overline{A_1}$ in the chimney. This information can be used to limit the number of iterations.

For each iteration the following parameters shall be obtained:

- $\overline{A_1}$ for each node j , the actual pressure ($P_{Ze,j}$, $P_{Z,j}$ or $P_{ZOe,j}$, $P_{ZO,j}$ and where required $P_{Zemax,j}$, $P_{Zmax,j}$ or $P_{ZOemin,j}$, $P_{ZOmin,j}$) and temperature values ($T_{o,j-1}$ at point 1, $T_{oV,j}$ at point 2, $T_{e,j}$ at point 3),
- for each segment between two nodes, the average values of the actual temperature, mass flow and velocity of the flue gas. $\overline{A_1}$

Before the first iteration an estimate of the calculated flue gas mass flow at the appliance outlet is necessary. A possible starting value for the calculated mass flow is the declared flue gas mass flow of the appliance $\dot{m}_{W,j}$.

Each iteration consists of the following two phases:

Phase 1: Calculate variables starting from the lowest node up to the outlet to the atmosphere as follows:

- calculated/estimated flue gas mass flow at the appliance outlet
- in each connecting flue pipe
 - calculated mass flow ($\dot{m}_{A1}$) Equation 14 ($\dot{m}_{A1}$);
 - average density of the flue gas (formula 29);
 - average velocity of the flue gas (formula 30);
 - flue gas temperature at the end (see EN 13384-1:2002, 5.8);
 - average flue gas temperature (see EN 13384-1:2002, 5.8).
- in each $\dot{m}_{A1}$ segment section of the flue
 - calculated mass flow after the confluence of each segment (point 3 in Figure 2) (Equation 13) ($\dot{m}_{A1}$);
 - temperature of the flue gas after the confluence (formula 15)
 - average density of the flue gas (formula 27);
 - average velocity of the flue gas (formula 28);
 - flue gas temperature at the end (see EN 13384-1:2002, 5.8);
 - average flue gas temperature (see EN 13384-1:2002, 5.8).

Phase 2: Calculate the draught $\dot{m}_{A1}$ or positive pressure $\dot{m}_{A1}$ values in each node tracking the flue duct backwards from the outlet into the atmosphere down to the node that is at the greatest distance:

- draught required $\dot{m}_{A1}$ or differential pressure available at the flue gas inlet into the chimney (Equation 3 or 3c) ($\dot{m}_{A1}$);
- draught due to chimney effect at the inlet of the chimney segment (formula 31);
- pressure resistance in the chimney segment (using formula 32);
- draught $\dot{m}_{A1}$ or positive pressure at the inlet of the chimney segment (using Equation 2 or 3b) ($\dot{m}_{A1}$);

The iteration described above (phase 1 and phase 2) at the working conditions under consideration (i.e. nominal, minimum load and out of action) shall be continued until the pressure equilibrium condition is fulfilled (formula 1).

When the pressure equilibrium condition is fulfilled, the values calculated at the last iteration can be considered, for the purpose of this standard, to be those regarding the operation of the chimney.

If the pressure equilibrium condition is not fulfilled a new estimate of $\dot{m}_{W,j}$ based on the observed difference between $P_{Z,j}$ and $P_{Ze,j}$ ($\dot{m}_{A1}$) or $P_{Zo,j}$ and $P_{Zoe,j}$ ($\dot{m}_{A1}$) and a new iteration shall be made.

6 Flue gas data characterising the heating appliance

For the calculation of the temperature and pressure values the relevant flue gas data characterising the heating appliance shall be specified. This includes:

- minimum, declared draught $\dot{m}_{A1}$ or maximum declared differential pressure of the heating appliance ($P_{W,j}$ or $P_{WO,j}$) ($\dot{m}_{A1}$);
- declared flue gas temperature of the heating appliance ($t_{W,j}$)

Both values shall be given in relation to the flue gas mass flow at various working conditions of the heating appliances (in operation, out of action). The calculated draught $P_{Wc,j}$ ($\dot{m}_{A1}$) or differential pressure $P_{Woc,j}$ ($\dot{m}_{A1}$) of the heating appliance shall be given for both working conditions in form of a 4th degree poly-nominal (formula 10).

$$P_{Wc,j} = b_0 + b_1 \cdot \left(\frac{\dot{m}_{Wc,j}}{\dot{m}_{Wj}} \right) + b_2 \cdot \left(\frac{\dot{m}_{Wc,j}}{\dot{m}_{Wj}} \right)^2 + b_3 \cdot \left(\frac{\dot{m}_{Wc,j}}{\dot{m}_{Wj}} \right)^3 + b_4 \cdot \left(\frac{\dot{m}_{Wc,j}}{\dot{m}_{Wj}} \right)^4 \text{ in Pa} \quad (10)$$

$${}^{A1} P_{Woc,j} = c_0 + c_1 \cdot \left(\frac{\dot{m}_{Wc,j}}{\dot{m}_{W,j}} \right) + c_2 \cdot \left(\frac{\dot{m}_{Wc,j}}{\dot{m}_{W,j}} \right)^2 + c_3 \cdot \left(\frac{\dot{m}_{Wc,j}}{\dot{m}_{W,j}} \right)^3 + c_4 \cdot \left(\frac{\dot{m}_{Wc,j}}{\dot{m}_{W,j}} \right)^4 \quad \text{in Pa} \quad (10a) \quad {}^{A1}$$

$$t_{Wc,j} = y_0 + y_1 \cdot \left(\frac{\dot{m}_{Wc,j}}{\dot{m}_{W,j}} \right)^{y_2} \quad \text{in } ^\circ\text{C} \quad (11)$$

Where:

$b_0, b_1, b_2,$

b_3, b_4 factors for the poly-nominal in the ^{A1} equation for calculated draught of heating appliance j

y_0, y_1, y_2 factors for the exponential in the equation for calculated flue gas temperature of heating appliance j

$\dot{m}_{Wc,j}$ calculated flue gas mass flow of heating appliance j in kg/s

$\dot{m}_{W,j}$ declared flue gas mass flow of heating appliance j in kg/s

$P_{Wc,j}$ calculated draught of the heating appliance in Pa

$P_{Woc,j}$ calculated differential pressure of the heating appliance in Pa

$t_{Wc,j}$ calculated flue gas temperature of the heating appliance in $^\circ\text{C}$

c_0, c_1, c_2, c_3, c_4 factors for the poly-nominal in the equation for calculated differential pressure of heating appliance j

For negative pressure chimneys the values for b and y shall be obtained for “in operation” and “out of action” conditions separately. In case these values are not given, the flue gas data characterising the appliance are given in Annex B.

For positive pressure chimneys the values for c and y shall be obtained for the “in operation” conditions, from the heating appliance manufacture’s data.

NOTE 1 If the data for the “in operation” conditions are not available the calculation is not possible.

For the “out of action” condition c_0, c_1, c_3, c_4 and y_0, y_1, y_2 shall be 0 and $c_2 = -1\,000\,000$.

NOTE 2 For positive pressure applications the validation of the mass flow relies in the fact that there is no possibility of backflow of flue gas through a heating appliance that is out of action. ^{A1}

In addition the declared volumetric concentration of CO_2 of the flue gases at the relevant working conditions (nominal heat output and minimum heat output for the appliances $\sigma(\text{CO}_2)_{W,j}$ shall be specified. The declared content of CO_2 of the flue gases at the two working conditions can also be determined with Table B.1 and Table B.2 of EN 13384-1:2002.

The calculated CO_2 content of the flue gas of the heating appliance j $\sigma(\text{CO}_2)_{Wtat,j}$ shall be determined for the two working conditions “in operation at nominal heat output” and “in operation at minimum output” using the following formula:

- for heating appliances for liquid and gaseous fuels and heating appliances for solid fuels with automatic feed

$$\sigma(\text{CO}_2)_{Wc,j} = \frac{1}{\left(\frac{\dot{m}_{Wc,j}}{\dot{m}_{W,j}} \right) \frac{1}{\sigma(\text{CO}_2)_{W,j}} + \left[\left(\frac{\dot{m}_{Wc,j}}{\dot{m}_{W,j}} \right) - 1 \right] \frac{f_{m2}}{f_{m1}}} \quad \text{in Vol.-%} \quad (12)$$

– in other cases

$$\sigma(\text{CO}_2)_{\text{Wc},j} = \sigma(\text{CO}_2)_{\text{W},j} \quad \text{in Vol.-%}$$

Where:

$\sigma(\text{CO}_2)_{\text{W},j}$	declared CO_2 content of the flue gas of heating appliance j	in Vol.-%
$\sigma(\text{CO}_2)_{\text{Wc},j}$	calculated CO_2 content of the flue gas of heating appliance j	in Vol.-%
$f_{\text{m}1}, f_{\text{m}2}$	coefficients according to EN 13384-1	
$\dot{m}_{\text{Wc},j}$	calculated flue gas mass flow of heating appliance j	in kg/s
$\dot{m}_{\text{W},j}$	declared flue gas mass flow of heating appliance j	in kg/s

ⓘ For the calculation of a negative pressure chimney the value of the maximum draught for the heating appliance P_{Wmax} and 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. ⓘ

7 Data for chimney and connecting flue pipes

ⓘ The mean roughness value for the inner wall (r_j and/or ($r_{\text{V},j}$) and the thermal resistance ($\left(\frac{1}{\lambda}\right)_{,j}$ and/or ($\left(\frac{1}{\lambda}\right)_{\text{V},j}$) for each connecting flue pipe and each chimney segment shall be identified (see EN 13384-1:2002, 5.6.2). ⓘ

8 Basic data for the calculation

The basic data for the calculation shall be identified for each chimney segment unless otherwise specified in this clause.

8.1 Air temperatures

8.1.1 External air temperature (T_{L})

For the calculation of the external air temperature (T_{L}) see EN 13384-1:2002, 5.7.1.2; a single value is relevant for all chimney segments.

8.1.2 Ambient air temperature (T_{u})

For the calculation of the ambient air temperature (T_{u}) see EN 13384-1:2002, 5.7.1.3.

8.2 External air pressure (p_{L})

For the calculation of the external air pressure (p_{L}) see EN 13384-1:2002, 5.7.2, a single value is relevant for all chimney segments.

8.3 Gas constant

8.3.1 Gas constant of the air (R_{L})

For the calculation of the gas constant of the air (R_{L}) see EN 13384-1:2002, 5.7.3.1, a single value is relevant for all chimney segments.

8.3.2 Gas constant of flue gas (R)

For the calculation of the gas constant of flue gas (R) see EN 13384-1:2002, 5.7.3.2.

For gas mixing use formula 19 in this standard.

8.4 Density of air (ρ_L)

For the calculation of the density of air (ρ_L) see EN 13384-1:2002, 5.7.4. A single value is relevant for all chimney segments.

8.5 Specific heat capacity of the flue gas (c_p)

For the calculation of the specific heat capacity of the flue gas (c_p) see EN 13384-1:2002, 5.7.5.

For gas mixing use formulae 20, 21, 22 in this standard.

8.6 Water vapour content ($\sigma(\text{H}_2\text{O})_{\text{j}}$) and condensing temperature (T_{sp})

For the calculation of the water vapour content ($\sigma(\text{H}_2\text{O})_{\text{j}}$) and condensing temperature (T_{sp}) see EN 13384-1:2002, 5.7.6.

For gas mixing use formula 18 in this standard.

8.7 Correction factor for temperature instability (S_H)

A single value is relevant for all chimney segments.

[A1] For the check of the mass flow requirement and for the check of the pressure requirement for minimum draught and maximum positive pressure $S_H = 0,5$ shall be used for each chimney segment; for maximum draught or minimum positive pressure the correction factor S_H for temperature instability shall be 1.

8.8 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, and for room sealed appliances with forced draught burners.

For the calculation of maximum positive pressure of positive pressure chimneys the safety coefficient $S_E = 1,2$ shall be used.

For the air supply duct a flow safety coefficient $S_{EB} = 1,2$ shall be used.

For the calculation of maximum draught or minimum positive pressure the safety coefficient S_E and S_{EB} shall be 1. **[A1]**

8.9 External coefficient of heat transfer

For the calculation of the **[A1]** external **[A1]** coefficient of heat transfer see EN 13384-1:2002, 5.8.3.3.

9 Determination of temperatures

The following temperature values shall be calculated according to EN 13384-1:2002, 5.8

- the calculated flue gas temperatures of the heating appliance ($T_{\text{wc,j}}$) using flue gas data characterising the appliance (formula 11),
- the mean flue gas temperatures in the connecting flue pipes ($T_{\text{mv,j}}$),
- the flue gas temperatures at the end of the connecting flue pipes ($T_{\text{ov,j}}$),
- the flue gas temperatures after gas mixing at the beginning of the chimney segments (T_{ej} , formula 7),