

**Heating systems in buildings — Method for calculation of system energy requirements and system efficiencies — Part 4-7 Space heating generation systems, biomass combustion systems**

*Einführendes Element — Haupt-Element — Ergänzendes Element*

*Élément introductif — Élément central — Élément complémentaire*

ICS:

Descriptors:

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## Foreword

This document (prEN 15316-4-7:2006) has been prepared by Technical Committee CEN/TC 228 "Heating systems in buildings", the secretariat of which is held by DS.

The subjects covered by CEN/TC 228 are the following:

- design of heating systems (water based, electrical etc.);
- installation of heating systems;
- commissioning of heating systems;
- instructions for operation, maintenance and use of heating systems;
- methods for calculation of the design heat loss and heat loads;
- methods for calculation of the energy performance of heating systems.

Heating systems also include the effect of attached systems such as hot water production systems.

All these standards are systems standards, i.e. they are based on requirements addressed to the system as a whole and not dealing with requirements to the products within the system.

Where possible, reference is made to other European or International Standards, a.o. product standards. However, use of products complying with relevant product standards is no guarantee of compliance with the system requirements.

The requirements are mainly expressed as functional requirements, i.e. requirements dealing with the function of the system and not specifying shape, material, dimensions or the like.

The guidelines describe ways to meet the requirements, but other ways to fulfil the functional requirements might be used if fulfilment can be proved.

Heating systems differ among the member countries due to climate, traditions and national regulations. In some cases requirements are given as classes so national or individual needs may be accommodated.

In cases where the standards contradict with national regulations, the latter should be followed.

## Introduction

This standard presents methods for calculation of the additional energy requirements of a heat generation system in order to meet the distribution and/or storage subsystem demand. The calculation is based on the performance characteristics of the products given in product standards and on other characteristics required to evaluate the performance of the products as included in a system.

This method can be used for the following applications:

- judging compliance with regulations expressed in terms of energy targets;
- optimisation of the energy performance of a planned heat generation system, by applying the method to several possible options;
- assessing the effect of possible energy conservation measures on an existing heat generation system, by calculating the energy use with and without the energy conservation measure.

The user shall refer to other European Standards or to national documents for input data and detailed calculation procedures not provided by this standard.

## 1 Scope

This standard is part of a series of standards on a method for calculation of system energy requirements and system efficiencies.

The scope of this specific part is to standardise the:

- required inputs;
- calculation methods;
- required outputs

for space heating generation by combustion sub-systems using biomass fuels, including control.

In some cases it is recommended to extend the generation system with an energy storage system to improve the operation conditions regarding thermal efficiency and environmental impact.

The standard can also be used for generation for domestic hot water production.

## 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 303 -5, *Heating boilers Part 5: Heating boiler for solid fuels, hand and automatically stocked, nominal heat output of up to 300 kW*

CEN/TS 14588:2003, *Solid bio fuels - Terminology, definitions and descriptions*

prCEN/TS 14961, *Solid fuels – Fuel specification and classes*

EN ISO 7345:1995, *Thermal insulation - Physical quantities and definitions (ISO 7345:1987)*

EN ISO 12241, *Thermal insulation for building equipment and industrial installations – Calculation rules*

EN ISO 13790, *Thermal Performance of Buildings - Calculation of Building Energy Demand for Heating*  
Terms and definitions

### **3.1 Definitions**

For the purposes of this document, the terms and definitions given in EN ISO 7345:1995 and CEN/TS 14588:2003 and the following apply.

#### **3.1.1**

##### **accumulator (storage) system**

part of the generation system tank which stores excess heat during operation time (resulting from the difference between the boiler output and the actual heat input to the heating system)

#### **3.1.2**

##### **auxiliary energy**

energy, often in form of electric energy, used by heating, and domestic hot water to transform and transport the delivered energy into the useful energy

NOTE: This includes energy for fans, pumps, pilot flames, stocking devices, electronics, etc., but not the energy that is transformed

#### **3.1.3**

##### **biomass boiler**

a biomass fuelled appliance designed to provide heating medium ( water, fluid etc. ) for space heating

#### **3.1.4**

##### **calculation period**

discrete time interval for the calculation of the heat losses of the space heating generation systems

#### **3.1.5**

##### **combustion power**

product of the fuel flow rate and the lower combustion heat

#### **3.1.6**

##### **generation loss**

heat loss due to losses through the chimney and through the generation envelope

#### **3.1.7**

##### **load factor**

ratio between the time with the boiler ON and the total generator operation time

#### **3.1.8**

##### **load balancing system**

part of the generation system which is balancing the heat output of the generation system

#### **3.1.9**

##### **operation cycle**

time period of the operation cycle of a boiler

#### **3.1.10**

##### **thermal technical system losses**

thermal systems losses from the technical equipment for heating to the surroundings and which are directly taken into account within the subsystem

NOTE: The thermal loss becomes an internal gain if it is recovered

### 3.1.11

#### recoverable thermal system losses

part of the thermal technical system losses which may be recovered to lower the energy need for heating

### 3.1.12

#### recovered thermal system losses

part of the recoverable thermal system losses which may be recovered to lower the energy need for heating

## 3.2 Symbols and units

For the purposes of this standard, the following symbols and units (Table 1) and indices (Table 2) apply:

**Table 1 — Symbols**

Symbol	Name of quantity	Unit
b	temperature reduction factor	-
e	system performance coefficient.	-
f	factor	-
FC	heat generator part load ratio, load factor	-
G	parameter	-
LH	lower combustion heat of fuel	Mj/kg
k	part of recoverable auxiliary energy	-
m	mass	kg
p	part of electric power transmitted to air	%
P	specific heat loss	W
Q	quantity of heat,energy	J,Wh
r	recoverable heat factor	-
t	time, period of time	S,h
V	volume	m <sup>3</sup> , ltr
W	electrical auxiliary energy	Wh, kWh
$\beta$	load factor	-
$\theta$	Celsius temperature	°C
$\eta$	efficiency, utilisation factor	-
$\Phi$	heat flow rate, thermal power	W

## 3.3 Indices

Table 2 — Indices

acc	accumulator	fl	fluid ( water )	Pint	power at intermediate load
af	after	fue	fuel	P0	power at zero load
amb	ambience	g	generation	Pn	power at nominal load
aux	auxiliary	h	heat, heating	Px	power at x load
aux	auxiliary	hp	heating up	Pu	pump
bf	before	hyd	hydraulic	ret	return
cam	chamber	in	in to system	ref	reference
cd	cooling down	ins	inside	rd	recovered
ch	chimney	int	intermediate	rel	recoverable
ci	calculation period	j	indices	sb	standby
cn	combustion	l	loss	sta	stand alone
con	control	Max	maximum	t	total
cor	corrected	min	minimum	test	test
d	distribution	n	nominal	tk	tank
e	emission	nr	non recoverable	w	water heating system
el	electrical	no	non	x	indices
en	energy	OFF	off	100	100%
env	envelope	ON	on	30	30%
ext	external	op	operating		
fb	fire bed	out	output from system		

Note: The subscripts for the symbols and the terms in this standard shall be put in the following order:

- the first index represents the use (h = space heating, w = domestic hot water);
- the second index represents the the heat balance element (ls losses , dis = distribution, etc.);
- the third index represents the appreciation (ut = utilised, nut non utilised );

The indices are separated by a comma.



## 4 Principle of the method

### 4.1 Heat balance of the generation sub-system, including control of heat generation

#### 4.1.1 Physical factors taken into account

The calculation method of the generation sub-system takes into account heat losses and/or recovery due to the following physical factors:

- heat losses to the chimney (or flue gas exhaust) during total time of generator operation (running and stand-by);
- heat losses through the generator(s) envelope during total time of generator operation (running and stand-by);
- auxiliary energy.

#### 4.1.2 Calculation structure (input and output data)

The calculation method of this standard shall be based on the following input data from other parts of the EN 15316-X-X standards series:

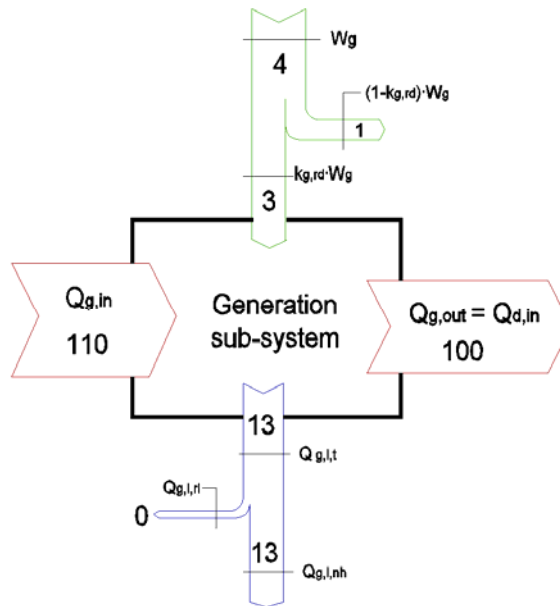
- heat demand of the heating system heat distribution sub-system(s)  $\Sigma Q_{h,d,in}$  calculated according to EN15316-2-3;
- heat demand of the domestic hot water distribution sub-system  $\Sigma Q_{w,d,in}$  calculated according to EN 15316-3-2, where appropriate.

The performance of the generation sub-system may be characterised by additional input data to take into account:

- type and characteristics of the generation sub-system;
- boiler settings;
- type of the generation control system;
- location of the boiler ;
- size of storage system ( if required )
- operating conditions;
- heat requirement.

Based on these data, the following output data shall be calculated in the generation sub-system module:

- generation total heat loss (flue gas and generator envelope)  $Q_{g,l,t}$  ;
- auxiliary energy consumption  $W_g$  ;
- recoverable generation heat losses  $Q_{g,l,rl}$  .
- fuel heat requirement  $Q_{g,in}$  ;



**Figure 1: Generation sub-system inputs, outputs and energy balance**

Figure 1 shows the calculation inputs and outputs of the generation sub-system.

NOTE: Values shown are sample percentage

where:

$W_g$  total auxiliary energy required by the generation sub-system (pumps, burner fan, etc.).

$k_{g,rd}$  part of auxiliary energy recovered by the generation sub-system (i.e. burner fan) (-)

$Q_{g,out}$  heat supplied to the distribution sub-systems (space heating and domestic hot water)

$Q_{g,in}$  heat requirement of the generation sub-system (fuel input)

$Q_{g,l,t}$  total losses of the generation sub-system (through the chimney, generator envelope, etc.)

$Q_{g,l,rl}$  recoverable losses of the generation sub-system for space heating (i.e. boiler installed inside the heated space) or for the generation sub-system (i.e. preheating of combustion air by flue gas)

$Q_{g,l,nh}$  unrecoverable losses of the generation sub-system

#### 4.2 Generation sub-system basic energy balance

The basic energy balance of the generation sub-system is given by:

$$Q_{g,in} = k_{ctrl} \cdot Q_{g,out} - k_{g,rd} \cdot W_g + Q_{g,l,t} \quad [W] \quad (1)$$

where symbols have the meaning defined in 4.1.2 and :

$k_{g,rd}$  part of auxiliary energy recovered by the generation sub-system (i.e. burner fan) (-)

$k_{ctrl}$  factor taking into account emission control losses. Default value of  $k_{ctrl}$  depending on the boiler control method are given in Annex B. Other values may be specified in a national annex, provided

that emission control losses has not been already taken into account in the emission part (EN 15316-2-1) or in the distribution part (EN 15316-2-3).

NOTE:  $Q_{g,t}$  takes into account flue gas and generator envelope losses, part of which may be recoverable according to location. See Table B.4

### 4.3 Auxiliary energy $W_g$

Auxiliary energy is the energy, other than fuel, required for operation of the burner, the primary pump and any equipment whose operation is related to operation of the heat generation sub-system. Auxiliary energy is counted in the generation part as long as no transport energy from the auxiliary equipment is transferred to the distribution sub-system (example: zero-pressure distribution array). Such auxiliary equipment can be (but need not be) an integral part of the generator.

Auxiliary energy, normally in the form of electrical energy, may partially be recovered as heat for space heating or for the generation sub-system.

Examples of recoverable auxiliary energy:

- electrical energy transmitted as heat to the water of the primary circuit;
- part of the electrical energy for the burner fan.

Example of non-recoverable auxiliary energy:

- electrical energy for electric panel auxiliary circuits, if the generator is installed outside the heated space.

### 4.4 Recoverable, recovered and unrecoverable heat losses

Not all of the calculated system heat losses are lost. Some of the losses are recoverable and part of the recoverable system heat losses are actually recovered.

Example of recoverable heat losses are:

- heat losses through the envelope of a generator installed within the heated space.

Example of non-recoverable heat losses are:

- heat losses through the envelope of a generator installed outside the heated space;
- heat losses through the chimney

According to EN 15315, recovery of heat losses to the heated space can be accounted for either:

as a reduction of total losses within the specific part (simplified method)

or taking into account globally recoverable losses as gains (holistic method)

This standard allows both approaches.

Generation losses recovered by the generation sub-system are directly taken into account in the generation performance (e.g. combustion air preheating by flue gas losses).

## 4.5 Calculation periods

The objective of the calculation is to determine the annual primary energy demand of the heating generation sub-system. This may be done in one of the following two different ways:

- by using annual data for the system operation period and perform the calculations using yearly average values;
- by dividing the year into a number of calculation periods (e.g. months, weeks, operation periods as defined in EN ISO 13790) and perform the calculations for each period using period-dependent values and adding up the results for all the periods over the year. For biomass boilers the calculation period shall be 24 hours. .

NOTE: Generation efficiency is strongly dependent on the load factor and this relation is not linear. To achieve a good precision, the calculation periods should not be longer than 1 month.

## 4.6 Multiple boilers or generation sub-systems

The primary scope of this standard is to calculate losses, fuel requirement and auxiliary energy requirements for an individual boiler.

If there are multiple generation sub-systems, the calculation procedure according EN 15316-4-1 may be used.

## 5 Biomass Combustion System calculation

The performance calculation methods for biomass combustion systems differ with respect to:

- type of stocking device (automatic or by hand);
- type of biomass fuel (pellets, chipped wood or log wood).

## 6 Calculation method for boilers with automatic stocking

The calculation method for biomass boilers with automatic stocking is comparable to the methods used for automatically fired boilers for oil or gas. The performance calculation methods for boilers with automatic stocking are described in EN 15316-4-1.

NOTE 1: Biomass boilers with automatic stocking were fired by pellets or chipped wood.

NOTE 2: For improving the efficiency and reduction of pollution it is recommended to operate biomass boilers with automatic stocking by an load balancing storage system. Details for the calculation of load balancing storage systems see EN 15316-4-1

## 7 Calculation method for boilers with stocking by hand.

### 7.1 Available methodologies

In this standard two performance calculation methods for boilers with stocking by hand are described. The calculation methods differ with respect to:

- required input data
- operating conditions ( operation cycles ) taken into account
- calculation period applied

The first method ( see 7.3 ) distinguish in a explicit way the losses of the boiler which occurs during the boiler cycling ( i.e. combustion losses ).Some of the parameters can be measured at site.

The second method ( see 7.4 ) is based on the data related to the test procedures according EN 303-5, but supplementary data are needed in order to take into account the specific operation conditions during the heating period.

NOTE 1: The boilers with stocking by hand were fired by logwood.

NOTE 2: According EN 303-5 it is recommended to operate the boiler with stocking by hand with an accumulator storage system. Details for the design see EN 303-5

## 7.2 Operation periods

The operation periods for biomass combustion sub-system with stocking by hand are variable according to the different types of operation cycles as follows.

### 7.2.1 Heating up operation cycle

The operation period for the heating up operation cycle  $t_{gn, hp}$  is influenced by:

- quality of the biomass fuel applied;
- quantity of the biomass fuel applied (according to the required quantity of the loaded biomass fuel)

### 7.2.2 Boiler ON operation cycle

The operation period of the biomass boiler ON operation cycle  $t_{gn, ON}$  is influenced by:

- quality of the biomass fuel applied;
- quantity of the biomass fuel applied (according to the required quantity of the loaded biomass fuel);
- intermediate load of the boiler;

The running time of the boiler ON operation cycle,  $t_{ge, on}$ , is calculated by:

$$t_{ge, on} = \frac{Q_{inp, d}}{\Phi_{out, avg}} \quad (h) \quad (5)$$

where:

- $t_{ge, on}$  running time within a 24 h operation period in (h)
- $Q_{inp, d}$  heat to be supplied to the distribution system within a 24 h operation period (kWh)
- $\Phi_{g, out, av}$  average boiler output within a 24 h operation period (kW)

The average boiler output is calculated by:

$$t_{ON} = \Phi_{cham} / \Phi_{cn, ref} \quad (kW)$$

where:

- $\Phi_{cham}$  heat output for each filling of the combustion chamber (kWh)  
If the performance of the boiler has been tested according to relevant EN 303-5. it can be take into account. If no values are available, default values are given in Annex B or in the relevant national annex.
- $\Phi_{cn, ref}$  reference combustion power (kW)

### 7.2.3 Cooling down operation cycle

The operation period of the cooling down operation cycle  $t_{g,cd}$  is influenced by:

- time when the operation cycle starts again;
- mass of the relevant parts of the boiler;
- water content of the boiler;
- heat loss of the envelope.

NOTE: For permanent operation cycle it is considered, that after the end of the cooling down operation cycle, the next heating up operation cycle is starting

### 7.2.4 Boiler non operation cycle

According the heat to be supplied to the distribution system during 24 h operation period two different types of non operation cycles are to be considered:

- boiler OFF operation cycle with the operation period  $t_{gn,OFF}$

NOTE 1: In this case the boiler temperature is same like ambience temperature

- boiler fire bed operation cycle with the operation period  $t_{gn,fb}$

NOTE 2: In this case the boiler temperature is same like the regular boiler operating temperature

## 7.3 Case specific boiler efficiency method for boilers with stocking by hand

### 7.3.1 Principle of the method

This method is related to the test values of EN 303-5 and is based on the following principle:

a) data are collected for three basic load factors or power outputs:

- efficiency at 100 % load,  $\eta_{gn,Pn}$  ;
- efficiency at intermediate load,  $\eta_{gn,Pint}$  ;
- losses at 0 % load,  $\Phi_{gn,l,Pnop}$ .

b) efficiency and losses data are corrected according to boiler operating conditions (temperature);

c) losses power at 100% load  $\Phi_{gn,l,Pn}$  and at intermediate load  $\Phi_{gn,l,Pint}$  are calculated according to corrected efficiencies;

d) losses at 0% load according the mode of operation ( fire bed operation, non operation mode )

e) calculation of losses power for the actual power output, is made by linear or polynomial interpolation between losses powers for the three basic power outputs.

NOTE: All powers and the load factor  $\beta_{gn}$  are referred to generation sub-system output

f) auxiliary energy is calculated taking into account the actual power output of the boiler;

g) recoverable generator envelope heat losses are calculated according to a tabulated fraction of stand-by losses and boiler location

h) recoverable auxiliary energy is added to recoverable generator losses to give total recoverable energy

### 7.3.2 Input data for the calculation method

#### 7.3.2.1 Biomass boiler data

The boiler is characterised by the following values:

$\Phi_{Pn}$	boiler output at full load
$\eta_{gn,,Pn}$	boiler efficiency at full load
$\theta_{gn,test,Pn}$	boiler average water temperature at test conditions for full load
$f_{cor,Pn}$	correction factor of full-load efficiency
$\Phi_{Pint}$	boiler output at intermediate load
$\eta_{gn,Pint}$	boiler efficiency at intermediate load
$\theta_{g,test,Pint}$	boiler average water temperature at test conditions for intermediate load
$f_{cor,Pint}$	correction factor of intermediate load efficiency
$\Phi_{gn,l,PO}$	stand-by heat loss at test temperature difference $\Delta\theta_{i,test}$
$\Delta\theta_{gn,test}$	Difference between mean boiler temperature and test room temperature in test conditions
$\Phi_{aux,gn,Pn}$	power consumption of auxiliary devices at full load
$\Phi_{aux,gn,Pint}$	power consumption of auxiliary devices at intermediate load
$\Phi_{aux,gn,PO}$	stand-by power consumption of auxiliary devices
$\theta_{gn,,min}$	minimum operating boiler temperature

Data to characterise the boiler shall be taken from one the following sources, listed in priority order:

- product data from the manufacturer, if the boiler has been tested according to EN 303-5
- default data from the relevant national annex;
- default data from Annex A

NOTE: It shall be recorded if the efficiency value includes or not auxiliary energy recovery

#### 7.3.2.2 Actual operating conditions

Actual operating conditions are characterised by the following values:

$Q_{gn,out}$	net heat output to the heat distribution sub-system(s);
$\theta_{gn,w,av}$	average water temperature in the boiler;
$\theta_{i,gn}$	boiler room temperature;
$b_g$	temperature reduction factor depending on the location of the generator.

### 7.3.3 Load factor for the boiler

#### 7.3.3.1 Generation sub-system average power

Generation sub-system average power  $\Phi_{gn}$  is given by:

$$\Phi_{gn} = \frac{Q_{g,out}}{t_{gn}} \quad [\text{kW}] \quad (6)$$

where

$t_{gn}$  total time of generator(s) operation [h]

### 7.3.3.2 Load factor for a single boiler generation sub-system

If there is only one generator installed, the load factor  $\beta_{gn}$  is calculated by:

$$\beta_{gn} = \frac{\Phi_{gn}}{\Phi_{Pn}} \quad [-] \quad (7)$$

where:

$\Phi_{Pn}$  nominal power output of the boiler [kW]

### 7.3.3.3 Generators with double service (space heating and domestic hot water production)

During the heating season, the heat generator can produce energy for the space heating installation and the domestic hot water (double service). For biomass generation subsystems it is not necessary to consider a specific calculation of the operating temperature.

NOTE: The minimum operating temperature of biomass boilers are always higher the required running temperature of the domestic hot water generation.

### 7.3.4 Biomass boiler heat losses.

#### 7.3.4.1 Operating temperature of the boiler

The operating temperature of the boiler depends on:

- technical limit of the generator (taken into account by the temperature limitation);
- type of control (taken into account by a return temperature reduction device );
- temperature of the storage sub-system connected to the boiler ( if required )

The effect of control on the boiler is assumed to be adjusting the average temperature of the heat storage system ( if required ).

The operating temperature of the generator is calculated by:

$$\theta_{gn,w} = \max(\theta_{gn,min}, \theta_{em}) \quad [^{\circ}\text{C}] \quad (8)$$

where:

$\theta_{gn,min}$  minimum operating boiler temperature for each generator [°C]

$\theta_{st}$  temperature for heat distribution and heat storage ( if required ) during the considered period [°C]

#### 7.3.4.2 Biomass boiler heat loss calculation at 100 % load

For biomass boilers the efficiency at full load is measured at a reference generator average water temperature  $\theta_{gn,test,Pn}$ . This efficiency has to be adjusted to the actual generator average water temperature of the individual installation.

The temperature corrected efficiency  $\eta_{gn,Pn,cor}$  is calculated by:



$$\eta_{gn,Pn,cor} = \eta_{gn,Pn} + f_{cor,Pn} \cdot (\theta_{gn,test,Pn} - \theta_{gn,w}) \quad [\%] \quad (9)$$

where:

$\eta_{gn,Pn}$	boiler efficiency at full load If the performance of the boiler has been tested according to relevant EN 303-5, it can be taken into account. If no values are available, default values are given in Annex A or in the relevant national annex.	[%]
$f_{cor,Pn}$	correction factor taking into account variation of the efficiency as a function of the boiler average water temperature. The value should be given in a national annex. In the absence of national values, default values are given in Annex A. If the performance of the boiler has been tested according to relevant EN 303-5, it can be taken into account.	[-]
$\theta_{gn,test,Pn}$	boiler average water temperature at test conditions for full load. See Annex A	[°C]
$\theta_{gn,w}$	average water temperature in the boiler as a function of the specific operating conditions. See Annex A	[°C]

In order to simplify the calculations, the efficiencies and heat losses determined at test conditions are adjusted to the actual boiler average water temperature. It is allowed, as it is physically correct, to adjust the performance at each load to the actual boiler average water temperature of each load.

The corrected boiler heat loss at 100 % load  $\Phi_{gn,l,Pn,cor}$  is calculated by:

$$\Phi_{gn,l,Pn,cor} = \frac{(100 - \eta_{gn,Pn,cor})}{\eta_{gn,Pn,cor}} \cdot \Phi_{Pn} \cdot 1.000 \quad [W] \quad (10)$$

where:

$\Phi_{Pn}$	boiler output at full load	[kW]
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### 7.3.4.3 Boiler heat loss calculation at intermediate load

The impact on efficiency from variation of the generator average water temperature is calculated by:

$$\eta_{gn,Pint,cor} = \eta_{gn,Pint} + f_{cor,Pint} \cdot (\theta_{gn,test,Pint} - \theta_{gn,w}) \quad [\%] \quad (11)$$

where:

$\eta_{gn,Pint}$	boiler efficiency at intermediate load If the performance of the boiler has been tested according to relevant EN 303-5, this values can be taken into account. If no values are available, default values are given in Annex A in the relevant national annex.	[%]
$f_{cor,Pint}$	correction factor taking into account variation of the efficiency as a function of the boiler average water temperature. The value should be given in a national annex. In the absence of national values, default values are given in Annex A. If the performance of the boiler has been tested according to relevant EN standard 303-5, it can be taken into account.	[-]
$\theta_{gn,test,Pint}$	boiler average water temperature at test conditions for intermediate load .See Annex A	[°C]
$\theta_{gn,w}$	average water temperature in the boiler as a function of the specific operating conditions. See Annex A	[°C]

The intermediate load depends on the boiler type. Default values are given in Annex A

The corrected boiler heat loss at intermediate load  $\Phi_{gn,l,P_{int},cor}$  is calculated by:

$$\Phi_{gn,l,P_{int},cor} = \frac{(100 - \eta_{gn,P_{int},cor})}{\eta_{gn,P_{int},cor}} \cdot \Phi_{P_{int}} \cdot 1.000 \quad [W] \quad (12)$$

where:

$\Phi_{P_{int}}$  boiler output at intermediate load [kW]

### 7.3.4.3 Boiler heat loss calculation at 0 % load

The boiler heat loss at 0 % load  $\Phi_{gn,l,P_0}$  is, determined for a test temperature difference according to relevant testing. If the performance of the boiler has been tested, these values can be taken into account.

The boiler heat loss at 0 % load  $\Phi_{gn,l,P_0}$  depends on the type of operation

- type of biomass boiler ( atmospheric or fan assisted );
- type of the operation cycle ( non operation or fire bed operation );

Note: For fan assisted boiler there might be 2 non operating cycles at 0% load, if the load factor is very low.

If no manufacturer or national annex data are available, default values are given in Annex A

The corrected boiler heat loss at 0% load  $\Phi_{gn,l,P_0,cor}$  is calculated by:

$$\Phi_{gn,l,P_0,cor} = \Phi_{gn,l,P_0} \cdot \left( \frac{\theta_{gn,w} - \theta_{i,gn}}{\Delta\theta_{test}} \right)^{1,25} \quad [W] \quad (13)$$

where:

$\Phi_{gn,l,P_0}$  stand-by heat loss at test temperature difference  $\Delta\theta_{i,test}$  [W]

$\theta_{i,gn}$  indoor temperature of the boiler room [°C]  
Default values are given in Annex A

$\Delta\theta_{test}$  Difference between mean boiler temperature and test room temperature in test conditions [°C]  
Default values are given in Annex A

### 7.3.4.4 Boiler heat loss at specific load ratio $\beta_{gn,i}$ and power output $\Phi_{Px}$

The specific load ratio  $\beta_{gn,i}$  of each boiler is calculated according to

$$\beta_{gn,i} = \Phi_{Px} / \Phi_{P_n} \quad [-] \quad (14)$$

If  $\beta_{gn,i}$  is between 0 (power output  $\Phi_{P_0} = 0$ ) and  $\beta_{int}$  (intermediate load, power output  $\Phi_{P_{int}}$ ), the boiler heat loss  $\Phi_{gn,l,P_x}$  is calculated by:

$$\Phi_{gn,l,P_x} = \frac{\Phi_{P_x}}{\Phi_{P_{int}}} \cdot (\Phi_{gn,l,P_{int},cor} - \Phi_{gn,l,P_0,cor}) + \Phi_{gn,l,P_0,cor} \quad [W] \quad (15)$$

If  $\beta_{gn,i}$  is between  $\beta_{int}$  (intermediate load, power output  $\Phi_{P_{int}}$ ) and 1 (power output  $\Phi_{P_n}$ ), the boiler heat loss  $\Phi_{gn,l,P_x}$  is calculated by:

$$\Phi_{gn,l,Px} = \frac{\Phi_{Px} - \Phi_{Pint}}{\Phi_{Pn} - \Phi_{Pint}} \cdot (\Phi_{gn,l,Pn,cor} - \Phi_{gn,l,Pint,cor}) + \Phi_{gn,l,Pint,cor} \quad [W] \quad (16)$$

$\Phi_{gn,l,Px}$  may also be calculated by 2<sup>nd</sup> order polynomial interpolation. A formula for such interpolation is given in informative in EN 15316-4-1 .

### 7.3.4.5 Total boiler heat loss

The total boiler heat loss  $Q_{gn,l,t,i}$  during the considered period is calculated by:

$$Q_{gn,l,t} = \Phi_{gn,l,Px} \cdot t_{gn} \quad [W] \quad (17)$$

If there are several boilers, total generation sub-system losses are the sum of boiler total losses.

### 7.3.5 Total auxiliary energy

The total auxiliary energy for a boiler  $W_g$  is given by:

$$W_g = \Phi_{aux,Px} \cdot t_{gn} + \Phi_{aux,SB} \cdot (t_{ci} - t_{gn}) \quad [W] \quad (18)$$

where

$\Phi_{aux,SB}$  auxiliary power when the generation system is inactive.

NOTE: If the generator is electrically isolated when inactive,  $\Phi_{aux,SB} = 0$ ; otherwise  $\Phi_{aux,SB} = \Phi_{aux,P0}$

$t_{ci}$  is the calculation interval

$t_{gn}$  is the operation time of the boiler generator within the calculation interval

The average auxiliary power for each boiler  $\Phi_{aux,Px}$  is calculated by linear interpolation, according to the boiler load  $\beta_{gn}$ , between:

$\Phi_{aux,Pn}$  auxiliary power of the boiler at full load ( $\beta_{gn}=1$ ).

$\Phi_{aux,Pint}$  auxiliary power of the boiler at intermediate load ( $\beta_{gn} = \beta_{int}$ ).

$\Phi_{aux,P0}$  auxiliary power of the boiler in stand-by ( $\beta_{gn}=0$ ).

measured according to prEN 15456

If  $0 \leq \beta_{gn} \leq \beta_{int}$  then  $\Phi_{aux,Px}$  is given by

$$\Phi_{aux,Px} = \Phi_{aux,P0} + \frac{\beta_{gn}}{\beta_{int}} \cdot (\Phi_{aux,Pint} - \Phi_{aux,P0}) \quad [W] \quad (19)$$

If  $\beta_{int} < \beta_{gn} \leq 1$  then  $\Phi_{aux,Px}$  is given by:

$$\Phi_{aux,Px} = \Phi_{aux,Pint} + \frac{\beta_{gn} - \beta_{int}}{1 - \beta_{int}} \cdot (\Phi_{aux,Pn} - \Phi_{aux,Pint}) \quad [W] \quad (20)$$

### 7.3.6 Recoverable generation heat losses

#### 7.3.6.1 Auxiliary energy

Auxiliary energy **already taken into account in efficiency data** shall not be calculated for recovery again (example: oil heating, combustion air fan, primary pump).

For the recoverable auxiliary energy, a distinction is made between:

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- recoverable auxiliary energy transmitted to the heating medium (e.g. water)  
It is assumed, that the auxiliary energy transmitted to the energy vector is totally recovered;
- recoverable auxiliary energy transmitted to the heated space.

The recoverable auxiliary energy transmitted to the heated space is calculated by:

$$W_{g,rl} = W_g \cdot (1 - b_g) \cdot P_{aux,g} \quad [W] \quad (21)$$

where

$p_{aux,g}$  part of the nominal electrical power transmitted to the distribution sub-system [-]  
The value should be given in a national annex. In the absence of national values, a default value is given in Annex A. If the performance of the generator has been certified, it can be taken into account.

$b_g$  temperature reduction factor depending on location of the generator [-]  
The value of  $b$  should be given in a national annex. In the absence of national values, a default value is given in Annex A.

### 7.3.6.2 Boiler heat loss (boiler envelope)

Only the heat losses through the boiler envelope are considered as recoverable and depend on the boiler type. For biomass fired boilers, the heat losses through the boiler envelope are expressed as a fraction of the total stand-by heat losses.

The recoverable heat losses through the boiler envelope  $Q_{gn,env,rl}$  are calculated by:

$$Q_{gn,env,rl} = \Phi_{gn,l,P0,cor} \cdot (1 - b_g) \cdot p_{gn,env} \cdot t_{gn} \quad [W] \quad (22)$$

where:

$p_{gn,env}$  heat losses through the generator envelope [-]  
expressed as a fraction of the total stand-by heat losses. The value of  $p_{gn,env}$  should be given in a national annex. In the absence of national values, default values are given in Annex A. If the performance of the boiler has been tested, it can be taken into account.

$t_{gn}$  boiler operating time [h]

### 7.3.6.3 Total recoverable generation heat losses

The total recoverable generation heat losses  $Q_{g,l,rl}$  are calculated by:

$$Q_{g,l,rl} = Q_{gn,env,rl} + W_{g,rl} \quad [W] \quad (23)$$

### 7.3.7 Calculation procedure

The calculation procedure and an example are described in Annex E

## 7.4 Boiler cycling method

### 7.4.1 Principle of the method

This calculation method is based on the following principles.

### 7.4.1.1 Operation period

The operation period is divided in two main parts:

boiler in operation  $t_{ON}$  consisting of 3 subparts:

- boiler heating up  $t_{gn, hp}$
- boiler heating operation  $t_{gn, h}$
- boiler cooling down  $t_{gn, cd}$

boiler in non operation  $t_{OFF}$  consisting of 2 subparts:

- boiler in fire bed operation  $t_{gn, fb}$
- boiler in non operation  $t_{gn, no}$

The total operation period  $t_{g,t}$  of the boiler is given by:

$$t_{g,t} = t_{gn, hp} + t_{gn, h} + t_{gn, cd} + t_{gn, fb} + t_{gn, no} \quad (h) \quad (24)$$

Note: Boiler in fire bed operation is only relevant for boilers with fan assistance

### 7.4.1.2 Heat losses

Heat losses are taken into account separately for these five periods of time.

During the boiler heating up operation, the following heat losses are taken into account:

- heat of flue gas of the boiler according the intermediate load
- heat losses through the boiler envelope at the running temperature

During boiler heating operation, the following heat losses are taken into account:

- heat of flue gas of the boiler according the intermediate load
- heat losses through the boiler envelope at the running temperature

During the boiler cooling down operation, the following heat losses are taken into account:

- no heat of flue gas loss of the boiler
- heat losses through the boiler envelope at the running temperature

During boiler firebed operation, heat losses are taken into account as follows

- heat of flue gas loss of the boiler with the fire bed load
- heat losses during the fire bed operation through the boiler envelope at the running temperature

During boiler off operation, heat losses are taken into account as follows:

- no flue gas heat loss through the chimney .
- no heat losses through the boiler envelope at the boiler room temperature:

### 7.4.1.3 Auxiliary energy

Auxiliary energy is considered separately for appliances before and after the boiler:

- $W_{br}$  is the auxiliary energy required by components and devices that are before the combustion chamber following the energy path (typically burner fan, see figure 2)

NOTE: typically these components and devices are running only when the burner is on, i.e. during  $t_{ON}$

—  $W_{af}$  is the auxiliary energy required by components and devices that are before the combustion chamber following the energy path (typically primary pump, see figure 2)

NOTE: typically these components and devices are running during the entire operation period of the boiler  
i.e. during  $t_{g,t} = t_{ON} + t_{OFF}$

**7.4.1.4 Recovered auxiliary energy**

The recovered auxiliary energy is calculated according the appliances as follows:

—  $Q_{br} = k_{br} \cdot W_{br}$  is the auxiliary energy recovered from appliances before the boiler (25)

—  $Q_{af} = k_{af} \cdot W_{af}$  is the auxiliary energy recovered from appliances after the boiler (26)

$k_{af}$  and  $k_{br}$  express the fractions of the auxiliary energy for these appliances recovered to the heating medium (typically the efficiency of the primary pumps and the boiler fan).

Auxiliary energy transformed into heat and emitted to the heated space may be considered separately and is added to the recoverable heat losses.

**7.4.1.5 Basic energy balance**

The basic energy balance of the generation sub-system is:

$$Q_{g,out} = Q_{cn} + Q_{br} + Q_{af} - Q_{ch,on} - Q_{ch,off} - Q_{gn,env} \quad [kW] \quad (27)$$

A schematic diagram of the energy balance of the generation sub-system is shown in Figure 2.

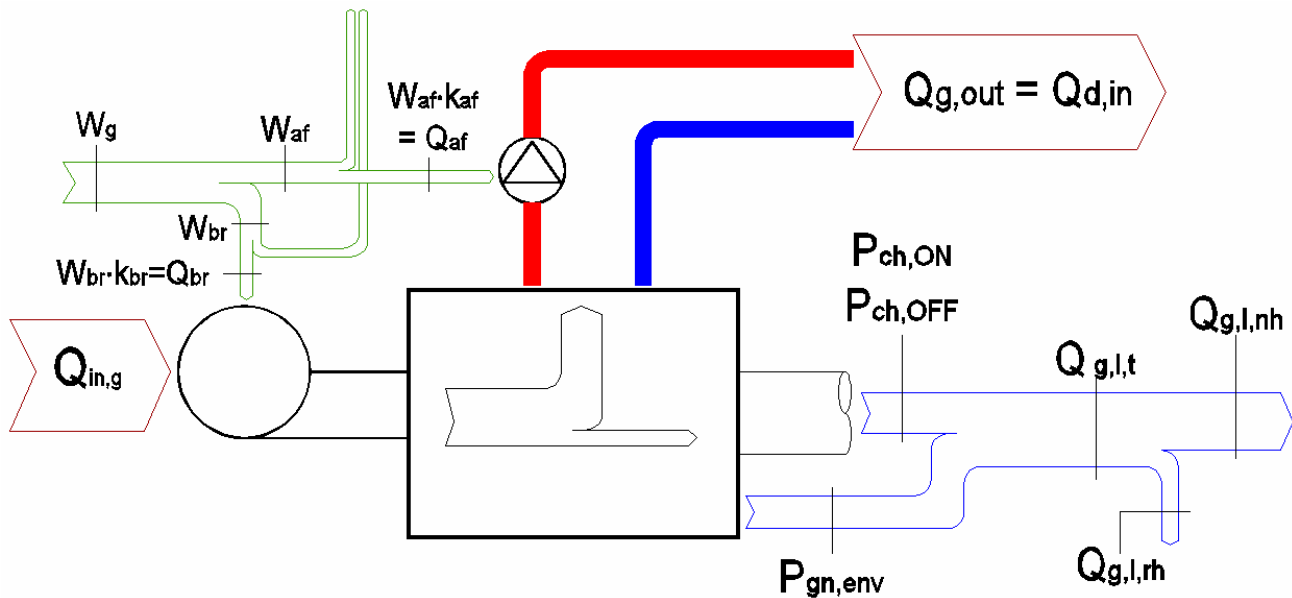


Figure 2 : Schematic energy balance of generation sub-system

**7.4.2 Input data for the method**

**7.4.2.1 Biomass boiler data**

The boiler is characterised by the following values:

$\Phi_{cn}$	combustion power of the boiler, which is the reference power for $P'_{ch,on}$ (either design or actual value)
$\Phi_{cn,min}$	minimum combustion power of the boiler
$\Phi_{ref}$	reference power for the heat loss factors $P'_{ch,off}$ and $P'_{gn,env}$ (usually $\Phi_{ref} \equiv \Phi_{cn}$ )
$P'_{ch,on}, P'_{ch,off}, P'_{gn,env}$	heat loss factors at test conditions
$P'_{ch,on,min}$	heat loss factor $P'_{ch,on}$ at minimum combustion power $\Phi_{cn,min}$
$\Phi_{br}$	electrical power consumption of auxiliary appliances (before the generator)
$k_{br}$	recovery factor of $\Phi_{br}$
$\Phi_{af}$	electrical power consumption of auxiliary appliances (after the generator)
$\Phi_{br,min}$	electrical power consumption of auxiliary appliances (before the generator) at minimum combustion power $\Phi_{cn,min}$
$k_{af}$	recovery factor of $\Phi_{af}$
$\theta_{gn,test}$	average boiler water temperature at test conditions for $P_{ch,on}$
$\theta_{ch,test}$	flue gas temperature at test conditions for $P_{ch,on}$
$\theta_{i,test}$	temperature of test room for $P_{gn,env}$ and $P_{ch,off}$
$\Delta\theta_{g,env,ref}$	difference between mean boiler temperature $\theta_{gn,test}$ and test room temperature $\theta_{i,test}$ at test conditions for $P_{g,env}$ and $P_{ch,off}$

Exponents n, m and p for the correction of heat loss factors

NOTE: Biomass boilers operate in a modulating mode regularly.

#### 7.4.2.2 Actual operation conditions

Actual operation conditions are characterised by the following values:

$Q_{g,out}$	net heat output to the heat distribution sub-system(s)
$\theta_{gn,w,av}$	average water temperature in the boiler
$\theta_{i,gn}$	boiler room temperature
$k_{gn,env}$	reduction factor taking into account recovery of heat losses through the generator envelope depending on location of the boiler
FC	load factor

NOTE: All powers and the load factor FC are referred to generator input (combustion power).

#### 7.4.3 Load factor

The load factor FC is the ratio between the time with the boiler ON operation and the total time of boiler operation (ON period and OFF period):

$$FC = \frac{t_{ON}}{t_{gn}} = \frac{t_{ON}}{t_{ON} + t_{OFF}} \quad [\%] \quad (28)$$

where

$t_{gn}$	total time of boiler operation	[h]
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$t_{ON}$  time with the boiler ON (pre- and post-ventilation are not considered) [h]

Note: The boiler time in operation  $t_{g,ON} = t_{gn,hp} + t_{gn,h}$  [h] (29)

$t_{OFF}$  time with the boiler OFF [h]

Note: The boiler time in non operation  $t_{g,OFF} = t_{gn,cd} + t_{gn,fb} + t_{gn,off}$  [h] (30)

The load factor shall either be calculated according to the actual energy,  $Q_{g,out}$ , to be supplied by the generation sub-system or be measured (e.g. by time counters) on existing systems.

NOTE 1: The boiler heating up time  $t_{gn,hp}$  depends on:

- total mass of the boiler ( metal + refractory + insulating materials )
- net calorific value of the fuel ( logwood )

NOTE 2: The boiler cooling down time  $t_{gn,cd}$  depends on:

- total mass of the boiler ( metal + refractory + insulating materials )
- quality of the insulating materials of the boiler

### 7.4.4 Heat losses

#### 7.4.4.1 General

Heat losses at test conditions are expressed as a percentage ( $P'_{ch,on}$ ,  $P'_{ch,off}$  and  $P'_{gn,env}$ ) of a reference power at test conditions.

Heat losses of the boiler are given at standard test conditions. Test conditions are identified by a quote.

Test values shall be adjusted according to actual operation conditions. This applies both to standard test values and to field measurements.

#### 7.4.4.2 Heat losses through the chimney with the boiler on $P_{ch,on}$

The correction method for this losses factor takes into account the effects of:

- average water temperature in the boiler;
- load factor;
- boiler settings (power and excess air changing the heat exchange efficiency).

Heat losses through the chimney shall be expressed as a percentage of the combustion power  $\Phi_{cn}$ . Actual specific heat losses through the chimney with the boiler on  $P_{ch,on}$  are given by:

$$P_{ch,on} = \left[ P'_{ch,on} + (\theta_{gn,w,av} - \theta_{gn,test}) \cdot f_{cor} \right] \cdot FC^n \quad [\%] \quad (30)$$

where:

$P'_{ch,on}$  Heat losses through the chimney at test conditions [ % ]  
(complement to 100 of the combustion efficiency)

$P'_{ch,on}$  is measured with the average water temperature  $\theta_{gn,test}$ .

For the design of new systems,  $P'_{ch,on}$  is the value declared by the manufacturer.

For existing systems,  $P'_{ch,on}$  is given by a measure of combustion efficiency.

Combustion efficiency measurement shall be realised according to national standards or recommendations.

When combustion efficiency is measured, the corresponding average water temperature  $\theta_{gn,test}$  and



combustion power  $\Phi_{cn}$  shall be measured as well.

If no data is available, default values are given in Annex B  
The source of data shall be clearly stated in the calculation report.

$\theta_{gn,test}$  average water temperature in the boiler at test conditions [°C]  
(average of flow and return temperature, usually flow temperature 80 °C, return temperature 60 °C).

For the design of new systems,  $\theta_{gn,test}$  is the value declared by the manufacturer.  
For existing systems,  $\theta_{gn,test}$  is measured together with combustion efficiency.

If no data is available, default values are given in Annex B.  
The source of data shall be clearly stated in the calculation report.

$\theta_{gn,w,av}$  average water temperature in the boiler at actual conditions [°C]  
(average of flow and return temperature).

$f_{cor}$  correction factor for  $P'_{ch,on}$  [-]  
Default values for this factor is given in Annex B

$n$  exponent for the load factor FC [-]  
Default values for this exponent are given in Annex B

NOTE 1:  $FC^n$  takes into account the reduction of losses with high intermittencies, due to a lower average temperature of the flue gas (higher efficiency at start). An increasing value of  $n$  corresponds to a higher value of  $M_{ch,on}$ , defined as heat capacity per kW of the heat exchange surface between flue gas and water

NOTE 2: Equation (30) takes into account variation in combustion efficiency depending on average temperature of water in the generator by a linear approximation. The assumption is, that temperature difference between water and flue gas is approximately constant (i.e. a 20 °C increase of average water temperature causes a 20 °C increase of flue gas temperature). A 22 °C increase of flue gas temperature corresponds to 1% increase of losses through the chimney, hence the default value 0,045 for  $f_{cor}$ . Equation 30 does not include the effect of any latent heat recovery.

NOTE 2: Equation (30) does not take into account explicitly the effect of varying air/fuel ratio. The constant 0,045 is valid for standard excess air (3% O<sub>2</sub> in flue gas). For new systems, a correct setting is assumed. For existing systems, the air/fuel ratio contributes to  $P'_{ch,on}$ . If required, the constant 0,045 should be recalculated according to the actual air/fuel ratio.

NOTE 3: Equation (30) does not take into account explicitly the effect of varying combustion power  $\Phi_{cn}$ . If the combustion power is significantly reduced, the procedure for existing systems shall be followed (i.e.  $P_{ch,on}$  shall be measured)

#### 7.4.4.3 Heat losses through the boiler envelope $P_{gn,env}$

Actual heat losses through the generator envelope  $P_{gn,env}$  are given by:

$$P_{gn,env} = P'_{gn,env} \cdot k_{gn,env} \cdot \frac{(\theta_{gn,w,av} - \theta_{i,gn})}{(\theta_{gn,test} - \theta_{i,test})} \cdot FC^m \quad [\%] \quad (31)$$

where

$P'_{gn,env}$  heat losses through the boiler envelope at test conditions [%]

$P'_{gn,env}$  is expressed as a percentage of the reference power  $\Phi_{ref}$  (usually nominal combustion power of the boiler). For the design of new systems,  $P'_{gn,env}$  is the value declared by the manufacturer.  
If no data is available, default values are given in Annex B.  
The source of data shall be clearly stated in the calculation report.

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$k_{gn,env}$	reduction factor taking into account the location of the boiler Takes into account recovery of heat losses as a reduction of total losses. Default values are given in Annex B	[-]
$\theta_{i,test}$	temperature of the test room. Default values are given in Annex B.	[°C]
$\theta_{i,gn}$	actual temperature of the room where the boiler is installed. Default values are given in Annex B	[°C]
$m$	exponent for the load factor FC. Default values are given in Annex B	[-]

Default values for this exponent are given in Annex A depending on the parameter  $M_{gn,env}$ , defined as the ratio between the total weight of the boiler (metal + refractory materials + insulating materials) and the nominal combustion power  $\Phi_{cn}$  of the boiler.

NOTE 1: The factor  $FC^m$  takes into account the reduction of heat losses through the boiler envelope if the boiler is allowed to cool down during non operating cycle. In all cases  $m = 0$  inhibits this correction.

It is assumed that heat losses through the envelope are related to the temperature difference between the average water temperature in the boiler and the temperature of the boiler surroundings. The relation is assumed to be linear (heat conduction through the boiler insulation).

$P'_{gn,env}$  can be determined as the difference between the combustion efficiency and the net efficiency of the boiler at test conditions (continuous operation).

Recovery of heat losses through the boiler envelope are taken into account as a reduction of total losses (by the reduction factor  $k_{gn,env}$ ).

As an alternative, it is possible to determine the actual total boiler envelope heat losses  $P_{gn,env}$  from the total heat losses at test conditions  $P'_{gn,env}$  by:

$$P_{gn,env} = P'_{gn,env} \cdot \frac{(\theta_{gn,w,av} - \theta_{i,gn})}{(\theta_{gn,test} - \theta_{i,test})} \cdot FC^m \quad [\%] \quad (32)$$

and determine the actual recoverable heat losses,  $P_{gn,rl}$  by:

$$P_{gn,rl} = P_{gn,env} \cdot (1 - k_g) \quad [\%] \quad (33)$$

where

$k_g$  reduction factor taking into account according Annex B

**7.4.4.4 Heat losses through the chimney with the boiler off  $P_{ch,off}$**

This heat loss takes into account the stack effect of the chimney, which causes a flow of cold air through the boiler.

A correction according to the average water temperature in the boiler and the boiler room temperature is required. During each boiler off period, the maximum energy which can be lost is the heat stored in the boiler (in the metallic parts and in the water). Therefore, the load factor is a function of the heat capacity of the boiler.

Actual heat losses through the chimney when the burner is off  $P_{ch,off}$  are given by:

$$P_{ch,off} = P'_{ch,off} \cdot \frac{(\theta_{gn,w,av} - \theta_{i,gn})}{(\theta_{gn,test} - \theta_{i,test})} \cdot FC^p \quad [\%] \quad (34)$$

where

$P'_{ch,off}$  heat losses through the chimney when the boiler is off at test conditions [%]

$P'_{ch,off}$  is expressed as a percentage of the reference power  $\Phi_{ref}$  (usually nominal combustion power of the generator). For the design of new systems,  $P'_{ch,off}$  is the value declared by the manufacturer. For existing systems,  $P'_{ch,off}$  can be calculated by measuring the flow rate and the temperature at the boiler flue gas outlet.

If no data is available, default values are given in Annex B. The source of data shall be clearly stated in the calculation report.

$p$  exponent for the load factor FC. [-]

Default values for this exponent are given in Annex B depending on the parameter  $M_{ch,off}$ , defined as the ratio between the total weight of the boiler (metal + refractory materials + insulating materials) and the nominal combustion power  $\Phi_{cn}$  of the boiler.

NOTE: The factor  $FC^p$  takes into account the reduction of heat losses through the chimney with the burner off if the generator is allowed to cool down during stand-by. In all cases  $p = 0$  inhibits this correction.

#### 7.4.4.5 Heat losses

Heat losses through the chimney with the boiler on:

$$Q_{ch,on} = \frac{P_{ch,on}}{100} \cdot \Phi_{cn} \cdot t_{ON} \quad [W] \quad (35)$$

Heat losses through the chimney with the boiler off:

$$Q_{ch,off} = \frac{P_{ch,off}}{100} \cdot \Phi_{ref} \cdot t_{OFF} \quad [W] \quad (36)$$

Heat losses through the generator envelope:

$$Q_{gn,env} = \frac{P_{gn,env}}{100} \cdot \Phi_{ref} \cdot (t_{OFF} + t_{ON}) \quad [W] \quad (37)$$

#### 7.4.4.6 Total heat losses:

The total heat losses are described as:

$$Q_{g,t} = \sum Q_{ch,on} + Q_{g,OFF} + Q_{g,env} \quad [W] \quad (38)$$

### 7.4.5 Auxiliary energy

#### 7.4.5.1 Specific auxiliary energy consumption

For each auxiliary device of the biomass generation sub-system, the following data shall be determined:

— Electrical power consumption  $\Phi_{W,i}$ . Values can be:

- declared by the manufacturer;
  - measured;
  - or default values given in Annex B
- The source of data shall be clearly stated in the calculation report.

— Running time  $t_{on,i}$ , as a function of load factor FC where appropriate (i.e. burner auxiliaries)

EXAMPLE 1: Running time of the boiler fan:  $t_{on} = FC \cdot t_{gn}$  [h] (39)

- Part of the electrical energy converted to heat and recovered to the system before the combustion chamber  $k_{br,i}$  (auxiliary energy recovery factor). The default value for  $k_{br}$  is given in Annex B

EXAMPLE 2: Examples of such auxiliaries are combustion air fan

- Part of the electrical energy converted to heat and recovered to the system after the generator  $k_{af,i}$  (auxiliary energy recovery factor). The default value for  $k_{af}$  is given in Annex B

EXAMPLE 3 Examples of such auxiliaries are primary pumps.

Variable electrical power consumption should be approximated by an equivalent constant average electrical power consumption.

#### 7.4.5.2 Total auxiliary energy consumption

The total auxiliary energy required by the generation sub-system is given by:

$$W_g = \sum_i \Phi_{W,i} \cdot t_{on,i} \quad [\text{W}] \quad (40)$$

#### 7.4.5.3 Recovered auxiliary energy

The auxiliary energy converted to heat and recovered to the system before the boiler is given by (assuming  $t_{on,i} = t_{ON}$ ):

$$Q_{br} = \sum_i \Phi_{br,i} \cdot t_{on,i} \cdot k_{br,i} = \Phi_{br} \cdot k_{br} \cdot t_{ON} \quad [\text{W}] \quad (41)$$

The auxiliary energy converted to heat and recovered to the system after the generator is given by (assuming  $t_{on,i} = t_{gn}$ ):

$$Q_{af} = \sum_i \Phi_{af,i} \cdot t_{on,i} \cdot k_{af,i} = \Phi_{af} \cdot k_{af} \cdot t_{gn} \quad [\text{W}] \quad (42)$$

#### 7.4.5.4 Calculation procedure for a modulating biomass boiler

The calculation procedure and an example are in the Annex F

## Annex A (informative)

### Default values for parametering boiler with biomass combustion systems by the case specific method

#### A.1 Boiler efficiencies at full load and intermediate load as a Function of the heat output:

Boiler efficiencies at full load and intermediate load, as a function of the nominal heat output, can be expressed as:

$$\text{Full load:} \quad \eta_{g,n} = (A + B \times \log \Phi_{g,nom}) \quad (\%) \quad (\text{A.1})$$

$$\text{Intermediate load:} \quad \eta_{g,int} = (C + D \times \log \Phi_{g,nom}) \quad (\%) \quad (\text{A.2})$$

where:

$\Phi_{g,nom}$  nominal heat output in kW (maximum 400 kW)

A,B,C,D parameters given in Table 1

**Table 1 Parameters for biomass boiler efficiency**

Boiler type	A	B	C	D
Standard boiler Class 3	67	6	68	7
Standard boiler Class 2	57	6	58	7
Standard boiler Class 1	47	6	48	7

NOTE: The requirements for biomass boiler classes are described in EN-303-5

#### A.2 Standby heat losses

Default values for the standby losses of biomass boilers  $\Phi_{lo,stby}$  depending on the nominal heat output are calculated by:

$$\Phi_{lo,stby} = (E - F \times \log \Phi_{ge,nom}) \times \Phi_{g,n} \quad (\text{W}) \quad (\text{A.3})$$

where:

$\Phi_{ge,nom}$  nominal heat output in kW (maximum 400 kW)

E,F parameters given in Table 2

**Table 2 Parameters for stand by losses**

Boiler type	E	F	$\Delta\theta_{test}$ °C
Atmospheric boiler	12	- 0,1	30
Fan assisted boiler	10	-0,2	30

### A.3 Correction factor taking into account variation of the efficiency with the average water temperature

The correction factor  $f_{cor,Pn}$ , for heat loss calculation at 100% load, is given in Table 3.

**Table 3 Correction factor  $f_{cor,Pn}$**

Boiler type	Average temperature at boiler test conditions at full load $\theta_{ge,test,Pn}$	Correction factor $f_{cor,Pn}$
Standard boiler	70 °C	0,4

The correction factor  $f_{cor,Pint}$ , for heat loss calculation at intermediate load, is given in Table 4.

**Table 4 Correction factor  $f_{cor,Pint}$**

Boiler type	Average temperature at boiler test conditions at intermediate load $\theta_{ge,test,Pint}$	Correction factor $f_{cor,Pint}$
Standard boiler	50°C	0,05

### A.4 Auxiliary consumption

Default value for the power consumption of auxiliary equipment  $\Phi_{aux,gn}$  is calculated by:

$$\Phi_{aux,gn} = G + H \times \Phi_{Pn}^n \quad (W) \quad (A.4)$$

where:

$\Phi_{,nom}$  nominal heat output in kW (maximum 400 kW)

G,H,n parameters given in Table 5

**Table 5 Parameters for calculation of power consumption of auxiliary equipment**

		Factor G	Factor H	Factor n
Fan assisted boiler	Full load	0	45	0,48
	Part load	0	15	0,48
	fire bed load	15	0	0
Atmospheric boiler	Non operating	0	0	0
	Full load	40	0,35	1
	Part load	20	0,1	1
	Non operating	0	0	0

### A.5 Recoverable heat generation losses

#### A.5.1 Auxiliary energy

The part of the nominal electrical power transmitted to the distribution sub-system  $p_{aux,g}$  is calculated by:

$$p_{aux,g} = 1 - \eta_{hydraulic} \quad [-] \quad (A.5)$$

Default value of the hydraulic efficiency  $\eta_{hydraulic}$  is 0,75.

### A.5.2 Generator envelope

The part of stand-by heat losses attributed to heat losses through the generator envelope is given by  $p_{gn,env}$ . Default values of  $p_{gn,env}$  are given in Table 6.

**Table 6 Part of stand-by heat losses attributed to losses through the generator envelope**

Burner type	$p_{gn,env}$
Atmospheric burner	0,50
Fan assisted burner	0,75

### A.5.3 Default data according to boiler location

**Table 7 Temperature reduction factor  $b_g$  and default installation room temperature**

Generator location	Temperature reduction factor $b_g$	Installation room temperature °C
Outdoors	1	$\theta_{ext}$
In the boiler room	0,3	13
Under roof	0,2	5
Inside heated space	0	20

## Annex B (informative)

### Additional information and default values for parametering the boiler cycling method for biomass boiler

#### B.1 Information on the method

##### B.1.1 Basic assumptions and intended use

This method is intended for use with existing boilers where data non available according test measurements or measurements at site

This methodology is based on an physical analysis of losses and takes in to account two operating conditions:

- boiler in operation;
- boiler in non operation

This methodology is suitable for modulating boilers according the operation cycles described in 7.3

All data given in this annex are based on net calorific values  $H_i$ . If losses have to calculated with respect to gross calorific value  $H_g$ , this has to be done with the procedure defined in prEN 15316-1

NOTE. The gross calorific  $H_g$  of biomass fuel used for biomass boilers with stocking by hand is depending very strong from the humidity of the fuel. For comparison of results therefore agreed test fuel shall be used.

##### B.1.2 Known approximations

Additional losses during ignition cycles (ventilation before ignition) are not taken into account.

Losses through the chimney of boiler with stocking by hand during non operation are not easily measured. However this loss factor has been considered by formula 35 and table 13.

#### B.2 Default values for heat output of combustion chambers

Default value for the heat output of combustion chambers is calculated by:

$$\Phi_{aux,gn} = f_{cham} \times \Phi_{Pn} \quad (W) \quad (B.1)$$

where:

$\Phi_{PN}$  nominal heat output in kW (maximum 400 kW)

$f_{cham}$  correction factor for combustion chamber filling.

Default value  $f_{cham} = 5,0$  (h)

#### B.3 Default specific losses

##### B.3.1 Default values of $\theta_{gn,test}$ , $P'_{ch,on}$ and $n$



**Table 8** Default value of  $\theta_{gn,test}$  and  $P'_{ch,on}$ 

Description	$\theta_{gn,test}$ [°C]	$P'_{ch,on}$ [%]	$\theta_{i,test}$ [°C]	$f_{cor}$
Atmospheric boiler	70	12	20	0,045
Fan assisted boiler	70	10	20	0,045

**Table 9** Default value of exponent n

Description	$M_{ch,on}$ [kg/kW]	n [-]
Steel boiler	1 – 2	0,1

where  $M_{ch,on}$  is heat capacity per kW of the heat exchange surface between flue gas and water.

### B.3.2 Default values of $P'_{gn,env}$ , $k_{gn,env}$ and m

The default losses through the boiler envelope  $P_{gn,env}$  are given by:

$$P_{gn,env} = A - B \cdot \log \Phi_{cn} \quad [\%] \quad (B.2)$$

where

A, B parameters given in Table 10  
 $\Phi_{cn}$  boiler nominal combustion power [kW]

**Table 10** Value of parameters A and B

Boiler insulation type	A [-]	B [-]
Well insulated, high efficiency new boiler	1,72	0,44
Well insulated and maintained	3,45	0,88

**Table 11** Default value of factor  $k_{gn,env}$  and installation room temperature

Boiler type and location	$k_{gn,env}$ [-]	$\theta_{i,gn}$ [°C]
Boiler installed within the heated space	0,1	20
Atmospheric boiler installed within the heated space	0.2	20
Boiler installed within a boiler room	0.7	13
Boiler installed outdoors	1	External temperature

Default values for temperature in the testroom  $\theta_{i,test} = 20^{\circ}\text{C}$

**Table 12 Default value of exponent m**

Description	$M_{gn,env}$ [kg/kW]	m [-]
The primary pump is always running		0,0
The primary pump stops a few minutes after the boiler turns off	1 - 3	0,10

$M_{gn,env}$  is the ratio between the total weight of the boiler (metal + refractory materials + insulating materials) and the nominal combustion power  $\Phi_{cn}$  of the boiler.

### B.3.3 Default values of $P'_{ch,off}$ and p

**Table 13 Default value of  $P'_{ch,off}$**

Description	$P'_{ch,off}$ [%]
Fan assisted boiler with the fan and no closure of air intake with boiler off:	
Chimney height < 10 m	1,0
Chimney height > 10 m	1,2
Atmospheric fired boiler:	
Chimney height < 10 m	1,2
Chimney height > 10 m	1,6

**Table 14 Default value of exponent p**

Description	$M_{ch,off}$ [kg/kW]	p [-]
The primary pump is always running		0,0
The primary pump stops a few minutes after the boiler turns off	1 - 3	

$M_{gn,env}$  is the ratio between the total weight of the boiler (metal + refractory materials + insulating materials) and the nominal combustion power  $\Phi_{cn}$  of the boiler.

### B.4 Default auxiliary power consumption

**Table 15 Default value of electrical power consumption of auxiliary devices**

Description	Electrical power consumption [kW]
Atmospheric boilers	$\Phi_{br} = 20 + \Phi_{cn} \cdot 0,00035$

Description	Electrical power consumption [kW]
Atmospheric boilers	$\Phi_{br} = 20 + \Phi_{cn} \cdot 0,00035$
Burner fan and auxiliaries	$\Phi_{br} = \Phi_{cn} \cdot 0,003$
Primary pump	$\Phi_{af} = \Phi_{cn} \cdot 0,001$
Control system	$\Phi_{br} = 0,015$

where  $\Phi_{cn}$  is the boiler nominal combustion power [kW]

**Table 16 Default value of auxiliary energy recovery factors**

Description	Value [-]
$k_{br}$	0,8
$k_{af}$	0,8

### B.5 Additional default data

The default minimum combustion power of the boiler is given by:

$$\Phi_{cn,min} = \Phi_{cn} \cdot M \quad [\text{kW}] \quad (\text{B.3})$$

where:

M parameter given in Table C.10

$\Phi_{cn}$  boiler nominal (maximum) combustion power [kW]

**Table 17 Parameter M for modulating boiler**

Description	M [-]
Biomass boiler	0,5

**Table 18 Default value of  $\theta_{gn,test}$  and  $P'_{ch,on,min}$**

Description	$\theta_{gn,test}$ [°C]	$P'_{ch,on,min}$ [%]
Atmospheric boiler	70	11
Force draught boiler	70	9

**Table 19 Default value of electrical power consumption of auxiliary devices at  $\Phi_{cn,min}$**

Description	$\Phi_{br,min}$ [kW]
Atmospheric boilers	$\Phi_{br,min} = 10 + \Phi_{cn,min} \cdot 0,00035$

Boiler fan and auxiliaries	$\Phi_{br,min} = \Phi_{cn,min} \cdot 0,003$
Primary pump	$\Phi_{br,min} = 0,01515$

where  $\Phi_{cn,min}$  is the minimum combustion power of the boiler (kW).

**Table 20 Default value of auxiliary energy recovery factors**

Description	Value (-)
$k_{br}$	0,8
$k_{ba}$	0,8

## ANNEX C (informative)

### Design values for solid bio fuels

The quality and specification of solid fuels are described in prCEN/TS 14961

Solid fuels for household use are recommended according to Tabel B.1.

**Table 21 Solid fuels for household use**

Type of solid fuel	Description	Moisture content	Net calor value
Log wood (deciduous wood)	Oven ready selected stem wood	Under 20%	above 1.700kWh / m <sup>3</sup> (by stacked wood)
Log wood (coniferous wood)	Oven ready selected stem wood	Under 20%	above 1.300kWh/ m <sup>3</sup> (by stacked wood)

## ANNEX D ( informative )

### Storage systems for biomass combustion systems

#### D.1 Accumulator storage system

##### D 1.1 General

According to the European Standard EN 303.5, it is recommended to extend the boiler system with stocking by hand by an accumulator storage system, if the relation between the nominal heat output of the boiler  $Q_{g,nom}$  and the design heat load  $\Phi_h$  is greater than 1,5.

The main objective of an accumulator storage system for the boiler is to:

- store the heat between the operation cycles;
- improve the heating comfort for the user.

A further objective is, as with a load balancing storage system, to improve the operation conditions regarding thermal efficiency and environmental impact as well.

An accumulator storage system comprises the following components:

- accumulator storage tank;
- distribution piping between the boiler and the accumulator storage tank, including circulation pump;
- control device.

NOTE: The components are the same as for a load balancing system but the sizing is quite different.

##### D.1.2 Sizing of the volume of the accumulator storage tank

The volume of the accumulator storage tank  $V_{ac}$ , is determined by:

$$V_{lb,ta} = 15 \times t_{ge,on} \times \Phi_{ge,nom} \times \left(1 - 0,3 \times \frac{\Phi_{ge,nom}}{P_{bg}}\right) \quad (\text{ltr}) \quad (\text{D.1})$$

where:

$t_{g,on}$	operation of the boiler	(h)
$\Phi_{g,n}$	nominal heat output of the boiler(s)	(kW)
$P_{bg}$	(design) heat load of the building	(kW)
Default value for the volume $V_{ac} = 50 \times P_{bg}$		(ltr)

#### D. 1.3 Heat losses

##### D 1.3.1 Heat loss of the accumulator storage tank

Calculation of the heat losses of the accumulator storage tank  $Q_{l,at}$  is similar to the calculation for storage tanks for domestic hot water. Relevant values are given by:

- information by the manufacturer (standby value);

- calculation procedure according to the specification of the accumulator storage tank (see EN ISO 12241);
- default values according to tables (to be completed)

### D 1.3.2 Heat loss of the accumulator storage piping

Calculation of the heat losses of the accumulator storage tank  $Q_{l,ac,pip,at}$  is similar to the calculation for storage tanks for domestic hot water. Relevant values are given by:

- information by the manufacturer (standby value);
- calculation procedure according to the specification of the accumulator storage piping;
- default values according to tables (to be completed).

### D.1.3.3 Total heat losses

The total heat losses of the accumulator storage system  $Q_{lo,ac,sys,tot}$  are calculated by:

$$Q_{l,t,ac} = Q_{l,tk} + Q_{l,pi} \quad (\text{kWh}) \quad (\text{D.2})$$

### D.1.4 Energy loss of the circulation pump

The auxiliary consumption of the circulation pump  $W_{ac,pu}$  is calculated by:

$$W_{pu,ac} = f_{cor,ci} \times \Phi_{el,pu} \times t_{ci} \quad [\text{kW}] \quad (\text{D.3})$$

where:

$f_{cor,ci}$	correction factor running time. Default value $f_{cor,ci}$ 0 1,2	[-]
$\Phi_{el,pu}$	nominal output of the circulation pump	[kW]
$t_{ci}$	running time of the circulation pump	[h]

The recoverable energy loss of the circulation pump  $Q_{l,ac,pu}$  is calculated by:

$$Q_{l,ac,pu} = W_{ac,pu} \times f_{ac,sys} \quad [\text{kW}] \quad (\text{D.4})$$

where :

$f_{ac,sys}$	factor considering the operation conditions of the accumulator storage system Default value $f_{ac,sys} = 0,75$
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## D.2 Calculation of the heat loss of the load balancing system

The object of a load balancing system for boilers is to improve the operation conditions regarding thermal efficiency and environmental impact by:

- reduction of the start and stop cycles during operation of the boiler;
- extension of the minimum running time between start operation and stop operation of the boiler

Load balancing systems are used for boilers with automatic stocking. Details for the calculation of load balancing storage systems see En 15316-4-1

## Annex E (informative)

### Calculation procedure with an example for biomass boiler with stocking by hand (Case specific method)

Description	Advise	Calculation
<b>Specific boiler data</b>		
Type of biomass combustion system		Standard boiler, constant boiler running temperature, no accumulating storage tank
Type of control		Modulating, fan assisted
Nominal power ( 100% load )		$\Phi_{Pn} = 36,0 \text{ kW}$
Full load net efficiency based on test results	Test value	$\eta_{gn,Pn} = 88 \%$
Minimum part load	Test value	$Q_{g,int} = 18,0 \text{ kW}$
Part load net efficiency	Test value	$\eta_{gn,Pint} = 90 \%$
Minimum boiler temperature		$\Theta = 60^\circ \text{ C}$
<b>Other input data:</b>		
Energy supplied to the distribution system according to EN15316-3-2		$Q_{d,out} = 6000 \text{ kWh/ m}$
Calculation period		$t_{ci} = 30 \times 24 = 720 \text{ h}$
Boiler location		Inside boiler room
Boiler room temperature		$\Theta_{i,gn} = 15^\circ \text{ C}$
<b>Calculation procedure</b>		
Running temperature of the boiler		$\Theta = 65^\circ \text{ C}$
Correction factor for 100% load	Table 3	$f_{cor,Pn} = 0,4$
Boiler average water temperature at test conditions	Table 3	$\Theta_{gn,test,Pn} = 70^\circ \text{ C}$
Corrected boiler efficiency at 100% load	Formula 9	$\eta_{gn,Pn,cor} = \eta_{gn,Pn} + f_{cor,Pn} \cdot (\theta_{gn,test,Pn} - \theta_{gn,w}) =$ $= 88,0 + 0,4 ( 70 - 65 ) = 90,0\%$
Boiler heat loss at 100% load	Formula 10	$\Phi_{gn,l,Pn,cor} = \frac{(100 - \eta_{gn,Pn,cor})}{\eta_{gn,Pn,cor}} \cdot \Phi_{Pn} \cdot 1.000 =$ $= ((100 - 90) / 90) \times 36 \times 1000 = 4000 \text{ W}$
Correction factor for intermediate load	Table 4	$f_{cor,Pint} = 0,05$
Boiler average water temperature at test conditions		$\Theta_{gn,test,Pn} = 70^\circ \text{ C}$
Corrected boiler efficiency at intermediate load	Formula 11	$\eta_{gn,Pn,cor} = \eta_{gn,Pn} + f_{cor,Pn} \cdot (\theta_{gn,test,Pn} - \theta_{gn,w}) =$ $= 90,0 + 0,05 ( 70 - 65 ) = 90,25\%$
Boiler heat loss at intermediate load	Formula 12	$\Phi_{gn,l,Pint,cor} = \frac{(100 - \eta_{gn,Pint,cor})}{\eta_{gn,Pint,cor}} \cdot \Phi_{Pint} \cdot 1.000 =$ $= (( 100 - 90,25 ) / 90,25) \times 36 \times 1000 = 3890 \text{ W}$
Parameters for fire bed operation	Table 5	$E = 10, \quad F = - 0,2$



Heat loss at 0% load ( Fire bed operation )	Formula 4	$\Phi_{gn,l,P0} = \Phi_{Pn} \cdot (E + F \cdot \log \Phi_{Pn}') =$ $= 36 \times ( 10 - 0,2 \times \log 36 = 348 \text{ W}$
Heat loss at 0% load ( boiler non operation )	Table	$\Phi_{gn,l,no} = 0$
Corrected boiler heat loss at 0% load	Formula 13	$\Phi_{gn,l,P0,cor} = \Phi_{gn,l,P0} \cdot \left( \frac{\theta_{gn,w} - \theta_{i,gn}}{30} \right)^{1,25} =$ $= 348 \times ( ( 65 - 15 ) / 30 )^{1,25} = 628 \text{ W}$
Average power of the biomass boiler		$\Phi_{d,in} = Q_{d,out} / t_{ci} = 6000 / 720 = 8,33 \text{ kW}$
Load factor	Formula 6	$FC = \frac{\Phi_{d,in}}{\Phi_{Pn}} = 8,33 / 36,0 = 0,23$
Linear interpolation between 0% load and 50% load	Formula 15	$\Phi_{gn,l,Px} = \frac{\Phi_{Px}}{\Phi_{Pint}} \cdot (\Phi_{gn,l,Pint,cor} - \Phi_{gn,l,P0,cor}) + \Phi_{gn,l,P0,cor}$ $= ( 8,33 / 18 ) \times ( 3890 - 628 ) + 628 = 2138 \text{ W}$
Total boiler heat loss		$Q_{g,l,t} = \Phi_{gn,l,t} \times t_{ci} = 2138 \times 720 = 1540 \text{ kWh}$
Periodical efficiency of the biomass boiler		$\eta_{g,m} = 1 - Q_{g,l,t} / (Q_{d,out} + Q_{g,l,t}) =$ $= 1 - 1540 / (6000 + 11540) = 79,4\%$
Parameters for power consumption of auxiliary equipment	Table 5	$G = 0, \quad H = 15, \quad n = 0,48$
Power consumption of auxiliary equipment at part load	Formula A.4	$\Phi_{aux,gn} = G + H \times \Phi_{Pn} = 0 + 15 \times 18^{0,48} = 66 \text{ W}$
Parameters for auxiliary power at 0% load	Table 5	$G = 15, \quad H = 0, \quad n = 0$
Power consumption of auxiliary equipment at 0% load	Formula A.4	$\Phi_{aux,gn} = G + H \times \Phi_{Pn} = 15 + 0 \times 36^{0,48} = 15 \text{ W}$
Power consumption of auxiliary equipment at intermediate load	Formula 19	$\Phi_{aux,Px} = \Phi_{aux,P0} + \frac{\beta_{gn}}{\beta_{int}} \cdot (\Phi_{aux,Pint} - \Phi_{aux,P0}) =$ $= 15 + (0,5 / 0,23) \times ( 66 - 15) = 38 \text{ W}$
Auxiliary energy consumption	Formula	$W_g = \Phi_{aux,gn} \times t_{ON,gn} = 38 \times 720 = 2736 \text{ W}$
Recoverable auxiliary energy	Formula 21	$W_{g,rl} = W_g \times ( 1 - b_g ) \times \eta_{aux,g} =$ $= 2736 \times ( 1 - 0,3 ) \times 0,75 = 1436 \text{ W}$
<b>Output data</b>		
Fuel heat requirement		$Q_{g,n} = 6000 + 1540 - 1,4 = 7538,6 \text{ kWh}$
Total generation loss		$Q_{g,l,t} = 1540 \text{ kWh}$
Auxiliary energy consumption		$W_g = 2,74 \text{ kWh}$
Total recoverable heat loss		$W_{g,rl} = 1,4 \text{ kWh}$

## Annex F (informative)

### Calculation procedure with an example for biomass boiler with stocking by hand (Cycling method)

<i>Description</i>	<i>Advise</i>	<i>Calculation</i>
<b>Specific boiler data</b>		
Type of biomass combustion system		Standard boiler, constant boiler running temperature, no accumulating storage tank
Type of control		Modulating, fan assisted
Nominal power ( 100% load )		$\Phi_{Pn} = 36,0 \text{ kW}$
Volume burning chamber		$V_{\text{cham}} = 146 \text{ ltr}$
Heat loss through the chimney with boiler on	Test value	$P_{\text{ch,on}}^* = 12 \%$
Heat loss through the chimney with boiler off	Table 8	$P_{\text{ch,off}}^* = 1,2 \%$
Parameter default losses through envelope ( high efficiency boiler )	Table 10	$A = 3,54, B = 0,88$
Heat loss through the boiler envelope	Table B.6	$P_{\text{gn,env}} = A - B \times \log \Phi_{Pn} =$ $= 3,54 - 0,88 \times \log 36 = 3,54 - 1,37 =$ $= 2,08\%$
Reduction factor of boiler envelope heat losses	Formula B.1	$k_{\text{gn,env}} = 0,7$
Electrical power consumption of boiler auxiliary ( after the boiler ) load	Table 11	$\Phi_{\text{af}} = \Phi_{Pn} \times 0,003 = 36 \times 0,003 \times 1000 = 108 \text{ W}$
Default recovery factor	Table 16	$k_{\text{br}} = 0,7$
Boiler average water temperature at test conditions	Table 8	$\Theta_{\text{gn,test,Pn}} = 70^\circ\text{C}$
Temperature of test room for $P_{\text{ch,off}}^*$ and $P_{\text{gn,env}}$	Table 8	$\Theta_{\text{gn,test,Pn}} = 20^\circ\text{C}$
Temperature difference at test conditions		$\Delta\Theta_{\text{gn,env,ref}} = \Theta_{\text{gn,test,Pn}} - \Theta_{\text{gn,test,Pn}} = 70 - 20 = 50^\circ\text{C}$
Exponent for load factor for $P_{\text{ch,on}}^*$ ( steel boiler )	Table 9	$n = 0,1$
Exponent for load factor for $P_{\text{gn,env}}$ ( pump always running )	Table 12	$m = 0$
Exponent for load factor for $P_{\text{ch,off}}^*$ ( steel boiler )	Table 13	$p = 0$
Minimum combustion power	Test value	$\Phi_{\text{cn,min}} = 18,0 \text{ kW}$
Heat loss through the chimney at minimum combustion power	Test value	$P_{\text{ch,min}}^* = 10 \%$
Electrical power consumption of boiler auxiliary at minimum combustion power		$\Phi_{\text{br,min}} = \Phi_{\text{cn,min}} \times 0,003 = 18 \times 0,003 \times 1000 =$ $= 54 \text{ W}$
<b>Other input data:</b>		
Energy supplied to the distribution system	EN15316-3-2	$Q_{\text{d,out}} = 6000 \text{ kWh/ m}$
Caloric net value ( log wood )	Table 21	$H_{\text{i,fue}} = 1850 \text{ kWh/ rm}$
Heat output each filling		$\Phi_{\text{cham}} = V_{\text{cham}} \times H_{\text{i,fue}} \times ( 1 - P_{\text{ch,on}}^* - P_{\text{gn,env}} ) =$ $= 0,146 \times 1850 \times ( 1 - 11,0 - 2,08 = 237,6 \text{ kWh}$
Number of cycles at minimum		$N_{\text{cyc}} = Q_{\text{d,out}} / \Phi_{\text{cham}} = 6000 / 237,6 = 25,3 \text{ cycles}$

combustion power		$t_{g,fil} = 24 \text{ h}$
Interval of chamber filling		$t_{ON} = \Phi_{cham} / \Phi_{cn,min} = 237,6 / 18 = 13,2 \text{ h}$
Operation period ON		$t_{OFF} = t_{g,fil} - t_{ON} = 24,0 - 3,2 = 10,8 \text{ h}$
Operation period OFF		$t_{ci} = 30 \times 24 = 720 \text{ h}$
Calculation period		8,0 m
Chimney height		Inside boiler room
Boiler location		$\Theta_{i,gn} = 15^\circ \text{ C}$
Boiler room temperature		$\Theta = 65^\circ \text{ C}$
<b>Calculation procedure</b>		$\Phi_{d,in} = Q_{d,out} / t_{ci} = 6000 / 720 = 8,33 \text{ kW}$
Running temperature of the boiler		
Average power of the biomass boiler		
Load factor	Formula 28	$FC = \frac{\Phi_{d,in}}{\Phi_{Pn}} = 18,0 / 36,0 = 0,5$
Specific heat loss through the chimney with the boiler ON	Formula 31	$P_{ch,on} = [P_{ch,on,min}^* + (\theta_{gn,w,r} - \theta_{gn,test}) \cdot 0,045] \cdot FC^n$ $= (10 + (65 - 70) \times 0,045) \times 0,5^{0,1} = 9,12\%$
Heat loss through the chimney with boiler ON	Formula 36	$Q_{ch,on} = \frac{P_{ch,on}}{100} \cdot \Phi_{cn} \cdot t_{ON} =$ $= 91,2 \times 18 \times 13,2 = 21,7 \text{ kWh}$
Specific heat loss through the chimney with the boiler OFF	Formula 33	$P_{ch,off} = P_{ch,off}' \cdot \frac{(\theta_{gn,w,av} - \theta_{i,gn})}{(\theta_{gn,test} - \theta_{i,test})} \cdot FC^p =$ $= 1,04 \times (65 - 15) / (50 - 20) \times 0,5^0 = 1,4\%$
Heat loss through the chimney with boiler OFF	Formula 37	$Q_{ch,off} = \frac{P_{ch,off}}{100} \cdot \Phi_{ref} \cdot t_{OFF} =$ $= 1,2 \times 18,0 \times 10,8 = 2,33 \text{ kWh}$
Specific heat loss through the envelope at minimum load	Formula 32	$P_{gn,env} = P_{gn,env}' \cdot k_{gn,env} \cdot \frac{(\theta_{gn,w,av} - \theta_{i,gn})}{(\theta_{gn,test} - \theta_{i,test})} \cdot FC^m$ $= 2,08 \times 0,7 \times (65 - 15) / (70 - 20) \times 0,5^0 = 1,5\%$
Heat loss through the through the envelope at minimum load	Formula 38	$Q_{gn,env} = \frac{P_{gn,env}}{100} \cdot \Phi_{ref} \cdot (t_{OFF} + t_{ON}) =$ $(1,5 / 100) \times 18 \times 24 = 10,8 \text{ kWh}$
Total generation heat loss	Formula 39	$Q_{g,l,t} = (Q_{ch,ON} + Q_{ch,OFF} + Q_{gn,env}) \times 30 =$ $= (21,7 + 2,3 + 10,8) \times 30 = 1044 \text{ kWh}$
Electrical power consumption of boiler auxiliary ( after the boiler ) load	Table 11	$\Phi_{af} = \Phi_{int} \times 0,003 = 18 \times 0,003 \times 1000 = 54 \text{ W}$
Total auxiliary consumption	Table 41	$W_g = \Phi_{af} \times t_{ON} = 54 \times 13,2 \times 30 = 2138 \text{ W}$
Recovered auxiliary energy	Table 43	$Q_{af} = W_g \times k_{af} = 2138 \times 0,8 = 1710 \text{ kWh}$
<b>Output data</b>		
Fuel heat requirement		$Q_{g,in} = 6000 + 1044 - 1,7 = 7042,3 \text{ kWh}$
Total generation loss		$Q_{g,l,t} = 1044 \text{ kWh}$
Auxiliary consumption		$W_g = 2,1 \text{ kWh}$
Total recoverable loss		$Q_{af} = 1,7 \text{ kWh}$

## Bibliography

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