SAVE II ACTION
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Labelling and other measures for heating systems in dwellings

Appendix 3

Technical improvements and technological change

including a first exploration of ranking heating systems

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1 Introduction

1.1 General purpose of technical economic analysis

The objective of Task 2, the technical economic analysis, is to establish a basecase, identify technical design options to improve on the basecase and assess their Life Cycle Costs (machine price increase and discounted savings). The basecase is defined as the average EU equipment, usually subdivided in performance categories with one basecase for each category. The design options, that improve on this average basecase, are identified and then ranked according to Payback Period in order to establish what is the most suitable level for policy targets –the so-called Least Life Cycle Cost point (LLCC)– taking into account the accumulative effect of the options. The last point of the Life Cycle Cost curve is the point with the highest (accumulated) energy saving, also known as the Technical Potential point (TP). This point usually serves as a reference for the highest ('A') qualification in the EU energy labelling scheme.

1.2 The case of heating systems

Heating systems have to be treated different from single appliances. If we look at heating boilers, we see that they are usually categorised not in terms of performance but in terms of:

- energy source of the heat generator (gas, oil, solid, electric, district heating);
- heat distribution system (local vs. central heating, the latter subdivided in hydronic and air heating systems, with a possible further subdivision in high, medium or low-temperature systems, etc.).

If we follow this categorisation, we end up with at least 10 categories of heat generators and possibly 3 to 5 categories of heat distribution / emission systems. And we could describe per category what the EU average (basecase) is and what specific design options are available. In Annex I you will find (a start of) an elaborated example of how this looks like, from the technical point of view, for the most common types of heating systems.

However, for the main stakeholders this adds very little to what already exists today and what is already known. Each country has its own labelling[1] scheme for specific categories of heating boilers, national building codes and performance standards to implement the heating systems, etc. Also, the manufacturers are familiar with most solutions to make their appliance more efficient, but there are economic and commercial reasons why they offer a range of solutions on the market. Therefore this study takes a more holistic approach, looking at the heating system as a whole and trying to work out a classification scheme for that.

This systems approach does not make the technical analysis very easy, as we are treading on new ground. Therefore we will start by making some exploratory first steps before we start with a thorough bottom-up approach. And the first question to ask is 'How would a heating system classification look like?', 'What would be the best and the worst heating systems in terms of energy efficiency?'.

1.3 Ranking heating systems: A first exploration

To start with the latter: the most efficient heating system (in terms of energy use and CO_2 output) is no heating system. Through the use of passive solar energy, internal heat gain, a properly designed building shell, orientation of the building and - above all else - a mild climate there are houses in parts of Europe that

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[1] Or employs the 'star' system from the EU SAVE boiler directive

don't need an active heating system. The problem of cooling in the summer can be resolved by active cooling (which is outside the scope of this study) or preferably proper design of the house.[2]

The next best thing is active heating using specific renewable energy sources such as solar energy (heat, power) or geothermal heat. The use of active solar systems for space heating is relatively rare. But, for instance in Iceland, heating systems based on geothermal heat can be very common in certain areas. At a much more superficial level, ground source heat pumps that use the geothermal properties of the earth shell are technically feasible solutions in many parts of Europe.

Also seen as 'renewable' is the use of biomass (wood) for space heating. This is quite common in e.g. Austria. The problem with this energy source is, that it may be renewable, but - in terms of energy efficiency and CO_2 emissions - it may not always be the best solution.

The question is of course, whether these heating solutions that are specific for favourable local circumstances should be part of a EU classification scheme or whether the classification should be limited where the people do have a real choice and where this choice afflicts the energy efficiency and CO_2-emissions.

By today's standards, the most efficient active heating system using fossil fuels would probably be a low-temperature system with hydronic floor- and wall heating or over-sized radiators, driven by a gas or oil-fired heat pump with an efficiency of 140% (lower heating value). Next would be a low-temperature system with the latest generation –107% efficiency—gas-fired condensing boiler. In the top-range of condensing boilers oil- or LPG-fired boilers are slightly less efficient, so they would probably be the next category. With all these highly efficient systems, one would preferably see a weather dependent boiler temperature control and a modulating burner going down at least 10 (with segmented burners) to 20% of nominal capacity. But also modulating burners that only can reduce their capacity to 30 or 40% of nominal value play a role. All have electronic ignition and presumably pre-mix burners. The (variable speed) pumps and fans are electronically controlled through the boiler control. In the electrically less efficient versions you will find (stand alone) circulator pumps that run the whole year through and are –at best—self-controlled.

Also in this category –counting from marginal primary energy of new power plants—we should include the electrical heat pumps. This is a second problem:

How can one compare a heating from an indirect energy source –such as electricity but also district heating—with a heating system that consumes fuel directly.

Should power plants be included? Should it be based on an EU average, EU average marginal or local circumstances with nuclear or large hydro? What conversion factors should be used? What is fair and what is practical?

And what about district heating? Should it be based on CHP with high efficiency for power generation? Or should we consider it as waste heat e.g. from a power plant or fuel incineration?

Gradually we then slide down to mid-efficiency gas or oil-fired boilers and normal radiator heating. They may have modulating burners and electronic ignition, but also on-off type burners and pilot flames can be found in the lower part of this category.

In this efficiency range up to 85-90% we also find most high-efficiency gas- or oil-fired local heaters. And this is where a second problem arises:

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[2] In case the building shell is not optimally designed and the heating season is very short (2 months) a solution is heating through reversible air conditioners ('heat pumps').

How can we compare a local heating in just one or two rooms of the house with a radiator heating or low temperature heating in every room?

Clearly, the local heating has to work with much larger heat gradients and less comfort, but how can one express this? If the inhabitants of a dwelling are willing to adapt themselves to the local heating and –on cold days- gather around the stove and put thick blankets on their beds, the local heater might be less efficient but the total energy requirement of this household would be lower than one with a central heating system. For instance in Germany, after the reunification, many families in the former German Democratic Republic got rid of their old stove and renovated their heating systems. As a consequence heating energy requirements went down in the first couple of years. But already in 1994 the heating requirements in Eastern Germany went up. The central heating boilers that replaced the stoves were much more efficient, but this was outweighed by the comfort of having every room in the house heated and probably also not making the effort of closing the radiator valve when there was no-one in the room. The same goes for Japan, where Western Europeans long marvelled about the low energy consumption for the average household. The houses are not particularly well insulated and the climate is comparable to a Mid European climate. Yet, the Japanese are used to local heaters where they gather round on cold days.

And then we also end up with advanced wood stoves or other forms of renewable solid fuels that were discussed. If we don't give them a 'special treatment' because they are renewable their thermal efficiency might be seen as low as 70% even for the technically most advanced solutions.

Still less efficient are conventional boilers, some local heaters and finally at the very low end (of primary energy efficiency) we find electrical resistance heaters, which should be split in storage (ceramic or immersion) heaters that make use of night current and electric radiators / convector systems.

1.4 Structure of report

From the above it is clear that the definition, classification and ranking of heating systems is highly complex. We propose to treat this subject step-by-step and component-by-component. The first step must be the establishment of a common ground for comparing the performance of heating systems. A first exploration of such an approach is presented in Chapter 2.

Chapter 3 to 8 contain short descriptions of heating supply systems and their components (heat generators, distribution and emitters, controls and auxiliary energy consumption). Chapter 3 explicitly addresses issues that concern heating with indirect energy sources (such as electricity and district heating). Chapter 4 to 7 describe several components of dwelling based heating systems such as boilers, emitters and control systems and Chapter 8 addresses room based heating systems. The purpose of these chapters is to give insight in the most relevant trends and features. More detailed technical information on heating system components is provided for in Annex 1.

Chapter 9 brings together the conclusions of Chapter 2, Chapter 3-8 and all annexes, by presenting a first draft of a possible method for ranking of heating systems. This ranking is based upon the establishment of comfort classes and energy efficiency of heating systems. Besides the ranking approach this chapter also contains an overview of the technical design options that might improve energy efficiency of heating systems.

2 Performance

2.1 Definition

Per definition, energy efficiency is the energy consumption weighed against performance. Energy consumption can relatively easily be measured / calculated but the definition of performance of a heating system is not as easy as it may seem. The heating power (in kW) of the heat generator is the most obvious parameter, but not per se the correct one. One can also express performance in a unit like "energy consumption per square meter floor space heated". This allows for comparison of a small double room apartment with only one local heater with a large family dwelling with central heating in all rooms. The problem however is that there are several kinds of "... floor space heated", or to put it simply: there is a big difference between the "heating quality" provided for by the local heater in the double room apartment and the central heating in the family dwelling. When looking at performance of heating systems the comfort it provides must be taken into account.

The objective of any heating system is to create a warm, comfortable and safe indoor climate. Heating comfort is defined according to:

- presence or lack of unheated habitable rooms in the dwelling;
- average temperature per room versus the desired ('set') temperature;
- the fluctuations (bandwidth) of the temperature per room;
- local temperature differences within the room (cold feet, warm head, solar influx, etc.);
- undesirable air movements within the dwelling (draughts, etc.);
- the air quality (e.g. oxygen in the room as far as it is influenced by the heating system, e.g. open versus closed systems, dust particles, dust burn);
- the perceived comfort of heat transfer by radiation vs. convection.

In other words, the ideal heating comfort is a dwelling with an average temperature equal to the desired temperature (e.g. 20 °C), within a very small bandwidth in time (e.g. less than 0.5 °C), with no hot spots (e.g. local temperature fluctuations less than 0.5 °C), with minimum air movement (no more than which is required for ventilation) and a heat source which doesn't influence the air quality in a negative sense.(e.g. combustion air is taken from outside and flue gases are expelled to the outside).

2.2 Classification of heating comfort

There are three physical parameters that define the heating comfort that can at best be achieved in a dwelling. These parameters are:

1) The thermal properties of the dwelling itself (air-tightness, degree of insulation, type of glazing, poor ventilation);
2) Type of heat emitters and controls that are used (they influence amongst others temperature gradients, air velocity, temperature fluctuations);
3) The portion of unheated habitable rooms in a dwelling.

The first parameter is directly related to the quality of the building or house and is not related to the heating system. The thermal properties of the building however do define the type of emitters that can best be installed. Windows with single glazing and a lot of cracks and crazes around the window-frame can better not be combined with low temperature floor heating. On the other hand very well insulated and airtight buildings should not be combined with open local gas heaters. In this way the building quality indirectly defines the heating comfort that can at best be achieved.

Furthermore, if the dwelling has poor thermal properties (draught, insufficient insulation, etc.) the heating supply system sometimes cannot compensate for (all of) these discomforts and the final perceived comfort is low.

The second parameter and third parameter are directly related to the heating system itself and will be discussed further on.

The emitter and control system that is used, defines the thermal comfort that is achieved in a specific *room*. The differences in heating comfort can be considerable for different types of emitters/controls. This is illustrated in the following table.

Table 2.1 Heating comfort related to emitter / control-systems

Emitter system	**floor heating (electric or hydronic)**	**wall heating (electric or hydronic)**	**LT-radiators (electric or hydronic)**	**LT-convectors (electric or hydronic)**	**LT-air heating (electric, hydronic or direct fired)**	**HT closed room heaters (electric or direct fired)**	**Direct fired open room heaters**
Reference	*radiators 90/70*	*Radiators 90/70*	*radiators 90/70*	*convectors 90/70*	*HT-air 90/70*	*radiators 90/70*	*radiators 90/70*
Thermal comfort							
• percentage radiation	+++	++	+	0	0	0/-	0/-
• vertical temperature gradient	+++	++	++	++	++	-	-
• radiation symmetry windows	0	0	0	0	0	0/-	0/-
• radiation symmetry other	0	0	0	0	0	0/-	0/-
• floor temperature	+++	0	0	0	0	-	-
• temperature fluctuations	++	+	+	+/0	+/0	-	-
• heating speed	-	-	0	0	0	+	+
• possibilities cooling	+++	++	0	0	+	0	0
• draught	+	+	+	+	0	-	--
• relative humidity	+/0	+/0	+/0	0	0	0	-
• consumer experiences	++	++	?	?	0	0	-
Air quality							
• floating dust particles	+++	++	+	+	0	-	-
• mite	+++	+	0	0	0	-	-
• composition indoor air	0	0	0	0	0	0	-
• smell and dust burn	++	++	+	+	+	-	-

The portion unheated rooms in a dwelling is an indicator for the thermal comfort that is realised in the overall dwelling. The thermal comfort in a dwelling with only one heater (installed e.g. in the living room) will be lower than in a dwelling where all habitable rooms are equipped with a heat emitter. This aspect must also be taken into account when the thermal comfort-classes are described.

On the basis of the above the following proposal is made for introduction of thermal comfort classes:

Table 2.2: Comfort Classes

Class	*Thermal Comfort*	*Type of heating/emitter/control system*
I	Low	Single (open) heat generator/emitter in only one habitable room of an non-insulated dwelling
II	Mediocre	Local heat generators/emitters in no more than only half of the habitable rooms of an average insulated dwelling.
III	Average	Heat emitter in every habitable room (several local heaters or a boiler with radiators/convectors with manual boiler temperature control and room thermostat) in a well insulated house
IV	Good	Heat emitter in every habitable room (several local heaters or a boiler with radiators/convectors with weather dependant temperature control and thermostatic valves, modulating burners) in a well insulated house
V	Excellent	Low temperature heat emitter in every habitable room (floor-, wall- heating or oversized radiators, with weather dependant temperature control and thermostatic valves, modulating burners) in a perfect insulated house

Although this definition of comfort classes may look rather arbitrary (and to a certain degree it inevitably is), there is a sound basis for defining classes in heating comfort.

3 Indirect Energy

3.1 Introduction

For heating systems that use indirect energy, such as electricity or collective / district heating, the analysis of the energy consumption starts at the power plant, CHP-installation, etc. Following the example of the German Energiesparverordnung it is proposed to work with conversion factors. In our case we propose that they are based on marginal energy efficiency according to best available energy.

3.2 Electric power generation & distribution

For electricity this marginal energy efficiency according to best available energy would be a CCGT ([3]) plant with an efficiency of 60%. Distribution losses are set at around 3% in an optimal configuration, therefore total efficiency is not higher than 56-57% for electricity when it reaches the home.

In order to arrive at an heat generator efficiency based upon primary energy consumption the nominal energy efficiency of every electric heat generator must be multiplied by this factor.

3.3 District heating and CHP

District heating started out in the 1980's as a way to utilise waste heat from large power plants. In those days, power generation efficiency was not higher than 35 to 38% on average and the waste heat was just a nuisance, requiring extensive cooling. As such, the heat source could be considered 'for free' and apart from the hefty heat losses in the warm water grid, requiring intermediate boiler stations for reheating, and the pump energy there were no real energy costs attributed. Prices were based on the principle that consumers with district heating should not pay more than consumers with 'normal' alternative fuels (e.g. gas). Investments and maintenance costs for the warm water grids are substantial but –with a payback period of 20 years—the whole activity was deemed economical to the utilities.

In the 1990's utilities started to make district heating grids not based on waste heat from power plants (or waste incinerators as also happened to be the case) but based on so-called mini-CHP (co-generation) plants for new housing districts. CHP was considered the way forward in economical energy conservation. Investments were considerable, but payback times of 20 years or more were seen as acceptable. The projected power generation efficiency of mini-CHP was in the range of 40%, which is comparable to a large power plant. Therefore –again—the heat output was considered 'for free'.

However, in the late 1990's things started to change on the economics of mini-CHP. The electricity market became liberalised and –with it—the power sector was split up between companies owning the power plants, a grid owner and distributors. A fierce cost competition started, requiring much shorter payback times and a very critical look at operational costs.

Furthermore, the actual efficiency and utilisation rate of many mini-CHP installations was lower than the planned efficiency. Many CHP-plants were built to service the heat demand of dwellings, with the electricity considered as a surplus. This meant, that utilisation rates in summer are extremely low (just for

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[3] CCGT = Combined Cycle Gas Turbine

hot water heating if there was a double grid). Furthermore, planned capacities were abundant, starting from a 'worst case' scenario. However, as most district heating projects took place in new housing districts the houses were very well insulated leading to a very low space heating demand per dwelling.

On the cost side, the real maintenance costs were higher than projected costs. All these factors made, that the building of mini-CHP plants came almost to a halt at the end of the 1990's. And –with the event of rising gas prices-- even some CHP-plants that were built several years before, were stopped.

For the EU, with a target of 18% of CHP for power generation in 2010, this development is disappointing. At the moment CHP in the EU is at a level of 9-10% with specific energy (and CO_2-emission) savings lower than projected.

Governments, disappointed by the low energy efficiency started to make very strict demands on the efficiency of CHP plants. Germany and the UK demanded overall efficiencies of 70-75% in practice. In the Netherlands, the efficiency requirements for district heating –which was previously also set at 70% overall—recently was changed to differentiate between heat generation efficiency (which should be counted for only two thirds) and power generation efficiency. The total, calculated in that particular way, should now be a minimum of 65%. In other words, a good CHP-plant with 40% power generation efficiency and 40% heat generation efficiency would now barely be over the Dutch 65% mark.

This now seems the way forward and –when incorporating the possibility of district heating in a labelling or standard scheme—we propose to take a CHP plant with 40/40 efficiency.
In the meanwhile, power generation technology has not been standing still and now power generation, re-utilising waste heat (e.g. in a CCGT), can reach an efficiency of up to 55-60%. And the most efficient gas-fired heat generator is still a condensing boiler boosting efficiencies of 90-95%.

Table 3.1: Primary energy consumption of CHP and separate generation

	CHP (80% overall efficiency)			**Separate generation**				
	Input	Efficiency (lower heating value)	Output	Output	Efficiency (lower heating value)	Remark	Separate Input	Total Input
A	100	power 10%	power 10	power 10	power 42%	conventional efficiency of grid	24	89
		heat 70%	heat 70	heat 70	heat 107%	condensing boiler	65	
B	100	power 40%	power 40	power 40	power 42%	conventional efficiency of grid	95	132
		heat 40%	heat 40	heat 40	heat 107%	condensing boiler	37	
C	100	power 40%	power 40	power 40	power 55%	CCGT	73	110
		heat 40%	heat 40	heat 40	heat 107%	condensing boiler	37	

Therefore, if we take these best available single options as a yardstick for efficiency, the good quality district heating option would rank more or less as a 'boiler' with an efficiency of 110% (see table). To this distribution losses in the grid still have to be added, which falls within in the range of 5-40% [4]. In this study we assume grid losses of 10% which results in an average efficiency of District heating of 100% at the point where it enters the dwelling.

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[4] Sources (see end of footnote) point towards an average annual heat loss between 5-40%, depending on grid temperature range and the average ground temperature. A typical Northern European grid with a ground temperature of 10°C and a grid temperature of 90/70°C has an average 10 GJ (source 1) to 13 GJ (source 2) of heat losses per dwelling per year. If the dwelling heat demand is 30GJ the heat losses are 25% (10/(10+30)=0.25). [source 1: "Energy efficient heat supply" -org. Dutch: Energie efficiënte warmtevoorziening voor nieuwbouwwijk-, Novem DV 1.1.101.97.12], [source 2: "Heat distribution" - org. Dutch: Warmtedistributie - basisgegevens, Novem, November 1997].

3.4 Block Heating

Block heating is in many ways similar to district heating, however with one major difference: Distribution losses for block heating are much less because of the limited size of the grid. Regarding heat generators, controls and emitters the same principles as for district heating apply.

Most district and block heating systems are fed directly into the radiators of the dwelling and controlled only through the radiator valves. In rare occasions, for instance if there is only a high temperature district heating grid (70 °C constant), then a heat exchanger may be introduced between the CH-network in the home and the district heating network. This district heating ‘boiler’ would normally add some 10 to 15% to the heat losses of the heat generating system. But –as mentioned—it is very rare and we will not expand on this issue.

3.5 Transport and distribution of fossil fuels

Any energy analysis of the supply system would also include transportation and distribution energy for fossil fuels. In the case of natural gas and oil these ‘losses’ are quite small (2-3% of heating value), but in some particular cases like bottled gas or gas that has been transported as liquefied gas the energy consumption can be significant (order of magnitude 5%).

4 Dwelling Based Heating – Boilers

4.1 Introduction

This chapter describes the heat generator (boiler) of dwelling based heating systems, also called central heating. The paragraphs refer to a split up according fuel type. Gas- and oil fired central heating boilers cover some 75% of the EU market in moderate and cold climate zones. Other heat generators are electric boilers and/or heat pumps, wood and coal fired boilers, district heating (11 million households in 1998) [5] and of course all sorts of local heaters [6], ranging from electric resistance radiator panels, wood- and fossil fuel fired stoves, up to reversible room air conditioners (RAC's). And even active solar heating panels for space heating holds a very small market share.

4.2 Gas and oil fired central heating boilers

4.2.1 Conventional boilers

After having established a comfort class we need to assess and rank the efficiency of the heat generator. The efficiency of boilers can be determined by testing according European Standards. For ranking the 'star' system (EU Boiler Directive) can be used, extended with the heaters that have come on the market since its creation in 1992.

Table 4.1: Minimum Efficiency Standards Boiler Directive (92/42/EEC); efficiency figures are based on lower heating value.

	Range of power output	**Efficiency at rated output (Pn in kW)**		**Efficiency at partload**	
Type of boiler	kW	Average boiler-water temperature in ºC	Efficiency requirement expressed in %	Average boiler-water temperature in ºC	Efficiency requirement expressed in %
Standard boilers	4 to 400	70	≥ 84 + 2 log Pn	≥50	≥ 80 + 3 log Pn
Low temperature boilers (*)	4 to 400	70	≥ 87,5 + 1,5 log Pn	40	≥ 87,5 + 1,5 log Pn
Gas condensing boilers	4 to 400	70	≥ 91 + 1 log Pn	30 (**)	≥ 97 + 1 log Pn

(*)= Including condensing boilers using liquid fuels

(**)= Temperature of boiler water supply

Council Directive 92/42/EEC is actually a combination of a minimum efficiency standard and a labelling scheme for fossil fuel fired domestic boilers between 4 and 400 kW.
Table 4.1 gives an overview of the Minimum Efficiency Standards in 92/42/EEC. Of course there are a number of boiler types - many typical for the UK - that are excluded, such as the multi-fuel boiler (including solid fuels), cookers and appliances designed mainly to heat the premises in which they are installed (e.g. the 'AGA cooker'), instantaneous water heaters, hot water appliances with a capacity of lower than 6 kW, boilers designed to run on industrial waste gas/ biogas/ etc., equipment for the instantaneous preparation of hot water and boilers manufactured on a one-off basis.

Also 'back-boilers' (placed in a fireplace and intended to contribute to the central heating system) and boilers meant for the living room have more lenient Minimum Standards (4% below the requirements in table 1). In the case of combi-boilers (heating and hot water) the efficiency requirements in Table 4.1

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[5] District and collective heating systems are addressed in Chapter 3

[6] Local heating is addressed in Chapter 8

concern the heating function only. The Directive states that Member States are to incorporate the directive in national law by 1.1.1993 and it shall enter in force by 1.1.1994. Boilers that don't comply are permitted until 31.12.1997.

The labelling scheme works with stars 'φ'. One star is awarded to boilers with an efficiency at rated output higher than or equal to 84 + 2 log Pn, where Pn is the rated output in kW. Also the boiler has to have –at partload—an efficiency of 80 + 3 log Pn. For every 3 percentage points higher than these efficiency values an extra star is awarded. For instance, at two stars the boiler has an efficiency of 87 + 2 log Pn (rated output) and 83 + 3 log Pn (partload), etc. This labelling scheme is voluntary. Member States may decide to apply it, but so far very little Member States have. One of the reasons is, that the boiler market has traditionally been a national, not an international market. Now we see a dominating influence of a number of multinationals such as Vaillant, Viessman, Buderus, etc., but 10 years ago there were many more small, national and even local producers. Also the quality marks and environmental labels ('HR', 'LowNOx', etc.) differ per country and there has been no desire so far to add the European label. For multinationals, one EU marking might in principle be attractive, but given that –if not for anything else but the different calorific values of the fuels per country—the boiler always has to be country-specific for technical reasons, uniform EU labelling did not add a great bonus so far.

As far as design options are concerned, we refer to Appendix I, chapter 3. In terms of payback periods and Life Cycle Costs it is quite simple: In all cold and moderate EU climate zones the 4 star condensing boiler or the low temperature boiler is economical. Only in regions with a short heating season of 2 to 4 months there may be a case to fall back on so-called 'improved efficiency boilers', but already now the price difference between an 'improved efficiency boiler' (> 84 + 2 log Pn % efficiency) and a condensing boiler is small (less than 100 Euro).

The reasons why people are not choosing condensing boilers may be:

- lack of information/training of the installers (and consumers);
- in new housing with a very critical cost factor (e.g. social housing) the extra 100 Euro for a condensing boiler may still be a factor of importance;
- in retrofitting applications the existing chimney is often not fit and it may not always be possible to find an economical solution for the 'wet' flue gases from a condensing boiler.

4.2.2 Gas-fired absorption heat pump

In 2001(at the ISH 2001) a new type of gas-fired heat generator became available: An innovative gas-fired absorption heat pump developed by the Dutch company Nefit-Buderus. The heat pump is a 4 kW base load device combined with a condensing boiler for peak loads. Efficiencies are up to 140% (lhv). More information on heat pumps is provided for in Annex 2, chapter 4.

4.3 Solid fuel fired central heating boilers.

Coal fired central heating boilers are very rare, but wood pellet central heating systems are starting up now, taking advantage of the 'green image' of biomass (wood) burning. Also in some EU countries in Scandinavia and Austria, traditional wood heating has always been quite popular.

Wood is earmarked as a 'renewable energy source' and therefore –even though the efficiency of the system in general barely surpasses 60%-- e.g. the German Energiesparverordnung is a priori excluding any house with biomass heating as the main heating from the restrictions of this law.

A similar solution could be proposed on an EU scale, but the exact source and nature of the biomass has to be well defined as well as the nature of the heating system. E.g. ‘waste’ wood from forestry activities is very welcome, but the chopping of healthy old trees is not seen as a contribution to fighting climate change. Also, wood as the main heating system is very welcome, but it is not desirable that any wood stove or fireplace is turned into an excuse not to implement other energy conservation measures.

4.4 Electric central heating boilers

4.4.1 Traditional electric boilers

Pure electric central heating boilers (with hydronic distribution of heat) are very rare in the EU. In most cases electric heating concerns resistance heating elements for radiative and convective heat transfer. These appliances can both be used as room based or dwelling based heating systems, the difference based upon whether a central control device for dwelling temperature is applied.

However, as an auxiliary energy source electricity is sometimes used in multi-fuel central heating boilers, e.g. in Scandinavia. The efficiency is obviously not high, starting from 57% at the plug (see Chapter 3) and then still having to add the standing losses (radiation and convection) from a boiler that is not placed in a habitable area.

4.4.2 Electric heat pumps

A far better solution is a central heating system based on a heat pump. A ground source electrical heat pump can reach a real-life COP (Coefficient of Performance) of 2.6. Even taking into account the power generation and standing losses of the boiler (57%), this still leads to real efficiencies of around 120-150% on primary energy. Payback times are still prohibitive (investment 8,900 EUR according to Ecofys[7]), but in special circumstances (e.g. sharing the ground source for many houses simultaneously) costs could be substantially lowered and –given mass production—also the price of the equipment could be substantially lower in the future. See also Annex 2.

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[7] Joosen, S. and Blok, K., ‘Economic Evaluation of Carbon Dioxide Emission Reduction in the Household and Services Sectors in the EU’, Ecofys for EC DG ENV, Final Report. Jan. 2001.

5 Dwelling Based Heating - Distribution and Emitters

5.1 Introduction

This chapter describes the technologies and characteristics of typical distribution and emitter-systems of central heating systems. The two systems that are applied here are hydronic (water as heat transport medium) and air (air as heat transport and transfer medium)

5.2 Hydronic distribution

5.2.1 Insulated tubing

The efficiency of the piping network is mainly determined by heat losses through uninsulated pipes where the pipes run through non-habitable spaces in the house. This could be an attic, a cellar, etc. This is not uncommon, because the attic and cellar are also popular places for installers to put the CH ring-network from which the vertical feed of the radiators starts. Insulation of the pipes could save up to 10%.

Electricity use of distribution (circulation pumps, fans, etc.) is addressed in paragraphs concerning auxiliary energy use.

Efficiency of distribution is also partly determined by the way flow through the radiators is “evened out” (DE: “ausgleichen”, NL: “waterzijdig inregelen”): Little radiators need little flow, large radiators (or radiators further away) need more flow. See also paragraph 6.4.2 on “Outgoing flow: Screw-type valves”.

5.3 Hydronic emitters

5.3.1 Conventional radiators / convectors

Heat emitters can differ in size and water content, together determining the heating capacity (in kW). This in itself may contribute to heating efficiency as oversized radiators allow for low temperature heating (e.g. typical of retrofit situations).

Geometry may make a difference in the relative contribution of radiation and convection heat (hence ‘convectors’ e.g. in the shape of a finned heat pipe or ‘radiators), but does not really influence the heating efficiency. Badly installed vertical radiators are more likely to show large accumulations of air, affecting the capacity, but even this in itself says very little about the heating efficiency.

What can make a difference is the immediate surrounding of the radiator or convector. Usually they are placed under a window and thereby (through the higher temperature) transmission losses through the building shell may locally be higher. This has also been the argument to put reflective foil behind the radiator in retrofit situations. The effect of this measure, though cheap, should not be overrated. Even with a relatively high temperature CH system (70/90°C) savings may not be more than 3-5%. With low temperature systems (40/60°C and lower) the effect is negligible.

5.3.2 Floor and wall heating

Especially in new houses, the CH system can contain subsystems such as floor heating systems for bathroom or kitchen, besides a traditional radiator heating. In system terms, the subsystem then can be seen as a type of radiator but with an internal circuit that requires a pump. For the temperature control there are various, more or less sophisticated solutions ranging from what looks similar to a thermostatic valve up to (wireless) timer controlled thermostats.

In low energy houses the floor (and wall) heating systems can even be the only ‘heat emitters’. In terms of heating comfort (Chapter 2) this is an optimal solution. For the energy efficiency of boiler operation the low temperature (usually not exceeding 30 °C) is a big bonus. Also heat losses through ventilation losses are less, because of the lower average room temperature (18°C instead of 20°C).

Disadvantage is, that it uses the building shell (floors, walls) as a heat emitting medium and –when not thoroughly planned and well insulated, may heat parts of the building shell connected to the outside. Also the almost continuous use of a circulator pump poses a disadvantage.

6 Dwelling Based Heating – Control

6.1 Introduction

The growing discrepancy between capacity and the demand makes traditional on-off burner control extremely difficult, leading to temperature overshoots (lower efficiency and heating comfort) and boiler malfunction (e.g. due to many very short on-off cycles).

6.2 Combi versus single

With the growing popularity of combi-boilers and the increased insulation of new houses, the dimensioning of the boiler with respect to the space heating demand has become a problem. For hot water heating the minimum capacity of a combi-boiler should be around 22-24 kW. However, in a well insulated house the space heating –at its peak—may require less than 8-10 kW. And in spring and autumn –in a moderate climate—the space heating requirement may on average be only 1 to 2 kW.

Especially for a house where space heating demand is in the same range as capacity needed for hot water heating (22 kW and upwards), there is an advantage of a combi-boiler over two single appliances if the combi-boiler is a storage device. In that case, after the hot water demand has been fulfilled the three way valve can switch to the space heating circuit and utilise any remaining heat in the water and heat exchanger. How much that gain really is, is difficult to say. We estimate an advantage of 3 to 5 %.

6.3 Boiler water temperature control

There are ways to overcome problems caused by the discrepancy between the capacity of the burner needed for heating and hot water production and the capacity required for solely heating. These solutions affect the feed temperature (or boiler water temperature).

The first is the modulating burner, which can regulate the burner capacity to at least 40% of nominal value. This is now becoming the standard for new houses. With a bit more expensive components on the part of the gas valve and boiler fan values of 30% modulation could be reached. And, in case of segmented burners, even 10-20% modulation is now possible. An interesting combination is a modulating burner with a 'modulating' (room) thermostat. The modulating thermostat 'senses' the difference between the set and actual room temperature and regulates burner modulation according this difference (the lower the difference, the more modulation occurs). This helps to prevent temperature overshoots.

Another way to prevent temperature overshoots is applying a weather-dependent boiler temperature control. This control type has already become the standard in some countries like Germany for a quite some time. This control tunes the boiler temperature to the outside temperature. E.g. in spring the boiler could run at a 30/50°C regime, whereas in winter it needs 40/60°C. This does avoid some of the temperature overshoot, but does little for the boiler malfunction.

The main gain of modulating and weather dependant systems is in heating comfort and avoiding boiler malfunction. And there is also a gain in energy efficiency on the fuel side. There are penalties on the part of the electricity consumption of the fan (35-40W) and the pump (60-80W, in a typical residential boiler) that now have to run non-stop during the whole heating system.

Whether these solutions actually represent an efficiency increase remains to be seen. In fact, from that point of view, it would probably be better to split water heating and space heating as before in two separate devices and dimension the space heating device according to need, despite the fact that there is some efficiency gain to be had from a combi.

6.4 Room temperature control

A well-controlled boiler water temperature does not automatically means, that the temperature in the different rooms of a dwelling is set correctly. Additional room controls are necessary, both for the incoming flow of the radiator and for the outgoing flow.

6.4.1 Incoming flow: Thermostatic valves versus radiator knobs

For heat emitters, like radiators and convectors, the incoming flow can be controlled through:

- a traditional radiator knob;
- a thermostatic valve (can be equipped with an automatic timer);
- no control at all.

The first is just a manual plug valve, controlling the incoming hot water flow. The second automatically regulates the incoming hot water flow on the basis of a temperature setting. Consumer associations reckon that the latter will save some 10% on total heating costs because over-heating of single rooms is avoided and - given the low extra costs of 30-40 Euro per valve - it is an economical investment. The third option can be seen on some CH systems, e.g. in Germany, where the radiators are meticulously dimensioned for the expected heat load and all temperature control takes place through the central boiler temperature. It goes without saying that for such systems even normal radiator knobs, operated when people are in a room, yield substantial savings.

6.4.2 Outgoing flow: Screw-type valves

Apart from a knob regulating the incoming flow, which is very visible for the consumer, there is also a simple screw-type valve preventing the hot water leaving the radiator. These valves control the efficiency of distribution of hot water when the valves (manual or thermostatic) are completely opened. Especially in larger buildings the exact and correct setting of these screw-type valves for the outgoing water can yield substantial savings of up to 10-20% especially when there are no thermostatic valves.

The rationale behind this saving is of course, that for proper operation small heat emitters and heat emitters closest to the heating boiler –i.e. receiving the highest temperature water—should be ‘squeezed’ the most, whereas larger heat emitters or heat emitters far away should be fully open. With traditional radiator knobs it is obvious that the closest room will be overheated, but also with thermostatic valves the boiler will run longer than absolutely necessary

General

Savings for room control systems are very hard to estimate. The main reason for this is that the savings largely depend on consumer behaviour. Basically the consumer can do everything an advanced electronic control system does. Like lowering the temperature at night, closing radiators in not used rooms etc. Especially for the lazy consumer or for the consumer who is not aware of the energetic consequences of his behaviour, advanced control systems can be a good help to save energy.

7 Dwelling Based Heating – Auxiliary energy

Note: The electrical efficiency is part of subtask 2.3. This report only contains some of the headlines, more detailed information can be found in the report on this subtask [8].

7.1 Introduction

This chapter deals with the often unnoticed auxiliary electricity use by electrical and electronic components in the central heating system. This electricity consumption can either be wholly attributed to the boiler itself, in case the circulator is integrated and controlled by the boiler, or to the total boiler room, in case the circulator, circulator controls and other electric / electronic equipment is separately installed and powered.

7.2 Circulators

A recent SAVE study deals with circulators. A common circulator in an individual boiler uses some 65 W. If the pump is integrated in and controlled by the boiler, the run time is limited to the times the boiler is running plus an after-run (for many western European countries some 2,000 - 3,000 hours a year). The most efficient circulator system is the high efficiency circulator with a permanent magnet motor, controlled by the boiler, that can use less than 100 kWh/year. The worst option is an uncontrolled, fixed speed pump that can use up to 500-600 kWh.

Hybrid heating systems with low temperature heating (hydronic floor and wall heating) and medium or high temperature heating (radiators) require extra circulators for the low temperature circuit.

Oil-fired burners require a pump for spraying the oil in the combustion chamber.

7.3 Fans

Any non-atmospheric boiler uses a fan. Average power is around 35 to 40 W. The fan runs only when the burner runs, therefore some 1000 to 2000 hours (35 to 70 kWh/year).

Some gas-fired local heaters may also be equipped with an flue gas fan, which allows for more flexible placing of the heater.

7.4 Electronic controls

The electronic controls that are common in every middle and top-range boiler use some 7 to 8 W continuously (standby and on-mode, 8760 h per year). This amounts to some 60-70 kWh/year. By analogy with other electronic controls it is estimated that this can be reduced to around 1 W in standby and 5-6 W in on-mode. Electricity consumption could therefore be reduced to one third or less.

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[8] See Report “T 2.3 - Electrical Efficiency of Gas and Oil- fired Heating Systems”, by M. Ohlson, April 2001.

8 Room based heating systems

Room based heating systems (or local heaters) are an attractive heating solution to some people, because they are cheap in terms of investment and flexible in a sense that little infrastructure in the house is required.

Traditionally, gas- or oil-fired local heaters are open, atmospheric devices i.e. taking combustion air from the room and using the chimney for flue gases. Alternatively, we are talking about electric resistance heaters, which can be just installed for comfort heating but in some cases make up a complete central heating system. And finally the most popular way to utilise solid fuels (wood, coal) in the house are woodstoves (built-in or free standing).

The efficiency of the traditional fossil fuel-fired local heaters is in the range of 50-70%. However, at present we also see high-efficiency --almost condensing—gas-fired local heaters on the market, also with closed systems and sometimes with electronic ignition instead of a pilot flame. More information on local heaters is provided for in Annex 3.

As far as the ranking is concerned, we can apply the same indexation as for backboilers and boilers in living areas (1 star efficiency = 80 + 2 log Pn, 1 star more for every 3% more).

9

Conclusions

9.1 Introduction

This Chapter brings together the results of Chapter 2 ("Performance") and Chapter 3-8 ("Heating Systems") by presenting a first draft of the ranking of heating systems. This ranking is based upon the establishment of comfort classes and energy efficiency of heating systems. Besides the ranking approach this chapter also contains an overview of the technical design options that could improve energy efficiency of heating systems.

9.2 First draft of a rating system.

A possible rating system of heating systems should comprise of at least the following steps:
1) Establishment of the comfort class of the heating system to be assessed;
2) Establishment of the energy efficiencies of the (components of the) heating system.

The comfort classes can be established by reference to the table 9.1 (also presented in Chapter 2).

Table 9.1: Comfort classes

Class	*Thermal Comfort*	*Type of heating/emitter/control system*
I	Low	Single (open) heat generator/emitter in only one habitable room of an non-insulated dwelling
II	Mediocre	Local heat generators/emitters in no more than only half of the habitable rooms of an average insulated dwelling.
III	Average	Heat emitter in every habitable room (several local heaters or a boiler with radiators/convectors with manual boiler temperature control and room thermostat) in a well insulated house
IV	Good	Heat emitter in every habitable room (several local heaters or a boiler with radiators/convectors with weather dependant temperature control and thermostatic valves, modulating burners) in a well insulated house
V	Excellent	Low temperature heat emitter in every habitable room (floor-, wall- heating or oversized radiators, with weather dependant temperature control and thermostatic valves, modulating burners) in a perfect insulated house

Then the energy efficiency of a heating system can be established according to the principle, illustrated below.

Efficiency Heating System:

$$\eta_{HS} = \eta_{gen \cdot an.} \cdot \eta_{distr} \cdot \eta_{emitt} \cdot \eta_{contr.}$$

Where,

$\eta_{gen \cdot an.}$ = Steady state efficiency (lhv) converted to annual efficiency (lhv) according to SEDBUK
η_{distr} = Multiplier related to distribution losses
η_{emitt} = Multiplier related to energy losses caused by the emitter system
η_{contt} = Multiplier related to energy losses caused by the control system

For the heating systems in the various thermal comfort classes, we can make some preliminary calculations based on this method.

Table 9.2: Total heating system efficiency (Note: multipliers based upon lower heating value)

Thermal Comfort Class	Heating system	$\eta_{genst.st}$ *(serves as input for* $\eta_{gen\cdot an}$	$\eta_{gen\cdot an}$	η_{distr}	η_{emitt}	η_{contr}	η_{hs}
I	One single ‘state-of-the-art’ gas-fired local heater in a dwelling	*0.8*	0.75	1	0.85	0.9	Prim. energy 0.57
	One single ‘old’ oil heater in a dwelling	*0.6*	0.5	1	0.85	0.85	Prim. energy 0.36
II	Two ‘state-of-the-art’ gas-fired local heaters in a dwelling	*0.8*	0.75	1	0.85	0.9	Prim. energy 0.57
	Two ‘old’ oil heater in a dwelling	*0.6*	0.5	1	0.85	0.85	Prim. energy 0.36
III	Central boiler, on/of burner control, on/of room thermostat with rad/conv. 70-90˚C in every habitable room,	*0.9*	0.85	0.90	0.9	0.9	Prim. energy 0.62
	Electric radiators/convectors with thermostat in every habitable room, controlled with central on/off room thermostat	*0.95*	0.95	1	0.9	0.9	El. energy 0.77
IV	Central condensing boiler, modulating burner control, weather dependent boilertemp. control, rad/conv with thermostatic valve in every habitable room,	*1.07*	1.0	0.90	0.90	0.95	Prim. energy 0.77
V	Central gas heatpump, weather dependent boilertemp. control, floor heating with thermostatic valves with clock program in every habitable room,	*1.40*	1.30	0.95	1	0.98	Prim. energy 1.21
	Electric Floor Heating with clock-thermostats in every habitable room.	*0.95*	0.95	1	1	0.98	El. energy 0.93

Note that, although the overall efficiency figure of a heating system in thermal comfort class I is lower than the figures in comfort class III, the actual energy consumption of a class-I heating system can very well be lower than the class-III heating system. The class I system only heats up a part of the dwelling; the class II system heats up the whole house.

Also note that the auxiliary power consumption is not included in this overall efficiency figure. It will be added separately with its specific conversion factor later on in the stock-model.

9.3 Overview of design options

The table below is a preliminary summary of the design options discussed in the attached annexes. Note that the savings indicated cannot be added up.

Table 9.3: Overview design options - dwelling based heating systems

				Efficiency on lhv	Indication on savings
Dwelling Based Heating System (Central Hydronic Heating System)					
	Design options related to generator				
		Improve steady state efficiency			
			- Conventional boiler (gas/oil)	85%	*Reference*
			- Improved efficiency boilers (gas/oil)	90%	6%
			- Condensing boilers (gas/oil)	107%	26%
			- Gas fired heatpump with additional condensing boiler	140%	65%
			- Electric heat pump (efficiency based on primary energy)	140%	65%
		Reduce standing losses			
			- Replacement pilot flame by electronic ignition		$< 550\ \mathrm{kWh_{pr}/yr}$
			- Storage heaters (coal & wood) : Improve insulation		$< 350\ \mathrm{kWh_{pr}/yr}$
			- : Install flue damper		$< 350\ \mathrm{kWh_{pr}/yr}$
		Reduce start/stop losses			
			- Improve appliance insulation		$< 200\ \mathrm{kWh_{pr}/yr}$
			- Install flue damper		$< 300\ \mathrm{kWh_{pr}/yr}$
			- Reduce heat capacity of generator (important for on/of burners)		$< 400\ \mathrm{kWh_{pr}/yr}$
		Reduce auxiliary power consumption			
			- Use pump with permanent magnet motor, controlled by the boiler (also relevant for sub-systems such as floor heating)		$< 400\ \mathrm{kWh_{pr}/yr}$
			- Reduce stand-by power consumption		$< 40\ \mathrm{kWh_{pr}/yr}$
		Improve generator control (boiler water temperature)			
			- Boiler water temp. controlled by max. thermostat in boiler (90˚C), combined with conventional on/of room thermostat		*Reference*
			- Modulating burner control		<5%
			- Boiler water temp. weather controlled (or controlled by modulating room thermostat)		<3%
	Design options related to distribution system				
			- No insulation of pipes / 90-70 temp. regime		*Reference*
			- Insulation distribution pipes		...
			- Hydraulically evened out system (“Ausgleichen”)		...
	Design options related to emitter system				
			- High temperature / small surface emitter (>90˚C)		*Reference*
			- Average temperature / small surface emitter (90-70˚C)		<5%
			- Low temperature / large surface radiators (30 – 50˚C)		<10%
	Design options related to control system (room temperature)				
			- Clock room thermostat (for modulating room thermostat - see above)		<5%
			- Thermostatic radiator valves		<3%
			- Behavioural Feed Back Control Unit combined with Room Thermostat		<10%

Table 9.4: Overview design options - room based heating systems

Room Based Heating System (local heating)				efficiency	Indication on savings
	Design options related to heat generator-part				
		Gas / oil fired local heaters		*75%*	*Reference*
			- Improved efficiency	90%	20%
			- Condensing heaters (provision for condensate necessary)	100%	33%
			- Modulating burner		<5%
			- Clock thermostat		<5%
			- Electronic ignition		450 kWh_{prim}
		Electric local heaters			
			- Reduction of auxiliary energy use (use efficient fans / motors)		--%
	Design options related to emitter-part				
			- Enhance emitter surface / decrease temperature		--%
	Design options related to controls				

Table 9.5: Overview design options - block and district heating systems

Block and District Heating Systems				efficiency	Indication on savings.
	Design options related to heat generator-part				
		Block / district heating generators			
			Steady state efficiency conventional	*75%*	*reference*
			- Improved efficiency	90%	20%
			- Condensing heaters (provision for condensate necessary)	100%	33%
			- CHP (40/40)	110%	35%
			- waste heat (heat from existing plant, for ‘new’ see CHP)	Total: 100% + ref.	233%
	Design options related to heat generator controls				
			- Modulating burners		<5%
			- Boilers in cascade		<5%
	Design options related to distribution / emitter-part				
		Block resp. District Heating		*85% resp. 75%*	*reference*
			- Decrease grid temperature (from 90/70 to 55/40)		20%
			- Heat exchanger in habitable room (provisions for noise)		PM
	Design options related to controls				
			- Clock thermostat		5%
	Design options related to auxiliary energy use				
			- Use efficient circulators (self-controlled)		35% of electrical pump energy

List of sources

Gas- / oil boilers

product brochures

- ACV
- Atag
- Beretta
- Bomat
- Brötje Heizung
- Buderus, Nefit- (inc. gas heat pump)
- CTC (heat pumps, solid fuel boilers)
- Ferroli, Agpo-
- Fontecal
- Geminox
- Giwatec
- Hydrotherm
- Immergas
- Intergas
- Joannes
- Junkers-Bosch
- Remeha
- Rotex
- Sieger
- Sime
- Vaillant
- Viessmann
- Weishaupt

CHP, district / collective heating

product brochures

- MDE Dezentrale Energiesysteme
- Omnical - Borsig Energy

reports

- State-of-the-art mini- and micro-CHP, VHK, Delft, December 1999.
- Bussel, ir. F. van, Warmtedistributie - basisgegevens, Novem, 1996.
- Energie-efficiënte warmtevoorziening voor nieuwbouwwijk, Novem, 1997.
- Technische aanlsuitvoorwaarden voor levering van warmte, NUON, March 1996.

Local heating

product brochures

- AWB (gas)
- DRU (gas)
- Etna (gas)
- Gutbrod Keramik (ceramic tiles woodstove)
- Juno (gas)
- Seppelfricke (gas)
- Tekon (wood)
- Tulikivi (soapstone)
- Zehendner (ceramic tiles woodstove)

websites

- www.sfeerverwarming.nl
- www.brwalphen.nl
- www.altech-nedar.nl
- www.burley.co.uk
- www.drufire.com
- www.faber.nl

Electric heating / Air heating

product brochures

- Blomberg (el. heat pump)
- Campa Chauffage Electrique
- CTC (el. heat pump)
- Dimplex Air Comfort
- Emco Klima Gmbh
- Stiebel Eltron (el. heat pump)
- Vaillant
- Wölfle

Radiators

product brochures

- Arbonia
- Brugman Radiatoren
- Thermic

Low-temperature heating

product brochures

- BEST Heiz-Kühlelemente HKE
- Purmo Fussbodenheizung

reports

- Lage temperatuursystemen - méér comfort met minder energie, Novem, 1998.

Heating - general

reports

- Blok, C., Economic evaluation of Carbon Dioxide Emission Reduction [...] in the EU, Ecofys for EC DG ENV, January 2001.
- Actualiseren Referentiewoningen, DHV, May 1998.
- EP Variantenboek woningbouw, Novem, March 1996.
- Energieprestaties in de woningbouw, Novem May 1996.

- EPC=1,0 en lager in de woningbouw, Novem June 1997.
- Deinum, H., Meer comfort met minder energie, Delfzijl, November 2000.
- TNO-MEP, energy losses of ch-boilers, 2000

websites

- www2.novem.nl/epn (measures)
- www.homeenergy.org (archives)

norms / standards

- NEN5128 (Energy performance of dwellings), NNI, 1st issue September 1994, revised in 1998.
- NEN 5129 (Calculation program), NNI, March 1995.

ANNEXES

Annex 1 - Heating Systems
Annex 2 - Central Heating
Annex 3 - Local Heating
Annex 4 - Block and District Heating

ANNEX

1 Heating systems

1.1 Introduction

The primary energy consumption of space heating is not only determined by the type of heat generator and its efficiency. Other important influencing factors are the thermal properties of the house itself, the installation parameters (distribution system, emitter systems, controls, etc.), the energy source that is used (gas, electricity, oil, coal, wood, etc.) and, last but most certainly not least, the behaviour of the consumer. Especially these system- and behavioural- parameters are important energy-related issues, that need to be well understood before appliance related efficiency improvements can be proposed. In a brief introduction, the next paragraphs will give information on heating demand, the heating supply system and how they interact.

1.2 Heating Demand

The heating system has to be designed to meet the specifications and heating demands of the users of the dwelling. There are two main determining factors and several sub-factors that determine heating demand:

1) Thermal properties:
    a) heat loss:
        i) transmission losses - insulation, thermal bridging, mass, etc. (a/o. age of buildings, construction);
        ii) ventilation losses (ventilation rates, controls, heat recovery, fresh air / redistributed air);
        iii) surface area losses - type and size of building construction (apartment, free standing, etc.);
    b) heat gain:
        i) solar heat gain (window aperture, orientation of building)
        ii) internal heat gain (heat emitted by persons, appliances, etc.)
2) Behavioural aspects (comfort aspects):
    a) desired temperature(s) (in what room, at what time);
    b) number of rooms heated (living room(s), kitchen, hallway, sleeping rooms, bathroom, study, etc.);
    c) waiting time needed to heat up the house;
    d) acceptable temperature fluctuations;
    e) acceptable air-flow (draught);
    f) amount of radiation heat.

Consumer behaviour like keeping doors and windows open for an unnecessary long time, may have also a considerable negative effect on heating demand.

The graphs on the following page present a split up of heating demand according heat loss and heat gain factors.

Figure 1.1a: Heat demand

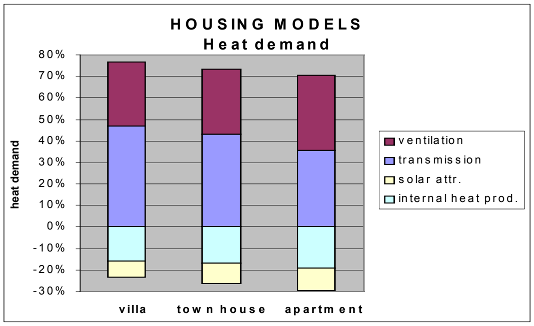
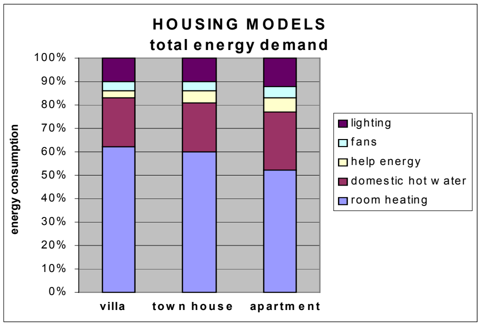


Figure 1.1b. Total energy demand



Note: The percentage shown here is that of the total energy demand of the house.

What we can see from these graphs is that about half of the heat demand is due to transmission losses and about one-third is due to ventilation losses. The apartment shows large losses due to ventilation; because other apartments surround the apartment, the transmission losses are lower of course.

In the next table and figures some examples are given for three common types of dwellings[9]. All dwellings have comparable energy performance (EP).

Table 1.1: Heat demand common dwellings

	villa (free standing)		**town house (in row)**		**apartment**	
	GJ	*%*	*GJ*	*%*	*GJ*	*%*
total heat loss	79	78	45	79	32	76
- transmission	48	48	27	46	16	39
- ventilation	30	30	18	32	16	38
total heat gain	25	25	16	28	13	32
- solar attr.	8	8	6	10	5	11
- internal heat prod.	17	16	10	18	9	21
heat demand	54	53	29	51	19	45
heated floor area	150 m^2		92 m^2		78 m^2	
surface area loss	360 m^2		180 m^2		79 m^2	
Energy Performance	1,39		1,35		1,35	

To get an idea of the effect of better insulation, better air tightness, and ventilation with heat recovery on the heat demand, an example is given for the town house. The standard house has an EP around 1.3; the improved house around 1. The net heat demand for the standard house is 29 GJ (51% of the total energy demand); for the improved house 14 GJ (32% of the total energy demand).

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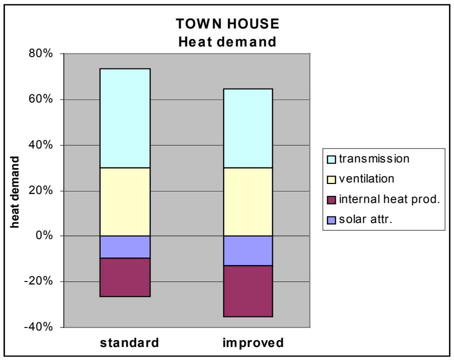
[9] Based on: “EP-berekeningen 3 woningmodellen” Novem 1996

Figure 1.2: heat demand improved town house



Note: The percentage shown here is that of the total energy demand of the house.

The next table shows the effect the age of the house on the energy consumption for heating.

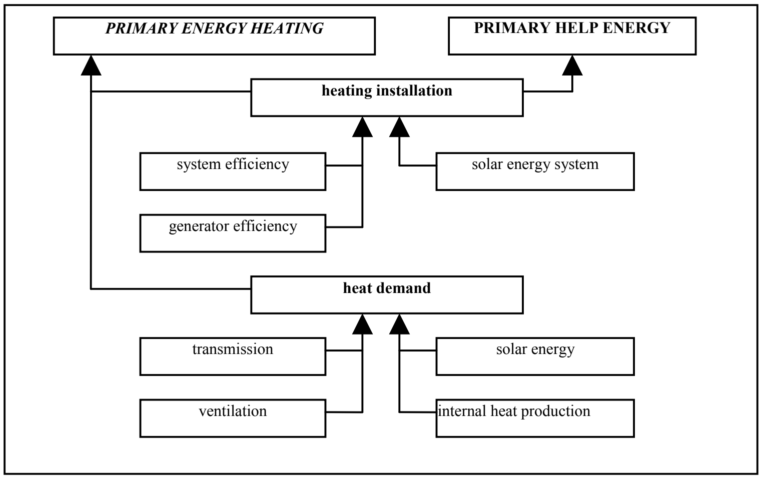
Table 1.2: Natural gas consumption space heating (in m³)

	villa (free standing)	town house (in row)	apartment	total
before 1945	2555	1610	1660	2035
1945 to 1981	2775	1515	1045	1750
1982 and later	1870	1080	710	1225
total	2475	1430	1050	1660

Source: BAK 1997; 1660 m³ is the average natural gas consumption for all Dutch houses in 1996.

The primary energy consumption for heating is based on the efficiency of the heating system and on the heat demand of the house. The EPN[10] gives a good basis to explain the amount of primary energy that is used for heating. The EPN calculation uses a calculation method, which is explained in figure 1.3.

Figure 1.3: EPN calculation method



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[10] The EPN (Energie Prestatie Norm (=Energy Performance Standard)) incorporates a calculation method for the energy consumption in houses for a/o. space and water heating, ventilation lighting etc. The EPN is used in the Netherlands to set a minimum efficiency standard for new houses.

1.3 Heating supply systems

The resulting heat demand has to be met by the heating supply system, or simply: the heating system. The heating system is defined as the aggregate of:

1. heat generator (including energy source and);
2. distribution system;
3. emitter system;
4. control system;
5. auxiliary energy use (auxiliary energy is treated as a separate item, since important components like circulators do not necessarily form part of the heat generator).

1.3.1 Heat generators

Categorisation of heat generators usually is based upon energy source and application (local or central). For the purpose of this study the product group "heating systems" is limited to installed products only. Portable products are excluded from this technical study (the purpose of this study is not to enable labelling of electric blankets).

Table 1.3: Overview of heat generators per fuel type, per application (local / central heating)

	Local Heating	**Central Heating**
Energy source	**Type of heat generator**	**Type of heat generator**
Direct		
Gaseous (natural gas, propane/butane, LPG)	- stove, heater	- back-boiler - boiler (combined, conv. / impr. / condensing) - gas-fired heat pump boiler - (micro-)CHP
Liquid (oil, petroleum)	- stove, heater	- boiler (conv.. / impr. / condensing)
Solid (wood, peat, pellets, coal)	- stove, heater	- boiler (storage / combined)
Indirect		
Electric	- portable heater (blowers, radiant panels) - installed heaters (radiator/convectors, floor heating, reversible room air conditioners, electrically heated glass)	- electric storage boiler - electric heat pump boiler (similar to reversible room air conditioner)
Heat	- N/A.	- Block- / District heating: central boiler plant / (mini) CHP-plant or waste heat from utility or industry - possibly in combination with heat pumps (electric or gas-fired)
Renewable energy		- only in combination with boilers

Definitions:

- Local heating: the heat generator supplies only one room with heat;
- Central heating: the heat generator supplies two or more rooms with heat, this implies the use of a 'heat' distribution and emitter system;
- Stove: a heat generator of the 'open' type in a local heating system
- Heater: a heat generator of the 'closed' type in a local heating system
- Boiler: a heat generator in a central heating system

In some heating systems generator, and emitter are integrated (e.g. local gas heaters, most electric heaters). There are also appliances available that use combined energy sources e.g. the heat pump (an electric heat pump uses electricity from the grid and for instance recovered heat from ventilation air as energy sources).

A way to refine this overview is by introducing a sub-categorisation according generator efficiency: In this way gas boilers can be subdivided into conventional, improved efficiency and condensing. A similar approach is possible for other direct fuelled heat generators and some electric heat generators.

The efficiency of the total heating system depends on the efficiency of the heat generator and on the efficiency of the distribution system (type of system (local, central, air/hydronic, individual/collective, etc)). In case of a solar system the efficiency of the solar system is considered too. Except for primary energy for heating (in most cases gas) also the (electric) help energy for pump, fan and controls should be incorporated in the calculation of system efficiency, but this is however not standard procedure.

In the table below the typical efficiency for a number of heat generators is given. Efficiencies and savings given here have to be handled with some care but might sketch the broad outlines.

Table 1.4: Typical heating system efficiencies and energy savings

Energy source	**Technology**	**Seasonal efficiency AFUE** *(in %)*	**Energy savings** *(% of base)*
Natural gas	conventional	60	base
	vent damper with non continuous pilot light	62-67	3-10
	mid-efficiency	78-84	23-28
	high efficiency condensing furnace	89-96	33-38
	integrated condensing space/tap water	89-96	33-38
Propane	conventional	62	base
	vent damper with non continuous pilot light	64-69	3-10
	mid-efficiency	79-85	21-27
	condensing	87-94	29-34
Electricity	electric baseboards	100	
	electric furnace or boiler	100	
	air-source heat pump	150	
	earth-energy system (ground-source heat pump)	260	
Oil	cast-iron head burner (old furnace)	60	base
	flame retention head replacement burner	70-78	14-23
	high static replacement burner	74-82	19-27
	new standard furnace	78-86	23-30
	mid-efficiency	83-89	28-33
	condensing furnace	85-95	29-37
	integrated space/tap water	83-89	28-33
Wood	central furnace	45-55	
	conventional stove (properly located)	55-65	
	high-tech stove (properly located)	65-80	
	advanced combustion fireplace	50-70	

Source: Home energy magazine online March/April 1996

The nature and the amount of the energy losses can be quite different for the various appliance categories. In Annex 2 the various types of energy losses are roughly described. These losses are applicable to both heat generators in central and local heating systems. In general, energy losses in heating appliances are caused by:

a. Energy losses in the steady-state heat exchange process;
b. Standing losses;
c. Start/stop losses;
d. Unnecessary standby electricity consumption;
e. Excessive auxiliary power consumption.

1.3.2 Distribution and emitter system

The distribution system is tightly linked to the emitter system and sometimes the difference is almost invisible (e.g. floor and wall heating). The main differences lie in the medium for heat transport: Air or water (“hydronic systems”). The efficiency of the distribution system is mainly determined by unintended heat loss and energy needed for circulation of the heat transport medium (e.g. pump energy for hydronic systems).

The emitter system transfers the heat from the transport medium to the users (the residents of the dwelling). The distribution system (air or water) also determines the type of emitters (nozzles in case of air heating, or heated surfaces in case of hydronic systems). Heat transfer however always takes place through fixed physical mechanisms: convection, radiation or both. Heat transfer through conduction is rarely seen (not practical)
Local heat generators do not necessarily have air or hydronic distribution systems but do use the same heat transfer mechanisms, based upon the same principles (heat transfer through radiation, convention or combined).

Emitter systems (‘product category’	- mode of heat transfer):
1) hydronic ‘convectors’	- convection
2) hydronic ‘radiators’	- convection / radiation
3) hydronic ‘wall/floor heating’	- radiation
4) air ‘nozzle’	- convection
5) electric radiators (‘air’)	- convection
6) electric radiators (‘immersion’)	- convection / radiation
7) electric radiators (‘lamp’)	- radiation

Annex 2 describes distribution and emitters systems

1.3.3 Controls

Control systems control the room temperature which is tightly linked to the boiler temperature, depending on the type of installation.

1) central control:
    a) room thermostat;
    b) outside temperature sensor (“weather dependent”);
2) local control (on room emitters - radiator or local heater):
    a) manually operated;
    b) thermostatically operated.

The efficiency of the control system is determined by:

1) temperature overshoot (capacity of heat generator and emitter system);
2) heating without people present;
3) night-time duty;
4) relation to outside temperature;
5) on/off versus modulating;

Controls are described in more detail in Annex 2.

1.3.4 Auxiliary energy consumption

Auxiliary energy consumption (by circulation pumps, fans and electronic -boiler- control) is described in more detail in Annex 2.

ANNEX

2 Dwelling based heating systems

This Annex describes the components of dwelling based heating systems and their design options. The components are: heat generators, distribution and emitter systems and control systems. Auxiliary electricity consumption is also an important issue for central heating systems and is discussed in chapter 2.4.

2.1 Heat generators

2.1.1 System description

There are numerous types of heating appliances on the market. In order to be able to say something about the technical saving potential of the different appliances, it is necessary to make some kind of categorisation. This chapter gives a general introduction on the types and energy losses of heat generators.

Figure 2.1: Categorisation of heat generators dwelling based heating systems

CENTRAL HEATING BOILERS

1. FUNCTION

• space heating	• boiler
• space heating / domestic hot water	• instantaneous combi-boiler • storage combi-boiler
• space heating / domestic hot water / solar energy	• solar storage combi-boiler

2. FUEL TYPE

- gaseous (natural gas / LPG), liquid (oil), solid (wood, pellets, peat) and electric

3. EFFICIENCY

- conventional / improved / condensing /

4. BURNER CONTROL SYSTEM

• on/off	
• modulating	• based on Tsend • based on dTsend/return • based on dTset /actual room thermostat • based on Toutside • based on slow increase power

5. FLUE SYSTEM

- open (from the boiler room (atmospheric)) / closed (from outside (fanned or balanced flue))

6. FAN SYSTEM

• natural venting (no fan)	
• forced air (with fan)	• fan in air inlet • fan in air outlet

7. TYPE OF IGNITION

- pilot flame / electronic ignition / hand ignition

8. ROOM TEMPERATURE CONTROL SYSTEM

• local/individual	
• central (room thermostat)	• on/off • modulating
• weather dependant	

9. PLACEMENT

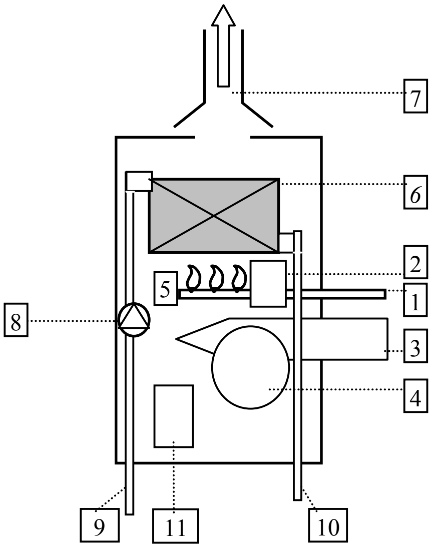
- wall hanging / floor standing

Dwelling based heating systems based upon electric heaters will be covered in Annex 3 “Room based heating systems”. The technical characteristics of these heaters are identical for both dwelling and room based heating. The difference lies in the way the heaters are controlled: centrally or locally. See Annex 3 for more information.

Gas- fired boilers

Most common (and showing increasing sales) are natural gas based boilers. In general, the same technologies apply to LPG (propane) as to natural gas, with slight differences in efficiencies. Propane has a lower hydrogen level than natural gas. About 3% less energy is tied up in the form of latent heat. This is compensated by the fact that condensation is more difficult with propane.

Figure 2.1 gives a schematic reproduction of a gas boiler.



1. Gas supply
2. Gas valve
3. Combustion air
4. Fan
5. Burner
6. Heat exchanger
7. Flue gas exhaust
8. Pump
9. Return CH-system
10. Supply CH-system
11. Control system

Figure 2.1: Principle CH-boiler

The major technical components are:

- Gas valve;
- Fan;
- Burner;
- Heat exchanger;
- Pump (for floor standing type boilers often a separate component);
- Control system.

All burner types can be applied: atmospheric, ventilation and pre-mix. For atmospheric burners, the combustion air comes from the boiler room. Forced ventilation burners are often applied with an air inlet originating from outside of the dwelling. Modern pre-mix burners may have constant gas/air-ratio control. For burner ignition both a pilot flame (atmospheric burners) or electronic ignition (all types of burners) may be used. All boilers use auxiliary electric power (pump, controls, fan). The load ranges from 11 kW up to 40 kW and more.

The most distinctive parameter is the function of the heat generator. In its most simple form the heat generator is used for space heating. In case the heat generator is also used for heating domestic hot water we will use the term “combi”. In the next paragraph an explanation is given of the technical principle.

Combi’s:

Gas fired Combi Instantaneous Water Heaters (‘combi’s’) are appliances that generate heat for two functions: space heating and domestic hot water production. The water heater function can be realised with different kinds of heat exchangers:

A. a water-to-water (plate) heat-exchanger (in which central heating water heats the tap water);
B. a small storage tank with a spiral shaped water containing pipe;
C. an air-to-water heat exchanger, integrated in the air-to-water heat-exchanger for the boiler function.

In the first two types the central heating fluid (water) is used as an intermediate. First the central heating (ch-) water is heated by the burner in the primary heat-exchanger; then the sanitary water is heated by the ch-water in a secondary heat-exchanger. In the last type of combi (C), the sanitary water is directly heated by the burner in the primary heat exchanger (see also figure 4.3).

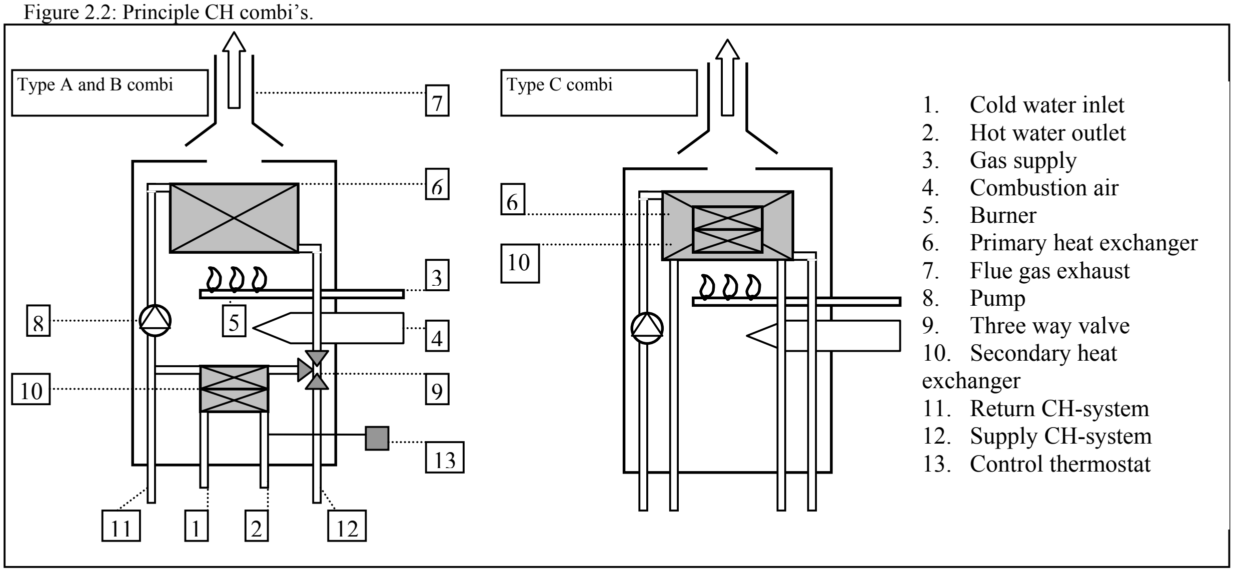
A and B- type combi’s:

When sanitary hot water is required the three-way valve opens the by-pass to the secondary heat exchanger and the burner is ignited. The water of the heating system is heated in the primary heat exchanger and flowing through the secondary heat exchanger. At the end of the tapping period, the valve closes the by-pass and opens the heating circuit again. The burner is turned off. The “A”-type combi’s are equipped with a modulating burner, in which the gas supply is diminished if the water flow is below a nominal level (using pressure difference of temperature control). The “B”-type combi’s may use both on/off-burners and modulating burners.

C-type combi’s:

In the integrated heat exchanger both the water of the heating system and the sanitary hot water are heated. When sanitary hot water is required the heating system pump is turned off and the burner is turned on. At the end of the tapping the boiler pump is released and the burner is turned off again.

Figure 2.2: Principle CH combi’s.



Oil-fired boilers

An oil-fired boiler is similar to a natural gas heating appliance, but the dilution device is a barometric damper. This is a plate that acts as a valve on the side of the flue pipe. The damper isolates the burner from changes in pressure at the chimney exit. The burner typically is a high-pressure gun type with a blower fan to help mixing the oil and air for a good combustion. Replacing the conventional cast-iron head burner with a flame retention head burner will save 10 - 15%, improving efficiency from 60 to 70-75%. Non condensing (improved or mid-efficiency) systems use a high-static retention burner and often an improved low-mass combustion chamber (usually ceramic fibre) combined with a superior heat exchanger. The barometric damper is often eliminated. Efficiencies of improved efficiency oil heat generators are between 85 and 89%. Oil produces only half the water vapour of gas. The condensate is also much more aggressive. Condensing systems are therefore expensive and not popular.

Brands and Manufacturers

Germany:
- Vaillant,
- Schaefer
- Blomberg Vertriebgesellschaft GmbH
- Weishaupt
- Viessmann
- Hydro Therm GmbH
- Junkers
- Buderus

Italy:
- Immergas S.p.A
- Ariston MTS S.p.A.
- Gruppo Imar S.p.A.
- Ecoflam S.p.A.
- Savio Caldaie S.p.A.
- Ocean Idroclima S.p.A.

France:
- Geminox SA

UK:
- Baxi
- Caradon PLC

Netherlands:
- ATAG
- AWB
- Intergas
- Nefit Fasto
- Remeha

Gas heat pump
large scale:
- Climaventa (compressor)
- AWT (absorption)
- York Triathlon (compression)
- Sanyo (absorption)

Household scale:
- Nefit (absorption)

Efficiency losses

Table 2.2. Lists the various kinds of losses for nine different boiler types.

Table 2.2: Boiler losses

Major specifications	Efficiency *(%)*	Jacket loss *(W/K)*	Draught loss *(W/K)*	Flue gas loss *(W/K)*	Total losses *(W/K)*
1. non condensing forced draught burner no fan open air supply on/off burner	91	1,34	1,1	8,09	10,5
2. non condensing atmospheric burner no fan open air supply on/off burner	81	2,99	0,36	7,02	10,4
3. condensing atmospheric burner fan assisted open air supply on/off burner	102	2,59	1,9	5,85	10,3

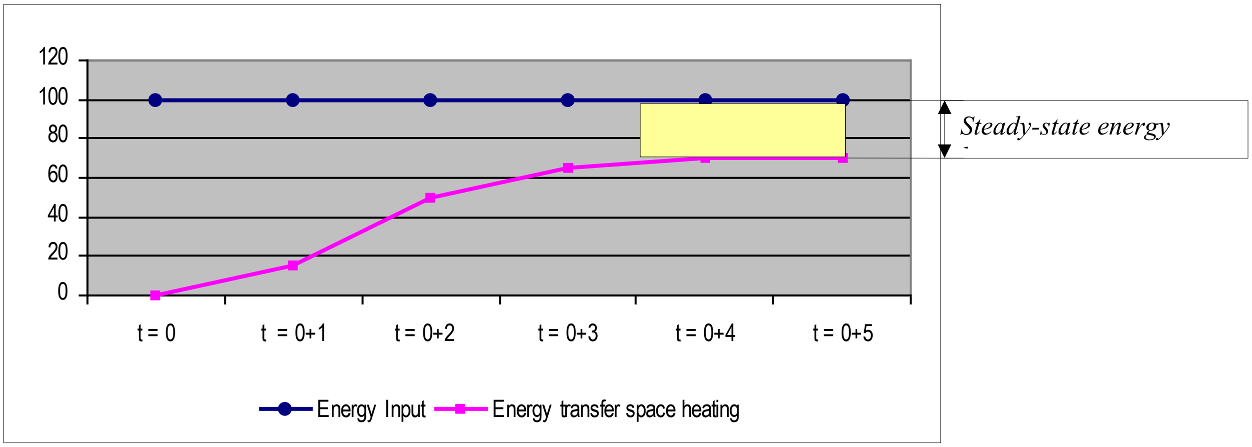
Major specifications	Efficiency (%)	Jacket loss (W/K)	Draught loss (W/K)	Flue gas loss (W/K)	Total losses (W/K)
4. non condensing atmospheric burner fan assisted open air supply on/off burner	88	2,04	0,53	3,96	6,53
5. non condensing atmospheric burner no fan open air supply on/off burner	84	1,72	0,67	4,43	6,82
6. non condensing atmospheric burner fan assisted closed air supply on/off burner	91	1,27	1,08	3,31	5,66
7. condensing atmospheric burner fan assisted closed air supply on/off burner control	97	1,94	1,36	7,57	10,87
8. condensing atmospheric burner fan assisted closed air supply modulating burner	97	1,2	1,11	3,63	5,94
9. condensing burner? fan assisted air supply? on/off burner	103	1,65	1,17	4,24	7,06

Source: TNO-MEP

Energy losses in the steady-state heat exchange process

Every heating appliance is designed to transfer heat from an energy source to the space. After a certain period of time, a heating appliance in operation reaches a point, where the fraction of input energy that is transferred, remains constant. This is the point were the mass of the involved heater components (pipes, heat exchanger, pump, jacket, control, etc.) has reached the operating temperature, and the heat exchanger reaches its maximal efficiency. Unfortunately this fraction is in most cases much lower than the ideal figure of 100%. Depending on the efficiency of the heat exchanger itself, the heat losses through flue ducts and the radiation- and convection- losses of the appliance, these steady-state energy losses can vary from approximately 5% to in worst cases 40 – 50%.

Figure 2.3: Graph Steady-state energy losses



Minimising steady state efficiency losses

Important parameters:

- water temperature;
- water amount;
- heat exchanger efficiency;
- heat conductivity;
- heat capacity;
- emission coefficient;
- insulation;
- heat traps;
- flue duct construction.

Standing losses

Standing losses refer to the heat losses that occur when the heating appliance is not used. Standing losses are caused by the fact that heating appliance transfers heat to its surroundings through convection and radiation. Since space heating appliances in general do not incorporate heat storage (e.g. combi and solar boilers excluded) standing losses are little. Another type of standing losses is caused be the ‘pilot flame’. Some heating appliances use pilot flames for the ignition of the burner. These pilot flames continuously consume energy.

Minimising standing losses

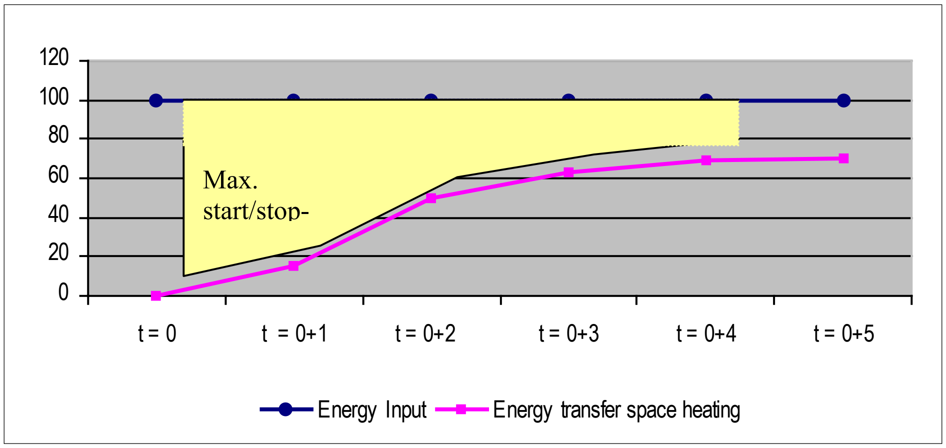
Important parameters:

- ignition system;
- pump control;
- insulation;
- flue duct construction.

Start/stop losses

Start/stop losses are the losses that are caused by the heating up and cooling down of the involved appliance-components. Before the “steady-state” in heat transfer is reached, various components are heated up. Depending on the type of appliance this can be components like pipes, fittings, heat-exchanger, flue ducts, pump, valves, fan, jacket, etc. The heat-capacity of these components/materials determine how much energy will be absorbed, before the steady-state situation is reached. The quality of the insulation determines the speed with which this absorbed heat can be lost through convection and radiation. Gas fired boilers may have increased start/stop losses, when flue-ducts are used without any heat-block provisions. The flue-duct then works as a chimney.

Figure 2.4. Graph start/stop energy losses



In the graph above the start/stop-losses are illustrated. If the time between two heating periods is long enough to cool down the heating system and its components, than the indicated area really is the amount of energy that is lost. If heating periods are done with short intervals, only a fraction of the accumulated heat will be lost. The appliance is still warm when the next heating period starts. The actual start/stop losses will therefore depend upon:

- the heat-capacity (the max. amount of heat that can be stored in the heating system during a heating period),
- the daily/yearly heating pattern (the real amount of heat that is stored in the heating system).
- the insulation (the *speed* with which the heated appliance cools down when it is not used); (note that there might be an adverse effect here because of the heat-capacity of the insulation)

Start/stop losses can be minimised by optimising the insulation (jacket, heat traps in pipes and flue ducts) and/or by minimising the heat capacity of the appliance (weight & specific heat of the material used).

Minimising start/stop losses

- water temperature;
- water amount;
- heat exchanger efficiency;
- heat conductivity;
- heat capacity;
- weight;
- emission coefficient;
- insulation;
- heat traps;
- flue duct construction

Burner system efficiency (modulating burners)

The burner system does not only concern the burner itself, also the gas and air supply (gas valve and fan), the mixing of the two and the burner (gas valve and fan) control are important matters. One of the most interesting issues is the use of modulating burners. This design option will be the main subject of this chapter.

In earlier years, CH-boilers were equipped with on/off type burner control. Burners of on/off heating systems have only two settings “off” or “full power”. The last decade the burner control system has gone through quite some developments. Starting with multi-stage type controls, nowadays continuous burner control systems (modulating burner control) tends to become the standard.

The major advantage of modulating systems is that the power can be adjusted to the desired send temperature. The consequence is less temperature fluctuation of the CH-water and therefore less fluctuation in air temperature in the house. Besides the comfort aspect there are also energetic advantages:

- a modulating system burns longer on low power. There will be less overshoot (less water temperature fluctuations). Moreover there will be less methane-slip (during start-up not all the gas will immediately ignite);
- the return water temperature will be lower as well. This improves condensation of flue gasses and will therefore improve efficiency;
- There will be less losses during start-up (for heating up the boiler).

The “optimal” burner power can be based on:

- CH (send) water temperature;
- difference between CH send and return water temperature;
- slow increase of burner temperature;
- difference between set and actual temperature of room thermostat (it is necessary to have communication between room thermostat and boiler e.g. with OpenTherm);
- outside temperature sensor (weather dependent control system).

In most cases a combination of these techniques is used.

Two air/gas control systems can be distinguished:

1. Only the gas flow is changed:

A disadvantage of this system is that the amount of air is always the same. Due to the drop of the CO_2 percentage, the dew point temperature of the flue gasses goes down and there will be less condensation. As a consequence the efficiency is lower at lower power (the minimum modulation rate is limited to 40% of the maximum power). For this reason this principle is seldom used in HR-boilers.

2. Both the gas and the airflow are changed:

The fan speed is adjusted to the desired burner power; a pneumatic connection from fan to gas-valve controls the gas flow. With this type of control the efficiency improves at lower power. Typically the minimum modulation rate for this kind of systems is limited to 30%; the market best systems reach modulation rates between 20 and 17%. To reach even lower rates (10%) larger non-domestic boilers use segmented burners.

Low modulation rates are especially important for Combi boilers. For domestic hot water heating a relatively high maximum power is needed up to 24 to 30 kW. The minimum power with a modulation rate of 30% is still 7 to 9 kW. For space heating in modern well-insulated houses, a power of 10 kW during cold winter days suffices. During 90% in the heating season a maximum of 5 kW is needed. During spring and autumn 2 to 3 kW are plenty.

Heat exchanger efficiency and losses

In the past cast iron was a frequently used material for heat exchangers. Nowadays Aluminium and stainless steel are the common materials. Both materials show good qualities to withstand the aggressive condense in HR boilers. Especially aluminium has some clear advantages concerning energy efficiency and is becoming the most popular heat exchanger material.

Aluminium shows good heat conductivity (7 times higher than stainless steel). Aluminium heat exchangers can therefore be very compact and lightweight. A compact heat exchanger also means less water content. As long as the control strategy of the boiler is able to prevent overheating of the system, e.g. when all radiators are closed, a boiler with a very low heat capacity can be designed. Furthermore Aluminium has a low emission coefficient and therefore low radiation losses.

The most important parameters for the energy efficiency of the CH-boiler are the start/stop-losses, the steady-state efficiency, and the auxiliary power consumption.

Heat pump (electric and gas-fired absorption)

As an alternative for gas fired boilers as heat generator there are several new technologies which might become of great interest in the next decade(s). One of these technologies is the heat pump. Electric heat pumps are already available on the market. What is especially interesting is the development of gas fired heat pumps.

A heat pump is a device that extracts heat from one place and transfers this to another. The technique is basically the same as that of a refrigerator but in this case it is the heat we are after and not the cold. The electric heat pump transfers the heat by circulating a refrigerant through a cycle of alternating evaporation and condensation. A compressor pumps the refrigerant between two heat exchanger coils. In one coil the refrigerant is evaporated at low pressure and absorbs heat (at a relatively low temperature level) from its surroundings. The refrigerant is than compressed and routed to the other coil, where it condenses at high pressure. At this point, it releases the heat (at a relatively high temperature level) it absorbed earlier in the cycle. The use of a compressor implies the use of electricity to drive the system.

More promising is the use a gas fired absorption cycle. The main advantages are: no moving parts, no sound and less critical/lower demand for heat source (2.5 x less). The gas-fired heat pump is essentially an up-scaled version of a (reversed) gas-fired absorption refrigerator. There are some developments of gas-engine driven compressor systems but for house scale applications this does not seem to be realistic.

Because a heat pump extracts energy from the environment, the efficiency is more than 100%. Efficiencies of gas fired absorption heat pumps vary between 130 and 150%. Savings compared to high efficiency boilers vary between 500 and 600 m³ natural gas i.e. 15 to 20% (for a typical Dutch situation). Compressor type gas fired heat pumps show efficiencies between 120 and 200%. Electric heat pumps show higher efficiencies (COP's) in the range of 250 to 500%. For electric systems of course the losses of electricity generation and transport are taken into account and actual efficiencies are therefore between 120 and 250%.

The efficiency of the heat pump is higher when the temperature difference between the source and the desired boiler water temperature is small. Low temperature emitter systems are therefore a necessity.

Heat pumps use either ventilation air as a source or heat from ground or surface water. A heat pump can be used for both heating and cooling.

2.2 Distribution and Emitters

2.2.1 System description

Depending on building-practice and –regulations, the heat generator is placed in the attic, the cellar, the scullery, the kitchen and sometimes the bathroom (combustion air from outside). Because there are strict regulations in most countries concerning the position of outlet of the flue-duct (through walls and roofs), it is not always easy to install the product in the most profitable place (= short distance from taps). All combi boilers need electric power for the pump, the controls and the fan.

The efficiency of the piping network is mainly determined by heat losses through uninsulated pipes where the pipes run through non-habitable spaces in the house. This could be an attic, a cellar, etc. This is not uncommon, because the attic and cellar are also popular places for installers to put the CH ring-network from which the vertical feed of the radiators starts. Insulation of the pipes could save up to 10%.

Hydronic central heating systems use water as a medium to transport and emit heat from the heat generator to the individual rooms. Figure 2.x shows a categorisation of the emitter systems.

Figure 2.3: Categorisation of emitter systems

CENTRAL HEATING EMITTER SYSTEMS

1. *SEPARATE FROM BUILDING CONSTRUCTION*

• radiators	• high temperature system • low temperature system
• convectors	• high temperature system • low temperature system

2. *INCORPORATED IN BUILDING CONSTRUCTION*

• floor heating systems	• low temperature system
• wall heating systems	• low temperature system
• ceiling heating systems	• low temperature system

For hydronic central heating systems so called 'radiators' are the most popular emitters. Floor heating however is becoming more popular. The shift from conventional high temperature systems (HTS: send/return 90/70°C) to medium temperature systems (MTS: 65/55°C) and low temperature systems (LTS: 55/35°C) is the one of the most important issues to be discussed in this chapter.

Conventional radiators / convectors

Radiators

- multiple section radiators (ribbed, sectional radiators);
- panel radiators (single/double).

Table 2.4 heat emitters, radiation versus convection

	radiation (in %)	**convection** (in %)
sectional radiator	30	70
single panel radiator	50	50
double panel radiator	20	80
convector	0	100

Convectors

Convectors are made out of thin metal tubes surrounded with a range of narrow spaced thin metal fins. Convectors can be placed in a shaft/pit (e.g. in front of sliding doors) or in a casing (placed e.g. under a window). Because the emitter is completely enclosed, there is hardly any radiation. Convector systems have little water content and therefore have short heating times.

Low Temperature Heating (LTH)

Floor heating

Typically floor-heating systems use plastic tubes, which are poured in a layer of concrete (heavy systems). It is important that under and around this layer insulation material is used (floating system). Besides "heavy systems" there are also "light systems" for use in existing houses and for new-built timber frame houses. The temperature of the floor can be maximum 29°C; the maximum send temperature is therefore 45°C. In direct systems the water heated by the heat generator flows directly through the tubes. If the send temperature is too high, an indirect system can be used. The latter is less efficient.

Wall heating

Wall heating systems show a lot of similarities with floor heating. Plastic tubes are placed in into the wall milled channels or into specially formed bricks. The walls are finished with plaster. There are also "light systems". The maximum wall temperature is 40°C, the maximum send temperature is 55°C. Also in wall heating systems a distinction is made between direct and indirect systems.

Ceiling heating can also be used but offers a less comfortable climatisation when compared to floor- or wall heating (higher vertical temperature gradient). One advantage of ceiling heating is the easy combination with ceiling cooling (which is regarded as highly comfortable).

Table 2.5: Costs

Emitter system	**floor heating**	**wall heating**	**LT-radiators**	**LT-convectors**
Reference	*radiators 90/70*	*radiators 90/70*	*radiators 90/70*	*convectors 90/70*
Extra costs (in Euro)	500 to 1600	500 to 1600	250 to 500	250 to 500

Source: Novem

Advantages and disadvantages

The main advantages of LTH are higher boiler efficiencies for condensing boilers (the low return temperature increases the effect of condensing). Combination with heat pumps are also possible since the temperature difference between source and delivered heat is smaller. Low temperature heating also opens up possibilities for making use of renewable (solar) energy.

Low temperature systems especially score better on thermal comfort and air quality, thanks to higher amount of heat transfer through radiation, less turbulence en less dust burn.

Savings for HR central heating systems 3 to 9%. Extra costs for larger LT-radiators are 300 Euro per house. Extra costs for floor and wall heating are 1370 Euro per house (source: Gas, Febr. ’99). With low temperature floor heating the room thermostat can be set 2 to 3°C lower than with conventional radiator heating.

A disadvantage of LTS is the longer heating time. For new, well-insulated houses this need not be a problem because setting a lower night temperature is not necessary. Another drawbacks for floor and wall heating are the higher transmission and distribution losses.

Thanks to insulation and improvements in ventilation in older houses, LT-radiators can have approximately the same size (area) as conventional radiators.

2.3 Control system

This paragraph will deal with topics related to temperature control, thermostats and (radiator) valves.

2.3.1 System description

Heat transfer from emitters to the room is ultimately dependent on the feed temperature (boiler water) of the radiators and the valves that control the flow through the radiators.

Room temperature control can be either central or local (at the emitter).

Room temperature control - central

The so-called central control systems are also referred to as closed control system. A room thermostat (temperature sensor) which in most cases is placed in the living room gives a signal to the boiler CPU, which then switches on or off the burner (and consequently the fan and circulator) when the room temperature gets respectively below or above the desired temperature. A major disadvantage of this type of control system is that the temperature in other rooms in the house is not optimal and worse, in case there is no heat demand in the living room, these rooms will not be heated at all. Mainly for comfort reasons but also for improved control these emitters in other rooms may be equipped with a local thermostat, regulating the flow through the emitter. However, it is clear from the text above that this system will only work when there is a heat demand in the main living room.

Room thermostats:
- on/off room thermostat;
- clock room thermostat;
- modulating room clock thermostat;
- weather dependent clock thermostat.

Besides setting the desired temperature room thermostats often have additional functions, the most important are listed in the table below.

Table 2.6: Additional functions room thermostat

Functions:	• clock program for space heating • clock program for hot water • modulation(two-way communication required) • start-up optimisation (self learning) • power-down optimisation • booster (extra fast heating of the house)

Display:	• set room temperature
	• actual room temperature
	• time, date
	• program period
	• boiler data (two-way communication required) e.g.:
	  • boiler status (on/off, igniting, etc.)
	  • send temperature
	  • modulation rate
	  • error code

Other specs:	• wireless • removable from socket • power supply from boiler or batteries

As can be seen from table 8.2 some functions require a two-way communication between room thermostat and boiler. Some manufacturers use their own communication protocol, but recently some kind of standard protocol has been developed. The name of this protocol is “OpenTherm” and is already being used by a large number of boiler and thermostat manufacturers.

Brands and Manufacturers of thermostat

- Honeywell
- Nefit
- Atag
- Agpo
- Vaillant
- Remeha
- Bosch/Siemens
- Danfoss
- Cenvax
- Kromschröder
- Eberle
- Amfra

Room temperature control - local

The second control system, also referred to as individual or open control system, deals with the problem mentioned above. In this case the central heating water is kept warm and is being circulated through the piping at all times. Radiator valves with a built-in thermostat control the temperature in individual rooms. These radiator valves can be set at the desired room temperature either manually (mechanical) or automatically (timer controlled).

Boiler water temperature control

Besides these types of room temperature control there is also a boiler temperature or feed water temperature control: The burner is switched off when the maximum send temperature is reached and when the temperature-difference between send and return becomes to small, e.g. when all radiator-valves are closed. Furthermore the maximum send temperature can also be set. When the send temperature is set low, it will take longer to reach the desired room temperature. In case of a large heat demand it is therefore better to set a high send temperature. When the heat demand is little, it is better to set a low send temperature. Because the return will also be lower, condensation in the heat generator will be stimulated. Furthermore a low send temperature will prevent overshoot[11]. Setting the send temperature manually is not optimal. Installers often

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[11] Another way to prevent overshoot is to build in an integrating action into the room thermostat (anticipation element) which switches of the burner well before the set temperature is reached.

set it too high to make sure the system will work properly in wintertime. Consumers are often too ignorant or not willing to take the effort to change it.

A more intelligent way to control the maximum send temperature is used in a weather dependent control system. The send temperature is high when the outside temperature is low and vice versa. The system requires an extra temperature sensor outside the house and is therefore more expensive. When there is a good correlation between inside and outside temperature such a system will save energy and will improve comfort. However in modern well-insulated houses this correlation is not so good. In this cases it is better to use a modulating room thermostat. In this case the burner power is controlled by the difference in desired and actual temperature measured at the room thermostat. The heat generator must of course support the modulation system. This implies a two-way communication system between room thermostat and boiler.

Savings for control systems are very hard to estimate. The main reason for this is that the savings largely depend on consumer behaviour. Basically the consumer can do everything an advanced electronic control system does: Like lowering the temperature well before bedtime, closing radiators in unused rooms etc. Advanced control systems can especially be of good help to save energy for the lazy consumer or for the consumer who is not aware of the energetic consequences of his behaviour.

2.4 Auxiliary Energy

Note: The electrical efficiency is part of subtask 2.3. This report only contains some of the headlines, more detailed information can be found in the report on this subtask.

2.4.1 System description

Besides the energy that is needed for heating, many appliances use electricity for the control- functions. Most of these control- components are switched off when there is no heat demand. But some of them may be designed in a way that they constantly use electricity. Like standing losses, this '*stand by electricity consumption'* can be important because of its continuous and ever lasting nature.

A considerable number of heating appliances use electric components in order to fulfil their function as space heater. These are components like pumps, fans, controls, and electronic ignition. The electricity consumption of these components has to be taken into account when something is to be said about the energy efficiency of heating appliances.

According to the Dutch EPN calculation method (see also chapter 2.4) 2 to 3% of the total energy for a house is needed for the fan, the pump and the control system of the (combi) boiler. On the total primary energy needed for heating this varies between 5 and 14%.

Table 2.7: Auxiliary electric energy heating

(in MJ)	**villa (free standing)**	**town house (in row)**	**apartment**
pump	1800	1100	941
fan	600	600	600
controls	950	950	950
Total help energy	**3350**	**2650**	**2491**
Total heating energy	62650	34080	21770

source: EP variantenboek, Novem 1996

According to BEK the Dutch average auxiliairy energy electricity consumption is 283 kWh/appliance/year (=2540 $MJ_{primary}$) of which 34 kWh is standby energy consumption.

Reducing Auxiliary Power

The total electric load for components like pump, controls and fan mounts up to 110 – 130 Watts. When no fan is used the load is reduced to 70 – 80 Watt.

With efficient pumps, fans and controls the electricity consumption can be reduced with maximal 50% (selection of the right pump, improvement of electrical efficiency of the motors (fan & pump)). Also the use of reciprocating pumps should be investigated.
For Combi's there will also be an effect on the efficiency of water heating but of course the savings will have a greater impact on the power consumption for boiler function, where the average operating times are approximately 2000 – 2500 hours per year versus 300 – 400 minutes for water heating.

Stand-by Power Consumption

All CH-appliances must be installed with an electrical connection. Most of these appliances use power in their stand-by mode, because of the controls. When LED's are used (e.g. to indicate the operation mode of the appliance) the standby power consumption is approximately 8 Watts. Per year this is approximately 70 kWh_{el}. With proper electronic design this can be reduced with 50 to 60%.

2.5 Design options

Table 2.8: Design options dwelling based heating systems

				Efficiency on lhv	Indication on savings
Dwelling Based Heating System (Central Hydronic Heating System)					
	Design options related to generator				
		Improve steady state efficiency			
			- Conventional boiler (gas/oil)	85%	*Reference*
			- Improved efficiency boilers (gas/oil)	90%	6%
			- Condensing boilers (gas/oil)	107%	26%
			- Gas fired heatpump with additional condensing boiler	140%	65%
			- Electric heat pump (efficiency based on primary energy)	140%	65%
		Reduce standing losses			
			- Replacement pilot flame by electronic ignition		< 550 kWh_{pr}/yr
			- Storage heaters (coal & wood) : Improve insulation		< 350 kWh_{pr}/yr
			- : Install flue damper		< 350 kWh_{pr}/yr
		Reduce start/stop losses			
			- Improve appliance insulation		< 200 kWh_{pr}/yr
			- Install flue damper		< 300 kWh_{pr}/yr
			- Reduce heat capacity of generator (important for on/of burners)		< 400 kWh_{pr}/yr
		Reduce auxiliary power consumption			
			- Use pump with permanent magnet motor, controlled by the boiler (also relevant for sub-systems such as floor heating)		< 400 kWh_{pr}/yr
			- Reduce stand-by power consumption		< 40 kWh_{pr}/yr
		Improve generator control (boiler water temperature)			
			- Boiler water temp. controlled by max. thermostat in boiler (90˚C), combined with conventional on/of room thermostat		*Reference*
			- Modulating burner control		<5%
			- Boiler water temp. weather controlled (or controlled by modulating room thermostat)		<3%
	Design options related to distribution system				
			- No insulation of pipes / 90-70 temp. regime		*Reference*
			- Insulation distribution pipes		<10%
			- Hydraulically evened out system ("Ausgleichen")		...
	Design options related to emitter system				
			- High temperature / small surface emitter (>90˚C)		*Reference*
			- Average temperature / small surface emitter (90-70˚C)		<5%
			- Low temperature / large surface radiators (30 – 50˚C)		<10%
	Design options related to control system (room temperature)				
			- Clock room thermostat (for modulating room thermostat - see above)		<5%
			- Thermostatic radiator valves		<3%
			- Behavioural Feed Back Control Unit combined with Room Thermostat		<10%

ANNEX

3 Room Based Heating

3.1 System description

Room based heating systems (or local heating) are heating systems characterised by the integration of heat generator, distribution, emitter(s) and control integrated in one appliance, intended for heating one room only. Furtheron this integrated appliance is called a "heater". Portable stoves (many for liquid fuels) are not included in the scope of the study. Also not included are room based heating systems that do not function as the main heating system but as extra or comfort heating alongside a dwelling based main heating system.

This chapter will describe room based heating systems in terms of efficiency and possible design options. The first paragraph will show that there are large differences in efficiencies of heaters (from say 20% for simple open fireplaces to > 90% for soapstone stoves or free standing gas stoves). The second paragraph will go into more detail with regard to possible design options for room based heating systems.

3.2 Efficiency

In this study we distinguish between the following types of room based heaters:

1) built-in heaters (hearth, fireplace, stove made up of bricks):
    a) type: open or closed;
    b) fuel: mainly solid (wood, pellets) or gaseous;
2) free standing heaters (cast iron / plate steel woodstoves, gas / oil stoves, etc.):
    a) type: open or closed;
    b) fuel: gaseous or solid (oil is more often used for portable heaters);
3) electric heaters:
    a) type: convection/radiation (forced convection) or LTH (radiant panels, electric floor heating, electrically heated glass);
    b) fuel: electricity.

The efficiency of electric heating is considered to be close to 100% (not based on primary energy).

The efficiency of heaters on primary fuels (whether built-in or free standing) are determined by its losses. These losses are due to:

1. unburned particles in the ashes or flue gasses;
2. heat of flue gasses, not transferred to the room.

The efficiency figures presented in the next paragraphs are assumed to be based upon steady-state efficiency (although not always mentioned in the source). Annual average efficiency will evidently be lower, since start-stop and standing losses are

One advantage of room based heating systems compared to dwelling based heating systems is the fact that standing losses do not permanently occur since the heat generator is placed in the habitable room. Standing losses can only occur at times the habitant is not present.

3.2.1 Built-in heaters

Built-in **open** heaters (open fireplace, no doors, solid fuels like wood or pellets) have very poor efficiency, generally speaking between 10-20% (probably lower heating value). Reasons for this are poor control of the combustion process and the large losses through the chimney (hot flue gasses). There is also considerable heat loss due to the need for ballast air: An open fireplace may require an air flow 250 m^3/hr of which only 50 m^3 is needed for combustion and 200 m^3 is needed for ballast[12]. This ballast air is taken from the room (in case of an 'open system') and needs to be replenished by (cooler?) air from outside the room. This ventilation rate normally exceeds the nominal ventilation rates mentioned in literature (circa 15-25 m^3 per person per hour). Heat transfer is almost entirely based upon radiation.

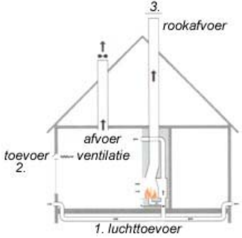

Figure 3.1: Open fireplace and airflow

Built-in **closed** heaters (e.g. a fireplace with doors) have better efficiency, generally up to 50-60%, because of better control of the combustion process (additional combustion chambers) and heat transfer through convention (also for safety reasons: the mantle must be cooled by air in order to prevent excessive temperatures). The air flow for combustion is limited to the 50m^3 mentioned before. Heat transfer is based on radiation and convection, the ratio depending on type and features and in general approximately 30% radiation and 70% convection. Higher efficiencies are obtained through use of extra combustion chambers, heat accumulating materials and ribs and panels to direct air flow.

Some built-in fireplaces can be equipped with a heat exchanger which allows external radiators to be heated as well. Usually the heat exchanger is a simple device (housing of metal, filled with water or with internal tubes as heat exchanger), without circulator or temperature control of the water flow which have to be added to the heater. These type of 'boilers' are however rare and will not be discussed further in this chapter.

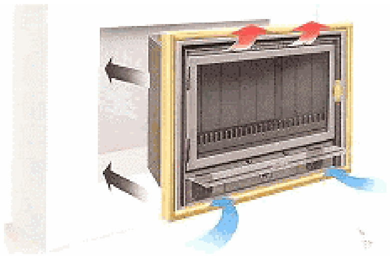

Figure 3.2: Detachable fireplace with convective airflow

A special type of "built-in" heaters are the **soapstone** stoves that are hand-built on site (weighing up to 1,000 kg or more). These heaters direct the hot flue gasses through two or more combustion chambers where the hot gasses transfer the heat to the soapstone. The large heat capacity of the soapstone makes it possible to retain the heat up to 24 hr (or more, depending on capacity) with only 1-2 hours of firing. The combustion process is relatively clean due to the high temperatures in the additional combustion chambers

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[12] Ballast air is air that is transported and expelled by the flue gasses.

(>1,000°C). The efficiency is very high and may reach from 75% to more than 90-95%. Heat transfer is almost entirely based upon radiation.

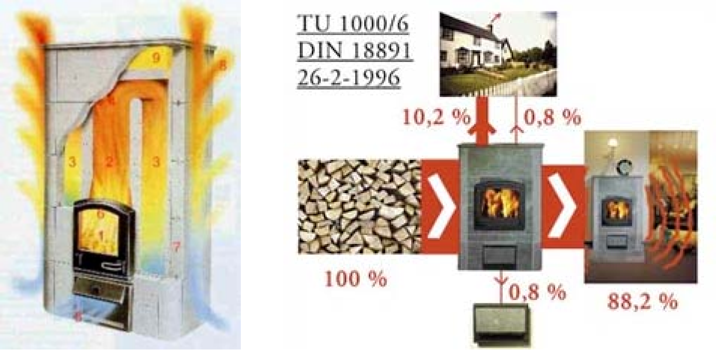

Figure 3.3: Soapstone stove (picture: Tulikivi)

3.2.2 Free standing heaters

Free standing heaters (solid, gaseous) have efficiencies of 60 to >85%, depending on fuel type, size, placing of flue pipe and features such as extra combustion chambers, (soapstone or ceramic) heat accumulating elements and fins / ribs / tubes for more convective heat transfer[13]. The combustion process of the solid fuel stoves is relatively clean (but not as clean as for wood in soapstone stoves), with a combustion temperature of around 850°C and an maximum efficiency of around 75%.

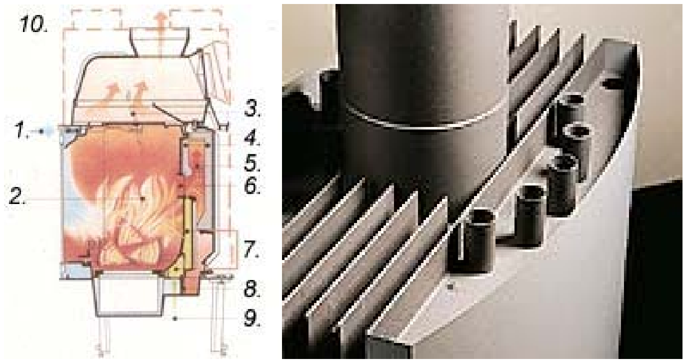

Figure 3.4: Left - combustion process, right - ribs and convection pipes (picture: Harrie Leenders, NL)

The combustion process of gas heaters is cleaner than for woodstoves. The steady state efficiency of a modern gas heater may reach 75 to 85%, some even reach > 90%. Standing losses occur since most gas heaters use pilot flames as source for ignition. These pilot flames may consume up to 0.33MJ/hr ([14]). On annual basis this amounts to 1.6 GJ or close to 40 m^3 natural gas (assuming 4900 operating hours per year).

Closed heaters are available in both balanced flue or forced flue (ventilator assisted) arrangements. The forced flue heaters function with smaller flue ducts than the balanced flue types (70 mm as opposed to 165 mm diameter) and allow for more flexibility in placing of the heater.

Like some built-in fireplaces free standing heaters can also be equipped with a heat exchanger that allows external radiators to be heated as well. The efficiency of this heat exchange is rarely documented, anecdotal

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[13] Free standing heaters might also include heaters (such as woodstoves) that need to be attached to the building fabric (hanging) and thus do not “stand on the floor”. However these “installed heaters” have identical performance as heaters that stand on legs and are considered to be covered in the same product group.

[14] Product brochure “Juno Gasheizautomaten”, January 1992.

information suggest a somewhat lower efficiency of the heater (77% compared to >80%), but there are also gas stoves specially designed for this purpose that show relatively high efficiencies of 91.6%. The latter thus combine the function of improved efficiency central heating gas boilers with the ‘cosiness’ and warmth of local heaters (visible flames, high intensity of infra-red radiation). Around 20% of the heat is transferred directly to the room (by radiation and convection), the remaining 80% is transferred to the central heating circuit.

Heat transfer of free-standing stoves depends on type and features and is in general 30% through radiation and 70% convection.

The required capacity of room based heating systems depends mainly on the thermal properties of the room and the type of use (as main heating or comfort heating only). There are tables available indicating a certain Wattage (capacity) per square meter room area. The capacity needed varies according the degree of insulation of the room and the heat loss to its surroundings (e.g. a free standing dwelling versus an apartment). The table below provides a first estimate (figures representative for Dutch / Belgian dwellings).

Table 3.1: Required capacity

Type of dwelling	**required capacity per m²**
in-between dwelling, non insulated	200 W/m²
corner dwelling, non insulated	225 W/m²
free standing dwelling, non insulated	250 W/m²

Table 3.2: Required capacity - continued

Type of dwelling	**floor insulation**	**facade insulation**	**double glazing**
in-between dwelling	10 W/m²	10 W/m²	30 W/m²
corner and free standing dwelling	10 W/m²	40 W/m²	30 W/m²

A 20m^2 room in a poorly insulated free standing dwelling would thus require a heater of 5kW.

3.2.3 Electric heating

The following definition of electric heating systems is used:

Definition:
- Central Heating Electric refers to a system which heats the whole house, using fixed electric heaters as the main type of heating. This includes storage heaters, floor heating, and other direct electric heaters where it heats the whole house;
- Local electric or 'room heating electric' refers to electric room heaters which heat only a few rooms, and where this is the main type of heating;
- If the electric heating is secondary to another heating type such as gas CH, it is defined as that other heating type.

Electric heaters with heat storage facilities (ceramic elements) offer low operational costs since electricity on cheap rate tariffs can be used to ‘load’ heat. Intelligent controls for optimising the heat load process are available and can be combined with some kind of central temperature control (this is then electric central heating). All modern heaters are equipped with thermostats for easy temperature control and safety (prevent excess surface temperatures). The centrally controlled heaters can be switched according room temperature, but weather dependant controls are also common.

As stated before the efficiency of electric heating is considered to be 100% for resistance heating based appliances but this has to be recalculated in order to express primary energy use. Electric heat pumps show higher efficiencies (COP up to 2.6 - 3.0 or circa 150% on primary energy use).

Main differences in electric heaters lie in the type of heat transfer: natural convection, forced convection or low temperature heating (LTH). There are also models on market that combine heating with heat recovery ventilation through use of a heat pump. The highest comfort is obtained by electric LTH, e.g. floor heating.

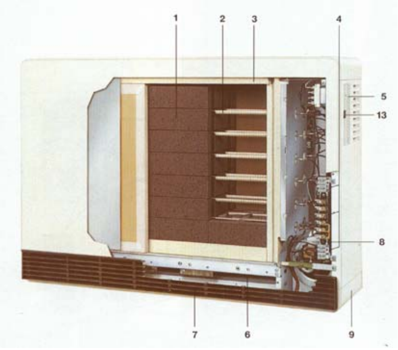

Figure 3.5: Electric storage heater (picture: Vaillant, DE)

Standing losses (heat losses) of electric heating are generally speaking very low (except for the storage type heaters when residents are not at home). Electric energy consumption at stand-by mode might be a relevant loss-factor but unfortunately is rarely documented.

A rule of thumb for installed capacity of electric heating is 10 W/sq.ft = 10 W/0.09m^2 (1 ft = 0.3048m) or 108W/m^2 for primary heating with forced convection, US climate (roughly half the capacity of stoves).

3.3 Design options

3.3.1 Built-in heaters

Improvement of the combustion process is possible through:

- adding doors and controllable ventilation openings (improve efficiency from say 20% to 40-50%);
- adding ‘afterburn’ chambers (improve efficiency from say 40-50% to 50-60%);
- adding heat accumulating materials (improve efficiency from say 50-60% to 80-90% for so-called “soapstone stoves”);
- fuel switch: Built-in gas heaters in general have higher efficiencies than solid fuel heaters (the combustion process of gas heaters is more easy to control);
- replace pilot flame of built-in gas heaters by electronic ignition.

However, all of these changes to the original product (e.g. a simple open fireplace) describe existing products that are now available on the market. Therefore these options cannot be considered design options in the true sense. Some examples:

- The electronic ignition option has been tried on the market but with little success since most appliances still use pilot flames: Companies that have applied this option experienced lack of interest of consumers, increase of product price and problems with reliability of the electronic ignition.
- The emitter efficiency of built-in heaters can be improved by enhancement of the radiative surface and/or combination with enhanced convective heat transfer. These aspects can be tightly linked to combustion efficiency. The difference in efficiency between existing models can partly be explained by these factors.
- The efficiency of the controls (thermal comfort, time) are poor for these type of heaters. Some heaters have built-in bimetal switches that can control internal valves to regulate the combustion process. These controls replace actions that could also be performed manually.

3.3.2 Free standing heaters

The highest efficiency is obtained by gas heaters (80-85%). Ways of improving efficiency are:

- replacement of pilot flame by electronic ignition (reduce standing losses);
- Improvement of combustion efficiency: condensing burners, forced ventilation (improve steady state efficiency).

As stated before sources suggest that manufacturers have tried these options in the past but that they failed in the market. Especially the option regarding condensing burners was not pursued further for several reasons, the most important one being the high costs: A local (gas)heater with an improved (condensing) burner would have a price per kW heating capacity that would never be competitive when compared to other heating systems. Combined with the fact that efficiency is an issue of relatively small interest to the typical buyer but robust, non-complicated appliances are, this left little room for success for the condensing heater in this segment of the market.

3.3.3 Electric heaters

Electric heaters already have a high conversion efficiency. Further improvement is possible through the use of:

- sophisticated controls (check presence of residents);
- reduction of auxiliary energy use (use of efficient fans in the case of forced ventilation).

Table 3.3: Design options room based heating systems

Room Based Heating System (local heating)				efficiency	savings compared to reference
	Design options related to heat generator-part				
		Gas / oil fired local heaters		*75%*	*reference*
			- Improved efficiency	90%	20%
			- Condensing heaters (provision for condensate necessary)	100%	33%
			- Modulating burner		<5%
			- Electronic ignition		450 kWh$_{prim}$
		Electric local heaters			
			- Reduction of auxiliary energy use (use efficient fans / motors)		--%
	Design options related to emitter-part				
			- Enhance emitter surface / decrease temperature		--%
	Design options related to controls				
			- Clock thermostat		<5%

ANNEX

4 Block and District Heating

4.1 System Description

Block and district heating systems are collective heating systems in which individual households share the heat generator and some of the distribution grid. For block heating this grid is confined the building or block, whereas in district heating the grid may expand for several miles, serving thousands of households.

In both block and district heating it is possible to either inject the heat directly in the heating system of the dwelling (the medium circulates through the radiators) or use the heat indirectly (a heat exchanger provides in a hydraulic separation between the primary grid from plant to dwelling and a secondary grid within the dwelling). The first option ('direct-fed') is usually seen as the more cost effective and efficient one. The second option is used in those cases where e.g. the necessary pressure difference and/or temperature requirements cannot be met.

The heat generator for block heating systems is usually placed in a boiler room in the building. District heating systems use a central boiler plant (e.g. an electricity plant or waste incinerator) and some back-up boiler stations. The back-up stations consist of large boilers that assist the central boiler plant during periods of peak demand or replace the boiler plant when operation is not feasible (heat demand is too low or during maintenance). In general 90% of the heat demand is supplied by the plant.

4.2 Efficiency

Block and district heating systems show higher heat losses, especially in the distribution grid, when compared to individual systems. Also the control of the heating system is not as efficient in matching heat demand and supply. For, even if only one household requires heat, the whole system must be kept online. Start stop losses will also be higher than for the smaller individual heating systems, but will occur less frequent (as explained above).

The heat generator in block / district heating can be identified as being one of three types:
1. conventional boilers (including condensing);
2. combined heat power (CHP or cogeneration);
3. waste heat (from industrial processes, usually not limited to block heating).

The efficiency of conventional and CHP based heat generators can be expressed as shown in Chapter 3 (CHP with thermal/electric efficiency of 40/40 is comparable to a boiler efficiency of 110%). The third type, waste heat, is more difficult to express in efficiency numbers, since the heat is generated as a by-product and would otherwise be discarded. For this reason this study proposes to account for waste heat as 'free' energy: The total waste heat system efficiency is chosen as the total efficiency of a reference heating system, but counted through a "negative" multiplier. In other words, by using waste heat the energy use of a reference system - with a certain total system efficiency - is 'avoided'.
The possible use of waste heat however must never be the reason for setting up a new (CHP) plant. In those cases a careful assessment of the merits of cogeneration or separated generation must be made.

The losses in the distribution grid are very much dependant on the temperature range, the actual heat demand of the dwelling (dependant on thermal properties) and the annual average ground temperature. In a district heating system with a 90/70°C temperature regime losses may amount to 30-40%, whereas a 16/6 regime cuts losses to a mere 5-10%. However this last temperature requires auxiliary heaters (e.g. heat pumps) to deliver water of 50-60°C to the consumer. For block heating these distribution losses will be less (the grid is limited in size).

Reduction of distribution temperature does not only reduce system losses but also increases heat generation efficiencies: A low temperature system may result in savings in heat generation of 6-12% for CHP-gasmotor or 25-40% for CHP-CCGT[15]. Finally low temperature systems also lead to savings of 2.5 - 10% in actual heat demand of the dwelling (lower ventilation losses, lower average room temperature). These savings should be taken into account when assessing the efficiency of heat generation, distribution and emission. The control of boiler water temperature can be improved by applying modulating burners, boilers in cascade or weather dependant grid temperature. Control of room temperature occurs through thermostatic valves on the radiators or a centrally located room thermostat.

Auxiliary energy use occurs mainly through use of circulators in the grid (secondary grid if applicable). A rule-of-thumb for calculating electrical energy for transport and distribution pump energy is: 2 kWh per GJ per km. So if the heat demand of the dwelling is 20 GJ the required pump energy is 40 kWh per km (2 km - 80 kWh). The average efficiency of the circulator is 65%, pump losses are dissipated into the grid as heat. When compared to uncontrolled circulators self controlled circulators (that control speed according differential pressure or temperature, thereby saving energy) can reduce pump energy use by 35%. Probably many shared systems already show a high percentage of use of self-controlled circulators, since the payback times in most cases are very attractive.

4.3 Design options

Table 4.1: Design options block and district heating systems

Block and District Heating Systems				efficiency	savings compared to reference.
	Design options related to heat generator-part				
		Block / district heating generators			
			Steady state efficiency conventional	*75%*	*reference*
			- Improved efficiency	90%	20%
			- Condensing heaters (provision for condensate necessary)	100%	33%
			- CHP (40/40)	110%	35%
			- waste heat (heat from existing plant, for ‘new’ see CHP)	Total: 100% + ref.	233%
	Design options related to heat generator controls				
			- Modulating burners		<5%
			- Boilers in cascade		<5%
	Design options related to distribution / emitter-part				
		Block resp. District		*85% resp. 75%*	*reference*
			- Decrease grid temperature (from 90/70 to 55/40)		20%
			- Heat exchanger in habitable room (provisions for noise)		PM
	Design options related to controls				
			- Clock thermostat		5%
	Design options related to auxiliary energy use				
			- Use efficient circulators (PM, self-controlled)		50% of electrical pump energy

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[15] “Lage temperatuursystemen”, DV 2.2.106.98.12 Novem 1998