Thermochemical Power Group

Master Degree in InnovativeTechnologies in Energy Efficient Buildings for Russian & Armenian Universities and Stakeholders

Prof. Mario L. Ferrari

Thermochemical Power Group (TPG) - DIME – University of Genoa, Italy

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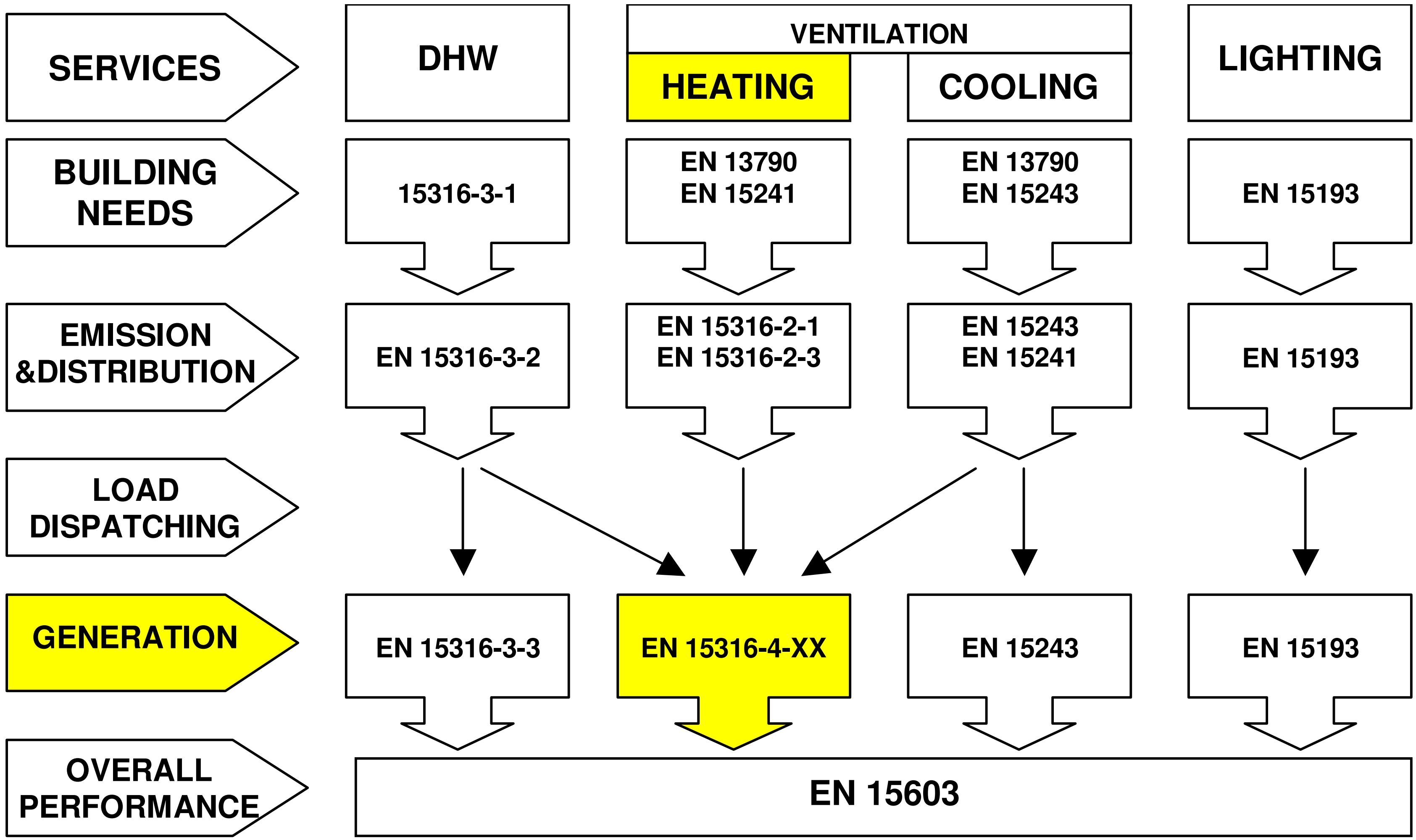
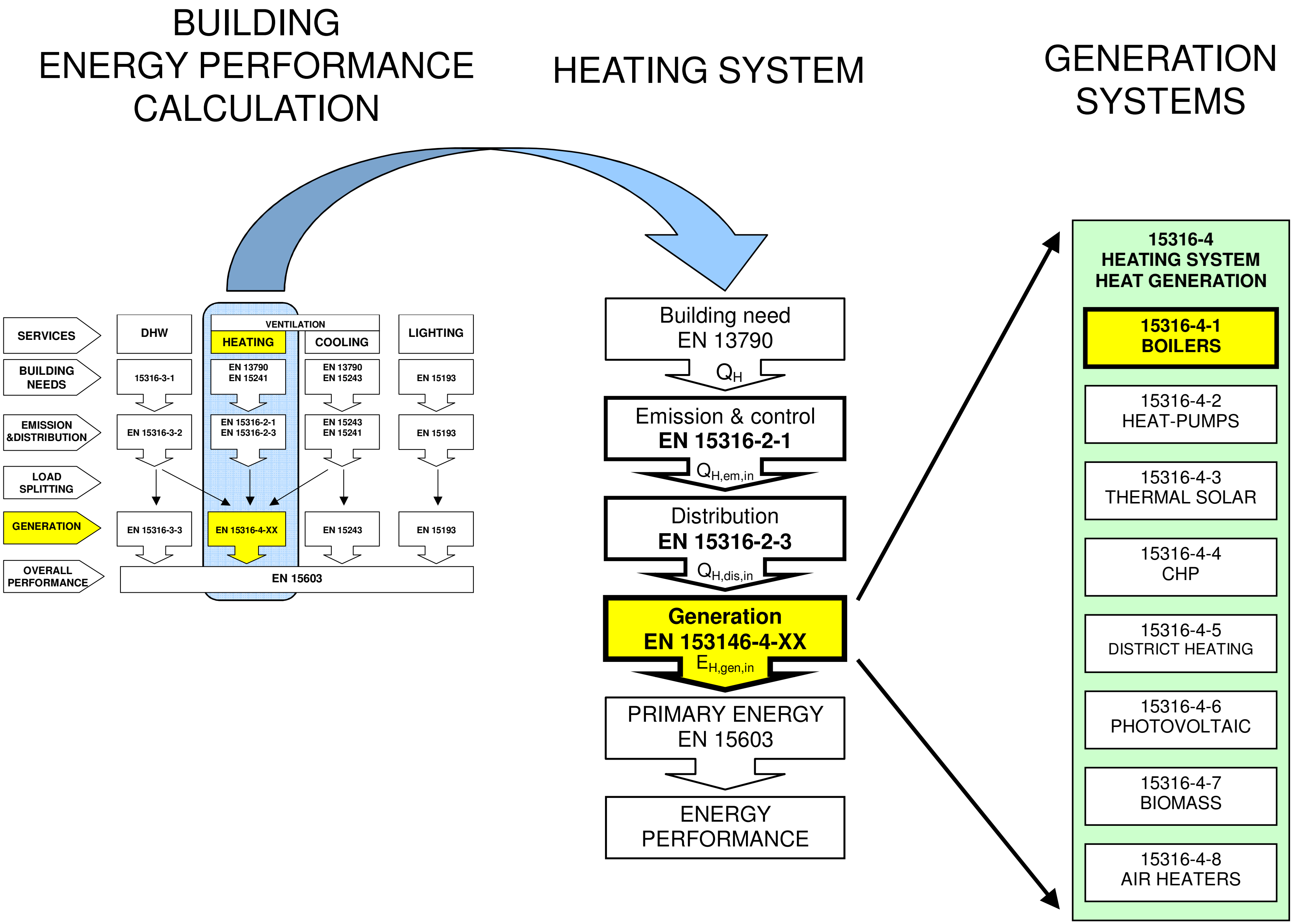
MARUEEB

Boiler thermal balance

FITTING INTO THE CALCULATION SCHEME




BUILDING
ENERGY PERFORMANCE
CALCULATION
HEATING SYSTEM
GENERATION
SYSTEMS
SERVICES
BUILDING NEEDS
EMISSION &DISTRIBUTION
LOAD SPLITTING
GENERATION
OVERALL PERFORMANCE
DHW
VENTILATION
HEATING
COOLING
LIGHTING
15316-3-1
EN 13790
EN 15241
EN 13790
EN 15243
EN 15193
EN 15316-3-2
EN 15316-2-1
EN 15316-2-3
EN 15243
EN 15241
EN 15193
EN 15316-3-3
EN 15316-4-XX
EN 15243
EN 15193
EN 15603
Building need
EN 13790
Q_H
Emission & control
EN 15316-2-1
$Q_{H,em,in}$
Distribution
EN 15316-2-3
$Q_{H,dis,in}$
Generation
EN 153146-4-XX
$E_{H,gen,in}$
PRIMARY ENERGY
EN 15603
ENERGY
PERFORMANCE
15316-4
HEATING SYSTEM
HEAT GENERATION
15316-4-1
BOILERS
15316-4-2
HEAT-PUMPS
15316-4-3
THERMAL SOLAR
15316-4-4
CHP
15316-4-5
DISTRICT HEATING
15316-4-6
PHOTOVOLTAIC
15316-4-7
BIOMASS
15316-4-8
AIR HEATERS

Calculation principles

Objective: **to calculate fuel and auxiliary energy consumption**
to fulfill the heat demand of the attached distribution subsystem(s)

Basic input data:
heat required by the attached distribution sub-system(s) $Q_{H,dis,in}$

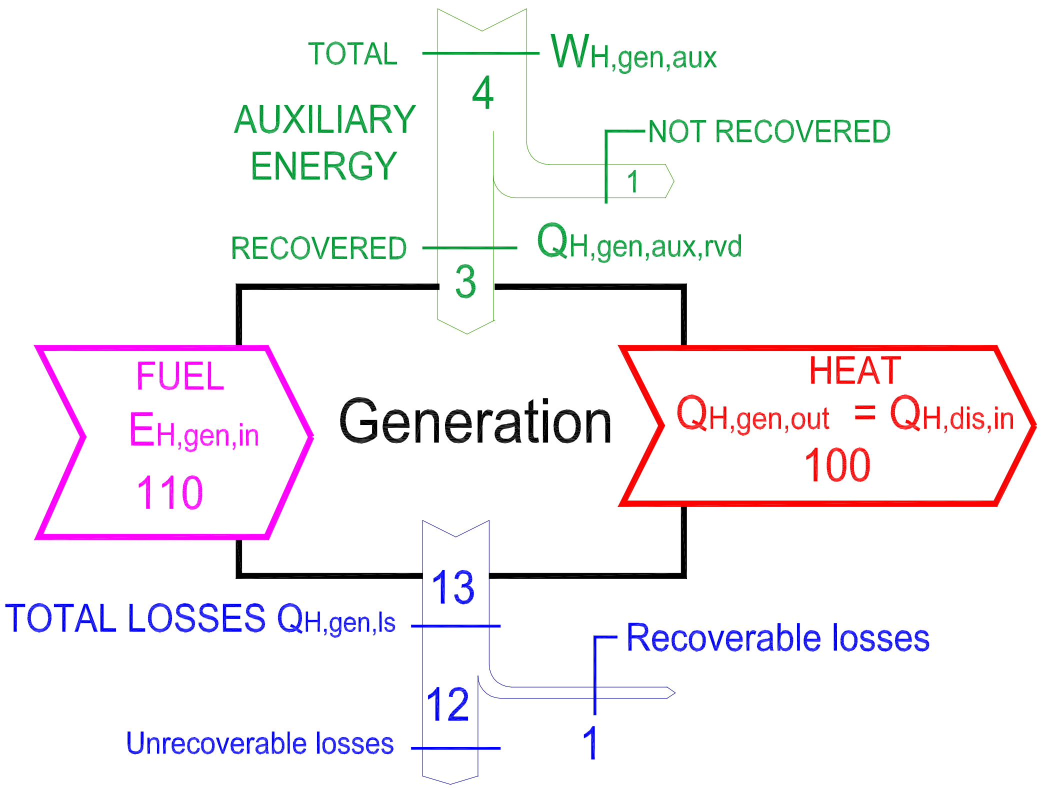
The calculation method takes into account

- **heat losses** (flue gas, envelope, etc.)
- **auxiliary energy** use and recovery
- *other input data* :
  - location of the heat generator(s) (heated room, unheated room, ..)
  - operating conditions (time schedule, water temperature, etc.)
  - control strategy (on/off, multistage, modulating, cascading, etc.)

Basic outputs is delivered energy as:

- **fuel consumption $E_{H,gen,in}$**
- **auxiliary energy consumption $W_{H,gen,aux}$**

Generation subsystem simplified energy balance



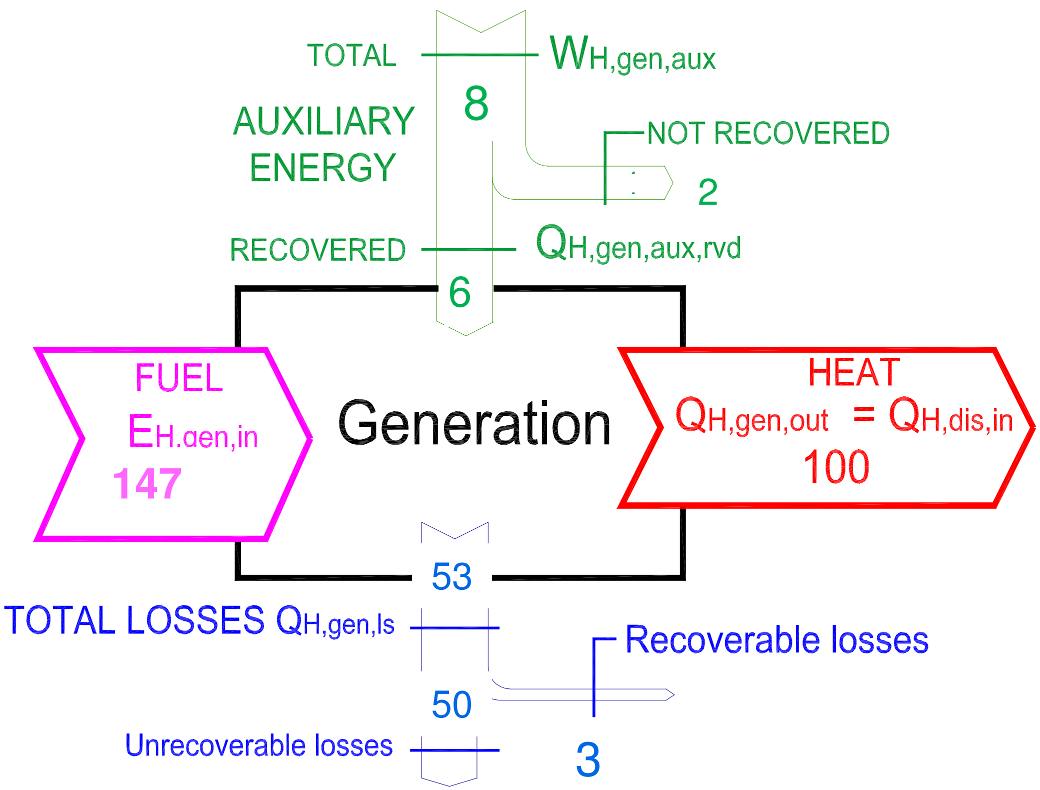
TOTAL & RECOVERED AUXILIARY ENERGY

GLOBAL BALANCE

$$E_{H,gen,in} = Q_{H,gen,out} + Q_{H,gen,ls} - Q_{H,gen,aux,rvd}$$

TOTAL LOSSES AND RECOVERABLE LOSSES

Biomass boiler
Generation subsystem simplified energy balance



TOTAL & RECOVERED AUXILIARY ENERGY

GLOBAL BALANCE

$$E_{H,gen,in} = Q_{H,gen,out} + Q_{H,gen,ls} - Q_{H,gen,aux,rvd}$$

TOTAL LOSSES AND RECOVERABLE LOSSES

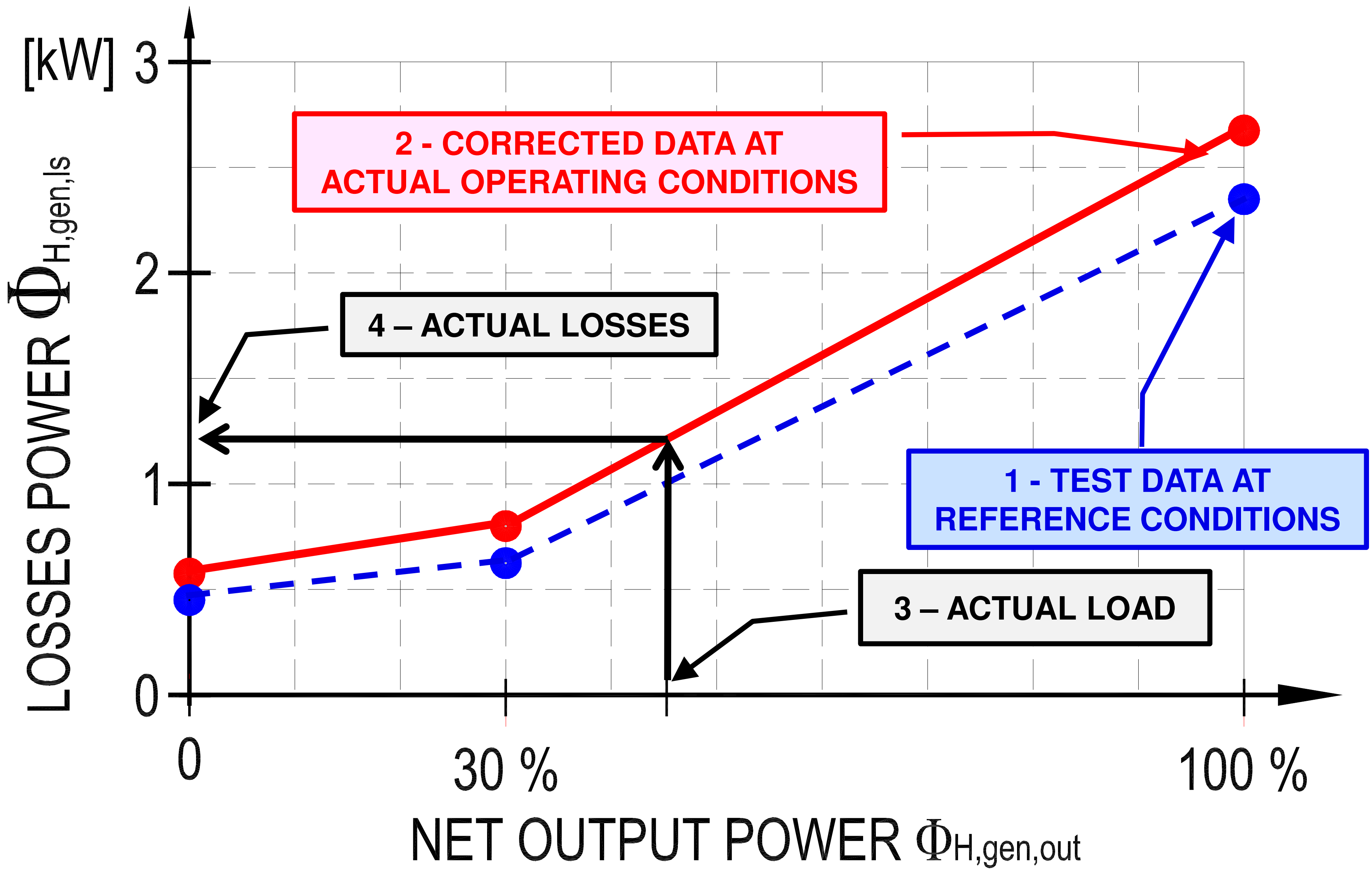
Boiler directive data ???

Available methods

- Case specific
  - Based on data declared according to Directive 2002/92/CE
  - Primarily intended for new or recent boilers for which this data is available
- Tabulated values (typology method)
  - Simplification to cover common case and avoid calculation burden to estimate simple repetitive cases
- Boiler cycling
  - Primarily intended for existing systems and condensing boilers

Case specific method calculation procedure

- Get performance data in standard conditions at 3 reference power levels
  - Efficiencies at 100% and 30% load *(according to Directive 92/42/EC)*
  - Stand-by losses power [W] at 0% load
- Correct data to take into account actual operating conditions (basically, the effect of water temperature in the boiler)
- Calculate losses power at 30% and 100% from corrected efficiencies
- Calculate losses at actual load by linear interpolation
- Use the same interpolation approach (based on data at 0…30%...100% load) for auxiliary energy calculation



[kW]
3
2
1
0
LOSSES POWER $\Phi_{H,gen,ls}$
2 - CORRECTED DATA AT
ACTUAL OPERATING CONDITIONS
4 – ACTUAL LOSSES
1 - TEST DATA AT
REFERENCE CONDITIONS
3 – ACTUAL LOAD
0
30 %
100 %
NET OUTPUT POWER $\Phi_{H,gen,out}$

Boiler directive data ???

Sample seasonal boiler performance method based on system typology (typology method)

- This method of calculation is applicable only to boilers for which the full load efficiency and the 30 % part load efficiency values, obtained by the methods deemed to satisfy Council Directive 92/42/EEC about Boiler Efficiency [1], are available.
- These are net efficiency values (higher efficiency values, referenced to the lower heat value of fuels).
- It is essential that both test results are available and that the tests are appropriate to the type of boiler as defined in Council Directive 92/42/EEC about Boiler Efficiency [1], otherwise the calculation cannot proceed.

Sample seasonal boiler performance method based on system typology (typology method)

The steps are as follows:

- a) Determine fuel for boiler type. The fuel for boiler type must be one of natural gas, LPG (butane or propane) or oil (kerosene or gas oil).
- b) Obtain test data. Retrieve the full-load net efficiency $\eta_{Pn,net}$ *and 30 % part-load net efficiency* $\eta_{Pint,net}$
- test results. Tests must have been carried out using the same fuel as the fuel for boiler type.
- c) Reduce to maximum net efficiency values $\eta_{Pn,net,max}$ *and* $\eta_{Pint,net,max}$. *Table A.1 gives the maximum* values of net efficiency depending on the type of boiler. Reduce any higher net efficiency test values to the appropriate value given in Table A.1.

Sample seasonal boiler performance method based on system typology (typology method)

Table A.1 – Maximum net efficiency values

Boiler type	Efficiency at full load $\eta_{Pn,net,max}$ %	Efficiency at 30 % load $\eta_{Pint,net,max}$ %
Condensing boilers	101,0	107,0
Non-condensing boilers	92,0	91,0

Sample seasonal boiler performance method based on system typology (typology method)

Convert the full load efficiency and the 30 % part load efficiency from net values to gross values. Use the following equation (A1) with the appropriate factor from Table A.2.

$$\eta_{\mathrm{Px,gross}} = f_{\mathrm{ntg}} \cdot \eta_{\mathrm{Px,net}} \qquad \text{(A1)}$$

Table A.2 – Efficiency conversion factors

Fuel	Net-to-gross conversion factor f_{ntg}
Natural gas	0,901
LPG (propane or butane)	0,921
Oil (kerosene or gas oil)	0,937

Additional default data for condensing boilers

Table C.13 – Default fuel data for condensation heat recovery calculation

Property	Symbol	Unit	Fuel			
			Natural gas (Groningen)	Propane	Butane	Light oil EL
Unit mass of fuel			1 Nm³	1 Nm³	1 Nm³	1 kg
Gross calorific value	H_s	kJ/kg or kJ/Nm³	35 169 kJ/Nm³	101 804 kJ/Nm³	131 985 kJ/Nm³	45 336 kJ/kg
Net calorific value	H_i	kJ/kg or kJ/Nm³	31 652 kJ/Nm³	93 557 kJ/Nm³	121 603 kJ/Nm³	42 770 kJ/kg
Stoichiometric dry air	$V_{air,st,dry}$	Nm³/kg or Nm³/Nm	8,4 Nm³/Nm³	23,8 Nm³/Nm³	30,94 Nm³/Nm³	11,23 Nm³/kg
Stoichiometric dry flue gas	$V_{fg,st,dry}$	Nm³/kg or Nm³/Nm	7,7 Nm³/Nm³	21,8 Nm³/Nm³	28,44 Nm³/Nm³	10,49 Nm³/kg
Stoichiometric water production	$m_{H2O,st}$	kg/kg or kg/Nm³	1,405 kg/Nm³	3,3 kg/Nm³	4,03 kg/Nm³	1,18 kg/kg

Sample seasonal boiler performance method based on system typology (typology method)

Table A.3 – Equation numbers for different boiler types

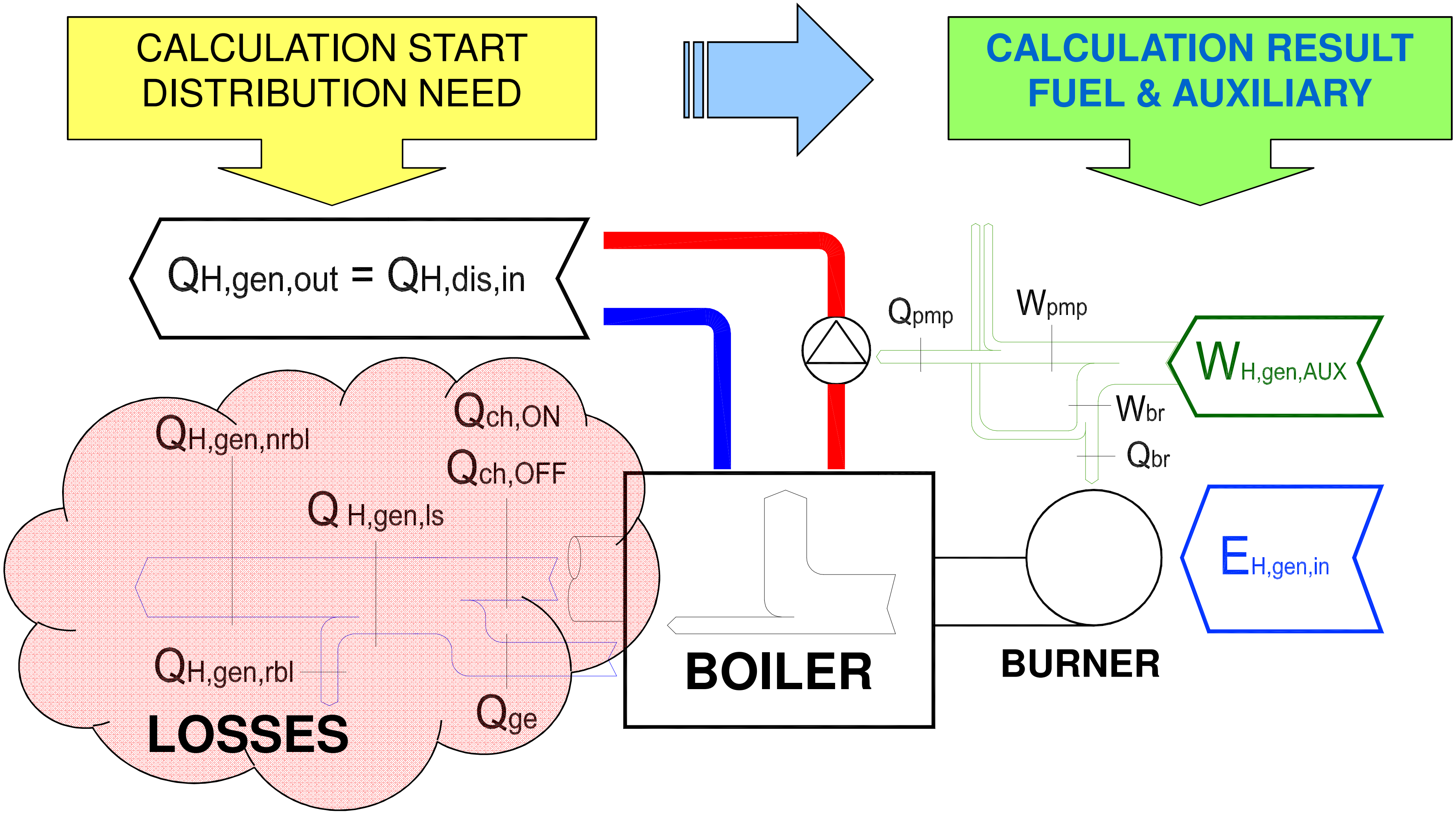
Boiler type	Non-condensing				Low-temperature	Condensing			
	Gas or LPG		Oil			Gas or LPG		Oil	
	On/off	Modulating	On/off	Modulating		On/off	Modulating	On/off	Modulating
Regular boiler	101	102	201	X	X	101	102	201	X
Istantaneous combi boiler	103	104	202	X	X	103	104	202	X
Storage combi boiler	105	106	203	X	X	105	106	203	X
Combined primary storage unit	107	107	X	X	X	105	106	X	X

Sample seasonal boiler performance method based on system typology (typology method)

Table A.4 – Seasonal efficiency calculation equations η_{gen} for natural gas boilers and LPG boilers

Gas or LPG boiler type	Eq. no.	Equation
On/off regular	101	$\eta_{gen,gross} = \left(\frac{\eta_{Pn,gross} + \eta_{Pint,gross}}{2} \right) - 2{,}5 - 4 \cdot f_{plt}$
Modulating regular	102	$\eta_{gen,gross} = \left(\frac{\eta_{Pn,gross} + \eta_{Pint,gross}}{2} \right) - 2{,}0 - 4 \cdot f_{plt}$
On/off instantaneous combination	103	$\eta_{gen,gross} = \left(\frac{\eta_{Pn,gross} + \eta_{Pint,gross}}{2} \right) - 2{,}8 - 4 \cdot f_{plt}$
Modulating instantaneous combination	104	$\eta_{gen,gross} = \left(\frac{\eta_{Pn,gross} + \eta_{Pint,gross}}{2} \right) - 2{,}1 - 4 \cdot f_{plt}$

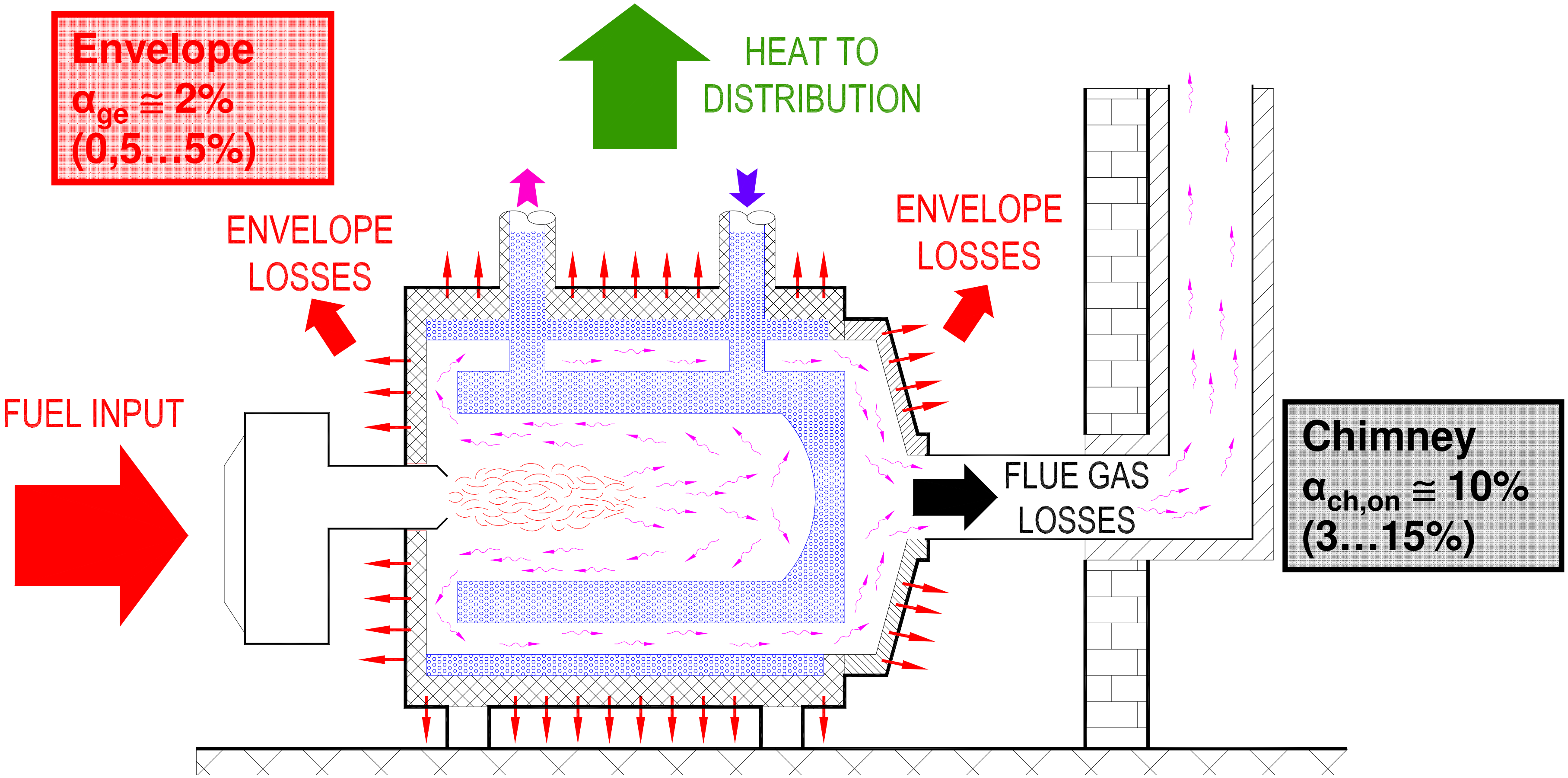
Boiler cycling generation energy balance



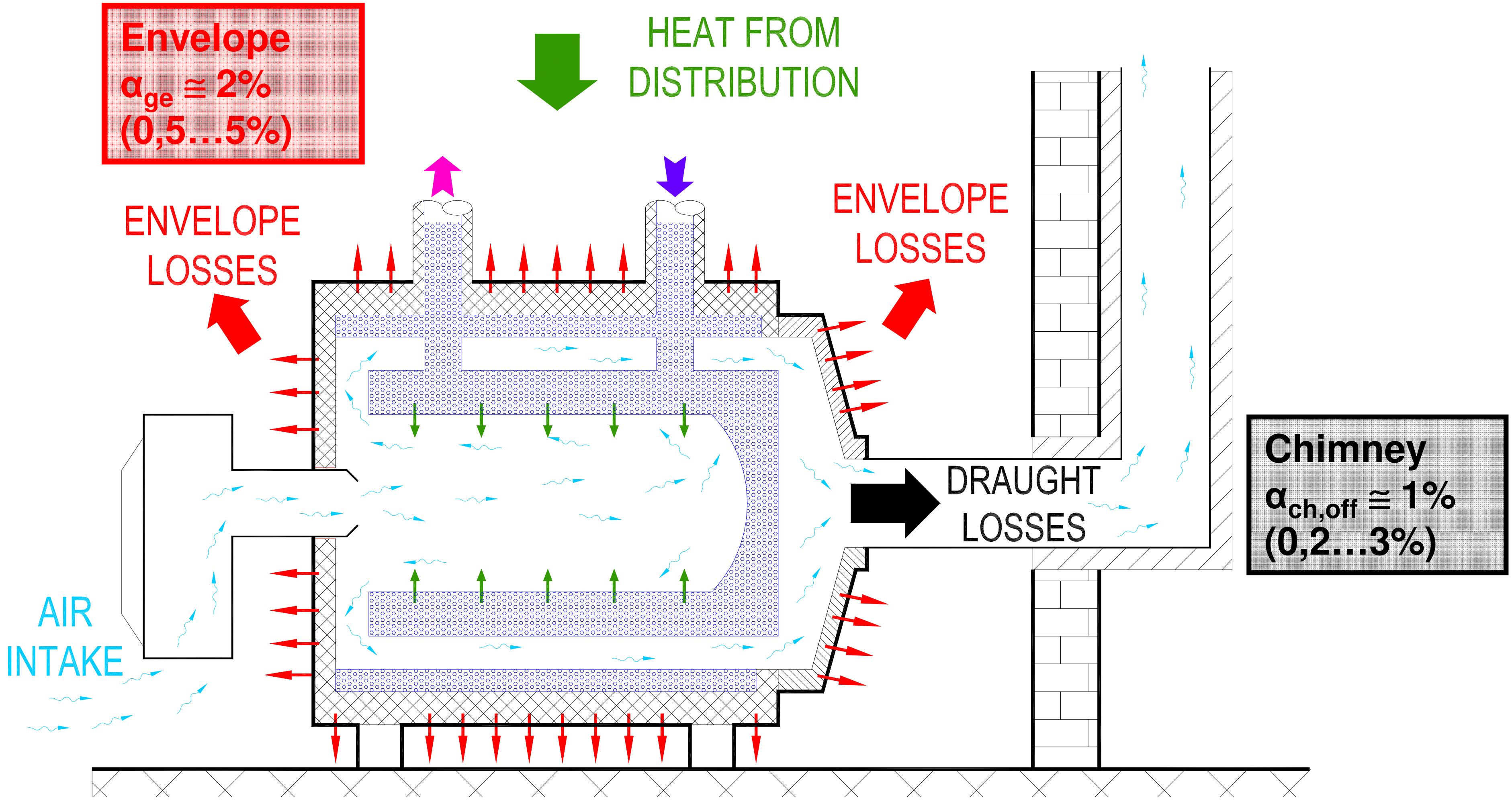
Boiler cycling method

- **For single stage burners**, the calculation interval is divided into two basic operating conditions, with different specific losses:
  - **Burner ON time**, with flue gas and envelope losses
  - **Burner OFF time** , with draught and envelope losses
- Loss factors are given as a percentage of combustion power (input to the boiler)
- Loss factors are corrected according to operating conditions (water temperature in the boiler, load factor)
- The required **input load factor** to meet output requirement is calculated

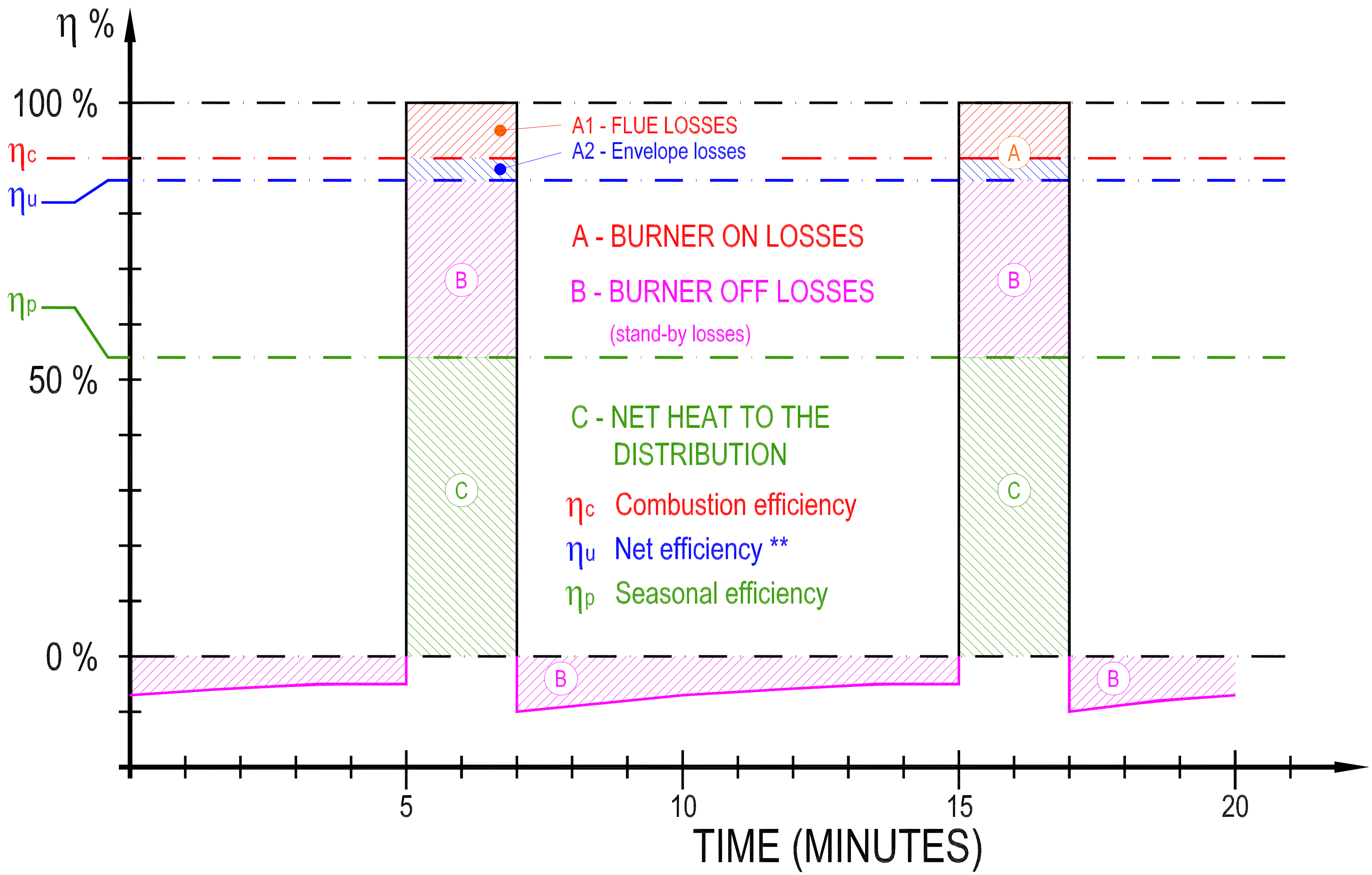
- **Modulating and multistage boilers** are taken into account with a third reference state: ***burner ON at minimum power***
- **Condensation heat recovery** is taken into account as a reduction of flue gas losses with burner ON



BOILER CYCLING METHOD: LOSSES WITH BURNER ON

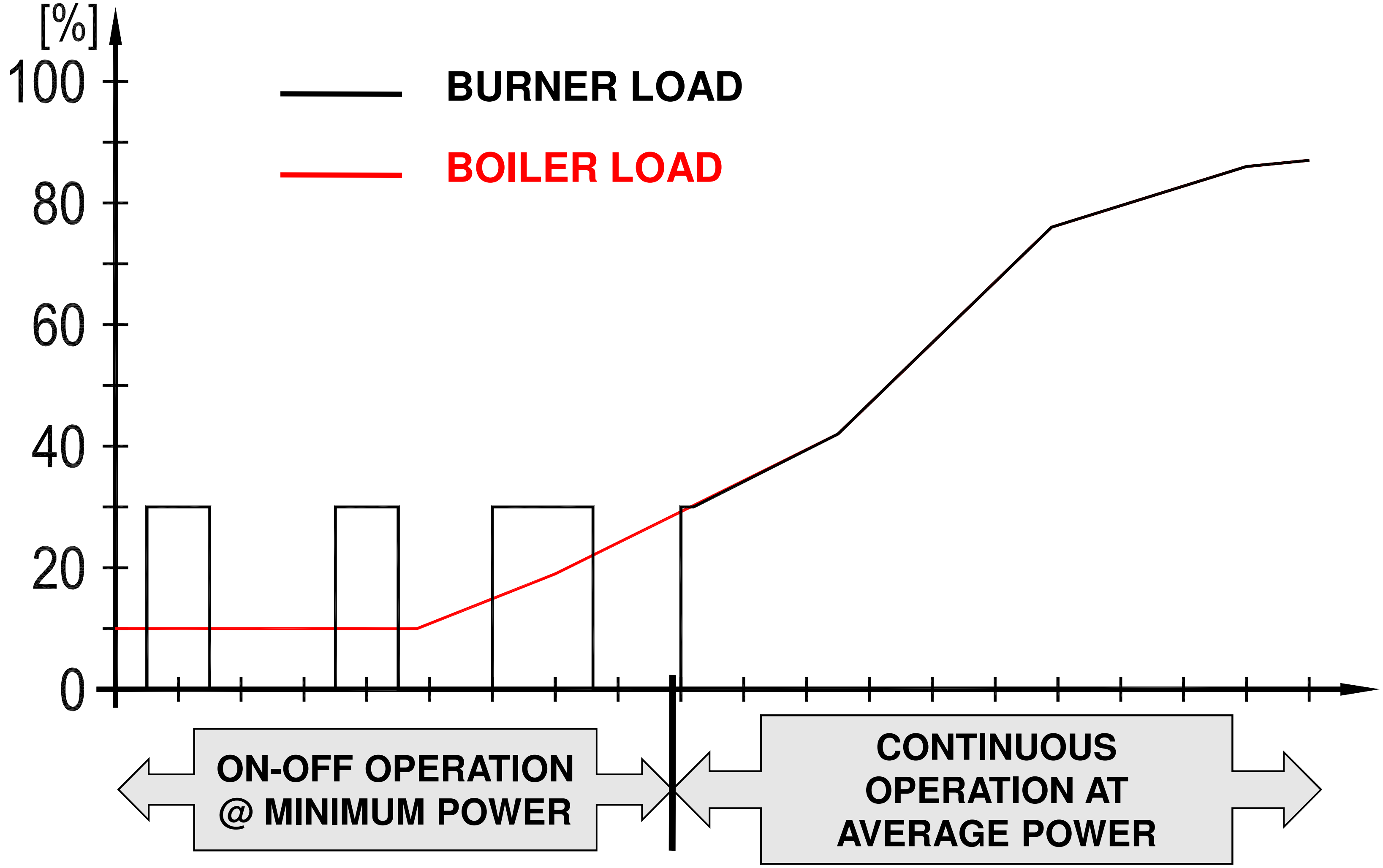


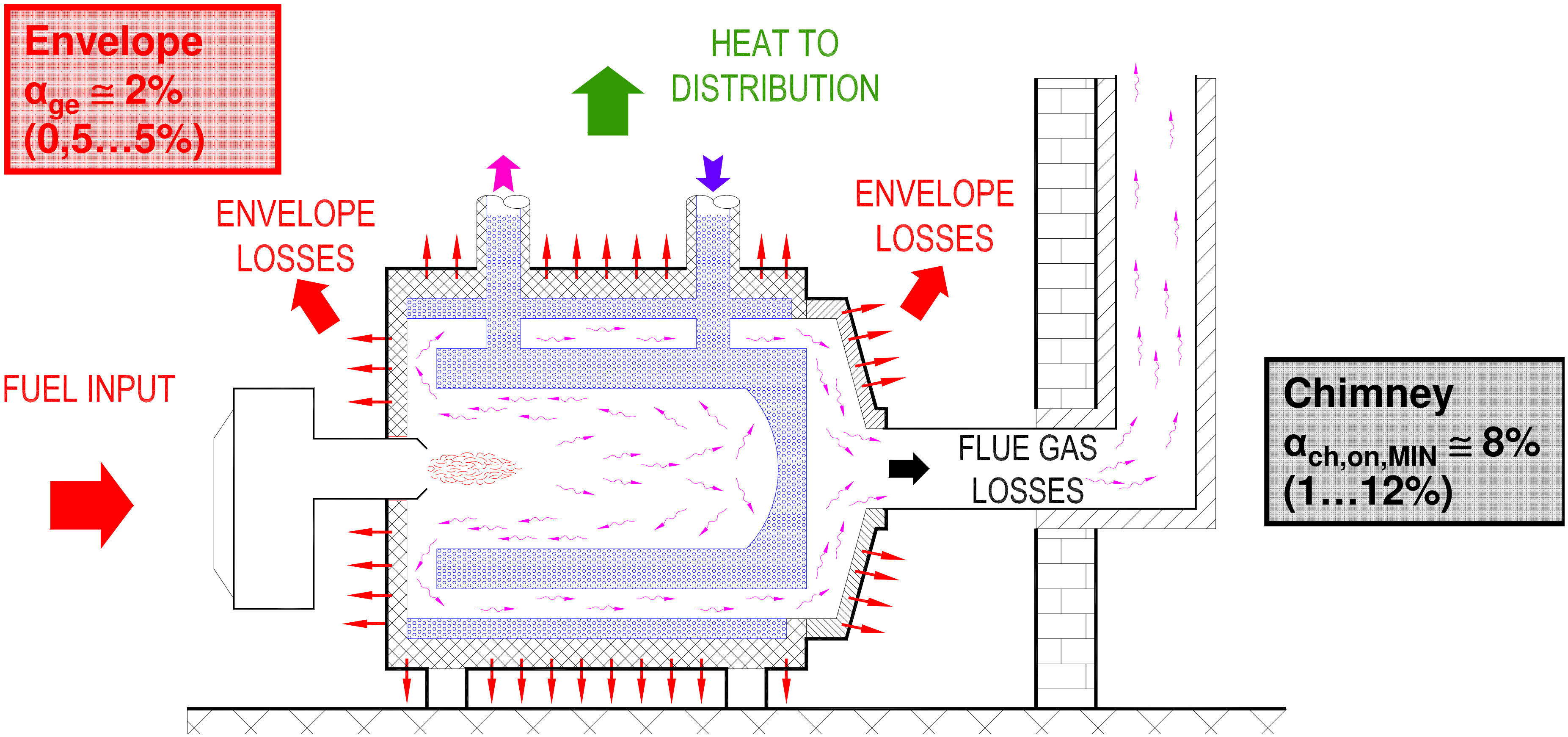
BOILER CYCLING METHOD: LOSSES WITH BURNER OFF



BOILER CYCLING METHOD: EFFECT OF INTERMITTENCY

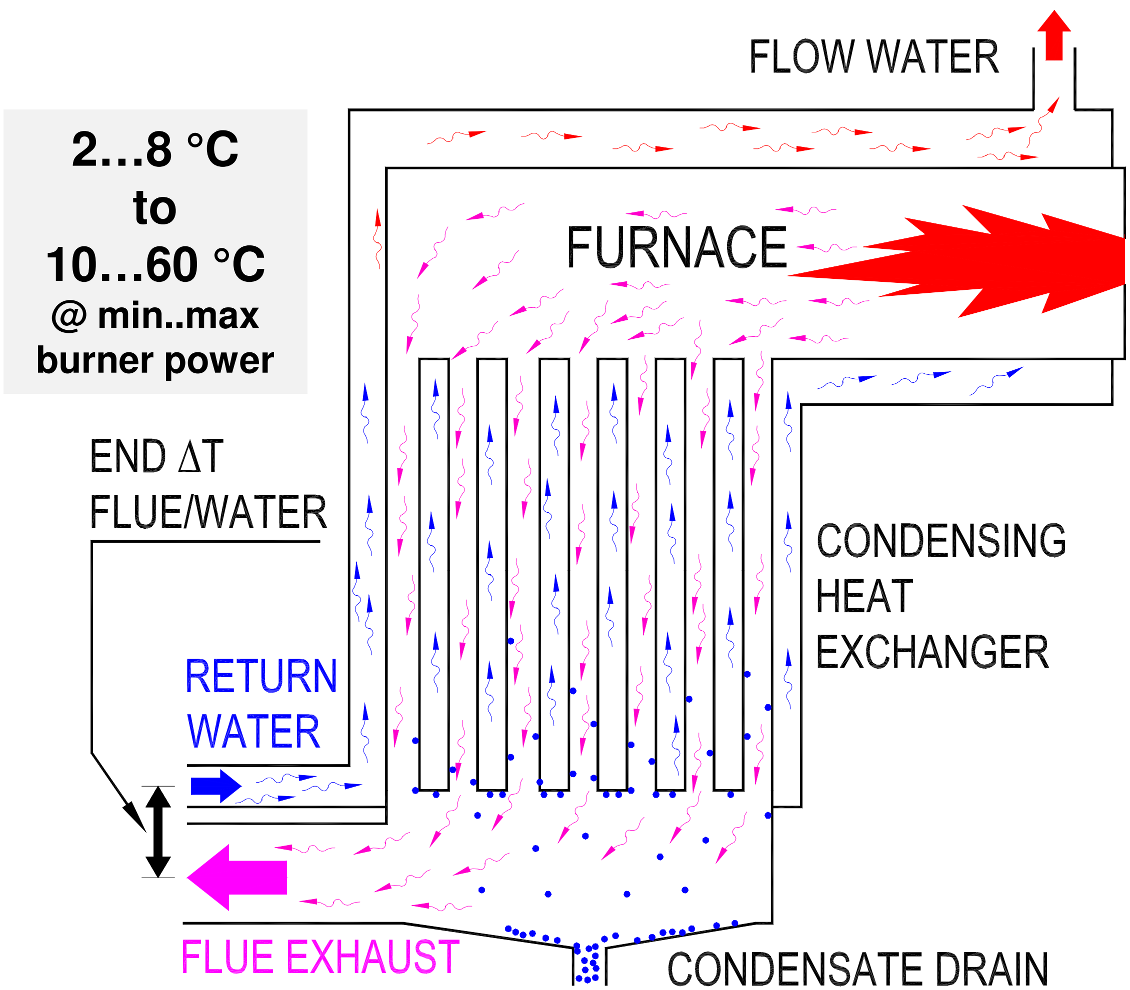
Modulating boilers





BOILER CYCLING METHOD: LOSSES WITH BURNER ON AT MINIMUM POWER (MODULATING AND MULTI STAGE BURNERS)
MINIMUM POWER IS THE SET VALUE (TYPICALLY 25…50% OF MAX. POWER)

Condensing boiler



Condensing boiler.

The furnace is in the high temperature upper part of the boiler

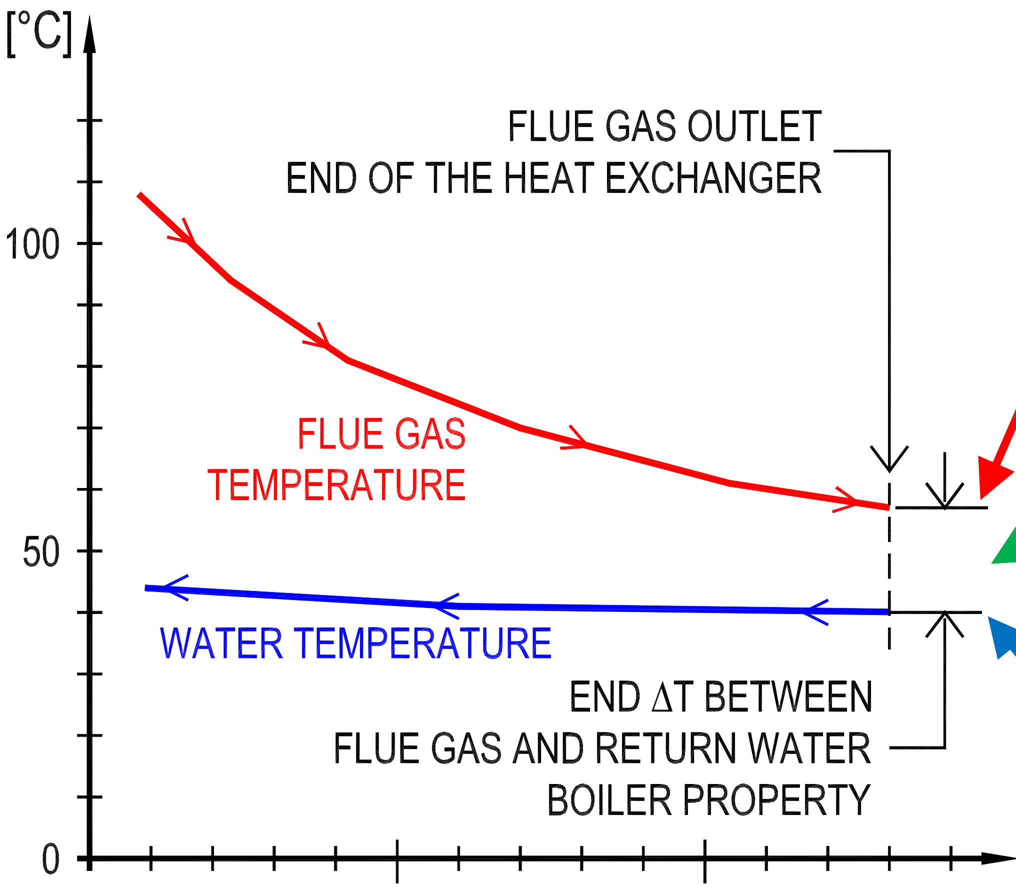
Condensing counter-current heat exchanger

Flue gases cool-down whilst doming down

Return water heats up whilst coming up.

Condensate falls on the bottom to be discharged

Flue gas temperature



FLUE GAS TEMPERATURE
and composition
→ CONDENSATION

BOILER EFFECT: INCREASE IN TEMPERATURE FROM WATER TO FLUE GAS

RETURN WATER TEMPERATURE
HEATING SYSTEM OPERATING CONDITIONS

Why 3 methods

No single method is the correct solution for all cases.
A too simple method may not be able to show the effect of improvements whilst
A detailed method may be time wasting for common repetitive situations.

- **The boiler typology method** aims to extreme **simplicity**.
- **The case specific method** is meant to use as far as possible **boiler directive data**.
- **The boiler cycling method** is meant to deal with **existing boilers/buildings**, to keep a connection with directly measurable parameters (flue gas analysis) and to calculate operating performances of **condensing boilers**.