One off Kachelgrundöfen/ Putzgrundöfen (tiled/ mortared stoves) — Dimensioning

ICS 97.100.30

British Standards

National foreword

This British Standard is the UK implementation of EN 15544:2009.

The UK participation in its preparation was entrusted to Technical Committee RHE/28, Domestic solid mineral fuel appliances.

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

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 August 2009

ISBN 978 0 580 57332 3

Amendments/corrigenda issued since publication

Date	Comments

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 15544

July 2009

ICS 97.100.30

English Version

One off Kachelgrundöfen/Putzgrundöfen (tiled/mortared stoves) - Dimensioning

Poêles en faïence, poêles en maçonnerie fabriqués in situ - Dimensionnement

Ortsfest gesetzte Kachelgrundöfen/Putzgrundöfen - Auslegung

This European Standard was approved by CEN on 19 June 2009.

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COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 15544:2009: E

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Foreword

This document (EN 15544:2009) has been prepared by Technical Committee CEN/TC 295 "Residential solid fuel burning appliances", the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2010, and conflicting national standards shall be withdrawn at the latest by January 2010.

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Introduction

This standard specifies a calculation method for the dimensioning of Kachelgrundöfen/Putzgrundöfen (tiled/mortared stoves) based upon the required nominal heat output of the stove as declared by the producer. If the calculations of this standard are observed, the minimum energy efficiency of 78% and the emission values of carbon monoxide 1 500 mg/m_n^3 (1 000 mg/MJ), nitrogen dioxide 225 mg/m_n^3 (150 mg/MJ), organically bound carbon 120 mg/m_n^3 (80 mg/MJ) and dust 90 mg/m_n^3 (60 mg/MJ) will be observed too.

This calculation method for the dimensioning of Kachelgrundöfen/Putzgrundöfen (tiled/mortared stoves) is based on appropriate literature as well as EN 13384-1, and where empirically determined correlations are used in addition to physical and chemical formulas.

NOTE In case of a calculation method for different interior materials than fireclay the proof of the compliance of the emission values should be delivered separately. Furthermore the empiric data of the combustion chamber dimensions, the minimum flue pipe length, the burning rate as well as the combustion chamber temperature and the decrease of the temperature along the flue pipe should also be determined.

1 Scope

This standard specifies calculations for the dimensioning of Kachelgrundöfen/Putzgrundöfen (tiled/mortared stoves) based upon the required nominal heat output of the stove as declared by the producer. The Kachelgrundöfen/Putzgrundöfen (tiled/mortared stoves) are of individual one-off construction design. The standard can be used for log wood fired Kachelöfen (tile stoves) that burn one fuel load per storage period with a maximum load between 10 kg and 40 kg and a storage period (nominal heating time) between 8 h and 24 h.

This standard is valid for Kachelgrundöfen/Putzgrundöfen (tiled/mortared stoves) equipped with fireclay as interior material, with an apparent density between 1,750 kg/m³ and 2,200 kg/m³, a degree of porosity from 18 % up to 33 % by volume and a heat conductivity from 0,65 W/mK up to 0,90 W/mK (temperature range 20 °C to 400 °C).

This standard is valid for Kachelgrundöfen/Putzgrundöfen (tiled/mortared stoves) with sidewise combustion air supply of the combustion chamber and an inflow speed from 2 m/s to 4 m/s, whereas the height of the lowest opening is at least 5 cm above the bottom of the combustion chamber.

This standard is not valid for combinations with water heat exchangers for central heating or other heat absorbing elements like glass plates greater than 1/6 of the combustion chamber surface, open water tanks, etc. It is also not valid for combinations with heating/fireplace elements according to EN 13229. Furthermore this standard is not valid for mass-produced prefabricated or partly prefabricated slow heat release appliances according to EN 15250.

NOTE Although for the purposes of this standard these calculations are applicable only to the requirements of this standard, the same calculations can be used for other purposes, e.g. to verify emission levels and energy efficiency in case of burning log wood or wood briquettes according to the producer's manual.

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

3 Terms and definitions

3.1
construction with air gap
construction, with an air gap between the inner and the outer shell

3.2
construction without air gap
construction, with no air gap between the inner and the outer shell

3.3
combustion chamber base A_{BR}
area of a horizontal cut through the combustion chamber at the height of the lower edge of the firebox opening

3.4
combustion chamber height H_{BR}
mean vertical distance between the combustion chamber base and the combustion chamber ceiling

3.5
combustion chamber surface O_{BR}
sum of the inner surfaces of the combustion chamber

3.6
mean combustion chamber temperature t_{BR}
value to calculate the thermal lift in the combustion chamber

3.7
burning rate m_{BU}
mean fuel load divided by burning time

3.8
combustion chamber admeasurement U_{BR}
admeasurement of the combustion chamber base

3.9
gas groove
additional opening for the conduction of the flue gas

3.10
flue pipe length L_Z
length of the connecting line of all geometric centres of the flue pipe profiles from the combustion chamber exit to the connecting pipe entrance

3.11
Kachelgrundofen/tiled stove (also Kachelofen)
one off slow heat release appliance, which is adapted individually to local conditions and whose visible surface is predominantly made of tiles

3.12
short flue pipe section
section of the flue pipe, where the length of the section is shorter than the hydraulic diameter

3.13
minimum flue pipe length L_{Zmin}
minimal acceptable length of the flue pipe

3.14
maximum load m_B
load of the fuel at nominal heat output

3.15
minimum load m_{Bmin}
load of the fuel at the lowest reduced heat output

3.16
nominal heat output
mean useable heat output of the heating appliance

3.17
Putzgrundofen/mortared stove (also Putzofen)
one off slow heat release appliance, which is adapted individually to local conditions and whose visible surface is predominantly plastered

3.18
storage period (nominal heating time)
period of time specified by the producer where the nominal heat output is set free

3.19
efficiency
proportion (in percent) of the nominal heat output multiplied with the storage period to the total heat input

4 Calculations

4.1 Nominal heat output

The required nominal heat output (P_n) of the stove shall be specified by the producer so that the dimensions of the stove can be calculated in accordance with clauses 4.2 to 4.10.

4.2 Load of fuel

4.2.1 Maximum load

The maximum load of fuel shall be calculated as follows:

$$m_B = \frac{P_n \times t_n}{3{,}25} \quad (1)$$

NOTE 1 To calculate the factor 3,25 in equation (1), a net calorific value of wood of 4,16 kWh*kg^{-1} and an efficiency of 0,78 (78%) was presumed.

where

m_B is the maximum load (kg);

P_n is the specified nominal heat output (kW);

t_n is the specified storage period (h).

NOTE 2 The specified storage period can vary between 8 h and 24 h.

4.2.2 Minimum load

The minimum load shall be calculated as 50 % of the maximum load as follows:

$$m_{Bmin} = 0{,}5 \times m_B \quad (2)$$

where

m_B is the maximum load (kg);

m_{Bmin} is the minimum load (kg).

4.3 Design of the essential dimensions

4.3.1 Combustion chamber dimensions

NOTE Designing the dimensions of the combustion chamber serves two main purposes: firstly to ensure that sufficient room is available to contain the fuel needed to be charged and secondly that the requirements for clean combustion are met.

4.3.1.1 Combustion chamber surface

The dimension of the combustion chamber surface shall be calculated as follows:

$$O_{BR} = 900 \times m_B \tag{3}$$

where

m_B is the maximum load (in kg);

O_{BR} is the combustion chamber surface (in cm^2).

For the calculation of the combustion chamber surface all its walls, the ceiling and the base including the area of the combustion chamber opening and the combustion chamber exit for the flue gas shall be regarded equally i.e. calculated as if there were no combustion openings or exits.

4.3.1.2 Combustion chamber base

The combustion chamber base can be varied between a minimum and a maximum value.

The minimum value results from the requirement that at maximum load a height of the fuel of 33 cm shall not be exceeded. Therefore the base shall be calculated using 100 cm² per kg fuel as follows:

$$A_{BRmin} = 100 \times m_B \tag{4}$$

where

m_B is the maximum load (in kg);

A_{BRmin} is the minimum combustion chamber base (in cm^2).

The maximum area of the base of the combustion chamber shall be defined as a result of equations (3) and (6) as follows:

$$A_{BRmax} = \frac{900 \times m_B - (25 + m_B) \times U_{BR}}{2} \tag{5}$$

where

m_B is the maximum load (in kg);

A_{BRmax} is the maximum combustion chamber base (in cm^2);

U_{BR} is the combustion chamber admeasurement (in cm).

When the base is square, the proportion of length to width can be varied from 1 to 2, but there shall be a minimum width of 23 cm.

4.3.1.3 Combustion chamber height

The minimum combustion chamber height shall be defined as follows:

$$H_{BR} \geq 25 + m_B \tag{6}$$

where

m_B is the maximum load (in kg);

H_{BR} is the combustion chamber height (in cm).

On the basis of the specifications of the combustion chamber base and the combustion chamber surface the combustion chamber height shall be calculated as follows:

$$H_{BR} = \frac{900 \times m_B - 2 \times A_{BR}}{U_{BR}} \quad (7)$$

where

m_B is the maximum load (in kg);

A_{BR} is the combustion chamber base (in cm^2);

H_{BR} is the combustion chamber height (in cm);

U_{BR} is the combustion chamber admeasurement (in cm).

4.3.2 Minimum flue pipe length

4.3.2.1 Construction without air gap

The minimum flue pipe length shall be calculated as follows:

$$L_{Zmin} = 1{,}3 \times \sqrt{m_B} \quad (8a)$$

where

m_B is the maximum load (in kg);

L_{Zmin} is the minimum flue pipe length (in m).

4.3.2.2 Construction with air gap

The minimum flue pipe length shall be calculated as follows:

$$L_{Zmin} = 1{,}5 \times \sqrt{m_B} \quad (8b)$$

where

m_B is the maximum load (in kg);

L_{Zmin} is the minimum flue pipe length (in m).

4.3.3 Gas groove profile

The gas groove profile shall be calculated as follows:

$$A_{GS} = 1 \times m_B \quad (9)$$

where

A_{GS} is the profile of the gas groove (in cm^2);

m_B is the maximum load (in kg).

4.4 Calculation of the burning rate

The burning rate shall be calculated as follows:

$$m_{\mathrm{BU}} = 0{,}78 \times m_{\mathrm{B}} \tag{10}$$

where

m_{B} is the maximum load (in kg);

m_{BU} is the burning rate (in kg/h).

4.5 Fixing of the air ratio

A combustion in a Kachelofen/Putzofen (tiled/mortared stove) is a process which is not stationary. The mean air ratio shall be fixed as follows:

$$\lambda = 2{,}95 \tag{11}$$

where

λ is the air ratio.

4.6 Combustion air, flue gas

4.6.1 Combustion air flow rate

4.6.1.1 General

The mean combustion air flow rate shall be calculated as follows:

$$\dot{V}_{\mathrm{L}} = 0{,}002\,56 \times m_{\mathrm{B}} \times f_{\mathrm{t}} \times f_{\mathrm{s}} \tag{12}$$

NOTE To calculate the factor 0,00256 in equation (12) a theoretical air flow of 4,0 $m_N^3 * kg^{-1}$, an air ratio of 2,95 and a burning rate of 0,78*m_{B} have been presumed.

where

$\dot{V}_{\mathrm{L}}$ is the combustion air flow rate (in m^3/s);

m_{B} is the maximum load (in kg);

f_{t} is the temperature correction factor;

f_{s} is the altitude correction factor.

4.6.1.2 Temperature correction

The temperature correction factor shall be calculated as follows:

$$f_{\mathrm{t}} = \frac{273 + t}{273} \tag{13}$$

where

f_t is the temperature correction factor;

t is the temperature (in °C).

4.6.1.3 Altitude correction

The altitude correction factor shall be calculated as follows:

$$f_s = \frac{1}{e^{(-9,81 * z)/78624}} \qquad (14)$$

where

f_s is the altitude correction factor;

z is the geodetical height (in m).

4.6.2 Flue gas flow rate

The knowledge of the flue gas flow rate is important for the calculation of the flue pipe diameter and shall be calculated as follows:

$$\dot{V}_G = 0{,}002\ 73 \times m_B \times f_t \times f_s \qquad (15)$$

NOTE To calculate the factor 0,00273 in equation (15) a theoretical flue gas flow of 4,8 $m_N^3 * kg^{-1}$, an air ratio of 2,95 and a burning rate of 0,78*m_B have been presumed.

where

$\dot{V}_G$ is the flue gas flow rate(in m³/s);

m_B is the maximum load (in kg);

f_t is the temperature correction factor;

f_s is the altitude correction factor.

NOTE f_t is calculated using the flue gas temperature of the flue pipe section. This means that along the flue pipe the decreasing temperature leads to a lower flue gas flow rate.

4.6.3 Flue gas mass flow rate

The flue gas mass flow rate shall be calculated as follows:

$$\dot{m}_G = 0{,}0035 \times m_B \qquad (16)$$

where

$\dot{m}_G$ is the mass flow rate (in kg/s);

m_B is the maximum load (in kg).

4.7 Calculations of the density

4.7.1 Combustion air density

The density of the combustion air at standard conditions (0 °C and ≈ 1 013 mbar) is 1,293 kg/m³. As the combustion air is not in standard conditions a correction is necessary. This correction shall be calculated using Equation 17 where the decrease of the density at higher temperatures is described by the temperature correction factor; and the decrease at higher altitudes is described by the altitude correction factor.

$$\rho_{\mathrm{L}} = \frac{1{,}293}{f_{\mathrm{t}} \times f_{\mathrm{s}}} \tag{17}$$

where

ρ_L is the combustion air density (in kg/m³);

f_t is the temperature correction factor;

f_s is the altitude correction factor.

4.7.2 Flue gas density

The density of the flue gas at standard conditions is 1,282 kg/m³. As the flue gas is not in standard conditions a correction is necessary. This correction shall be calculated using Equation 18 where the decrease of the density at higher temperatures is described by the temperature correction factor; and the decrease at higher altitudes is described by the altitude correction factor.

$$\rho_{\mathrm{G}} = \frac{1{,}282}{f_{\mathrm{t}} \times f_{\mathrm{s}}} \tag{18}$$

where

ρ_G is the flue gas density (in kg/m³);

f_t is the temperature correction factor;

f_s is the altitude correction factor.

4.8 Calculation of the flue gas temperature

4.8.1 Mean combustion chamber temperature

The combustion chamber temperature is required in order to calculate the standing pressure in the combustion chamber. Due to the calculation of the combustion chamber surface the calculation temperature of all combustion chambers is similar. The temperature shall be fixed as follows:

$$t_{\mathrm{BR}} = 700 \tag{19}$$

where

t_{BR} is the combustion chamber temperature (in °C).

4.8.2 Flue gas temperature in the flue pipe

The decrease of the temperature along the flue pipe shall be calculated as follows:

$$t = 550 \times e^{\frac{-0{,}83 \cdot L_Z}{L_{Z\min}}} \tag{20}$$

where

t is the temperature decrease (in °C);

L_Z is the flue pipe length (in m);

$L_{Z\min}$ is the minimum flue pipe length (in m).

NOTE This development of the temperature is valid from the combustion chamber exit to the connecting pipe.

4.8.3 Flue gas temperature in the connecting pipe

The flue gas temperature in the connecting pipe shall be calculated in accordance with EN 13384-1.

4.8.4 Flue gas temperature at chimney entrance, mean flue gas temperature of the chimney and temperature of the chimney wall at the top of the chimney

The flue gas temperature at chimney entrance, the mean flue gas temperature of the chimney and the temperature of the chimney wall at the top of the chimney shall be calculated in accordance with EN 13384-1. The outside temperature for the calculation shall be fixed as 0°C.

4.9 Calculation of flow mechanics

4.9.1 Calculation of the standing pressure

The standing pressure is the difference between the densities of the flue gas and the air and shall be calculated as follows:

$$p_h = g \times H \times (\rho_L - \rho_G) \tag{21}$$

where

p_h is the standing pressure (in Pa);

g is the acceleration of gravity (= 9,81 m/s^2);

H is the effective height (in m);

ρ_L is the air density (in kg/m^3);

ρ_G is the flue gas density (in kg/m^3).

The effective height is the vertical difference between the flue gas exit and the flue gas entrance of a flue pipe section, the connecting pipe or the chimney. For the combustion the combustion chamber height H_{BR} shall be used. The air density shall be calculated in accordance with equation (17) using a temperature of 0°C, the flue gas density shall be calculated in accordance with equation (18) using the temperature in the middle of the flue pipe section, connecting pipe or chimney. For the combustion chamber the combustion chamber temperature t_{BR} shall be used.

4.9.2 Calculation of the flow velocity

The velocity shall be calculated by dividing the air or flue gas flow rates by the profile as follows:

$$v = \frac{\dot{V}}{A} \tag{22}$$

where

v is the flow velocity (in m/s);

$\dot{V}$ is the air- or flue gas flow rate (in m^3/s);

A is the profile (in m^2).

The flow velocity in the flue pipe, the connecting pipe and the chimney shall be between 1,2 m/s and 6,0 m/s.

4.9.3 Calculation of the static friction

4.9.3.1 General

The static friction in the flue pipe, the connecting pipe and the chimney shall be calculated in accordance with EN 13384-1 as follows:

$$p_R = \frac{\lambda_f \times p_d \times L}{D_h} \tag{23}$$

where

p_R is the static friction (in Pa);

p_d is the dynamic pressure (in Pa);

λ_f is the friction coefficient;

L is the length of flue pipe section, connecting pipe or chimney (in m);

D_h is the hydraulic diameter (in m).

4.9.3.2 Dynamic pressure

The dynamic pressure shall be calculated as follows:

$$p_d = \frac{\rho \times v^2}{2} \tag{24}$$

where

p_d is the dynamic pressure (in Pa);

ρ is the density (in kg/m^3);

v is the flow velocity (in m/s).

4.9.3.3 Friction coefficient

The friction coefficient shall be calculated according to an approximation as follows:

$$\lambda_f = \frac{1}{(1{,}14 + 2{,}0 \times \log \frac{D_h}{k_f})^2} \qquad (25)$$

where

λ_f is the friction coefficient;

k_f is the roughness height (in m);

D_h is the hydraulic diameter (in m).

The roughness height k_f of some typical materials is given in table 1.

Table 1 — Values for k_f

Material	Roughness height k_f
Chamotte pipes	0,002
Chamotte slabs	0,003

4.9.3.4 Hydraulic diameter

The hydraulic diameter shall be calculated as follows:

$$D_h = \frac{4 \times A}{U} \qquad (26)$$

where

D_h is the hydraulic diameter (in m).

A is the profile (in m^2).

U is the admeasurement (in m);

4.9.4 Calculation of the resistance due to direction change

The resistance due to direction change shall be calculated by multiplication of the dynamic pressure with the resistance coefficient as follows:

$$p_u = \zeta \times p_d \qquad (27)$$

where

p_u is the resistance due to direction change (in Pa);

ζ is the resistance coefficient due to direction change;

p_d is the dynamic pressure (in Pa).

For standard geometric designs the resistance coefficient is given in table 2.

Table 2 — Resistance coefficient for standard geometric designs

Geometric design	**ζ-value**
Angle 10°	0,1
Angle 30°	0,2
Angle 45°	0,4
Circular arc 60	0,7
Angle 60°	0,8
Angle 90°	1,2
Angle 180°	2.4

Interim values shall be obtained by linear interpolation.

If a flue pipe section is shorter than its hydraulic diameter (short flue pipe section: L < Dh), the resistances of the direction changes before and after the section are not fully effective Therefore, the resistance coefficient shall be calculated as follows:

$$\zeta_1 = \zeta_{\alpha 1} + \frac{\alpha_1}{\alpha_1 + \alpha_2} \times (\zeta_{\alpha 3} - \zeta_{a2} - \zeta_{a1}) \times \left(1 - \frac{L_Z}{D_h}\right) \quad (28)$$

$$\zeta_2 = \zeta_{\alpha 2} + \frac{\alpha_2}{\alpha_1 + \alpha_2} \times (\zeta_{\alpha 3} - \zeta_{a2} - \zeta_{a1}) \times \left(1 - \frac{L_Z}{D_h}\right) \quad (29)$$

where

D_h is the hydraulic diameter (in m);

L_Z is the flue pipe length (in m);

α_1 is the angle between flue pipe section in front and short flue pipe section (in °);

α_2 is the angle between short flue pipe section and following flue pipe section (in °);

ζ_1 is the modified resistance coefficient for α1;

ζ_2 is the modified resistance coefficient for α2;

$\zeta_{\alpha 1}$ is the resistance coefficient for α_1;

$\zeta_{\alpha 2}$ is the resistance coefficient for α_2;

$\zeta_{\alpha 3}$ is the resistance coefficient for α3, where α3 is the angle between flue pipe section in front of and flue pipe section after short flue pipe section (in °).

4.10 Operation control

4.10.1 Pressure condition

At nominal heat output the sum of all buoyancies (p_h) shall be compared with the sum of all resistances (p_r, p_u).

The calculation shall be sequenced section by section starting with the air inlet and ending with the exit of the chimney. For the calculation the conditions (temperature, velocity) in the middle of each section shall be taken.

The following term shall be fulfilled:

$$\sum \rho_r + \sum \rho_u \leq \sum \rho_h \leq 1{,}05 \times \left(\sum \rho_r + \sum \rho_u \right) \quad (30)$$

where

$\sum \rho_r$ is the sum of all static frictions (in Pa);

$\sum \rho_u$ is the sum of all resistances due to direction change (in Pa);

$\sum \rho_h$ is the sum of all buoyancies (in Pa).

4.10.2 Dew point condition

At lowest load the temperature of the chimney wall at its top shall be compared with the dew point temperature of the flue gas.

The following term shall be fulfilled:

$$t_{i,2} \geq 45 \quad (31)$$

where

$t_{i,2}$ is the chimney wall temperature at its top (in °C).

For this calculation a dew point temperature of 45 °C shall be used. The chimney wall temperature at its top shall be calculated in accordance with EN 13384-1.

4.10.3 Efficiency of the combustion η

The efficiency of the combustion η shall be calculated as follows:

$$\eta = 101{,}09 - 0{,}0941 \times t_F - 6{,}275 \times 10^{-6} \times t_F{}^2 - 3{,}173 \times 10^{-9} \times t_F{}^3 \quad (32)$$

where

η is the efficiency of the combustion;

t_F is the inlet temperature into the connecting pipe (in °C).

NOTE In calculating the efficiency of the combustion the following values are accepted: carbon content of the wood 38 % by mass, hydrogen content of the wood 5 % by mass, water content of the wood 17 % by mass, room temperature

20 °C, carbon monoxide concentration 0,1 % by volume, carbon dioxide concentration 7,05 % by volume, net calorific value of the dry wood 18.500 kJ/kg and heat losses through combustible constituents in the residue 0 % by mass.

4.10.4 Flue gas triple of variates

The flue gas triple of variates shall be specified. The flue gas temperature is the outlet temperature of the flue pipe calculated according to 4.8.2 with the total flue pipe length. The flue gas mass flow rate shall be calculated according to 4.6.3. The required delivery pressure shall be calculated as the sum of all resistance pressures due to direction change (p_u) plus the sum of all resistance pressures due to friction (p_r) reduced by the standing pressure (p_h) for the combustion chamber, the combustion air supply and the flue pipe.

Bibliography

[1] EN 13229, *Inset appliances including open fires fired by solid fuels - Requirements and test methods*

[2] EN 15250, *Slow heat release appliances fired by solid fuel - Requirements and test methods*

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