BS EN 13084-1:2007

BSI Standards Publication

Free-standing chimneys

Part 1: General requirements

National foreword

This British Standard is the UK implementation of EN 13084-1:2007. It supersedes BS EN 13084-1:2000 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee B/506/14, Structural Chimneys and Flues.

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

BSI, as a member of CEN, is obliged to publish EN 13084-1 as a British Standard. However, attention is drawn to the fact that during the development of this European Standard, the UK committee voted against its approval as a European Standard. Reasons for the objection are as follows:

– There is no calibration between this standard, BS EN 1993-3-2 and the National Annex to BS EN 1991-1-4, and existing design practice, which would ensure the BS EN standards provide safe designs.

– BS EN 13084-1 refers to the Wind Code in BS EN 1991-1-4. According to the UK committee, the National Annex to EN 1991-1-4 is not compatible with modern computer design for free-standing chimneys.

– The UK committee believes that BS EN 13084-1 contains ambiguities that could lead to incorrect data input and would draw users attention to the following concerns in particular:

- The factors C_{DIR} and C_{SEASON}, referred to in Subclause 5.2.3.2.2, only cover aspect ratios below 10, which could be considered too low for many chimneys.
- In relation to Subclause 5.2.4.1, it is the opinion of the UK committee that the steel chimneys mentioned in the note refer to *unlined* steel chimneys. Seismic loading can be significant on refractory-lined stacks and particularly brick-lined steel stacks.
- The degree of uplift allowed in Subclause 5.4 could allow for uplift to occur in relatively low winds with consequent softening of the substrate. This risk would increase with a foundation on clay soil.

Consequently, the UK committee recommend the continued use of the relevant CICIND Codes for the design and build of concrete and steel industrial chimneys. CICIND stands for 'Comité International des Cheminées Industrielles'.

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

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

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Freistehende Schornsteine - Teil 1: Allgemeine Anforderungen

This European Standard was approved by CEN on 23 December 2006.

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.

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Foreword

This document (EN 13084-1:2007) has been prepared by Technical Committee CEN/TC 297 “Free- standing industrial chimneys”, the secretariat of which is held by DIN.

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 August 2007, and conflicting national standards shall be withdrawn at the latest by August 2007.

This document supersedes EN 13084-1:2000

This document is part 1 of a package of standards as listed below.

- EN 13084-1, *Free-standing chimneys - Part 1: General requirements*
- EN 13084-2, *Free-standing chimneys - Part 2: Concrete chimneys*
- EN 13084-4, *Free-standing chimneys - Part 4: Brick liners – Design and execution*
- EN 13084-5, *Free-standing chimneys - Part 5: Material for brick liners - Product specifications*
- EN 13084-6, *Free-standing chimneys - Part 6: Steel liners - Design and execution*
- EN 13084-7, *Free-standing chimneys – Part 7: Product specifications of cylindrical steel fabrications for use in single wall steel chimneys and steel liners*
- EN 13084-8, *Free-standing chimneys – Part 8: Design and execution of mast construction with satellite components*

Additionally applies:

- EN 1993-3-2, *Eurocode 3 - Design of steel structures – Part 3-2: Towers, masts and chimneys – Chimneys*

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.

1 Scope

This European Standard deals with the general requirements and the basic performance criteria for the design and construction of all types of free-standing chimneys including their liners. A chimney may also be considered as free-standing, if it is guyed or laterally supported or if it stands on another structure.

Chimneys attached to buildings have to be structurally designed as free-standing chimneys in accordance with this European Standard when at least one of the following criteria is met:

- the distance between the lateral supports is more than 4 m;
- the free-standing height above the uppermost structural attachment is more than 3 m;
- the free-standing height above the uppermost structural attachment for chimneys with rectangular cross section is more than five times the smallest external dimension;
- the horizontal distance between the building and the outer surface of the chimney is more than 1 m.

Chimneys attached to free-standing masts are considered as free-standing chimneys.

The structural design of free-standing chimneys takes into account operational conditions and other actions to verify mechanical resistance and stability and safety in use. Detailed requirements relating to specialized designs are given in the standards for concrete chimneys, steel chimneys and liners.

NOTE In other parts of the series EN 13084 rules will be given where chimney products in accordance with EN 1443 (and the relating product standards) may be used in free-standing chimneys.

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.

EN 287-1, *Qualification test of welders - Fusion welding - Part 1: Steels*

EN 1418, *Welding personnel - Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanized and automatic welding of metallic materials*

EN 1443, *Chimneys - General requirements*

EN 13084-2, *Free-standing chimneys – Part 2: Concrete chimneys*

EN 13084-4, *Free-standing chimneys – Part 4: Brick liners – Design and execution*

EN 13084-5, *Free-standing chimneys – Part 5: Materials for brick liners - Product specifications*

EN 13084-6, *Free-standing chimneys – Part 6: Steel liners - Design and execution*

EN 13084-7, *Free-standing chimneys – Part 7: Product specifications of cylindrical steel fabrications for use in single wall steel chimneys and steel liners*

EN 13084-8, *Free-standing chimneys – Part 8: Design and execution of mast construction with satellite components*

EN 1990, *Eurocode – Basis of structural design*

EN 1991-1-1, *Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings*

EN 1991-1-4:2005, *Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions*

EN 1993-3-2, *Eurocode 3 - Design of steel structures - Part 3-2: Towers, masts and chimneys - Chimneys*

EN 1998-6, *Eurocode 8: Design of structures for earthquake resistance - Part 6: Towers, masts and chimneys*

EN ISO 3834-2, *Quality requirements for fusion welding of metallic materials - Part 2: Comprehensive quality requirements (ISO 3834-2:2005)*

EN ISO 14731, *Welding co-ordination - Tasks and responsibilities (ISO 14731:2006)*

EN ISO 15607, *Specification and qualification of welding procedures for metallic materials - General rules (ISO 15607:2003)*

EN ISO 15609-1, *Specification and qualification of welding procedures for metallic materials - Welding procedure specification - Part 1: Arc welding (ISO 15609-1:2004)*

EN ISO 15610, *Specification and qualification of welding procedures for metallic materials - Qualification based on tested welding consumables (ISO 15610:2003)*

EN ISO 15611, *Specification and qualification of welding procedures for metallic materials - Qualification based on previous welding experience (ISO 15611:2003)*

EN ISO 15612, *Specification and qualification of welding procedures for metallic materials - Qualification by adoption of a standard welding procedure (ISO 15612:2004)*

EN ISO 15613, *Specification and qualification of welding procedures for metallic materials - Qualification based on pre-production welding test (ISO 15613:2004)*

EN ISO 15614-1, *Specification and qualification of welding procedures for metallic materials - Welding procedure test - Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys (ISO 15614-1:2004)*

EN ISO 15614-2, *Specification and qualification of welding procedures for metallic materials - Welding procedure test - Part 2: Arc welding of aluminium and its alloys (ISO 15614-2:2005)*

3 Terms and definitions

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

3.1
windshield
structural shell designed for load bearing purposes and to protect the flue from wind actions

NOTE It may also function as a flue.

3.2
lining system
total system, if any, which separates the flue gases from the windshield. This comprises a liner and its supports, the space between liner and windshield and insulation, where existing

3.3
liner
structural membrane of the lining system

3.4
accessible space
space between windshield and liner that is designed for entry by personnel

3.5
spoiler
device attached to the surface of a chimney with the objective of reducing cross wind response

3.6
protective cap
cap at the top of the chimney which covers the space between windshield and liner

3.7
climbing sockets
threaded sockets inserted in the concrete windshield to enable climbing dogs to be attached to the surface

3.8
down draught
negative pressure on the lee-side of the chimney top, which can cause the flue gases to be drawn down

3.9
guyed chimney
chimney, the stability of which is ensured by guy ropes

3.10
intransient heat flow
flow of heat, where the temperature of each point does not change with time

3.11
transient heat flow
flow of heat, where the temperature changes with time

3.12
positive pressure
pressure inside the liner which is greater than the pressure outside the liner

3.13
negative pressure
pressure inside the liner which is lower than the pressure outside the liner

3.14
flue gas
gaseous products of combustion or other processes, including air, which may comprise of solids or liquids

3.15
concrete chimney
chimney, the windshield of which is made of concrete

3.16
steel chimney
chimney, the windshield of which is made of steel

4 Performance requirements; general design

4.1 Materials

Materials shall conform to the appropriate CEN or ISO standards. Where no such standards exist, other materials may be used if their properties are well defined and their suitability has been proven. This proof shall take account of the mechanical, thermal and chemical loads.

For concrete and steel chimneys as well as for liners see EN 13084-2, EN 13084-4, EN 13084-5, EN 13084-6, EN 13084-7, EN 13084-8 and EN 1993-3-2.

4.2 Flue gas considerations

4.2.1 General

Thermal and flow calculations shall be carried out to ensure that the flue gases will be conveyed from the combustion appliance to atmosphere taking into account the effects of the flue gases on the environment and the safety in use. However, the effect of the flue gases concerning the pollution with gaseous and particle components is not the subject matter of this standard.

To carry out these calculations, design parameters as stated in 4.2.2 are required. These also apply to the assessment of chemical attack on those structural elements which are in contact with flue gases.

4.2.2 Design parameters

The following design parameters shall take into account the various operating conditions during normal and defined abnormal operations:

a) nature of chimney operation, whether continuous, intermittent or occasional;

b) planned frequency of shut-downs for internal inspection and maintenance;

c) composition of the flue gases and concentrations of chemicals in the flue gases deleterious for the chimney;

d) concentration of dust and particularly of abrasive dust in the flue gas;

e) mass flow of each flue gas stream;

f) flue gas temperature at entry of each flue gas duct into chimney;

g) range of maximum acid dew point temperatures of the flue gases;

h) admissible or required pressure at entry of flue gas ducts into chimney;

i) altitude of the site and any special local topographic features (e.g. nearby hills, cliffs);

j) maximum, average and minimum outside temperature;

k) maximum, average and minimum atmospheric pressure;

l) maximum, average and minimum humidity of the ambient air;

m) relevant design parameters used for appliances (for example boiler) to which the chimney is connected.

4.2.3 Heat flow calculations

Temperatures in the flue gas carrying tube, in thermal insulating layers and in the windshield shall be determined. The drop in the temperature of the flue gases as they pass up to the outlet shall be calculated.

Values for thermal conductivity and the heat transfer coefficient may be taken from Table 1 and Table 2 respectively. Values for materials not included in these tables or values differing from these, may be taken if their source is referenced.

Table 1 — Thermal conductivities for building materials

Material	Description	Bulk density ρ kg/m^3	Temperature T °C	Thermal conductivity λ W/(m·K)
Concrete		2400		2,1
Lightweight concrete		1000 1200 1400 1600 1800 2000		0,47 0,59 0,72 0,87 0,99 1,20
Brickwork		1800 2000 2200		0,81 0,96 1,00
Acid resistant brickwork				1,2
Brickwork of diatomaceous clay		800 800 800 500 [a] 500 [a] 500 [a]	200 400 600 200 400 600	0,18 0,19 0,21 0,09 0,10 0,11
Cellular glass		130	20 200 300	0,05 0,09 0,12
Mineral wool resistant up to 750 °C		90	50 100 150 200 250 300 400 500 600	0,038 0,045 0,053 0,064 0,076 0,090 0,122 0,168 0,230
		125	50 100 150 200 250 300 400 500 600	0,039 0,046 0,053 0,061 0,070 0,080 0,105 0,140 0,180
Structural steel and weather resistant structural steel		7850		60
Stainless steel	X5CrNi18-10 X6CrNiTi18-10 X6CrNiMoTi17-12-2 X2CrNiMo17-12-2 X2CrNiMo18-14-3 X1NiCrMoCu25-20-5	7900 7900 7980 7950 7980 8000		15 15 15 14 15 14

NOTE Where no values for bulk density and temperature are given, the thermal conductivity λ may be assumed as independent of these values.

a Shall only be used as insulation.

Table 2 — Heat transfer coefficients[a]

Zone	Heat transfer coefficient α W/(m²·K)
Inner surface of the liner	$8+w$ [b]
In case of accessible space between windshield and liner: — outer surface of the liner — inner surface of the windshield	 8 8
In case of non-accessible space between windshield and liner: — outer surface of the liner: — temperature > 80 °C; — temperature ≤ 80 °C — inner surface of the windshield	 20 12 8
Outer surface of the windshield	24 [c]

[a] These values are approximate values which lead to sufficiently accurate results for flue gas carrying tubes with an interior diameter of more than 1 m.

[b] w is the mean flue gas velocity in m/s. A detailed calculation of α is given in Annex A.

[c] For verification of the suitability of the materials as regards temperature a value α = 6 W/(m²·K) shall be taken.

4.2.4 Flow calculations

Flow calculations shall include calculations of pressure conditions inside the flue gas carrying tube and of flow velocity. They have to take into account the density of the flue gases and of the ambient air as well as energy losses, such as directional losses, losses due to friction and due to the joints.

If flue gas can permeate through the liner, for example in a brickwork liner, no positive pressure is allowed during normal operation conditions.

NOTE The start up pressure is not a normal operating condition in accordance with this European Standard.

The calculation should be carried out in accordance with Annex A. In the case of chimneys with a height of less than 20 m, the calculation may be carried out in accordance with EN 13384-1, provided that the conditions given in that standard apply.

4.2.5 Chemical attack

Chemical attack of the structural elements in contact with flue gases can occur by condensation of different flue gases to acid, for example sulphuric or hydrochloric acid polluted by chlorides or fluorides. Depending on the nature and period of time of the attack the chemical effect is graded into:

1) low;
2) medium;
3) high;
4) very high.

The chemical attack of flue gases containing SO_3 is graded according to Table 3 depending on the period during which the temperature of the liner wall falls below the acid dew point. Periods during which the installation is out of service are to be disregarded when determining the operating hours.

Table 3 applies to flue gases containing 50 mg/m^3 of SO_3. In the case of other values of SO_3 concentration, the operating hours given in Table 3 vary in inverse proportion to the SO_3 content. If the SO_3 content is not known, a 2 % conversion of SO_2 into SO_3 may be assumed unless other values can be proven.

For other flue gases, the level of chemical attack shall be determined by other methods.

The temperature of the acid dew point of flue gases containing water vapour (H_2O) and sulphur trioxide (SO_3) can be taken from Figure 1.

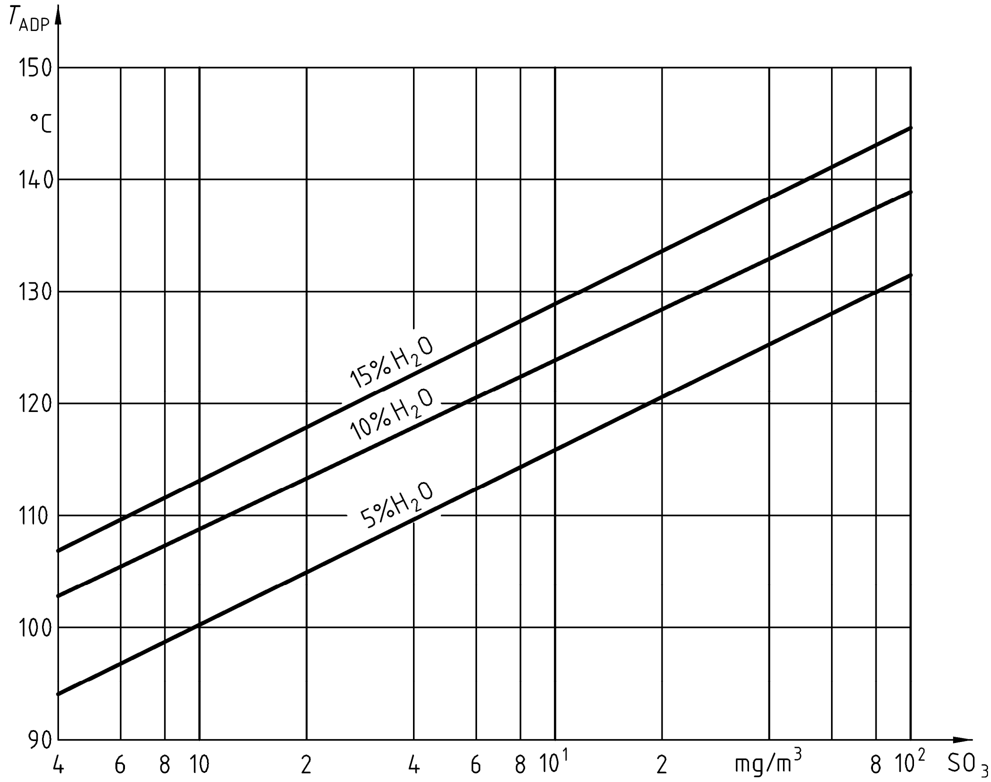


Figure 1 — Temperature of the acid dew point, T_{ADP}, of flue gases containing water vapour (H_2O) and sulphur trioxide (SO_3)

Table 3 — Chemical attack due to flue gases containing 50 mg/m^3 of SO_3

Degree of chemical attack	Operating hours per year [a]			
	Liner face in contact with flue gas		Parts of the chimney protected by the liner	
	$T_{ADP} > 150$ °C	$T_{ADP} \leq 150$ °C	$T_{ADP} > 150$ °C	$T_{ADP} \leq 150$ °C
Low	< 10	< 30	< 50	< 150
Medium	10 to 50	30 to 150	50 to 250	150 to 750
High	50 to 1 000	150 to 3 000	250 to 5 000	750 to 15 000[b]
Very high	> 1 000	> 3 000	> 5 000	> 15 000[b]

[a] During which the temperature of the attacked component is below the acid dew point of the flue gases which are in contact with that component.

[b] Only for interpolation purposes (see 3rd paragraph of 4.2.5), however, in no case more than 8760 h (1 year).

The presence of chlorides or fluorides in the flue gas condensate can radically increase corrosion rates. Estimation of the corrosion rate in these circumstances depends upon a number of complex factors and would require the advice of a corrosion expert in each individual case.

In the absence of such advice,

— the degree of chemical attack may be considered as "low", if the temperature of chimney components in contact with flue gas is below acid dew point for periods of less than 25 h per year and the concentrations of $HCl \leq 30\ mg/m^3$ and $HF \leq 5\ mg/m^3$;

— the degree of chemical attack shall be considered as "very high", regardless of temperature and exposure time, if halogen concentrations at 20 °C and 1 bar pressure exceed the following limits:

  — hydrogen fluoride: 300 mg/m^3;
  — elementary chlorine: 1300 mg/m^3;
  — hydrogen chloride: 1300 mg/m^3.

Condensing flue gas conditions occurring longer than 10 h per year downstream of a flue gas desulphurization system shall be classified as causing "very high" chemical attack.

While a chimney may generally be at a temperature above acid dew point, care shall be taken to prevent small areas being subjected to local cooling and therefore being at risk of localised acid corrosion. Local cooling may be due to

— air leaks;
— fin cooling of flanges, spoilers or other attachments;
— support points;
— down draught effects at the top of the chimney.

Chemical attack can also occur if, for example, dry flue gases become moist at the chimney top as a result of atmospheric influences and affect the inside or outside of the chimney or if the flue gases passing up towards the top or during start-up of the installation cool down to such an extent that condensation occurs.

4.3 Environmental aspects

4.3.1 Noise

The noise produced from the chimney shall not exceed permissible noise levels. Under normal conditions this requirement is met if the velocity of the flue gases at the chimney top is less than 25 m/s. In exceptional cases, for example if the flue gas fan is situated in the chimney, or if the velocity is more than 25 m/s, it has to be proven that the permissible noise level is met.

4.3.2 Temperature

The temperature of the outer surfaces of chimney areas that can be contacted by people, due to the temperature of the flue gases and based on ambient temperature values taken from official data, shall meet one of the following conditions:

a) temperature shall not exceed 50 °C,

b) temperature increase shall not exceed 10 K.

If this requirement is not met a protective device shall be installed to prevent unintentional contact with the chimney wall.

The maximum temperature of adjacent combustible materials shall not exceed 85 °C when related to an ambient temperature of 20 °C. The distance between the outer surface of the chimney and the combustible material shall be chosen accordingly.

The temperature of the air within an accessible space between windshield and liner shall meet one of the following conditions:

a) temperature of the air shall not exceed 40 °C;
b) temperature increase due to the temperature of the flue gases shall not exceed 10 K.

4.3.3 Protection against falling ice

If the possibility cannot be excluded, that ice can form at the chimney or at parts of the chimney, provision shall be made that no damage can be caused by falling ice. This can be achieved for example by protective devices or by heating equipment.

4.3.4 Gas tightness

Chimneys with positive pressure in normal operating conditions shall be gastight and shall be conform to the specifications on gas tightness given in EN 1443.

4.4 Insulation

A valid insulation system has the following purpose:

a) it reduces the thermal gradient and, therefore, the thermal stress in the liner material.

b) it reduces the heat loss of the flue gases as they flow upwards, within the flue gas carrying tube. This has the following advantages:

— it reduces the temperature drop of the flue gases as they progress up the chimney. This is important in the case of flue gases whose entry temperatures are close to acid dew point, where cooling could result in acid deposition or smutting.

— it increases the available thermal lift.

c) it reduces the thermal gradient and thermal stress in the windshield.

In selecting the insulation system, the following characteristics shall be taken into account:

i) its structural stability, long term. It is important that the insulation material does not sag, exposing uninsulated surfaces;

ii) its thermal conductivity;

iii) its performance and integrity at the temperatures it will be subjected to in service;

iv) the acid resistance and moisture absorption of the insulating material and its supports. This is important in brickwork liners, as limited quantities of flue gas can permeate through the liner, condensing as they pass to the cool side of the insulation;

v) its accessibility.

The thermal insulating material shall be incombustible.

4.5 Ventilation

It may be useful to provide a ventilated air space between liner and windshield. The purposes of this air space are:

- to help eliminate flue gases which may have leaked through the liner due to diffusion or to positive pressure conditions;
- to reduce the partial vapour pressure of the sulphur oxides of any flue gas that may have leaked through the liner, thereby reducing its acid dew point and minimizing deposition of acid on vulnerable surfaces;
- to allow access for maintenance and inspection into an air space large enough for this purpose.

The ventilation shall be operative at all times. Where an accessible space is provided, its efficacy shall be verified by thermal and flow calculations.

A clear path shall be provided for vertical passage of the air through the total or sectional height of the air space. This requires provision of adequately sized openings through corbels or slabs supporting sectional liners or in the windshield respectively.

4.6 Protective coatings

Generally, chimneys have to be protected against corrosion or chemical attack by means of protective coatings. A distinction shall be made between attack by the flue gases and attack by environmental conditions.

Attack by the flue gases happens at

- the interior surface of the flue gas carrying tube;
- the exterior surface of the chimney and the access facilities such as ladders, platforms and their fixings exposed to the flue gas trail;
- all exterior surfaces exposed to the flue gases of adjoining chimneys.

Bearing the intended use in mind, protective coatings shall be chemically and thermally resistant, impermeable to liquids and adequately resistant to diffusion and to ageing.

4.7 Foundation

The foundation shall be protected against thermal and chemical effects. If condensation is to be expected, the upper surface of the foundation shall be sloped and provided with a coating which is acid-resistant and impervious to liquids.

It may be useful to provide a space between the liner and the foundation and to design it in such a way that this space can be entered and ventilated.

4.8 Accessories

4.8.1 Access

Chimneys of more than 5 m height above a structurally accessible level (for example a roof of an adjacent building) shall be provided with an access system from this level to the top with the purpose of allowing inspection and maintenance of the following particular items:

- aircraft warning lights, if any (see 4.8.3);

— instrumentation (thermocouples, flue gas analyzers, opacimeters, manometers, etc.), if any (see Clause 8);
— lightning conductor system, if any (see 4.8.2);
— chimney cap.

The access system, however, shall allow the inspection of other critical items such as:

— outside of the windshield: an integrated facility to support a "sky-climber" may be useful - mainly in the upper part of the chimney - where there will be a local heavier chemical attack and where a day-time painting can be required (see 4.8.3);
— flue openings;
— drainage system, if any;
— dynamic vibration absorber;
— erection joint.

The access system shall be installed on the outer windshield surface in case of chimneys with non accessible space and - preferably - on the inner windshield surface in case of chimneys with accessible space. It may consist of permanent ladders or climbing sockets to which ladders may be attached.

In the case of tall and important chimneys the access system may be integrated with a lift (usually rack and pinion type).

Permanent access systems inside the flue gas carrying tube are not permissible in case of chemical attack.

4.8.2 Lightning protection

Chimneys generally shall be provided with a lightning protection system, and all metallic parts of the structure (ladders, platforms, iron caps etc.) shall be connected to the down conductors. Steel chimneys, however, can be considered as continuous metal structures and thus can be used as their own lightning protection system. In case of steel chimneys without continuous conductivity additional appropriate measures have to be provided.

Lightning earth protection should consist of metal rods or strips or a combination of both.

The point at which the earth tape connects to the chimney should be accessible.

If the chimney passes into a building it may be earthed at this point by bonding it to the building's lightning protection circuit.

Chimneys supported by guy ropes shall have the upper ends of the guy ropes bonded to the chimney and the lower ends earthed.

A stayed chimney shall be bonded to its stays. If there will be horizontal or vertical movement between the stay and the chimney, an expansion loop shall be provided.

In areas where high temperatures are likely to occur in the subsoil, for example in the neighbourhood of brick kilns, the earth rods or earth strips may have to be installed at a distance from the chimney where the ground is not likely to be dried out.

A chimney standing upon bare rock requires special consideration for its lightning protective system and expert advice should be sought.

4.8.3 Aircraft warning system

If required by local civil or military aviation authorities, chimneys shall be provided with aircraft warning lights or day-time warning facilities or both. Day-time warning facilities are such as the painting of the upper part or even of the total height. Painting, particularly for the upper part, shall guarantee an adequate chemical protection of the structure.

In the case of chimneys with non accessible space, warning lights should be connected to the railing of circumferential platforms; if platforms are not fitted the lights should be attached to the windshield. For chimneys with accessible space the warning lights should be located on the outside of the windshield through openings accessible from the internal platforms.

4.8.4 Additional accessories

It may be necessary to provide other items such as:

- telephone system;
- chemical washing system;
- cranes and hoists to lift maintenance parts and equipment;
- drainage system for rain as well as for draining possible condensate from liner(s) from the relevant levels to the waste systems at the base;
- access and inspection openings;
- dynamic vibration absorber.

5 Performance requirements: Structural design

5.1 Basic design principles

The following basic design principles are in accordance with EN 1990. They shall also be applied analogously to materials not covered by the respective European Standards.

Chimneys are to be designed for stability and serviceability at their final state as well during construction phases. This includes verification of resistance and of overall stability against overturning.

Unless otherwise stated in the following clauses, reference shall be made to the relevant basic standards for structural analysis, particularly to the respective Eurocodes.

Limit state theory shall be applied.

The limit states are classified into

- ultimate limit states;
- serviceability limit states.

At ultimate limit state the design value of the effect of actions such as internal force, moment, stress or strain, E_d, shall not exceed the corresponding design value of the resistance, R_d.

$E_d \leq R_d$

At serviceability limit state it shall be verified, that

$E_d \leq C_d$

where:

E_d is the design value of the action effect, for example displacement;

C_d is a nominal value of certain structural design properties related to the design effects of actions considered.
The design values for actions are derived from the characteristic values of the actions specified in 5.2, multiplied by the partial safety factor γ_F.

The design values of the resistances, R_d, may be derived from the characteristic values of the relevant structural properties, as material properties or geometrical data, taking into account a partial safety factor γ_M.

Second order effects shall be taken into account if the increase of the relevant moments or internal forces due to deformations calculated from first order theory exceeds 10 %.

5.2 Actions

5.2.1 General

The following actions shall be taken into account in the design of chimneys:

— permanent actions;

— variable actions:
  i) imposed loads;
  ii) wind actions;
  iii) internal pressure;
  iv) thermal effects;

— accidental actions:
  v) seismic actions;
  vi) explosions and implosions;
  vii) impact.

5.2.2 Permanent actions

The permanent actions shall include the estimated weight of all permanent structures and elements, such as fittings, insulation, dust loads, clinging ash, present and future coatings and other loads. Selfweight shall be determined according to EN 1991-1-1.

A maximum and a minimum permanent action shall be determined for the calculation of stresses taking into consideration different construction phases.

5.2.3 Variable actions

5.2.3.1 Imposed loads

The characteristic value of imposed loads for the design of platforms shall be taken as 2 kN/m^2, unless prevailing conditions are likely to give rise to greater loads.

5.2.3.2 Wind actions

5.2.3.2.1 General

Wind loads act on the external surfaces of a chimney as a whole and on accessory components. Besides the drag forces due to the gusty wind acting in general in the wind direction, forces due to vortex shedding may cause cross vibrations of a chimney.

Other wind actions, for example due to uneven wind pressure distribution (ovalling) or interference effects have to be taken into consideration if they are relevant.

The wind actions mentioned above are essentially dynamic. The wind actions on slender and flexible structures such as chimneys can only be determined by dynamic calculation or by application of static equivalent loads. Methods for the determination of these dynamic wind actions are given in EN 1991-1-4.

5.2.3.2.2 Wind loads in the direction of wind

Wind loads in the wind direction shall be determined in accordance with EN 1991-1-4 based on the basic wind velocity, v_b, of the respective site for a statistical return period of 50 years and on the factors c_{DIR} and c_{SEASON} both to be assumed equal to 1,0.

Orographic influences on the wind velocity, for example for chimneys at exposed locations, such as hills or near escarpments in otherwise relatively flat terrain, shall be taken into account.

The influence of the terrain roughness on the wind velocity shall be taken into account.

NOTE It is recommended to use only categories 0, I and II of EN 1991-1-4:2005, Table 4.1.

Force coefficients c_F for chimneys with cross-sections other than those given in EN 1991-1-4 may be determined by wind-tunnel tests taking account of the variation of mean wind velocity with height and of the turbulence as appropriate to the terrain of the site or they may be taken from relevant publications based on such tests.

Vibration effects caused by the gusty nature of the wind shall be taken into account in accordance with EN 1991-1-4.

5.2.3.2.3 Vortex shedding

Chimneys may be subjected to vortex shedding vibrations. Methods of calculating the vibration amplitudes are given in EN 1991-1-4.

Vortex shedding need not be considered for chimneys the Scruton number of which exceeds the value of 25 (for the determination of the Scruton number see EN 1991-1-4). This value is not applicable to chimneys positioned in a row or a group.

5.2.3.2.4 Other wind actions

Uneven wind pressure distribution around the circumference of a circular cylinder produces bending moments in vertical cross sections of the windshield. The design value M_d of the maximum positive as well as negative moment may be calculated according to the following formula:

$$M_d = \pm c_M \times q_d(z) \times d(z)^2 \qquad (1)$$

where:

$q_d(z)$ is the design value of the velocity pressure at height z of the chimney;
$d(z)$ is the diameter of the cross-section at height z of the chimney.
c_M = 0,125 for $R_e \leq 2 \times 10^6$
c_M = 0,095 for $R_e \geq 10^7$ (Interim values may be interpolated)
R_e is the Reynold's number in accordance with EN 1991-1-4

Due to vortex excitation, ovalling vibration of the shell, particularly near the top of the chimney, may occur. For the calculation of these vibrations see EN 1991-1-4.

Other nearby structures may cause interference vibrations. This mainly applies to chimneys arranged in a row or a group. Calculation methods for some arrangements are given in EN 1991-1-4. In other cases wind tunnel tests may be needed.

5.2.3.3 Internal pressure

Negative and positive pressure shall be taken into account as actions.

5.2.3.4 Thermal effects

Thermal stresses in the liner and in the windshield due to differences in temperature between the inner and outer surface of the respective walls shall be determined at the maximum flue gas temperature and the lowest outside temperature to be expected at site considering a statistical return period of 50 years.

For purposes of verifying the thermal stability of building materials, the maximum outside temperature to be expected at site considering a statistical return period of 50 years has to be assumed.

Circumferential variations in temperature due to uneven flow shall be taken into account.

Additional effects may be caused by transient heat flow.

When a chimney or chimney components are restrained from adopting a distorted shape in response to differential expansion, resulting stresses have to be taken into account. These stresses can be high, when a liner or a single unlined chimney carries flue gases from two or more sources at significant different temperatures or if a single side entry source introduces flue gases at very high temperatures. In addition, the resulting differential temperature will introduce secondary thermal stresses. Typical cases of such restraint are to be found in certain liners as well as in laterally supported and guyed chimneys.

5.2.4 Accidental actions

5.2.4.1 Seismic actions

The determination of seismic actions shall be carried out in accordance with EN 1998-6.
NOTE Seismic actions are normally not significant for steel chimneys.

5.2.4.2 Explosions and implosions

Internal explosions can occur due to the presence of soot or explosive flue gases in the chimney. The possibility of explosions inside the chimney has to be estimated in particular in cases where the flue gases derive from gaseous combustibles.

The pressure caused by implosions (sudden interruption of the flue gas stream) shall be determined in accordance with A.7.7.

Eventual actions due to external explosions shall only be considered in special circumstances.

5.2.4.3 Impact

If actions from impact cannot be excluded, they shall be taken into account.

5.3 Imperfections

Effects resulting from inaccuracies have to be taken into consideration.

Unless detailed investigation of the effects of solar radiation and construction tolerances are made, these effects may be taken into account together by assuming a total inclination of the axis of the chimney from the vertical of 1/500.

In addition account shall be taken of any expected deviations of the structure from plumb resulting from irregular settlement of the foundations or from changes in the support conditions, for example in the event of mining subsidence.

5.4 Foundation

Under the characteristic value of the wind load the joint between foundation and ground shall not open to more than the central axis of the foundation slab.

Temperature differences between windshield and foundation due to different exposure to atmospheric conditions and the differential in thermal inertia shall be taken into consideration.

5.5 Liner

The liner shall be capable of expanding in both vertical and horizontal directions without any adverse effect on windshield, support and liner. If a chimney has more than one liner, the individual liners shall be able to expand vertically and horizontally independently.

The influence of the deformations of the liner support on the movements of the liner has to be taken into consideration.

6 Site activities

Site construction shall be initiated only after completion of necessary written and drawn project documents, where all the essential chimney structural and non structural components are defined.

Site works shall be carried out only by companies with competent management, experienced staff and labour, which can demonstrate the ability to complete such works successfully.

For steel chimneys the following applies:

— The manufacturer shall be approved for compliance with the requirements of EN ISO 3834-2, EN ISO 14731 and EN ISO 15607. The welders shall be coded in accordance with EN 287-1 and/or EN 1418.

- Approved welding procedures in accordance with EN ISO 15609-1, EN ISO 15610, EN ISO 15611, EN ISO 15612, EN ISO 15613, EN ISO 15614-1, EN ISO 15614-2 series shall be used.

- All butt welds shall be full penetration and continuous.

- All welding shall be in accordance with EN 1993-3-2.

Further information on site activities is given in Annex B.

7 Inspection and maintenance

Chimneys shall be inspected regularly by a specialist. The intervals between two inspections should preferably be not more than two years. A written report shall contain recommendations for maintenance and repair.

8 Instrumentation

If required, chimneys shall be designed to incorporate appropriate facilities for the purpose of continuous or intermittent installation of instruments dedicated to the environmental monitoring. Monitoring may include

- pressure conditions;
- gas flow velocity;
- gas flow temperature;

- oxygen;
- nitrogen oxide;
- sulphur oxide;
- particles in suspension.

Platforms with sufficient clearance for personnel and for access to equipment should be constructed. These platforms should be located at a chimney height within the range of five times the diameter from the flue gas entrance section and three times the diameter from the exhaust top section of the chimney.

The platforms should have a clear and easy vertical access, whenever possible through staircase or elevator.

Instrumentation platforms should be equipped with electrical power and lighting. Compressed air, safety equipment or telephone would be useful.

Provision should be made for test ports with seals and covered openings to permit the installation of instrumentation. When continuous monitoring is required, appropriate devices should be provided to allow transmission of the information to the control centre.

Annex A
(normative)

Gas flow calculation

A.1 Principal features of the method of calculation

The gas flow calculation serves to determine the pressure conditions inside the flue gas carrying tube, from entry of the flue gas to the top of the chimney. This necessitates the calculation of the progress of the temperature change in the flue gas carrying tube. If the parameters vary over the length of the chimney, the calculation should be carried out section by section.

A.2 Parameters related to construction type

A.2.1 Roughness

The mean value of roughness, *r*, of the surfaces of commonly used construction materials in contact with the flue gases may be taken from Table A.3. The mean value of roughness of other construction materials shall be verified, for example by acknowledged literature or measurements.

A.2.2 Thermal resistance

The thermal resistance of the individual layers shall be calculated taking into account the thermal conductivity of the liner walls and windshield walls as well as the insulation. The thermal resistance of enclosed air layers is given in Table A.5.

The thermal resistance, $1/\Lambda$, in m^2 K/W is determined approximately in accordance with Equation (A.1):

$$\left(\frac{1}{\Lambda}\right) = y \times \sum_{n} \left[\frac{D_h}{2 \text{ x } \lambda_n} \times \ln \left(\frac{D_{h,n+1}}{D_{h,n}} \right) \right] \quad \text{(A.1)}$$

where:

y is the coefficient of form,

= 1,0 for circular and oval cross-sections

= 1,1 for square and rectangular cross-sections up to a side ratio of 1:1,5;

D_h is the internal hydraulic diameter, in m;

$D_{h,n}$ is the hydraulic diameter related to the inside of the n^{th} layer of the wall construction, in m;

λ_n is the thermal conductivity of the material of the n^{th} layer of the wall construction at operating temperature in W/m K, see Table 1.

The values for the thermal conductivity of the commonly used construction materials are given in Table 1.

A.3 Basic values for the calculation

A.3.1 Air temperature

The calculation shall be performed for the highest and lowest outside air temperatures to be expected while the chimney is in operation.

A.3.2 Outside air pressure

The outside air pressure p_L, in Pa, is calculated from Equation (A.2):

$$p_L = p_{L0} \times e^{(-g \times z) / (R_L \times T_L)} \quad \text{(A.2)}$$

where:

p_{L0} is the outside air pressure at sea level = 101 325 Pa at 15 °C;

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

R_L is the gas constant of air, in J/kg K, see Table A.1;

T_L is the outside air temperature, in K;

z is the height above sea level at half chimney height, in m.

A.3.3 Flue gas

The flue gas is composed principally of the components given in Table A.1. Table A.1 contains the values needed for further calculations.

Table A.1 — Gas data

Type of gas	Nitrogen (N_2)	Carbon dioxide (CO_2)	Oxygen (O_2)	Water (H_2O)	Sulfur dioxide (SO_2)	Air, dry
Molar mass M kg/kmol	28,0134	44,0098	31,9988	18,0153	64,0590	28,9627
Molar standard volume V_{mn} m^3/kmol	22,403	22,261	22,392	22,414	21,856	22,400
Standard density ρ kg/m^3	1,2504	1,9770	1,4290	0,8038	2,9310	1,2930
Gas constant R J/(kg · K)	296,66	187,63	259,58	461,50	126,56	287,10
Dynamic viscosity η 10^{-5} Pa·s	1,667	1,370	1,926	0,922	1,170	1,724
Sutherland constant C	102,0	270,0	126,0	641,0	462,0	-
Critical temperature T_k K	126,2	304,2	154,6	647,3	430,8	132,5
Specific heat capacity c_p J/(kg · K)	1038,7	816,5	914,8	1492,0	1740,0	1004,0
Thermal conductivity λ W/(m · K)	0,024	0,015	0,024	0,033	0,212 fluid	0,024

A.3.4 Gas constant

The gas constant of the flue gas, R, is calculated from Equation (A.3):

$$R = \sum X_i \times R_i \tag{A.3}$$

where:

X_i is the content by mass of component i;

R_i is the gas constant of component i according to Table A.1.

The value R for some important fuels for scheduled operation without condensation is given in Table A.2.

Table A.2 — Gas data for various fuels

Fuel	Carbon dioxide (CO_2) % by volume	Water (H_2O) % by volume	Gas constant R J/(kg· K)	Specific heat capacity c_p J/(kg· K)	Water dew point T_{WDP} °C
Natural gas H	12,0	18,5	299,4	1 101	58,7
Natural gas L	11,8	18,3	299,2	1 099	58,4
Domestic heating oil EL	15,4	13,3	287,6	1 060	51,8

A.3.5 Density of outside air

The density of the outside air, ρ_L, in kg/m^3, is calculated from Equation (A.4):

$$\rho_L = \frac{p_L}{R_L \times T_L} \quad \text{in kg/ m}^3 \qquad \text{(A.4)}$$

where:

p_L is the outside air pressure, in Pa, see A.3.2;
T_L is the outside air temperature, in K;
R_L is the gas constant of the air, in J/kg K, see Table A.1.

A.3.6 Specific heat capacity

The specific heat capacity, c_p, of the flue gas is calculated from Equation (A.5):

$$c_p = \Sigma X_i \times c_{pi} \qquad \text{(A.5)}$$

where:

X_i is the content by mass of component i;
c_{pi} is the specific heat capacity of component i according to Table A.1.

The value c_p for the most important fuels for scheduled operation without condensation is given in Table A.2.

A.3.7 Correction factor for temperature

The correction factor S_H in Equation (A.9) serves to take into account the influence of the temperature instability inside the flue gas carrying tube on the cooling down of the flue gases and consequently on the theoretical draught available due to chimney effect. Both the thermal resistance of the chimney determined for intransient operating conditions and the heat transfer coefficient on the outside surface of the chimney shall be corrected to enable the cross section of the flue gas carrying tube to be calculated also for a transient mode of operation which exists for example for all heating appliances with On/Off control, using the equations that apply to intransient operating conditions.

The correction factor is dependent principally on the mode of operation of the heating appliance and the type of construction of the chimney. Where no precise analyses are carried out, the correction factor S_H for heating appliances with On/Off controls may be taken as 0,5, with continuous operation, S_H = 1,0.

A.3.8 Flow safety coefficient

The purpose of the flow safety coefficient, S_E, is to cover the following unwanted irregularities in the operation and design of the chimney:

— deviations from the assumed resistance coefficients ζ;
— deviations from the assumed excess air in the flue gases;
— secondary air entrance to flue gas in the connecting flue pipe or flue gas carrying tube;
— deviation from the specified mean roughness of the inner wall of the flue gas carrying tube;
— deviation from the specified thermal resistance of the chimney walls;
— dimensional deviations in the internal cross section of the flue gas carrying tube;
— deviations from the assumed atmospheric influences.

The flow safety coefficient, S_E, shall be taken as 1,1.

A.4 Determination of temperatures

A.4.1 Flue gas temperatures

The mean flue gas temperature, T_m, in K, is calculated from Equation (A.6):

$$T_m = T_L + \frac{T_e - T_L}{K} \times (1 - e^{-K}) \tag{A.6}$$

The flue gas temperature at the top of the chimney, T_0, in K, is calculated from Equation (A.7):

$$T_0 = T_L + (T_e - T_L) \times e^{-K} \tag{A7}$$

where in the Equations (A.6) and (A.7):

T_L is the outside air temperature, in K;

K is the coefficent of cooling, see A.4.2;

T_e is the flue gas temperature at entry of flue gas into chimney, in K.

A.4.2 Coefficient of cooling

The coefficient of cooling, K, is calculated from Equation (A.8):

$$K = \frac{U \times k \times H}{m \times c_p} \tag{A.8}$$

where:

U is the internal circumference of the flue gas carrying tube, in m;

k is the heat transmission coefficient at the actual material temperatures, in W/m^2 K, see A.4.3;

H is the effective chimney height, in m;

m is the mass flow of flue gas, in kg/s;

c_p is the specific heat capacity of flue gas, in J/kg K, see A.3.6.

A.4.3 Heat transmission coefficient

The heat transmission coefficient, k, in W/m^2 K, is calculated from Equation (A.9):

$$k = \frac{1}{\frac{1}{\alpha_i} + S_H \times \left[\left(\frac{1}{\Lambda} \right) + \frac{D_h}{D_{ha} \times \alpha_a} \right]} \tag{A.9}$$

where:

α_i is the heat transfer coefficient for the inner surfaces in contact with flue gas, in W/m^2 K, see A.4.4;

α_a is the external heat transfer coefficient for the outer surface of the windshield, in W/m^2 K, see Table 2;

S_H is the correction factor for temperature instability, see A.3.7;

$1/\Lambda$ is the thermal resistance, in m^2 K/W, see A.2.2;

D_h is the internal hydraulic diameter, in m;

D_{ha} is the hydraulic diameter related to the outer surface of the windshield, in m.

A.4.4 Internal heat transfer coefficient

The internal heat transfer coefficient, α_i, in W/m^2 K, for the inner surfaces in contact with flue gas is calculated from Equation (A.10):

$$\alpha_i = \frac{\lambda_A \times Nu}{D_h} \quad (A.10)$$

where:

λ_A is the thermal conductivity of flue gas, in W/m K, see Equation (A.11);

Nu is the Nusselt number, see Equation (A.12);

D_h is the internal hydraulic diameter, in m.

The thermal conductivity of the flue gas, λ_A is dependent on the mean flue gas temperature T_m and is calculated with sufficient accuracy from Equation (A.11):

$$\lambda_A = 0{,}00455 + 0{,}000065 \times T_m \quad (A.11)$$

where:

T_m is the mean flue gas temperature in K, see Equation (A.6).

The mean Nusselt number Nu over the chimney height is calculated from Equation (A.12):

$$Nu = \left(\frac{\Psi}{\Psi_{smooth}} \right)^{0,67} \times 0{,}0214 \times (Re^{0,8} - 100) \times Pr^{0,4} \times \left[1 + \left(\frac{D_h}{H} \right)^{0,67} \right] \quad (A.12)$$

This equation may only be used when the following conditions are met:

$2\,300 < Re < 10\,000\,000$ and

$\left(\frac{\Psi}{\Psi_{smooth}} \right) < 3$ as well as

$0{,}6 < Pr < 1{,}5$)

where:

ψ is the flue friction coefficient for hydraulically rough flow, see A.7.4;

ψ_{smooth} is the flue friction coefficient for hydraulically smooth flow (r = 0), see A.7.4;

Re is the Reynolds number, see Equation (A.14);

Pr is the Prandl number, see Equation (A.13);

D_h is the internal hydraulic diameter, in m;

H is the effective chimney height, in m.

The Prandl number, Pr, is calculated from Equation (A.13):

$$Pr = \frac{\eta \times c_p}{\lambda_A} \quad (A.13)$$

The Reynolds number Re is calculated from Equation (A.14):

$$Re = \frac{w_m \times D_h \times \rho_m}{\eta} \quad (A.14)$$

where in the Equations (A.13) and (A.14):

w_m is the mean flue gas velocity, in m/s, see A..6;

D_h is the internal hydraulic diameter, in m;

η is the dynamic viscosity, in Pa s, see Equation (A.16);

ρ_m is the mean density of flue gas, in kg/m^3, see A.5;

c_p is the specific heat capacity of flue gas, in J/kg K, see A.3.6;

λ_A is the thermal conductivity of flue gas in W/m K, see Equation (A.11).

The dynamic viscosity, η_i, in Pa s, for the individual gas i at the actual temperature is calculated from Equation (A.15):

$$\eta_i = \eta_{0i} \times \sqrt{\frac{T}{273} \times \frac{1+\frac{C}{273}}{1+\frac{273}{C}}} \qquad \text{(A.15)}$$

where:

η_{0i} is the dynamic viscosity at 0 °C, in Pa s;

C is the Sutherland constant, see Table A.1;

T is the actual temperature, in K.

The dynamic viscosity, η, in Pa s, for the gas mixture at actual temperature is calculated from Equation (A.16):

$$\eta = \frac{Y_1 \times \eta_1 \sqrt{M_1 \times T_{k1}} + Y_2 \times \eta_2 \sqrt{M_2 \times T_{k2}} + \ldots +}{Y_1 \times \sqrt{M_1 \times T_{k1}} + Y_2 \times \sqrt{M_2 \times T_{k2}} + \ldots +} \qquad \text{(A.16)}$$

where for the individual gas i:

η_i is the dynamic viscosity at actual temperature, in Pa s;

Y_i is the content by volume;

T_{ki} is the critical temperature, in K, see Table A.1;

M_i is the molar mass, in kg/kmol, see Table A.1.

A.5 Density of flue gas

The mean density of the flue gas, ρ_m, in kg/m^3, is calculated from Equation (A.17):

$$\rho_m = \frac{P_L}{R \times T_m} \qquad \text{(A.17)}$$

where:

P_L is the outside air pressure, in Pa, see A.3.2;

R is the gas constant of the flue gas, in J/kg K, see A.3.4;

T_m is the mean flue gas temperature in K, see Equation (A.6).

A.6 Flue gas velocity

The mean flue gas velocity, w_m, in m/s, is calculated from Equation (A.18):

$$w_m = \frac{m}{A \times \rho_m} \qquad \text{(A.18)}$$

where:

m is the mass flow of flue gas, in kg/s;
A is the clear cross-section of the flue gas carrying tube, in m^2;
ρ_m is the mean density of the flue gas, in kg/m^3, see A.5.

A.7 Pressure at entry of flue gas into chimney

A.7.1 Calculation of pressure

The pressure at entry of the flue gas into the chimney, P_z, in Pa, is calculated from Equation (A.19):

$$P_z = -P_H + P_R \tag{A.19}$$

where:

P_H is the theoretical draught available due to chimney effect in the flue gas carrying tube, in Pa, see A.7.2;
P_R is the pressure resistance in the flue gas carrying tube, in Pa, see A.7.3.

A.7.2 Theoretical draught available due to chimney effect

The theoretical draught available due to chimney effect, P_H, in Pa, is calculated from Equation (A.20):

$$P_H = H \times g \times (\rho_L - \rho_m) \tag{A.20}$$

where:

H is the effective chimney height, in m;
g is the acceleration due to gravity = 9,81 m/s^2;
ρ_L is the density of outside air, in kg/m^3, see A.3.5;
ρ_m is the mean density of flue gas, in kg/m^3, see A.5.

A.7.3 Pressure resistance of the flue gas carrying tube

The pressure resistance of the flue gas carrying tube, P_R, in Pa, is calculated from Equations (A.21) and (A.22):

$$P_R = S_E \times P_E + S_{EG} \times P_G \tag{A.21}$$

$$P_E = \left(\Psi \times \frac{H}{D_h} + \sum_n \zeta_n \right) \frac{\rho_m}{2} \times {w_m}^2 \tag{A.22}$$

where in the Equations (A.21) and (A.22):

P_E is the pressure resistance due to friction and form resistance of the flue gas carrying tube, in Pa;
P_G is the difference in pressure due to change of velocity in the flue gas carrying tube, in Pa, see A.7.6;
S_E is the flow safety coefficient, see A.3.8;
S_{EG} is the flow safety coefficient for difference in pressure due to change of velocity;

for $P_G \geq 0$, $S_{EG} = S_E$ applies
for $P_G < 0$, $S_{EG} = 1{,}0$ applies

ψ is the flue friction coefficient, see A.7.4;
H is the effective chimney height, in m;
D_h is the internal hydraulic diameter, in m;
ζ_n is the individual resistance coefficient, see A.7.5;
ρ_m is the mean density of the flue gas, in kg/m^3, see A.5;

w_m is the mean flue gas velocity, in m/s, see A.6.

A.7.4 Flue friction coefficient

The flue friction coefficient, ψ, is calculated for different roughness with sufficient accuracy from Equation (A.23).

$$\frac{1}{\sqrt{\psi}} = -2 \times \log\left(\frac{2{,}51}{Re \times \sqrt{\psi}} + \frac{r}{D_h} \times 0{,}269\right) \tag{A.23}$$

where:

r is the roughness of the inner wall of the flue gas carrying tube, see Table A.3, in m;

D_h is the internal hydraulic diameter, in m;

Re is the Reynolds number, see Equation (A.14).

A.7.5 Individual resistance coefficient

The sum of the individual resistance coefficients of the chimney, $\Sigma\zeta_n$, is dependent on the cross-sectional and directional changes inside the flue gas carrying tube (see Table A.4). The individual resistance coefficient for the cross-sectional extension at the top of the chimney shall not be taken into account, nor shall the change in pressure due to a change of velocity at this point be considered.

A.7.6 Change in pressure due to change of velocity

The change in pressure due to change of velocity, P_G, in Pa, is calculated from Equation (A.24):

$$P_G = \frac{\rho_2}{2} \times w_2^2 - \frac{\rho_1}{2} \times w_1^2 \tag{A.24}$$

where:

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

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

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

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

The mean values for the corresponding sections may be substituted for the densities and velocities before and after a change of velocity.

A.7.7 Pressure caused by sudden interruption of the flue gas stream (Implosion)

A sudden interruption of the flue gas stream will cause negative or positive pressure. This depends on the duration of shut down.

If the duration of shut-down is less than 1 s, the value shall be determined by Equation (A.25).

$$\Delta P_0 = \rho_m \times w_m \times c_s \quad \text{in Pa} \tag{A.25}$$

where:

ρ_m is the mean density of the flue gas, in kg/m^3, see A.5;

w_m is the mean flue gas velocity, in m/s, see A.6;

c_s is the velocity of sound in the flue gas, in m/s.

If the duration of shut-down exceeds 10 s, the fluctuation in pressure may be neglected.

If the duration of shut-down exceeds 1 s but is less than 10 s, a precise check shall be carried out or the value for a duration of shut-down of less than 1 s shall be applied.

A.8 Minimum velocity

A minimum velocity of the flue gas at the chimney top should be maintained in order to ensure the applicability of the equations given in this annex. This minimum velocity, w_{min}, in m/s, as given in Equation (A.26) also limits penetration of secondary air of the top of the chimney.

$$w_{min} = f_g \times \sqrt[4]{\frac{A_M}{A_o}} \quad \text{(A.26)}$$

where:

f_g is the reference value for the minimal velocity = 0,5 m/s;

A_M is the clear cross-section of the flue gas carrying tube at the top of the chimney, in m^2;

A_0 is the reference value = 0,01 m^2.

Table A.3 — Mean roughness of liner materials

Liner material	Roughness r [a] m
welded steel	0,001
aluminium	0,001
glass, plastic	0,001
sheet metal, rabbeted	0,002
pre-cast concrete blocks	0,002
brickwork made of bricks[b]	0,005
sheet metal, corrugated	0,005

[a] These design values only apply to clean surfaces.

[b] For brickwork of shaped radial bricks with a joint thickness of less than 5 mm a roughness of 0,002 m may be assumed.

Table A.4 — Individual resistance coefficient for some forms
(Interpolations between the given parameters are permissible)

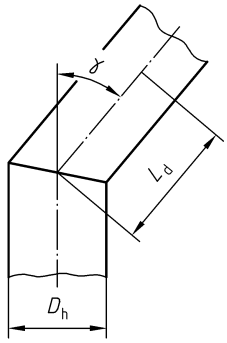
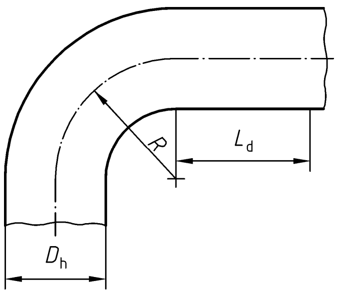
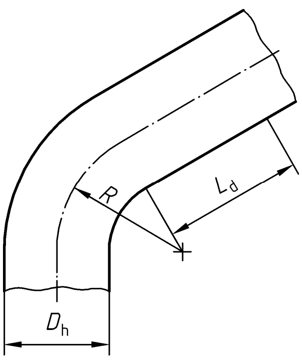
No	Forms	Geometric measurements	ζ-values	
			$L_d/D_h \geq 30$	$30 > L_d/D_h \geq 2$
1	**Straight angle form** 	angle γ in °		
		10	0,1	0,1
		30	0,2	0,3
		45	0,3	0,4
		60	0,5	0,7
		90	1,2	1,6
2	**90° arc** 	R / D_h		
		0,5	1,0	1,2
		0,75	0,4	0,5
		1,0	0,25	0,3
		1,5	0,2	0,2
		2,0	0,2	0,2
3	**60° arc** 	R / D_h		
		0,5	0,6	0,6
		0,75	0,3	0,3
		1,0	0,2	0,2
		1,5	0,2	0,2
		2,0	0,1	0,1

Table A.4 (continued)

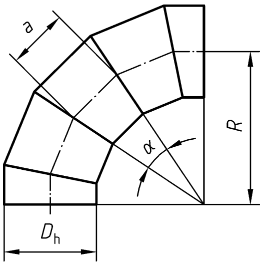
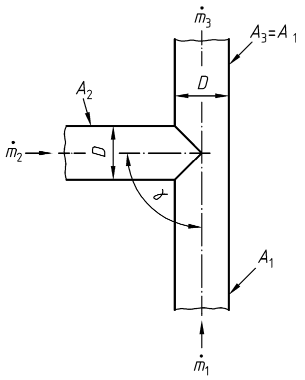
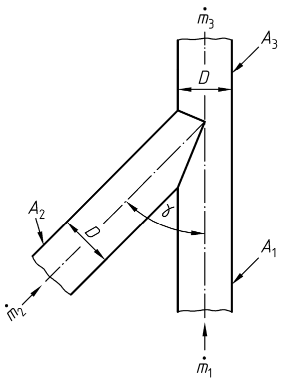
No	Forms	Geometric measurements	ζ-values		
4	**90° deflection** 	$a = 2 \cdot R \cdot \tan(\alpha/2)$	Number of segments		
			2×45°	3×30°	4×22,5°
		a / D_h			
		1,0	0,4	0,25	0,17
		1,5	0,3	0,18	0,13
		2,0	0,3	0,17	0,12
		3,0	0,35	0,19	0,13
		5,0	0,4	0,20	0,15
5	**90° branch and 45° junction**		**Mass flow ratio**	**ζ-values**	
		$\gamma = 90°$	m_2 / 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
		$\gamma = 45°$	m_2 / m_3	ζ_{2-3}	ζ_{1-3}
		$A_3 / A_2 = 1,0$	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

Table A.4 (continued)

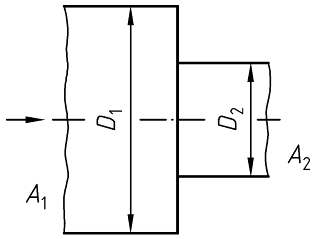
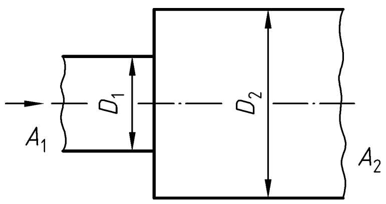
No	Forms	Geometric measurements	ζ-values
5	Formula for calculating the individual resistance coefficients at junctions $\zeta_{2\text{-}3} = -0{,}92\left(1-\frac{m_2}{m_3}\right)^2 - \left(\frac{m_2}{m_3}\right)^2\left[1{,}2\left(\frac{A_3}{A_2}\cos\gamma - 1\right) + 0{,}8\left(1-\left(\frac{A_3}{A_2}\right)^2\right) - \left(1-\left(\frac{A_3}{A_2}\right)^{-1}\right)\times\frac{A_3}{A_2}\cos\gamma\right] + \left(2-\left(\frac{A_3}{A_2}\right)^{-1}\right)\times\frac{m_2}{m_3}\left(1-\frac{m_2}{m_3}\right)$ $\zeta_{1\text{-}3} = 0{,}03\left(1-\frac{m_2}{m_3}\right)^2\times\left(\frac{m_2}{m_3}\right)^2\left[1+1{,}62\left(\frac{A_3}{A_2}\cos\gamma - 1\right) - 0{,}38\left(1-\left(\frac{A_3}{A_2}\right)^{-1}\right)\right]\times\left(2-\left(\frac{A_3}{A_2}\right)^{-1}\right)\times\frac{m_2}{m_3}\left(1-\frac{m_2}{m_3}\right)$		
6	**Reducer, straight form**  Reference velocity: w_2	A_2 / A_1 0,4 0,6 0,8	0,33 0,25 0,15 with rounded lead-in edge $\zeta = 0$
7	**Enlargement, straight form**  Reference velocity: 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

Table A.4 (concluded)

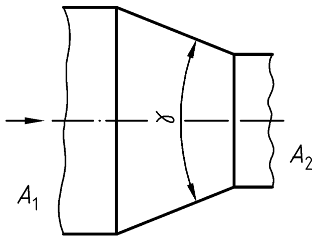
No	Forms	Geometric measurements	ζ-values		
		A_2 / A_1	γ= 30°	γ= 60°	γ= 90°
8	**Reducer, angle form**  Reference velocity: w_2	0,10 0,25 0,45 1,0	0,05 0,04 0,05 0,0	0,08 0,07 0,07 0,0	0,19 0,17 0,14 0,0

Table A.5 — Thermal resistance $(1/\Lambda)_n$ in m²K/W of enclosed layers of air (n^{th} layer of the wall construction, concentric radial clearance, vertically arranged), dependent on the thickness d of the layer of air and the surface temperature T of the heat-emitting wall

T in °C	d_n in 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 The effective thermal conductivity λ_n of an enclosed layer of air (n^{th} layer of the wall construction), in W/m K, is calculated with the values given above from the following equation:

$$\lambda_n = y \frac{D_{h,n}}{2\left(\frac{1}{\Lambda}\right)_n} \times \ln\left(\frac{D_{h,n} + 2\,d_n}{D_{h,n}}\right)$$

where:

y is the form coefficient:
= 1,0 for round and oval cross-section
= 1,1 for square and rectangular cross-section up to a side-ratio of 1 : 1,5

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

$\left(\frac{1}{\Lambda}\right)_n$ is the thermal resistance of the layer of air, in m² K/W; see values given above

d_n is the thickness of the layer of air, in m.

Annex B
(informative)

Site activities

B.1 Execution

Works should commence only after a proper, complete and approved project is in the possession of the responsible site personnel. Setting out of the works should be carried out and subsequently verified. The contractor should be prepared to provide statistics relating to the major progress parameters of the works including personnel and material means.

The characteristics of the equipment and workmanship to be used should comply with the expectations forecast. The equipment to be used should be subject to testing and certification for the works before commencing the site works. The personnel on site should wear safety equipment and the site areas should be illuminated properly, particularly during the night shift operations.

Before being used, materials should be stored in such a way that they are properly protected against weather and harmful influences and should, if necessary, be given proper curing when they have been installed. Materials should be installed in accordance with the supplier's instructions, unless the relevant standards specify otherwise in this respect.

During the works constant attention should be paid to the weather conditions especially wind and temperature. Appropriate devices for controlling the chimney shape and verticality should be used. Temporary warning lights and lightning protection should be mounted during construction of the chimney, if necessary.

B.2 Programming and coordination of works

The works should be subject to a detailed programme containing all activities to be performed, key date to be met for the job and reference to the different specialities and supplies, duly coordinated. The programme should be subject to modification and updated whenever required.

B.3 Site safety

The contractor's site activities should be governed by the safety site rules which should contain references to safety codes and standards. Especially, rules have to address:

— industrial hygiene;
— work safety including escape and rescue plans;
— fire safety;
— accident prevention.

B.4 Local conditions

A detailed plan should be drawn showing the location of the chimney to be constructed, the site installations for both personnel and equipment, parking lots for material storage, definition of the access routes to be used during the works.

The plan should include precise information regarding the location of power, illumination, telecommunications, water sewage, compressed air and other facilities and networks required to perform the site works.

Bibliography

[1] EN 13384-1, *Chimneys - Thermal and fluid dynamic calculation methods - Part 1: Chimneys serving one appliance*

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