Doc. CEN/TC 228 N541

CEN/TC 228

Date: 2006-08

CEN/TC 228 WI 026

CEN/TC 228

Secretariat: DS

Heating systems in buildings — Method for calculation of system energy requirements and system efficiencies — Part 4-4 Space heating generation systems, the performance and quality of CHP electricity and heat

Einführendes Element — Haupt-Element — Ergänzendes Element

Élément introductif — Élément central — Élément complémentaire

ICS:

Descriptors:

Document type: European Standard
Document subtype:
Document stage: Formal Vote
Document language: E

C:\Mine dokumenter\TC 228\WG 4\WI 00228026\TC version\N541_prEN 15316-4-4_WI00228026_2006-08.doc STD Version 2.1c

Contents

Foreword

This document (prEN 15316-4-4:2005) 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 is part of a series of standards defining methods for calculation of system energy requirements and system efficiencies.

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 defines a method for calculation of the energy requirements, electricity production, thermal output and recoverable losses of building-integrated cogeneration units forming part of heat generation system (space heating and domestic hot water) in a building.

The calculation is based on the performance characteristics of products, given in product standards, and on other characteristics required to evaluate the performance of the products as included in the technical building system.

The test of combi CHP systems for heating systems may be worked out in a national annex. As soon as European test methods are available these should be used.

NOTE: Primary energy savings and CO_2 savings, which can be achieved by cogeneration units compared to separate production of heat and consumption of electricity, are calculated according to prEN 15315. Indications about the savings calculations are given in informative annex C.

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 12831, *Heating systems in buildings - Method for calculation of the design heat load*

prEN 15315, *Heating systems in buildings – Energy performance of buildings - Overall energy use, primary energy and* CO_2 *emissions*

prEN 13790 Thermal performance of buildings – Calculation of energy use for space heating and cooling

prEN 15316-2.3 Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 2.3 Space heating distribution system

prEN 15316-3.1 Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 3.1 Domestic hot water systems, characterisation of needs (tapping requirements)

prEN 15316-3.2 Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 3.2 Domestic hot water systems, distribution

3 Definitions and symbols

To be updated according to the results of CEN/BT WG173

3.1 Definitions

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

3.1.1
building-integrated cogeneration

cogeneration unit installed to supply space heating, domestic hot water and possibly cooling within a building. It operates either as the only heating/cooling appliance of the building or in combination with other heat generators, such as boilers or electrical chillers. Unlike district heating systems, where heat and electricity are generated at central plants and transmitted through networks to a number of remote buildings, a building-integrated cogeneration unit produce heat solely for use within the building. The electricity produced by the integrated cogeneration unit may be used within the building or may be exported

3.1.2
cogeneration
simultaneous generation in one process of thermal energy and electrical and/or mechanical energy

3.1.3
cogeneration unit
unit designed to provide thermal energy and electrical and/or mechanical energy to a building using a cogeneration process. The unit may include supplementary burners and thermal storage

3.1.4
design heat loss
rate of heat loss of the building on the coldest day of a typical year, averaged over the day (see EN 12831)

3.1.5
dumped heat
wasted heat, which exceeds the current demand of the building and cannot be stored or used.

heat-led installations
unit controlled by the heat demand with no dumped heat
Note: This does not mean that the unit provides the whole heat demand

3.1.6
economically justifiable demand
demand, which does not exceed the needs for heating or cooling and which would otherwise be satisfied at market conditions by energy generation processes other than cogeneration

3.1.7
electricity from cogeneration
electricity generated in a process linked to the production of useful heat

3.1.8
plant size ratio
maximum rate of heat output of the cogeneration unit divided by the sum of the design heat loss and any additional daily heat load (averaged over the day)

3.1.9
useful heat
heat produced in a cogeneration process to satisfy an economically justifiable demand for heating or cooling

3.1.10
full load
operation state of the technical system (e.g. cogeneration unit) where the actual load requirement is equal to the nominal (maximal) output capacity of the device

3.1.11
preferential generation appliances
appliance in a multi-plant generation system (e.g. peak boilers and cogeneration units) which are operating in priority.

3.1.12

thermal efficiency of a cogeneration
heat output of the cogeneration divided by the fuel input.
NOTE: Efficiency can be based on annual load conditions or part-load conditions

3.1.13

electrical efficiency of a cogeneration

electrical power output of the cogeneration divided by the fuel input.

NOTE: Efficiency can be based on annual load conditions or part-load conditions“

3.1.14

annual heat efficiency

total annual heat output of the cogeneration unit divided by the total annual fuel input

3.1.15

annual electrical efficiency

total annual electrical power output of the cogeneration unit divided by the total annual fuel input

Symbols and units

To be updated according to the results of CEN/BT WG173

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

Table 1 — Symbols and units

Symbol	**Name of quantity**	**Unit**
f	factor	-
i	index of part load conditions	-
L	grid loss factor of the electrical network	-
ndays	number of days	days
P	nominal capacity	kW
Q	quantity of heat, energy	J
β	fraction	-
η	efficiency	-

Table 2 — Indices

cogen	cogeneration	elect	electrical	pes	primary energy savings
cool	cooling	i	indices	prim	primary
CHP	combined heat and power	max	maximum	ref	reference
distr	distribution	npref	non-preferential	dhw	domestic hot water
dem	demand	pref	preferential		

4 CHP system calculation

4.1 System boundaries

The system boundary for the cogeneration subsystem comprises only the cogeneration unit.

Electrical connection components are only taken into account if they are part of the unit and tested together.

Circulation pumps are taken into account if no transport energy is transferred to the distribution system, I;e; a hydraulic decoupling between the cogeneration unit and the distribution subsystem.

The cogeneration unit may be of any type, possibly including a supplementary burner and thermal store, provided it has been tested as a whole to provide the energy performance information needed.

Peak boilers of conventional design are used when the heat output of the CHP plant is insufficient to meet the instantaneous heat demand. Peak boilers are not included in the cogeneration subsystem boundaries.

Note: The generated heat is used for heating, domestic hot water and eventually an absorption chiller.

4.2 Auxiliary energy consumption

Auxiliary energy consumption is taken into account by applying only the net power production i.e. the total power production minus all auxiliary energy consumption, e.g. for pumps – inside the system boundaries.

4.3 Recoverable heat losses

No losses are recoverable for the diminution of the space heating needs.

4.4 Calculation period

Note: The objective of the calculation is to determine the annual energy use of the space heating and domestic hot water system.

Technical system losses should be calculated separately for each calculation period. The average values shall be consistent with the selected time intervals. This may be done in one of the following two different ways:

- by using annual data for the system operation period and performing the calculations using annual average values;
- by dividing the year into a number of calculation periods (e.g. months, weeks, etc.), performing the calculations for each period using period-dependent values and sum up the results for all the periods over the year.

If there is seasonal heating in the building, the year should be divided at least into time of the heating season and the time of the rest of the year.

4.5 Available methodologies

NOTE: The performance of a cogeneration unit (thermal efficiency, electrical output) varies strongly with the part-load. The operation mode depends on boiler/ CHP / buffer tank combinations, regulatory frameworks, etc.

Two main operation modes are distinguished:

- the cogeneration unit is sized to run at full load most of the time, thus the heat output of the CHP unit supplies the base load of the installation;

- the cogeneration unit operates as a boiler substitute and supplies the entire heat demand of the building.

In this standard, two calculation methods corresponding to the two operation modes are given:

- "fractional contribution method", for a CHP unit supplying the base load of the installation (fractional contribution of the heat demand);
- "annual load profile method", for a CHP unit operating as a boiler substitute.

Note: In principle, the annual load profile method could also be applied for the base load situation, but the fractional contribution method is easier to use and has a sufficient accuracy for the considered case.

Note: The cogeneration unit can be sized to supply to the maximum the base electricity demand and supplies part of the heat demand. In this standard not dumped heat is accepted. Therefore this case can be taken into account by mode 2. It is only a question of sizing.

All methods used to calculate part load and annual performance of CHP systems should be validated. At least the following influence factors should be taken into account:

- Water temperature (return/flow);
- Start/stop effects;
- Part load operation;
- Air inlet temperature.

4.6 Fractional contribution method

4.6.1 Heat output of the cogeneration installation

The heat output of the cogeneration installation excludes any dumped heat and is limited by the maximum heat demand within the building(s).

The heat output of the cogeneration installation $Q_{heat,cogen}$ is determined by:

$$\begin{aligned} Q_{heat,cogen} = & (Q_{dem,heating}/\eta_{distr,heating}) \text{ x } f_{heating,cogen} \\ & + (Q_{dem,dhw}/\eta_{distr,dhw}) \text{ x } f_{dhw,cogen} \\ & + (Q_{dem,cool}/\eta_{distr, cool}) \text{ x } f_{cool,cogen} \end{aligned} \quad [1]$$

where:

$Q_{dem,heating}$	heat demand for space heating according to prEN 13790
$Q_{dem,dhw}$	heat demand for domestic hot water according to prEN 15315-3.1
$Q_{dem,cool}$	heat demand for absorption cooling
$\eta_{distr,heating}$	efficiency of space heating distribution system according to prEN 15315-2.3
$\eta_{distr,dhw}$	efficiency of domestic hot water distribution system according to prEN 15315-3.2
$\eta_{distr,cool}$	efficiency of cooling distribution system
$f_{heating,cogen}$	share of the heat demand for space heating covered by the cogeneration installation
$f_{dhw, cogen}$	share of the heat demand for domestic hot water covered by the cogeneration installation
$f_{cool, cogen}$	share of the heat demand for absorption cooling covered by the cogeneration installation

If cogeneration is combined with other heating/cooling/warm water appliances, the relative share of heating, cooling and warm water provided by the cogeneration installation has to be determined.

For heating/cooling/warm water systems in existing buildings, the share of cogeneration could be determined on the basis of operational records.

In the case of new installations, the shares of cogeneration could be estimated on the basis of the design specifications and the control strategies of all relevant components of the heating/cooling/warm water systems. Detailed methods for determining the relative share of heating, cooling and warm water provided by the cogeneration installation should be specified in national annexes to this standard.

One possible calculation method is given in annex A.

4.6.2 Fuel input for the cogeneration installation

The fuel input for the cogeneration installation $Q_{fuel,cogen}$ is calculated by:

$$Q_{fuel,cogen} = Q_{heat,cogen}/\eta_{heat,cogen} \qquad [2]$$

where:

$\eta_{heat,cogen}$ annual heat efficiency

The heat efficiency of the cogeneration installation should be based on operational data or certified values for type-tested cogeneration units. Typical values should be given in national annexes to this standard. If the heat efficiency of a cogeneration unit is not known, indicative efficiency values given in informative annex B may be used.

4.6.3 Electricity output of the cogeneration installation

The electricity generated by the cogeneration unit $Q_{elect,cogen}$ is calculated by:

$$Q_{elect,cogen} = Q_{fuel,cogen} * \eta_{elect,cogen} \qquad [3]$$

where:

$\eta_{elect,cogen}$ annual electrical efficiency

The electrical efficiency of the cogeneration installation should be based on operational data or certified values for type-tested cogeneration units. Typical values should be given in national annexes to this standard. If the electrical efficiency of a cogeneration unit is not known, indicative efficiency values given in informative annex B may be used.

4.7 Annual load profile method

4.7.1 General approach

NOTE: This method develops the annual energy performance from knowledge of the performance at operating conditions (e.g. part-load, water temperature, ambient temperature) and the annual load profile. This method is well suited for cogeneration installations which supply the entire heat demand of the building, i.e. the cogeneration unit operates as a boiler substitute. For such installations, the load varies over a large range throughout the year, and operation at low load influences strongly the annual energy performance.

The thermal and electrical energy performance of the cogeneration unit over the full load range must be known. For preference, this should be ascertained by suitable laboratory tests under a number of different part-load conditions. The plant size ratio of the cogeneration unit, taking account of the demand for heat in the building, must be determined. An annual load profile is developed from relevant regional climate data (such as degree-days) in conjunction with the plant size ratio.

Annual energy input and output, and average annual efficiency, are then calculated by summing up the performance at different part-load levels. It is assumed, that the cogeneration unit is 'heat-led' and controlled so that there is no dumped heat.

Total annual quantities for fuel input, heat output and net electrical output are recorded as the output from this method. If the cogeneration unit is inadequately sized for the heat demand of the building, the heat deficit (to be produced by another heat generator) is also calculated. Combining these quantities for calculation of primary energy and CO_2 emissions is carried out according to prEN 15315.

4.7.2 Determining the energy performance for full range of load conditions

Knowledge of the energy performance of the installed cogeneration unit under different part-load conditions is obtained from either laboratory test results or other relevant data.

This information is used to establish the load-performance curves for thermal efficiency and electrical output of the cogeneration unit. An example of a load performance curves is illustrated in Figure 1.

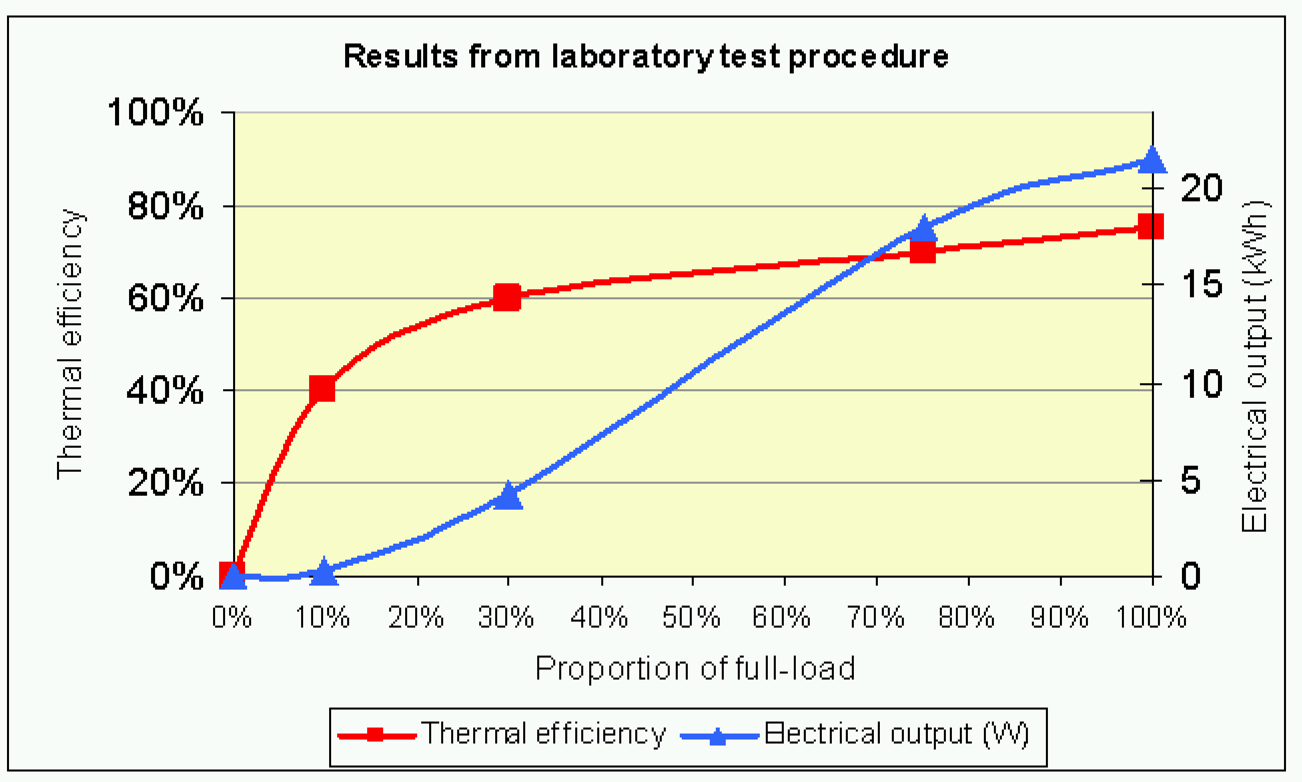

Figure 1 — Load-performance curves for thermal efficiency and electrical output (example only)

The load performance curve for thermal efficiency and for net electrical output can be representative of each cogeneration technology or for each cogenerator. The intervals defining the performance curve shall give reliable information over the whole part load range. These intervals are defined in the product standards.

Note: If product information based on product standards is not available, the load-performance curve for thermal efficiency should be given with values at 10% intervals over the load range 0 to 100% recorded as η_0 to η_{100}. From the load-performance curve for net electrical output, values at 10% intervals over the load range 0 to 100% should be recorded as $Q_{elect,0}$ to $Q_{elect,100}$ (kWh/day).

Note: It would be preferable if the thermal efficiency of the cogeneration unit is also given as a function of the temperature of the heat output. For some cogeneration unit parts, the output temperature could be very low (example: intercooler T_{out} = 35 °C). If the heat emission system of the building installation is not adapted accordingly, the heat output of the cogeneration unit can not be totally used.

4.7.3 Determining the annual load profile

The annual load profile for the cogeneration unit is determined taking account of the regional climate, design heat loss and plant size ratio.

An example of an annual load profile for a cogeneration unit with sufficient power to provide the entire heat demand of the building is given in Figure 2.

Note: For a cogeneration unit with insufficient power to provide the entire heat demand of the building, the annual load profile comprises a larger proportion of the time at full load.

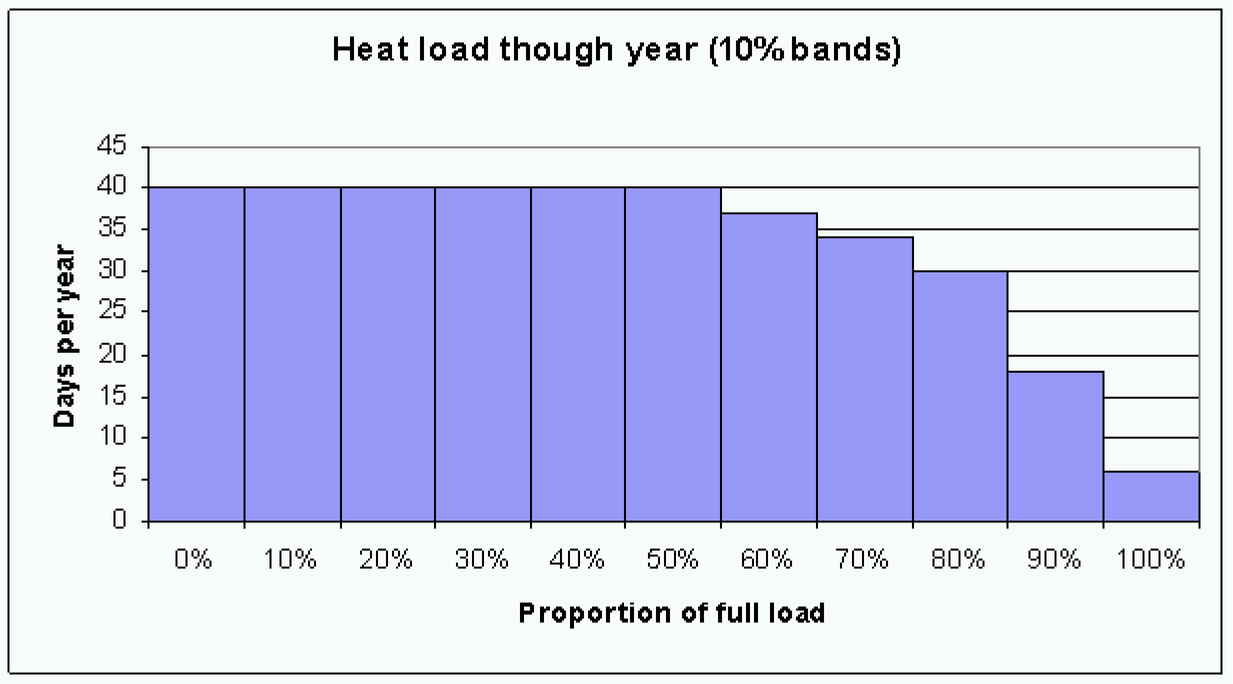

Figure 2 — Annual load profile (example only)

From the annual load profile, the number of days at 10% intervals over the load range 0 to 100% should be recorded as $ndays_0$ to $ndays_{100}$. Note that:

$$\sum_{i=0}^{i=100} ndays_i = 365.$$

The annual load profile and the values obtained from the load-performance curves are subsequently combined in order to determine:

- total heat output;
- total fuel input;
- total net electricity generated

during one year.

4.7.4 Heat output of the cogeneration installation

The annual heat output of the cogeneration unit $Q_{heat,cogen}$ is calculated by:

$$Q_{heat,cogen} = \sum_{i=0}^{i=100} i / 100 \times Q_{heat,max} \times ndays_i \qquad [4]$$

where:

i	index of part-load conditions, from 0 to 100% (increments of 10% for example)
$Q_{heat,max}$	maximum thermal output per day of cogeneration unit
$ndays_i$	number of days per year for which i% part-load applies

4.7.5 Fuel input for the cogeneration installation

The annual fuel input for the cogeneration unit $Q_{fuel,cogen}$ is calculated by:

$$Q_{fuel,cogen} = \sum_{i=0}^{i=100} i / 100 \times Q_{heat,max} / \eta_i \times ndays_i \qquad [5]$$

where:

i	index of part-load conditions, from 0 to 100% (increments of 10% for example)
$Q_{heat,max}$	maximum thermal output per day of cogeneration unit
η_i	thermal efficiency of cogeneration unit at i% part-load
$ndays_i$	number of days per year for which i% part-load applies

4.7.6 Electricity output of the cogeneration installation

The annual net electricity generated by the cogeneration unit $Q_{elect,cogen}$ is calculated by:

$$Q_{elect,cogen} = \sum_{i=0}^{i=100} Q_{elect,cogen,i} \times ndays_i \qquad [6]$$

where:

i	index of part-load conditions, from 0 to 100% (increments of 10% for example)
$Q_{elect,cogen,i}$	net electrical output per day of cogeneration unit at i% part-load
$ndays_i$	number of days per year for which i% part-load applies

4.7.7 Annual average thermal efficiency of the cogeneration installation

The annual average thermal efficiency of the cogeneration installation $\eta_{heat,cogen}$, defined as the total heat output of the cogeneration installation divided by the total fuel input during one year, is calculated by:

$$\eta_{heat,cogen} = Q_{heat,cogen} / Q_{fuel,cogen} \qquad [7]$$

Annex A
(informative)

Share of preferential CHP systems

The part of heat generated by preferential operated heat generation appliances (e.g. cogeneration unit) in the heat supply to the building is a function of β_{heat}.

β_{heat} is defined as the ratio of the total nominal capacity of the applied preferential generation appliances to the total nominal capacity of all heat generation appliances of the installation.

β_{heat} is calculated by:

$$\beta_{heat} = (P_{gen,heat,pref}) / (P_{gen,heat,npref} + P_{gen,heat,pref}) \quad [A1]$$

where:

$P_{gen,heat,pref}$	total nominal capacity of the preferential heat generation appliances
$P_{gen,heat,npref}$	total nominal capacity of the non-preferential heat generation appliances

The share of heat generated by preferential operated heat generation appliances in the heat supply, as a function of β_{heat}, is given in Table A.1.

Table A.1 — Share of heat generated by preferential operated heat generation appliances as a function of β_{heat}

β_{heat}	$f_{heating, cogen}$
From 0,1 to 0,2	0,4
From 0,2 to 0.8	0,6

This example show that is the cogeneration unit (preferential operated heat generation appliance) has a heat power output representing between 10 and 20 % of the total heat power output, than the cogeneration unit supplies 40 % of the annual heat energy to the building.
If the cogeneration unit has a much higher power (e.g 80%) than the supplied heat is only a little bit higher (60%).

Note: $f_{share,CHP}$ depends on the operation mode of the cogeneration unit, the technology, etc. In the example in Table A.1, the CHP is ‘heat led’ and the CHP is the preferential generation appliance. The example in Table A.1 is given only to illustrate the calculation method. It is strongly recommended to determine $f_{share,CHP}$ in a detailed manner in a national annex.

Annex B
(informative)

Efficiency of building integrated cogeneration units

Indicative efficiency at nominal load for building-integrated cogeneration installations are given in Table B.1.

Table B.1 — Indicative efficiency for different prime mover technologies for building-integrated cogeneration installations (based on the lower heating value of the fuel)[1]

	Unit	Internal combustion engine (gas)	Internal combustion engine (diesel)	Micro turbine	Stirling engine	Fuel Cell
Heat efficiency (at nominal load)	%	45 - 61	50 – 60	52 - 66	61 - 95	35 - 70
Electrical efficiency (at nominal load)	%	21 – 38	30 – 40	13 – 32	10 - 25	25 – 50
Total efficiency (at nominal load)	%	73 - 95	78 – 95	70 - 90	83 - 105	75 - 95

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[1] Preliminary figures, because most cogeneration systems using Stirling engine and fuel cell system technologies are currently still at the development or demonstration project stage.

Annex C
(informative)

Primary energy savings provided by CHP

C.1 Primary energy consumption of the cogeneration installation

The annual primary energy consumption of the cogeneration installation is determined by:

$$Q_{prim,cogen} = Q_{fuel,cogen} * f_{prim,fuel,cogen} \qquad [C1]$$

where:

$f_{prim,fuel,cogen}$	primary energy conversion factor of the fuel used by the cogeneration installation

National primary energy conversion factors should be given in national annexes to this standard.

C.2 Fuel consumption of the reference case

The reference fuel consumption of produced heat and electricity is calculated by:

$$Q_{ref,fuel,heat} = Q_{heat,cogen} / \eta_{ref,heat} \qquad [C2]$$

$$Q_{ref,fuel,elect} = Q_{elect,cogen} / (\eta_{ref,elect} - (\eta_{ref,elect} * L_{network})) \qquad [C3]$$

where:

$Q_{ref,fuel,heat}$	reference fuel consumption for separate heat production
$Q_{ref,fuel,elect}$	reference fuel consumption for separate electricity production
$\eta_{ref,heat}$	reference efficiency of the separate heat production
$\eta_{ref,elect}$	reference efficiency of the separate electricity production
$L_{network}$	grid loss factor of the electrical network

National efficiency reference values for separate production of heat and electricity and national grid loss factors should be given in national annexes to this standard.

Note: According to the European Cogeneration Directive[2], national values should be determined according to the following principles:

- comparison with separate electricity production shall be based on use of the same fuel category as for the cogeneration unit;
- each cogeneration unit and building shall be compared with the best available and economically justifiable technology for separate production of heat and electricity on the market in the year of construction of the cogeneration unit;
- efficiency reference values for separate heat and electricity production shall reflect the climatic differences between countries.

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[2] Annex III(f) of Directive 2004/8/EC

Note: According to the European Cogeneration Directive[3], the European Commission defines, no later than 21 February 2006, harmonised efficiency reference values for the separate production of heat and electricity. As soon as these harmonised values are defined, they replace the reference values for each country given in the national annexes to this standard.

C.3 Primary energy consumption of the reference case

The reference primary energy consumption of separately produced heat and electricity is calculated by:

$$Q_{ref,prim,heat} = Q_{ref,fuel,heat} * f_{ref,prim,heat} \qquad [C4]$$

$$Q_{ref,prim,elect} = Q_{ref,fuel,elect} * f_{ref,prim,elect} \qquad [C5]$$

$$Q_{ref,prim} = Q_{ref,prim,heat} + Q_{ref,prim,elect} \qquad [C6]$$

where:

$Q_{ref,prim,heat}$	reference primary energy for separate heat production
$f_{ref,prim,heat}$	primary energy conversion factor for heat of the reference case
$Q_{ref,prim,elect}$	reference primary energy for separate electricity production
$f_{ref,prim,elect}$	primary energy conversion factor for electricity of the reference case
$Q_{ref,prim}$	reference primary energy for separate heat and electricity production

National primary energy conversion factors for the reference cases should be given in national annexes to this standard.

C.4 Primary energy savings achieved by building-integrated cogeneration

The primary energy savings achieved by cogeneration $Q_{pes,cogen}$ is calculated by:

$$Q_{pes,cogen} = Q_{ref,prim} – Q_{prim,cogen} \qquad [C7]$$

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[3] Article 4(1) of Directive 2004/8/EC

Annex D

(informative)

Example: annual load profile method

In this example, the cogeneration unit has a specification as shown in Table D.1.

Table D.1 : Specification of cogeneration unit

Maximum rate of heat output =	17.36	kW
Net electrical output =	0.92	kW

$Q_{heat,max}$ is calculated from the specification as shown in Table D.2.

Table D.2 : Calculation of $Q_{heat,max}$

Maximum rate of heat output =	17.36	kW
=	417	kWh/day
=	1500	MJ/day
Thus $Q_{heat,max}$ =	1500	MJ/day

The performance of the cogeneration unit under part-load conditions at 10% intervals has been determined in laboratory tests, and the results are as shown in Table D.3.

It may be acceptable to interpolate some of the values, rather than measure performance at every 10% interval, provided the characteristics of the unit are well understood and it is known there are no discontinuities of value or gradient in the load-performance curves. Discontinuities are likely to occur in multi-stage plant; for example in units that have supplementary burners, or a limited modulation range, or generator cut-off at low thermal output. The tests show results for a whole day in every case, so the unit does not necessarily have to perform at a uniform rate throughout the day. The thermal efficiency at each part-load condition is calculated as the heat output divided by the fuel input.

Table D.3 : Results from performance tests

Part-load	Heat output	Fuel input	Net electrical output	Thermal efficiency
%	MJ/day	MJ/day	MJ/day	%
0	0	0	0.0	0%
10%	150	375	0.0	40%
20%	300	545	0.0	55%
30%	450	750	14.5	60%
40%	600	952	28.9	63%
50%	750	1136	43.4	66%
60%	900	1323	57.8	68%
70%	1050	1500	65.0	70%
80%	1200	1667	72.3	72%
90%	1350	1824	75.9	74%
100%	1500	2000	79.5	75%

From Table D.3 a load-performance curve can be drawn, as shown in Figure 1.

The heat demand from the building is calculated for each day of a typical year, using a heat loss method and knowledge of climatological conditions (e.g., degree-days). The daily heat demand values (in MJ) are divided into ranges, corresponding to 10% part-load intervals. The numbers of days in each month in each range of daily heat demand values are recorded, as shown in Table D.4.

Table D.4 : Building heat demand profile (days in typical year)

		<5%	5%-15%	15%-25%	25%-35%	35%-45%	45%-55%	55%-65%	65%-75%	75%-85%	85%-95%	>95%
	Days	less than 75 MJ	75 to 225 MJ	225 to 375 MJ	375 to 525 MJ	525 to 675 MJ	675 to 825 MJ	825 to 975 MJ	975 to 1125 MJ	1125 to 1275 MJ	1275 to 1425 MJ	1425 MJ or more
Jan	31					2	4	5	6	6	5	3
Feb	28				1	3	4	5	5	5	3	2
Mar	31			1	3	6	7	4	4	4	2	
Apr	30			1	5	6	5	5	4	3	1	
May	31		3	6	7	6	3	2	2	2		
Jun	30	4	6	7	9	4						
Jul	31	10	13	8								
Aug	31	18	8	5								
Sep	30	8	4	4	4	3	3	2	1	1		
Oct	31		3	4	6	4	4	4	3	2	1	
Nov	30		2	3	3	3	5	5	4	3	2	
Dec	31		1	1	2	3	5	5	5	4	4	1
TOTAL	365	40	40	40	40	40	40	37	34	30	18	6

The annual load profile consists of the number of days (ndays) at each part-load condition for the heat generator. It is shown in Table D.5. It can also be plotted as a histogram, as shown in Figure 2.

Table D.5 : Building heat demand

Range (MJ/day)			Number of days	Approx. loading on heat generator
	less than	75	40	0%
75	to	225	40	10%
225	to	375	40	20%
375	to	525	40	30%
525	to	675	40	40%
675	to	825	40	50%
825	to	975	37	60%
975	to	1125	34	70%
1125	to	1275	30	80%
1275	to	1425	18	90%
1425	or more		6	100%
	Total days =		365	

For each part-load condition, the heat output, fuel input, and net electrical output are known from the test results in Table D.3. The annual load profile and part-load performance are combined in Table D.6 to produce the annual energy totals, using equations [4], [5], and [6] from section 4.3.

Table D.6 : Annual energy calculations

i	Part-load	ndays $_i$	i/100 x $Q_{heat,max}$	$Q_{heat,cogen}$	η_i	$Q_{fuel,cogen}$	$Q_{elect,cogen,i}$	$Q_{elect,cogen}$
0	0%	40	0	0	0	0	0.0	0
10	10%	40	150	6000	40%	14999	0.0	0
20	20%	40	300	11999	55%	21817	0.0	0
30	30%	40	450	17999	60%	29998	14.5	578
40	40%	40	600	23998	63%	38093	28.9	1156
50	50%	40	750	29998	66%	45452	43.4	1734
60	60%	37	900	33298	68%	48967	57.8	2139
70	70%	34	1050	35698	70%	50997	65.0	2211
80	80%	30	1200	35998	72%	49997	72.3	2168
90	90%	18	1350	24298	74%	32836	75.9	1366
100	100%	6	1500	8999	75%	11999	79.5	477
	Totals	365		228285		345154		11829

The results from the annual energy calculations are summarised in Table D.7.

Table D.7 : Results

4.3.4 equation [4]	$Q_{heat,cogen}$ =	228285	MJ/yr
4.3.5 equation [5]	$Q_{fuel,cogen}$ =	345154	MJ/yr
4.3.6 equation [6]	$Q_{elect,cogen}$ =	11829	MJ/yr
4.3.7 equation [7]	$\eta_{heat,cogen}$ =	66%	