Technology Data

Heating installations

Energistyrelsen
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Technology descriptions and projections for long-term energy system planning

Technology Data for heating installations
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Amendment sheet

Publication date

Publication date for this catalogue "Technology Data for Individual Heating Plants and Energy Transport" is August 2016. In August 2017 an amendment sheet has been added and also the possibility to add descriptions of amendments in the individual chapters if required. Hereby the catalogue can be updated continuously as technologies evolve, if the data changes significantly or if errors are found.

In December 2017 an additional amendment was introduced. This amendment renamed the catalogue "Technology Data for Heating Installations".

The newest version of the catalogue will always be available from the Danish Energy Agency's web site.

Amendments after publication date

All updates made after the publication date will be listed in the amendment sheet below.

Date	Ref.	Description
3.2018	Chapter 17, 18, 19	Technology data about fuel cell micro CHP units are now included in the catalogue
12.2017	Datasheet 3.2	These datasheets are now included in the document as well as the excel sheet
12.2017	Datasheet 4, 5 & 6	Updated upper and lower levels for uncertainty of O&M for biomass boilers and wood stoves without water tank in one-family houses
10.2017	Datasheet 7.1, 7.2, 7.3 & 7.4	Updated technical lifetime of air-to-air and air-to-water heat pumps
10.2017	Datasheet 7.1, 7.2, 7.3 & 7.4	Updated O&M of air-to-air, air-to-water and ground source heat pumps
8.2017	Datasheet 7.9 & 7.10	Updated technical lifetime of ground source heat pumps in apartment complexes

Preface

The *Danish Energy Agency* and *Energinet*, the Danish transmission system operator, publish catalogues containing data on technologies for individual heating. The first edition of the catalogue was published in 2012 and it has since been updated several times. This current catalogue includes updates of a number of technologies which replace the corresponding chapters in the previous catalogue. The intention is that all technologies from the previous catalogue will be updated and represented in this catalogue. Also the catalogue will continuously be updated as technologies evolve, if data change significantly or if errors are found. All updates will be listed in the amendment sheet on the previous page and in connection with the relevant chapters, and it will always be possible to find the most recently updated version on the Danish Energy Agency's website.

The primary objective of publishing technology catalogues is to establish a uniform, commonly accepted and up-to-date basis for energy planning activities, such as future outlooks, evaluations of security of supply and environmental impacts, climate change evaluations, as well as technical and economic analyses, e.g. on the framework conditions for the development and deployment of certain classes of technologies.

With this scope in mind, it is not the target of the technology data catalogues, to provide an exhaustive collection of specifications on all available incarnations of energy technologies. Only selected, representative, technologies are included, to enable generic comparisons of technologies with similar functions.

Finally, the catalogue is meant for international as well as Danish audiences in an attempt to support and contribute to similar initiatives aimed at forming a public and concerted knowledge base for international analyses and negotiations.

Danish preface

Energistyrelsen og Energinet udarbejder teknologibeskrivelser for en række teknologier til brug for individuel opvarmning. Første udgave af kataloget blev offentliggjort i 2012, og det er efterfølgende blevet opdateret flere gange. Dette nuværende katalog indeholder opdateringer af en stor del af teknologibeskrivelserne, som erstatter de tilsvarende kapitler i det gamle katalog. Det er hensigten, at alle teknologibeskrivelserne fra det gamle katalog skal opdateres og integreres her. Desuden vil kataloget løbende opdateres i takt med at teknologierne udvikler sig, hvis data ændrer sig væsentligt eller hvis der findes fejl. Alle opdateringer vil registreres i rettelsesbladet først i kataloget, og det vil altid være muligt at finde den seneste opdaterede version på Energistyrelsens hjemmeside.

Hovedformålet med teknologikataloget er at sikre et ensartet, alment accepteret og aktuelt grundlag for planlægningsarbejde og vurderinger af forsyningssikkerhed, beredskab, miljø og markedsudvikling hos bl.a. de systemansvarlige selskaber, universiteterne, rådgivere og Energistyrelsen. Dette omfatter for eksempel fremskrivninger, scenarieanalyser og teknisk-økonomiske analyser.

Desuden er teknologikataloget et nyttigt redskab til at vurdere udviklingsmulighederne for energisektorens mange teknologier til brug for tilrettelæggelsen af støtteprogrammer for energiforskning og -udvikling. Tilsvarende afspejler kataloget resultaterne af den energirelaterede forskning og udvikling. Også behovet for planlægning og vurdering af klima-projekter har aktualiseret nødvendigheden af et opdateret databeredskab.

Endeligt kan teknologikataloget anvendes i såvel nordisk som internationalt perspektiv. Det kan derudover bruges som et led i en systematisk international vidensopbygning og -udveksling, ligesom kataloget kan benyttes som dansk udspil til teknologiske forudsætninger for internationale analyser og forhandlinger. Af disse grunde er kataloget udarbejdet på engelsk.

Table of contents

Introduction

This catalogue presents technologies for heat plants used in individual buildings and households.

Some of the technologies presented, besides individual heating, produce also electricity which will be either consumed at a household level or fed into the grid.

Some technologies are presented for different sizes and/or for existing and new buildings. Section 1.4 defines sizes and types of buildings and describes the specific assumptions.

The main purpose of the catalogue is to provide generalized data for analysis of energy systems, including economic scenario models and high-level energy planning.

These guidelines serve as an introduction to the presentations of the different technologies in the catalogue, and as instructions for the authors of the technology chapters. The general assumptions are described in this section. The following sections (1.2 and 1.3) explain the formats of the technology chapters, how data were obtained, and which assumptions they are based on. Each technology is subsequently described in a separate technology chapter, making up the main part of this catalogue. The technology chapters contain both a description of the technologies and a quantitative part including a table with the most important technology data.

1.2. Qualitative description

The qualitative description describes the key characteristics of the technology as concise as possible. The following paragraphs are included where relevant for the technology.

Contact information

Containing the following information:

- Contact information: Contact details in case the reader has clarifying questions to the technology chapters. This could be the Danish Energy Agency, Energinet.dk or the author of the technology chapters.
- Author: Entity/person responsible for preparing the technology chapters
- Reviewer: Entity/person responsible for reviewing the technology chapters.

Brief technology description

Brief description for non-engineers of how the technology works and for which purpose.

An illustration of the technology is included, showing the main components and working principles.

Input

The main raw materials and primarily fuels, consumed by the technology.

Output

The forms of generated energy, i.e. heat and in some cases electricity.

Typical capacities

The stated capacities are for a single unit or, in case of e.g. solar heating, for a typical system size.

This section includes a description of the relevant product range in capacity (kW).

Regulation ability and other power system services

Description of how the unit can regulate, e.g. a gas boiler is very flexible whereas a solar heating system depends on the solar radiation.

Regulation abilities are particularly relevant for electricity generating and consuming technologies. This includes the part-load characteristics, start-up time and how quickly it is able to change its production or consumption when already online.

Advantages/disadvantages

A description of specific advantages and disadvantages relative to equivalent technologies. Generic advantages are ignored; e.g. renewable energy technologies mitigating climate risks and enhance security of supply.

Environment

Particular environmental characteristics are mentioned, for example special emissions or the main ecological footprints.

The energy payback time or energy self-depreciation time may also be mentioned. This is the time required by the technology for the production of energy equal to the amount of energy that was consumed during the production and the installation of the equipment.

Research and development perspectives

This section lists the most important challenges to further development of the technology. Also, the potential for technological development in terms of costs and efficiency is mentioned and quantified if possible. Danish research and development perspectives are highlighted, where relevant.

Examples of market standard technology

Recent full-scale commercial projects, which can be considered market standard, are mentioned, preferably with links. A description of what is meant by "market standard" is given in the introduction to the quantitative description section. For technologies where no market standard has yet been established, reference is made to best available technology in R&D projects.

Prediction of performance and costs

Cost reductions and improvements of performance can be expected for most technologies in the future. This section accounts for the assumptions underlying the cost and performance in 2015 as well as the improvements assumed for the years 2020, 2030 and 2050.

The specific technology is identified and classified in one of four categories of technological maturity, indicating the commercial and technological progress, and the assumptions for the projections are described in detail.

In formulating the section, the following background information is considered:

Data for 2015

In case of technologies where market standards have been established, performance and cost data of recent installed versions of the technology in Denmark or the most similar countries in relation to the specific technology in Northern Europe are used for the 2015 estimates.

If consistent data are not available, or if no suitable market standard has yet emerged for new technologies, the 2015 costs may be estimated using an engineering based approach applying a decomposition of manufacturing and installation costs into raw materials, labor costs, financial costs, etc. International references such as the IEA, NREL etc. are preferred for such estimates.

Assumptions for the period 2020 to 2050

According to the IEA:

"*Innovation theory describes technological innovation through two approaches: the technology-push model, in which new technologies evolve and push themselves into the marketplace; and the market-pull model, in which a market opportunity leads to investment in R&D and, eventually, to an innovation*" [1].

The level of "market-pull" is to a high degree dependent on the global climate and energy policies. Hence, in a future with strong climate policies, demand for e.g. renewable energy technologies will be higher, whereby innovation is expected to take place faster than in a situation with less ambitious policies. This is expected to lead to both more efficient technologies, as well as cost reductions due to economy of scale effects. Therefore, for technologies where large cost reductions are expected, it is important to account for assumptions about global future demand.

The IEA's New Policies Scenario provides the framework for the Danish Energy Agency's projection of international fuel prices and CO_2-prices, and is also used in the preparation of this catalogue. Thus, the projections of the demand for technologies are defined in accordance with the thinking in the New Policies Scenario, described as follows:

"New Policies Scenario: A scenario in the World Energy Outlook that takes account of broad policy commitments and plans that have been announced by countries, including national pledges to reduce greenhouse gas emissions and plans to phase out fossil energy subsidies, even if the measures to implement these commitments have yet to be identified or announced. This broadly serves as the IEA baseline scenario" [2].

Alternative projections may be presented as well relying for example on the IEA's 450 Scenario (strong climate policies) or the IEA's Current Policies Scenario (weaker climate policies).

Learning curves and technological maturity

Predicting the future costs of technologies may be done by applying a cost decomposition strategy, as mentioned above, decomposing the costs of the technology into categories such as labor, materials, etc. for which predictions already exist. Alternatively, the development could be predicted using learning curves. Learning curves express the idea that each time a unit of a particular technology is produced, learning accumulates, which leads to cheaper production of the next unit of that technology. The learning rates also take into account benefits from economy of scale and benefits related to using automated production processes at high production volumes.

The potential for improving technologies is linked to the level of technological maturity. The technologies are categorized within one of the following four levels of technological maturity.

Category 1. Technologies that are still in the *research and development phase*. The uncertainty related to price and performance today and in the future is highly significant (e.g. wave energy converters, solid oxide fuel cells).

Category 2. Technologies in the *pioneer phase*. The technology has been proven to work through demonstration facilities or semi-commercial plants. Due to the limited application, the price and performance is still attached with high uncertainty, since development and customization is still needed. The technology still has a significant development potential (e.g. gasification of biomass).

Category 3. *Commercial technologies with moderate deployment*. The price and performance of the technology today is well known. These technologies are deemed to have a certain development potential and therefore there is a considerable level of uncertainty related to future price and performance (e.g. offshore wind turbines)

Category 4. *Commercial technologies with large deployment*. The price and performance of the technology today is well known and normally only incremental improvements would be expected. Therefore, the future price and performance may also be projected with a relatively high level of certainty. (e.g. coal power, gas turbine)

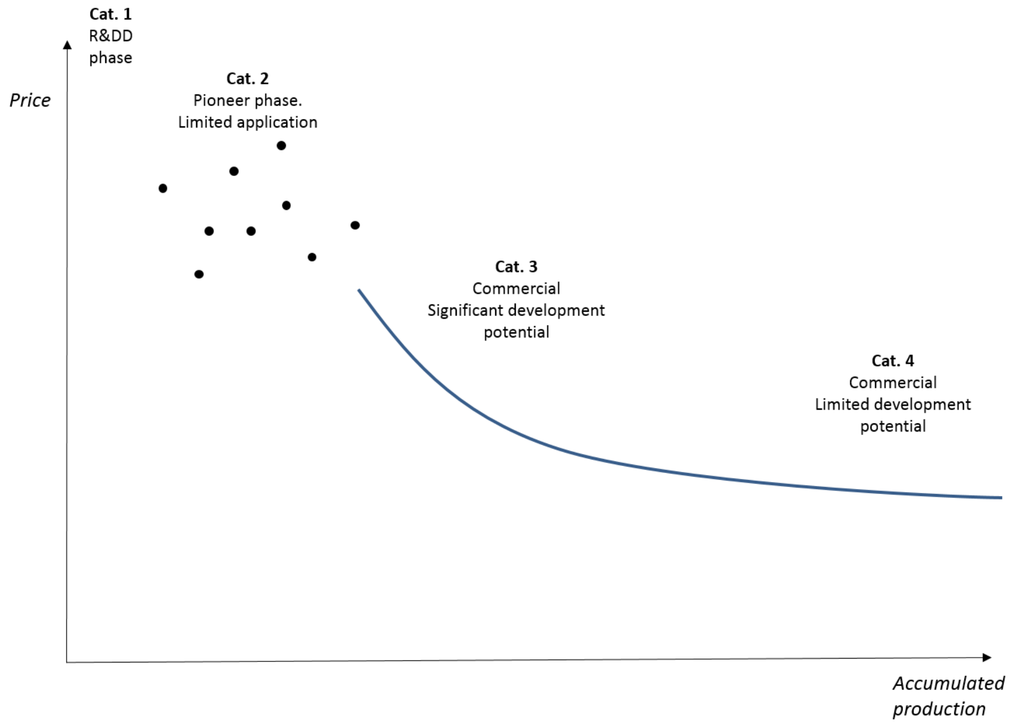

Figure 1: Technological development phases. Correlation between accumulated production volume (MW) and price.

Uncertainty

The catalogue covers both mature technologies and technologies under development. This implies that the price and performance of some technologies may be estimated with a relatively high level of certainty whereas in the case of others, both cost and performance today as well as in the future are associated with high levels of uncertainty.

This section of the technology chapters explains the main challenges to precision of the data and identifies the areas on which the uncertainty ranges in the quantitative description are based. This includes technological or market related issues of the specific technology as well as the level of experience and knowledge in the sector and possible limitations on raw materials. The issues should also relate to the technological development maturity as discussed above.

The level of uncertainty is illustrated by providing a lower and higher bound beside the central estimate, which shall be interpreted as representing probabilities corresponding to a 90% confidence interval. It should be noted, that projecting costs of technologies far into the future is a task associated with very large uncertainties. Thus, depending on the technological maturity expressed and the period considered, the confidence interval may be very large. It is the case, for example, of less developed technologies (category 1 and 2) and long time horizons (2050).

Additional remarks

This section includes other information, for example links to web sites that describe the technology further or give key figures on it.

References

References are numbered in the text in squared brackets and bibliographical details are listed in this section.

1.3. Quantitative description

To enable comparative analyses between different technologies it is imperative that data are actually comparable: All cost data are stated in fixed 2015 prices excluding value added taxes (VAT) and other taxes. The information given in the tables relate to the development status of the technology at the point of final investment decision (FID) in the given year (2015, 2020, 2030 and 2050). FID is assumed to be taken when financing of a project is secured and all permits are at hand. The year of commissioning will depend on the construction time of the individual technologies.

A typical table of quantitative data is shown below, containing all parameters used to describe the specific technologies. The datasheet consists of a generic part, which is identical for all technologies and a technology specific part, containing information, which is not relevant for all technologies. The generic part is made to allow for easy comparison of technologies.

Each cell in the table contains only one number, which is the central estimate for the market standard technology, i.e. no range indications.

Uncertainties related to the figures are stated in the columns named *uncertainty*. To keep the table simple, the level of uncertainty is only specified for years 2020 and 2050.

The level of uncertainty is illustrated by providing a lower and higher bound. These are chosen to reflect the uncertainties of the best projections by the authors. The section on uncertainty in the qualitative description for each technology indicates the main issues influencing the uncertainty related to the specific technology. For technologies in the early stages of technological development or technologies especially prone to variations of cost and performance data, the bounds expressing the confidence interval could result in large intervals. The uncertainty only applies to the market standard technology; in other words, the uncertainty interval does not represent the product range (for example a product with lower efficiency at a lower price or vice versa).

The level of uncertainty is stated for the most critical figures such as investment cost and efficiencies. Other figures are considered if relevant.

All data in the tables are referenced by a number in the utmost right column (Ref), referring to source specifics below the table. The following separators are used:

; (semicolon)   separation between the four time horizons (2015, 2020, 2030, and 2050)

/ (forward slash)   separation between sources with different data

+ (plus)   agreement between sources on same data

Notes include additional information on how the data are obtained, as well as assumptions and potential calculations behind the figures presented. Before using the data, please be aware that essential information may be found in the notes below the table.

The generic parts of the datasheets for individual heating technologies are presented below:

Technology	Name of technology									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)										
Electricity generation capacity for one unit (kW)										
Expected share of space heating demand covered by unit (%)										
Expected share of hot tap water demand covered by unit (%)										
Electric efficiency, annual average, net (%)										
Heat efficiency, annual average, net (%)										
Total efficiency, annual average, net (%)										
Auxiliary Electricity consumption (kWh/year)										
Technical lifetime (years)										
Regulation ability										
Change in capacity within 1 minute (%)										
Minimum load (% of full load)										
Warm start-up time (hours)										
Cold start-up time (hours)										
Environment										
SO_2 (g per GJ fuel)										
NO_X (g per GJ fuel)										
CH_4 (g per GJ fuel)										
N_2O (g per GJ fuel)										
Particles (g per GJ fuel)										
Financial data										
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)										
Possible additional specific investment (1000€/unit)										
Fixed O&M (€/unit/year)										
Variable O&M (€/MWh)										
Technology specific data										

Energy/technical data

Heat production and power generation capacity for one unit

The heat production and power generation capacities, preferably typical capacities (not maximum capacities), are stated for a single unit or, in case of solar heating, for a typical system size.

Both for heat and for power, any auxiliary electricity consumption for pumps etc. is not counted in the capacity.

The unit kW is used both for electric generation capacity and heat production capacity.

The relevant range of sizes of each type of technology is represented by a range of capacities stated in the notes for the “capacity” field in each technology table, for example 15-100 kW for a small domestic boiler.

In mCHP (micro combined heat and power) units, at part-load production the ratio between electric and heat capacity (C_b-coefficient for backpressure units) is considered constant.

Energy efficiencies

Efficiencies for all heating plants are expressed in percent at lower calorific heat value (lower heating value) at ambient conditions in Denmark, considering an average air temperature of approximately 8 °C.

The heat efficiency equals the net delivery of heat divided by the fuel consumption. The auxiliary electricity consumption is not included in the heat efficiency, but stated separately in kWh/year.

For heat pumps, a fuel efficiency of e.g. 300 % represents a COP of 3.

The energy supplied by the heat source for heat pumps (both electric and absorption) is not counted as input energy. The temperatures of the heat source are specified in the specific technology chapters.

If nothing else is stated in the technology description, the heat efficiency reflects the total heat efficiency covering both space heating and hot tap water.

The electric efficiency, expressed only for mCHP (micro combined heat and power) individual heating plants, equals the power delivered divided by the fuel consumption. As for heat efficiency, it does not include auxiliary electricity consumption.

The total efficiency is the sum of electric and heat efficiencies.

The efficiencies reflect annual average efficiencies as experienced by the consumer, assuming that the heat installations are installed correctly. The boundary of annual efficiency is shown in the figure below.

Often, the efficiencies decrease slightly during the operating life of a plant. This degradation is not reflected in the stated data. As a rule of thumb 2.5 – 3.5 % may be subtracted during the lifetime (e.g. from 40 % to 37 %).

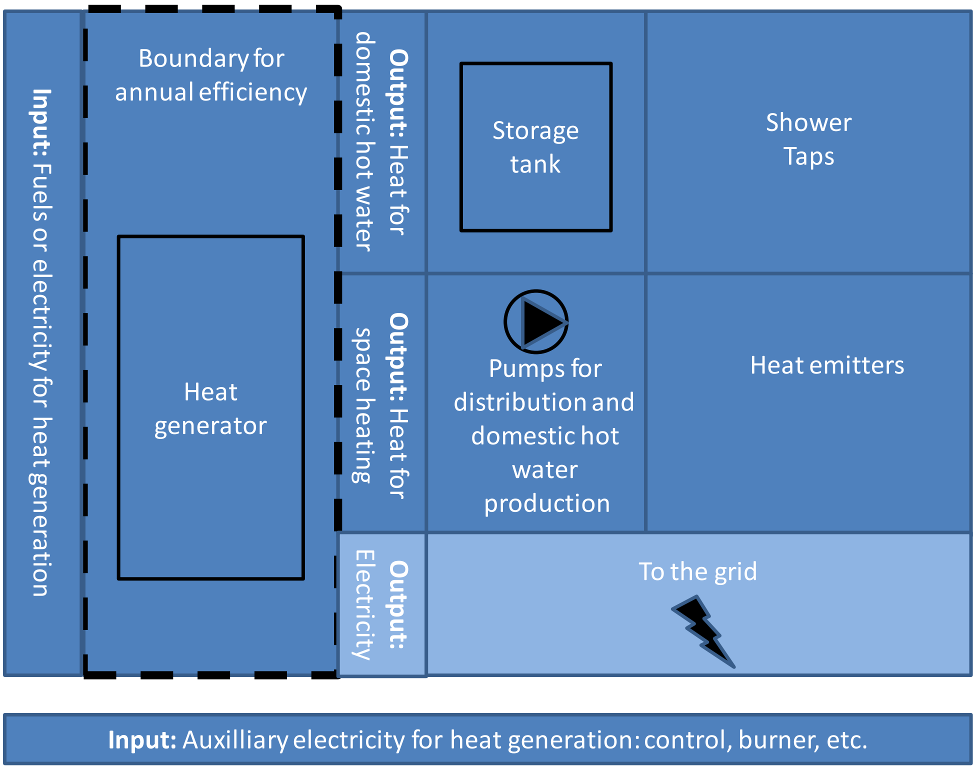

Figure 2: The dotted line shows the boundary for annual efficiency

Expected share of demand covered by unit

The expected share of total demand, both for space heating and for tap water, covered by the technology is specified in percentage (%).

Auxiliary electricity consumption

A specification of the annual auxiliary electricity demand for the heat installation is given in kWh/year. It accounts for the consumption of electricity from auxiliary systems such as pumps, ventilation systems, etc.

For heat pumps, internal consumption (inside the unit) is considered part of the efficiency (coefficient of performance, COP), while other electricity demand for external pumping, e.g. ground water pumping, and is stated under auxiliary electricity consumption.

The auxiliary electricity consumption is not included in the efficiencies, as it is possible to see from the boundaries in Figure 2.

Technical lifetime

The technical lifetime is the expected time for which an energy plant can be operated within, or acceptably close to, its original performance specifications, provided that normal operation and maintenance takes place. During this lifetime, some performance parameters may degrade gradually but still stay within acceptable limits. For instance, power plant efficiencies often decrease slightly (few percent) over the years, and O&M costs increase due to wear and degradation of components and systems. At the end of the technical lifetime, the frequency of unforeseen operational problems and risk of breakdowns is expected to lead to unacceptably low availability and/or high O&M costs. At this time, the plant is decommissioned or undergoes a lifetime extension, which implies a major renovation of components and systems as required to make the plant suitable for a new period of continued operation.

The technical lifetime stated in this catalogue is a theoretical value inherent to each technology, based on experience. The expected technical lifetime takes into account a typical number of start-ups and shut-downs.

In real life, specific plants of similar technology may operate for shorter or longer times. The strategy for operation and maintenance, e.g. the number of operation hours, start-ups, and the reinvestments made over the years, will largely influence the actual lifetime.

Regulation ability

Four parameters describe the electricity regulation capability of the technologies:

A. Change in capacity within 1 minute (%)
B. Minimum load (percent of full load).
C. Warm start-up time, (hours)
D. Cold start-up time, (hours)

For several technologies, these parameters are not relevant, e.g. if the technology is regulated instantly in on/off-mode.

Environment

All plants are assumed to be designed to comply with the regulation that is currently in place in Denmark and planned to be implemented within the 2020 time horizon.

The emissions below are stated in mass per GJ of fuel at the lower heating value.

CO_2 emission values are not stated, as these depend only on the fuel, not the technology.

SO_x emissions are expressed in grams per GJ of fuel.

NO_x. NO_x equals NO_2 + NO, where NO is converted to NO_2 in weight-equivalents.

Particles includes the fine particle matters (PM 2.5). The value is given in grams per GJ of fuel.

The emissions of CH_4 and N_2O can be converted to CO_2-equivalents by multiplying the CH_4 emission by 25 and the N_2O emission by 298.

Financial data

Financial data are all in Euro (€), fixed prices, at the 2015-level and exclude value added taxes (VAT) and other taxes.

Several data originate in Danish references. For those data a fixed exchange ratio of 7.45 DKK per € has been used.

The previous catalogue was in 2011 prices. Some data have been updated by applying the general inflation rate in Denmark (2011 prices have been multiplied by 1.0585 to reach the 2015 price level).

European data, with a particular focus on Danish sources, have been emphasized in developing this catalogue. This is done as generalizations of costs of energy technologies have been found to be impossible above the regional or local levels.

Investment costs

The investment cost is also called the engineering, procurement and construction (EPC) price or the overnight cost. Infrastructure and connection costs, i.e. electricity, fuel and water connections inside the premises of a plant, are also included. The investment cost includes the total costs of establishing the technology for the consumer.

Where possible, the investment cost is divided on equipment cost and installation cost. Equipment cost covers the components and machinery including environmental facilities, whereas installation cost covers engineering, civil works, buildings, grid connection, installation and commissioning of equipment.

Regarding the forecast of investment costs, it has been assumed that mature technologies without an expected technology leap have the same investment cost during the period. This is based on an assumption that costs of materials (e.g. steel prices) are also the same during the period (in fixed prices). If the costs of materials develop in one or another direction, it will most likely influence the technology costs.

Possible additional investment cost

Where relevant, also a line with possible additional specific investment costs has been included.
This is for instance relevant in connection with fluid-to-water heat pumps in city areas where it is necessary to establish vertical tubes (by use of drilling holes) instead of horizontal tubes.

Operation and maintenance (O&M) costs

The fixed share of O&M (€/unit/year) includes all costs, which are independent of how the plant is operated, e.g. administration, operational staff, payments for O&M service agreements, network use of system charges, property tax, and insurance. Any necessary reinvestments to keep the plant operating within the scheduled lifetime are also included, whereas reinvestments to extend the life beyond the lifetime are excluded. Reinvestments are discounted at 4 % annual discount rate in real terms. The cost of reinvestments to extend the lifetime of the plants may be mentioned in a note if the data has been readily available. Planned and unplanned maintenance costs may fall under fixed costs (e.g. scheduled yearly maintenance works) or variable costs (e.g. works depending on actual operating time), and are split accordingly.

The variable O&M costs (€/MWh) include consumption of auxiliary materials (water, lubricants, fuel additives), treatment and disposal of residuals, spare parts and output related repair and maintenance (however not costs covered by guarantees and insurances).

Fuel costs are not included.

Auxiliary electricity consumption is included. The electricity price applied is specified in the notes for each technology, together with the share of O&M costs due to auxiliary consumption. This enables corrections from the users with own electricity price figures.

It should be noticed that O&M costs often develop over time. The stated O&M costs are therefore average costs during the entire lifetime.

Technology specific data

Additional data is specified in this section, depending on the technology.

1.4 Definitions

Building types and heat demand

Some of the individual technologies are described for different unit sizes and/or for existing and new buildings, respectively. This is shown in the table below:

Table 1: Technology descriptions - relevant combinations technology and building

	Existing buildings		New buildings	
	One-family houses	Apartment complex	One-family houses	Apartment complex
Oil boiler (including bio oil)	X	X	X (bio oil)	X (bio oil)
Gas boiler	X	X	X	X
District heating substation	X	X	X	X
Biomass boiler, automatic stoking	X	X	X	X
Biomass boiler, manual stoking	X		X	
Wood stove	X		X	
Electric heat pump, air to air	X		X	
Electric heat pump, air to water	X	X	X	X
Electric heat pump, brine to water	X	X	X	X
Electric ventilation heat pump			X	X
Gas driven absorptions heat pump air/brine to water	X	X	X	X
Gas engine driven heat pump, air/brine to water		X		X
Gas driven adsorption heat pump brine to water	X		X	
Solar heating system	X	X	X	X
Electric heating			X	X
Micro CHP - natural gas fuel cell	X		X	
Micro CHP - hydrogen fuel cell	X		X	
Micro/Mini CHP - Stirling engine	X		X	X
Micro/Mini CHP - Gas engine	X	X	X	X

The highest heat capacity among the commercial Stirling engines on the market is 15 kW. Even though it is possible to install several units, a Stirling engine is mainly found relevant for one-family houses and for new apartment complexes with a relatively low heat demand (where the number of units can be limited).

As year 2015 is the base for the present status of the technologies, new buildings are considered to comply with the building code in 2015.

An existing one-family house is defined to have an annual heat demand of 16.8 MWh and a peak demand of 7 kW.

An existing one-family house, which has been energy renovated, is defined to have an annual heat demand of 8.4 MWh and a peak demand of 4.5 kW.

A new one-family house is defined to have an annual heat demand of 6.0 MWh and a peak demand of 3 kW. It should be noted that practical experiences have shown that new buildings - even though they have been designed according to the building code 2015 - can also have a higher heat demand.

An existing housing block is defined to have an annual heat demand of 960 MWh and a peak demand of 400 kW.

A new housing block is defined to have an annual heat demand of 320 MWh and a peak demand of 160 kW.

The size of buildings, the annual heat consumption and the peak-load demand is shown in the table below. New one-family houses are expected to have an average size of 150 m^2 (including terraced houses), whereas the average size of existing one-family houses is around 140 m^2.

Table 2: Annual heat consumption and peak load "an radiator"

	One-family house - existing building	One-family house - existing building Energy renovated	Apartment complex - existing building	One-family house - new building	Apartment complex - new building
Size, m^2	140	140	8,000	150	8,000
Annual heat consumption, MWh	16.8	8.4	960	6.0	320
Peak load, kW	7	4.5	400	3	160

The heat demands are based on a demand in existing buildings of 120 kWh/m2 (hereof 25 kWh/m2 for hot tap water including losses) and a heat demand in new buildings of 40 kWh/m2 (hereof 20 kWh/m2 for hot tap water including losses). The reason why the heat demand for hot tap water in new buildings is lower than in existing buildings is an expectation of more technical insulation etc. in new buildings. It can be seen from the figures that the hot tap water makes up app. 18 % of the total heat demand in existing buildings and 50 % of the total heat demand in new buildings.

The estimated peak loads are based on a peak load of 50 W/m2 in existing buildings and 20 W/m2 in new buildings.

By dimensioning heat production technologies, the capacity should be higher than the estimated peak load in the table above. For instance, oil and gas boilers should have a capacity of at least 10 kW for one-family houses to make sure that they can produce hot tap water fast enough - also depending on the size of the hot-water tank. For heat pumps which often have a larger hot-water tank, a smaller installed capacity than for oil and gas boilers may be sufficient.

The figures in the table above can be used for some rough estimates of the annual heat consumption and peak demand. However, in each specific project, the annual heat consumption and peak demand should be estimated more precisely, depending on the specific types of buildings and sizes.

Technologies and scope of investment

The catalogue is intended to work as a tool for energy planners including municipalities in their assessment, comparison and identification of future energy solutions for heat production in households etc. Hence, it is important to stress that the specific technical and economic data for each technology presented in the catalogue are not in all cases directly comparable, as data/figures cover different aspects of the energy supply of a building and the needed investment costs, respectively.

The table below includes the technologies, the scope of the technology definition used within the catalogue and direct and accompanying investment costs. The aim is to outline the different elements that have to be taken into consideration when using the catalogue data for a fair comparison of technologies.

Table 3: Overview of investment costs included in technology data sheets and necessary accompanying investment costs

	Abolition of prior heat production system/unit	Necessary improvements of building envelope	Necessary accompanying heat supply installations	**Installation of primary heat production technology - elements included in the technology descriptions**	Installation of secondary heat production technology
Oil boiler	Often necessary in existing buildings e.g. • dismantling of existing boiler, • removal of oil tank, etc.	Existing buildings: not directly needed but in many cases recommendable	• Water based heat supply system • Oil tank • Chimney/flue	**Investment /installation costs of boiler incl. pumps, hot tap water production and storage.**	
Gas boiler	Often necessary in existing buildings e.g. • dismantling of existing boiler, • removal of oil tank, etc.	Existing buildings: not directly needed but in many cases recommendable	• Water based heat supply system • Chimney/flue • Service gas pipe and meter	**Investment /installation costs of boiler incl. pumps, hot tap water production and storage.**	
Biomass boiler	Often necessary in existing buildings e.g. • dismantling of existing boiler, • removal of oil tank, etc.	Existing buildings: not directly needed but in many cases recommendable	• Water based heat supply system • Chimney/flue • Fuel storage facility	**Investment /installation costs of boiler incl. pumps, hot tap water production and storage.**	
Heat pumps – air to air/ ventilation	Often necessary in existing buildings e.g. • dismantling of existing boiler, • removal of oil tank, etc.	Existing buildings: energy saving measures often needed in order to optimise heat pump installation	• Existing buildings : measures to reduce radiator temperatures often needed	**Investment /installation costs of heat pump, back-up electrical heater**	• Back up heat e.g. electrical radiators • hot tap water supply needed
Heat pumps – air/fluid to water	Often necessary in existing buildings e.g. • dismantling of existing boiler, • removal of oil tank, etc.	Existing buildings: energy saving measures often needed in order to optimise heat pump installation	• Existing buildings :measures to reduce radiator temperatures often needed • Water based heat supply system	**Investment /installation costs of heat pump incl. pipes, pumps, back-up electrical heater and hot tap water production and storage.**	
Gas Absorption Heat pumps (air-to-water and brine-to-water)	Often necessary in existing buildings e.g. • dismantling of existing gas boiler,	Existing buildings: energy saving measures might be needed in order to optimise heat pump installation	• Water based heat supply system • Service gas pipe and meter •Chimney/flue (for indoor installation only)	**Investment /installation costs of heat pump incl. pumps, -and hot tap water production and storage.** ***• Specific for brine-to-water; pipes***	
Gas engine heat pump (air-to-water and brine-to-water)	Often necessary in existing buildings e.g. • dismantling of existing gas boiler	Existing buildings: energy saving measures might be needed in order to optimise heat pump installation	•Water based heat supply system • Service gas pipe and meter •Chimney/flue (for indoor installation only)	**Investment /installation costs of heat pump incl. pumps, -and hot tap water production and storage.** ***• Specific for brine-to-water; pipes***	
Gas Adsorption Heat pumps (brine-to-water)	Often necessary in existing buildings e.g. • dismantling of existing gas boiler	Existing buildings: energy saving measures might be needed in order to optimise heat pump installation	• Water based heat supply system • Service gas pipe and meter •Chimney/flue	**Investment /installation costs of heat pump incl. pumps, -and hot tap water production, storage and pipes**	

	Abolition of prior heat production system/unit	Necessary improvements of building envelope	Necessary accompanying heat supply installations	**Installation of primary heat production technology - elements included in the technology descriptions**	Installation of secondary heat production technology
District heating unit	Often necessary in existing buildings e.g. • dismantling of existing boiler, • removal of oil tank, etc.	Existing buildings: not directly needed but in many cases recommendable		**Investment /installation costs of DH unit incl. pumps, hot tap water production and storage and service DH pipe and meter.**	
Wood stove			• Fuel storage facility • Chimney/flue	**Investment /installation costs of stove (and water tank)**	• Supplementary heat supply •hot tap water production and storage depending on water tank
Solar heating		In some cases improvement of roof construction		**Investment /installation costs of panel incl. pipes, pumps and hot tap water storage.**	• Heat production facility • Supplementary hot tap water production
Electrical heating		Existing buildings: not directly needed but in many cases recommendable		**Investment /installation costs of electric radiators and hot tap water production and storage.**	
Micro CHP incl. fuel cells	Often necessary in existing buildings e.g. • dismantling of existing boiler, • removal of oil tank, etc.	Existing buildings: not directly needed but in many cases recommendable	• Water based heat supply system • Chimney/flue •Service gas pipe and meter	**• Investment /installation costs of CHP/ fuel cell unit incl. pumps, meter, hot tap water production and storage. • Fuel cell (H2); hydrogen storage, electrolyser and back-up electrical heater • Fuel cell (NG); service gas pipe and back-up gas burner • Stirling and gas engine; service gas pipe and back-up gas burner**	

As can be seen from the table, there are several elements related to the installation of a particular new heating technology in a building that are not directly reflected in the investment cost and descriptions of the different technologies following this chapter.

The following table shows some of the general costs of needed accompanying investment cost, which potentially could be added when comparing the different technology solutions.

Table 4: Cost of accompanying investments

Accompanying element		Costs (EUR 2015)
Dismantling of existing boiler	Single family houses:	
	Wall hung natural gas fired boiler: 2,100 DKK ex. VAT	290 EUR
	Floor standing oil fired boiler: 3,200 DKK ex. VAT	420 EUR
Removal of oil tank	Single family houses:	
	1,200 litre tank (standing tank) including removal of old oil: 4,200 DKK ex. VAT	570 EUR
	Underground tank, removal of old oil, sealing of connections (no removal): 4,200 DKK ex. VAT	570 EUR
Building envelope improvements	Costs depend on the building standard etc. More information and tools to estimate costs can be found at e.g. www.byggeriogenergi.dk (The Danish Knowledge Centre for Energy Savings in Buildings).	
Water based heat supply system in building	Existing single family house (140 m^2):	
	Radiator system: 52,500 DKK ex. VAT	7,100 EUR
	New single family house (150 m^2):	
	Radiator system: 47,500 DKK ex. VAT	6,350 EUR
	Floor heating (in concrete slap): 37,000 DKK ex. VAT	4,970 EUR
	Floor heating (with diffusion plates): 47,500 DKK ex. VAT	6,350 EUR
	All prices include manifolds, piping, insulation, heat emitters/surfaces, thermostats and man hours.	
Additional radiator surface	2.2 DKK ex. VAT pr Watt (standard radiators, 300-1,000 Watt)	
	Radiators installed including thermostats:	
	Existing single family house (140 m^2): 5,300 DKK ex. VAT	710 EUR
	New single family house (150 m^2): 4,200 DKK ex. VAT	570 EUR
Oil tank	1,200 litre standing tank including installations: 8,500 DKK ex. VAT	1,160 EUR
Flue	Single family houses:	
	5 meter stainless steel flue including fittings: 7,400 DKK ex. VAT	990 EUR
	5 meter vertical flue, balanced coaxial split installed in existing chimney: 4,200 DKK ex. VAT	570 EUR

References

Numerous reference documents are mentioned in each of the technology chapters and sheets.

References used in the introduction are mentioned below:

[1] International Energy Agency, Energy Technology Perspectives, 2012.
[2] International Energy Agency, Available at: http://www.iea.org/. Accessed: 11/03/2016.

201 Oil-fired boiler

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Date	Ref.	Description

Qualitative description

Brief technology description

Oil-fired boilers are made for hot water and steam production. In the following, only hot water boilers are considered. The boilers are made in a power range from 15 kW to several MW. The oil qualities considered are:

1. Domestic mineral fuel oil.
2. Domestic oil with added bio-oil up to 10 % (fatty acid methyl ester, FAME).
3. Raw bio oil, e.g. rapeseed oil.
4. Hydro treated vegetable oil (HVO), [10].

The complete oil-fired system includes a boiler, a burner, an oil tank and a chimney or an exhaust system. In the case of a condensing boiler, a floor drain for the condensate should be available.

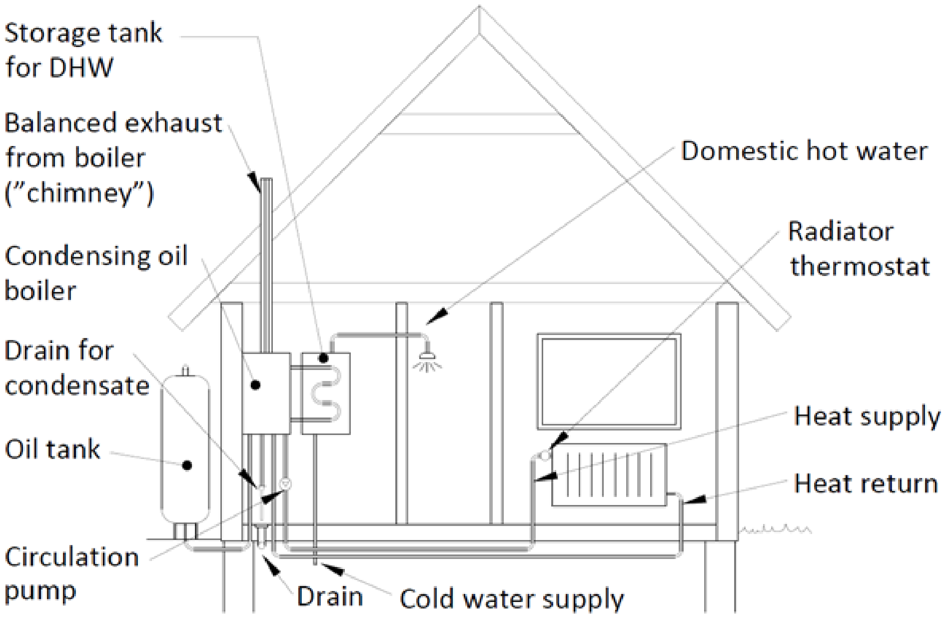

Figure 3: **A typical installation of a condensing oil-fired boiler in a single-family house**

The burner technology is atomisation by a high-pressure oil nozzle for minor boilers. For very large boilers, other technologies are available, for instance atomisation by a rotating cup. Some advanced recently developed small boilers are also using some rotating cup technology, which allows for modulating burner control. The burners may be yellow flame burners giving a small emission of soot or blue flame burners without soot emission but with a tendency to emit CO instead of soot. For the different fuels, the burner technologies are somewhat different - e.g. some fuels require preheating of the oil.

The boilers for all oil types are of almost similar design: a water-cooled combustion chamber and an integrated convection part. The materials are steel, cast iron or stainless steel. Modern boilers can be delivered with a corrosion resistant flue gas cooler that allows for condensation of the water vapour in the flue gas.

Small domestic boilers (15-70 kW)

The small boilers are used for domestic heating in single family houses. The 15 kW boiler heats up to 200-300 m2 of building area under Danish climate conditions. Very often, the boilers are built with an integrated hot water system, normally a tank of 80-150 l for the domestic tap water. Use of condensing technology is mandatory in Denmark.

In the range of 170.000 - 200.000 oil-fired boilers are installed in Denmark [9], the largest part in single-family houses in areas where natural gas or district heating are not available.

Larger boilers (70 kW - 1 MW)

These boilers are used in apartment complexes, institutions etc. If the connected heating system can deliver return temperatures below 45 °C, a condensing flue gas cooler will often be added. Units with integrated condensing flue gas cooler are also available. The efficiency is influenced by the flue gas temperature - in best cases only few degrees higher than the return temperature. In large boilers, the heat loss from the boiler can be reduced to only a fraction of a percent.

Oil-fired boilers can have annual efficiency in the range of 100 %, if the return temperature from the heating system is sufficiently low, say lower than 48 °C, [1], [2] and [3].

Input
Domestic fuel oil is more or less the same as diesel. Bio oil (FAME) can be added up to approximately 10 % without severe problems.

Output
Heat for central heating and for domestic hot water.

Typical capacities
The heat output range from 15 kW to 1 MW.

Regulation ability
The ability to reduce the heat output is excellent for most modern boilers. It should be emphasised that a boiler with a nominal heat output of 15 kW is able to operate at part load, many types will be

able to operate down to almost zero heat output still obtaining a high efficiency. The reason for this is that the heat loss from the boiler typically is low because of insulation and low-temperature operation.

Advantages/disadvantages

Advantages

The oil-fired boiler is a simple, reliable technology and operates with a high thermal efficiency. Also as stated above, the control ability of oil-fired burners is excellent.

Today, there are burners for pure bio oil on the market, operating with acceptable levels of problems, although some enthusiasm may be required.

Normally regular service is made on oil-fired boiler-burner combinations. This is recommended by the authorities. The manufacturers normally recommend annual service.

Disadvantages

Due to external factors including, changing and unpredictable demands, geopolitics and potentially resource scarcity fuel oil prices are unpredictable and volatile, meaning that not only is the oil boiler a potentially expensive heat source, it is also difficult to predict the cost of heat one or two seasons ahead.

The reliability and the maintenance (regular cleaning of the burner as an example) of bio oil burners cannot be compared with burners of mineral oil [10]. Some research and development is still needed in case of pure liquid bio fuels. The problems mostly concern practical issues with components (rubber gaskets), storage, sensibility to ambient temperature variations, preheating of the bio oil, electricity consumption of the burner etc. Burners for raw bio-oil may also have difficulties when running on condensing boilers. Nonetheless these issues are considered to be solvable. Hydro treated vegetable oil (HVO) is almost pure hydrocarbon and can be burnt almost without emission of pollution. HVO is presently not on the market in Denmark.

For large plants - in MW size - burning of 100% bio oil gives no problems. For domestic use, some problems still remain.

Environment

A boiler fired with modern domestic fossil fuel oil with low content of sulphur and nitrogen will - except from the greenhouse gas CO_2 – give rise to the same level of pollution as a natural gas boilers. The pollutants in concern are:

- Unburnt hydrocarbon (only traces),
- CO (less than 100 ppm in the flue)
- NOX (less than 110 mg/kWh ~ 30 g/GJ)
- Soot (Soot number 0 – 1), see [8].
- Voluntarily most boilers are cleaned, adjusted and then inspected once a year for flue gas loss, soot and CO (for blue flame burners).

In Denmark, boilers with an input energy larger than 100 kW must fulfil "Luftvejledningen", [6], which includes "OML" calculation of immissions (The pollution concentration in the landscape around the plant).

Research and development perspectives

The R&D in 60 years in combustion of mineral oil has resulted in very efficient, cheap and simple technology. Burner/boiler combinations with low emissions and efficiency close to the thermodynamic limits are common on the market.

The efficiency is regulated under the Eco design directive [12] that sets requirements for the minimum efficiency of products. The regulation for oil boilers entered into force in September 2015 and replaces the earlier demands concerning efficiency for boilers.

For boilers with a rated heat output between 70 kW and 400 kW the requirements are that efficiency (related to GCV) shall be higher than 86% at 100% load and higher than 94% at 30% partial load (based on gross calorific value). Based on lower calorific value this corresponds to 92 % respectively 100 %. This efficiency includes electricity consumption and also some adjustment due to automatic control. It can be shown that the ECO design demands corresponds reasonable to former demands in the BR 10. [13] and also with the assumptions in the tables.

Examples of market standard technology

The best modern boilers operates with annual efficiencies in the range of 100 % (lower calorific value), dependent on the heating system to which the boiler is connected. At the same time, the boiler/burner can be chosen with very low emissions of pollution. New types of bio oils are coming up, e.g., hydro treated vegetable oil (HVO), cf. [10]. This type of oil can be produced in a quality very close to domestic mineral fuel oil. They are, however, not available on the Danish market yet.

Prediction of performance and costs

Oil boilers are mature and commercial technology with a large deployment (a category 4 technology). Yet improvements are still possible and possible refinements of oil boilers are:

- Flue gas heat exchanger with exit temperature close to the return temperature from the heating system
- The connected heating system shall be able operate with return temperatures close to room temperature
- The connected hot tap water heat exchanger shall operate with return temperatures close to the cold tap water temperature.
- The boiler shall be placed inside the building so most of the heat loss from the boiler parts will be used in the building.
- The electricity consumption for burner, controls, preheating of oil etc. is to be minimized.

While the cost of oil boilers have decreased during the last 60 years, it is considered unlikely that this trend will continue with any significance – albeit smaller cost reductions are expected due to a general increase in productivity.

Uncertainty

The expected development in thermal efficiency is assumed driven by increasing oil prices. If the expectations to the oil prices are not fulfilled, it is likely that the above mentioned technological improvements will be delayed or not occur at all.

Economy of scale effects

A typical price for 15-30 kW boiler of best quality cost in the range of 6,000-7,000 Euros, a 400 kW boiler cost in the range 30,000-35,000 Euros. So the small ones cost around 230 Euros per kW and a 400 kW cost around 85 Euros per kW, hence oil boilers display a significant economy of scale effect.

Additional remarks

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Data sheets

Table 5: Oil boiler – one-family house, existing and energy renovated buildings

Technology	Oil boiler (mineral oil fired, < 10 % FAME) - One-family house, existing and energy renovated buildings									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	15	15	15	15	13	30	15	30	A	
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	92	92	93	95	90	95	95	98	N	1,2,3,4,14
Total efficiency, annual average, net (%)	92	92	93	95	90	95	95	98	N	1,2,3,4,14
Auxiliary Electricity consumption (kWh/year)	150	140	130	110	100	160	90	150	M	11
Technical lifetime (years)	20	20	20	20	15	25	15	25		
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Minimum load (% of full load)	0	0	0	0	0	0	0	0		
Warm start-up time (hours)	0	0	0	0	0	0	0	0		
Cold start-up time (hours)	0	0	0	0	0	0	0	0		
Environment										
SO_2 (g per GJ fuel)	0,5	0,5	0,5	0,5	0	1	0	1	B,E	
NO_X (g per GJ fuel)	30	25	20	15	20	30	0	25	C	5
CH_4 (g per GJ fuel)	0	0	0	0	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0	0	0	0	0		
Particles (g per GJ fuel)	0,03	0,02	0,01	0,01	0,01	0,03	0	0,02	D	
Financial data										
Specific investment (1000€/unit)	6	5,9	5,6	5,0	5	8	4	7	F, H, J	
- hereof equipment (%)	70	70	70	70	70	70	70	70		
- hereof installation (%)	30	30	30	30	30	30	30	30		
Possible additional specific investment (1000€/unit)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Fixed O&M (€/unit/year)	249	244	236	214	207	311	191	268		
- of which is electricity costs (€/unit/year)	9	10	13	13	7	11	11	18	M	
- of which is other O&M costs (€/unit/year)	240	234	223	201	200	300	180	250	H	
Variable O&M (€/MWh) at 15-40 kW	0	0	0	0	0	0	0	0		

Table 6: Oil boiler – apartment complex, existing building

Technology	Oil boiler (mineral oil fired, < 10 % FAME) - Apartment complex, existing building.									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	400	400	400	400	100	1000	100	1000		
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	92	92	93	95	90	95	95	98	N	1,2,3,4,14
Total efficiency, annual average, net (%)	92	92	93	95	90	95	95	98	N	1,2,3,4,14
Auxiliary Electricity consumption (kWh/year)	1500	1400	1300	1200	1000	1800	500	1500	M	11
Technical lifetime (years)	20	20	20	20	15	25	15	25		
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Minimum load (% of full load)	0	0	0	0	0	0	0	0		
Warm start-up time (hours)	0	0	0	0	0	0	0	0		
Cold start-up time (hours)	0	0	0	0	0	0	0	0		
Environment										
SO_2 (g per GJ fuel)	0,5	0,5	0,5	0,5	0	1	0	1	B,E	
NO_X (g per GJ fuel)	30	25	20	15	20	30	0	25	C	5
CH_4 (g per GJ fuel)	0	0	0	0	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0	0	0	0	0		
Particles (g per GJ fuel)	0,03	0,02	0,01	0,01	0,01	0,03	0	0,02	D	
Financial data										
Specific investment (1000€/unit)	35	34,1	32,5	29,4	32	38	26	33	F, H, K	
- hereof equipment (%)	70	70	70	70	70	70	70	70		
- hereof installation (%)	30	30	30	30	30	30	30	30		
Possible additional specific investment (1000€/unit)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Fixed O&M (€/unit/year)	855	838	836	778	669	1024	559	976		
- of which is electricity costs (€/unit/year)	95	97	131	140	69	124	59	176	M	
- of which is other O&M costs (€/unit/year)	760	741	705	638	600	900	500	800	H	
Variable O&M (€/MWh)	25	25	23	21	20	30	15	30		

Table 7: Oil boiler (bio oil) – one-family house, new building

Technology	Oil boiler (bio oil) - One-family house, new building. HVO is assumed from 2030									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	15	15	15	15	13	30	15	30	A,I	
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100	I	
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100	I	
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	88	88	92	94	85	95	90	98	G,N	1,2,3,4,14
Total efficiency, annual average, net (%)	88	88	92	94	85	95	90	98	G,N	1,2,3,4,14
Auxiliary Electricity consumption (kWh/year)	100	95	90	75	75	125	60	100	M	11
Technical lifetime (years)	20	20	20	20	15	25	15	25		
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Minimum load (% of full load)	0	0	0	0	0	0	0	0		
Warm start-up time (hours)	0	0	0	0	0	0	0	0		
Cold start-up time (hours)	0	0	0	0	0	0	0	0		
Environment										
SO_2 (g per GJ fuel)	0,5	0,5	0,5	0,5	0	1	0	1	B,E	
NO_X (g per GJ fuel)	30	25	20	15	20	30	0	25	C	7
CH_4 (g per GJ fuel)	0	0	0	0	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0	0	0	0	0		
Particles (g per GJ fuel)	0,03	0,02	0,01	0,01	0,01	0,03	0	0,02	D	
Financial data										
Specific investment (1000€/unit)	10	9,8	9,3	8,4	8	10	6	9	F,H,I,J,L	
- hereof equipment (%)	70	70	70	70	70	70	70	70		
- hereof installation (%)	30	30	30	30	30	30	30	30		
Possible additional specific investment (1000€/unit)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Fixed O&M (€/unit/year)	246	241	232	210	205	309	187	262		
- of which is electricity costs (€/unit/year)	6	7	9	9	5	9	7	12	M	
- of which is other O&M costs (€/unit/year)	240	234	223	201	200	300	180	250	H	
Variable O&M (€/MWh) at 15-40 kW	0	0	0	0	0	0	0	0		

Table 8: Oil boiler – apartment complex, new building

Technology	**Oil boiler (bio oil) - Apartment complex, new building. HVO is assumed from 2030**									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	160	160	160	160	100	1000	100	1000		
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	88	88	92	94	85	95	90	98	G,N	1,2,3,4,14
Total efficiency, annual average, net (%)	88	88	92	94	85	95	90	98	G,N	1,2,3,4,14
Auxiliary Electricity consumption (kWh/year)	1000	900	520	480	400	720	200	600		11
Technical lifetime (years)	20	20	20	20	15	25	15	25		
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Minimum load (% of full load)	0	0	0	0	0	0	0	0		
Warm start-up time (hours)	0	0	0	0	0	0	0	0		
Cold start-up time (hours)	0	0	0	0	0	0	0	0		
Environment										
SO_2 (g per GJ fuel)	0,5	0,5	0,5	0,5	0	1	0	1	B,E	
NO_X (g per GJ fuel)	40	25	20	15	20	30	0	25	C	7
CH_4 (g per GJ fuel)	0	0	0	0	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0	0	0	0	0		
Particles (g per GJ fuel)	0,03	0,02	0,01	0,01	0,01	0,03	0	0,02	D	
Financial data										
Specific investment (1000€/unit)	28	27,3	26,0	23,5	20	40	20	40	F,H,K,L	
- hereof equipment (%)	70	70	70	70	70	70	70	70		
- hereof installation (%)	30	30	30	30	30	30	30	30		
Possible additional specific investment (1000€/unit)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Fixed O&M (€/unit/year)	563	550	516	476	528	1050	473	970		
- of which is electricity costs (€/unit/year)	63	62	53	56	28	50	23	70	M	
- of which is other O&M costs (€/unit/year)	500	488	464	420	500	1000	450	900	H	
Variable O&M (€/MWh)	25	25	23	21	20	30	15	30		

Notes

A The minimum heat output for a pressure atomisation burner is in the range of 13 kW. Due to the insignificant economy of scale displayed by domestic boilers (se section on economy of scale) the savings achieved by reducing the capacity below 13 kW is limited or non-existing. Hence, the investment cost is not influenced by the capacity of the boilers installed.

B Domestic fuel oil can be desulphoried to the lower than 10 ppm Sulpur

C The last limit for NOx for Blaue Engel were 110 mg/kWh. The value is based on this. In Practise the value can be lower. In 2050 is assumed flue gas cleaning for NOx.

D Based on Soot number 0 - 1, which is the average value in DK

E Data for Sulphur content can be found at the homepages for the oile companies

F Installation and service prices given by Weishaupt, Denmark

G Burners for liqued raw biofuel is not suited for condensing boilers for different reasons. In the case HVO becomes feasible condensing technology will work well

H Assuming a cost-reduction of 0.5 % p.a., which in turn is assumed equivalent to the typical improvement of mature technologies.

I New single family houses will have a heat demand at 2- 4 kW for space heating and a power demand for hot water at 32 kW. Using a hot water tank the power need can go down to 0,5 kW depending on tank size. A typical compromise is a boiler at 20 kW and a tank at 80 liters.

J Exchanging an oil-fired boiler without changing the domestic hot water tank is normally not relevant. The price includes a tank.

K The price does not include the domestic hot water system.

L The price includes a chimney/exhaust system.

M The cost of auxiliary electricity consumption is calculated using the following electricity prices in €/MWh: 2015: 63, 2020: 69, 2030: 101, 2050: 117. These prices include production costs and transport tariffs, but not any taxes or subsidies for renewable energy.

N The typical efficiency is believed to be approx. 5 %-point lower than the Eco-design label cf. ref [12]

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202 Natural gas boiler

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Qualitative description

Brief technology description

Gas boilers are burning gas (natural gas, biogas etc.). The energy delivered by the combustion is used to heat water through a heat exchanger that is built into the boiler.

In a gas fired boiler, gas is burnt in a combustion section. It may be a traditional flame or a specially designed low-NOX burner. The heat is transferred to water through water cooled walls and through a water heat exchanger after the combustion section. Gas boilers can be wall hung or floor standing.

The hot water from the gas boiler is circulated in the radiators of the house (a pump is, therefore, required on the installation or in the boiler).

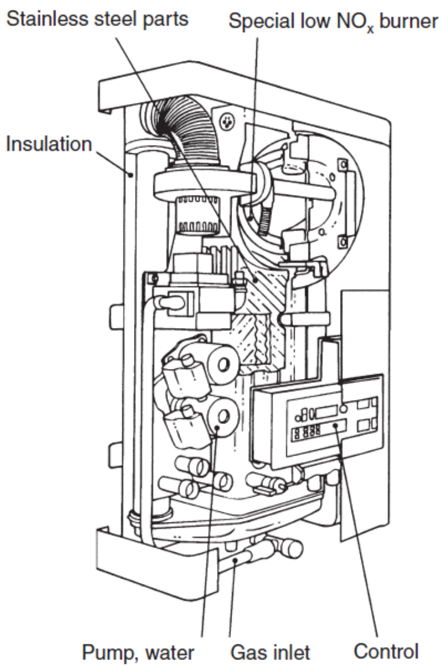

Figure 4: A wall hung gas boiler for a one-family house (Source: VarmeStåbi®, Nyt Teknisk Forlag)

A gas boiler is often called a "central heating (CH) boiler", as it is one of the elements of a central heating installation including boiler(s), a heat distribution system, heat emitters (radiators, convectors etc.) and a control system for the appliances.

Condensing gas boiler

A condensing boiler is a boiler designed for low-temperature operation including recovering low-temperature heat and the latent heat from water vapour produced during the combustion of the fuel. The condensing boilers include two stages of heat transfer, compared to traditional boilers (non-condensing boilers), which only include one stage. In the condensing boiler, a second heat exchanger is placed before the flue gas exit to collect the latent heat contained in the flue. Most gas-fired boilers also allow for condensation in the combustion chamber.

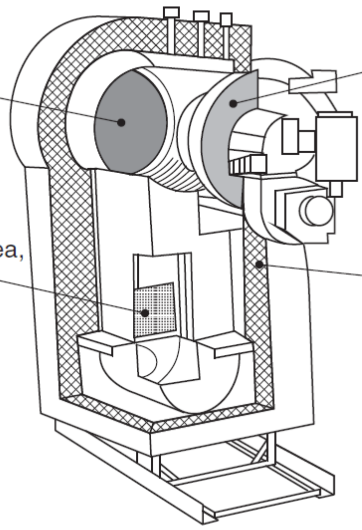

Figure 5: A floor standing medium size condensing gas boiler for apartment blocks etc. (Source: VarmeStåbi®, Nyt Teknisk Forlag)

Condensing flue gas recovery heat exchangers can also be installed as auxiliary equipment after the boiler. Traditional gas boilers (non-condensing boilers) can no longer be installed in Danish houses/buildings (Requirements of the building regulations [22]). Most gas boilers will accommodate a large variety of natural gas compositions or LPG's with slight technical changes to the burner. Gas boilers are often used for heating and domestic hot water production. For the later, hot water storage is mostly used (in Denmark), but it is also possible to have appliances producing hot water instantaneously.

Efficiency of gas boilers

Gas boiler's energy efficiency is mainly depending on water temperature. The improved insulation of boilers and new burner technologies makes it possible to come close to the theoretically achievable efficiency. Annual energy efficiencies in real installations are today above 100% and up to 104% (based on lower calorific value) [9], [10].

Annual energy efficiency referred to in the section "natural gas boilers" is calculated with BOILSIM a method developed with more than 15 EU partners [10], [11] and includes heating and hot water production based on Danish average houses.

Input

Natural gas boilers are using natural gas as fuel. They can also use LPG gases (in general with minor burner changes). Biogas can in principle be used as well. It can be injected into the gas grid and mixed with natural gas or used directly (this requires major CO2 removal from the gas to have a calorific value close to CH4). However, there is very limited practical experience with using un-upgraded biogas.

Output

The form of energy generated by gas boilers is heat transferred to heated water. So the output is hot water either used for heating or directly for domestic hot water.

Typical capacities

For the domestic market, most of the gas boilers (single units) have a nominal heat output of about 20 kW and are modulating (see next section) down to 1 kW for very new technologies. Up to 20/35 kW are needed to cover the domestic hot water production (especially in the case of boilers without water tank) [24], whereas for heating 10 kW or less would be sufficient for most of the domestic houses [25]. There is no real differentiation between boilers for the new buildings compared to the existing buildings because most of the boilers are designed to cover the domestic hot water demand which is not depending on new or existing building. In general, gas boilers are produced as a series of similar appliances having different capacities. Examples of nominal capacities are 10, 20, 30 and 50 kW. For apartment blocks and other large buildings, where the heat demand is larger than for one-family houses, larger boilers of several hundred kW are used, but alternatively the combination of several domestic appliances connected in so-called "cascade" is a possible solution. In that case, the number of appliances in operation is determined by the heat demand.

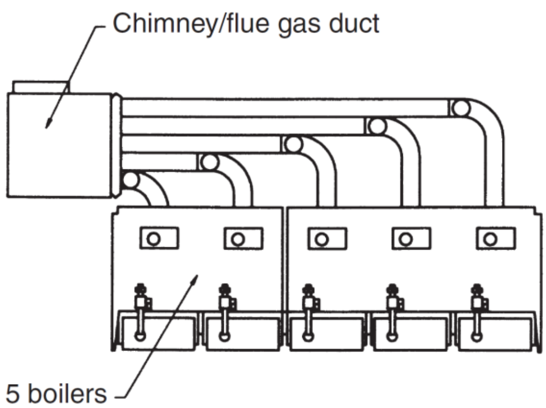

Figure 6: Cascade installation of boilers (Source: VarmeStåbi®, Nyt Teknisk Forlag)

Regulation ability

Boilers are generally sold with controls that enable the optimal matching between the user demand and the appliance's heat production and the actual hot water demand. For example, in case the user needs hot water, the control system will give production priority to that demand. The control systems are able to communicate with components such as external temperature sensor or pump.

The control system will also adapt to other control elements such as radiator thermostat etc. Some control systems are auto-adaptive: they will learn from the recent past to optimize the control of the boiler. Most of the boilers on the present market are so-called "modulating" boilers. This feature allows the appliance to deliver reduced heat output without stopping the burner (the gas and air flows to the burner are reduced). Most of such boilers are able to modulate down to about 20% of the nominal maximum output. For example, for domestic boilers modulating ranges from 4 to 20 kW are typical, and technologies allowing very low minimum range are developed (starting from 1 kW). The modulation feature reduces the too frequent start-stop of the boiler and improves the user's comfort and the lifetime of the appliance. The boiler can run start/stop below its minimum continuous heat output without significant loss of efficiency, so in principle the heat output can be controlled from 0 to maximum.

Advantages/disadvantages

Advantages

- Gas boilers offer an efficient way to use directly primary energy in homes and are designed to cover the entire heat and hot water demand of end users.
- CO_2 and NOx emissions of gas boilers are the lowest compared to any other fossil fuel boilers.
- The transport of natural gas to the buildings through the gas grid is less "energy costly" than the transport of oil.
- Because of the low investment costs and low gas prices, gas boilers are today one of the most cost effective solution for the end-user [21].

Disadvantages

- The laying of the branch pipe requires some extra construction work compared to other heating technologies especially in urban areas where pavements must be broken to establish the required infrastructure

Environment

Gas boilers have low NOx emissions (lower than oil boilers, due to the nature of the fuel) [4] and low CO emissions. Gas boilers have a net emission of CO_2 if fuelled with fossil based gas.

Research and development perspectives

Gas condensing boilers have today almost reached the highest possible energy efficiency and only a few per cent improvement is to be expected in the future. Still, improvements are possible for decreasing the electrical consumption and emissions. The electrical consumption has decreased due to the development of low-energy modulating pumps and labelling systems for gas boilers in Denmark [23]. NOx emissions have also been reduced with the introduction of the same label. Further improvements will be required when the Ecodesign requirements will enter into force in 2018.

Most progress, however, is foreseen in the field of combining gas boilers with other technologies in order to optimise the performances and to give more flexibility to adapt to the increasing production of versatile renewable energy. Hybrid systems are combining different technologies:

- Gas boilers can be used in combination with solar thermal energy, and dedicated and adapted products are found on the market.
- Gas boilers can also be used in combination with electrical heat pumps [17] and provide peak heating during periods with high heat demands and/or low external temperature. Such a setup increases the efficiency of the heat pump. Packages with electrical heat pumps and gas boilers are on the market already. Hybrid units can have good complementarity, which can achieve high system efficiency [20].
- Gas boiler as a backup for gas heat pump [18] and micro cogeneration (mCHP) [19]. For similar reasons as above, gas boilers can be used in combination with other technologies in order to optimize the efficiency of multi- technology systems. For example some gas heat pumps have a bad efficiency at low load (too much start stops) and the combination with a boiler increases the system efficiency.

Examples of market standard technology

A typical example of market standard technology would be a modulating, condensing boiler with a range of 5 to 20 kW. The efficiency is rather constant over the range of modulation, and NOx emission is low (low-NOx burner technology). Most of the condensing boilers on the market have now reached the highest achievable efficiency (with this technology) and can be considered to be BAT. The present gas condensing boilers may be partly replaced in the future by gas heat pumps with about 30% higher efficiency. A Robur gas absorption heat pump is already available on the market for apartment blocks [18].

Predictions of performance and costs

Gas boilers have been used for several decades and are a mature and commercial technology with a large deployment (a category 4 technology). Further development in the area of individual gas boilers is mainly dedicated to:

- Low-NO_X burners
- Combustion controls enabling appliances to self-adapt to variations in gas composition
- Integration in smart grid [20]

Most of the research is dedicated to the development of new technologies that might replace conventional gas boilers or are used combined with a gas boiler:

- Gas heat pump
- Combined heat and power (including mini- and micro CHP)

Gas heat pumps are covered in section 8, while micro CHP units are not part of this catalogue.

While the cost of gas boilers have decreased, it is considered unlikely that this trend will continue with any significance – albeit smaller cost reductions are expected due to a general increase in productivity.

Uncertainty

- **Heat efficiency, annual average, net (%)**: The uncertainty on the figures given in the table is rather low as the variation on Best Available Technology (BAT) boilers is quite small. The variations of annual efficiencies mostly depend on the way to use and install the boilers and especially the design of the radiator system (low-temperature or traditional), but for the BAT installed in a new building, the radiator system will be a low-temperature system resulting in the highest energy efficiency.

- **Auxiliary Electricity consumption (kWh/year)**: The uncertainty is larger, as the components and way to control them (after run time of pumps and ventilator) can be quite different.
- **NO_x (g per GJ fuel)**: Large variations are possible, but regulations will limit the emissions to a quite low level of emissions (Ecodesign).
- **Financial data**: The main uncertainty on financial data is due to the uncertainties on energy prices that may very much impact the market. However we have noticed in the last few years a decrease in boilers costs on the Danish market. With the increase of harmonisation of appliances in the EU, hardware prices are expected to fall further and align with prices in other EU countries that are lower than in Denmark.

Economy of scale effects

The price of boilers for small dwellings (<35 kW) is decoupled from the capacity of the boiler, instead the cost of small boilers depends on other features like material selection etc.. In other words the cost of boilers is not directly proportional to the power (a 24 kW boiler is not 2 times more expensive compared to a 12 kW boiler!) but of course in a serial of boilers of the same construction, there will be an increasing of the price with the increase of the power. For the large boiler, there is a clear impact of the size on the price, and average values /8/ are indicating a more or less linear growth of 50 Euro/kW for boilers above 35 kW (but below 700 kW or less).

Additional remarks

Only condensing boiler technology is allowed for new installations in Denmark. Fossil-based natural gas boilers are generally only allowed in new buildings, if the supply per 1.1.2013 is a dedicated “natural gas area” [22].

Data sheets

Table 9: Natural gas boiler – one-family house, existing and energy renovated buildings

Technology	Natural gas boiler - One-family house, existing and energy renovated buildings									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	10	10	10	10	5	35	5	35	U	
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	97	97	98	99	95	100	98	102	A, B	1,28
Total efficiency, annual average, net (%)	97	97	98	99	95	100	98	102	A, B	1
Auxiliary Electricity consumption (kWh/year)	150	140	130	110	100	160	90	150	T	28
Technical lifetime (years)	20	20	20	20	15	25	15	25		2
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Minimum load (% of full load)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Warm start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Cold start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Environment										
SO_2 (g per GJ fuel)	0	0	0	0	0	0,3	0	0,3		5
NO_X (g per GJ fuel)	20	10	5	3	5	15	0,2	0,3	D, E	3,7
CH_4 (g per GJ fuel)	2	1	0,5	0,25	0,5	2	0,1	0,5	F	5
N_2O (g per GJ fuel)	0	0	0	0	0	1	0	1		
Particles (g per GJ fuel)	0	0	0	0	0	0,1	0	0,1		
Financial data										
Specific investment (1000€/unit)	3,2	3,1	3,0	2,7	3,0	4,5	2,5	4,0	G, H, I	32
- hereof equipment (%)	63	63	63	63	50	75	50	75		
- hereof installation (%)	37	37	37	37	25	50	25	50		
Possible additional specific investment (1000€/unit)	2	2	2	2	1	3	1	3	K	6
Fixed O&M (€/unit/year)	209	205	199	181	187	261	141	218		
- of which is electricity costs (€/unit/year)	9	10	13	13	7	11	11	18	T	
- of which is other O&M costs (€/unit/year)	200	195	186	168	180	250	130	200	J	33
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Table 10: Natural gas boiler – apartment complex, existing building

Technology	Natural gas boiler - Apartment complex, existing building									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	400	400	400	400	70	750	70	750		
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	101	101	102	102	99	103	100	104	A,B,L,O,P,M	30, 31
Total efficiency, annual average, net (%)	101	101	102	102	99	103	100	104	A,B,L,O,P,M	30, 31
Auxiliary Electricity consumption (kWh/year)	750	700	600	500	500	1000	250	750	T,M	30
Technical lifetime (years)	25	25	25	25	20	30	20	30	M	31
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Minimum load (% of full load)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Warm start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Cold start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Environment										
SO_2 (g per GJ fuel)	0	0	0	0	0	0,3	0	0,3	N	5
NO_X (g per GJ fuel)	20	10	5	3	5	15	0,2	0,3	N	3,7
CH_4 (g per GJ fuel)	2	1	0,5	0,25	0,5	2	0,1	0,5	F,N	5
N_2O (g per GJ fuel)	0	0	0	0	0	1	0	1	N	
Particles (g per GJ fuel)	0	0	0	0	0	0,1	0	0,1	N	
Financial data										
Specific investment (1000€/unit)	25,2	24,6	23,4	21,1	20	30	16	26	C, O, P, R	
- hereof equipment (%)	84	84	84	84	84	84	84	84	H	
- hereof installation (%)	16	16	16	16	16	16	16	16		
Possible additional specific investment (1000€/unit)	2	2	2	2	1	3	1	3	C, J	6
Fixed O&M (€/unit/year)	683	669	651	620	531	814	478	761		
- of which is electricity costs (€/unit/year)	47	48	61	59	35	69	29	88	T	
- of which is other O&M costs (€/unit/year)	636	621	590	561	497	745	449	673	C, O, P, R, S	
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0	Q	

Table 11: Natural gas boiler – one-family house, new buildings

Technology	Natural gas boiler - One-family house, new buildings									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	10	10	10	10	5	35	5	35	U	
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	95	95	96	97	92	100	95	102	A, B	1,28
Total efficiency, annual average, net (%)	95	95	96	97	92	100	95	102	A, B	1
Auxiliary Electricity consumption (kWh/year)	80	75	70	50	60	100	40	80	T	28
Technical lifetime (years)	20	20	20	20	15	25	15	25		2
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Minimum load (% of full load)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Warm start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Cold start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Environment										
SO_2 (g per GJ fuel)	0	0	0	0	0	0,3	0	0,3		5
NO_X (g per GJ fuel)	20	10	5	3	5	15	0,2	0,3	D, E	3,7
CH_4 (g per GJ fuel)	2	1	0,5	0,25	0,5	2	0,1	0,5	F	5
N_2O (g per GJ fuel)	0	0	0	0	0	1	0	1		
Particles (g per GJ fuel)	0	0	0	0	0	0,1	0	0,1		
Financial data										
Specific investment (1000€/unit)	3,2	3,1	3,0	2,7	3,0	4,5	2,5	4,5	C, G, H, I	32
- hereof equipment (%)	63	63	63	63	50	75	50	75		
- hereof installation (%)	37	37	37	37	25	50	25	50		
Possible additional specific investment (1000€/unit)	2	2	2	2	1	3	1	3	K	6
Fixed O&M (€/unit/year)	209	205	199	181	187	261	141	218		
- of which is electricity costs (€/unit/year)	9	10	13	13	7	11	11	18	T	
- of which is other O&M costs (€/unit/year)	200	195	186	168	180	250	130	200	J	33
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Table 12: Natural gas boiler – apartment complex, new building

Technology	**Natural gas boiler - Apartment complex, new building**									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	160	160	160	160	35	500	35	500		
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	101	101	102	102	99	103	100	104	A,B,L,O,P,M	30, 31
Total efficiency, annual average, net (%)	101	101	102	102	99	103	100	104	A,B,L,O,P,M	30, 31
Auxiliary Electricity consumption (kWh/year)	375	350	300	250	250	500	200	400	T,M	30
Technical lifetime (years)	25	25	25	25	20	30	20	30	M	31
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Minimum load (% of full load)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Warm start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Cold start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L	
Environment										
SO_2 (g per GJ fuel)	0	0	0	0	0	0,3	0	0,3	N	5
NO_X (g per GJ fuel)	20	10	5	3	5	15	0,2	0,3	N	3,7
CH_4 (g per GJ fuel)	2	1	0,5	0,25	0,5	2	0,1	0,5	F,N	5
N_2O (g per GJ fuel)	0	0	0	0	0	1	0	1	N	
Particles (g per GJ fuel)	0	0	0	0	0	0,1	0	0,1	N	
Financial data										
Specific investment (1000€/unit)	18	17,6	16,7	15,1	15	20	12	18	C, O, P, R	
- hereof equipment (%)	80	80	80	80	80	80	80	80	H	
- hereof installation (%)	20	20	20	20	20	20	20	20		
Possible additional specific investment (1000€/unit)	2	2	2	2	1	3	1	3	C, J	6
Fixed O&M (€/unit/year)	448	438	424	403	348	531	323	496		
- of which is electricity costs (€/unit/year)	24	24	30	29	17	35	23	47	T	
- of which is other O&M costs (€/unit/year)	424	414	394	374	331	497	299	449	C, O, P, R, S	
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0	Q	

Notes

A Annual efficiency calculated with input test data carried out at DGC and using the model BOILSIM for the BAT [1].
B A slight improvement of efficiency is still possible over the next decades.
C Assuming a cost-reduction of 0.5 % p.a., which in turn is assumed equivalent to the typical improvement of mature technologies.
D Ecodesign limit for gas boilers = 70 mg/kWh = 70/3.6 = approx. 20 g/GJ fuel.
E NOx emission will probably decrease as an average. The level proposed for 2030 is already achievable today by some gas boilers.
F Ref [5] gives 5 mg/kWh, This is less than 2 g/GJ.
G All costs are based on Naturgas Fyn (today "Nature Energy") statistics. This is the most extensive data base indicating real costs paid by the customer including installation. The value given does not include the energy saving incentive funds that are given to the client for the purchase of a condensing boiler (3000 DKK = 400 Euro).
H Assuming a cost-reduction of 0.5 % p.a., which in turn is assumed equivalent to the typical improvement of mature technologies. The harmonisation of gas quality in EU, the more severe competition with district heating and electrical heat pumps, and the improvements in the manufacturing cost are the reason for such hypothesis. The statistics of Naturgas Fyn (today "NGF Nature Energy") shows that the costs have already decreased between 2012 and 2015.
I The "uncertainty" is based on Naturgas Fyn (today "NGF Nature Energy") statistics removing 5% at top and 5% at bottom list of the total cost. Additional uncertainties like labour cost variations in Denmark may add some more uncertainty in the prices given.
J HMN GasNets database contains comprehensive statistical data.
K Installation of a gas service line (grid connection). The price may change depending on the marketing by the gas distribution companies. For non-domestic appliances, the same price as for domestic is assumed. Only to be paid if the natural gas is not yet supplied to the house.
L Gas boilers can deliver their full power in a few seconds or few minutes depending on the heat capacity of the appliance and possible pre-purge time. The same applies for the modulating ability within the modulation range of the boiler according to ref. [7]
M The technical performance of an apartment complex boiler is considered to be very similar to that of a district heating boiler with the exception of more frequent start-ups and shutdowns. Consequently the efficiency is reduced accordingly.
N The emissions are considered to be very similar to the ones for domestic boilers. This is a quite conservative hypothesis as e.g. NOx emissions for larger boilers are in general lower compared to domestic boilers.
O Based on a 160 kW boiler (new building) and 400 kW (existing building)
P Based on average cost information from manufacturers (2015).
Q There is no statistics on variable O&M for large boilers, and the cost can very well be included in the service agreement. The estimates from manufacturers are quite low and, therefore, the variable O&M costs for large boilers are considered to be included in the Fixed O&M.
R Uncertainty +/- 20 %
S Service cost interpolated from manufacturers information (2015)
T The cost of auxiliary electricity consumption is calculated using the following electricity prices in €/MWh: 2015: 63, 2020: 69, 2030: 101, 2050: 117. These prices include production costs and transport tariffs, but not any taxes or subsidies for renewable energy.
U Due to the insignificant economy of scale displayed by domestic boilers (se section on economy of scale) the savings achieved by reducing the capacity of the boilers is limited or non-existing. Hence, the investment cost is not influenced by the capacity of the boilers installed.

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203 District heating substation

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Amendments after publication date

Date	Ref.	Description
12.2017	Datasheet 3.2	These datasheets are now included in the document as well as the excel sheet

Qualitative description

Brief technology description

District heating is a hydraulic system of pipes with the purpose of distributing thermal heat to end users of space heating and domestic hot water. The thermal heat comes from of a number of sources, including heat from combined heat and power production (CHP), surplus heat from industry, and heat from waste incineration plants and boilers. More than 60% of Danish households are supplied with district heating by more than 400 district heating networks. And in most major Danish cities, typically more than 95% of the end users are connected. Additionally in most major Danish cities, more than 95% of the end users are typically connected to the district heating system. District heating units are categorised as either direct or indirect units. The district heating sub-station is placed at the end user with the purpose of preparing domestic hot water and delivering heat for the space heating system. Each building with a district heating sub-station is supplied from a branch pipe

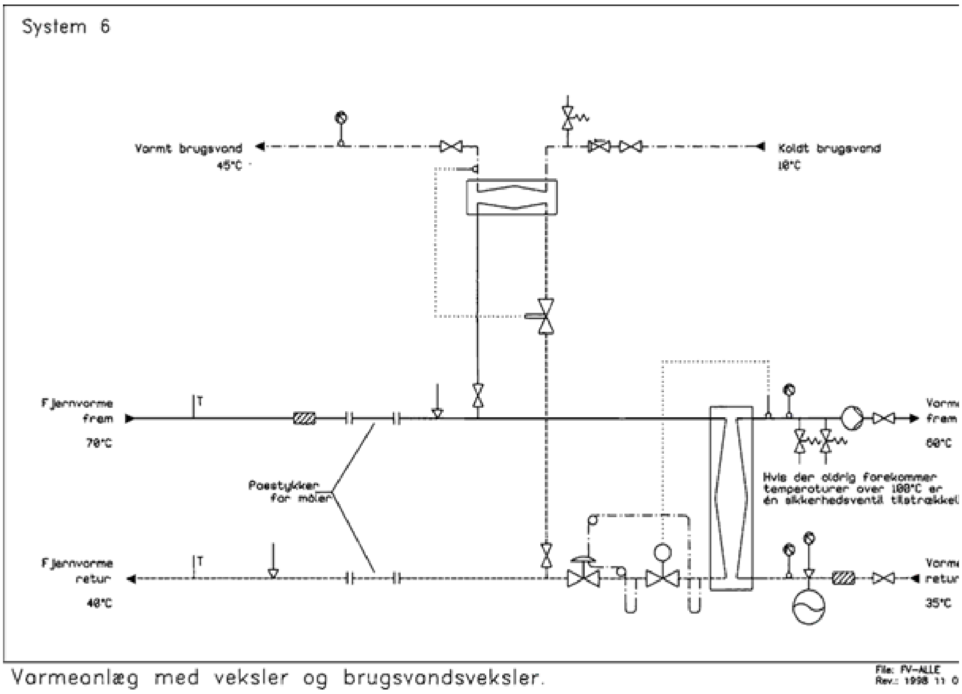

Figure 7: **Indirect district heating substation with domestic hot water heater and heat exchanger for space heating in a one-family house. A branch pipe is connecting the building with the district heating network [1].**

connecting the building to the overall distribution network. Figure 7 shows a sketch with typical components included in a an indirect substation for single-family houses [1].

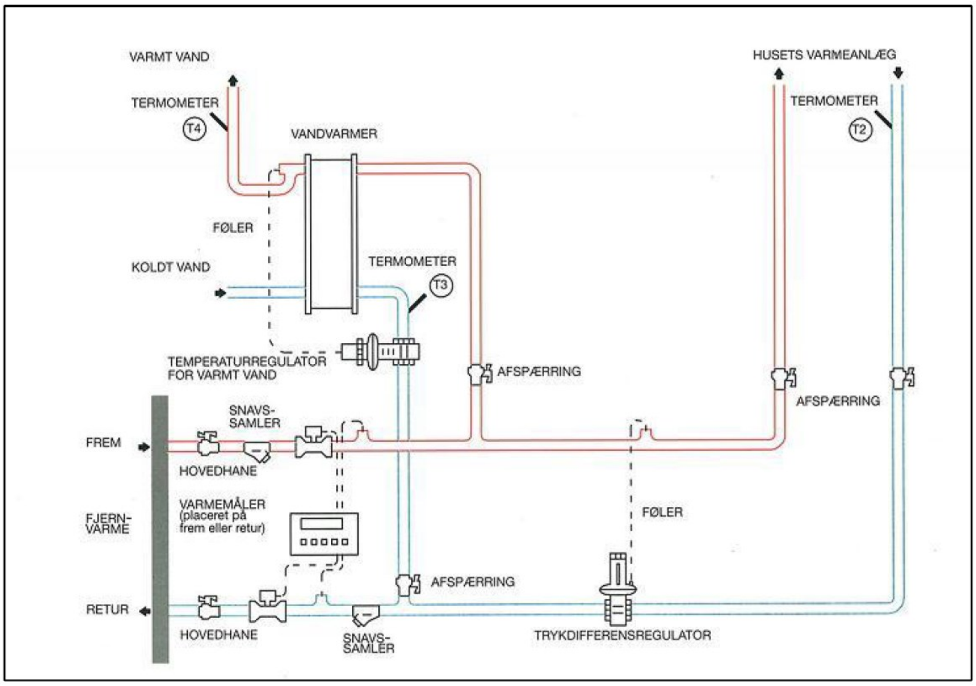

Figure 8: Direct district heating substation with domestic hot water heater and heat exchanger for space heating in a one-family house.

For comparison Figure 8 shows the design of a direct district heating unit. It is estimated that there is an even share of direct and indirect district heating units in Denmark. Additionally Figure 9 shows the district heating substation installed in a single-family house.

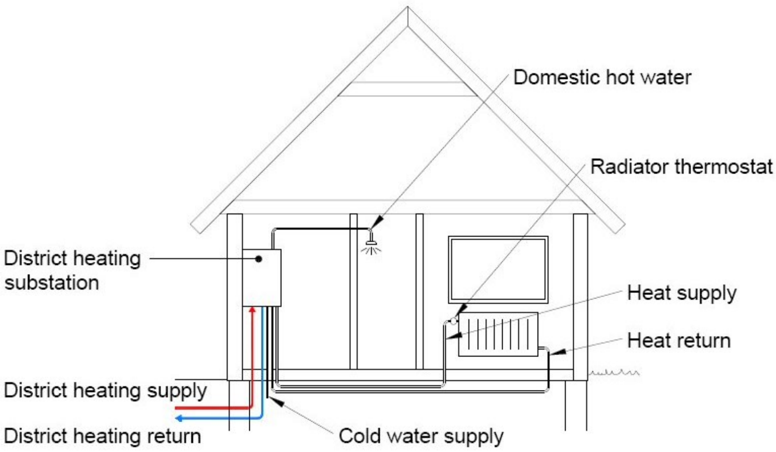

Figure 9: District heating substation with domestic hot water heater and heat exchanger for space heating

In apartment complexes, the standardized and prefabricated substation can be placed centrally, or small substations, the so-called flat stations, can be placed in each flat.

The substation is equipped with a domestic hot water heater based on either a storage tank with a heat exchanger embedded or a heat exchanger without storage, e.g. a plate heat exchanger. In some cases, a combination of an external heat exchanger and a storage tank is seen. The space heating is delivered by direct supply of district heating water or via a heat exchanger placed in between the district heating water (primary side) and the space heating water (secondary side). Further, the substation includes all valves, controllers, filters, pumps, etc. that are necessary for the operation. The substation also includes a heat energy meter. For substations constructed as units the unit is ready for convenient installation of the heat meter.

Input

Heat in the form of hot water supplied from the district heating pipeline.

Output

Heat (space heating and domestic hot water).

Typical capacities

The substation space heating capacity is dimensioned based on district heating temperatures and maximum allowable pressure drop. In single-family houses, the space heating capacity is typically in the range of 10 kW for district heating temperatures 70/40 °C and a maximal allowable pressure difference in the main pipes in the range of 0.3 bar. If the domestic hot water is prepared by an instantaneous water heater (normally including a plate heat exchanger) the heating demand for this is set to 33 kW for a single family house. For large buildings, the capacities typically range from 70 kW to 250 kW for standardised wall-hung products. Above 250 kW, the substations will be individually designed and manufactured. Figure 10 shows and example of a substation. The capacities of large buildings refer to district heating temperatures 70/40 °C in the following.

Figure 10: District heating substation for large buildings [2]

Regulation (control) ability

On component level, the design criteria include ability to control domestic hot tap water temperature, flow temperature to the heating system, pressure loss and ability to maintain a low return temperature. The present building regulation in DK states that the flow temperature shall be controlled according to the outdoor temperature. Radiator thermostats shall be installed at all radiators in the building. To conclude, the district heating substation can go from 0 – 100 % almost instantaneous.

Advantages/disadvantages

It is essential to realize that the district heating substation in itself cannot be compared to individual heating options like gas boilers or heat pumps. In order to make a whole techno-economic comparison, the whole district heating system must be taken into consideration, including distribution network and heat source. Hence the advantages and disadvantages considered in this chapter are compared to individual heating solutions.

Advantages

- Compact design - small installation space requirements
- Low maintenance costs
- Very low noise level
- No pollution produced locally.
- Can be used to utilizes surplus heat from industries and power production

Disadvantages

- The laying of the branch pipe requires some extra construction work compared to other heating technologies especially in urban areas where pavements must be broken to establish the required infrastructure
- Distribution network losses increase operation and maintenance costs
- Specific capital costs and distribution network losses of the district heating system increase with decreasing population density. This is a barrier which prevents district heating companies from providing district heating to customers in areas with low heat density.

Environment

The environmental characteristics are dependent on the heat input to the specific district heating network. Therefore, no such characteristics are presented. Environmental declarations exist for specific district heating networks, e.g. the declaration of the Greater Copenhagen DH system.

Research and development perspectives

Research and development are mainly taking place in the following areas:

- Plate heat exchanger design.
- Control strategies.
- Low-temperature operation (< 55oC district heating flow temperature).
- Reduction of standby losses (primarily in new single-family houses).
- Integration or combination with other technologies (mainly outside Denmark). In Denmark, low temperature district heating combined with electric immersion heating elements or heat pumps for hot water production in some cases combined with smart grids are new research areas.

Examples of market standard technology

Low-temperature district heating substations have been demonstrated e.g. in the low-energy buildings of the housing association "Boligforeningen Ringgården". The substations incorporate efficient plate heat exchanger technology and are able to supply domestic hot tap water at 47 °C with a district heating supply temperature of 50 °C and return temperatures below 25 °C [3]. An example of an efficient insulation of a substation is seen in **Fejl! Henvisningskilde ikke fundet.** (note that only the back insulation panel is shown on the photo, the front insulation has been removed).

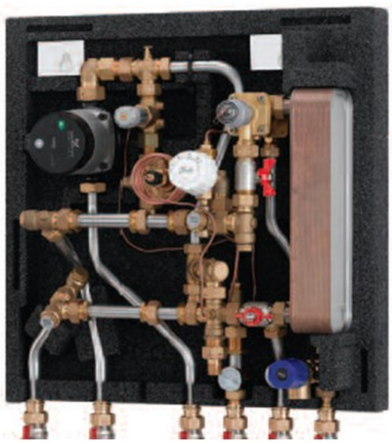

Figure 11: District heating substation with full body insulation for a single-family house [4]

Prediction of performance and costs

The substations have been used for several decades and are a mature and commercial technology with a large deployment (a category 4 technology). Some district heating utilities are working on decreasing the district heating supply temperature and have set new requirements for district heating substations [6]. In low-energy houses, low standby losses of technical installations are essential to comply with the Danish building code. Also new electronically controlled water heaters have entered the market and are expected to improve efficiency and comfort further [5]. While the cost of sub stations have decreased, it is considered unlikely that this trend will continue with any significance – albeit smaller cost reductions are expected due to a general increase in productivity.

Uncertainty

The technology is well established and it is likely that production cost for a district heating unit will decrease moderately in the future: improved and cheaper technology for producing heat exchangers, valves, electronics, new fitting and pipe systems will help this process.

Economy of scale effects

For the small unit in a single-family house, the price is in the range of 2000 Euros, equal to 150 Euros per kW. For a 400 kW unit the price is in the range of 28000 Euros equal to 70 Euros per kW.

Additional remarks

-

Data sheets

Table 13: Indirect district heating substation – one-family house, existing and energy renovated buildings

Technology	Indirect district heating substation - One-family house, existing and energy renovated buildings									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	10	10	10	10	5	15	5	15	H	
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	97	98	98	98	95	99	95	99	B, I	9
Total efficiency, annual average, net (%)	97	98	98	98	95	99	95	99		
Auxiliary Electricity consumption (kWh/year)	120	110	100	80	75	125	50	100	G	
Technical lifetime (years)	25	25	25	25	20	30	20	30		8
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Minimum load (% of full load)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Warm start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Cold start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	2,2	2,1	2,0	1,8	1	3	1	2,5	F	2,3,4,7
- hereof equipment (%)	70	70	70	70	70	70	70	70		
- hereof installation (%)	30	30	30	30	30	30	30	30		
Possible additional specific investment (1000€/unit)	3	3	3	3	2	4	2	4	C, F	
Fixed O&M (€/unit/year)	58	56	56	51	40	74	36	72		
- of which is electricity costs (€/unit/year)	8	8	10	9	5	9	6	12	G	
- of which is other O&M costs (€/unit/year)	50	49	46	42	35	65	30	60	D, F	8
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Table 14: Indirect district heating substation – apartment complex, existing building

Technology	Indirect district heating substation - Apartment complex, existing building									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	400	400	400	400	150	500	150	500	A	
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	100	100	100	100	98	100	98	100	B, I	
Total efficiency, annual average, net (%)	100	100	100	100	98	100	98	100		
Auxiliary Electricity consumption (kWh/year)	600	550	500	400	400	1000	250	800	G	
Technical lifetime (years)	25	25	25	25	20	30	20	30		8
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Minimum load (% of full load)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Warm start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Cold start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	16,0	15,6	14,8	13,4	12	20	10	20	F	2,4,7
- hereof equipment (%)	70	70	70	70	70	70	70	70		
- hereof installation (%)	30	30	30	30	30	30	30	30		
Possible additional specific investment (1000€/unit)	4	4	4	3	3	6	3	6	C, F	
Fixed O&M (€/unit/year)	139	136	144	132	108	189	94	199		
- of which is electricity costs (€/unit/year)	38	38	51	47	28	69	29	94	G	
- of which is other O&M costs (€/unit/year)	101	99	94	85	80	120	65	105	D, F	8
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Table 15: Indirect district heating substation – one-family house, new buildings

Technology	Indirect district heating substation - One-family house new buildings									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	10	10	10	10	5	15	5	15	H	
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	96	96	97	98	95	99	95	99	B, I	9
Total efficiency, annual average, net (%)	96	96	97	98	95	99	95	99		
Auxiliary Electricity consumption (kWh/year)	60	55	50	40	40	80	25	75	G	
Technical lifetime (years)	25	25	25	25	20	30	20	30		8
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Minimum load (% of full load)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Warm start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Cold start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	2,2	2,1	2,0	1,8	1	3	1	2,5	F	2,3,4,7
- hereof equipment (%)	70	70	70	70	70	70	70	70		
- hereof installation (%)	30	30	30	30	30	30	30	30		
Possible additional specific investment (1000€/unit)	3	3	3	3	2	4	2	4	C, F	
Fixed O&M (€/unit/year)	54	53	51	47	38	71	33	69		
- of which is electricity costs (€/unit/year)	4	4	5	5	3	6	3	9	G	
- of which is other O&M costs (€/unit/year)	50	49	46	42	35	65	30	60	D, F	8
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Table 16: Indirect district heating substation – apartment complex, new building

Technology	Indirect district heating substation - Apartment complex, new building									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	160	160	160	160	150	500	150	500	A	
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	100	100	100	100	98	100	98	100	B, I	
Total efficiency, annual average, net (%)	100	100	100	100	98	100	98	100		
Auxiliary Electricity consumption (kWh/year)	350	325	300	250	250	500	200	400	G	
Technical lifetime (years)	25	25	25	25	20	30	20	30		8
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Minimum load (% of full load)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Warm start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Cold start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	11,2	10,9	10,4	9,4	10	15	8	12	F	2,4,7
- hereof equipment (%)	70	70	70	70	70	70	70	70		
- hereof installation (%)	30	30	30	30	30	30	30	30		
Possible additional specific investment (1000€/unit)	4	4	4	3	3	6	3	6	C, F	
Fixed O&M (€/unit/year)	107	105	109	101	87	135	83	137		
- of which is electricity costs (€/unit/year)	22	22	30	29	17	35	23	47	G	
- of which is other O&M costs (€/unit/year)	85	83	79	71	70	100	60	90	D, F	8
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Table 17: Direct district heating substation – one-family house, existing and energy renovated buildings

Technology	Direct district heating substation - One-family house, existing, new and energy renovated buildings									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	10	10	10	10	5	15	5	15	H	
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	100	100	100	100	98	100	99	100	I	9
Total efficiency, annual average, net (%)	100	100	100	100	98	100	99	100		
Auxiliary Electricity consumption (kWh/year)	40	40	35	30	50	100	50	100	G	
Technical lifetime (years)	25	25	25	25	20	30	20	30		8
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Minimum load (% of full load)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Warm start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Cold start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	1,9	1,9	1,8	1,6	1	3	1	2,5	F	7
- hereof equipment (%)	70	70	70	70	70	70	70	70		
- hereof installation (%)	30	30	30	30	30	30	30	30		
Possible additional specific investment (1000€/unit)	3	3	3	3	2	4	2	4	C, F	
Fixed O&M (€/unit/year)	50	49	47	43	38	67	36	62		
- of which is electricity costs (€/unit/year)	3	3	4	4	3	7	6	12	J	
- of which is other O&M costs (€/unit/year)	47	46	44	39	35	60	30	50	D, F	8
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Table 18: Direct district heating substation – apartment complex, existing building

Technology	Direct district heating substation - Apartment complex, existing building									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	400	400	400	400	150	500	150	500	A	
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	100	100	100	100	98	100	99	100	I	
Total efficiency, annual average, net (%)	100	100	100	100	98	100	99	100		
Auxiliary Electricity consumption (kWh/year)	200	200	175	150	150	300	125	250	G	
Technical lifetime (years)	25	25	25	25	20	30	20	30		8
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Minimum load (% of full load)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Warm start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Cold start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	14,0	13,7	13,0	11,7	10	18	10	15	F	7
- hereof equipment (%)	70	70	70	70	70	70	70	70		
- hereof installation (%)	30	30	30	30	30	30	30	30		
Possible additional specific investment (1000€/unit)	4	4	4	3	3	6	3	6	C, F	
Fixed O&M (€/unit/year)	90	89	89	82	75	111	75	109		
- of which is electricity costs (€/unit/year)	13	14	18	18	10	21	15	29	J	
- of which is other O&M costs (€/unit/year)	77	75	71	65	65	90	60	80	D, F	8
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Table 19: Direct district heating substation – apartment complex, new building

Technology	Direct district heating substation - Apartment complex, new building									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	160	160	160	160	150	500	150	500	A	
Electricity generation capacity for one unit (kW)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Heat efficiency, annual average, net (%)	100	100	100	100	98	100	99	100	I	
Total efficiency, annual average, net (%)	100	100	100	100	98	100	99	100		
Auxiliary Electricity consumption (kWh/year)	200	200	175	150	150	300	125	250	G	
Technical lifetime (years)	25	25	25	25	20	30	20	30		8
Regulation ability										
Primary regulation (% per 30 seconds)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Secondary regulation (% per minute)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Minimum load (% of full load)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Warm start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Cold start-up time (hours)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	10,0	9,8	9,3	8,4	8	12	7	10	F	7
- hereof equipment (%)	70	70	70	70	70	70	70	70		
- hereof installation (%)	30	30	30	30	30	30	30	30		
Possible additional specific investment (1000€/unit)	4	4	4	3	3	6	3	6	C, F	
Fixed O&M (€/unit/year)	78	77	78	72	60	101	65	99		
- of which is electricity costs (€/unit/year)	13	14	18	18	10	21	15	29	J	
- of which is other O&M costs (€/unit/year)	65	63	60	55	50	80	50	70	D, F	8
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Notes

A The generating capacity for one substation is set at the space heating capacity at typical district heating flow/return temperatures of 70°C/40°C. The size of the water heater capacity is estimated based on the number of apartments that the substation can supply with space heating.

B The only losses related to the district heating substation are the standby heat losses. For large well-insulated substations, these are considered negligible – 100% efficiency. However, substations for single-family houses will have a heat loss during summer that cannot be considered useful. Applying best available technology, this is considered to be about 3%, resulting in 97% efficiency.

C Specific investment in branch pipe from the street network to the building and in the heat meter.

D The operation and maintenance costs are based on a maintenance check every second year, but calculated per year and per installation.

E Note that the branch pipe should be dimensioned for the use of hot tap water. If there is not any hot water tank, the branch pipe capacity should be higher than the capacity of the DH substation.

F Assuming a cost-reduction of 0.5 % p.a., which in turn is assumed equivalent to the typical improvement of mature technologies.

G The cost of auxiliary electricity consumption is calculated using the following electricity prices in €/MWh: 2015: 63, 2020: 69, 2030: 101, 2050: 117. These prices include production costs and transport tariffs, but not any taxes or subsidies for renewable energy.

H Due to the insignificant economy of scale displayed by domestic district heating substations (se section on economy of scale) the savings achieved by reducing the capacity of the substation is limited or non-existing. Hence, the investment cost is not influenced by the capacity of the substations installed.

I In contrast to boilers and heat pumps a district heating unit does not convert energy. Yet energy losses are still present in a district heating substation [9]. Some of these losses are included in the annual heat demand, while others are not. The efficiencies are calculated to reflect this.

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204 Biomass boiler, automatic stoking

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Amendments after publication date

Date	Ref.	Description
12.2017	Datasheet 4	Updated upper and lower levels for uncertainty of O&M for biomass boilers with automatic stoking in one-family houses

Qualitative description

Brief technology description

Wood pellets are usually applied in automatically stoking biofuel boilers. See Figure 12. However, some boilers, especially major ones, are also designed for firing with other types of biomass such as wood chips and grain.

The fuel is conveyed via an auger feeder from the fuel supply to the burner unit. In the burner, the combustion takes place during supply of primary and secondary air. The boiler is often a steel sheet boiler with a convection unit consisting of boiler tubes or plates.

The fuel can be supplied from an external earth storage tank, storage room or similar, or it can be supplied from an integral fuel hopper that is part of the boiler unit. Fuel is available in sacks and can be added to the silo manually, or - in case of wood pellets - the fuel can be blown into the storage tank or room.

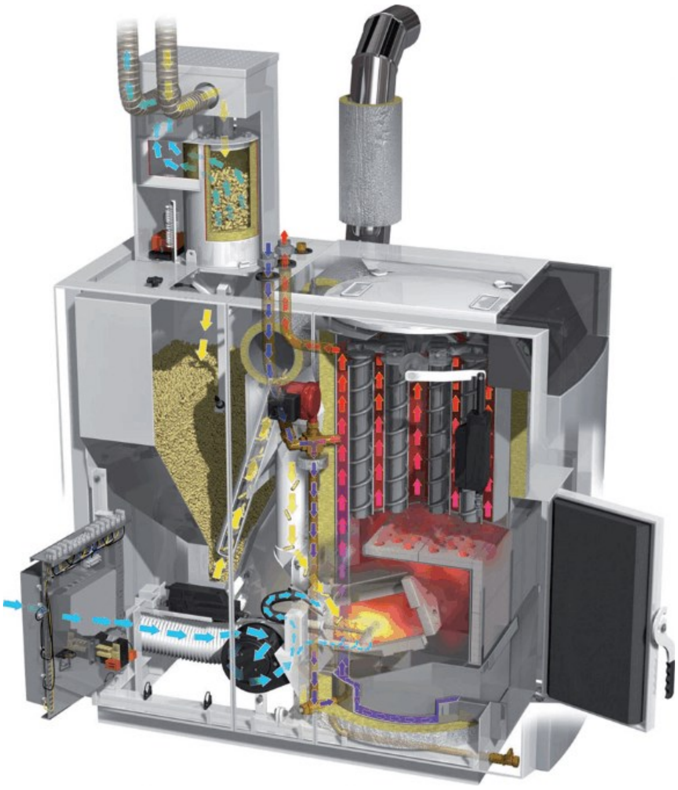

Figure 12: Biomass boiler, automatic stoking

Within automatic bio fuel boilers, there are two plant types: compact plants consisting of a boiler and a burner in the same unit, and boilers with a detachable burner. Detachable burners can be approved up to 70 kW and are exclusively applicable for stoking with pellets.

Automatic biofuel boilers can be a stand-alone solution, but hybrid systems like solar/biomass is an attractive combination. In the summer period hot tap water is produced from the thermal solar, while the biomass heating unit covers the heating demand for hot tap water and space heating during the rest of the year.

Input

Wood pellets or wood chips. Another possible fuel depending on the boiler type is non-woody biomass such as grain. See additional remarks for detailed description of wood pellets.

Output

Heat for space heating and hot tap water.

Typical capacities

From 8 kW to 500 kW, or even larger, detachable pellet burners from 8 kW to 70 kW.

Regulation ability

All boilers can be regulated from less than 30% to 100% of full capacity, without violating emission requirements. The best technologies can be regulated from 10 to 120% of the nominal heat output stated by the manufacturer on the boiler plate.

Advantages/disadvantages

Advantages

- The investment in a new biomass boiler is often limited if an existing oil burner must be replaced anyway.

Disadvantages

- Biomass boilers and storage capacities require room space and an appropriate boiler room.
- For larger boilers, and also in case of firing with other types of fuels (eg. Straw or wood chips) than pellets, the labour needed for maintenance must be considered.
- Compared to district heating, gas boilers or heat pumps a considerable effort must be put into transport and handling of the fuel wood.
- Boiler and flue gas system requires regular cleaning and maintenance by the owner.

Environment

Use of high fuel quality and advanced technological combustion concepts ensure that automatic combustion systems are environmentally sound and efficient residential heating technologies. The legislation requirements have been stringent continuously and regards safety, efficiency, emission limits etc.

Research and development perspectives

Biomass boilers with automated stoking are a technology undergoing continuous development, requiring R&D in the following areas:

- High-efficient and low-emission technologies
- Automation and comfort
- Fuel flexible boilers

- Improve system design of biomass heating systems
- Combined heat and power applications

Examples of market standard technology

Danish manufacturers of market standard technology can be found on web lists at [4]. The products on this list comply with the latest regulation of biomass boilers.

Prediction of performance and costs

Biomass boilers with automatic stoking are in development and commercially available with a moderate deployment (a category 3 technology).

Price and performance of the technology is today well known and only incremental improvements are expected. Therefore, the future price and performance projected is considered to be of fairly high certainty. Hence, technological improvements are expected to be realized without any significant increases in costs.

Use of biofuel boilers can be a relevant option for the approx. 500,000 households in Denmark found in rural areas or in areas without legal requirements of connecting to the public supply network. Biofuel boilers are common in Denmark and in the rest of Europe. Denmark is estimated to have approx. 47,000 automatically fired biofuel boilers in 2011 [2].

Uncertainty

Cost of smaller units varies much and depends of designs and brands more than on the capacity of the boiler. In general, the prices at small units reflect the level of automation meaning the higher automation the higher costs. Prices of large scale units also depends on the fuel flexibility e.g. whether the unit only are able for burning wood pellets or also wood chips etc.

Price and performance of the technology is today well known and only incremental improvements are expected. Therefore, the future price and performance may also be projected with fairly high certainty.

Economy of scale effects

As stated above, the costs differs significantly with other parameters than capacity, hence there is no economy of scale effects for biomass boilers with manual stoking.

Additional remarks

Wood pellets are small, compressed pellets made of e.g. wood shavings and sanding dust compressed under high pressure and with maximum 1% binding agents. Wood pellets have typically a diameter of 6 mm or 8 mm and a moisture content of about 6-8 %. The length varies up to 5 times the diameter. Wood chips consist of wood pieces of 5-50 mm in the fibre direction, longer twigs (slivers), and a fine fraction (fines). There exist three types of wood chips: Fine, coarse and extra coarse. The names refer to the size distribution only, and not to the quality.

Data sheets

Table 20: Biomass boiler, automatic stoking – one-family house, existing and energy renovated building

Technology	Biomass boiler, automatic stoking , wood pellets or wood chips - One-family house, existing and energy renovated buildings.									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	12	10	10	10	8	15	8	10	A	4
Electricity generation capacity for one unit (kW)	NA	NA	NA	NA	NA	NA	NA	NA		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Heat efficiency, annual average, net (%)	80	82	86	88	74	90	80	96	G	
Total efficiency, annual average, net (%)	80	82	86	88	74	90	80	96	B	5
Auxiliary Electricity consumption (kWh/year)	250	240	220	200	200	300	150	250	O	8
Technical lifetime (years)	20	20	20	20	15	25	15	25		7
Regulation ability										
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	NA	NA	NA	NA	NA	NA	NA	NA		
Minimum load (% of full load)	NA	NA	NA	NA	NA	NA	NA	NA		
Warm start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Cold start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Environment										
SO_2 (g per GJ fuel)	25	25	25	25	18	32	18	32		9
NO_X (g per GJ fuel)	90	70	50	40	62	120	32	48		
CH_4 (g per GJ fuel)	3	2	1	0	0	4	0	2		
N_2O (g per GJ fuel)	4.0	4.0	4.0	4.0	1	7	1	7		9
Particles (g per GJ fuel)	19	15	12	10	9	21	5	15	C	4
Financial data										
Specific investment (1000€/unit)	7.0	6.8	6.5	5.9	2.5	11	2	10	F, L	
- hereof equipment (%)	80	80	80	80	80	80	80	80		
- hereof installation (%)	20	20	20	20	20	20	20	20		5
Possible additional specific investment (1000€/unit)	1.6	1.6	1.5	1.3	1.5	2	1.2	2	D, E, L	
Fixed O&M (€/unit/year)	516	504	486	443	414	571	368	529		
- of which is electricity costs (€/unit/year)	16	17	22	23	14	21	18	29	N	
- of which is other O&M costs (€/unit/year)	500	488	464	420	400	550	350	500	L	11
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Table 21: Biomass boiler, automatic stoking – one-family house, new buildings.

Technology	Biomass boiler, automatic stoking , wood pellets or wood chips - One-family house, new buildings.									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	12	10	8	8	8	15	8	10	A	4
Electricity generation capacity for one unit (kW)	NA	NA	NA	NA	NA	NA	NA	NA		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Heat efficiency, annual average, net (%)	75	78	80	85	70	85	80	96	G	
Total efficiency, annual average, net (%)	75	78	80	85	70	85	80	96	B	5
Auxiliary Electricity consumption (kWh/year)	200	190	180	160	175	250	150	200	O	8
Technical lifetime (years)	20	20	20	20	15	25	15	25		7
Regulation ability										
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	NA	NA	NA	NA	NA	NA	NA	NA		
Minimum load (% of full load)	NA	NA	NA	NA	NA	NA	NA	NA		
Warm start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Cold start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Environment										
SO_2 (g per GJ fuel)	25	25	25	25	18	32	18	32		9
NO_X (g per GJ fuel)	90	70	50	40	62	120	32	48		
CH_4 (g per GJ fuel)	3	2	1	0	0	4	0	2		
N_2O (g per GJ fuel)	4	4	4	4	1	7	1	7		9
Particles (g per GJ fuel)	19	15	12	10	9	21	5	15	C	4
Financial data										
Specific investment (1000€/unit)	7.0	6.8	6.5	5.9	2.5	11	2	10	F, L	
- hereof equipment (%)	80	80	80	80	80	80	80	80		5
- hereof installation (%)	20	20	20	20	20	20	20	20		5
Possible additional specific investment (1000€/unit)	1.3	1.3	1.2	1.1	1,1	1,5	1	1,3	D, E, L	
Fixed O&M (€/unit/year)	513	501	482	438	412	567	368	523		
- of which is electricity costs (€/unit/year)	13	13	18	19	12	17	18	23	N	
Fixed O&M (€/unit/year)	500	488	464	420	400	550	350	500	L	11
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Table 22: Biomass boiler, automatic stoking – apartment complex, existing building

Technology	**Biomass boiler, automatic stoking , wood pellets or wood chips - Apartment complex, existing building**									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	400	400	400	400	200	600	200	600	A	
Electricity generation capacity for one unit (kW)	NA	NA	NA	NA	NA	NA	NA	NA	J	7
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		7
Heat efficiency, annual average, net (%)	80	85	90	90	79	91	85	95		
Total efficiency, annual average, net (%)	80	85	90	90	79	91	85	95	B	5
Auxiliary Electricity consumption (kWh/year)	2500	2400	2200	2000	2200	3000	1800	2500	O	
Technical lifetime (years)	20	20	20	20	15	25	15	25		6
Regulation ability										
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	NA	NA	NA	NA	NA	NA	NA	NA		
Minimum load (% of full load)	NA	NA	NA	NA	NA	NA	NA	NA		
Warm start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Cold start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Environment										
SO_2 (g per GJ fuel)	25	25	25	25	18	32	18	32		8
NO_X (g per GJ fuel)	90	70	50	40	62	120	32	48		5
CH_4 (g per GJ fuel)	3	2	1	0	0	4	0	2		2,5
N_2O (g per GJ fuel)	4	4	4	4	1	7	1	7		8
Particles (g per GJ fuel)	19	15	12	10	9	21	5	15	C	
Financial data										
Specific investment (1000€/unit)	90	88	83	76	80	95	68	83	K, L, M	
- hereof equipment (%)	80	80	80	80	80	80	80	80		
- hereof installation (%)	20	20	20	20	20	20	20	20		
Possible additional specific investment (1000€/unit)	15.0	14.6	13.9	12.6	7	22	5	20	H, L	
Fixed O&M (€/unit/year)	1758	1726	1706	1577	1152	2407	1011	2193		
- of which is electricity costs (€/unit/year)	158	166	222	234	152	207	211	293	N	
Fixed O&M (€/unit/year)	1600	1560	1484	1343	1000	2200	800	1900	I, L	11
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Table 23: Biomass boiler, automatic stoking – apartment complex, new building

Technology	Biomass boiler, automatic stoking , wood pellets or wood chips - Apartment complex, new building									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	160	160	160	160	80	400	80	400	A	
Electricity generation capacity for one unit (kW)	NA	NA	NA	NA	NA	NA	NA	NA	J	7
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		7
Heat efficiency, annual average, net (%)	80	85	90	90	79	91	85	95		
Total efficiency, annual average, net (%)	80	85	90	90	79	91	85	95	B	5
Auxiliary Electricity consumption (kWh/year)	1500	1400	1320	1250	1200	2000	1000	1800	O	
Technical lifetime (years)	20	20	20	20	15	25	15	25		6
Regulation ability										
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	NA	NA	NA	NA	NA	NA	NA	NA		
Minimum load (% of full load)	NA	NA	NA	NA	NA	NA	NA	NA		
Warm start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Cold start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Environment										
SO_2 (g per GJ fuel)	25	25	25	25	18	32	18	32		8
NO_X (g per GJ fuel)	90	70	50	40	62	120	32	48		5
CH_4 (g per GJ fuel)	3	2	1	0	0	4	0	2		2.5
N_2O (g per GJ fuel)	4	4	4	4	1	7	1	7		8
Particles (g per GJ fuel)	19	15	12	10	9	21	5	15	C	
Financial data										
Specific investment (1000€/unit)	54	53	50	45	45	60	38	53	K, L, M	6
- hereof equipment (%)	80	80	80	80	80	80	80	80		
- hereof installation (%)	20	20	20	20	20	20	20	20		
Possible additional specific investment (1000€/unit)	9.0	8.8	8.3	7.6	1	16	0	15	H, L	
Fixed O&M (€/unit/year)	1155	1130	1117	1036	883	1538	717	1411		
- of which is electricity costs (€/unit/year)	95	97	133	146	83	138	117	211	N	
Fixed O&M (€/unit/year)	1060	1034	983	889	800	1400	600	1200	I, L	11
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Notes

A Nominal heat delivered in 2015 from 10-20 kW in single family houses and 100 – 500 kW in apartment complexes. Regarding small units (20 kW and less) the insignificant economy of scale displayed by domestic boilers (se section on economy of scale) the savings achieved by reducing the capacity of the boiler is limited or non-existing. Hence, the investment cost is not influenced by the capacity of the boiler installed.

B Efficiency development from [5]

C EN303-5 measurement method

D Prerequisite: house with central heating system.

E Chimney

F Difference in price (2015) 2.5-11 (1000€/unit) mainly due to finish, design etc.

G Improved real life conditions for flue gas condensation technology will increase the efficiency to >100% (based on NCV).

H Biomass storage

I Contemporary value from [6]

J If production of electricity then ORC

K Boilers for production of heat only

L Assuming a cost-reduction of 0.5 % p.a., which in turn is assumed equivalent to the typical improvement of mature technologies.

M The cost is based on a unit with a capacity of 200 kW and assuming the cost for this unit is equally split between an initial cost and a linear dependence on the capacity of the unit.

N The cost of auxiliary electricity consumption is calculated using the following electricity prices in €/MWh: 2015: 63, 2020: 69, 2030: 101, 2050: 117. These prices include production costs and transport tariffs, but not any taxes or subsidies for renewable energy.

References

[1] Vurdering af brændekedlers partikelemission til luften i Danmark, Miljøprojekt nr. 6 2008, Kim Winther, Teknologisk Institut

[2] Emissioner fra træfyrede brændeovne og -kedler, Miljøprojekt nr. 1324 2010, Johnny Iversen, Thomas Capral Henriksen og Simon Dreyer, Carl Bro.

[3] Brændeovne og små kedler – partikelemissioner og reduktionstiltag, Miljøprojekt nr. 1164, 2007, Jytte Boll Illerup, DMU et al.

[4] www.teknologisk.dk/911; Listen over godkendte biobrændselsanlæg

[5] Strategic Research and Innovation Agenda for Renewable Heating & Cooling; RHC-Platform 2013; Renewable heating & Cooling; European Technology Platform.

[6] Energibesparelser - det behøver ikke være så svært; Energibranchen.dk, nr. 3, september 2009.

[7] Lot 15: Solid fuel small combustion installations-Base Case definition.

[8] Konvertering fra olie og el til fast biobrændsel; 2012; Videncenter for Energibesparelser

[9] Danish Emission Inventories for stationary combustion plants, inventories until 2011, Scientific Report from DCE n0. 102, 2014

[10] www.bios-bioenergy.at/en/electricity-from-biomass/

[11] Estimate by the Danish Energy Agency and Energinet, 2017

205 Biomass boiler, manual stoking

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Publication date

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Amendments after publication date

Date	Ref.	Description
12.2017	Datasheet 5	Updated upper and lower levels for uncertainty of O&M for biomass boilers with manual stoking in one-family houses

Qualitative description

Brief technology description

Modern manually fired boilers for stoking with solid wood have downwards draught or down-draught. The principle is that the fuel is heated, dried and degasified in the combustion chamber, after which the gases are led downwards (or down in case of down-draught) through a crevice in the bottom of the combustion chamber into the chamber where the combustion takes place during supply of secondary air. This type of boiler is often provided with an air fan for supply of combustion air or a flue gas fan. Older types of boilers are up-draught boilers and do not comply with the current environmental requirements. Manual boilers should be installed with an accumulation tank of appropriate size. A buildings heat demand can be covered solely with a manual biomass boiler with a well-insulated accumulation tank.

Figure 13: Double duty wood log boiler (manual stoking) prepared for mounting of pellet burner (automatic stoking)

Input

The input is log wood of different sizes, depending on the boiler.

Output

Heat for space heating and hot tap water.

Typical capacities

Log wood boilers are available from a few kW up to 100 kW.

Regulation ability

The boilers are installed with a storage tank. A few log wood boilers have regulation abilities.

Advantages/disadvantages

Advantages

- A biomass boiler with manual stoking is a simple and robust design.

Disadvantages

- Compared to district heating, gas boilers or heat pumps a considerable effort must be put into transport and handling of the fuel wood.
- Boiler and flue gas system requires regular cleaning and maintenance.

Environment

Examinations show that newer boilers with accumulation tank cause considerably less pollution compared to old up-draught boilers. Legislation requirements have been stringent continuously and regards safety, efficiency, emission limits etc.

Research and development perspectives

Biomass boilers with manual stoking are a technology undergoing continuous development, requiring R&D in the following areas:

- High-efficient and low-emission technologies
- Automation

Examples of market standard technology

Danish manufacturers of market standard technology can be found on web lists at [4]. The products on this list comply with the latest regulation of biomass boilers.

Assumptions and perspectives for further development

Manually fired biomass boilers are common in Denmark and in the rest of Europe. Denmark is estimated to have 48,000 manually fired boilers [2]. Costs and performance of the technology is today well known and only incremental improvements are expected. Therefore, the future price and performance may also be projected with fairly high certainty. Biomass boilers with manual stoking are commercially available with a moderate deployment (a category 3 technology).

Uncertainty

Costs depend on designs and brands as well as the level of automation more than on the capacity.

Economy of scale effects

Biomass boilers with manual stoking are only produced within a very small range of capacity, hence the economy of scale is considered limited if applicable at all.

Additional remarks

-

Data sheets

Table 24: Biomass boiler, manual stoking – one-family house, existing, new and energy renovated buildings

Technology	Biomass boiler, manual stoking, wood logs - One-family house, existing, new and energy renovated buildings									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	35	30	25	25	25	35	20	35	A	4
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	0	0	0	0	0	0	0	0		
Heat efficiency, annual average, net (%)	80	82	86	88	70	90	80	96		
Total efficiency, annual average, net (%)	80	82	86	88	70	90	80	96		5
Auxiliary Electricity consumption (kWh/year)	250	240	220	200	200	300	150	250	G	8
Technical lifetime (years)	20	20	20	20	15	25	15	25		7
Regulation ability										
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	NA	NA	NA	NA	NA	NA	NA	NA		
Minimum load (% of full load)	NA	NA	NA	NA	NA	NA	NA	NA		
Warm start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Cold start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Environment										
SO_2 (g per GJ fuel)	25	25	25	25	18	32	18	32		9
NO_X (g per GJ fuel)	80	70	60	50	62	120	42	58		5
CH_4 (g per GJ fuel)	3	2	1	0	0	4	0	2		2.5
N_2O (g per GJ fuel)	4	4	4	4	1	7	1	7		9
Particles (g per GJ fuel)	150	120	95	60	100	140	50	70	C	9
Financial data										
Specific investment (1000€/unit)	7.0	6.8	6.5	5.9	5	14	4	12	F	
- hereof equipment (%)	80	80	80	80	80	80	80	80		
- hereof installation (%)	20	20	20	20	20	20	20	20		
Possible additional specific investment (1000€/unit)	3.1	3.0	2.9	2.6	3	2.6	2.4	4	B, D, E, F	
Fixed O&M (€/unit/year)	466	455	440	401	364	521	318	479		
- of which is electricity costs (€/unit/year)	16	17	22	23	14	21	18	29	G	
- of which is other O&M costs (€/unit/year)	450	439	417	378	350	500	300	450	F	11
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Notes

A Nominal heat delivery in 2015 from 30-40 kW

B Storage tank

C EN303-5 measurement method

D Prerequisite: house with central heating system

E Chimney

F Assuming a cost-reduction of 0.5 % p.a., which in turn is assumed equivalent to the typical improvement of mature technologies.

G The cost of auxiliary electricity consumption is calculated using the following electricity prices in €/MWh: 2015: 63, 2020: 69, 2030: 101, 2050: 117. These prices include production costs and transport tariffs, but not any taxes or subsidies for renewable energy.

References

[1] Vurdering af brændekedlers partikelemission til luften i Danmark, Miljøprojekt nr. 6 2008, Kim Winther, Teknologisk Institut

[2] Emissioner fra træfyrede brændeovne og -kedler, Miljøprojekt nr. 1324 2010, Johnny Iversen, Thomas Capral Henriksen og Simon Dreyer, Carl Bro.

[3] Brændeovne og små kedler – partikelemissioner og reduktionstiltag, Miljøprojekt nr. 1164, 2007, Jytte Boll Illerup, DMU et al.

[4] www.teknologisk.dk/911; Listen over godkendte biobrændselsanlæg

[5] Strategic Research and Innovation Agenda for Renewable Heating & Cooling; RHC-Platform 2013; Renewable heating & Cooling; European Technology Platform.

[6] Energibesparelser - det behøver ikke være så svært; Energibranchen.dk, nr. 3, september 2009.

[7] Lot 15: Solid fuel small combustion installations-Base Case definition.

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[9] Danish Emission Inventories for stationary combustion plants, inventories until 2011, Scientific Report from DCE n0. 102, 2014

[10] www.bios-bioenergy.at/en/electricity-from-biomass/

[11] Estimate by the Danish Energy Agency and Energinet, 2017

206 Wood stove

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Date	Ref.	Description
12.2017	Datasheet 6	Updated upper and lower levels for uncertainty of O&M for wood stoves without water tank in one-family houses

Qualitative description

Brief technology description

A wood stove is an enclosed room heater used to heat the space in which the stove is situated. Usually, the wood stove is fired with a batch of 2-3 pieces of new firewood at a time. The firing takes place when there are no more visible yellow flames from the previous basic fire bed, and when a suitable layer of embers has been created. Modern wood stoves have up to three air inlet systems in order to achieve the best possible combustion and to ensure that the glass pane in the front door does not get sooty: primary air up through the bottom of the combustion chamber, secondary air as air wash to keep the combustion alive and to maintain the glass clean, and tertiary air in the backside of the combustion chamber for after-burning of the gases. Some stoves need to have the air inlet dampers manually adjusted in connection with each new fired batch (maximum 3-5 minutes after each charge); others are more or less self-regulating.

Figure 14: Wood stove

The chimney serves as the stove's motor, and is essential to the stove's functioning. The chimney draught sucks air through the air dampers to the combustion chamber.

Heat from wood stove is usually a supplement to other kinds of heat supply. Some stoves are assembled with a integrated boiler, and thus can be connected to the central heating system.

Input

Wood logs of different sorts like beech, birch and pine wood. The humidity should be of 12 to 20 %, and the size of the wood logs depends on the stove but usually about 250 to 330 mm with a weight of 700 to 1000 g.

Output
Space heating by convection and radiation. If the wood stove includes a water tank, it can also produce a certain amount of hot tap water.

Typical capacities
Typical capacities are 4 to 8 kW nominal output.

Regulation ability
By regulating the air dampers, the stove's heat output can be minimized or maximized within a few minutes, however, this can result in an increased emission.

Advantages/disadvantages
Advantages

- Wood stoves are usually independent of electricity supply.
- Can supplement primary heating unit, which in turn can reduce the dependency of the primary heating supply

Disadvantages

- Compared to district heating, gas boilers or heat pumps a considerable effort must be put into transport and handling of the fuel wood.
- High level of local emission of air pollutants e.g. particulate matter

Environment
Woodstoves emit a high level of air pollutants e.g. particulate matter at local level

Pollution from wood stoves is dependent on series of factors such as stoking conduct, the individual stove, the controlling of the combustion and chimney in relation to the surrounding topography. The chimney is the engine for the combustion and where the draft is an essential part of how much air is reaching the combustion, this can be affected by the height of the chimney, and how the surroundings e.g. Other houses, hills, forests wind direction are. If the draft is not sufficient it will lead to poor combustion and more emissions. Different voluntary environmental labelling of woodstoves exist e.g. the Nordic wan-labelling. The Swan label is well accepted and can be seen as the consumer guarantee that the stove meets some environmental requirements. But still the emission form a modern wood stove is much higher than from e.g. gas, oil or biomass boilers. Stricter requirements on the emissions are coming up in near future.

Research and development perspectives
There is a need for continuous development of stoves with the purpose of reducing the particle emissions and decreasing the supply to low-energy houses.

Examples of market standard technology
Some Danish manufacturers produce swan-labelled products, a list of which can be found at [4].

The swan label is a voluntary agreement, and labelled stoves must comply with relative stringent efficiency and emission requirements.

Prediction of performance and costs
Wood stoves are commercially available with a moderate deployment (a category 3 technology). Price and performance of the technology is today well known and only incremental improvements are expected. Therefore, the future price and performance may also be projected with fairly high certainty. Wood stoves are widely used in Denmark, and the number of installed stoves is 750,000 [2].

Uncertainty
Prices vary very little with the capacity of the stove compared to the variation that is related to designs and brands. Price and performance of the technology is today well known it is however expected that from 2030 more automatic stoves will be developed to overcome the legislation and future demands. Therefor an increment in investment is expected. After this period, it is expected that the technology becomes generic and therefor investments are expected to drop as the technology becomes cheaper.

Economy of scale effects
Wood stoves are only produced within a very small range of capacity, hence the economy of scale is considered limited if applicable at all.

Additional remarks
Wood stoves without integrated boilers / heat storage will often be oversized for use in new low energy houses. They can, however be used for peak load and for heating up the building after the room temperature has been lowered, e.g. during holidays.

Data sheets

Table 25: Wood stove without integrated water tank– one family house, existing and new building

Technology	Wood stove without water tank, wood logs - One-family house, existing, energy renovated and new buildings									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	6	5	4	4	4	8	4	8	F	
Electricity generation capacity for one unit (kW)	NA	NA	NA	NA	NA	NA	NA	NA		
Expected share of space heating demand covered by unit (%)	40	40	40	40	20	60	20	60	C	
Expected share of hot tap water demand covered by unit (%)	0	0	0	0	0	0	0	0	E	
Electric efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Heat efficiency, annual average, net (%)	65	70	75	75	62	78	67	83		
Total efficiency, annual average, net (%)	65	70	75	75	62	78	67	83		
Auxiliary Electricity consumption (kWh/year)	0	0	0	0	0	0	0	0		
Technical lifetime (years)	20	20	20	20	15	25	15	25		2
Regulation ability										
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	NA	NA	NA	NA	NA	NA	NA	NA		
Minimum load (% of full load)	NA	NA	NA	NA	NA	NA	NA	NA		
Warm start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Cold start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Environment										
SO_2 (g per GJ fuel)	25	25	25	25	18	32	18	32		3
NO_X (g per GJ fuel)	90	90	90	90	85	120	85	120		
CH_4 (g per GJ fuel)	320	125	100	100	100	300	50	200		1.3
N_2O (g per GJ fuel)	4	4	4	4	1	7	1	7		3
Particles (g per GJ fuel)	50	40	30	25	25	250	15	200	A	1
Financial data										
Specific investment (1000€/unit)	2.5	2.5	3.5	3.1	2	3	2.5	4	D	2
- hereof equipment (%)	100	100	100	100	100	100	100	100		2
- hereof installation (%)	0	0	0	0	0	0	0	0		2
Possible additional specific investment (1000€/unit)	1.6	1.6	1.5	1.3	1.5	2	1.2	2	B, G	
Fixed O&M (€/unit/year)	150	145	200	190	125	200	150	250		
- of which is electricity costs (€/unit/year)	0	0	0	0	0	0	0	0		
- of which is other O&M costs (€/unit/year)	150	145	200	190	125	200	150	250	D	6
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Table 26: Wood stove with integrated water tank– one-family house, existing, energy renovated and new building

Technology	Wood stove with water tank - One-family house, existing, energy renovated and new buildings									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	15	12	10	10	10	15	8	12		
Electricity generation capacity for one unit (kW)	NA	NA	NA	NA	NA	NA	NA	NA		
Expected share of space heating demand covered by unit (%)	45	45	45	45	20	70	20	70	C	
Expected share of hot tap water demand covered by unit (%)	20	20	20	20	10	40	10	40	E	
Electric efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Heat efficiency, annual average, net (%)	65	70	75	75	62	78	67	83		
Total efficiency, annual average, net (%)	65	70	75	75	62	78	67	83		
Auxiliary Electricity consumption (kWh/year)	150	140	130	110	100	160	90	150	H	
Technical lifetime (years)	20	20	20	20	15	25	15	25		2
Regulation ability										
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	NA	NA	NA	NA	NA	NA	NA	NA		
Minimum load (% of full load)	NA	NA	NA	NA	NA	NA	NA	NA		
Warm start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Cold start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Environment										
SO_2 (g per GJ fuel)	25	25	25	25	18	32	18	32		3
NO_X (g per GJ fuel)	90	90	90	90	85	120	85	120		
CH_4 (g per GJ fuel)	320	125	100	100	100	300	50	200		1,3
N_2O (g per GJ fuel)	4	4	4	4	1	7	1	7		3
Particles (g per GJ fuel)	50	40	30	25	25	150	15	100	A	1
Financial data										
Specific investment (1000€/unit)	4	4	4.5	4.2	3	5	3.5	5.5	D	2
- hereof equipment (%)	85	85	85	85	85	85	85	85		2
- hereof installation (%)	15	15	15	15	15	15	15	15		2
Possible additional specific investment (1000€/unit)	1.6	1.6	1.5	1.3	1.5	2	1.2	2	B, G	
Fixed O&M (€/unit/year)	209	205	263	253	157	261	161	268		
- of which is electricity costs (€/unit/year)	9	10	13	13	7	11	11	18	H	
- of which is other O&M costs (€/unit/year)	200	195	250	240	150	250	150	250	D	6
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Notes

A DIN Plus measurement method

B Chimney

C The share of space heating covered by a wood stove depends on the possibility to regularly charge the stove with wood logs and of the location of the stove in the house. With regularly charging and a central location of the stove, the coverage can be up to 80 % of the heating demand in the house. Approximately 10 % larger is possible for stoves with a integrated boiler. Taking into consideration that normally the average residents will have difficulties with regular fuel charging, the expected share of space heating covered by the wood stove without a integrated boilerwill be in the range of 20 % to 60 %.

D More automatic stoves are expected in the future.

E Only for stoves with integrated boiler, otherwise 0%.

F Nominal heat delivery in 2015 from 4-12 kW

G Assuming a cost-reduction of 0.5 % p.a., which in turn is assumed equivalent to the typical improvement of mature technologies.

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207 Electric heat pumps

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Amendments after publication date

Date	Ref.	Description
10.2017	Datasheet 7.1, 7.2, 7.3 & 7.4	Updated technical lifetime of air-to-air and air-to-water heat pumps
10.2017	Datasheet 7.1, 7.2, 7.3 & 7.4	Updated O&M of air-to-air, air-to-water and ground source heat pumps
8.2017	Datasheet 7.9 & 7.10	Updated technical lifetime of ground source heat pumps in apartment complexes

Qualitative description

Brief technology description

Heat pumps employ the same technology as refrigerators, moving heat from a low-temperature level to a higher temperature level. Heat pumps draw heat from a heat source (input heat) and convert the heat to a higher temperature (output heat) through a closed process; either compression type heat pumps or "thermally driven" heat pumps.

Descriptions of the most commonly applied heat pumps are included in the same sections in order to facilitate comparison of the features of the different types of commonly applied heat pumps.

Gas heat pumps are not commonly applied, and are described in separate sections after these first sections.

Heat pumps can be categorized according to their design or operational principle as follows:

- Compressor-driven heat pumps, which can be driven by gas or electricity.
- Sorption heat pumps (split into absorption and adsorption heat pumps), which can be driven by gas, pressurized hot water or oil. They are also called "thermally driven" heat pumps.

Other types can be found as well (Vuilleumier etc.), but are in an R&D stage and are not treated in the present document.

Geothermal heat, groundwater or surface water, the sun and the air are suitable as natural sources of heat for heat pumps.

Heat pumps are differentiated by the ways used to collect heat from the heat source and ways used to distribute the heat in the house.

- Air-to-Air heat pumps draw heat from ambient air and supply heat locally through air heat exchangers. Air-to-Water heat pumps draw heat from ambient air and supply heat through a hydraulic water based heat distribution system (radiator, convectors, floor heating).
- Brine-to-Water heat pumps ("ground-source" heat pumps) are generally taking heat from the ground circulating cold brine through pipes and are distributing heat in the house via a water based system (radiator, floor heating etc.) often called "ground-source" heat pumps.
- Ventilation heat pumps draws heat from ventilation outlet air and heats up the air intake in the ventilation system, and can be either air-to-air, air-to-water or a combination of both.

Heat pumps are utilized for individual space heating, industrial processes and district heat production. Today most small heat pump systems used for individual space heating are electrically driven compression heat pumps utilizing energy from the ambient air, exhaust ventilation outlets or ground heat. In Denmark this is the only type of heat pumps that is utilized for individual heating in some countries, other types (such as hybrid gas heat pumps) are utilized as well, especially for larger building complexes.

Heat pumps for water based distribution systems have a maximum outlet temperature of around 55˚C and the lower outlet temperature the higher efficiency of the heat pump, hence inlet temperature as low as 35° C is attractive. However outlet temperature around 35°C-55°C, requires distribution system that is compliant with temperatures in this range. In many cases it is necessary to install larger radiators, floor heating and/or improve the insulation level of the building envelope.

Domestic hot water is in general preheated in a storage tank using direct electric heating as the heat capacity of heat pumps is often inadequate for heating showering water directly.

For compression heat pumps, the actual heat output is usually 3 to 5 times the drive energy (the coefficient of performance (COP)). The energy flow is illustrated in the Sankey diagram in figure 1 below:

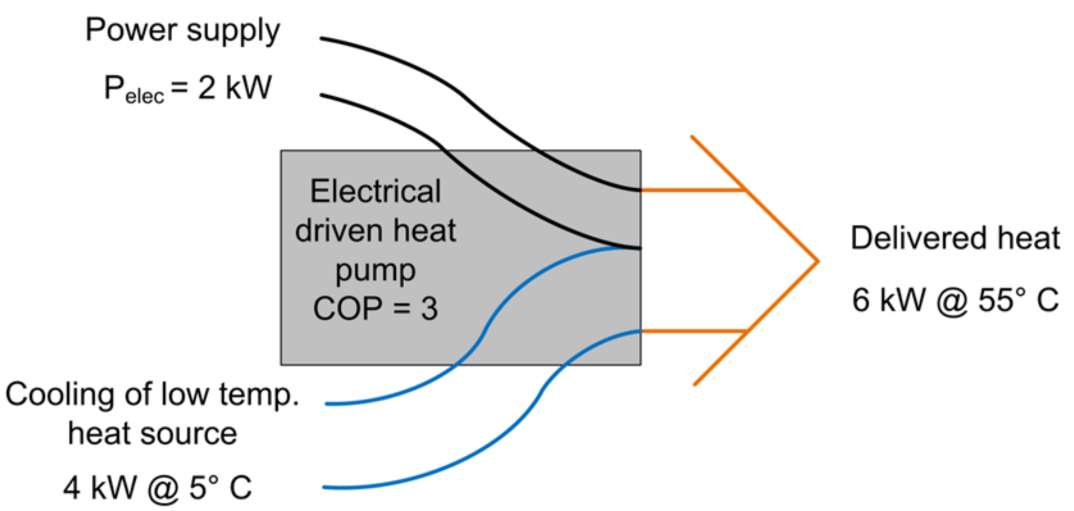

Figure 1: The electrical power consumption of 2 kW enables the heat pump to utilize 4 kW from a low temperature heat source at 5° C. Thus delivering 6 kW at 55° C (COP is 3).

The temperature difference between the temperature level of heat source and the temperature level of the heat delivered influence the COP. When the difference in temperature between the heat source and heat delivery decreases, the COP will increase and vice versa. This implies that the COP will vary e.g. according to the season – a low outdoor temperature implies a higher temperature difference, when the heat output is at the same temperature. Hence, in wintertime the COP will be less than during the summer.

As relatively few heat pumps has been installed in Denmark and the installation skill and knowledge is lower than for traditional technologies, therefore there have been issues regarding correct installation especially of the water based heat pumps (air-to-water and ground-source). Incorrect installation results in reduced efficiency and there is a development potential for better installations. This is however not expected to increase prices as poor installations often derive from inadequate thoroughness.

Air-to-air

Air-to-air heat pumps draw heat from the ambient air and supply heat locally through an air heat exchanger. Most air-to-air heat pumps have one outdoor unit and one indoor unit and are often referred to as "split-units". This configuration means that the heat pump can only supply heat at one location in the house and that larger coverage requires an air circulation system or that the doors to adjoining rooms are open. Remaining heat demand must be covered by other sources, e.g. electrical heaters or additional air-to-air heat pumps.

Air-to-air heat pumps with more than one indoor heat exchanger (multi-split units) are also available, but only few are being installed today.

Air-to-air heat pumps will usually cover between 60 % and 80 % of the space heating demand. Thus requiring additional heating during the coldest periods or if the air is not circulated throughout the house. Hence air-to-air is usually installed as an auxiliary heating unit in combination as supplement to an existing primary source of heat. The existing heat source could potentially be anything, but is usually either a gas boiler or oil boiler.

Many air-to-air heat pumps are reversible meaning that they can also be used for cooling (air-condition).

The number of air-to-air heat pumps installed in Denmark is 120,000 to 160,000 (2014) [1] [2] [3]. A large share of these is installed in summer residences.

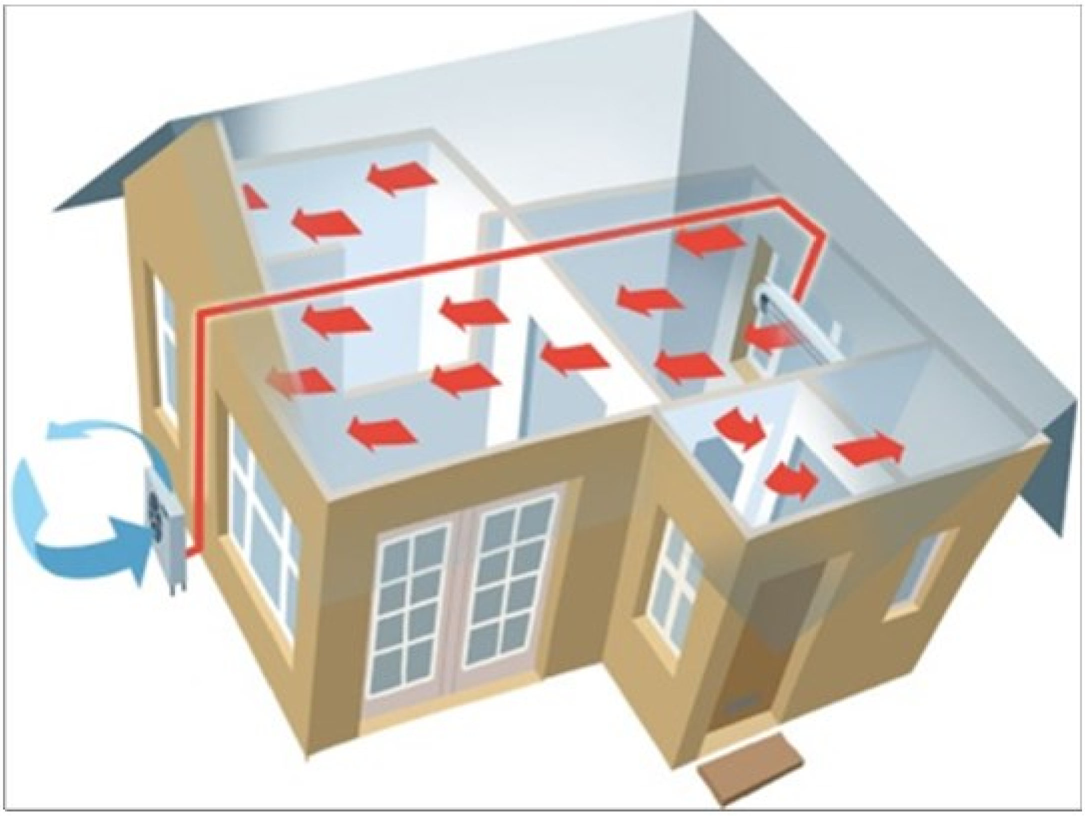

Figure 2: Air-to-air heat pump. The two units are placed according to concrete local conditions.

Air-to-water heat pump

Air-to-water heat pumps draw heat from ambient air and supply heat for space heating through a water based distribution system. Air-to-water heat pumps also heat water for domestic hot water consumption and will often be equipped with an electrical heater for supplement in peak load periods, so that the unit can supply 100 % of the heat demand.

Some air-to-water heat pumps are designed specifically for supplying only hot tap water. This type of air-to-water heat pump is used in a number of summer residences, especially if there is a large consumption of hot tap water.

The number of installations in Denmark of air-to-water heat pumps in early 2014 is approximately 17,000 - 22,000 [1] [2] [3].

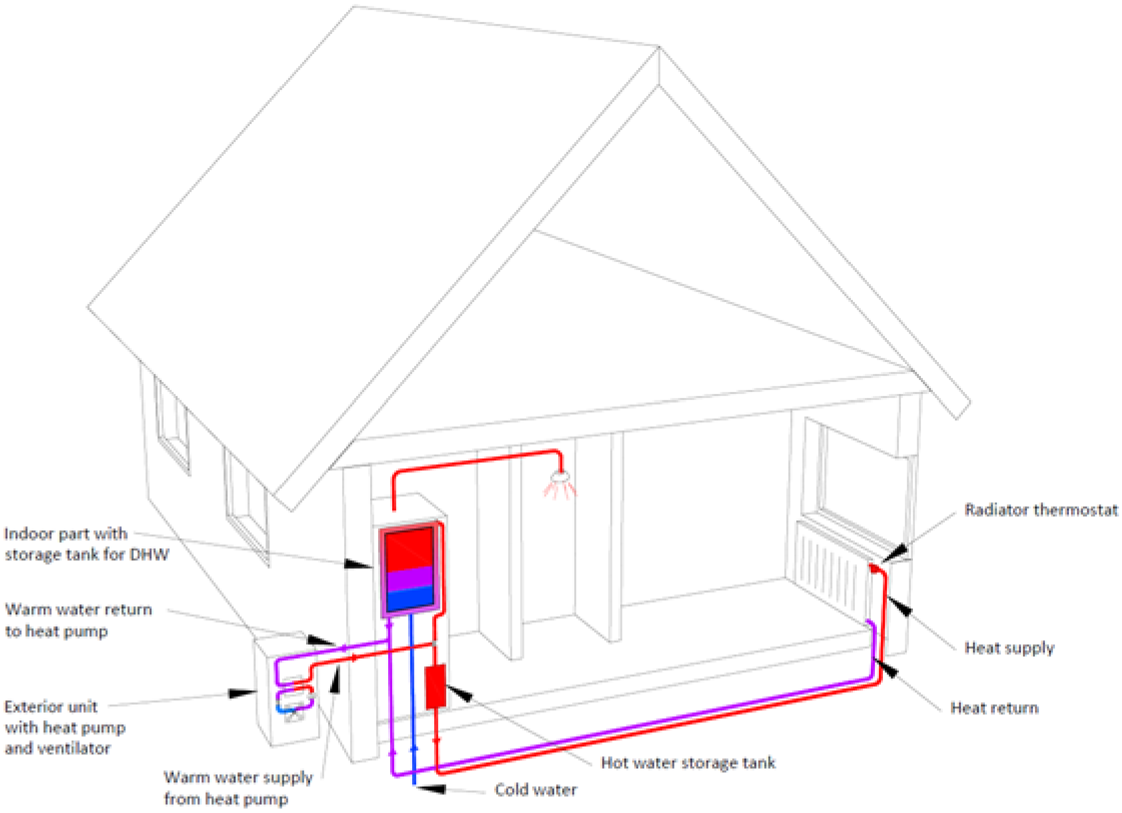

Figure 3: Air-to-water heat pump

Brine-to-water (Ground-source) heat pump

Brine-to-water heat pumps draw heat from the ground and supply heat for space heating through a water based distribution system. Brine-to-water heat pumps also heat water for domestic hot water consumption and will often be equipped with an electrical heater for supplement in peak load periods, so that the unit can supply 100 % of the heat demand.

Most ground-source heat pumps use a horizontal heat collector that consists of pipes containing anti-freeze brine, which is circulated to withdraw heat from the top soil layer.

In theory, ground sourced heat pumps will achieve a higher thermal efficiency during the heating season compared to air-to-water heat pumps. In practice, however, the difference is often small. If It is possible to use vertical pipes, which can reach depths of up to 250 m. These however, have higher investment costs and are primarily used where the surface area is inadequate or unsuited for installation of horizontal pipes e.g. rocky grounds [1] [2].

The number of installations in Denmark of ground source heat pumps is estimated to be 25,000 to 35,000 (early 2014).

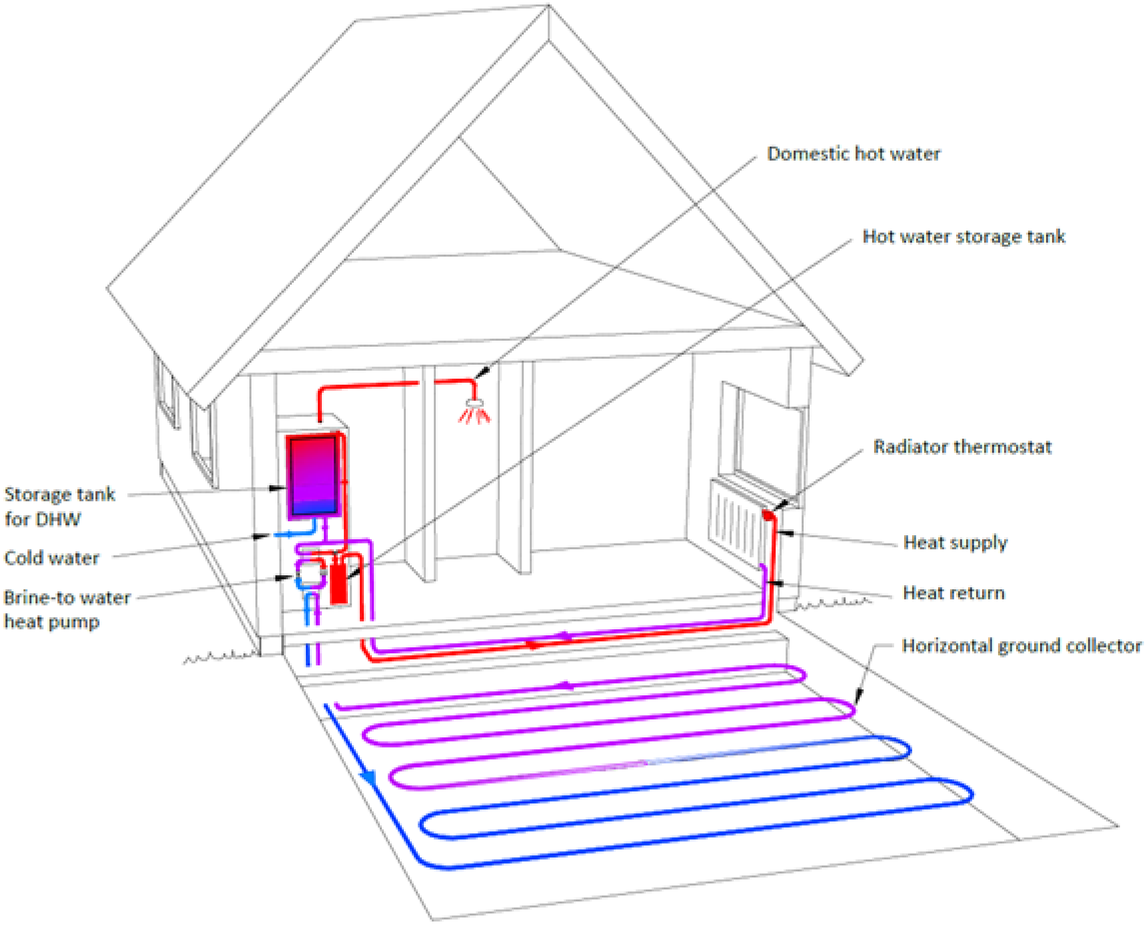

Figure 4: Ground-source heat pump (brine-to-water)

Ventilation air heat pump

Ventilation heat pumps can be either air-to-air, air-to-water or a combination of both. This type draws heat from ventilation outlet air and heats up the air intake in the ventilation system and usually domestic hot water as well. This type of heat pumps is also called exhaust air heat pumps.

The heat pump can heats the inlet air to a level providing more heat than the ventilation heat losses, and can thereby compensate for the transmission loss to some extent. Depending on the ratio between transmission heat losses and ventilation heat losses, this type of heat pump might require a supplementary heat source to cover the heat demand all year around and to make individual room regulation possible.

The system is often combined with a direct heat exchanger that will recover part of the heat from the outlet air. This means that the capacity of the heat pump is reduced, but the overall energy efficiency is increased. The number of exhaust air to water heat pumps is estimated to 17,000 to 22,000 in early 2014 [3]. This heat pump type is widely used in Germany [1].

Figure 5: Ventilation air heat pump

Input

Inputs for heat pumps are a heat source and drive energy.

Heat sources for individual heat pumps are primarily ambient air, ventilation outlet air or ground (soil). Typical ambient Danish temperatures are between -5 and 18 °C, while the ground temperature in a depth of 1 meter is between 2 and 14° C (dropping to around 0° C through a winter with heat withdrawal). Other heat sources could be solar heating panels, surface water (lake or seawater).

The drive energy for individual heat pumps is electricity or gas. See chapter 8 on gas heat pumps.

Output

The output is heat for space heating as hot air or water and for some installations domestic hot water as well.

Typical capacities

The heating capacities varies between the types as for example air-to-air and ventilation heat pumps typically only heat to part of a house whereas brine to water and air to water heat pumps supply heat for the entire house including domestic hot water.

Air-to-air

Typical heating capacities for a single air-to-air heat pump are 3-8 kW, which will usually cover between 60 % and 80 % of the space heating demand. Air-to-water and brine-to-water (ground-source)

Heat pumps supplying water based systems typically ranges from approximately 4 kW up to several hundred kW heating capacity, covering the needs for both space heating and domestic hot water in both low-energy buildings and other buildings.

Water based heat pumps are normally designed to cover between 95 % and 98 % of the heat demand.

Ventilation

The ventilation heat pumps heating capacity range from 1.5 kW in single family houses to several hundred kW in large office buildings. In private households, the heating capacity is normally up to 3 kW. Ventilation heat pumps will usually be inadequate as the only heat source for space heating and domestic hot water production. The reason is that the exhaust ventilation air can be insufficient as the only heat source. Consequently, and depending on the ratio between transmission heat losses and ventilation heat losses, a ventilation heat pump might require a supplementary heat source during some periods.

Regulation ability

All heat pumps have on/off regulation and some are also equipped with capacity regulation, meaning that the heat pump can balance the heat production to the demand continuously down to around 20 % of maximum [7].

Heat pumps for individual heating are able to stop immediately and a stopped heat pump is able to reach full power consumption within 1 minute.

It is important to acknowledge that varying the operation strategy of a heat pump over time has influence on the overall energy consumption and comfort levels. For heat pumps that are on/off regulated, the efficiency will drop with increasing numbers of starts and stops. Correct dimensioning and utilization of storage tanks is necessary to ensure the highest efficiencies. Heat pumps with capacity regulation have more components than on/off controlled heat pumps, which may increase the price.

The main part of air-to-air heat pumps installed today has capacity regulation. Only around 20 % of the installed air-to-water and ground-source heat pumps has capacity regulation. While most heat pumps on the market today are equipped with capacity regulation, meaning that the percentage of installed heat pumps with capacity regulation will increase.

As the water based distribution systems have a higher thermal inertia on/off regulation does not affect comfort in the same way as this regulation type would on air-to-air heat pumps.

Advantages/disadvantages

The general advantage of heat pump technologies is that the primary energy consumption is reduced compared to boilers or traditional electrical heating.

Noise from air-source heat pumps can be a problem. In general the noise level is regulated by law and must be less than 35 dB(A) [17] on the boundary to others properties. Additionally the EU ECO design regulation of heat pumps [16] includes specification of maximum noise from the heat pump itself. Air-to-air heat pumps of higher quality will normally have lower noise levels though.

Air-to-air heat pumps

Advantages of the Air-to-air heat pumps are that they are simple to install in rooms and buildings with electrical heating since a water based distribution system is not necessary and the air-to-air heat pumps have a higher efficiency than direct electric heating.

And the outdoor installation only need limited outdoor space and do not need any digging in the ground.

The main reasons for the large number of installed air-to-air heat pumps are low investment costs and easy installation.

A drawback of the air-to-air heat pump is that, unless it is installed as a multi-split unit, it is only able to deliver heat in a single room.

Additionally a disadvantage of air-to-air heat pumps is that the heat capacity is limited and they are unable to heat domestic water. Therefore, this type of heat pump requires a supplementary heat source.

Air-to-water heat pumps

Compared to ground-source heat pumps, air-to-water types are easier to install and does not require a large area for ground heat collectors.

Compared to air-to-air heat pumps, water based systems can deliver heat through the water based heating system in several rooms, and it is possible to regulate the heat transfer individually in each room.

Compared to ground-source heat pumps, the air-to-water heat pump is less efficient as the air temperature will be lower than the ground temperature during winter periods. Moreover, ice will build up on the outdoor heat exchanger and thereby decrease the evaporation temperature and the efficiency.

Gas hybrid air-to-water heat pumps are less expensive than standard air-to-water heat pumps, but are only applicable in areas with natural gas and have higher fuel costs due to consumption of gas.

Brine-to-water (ground- source) heat pumps

As for air-to-water heat pumps, the brine-to-water (ground-source) heat pump can deliver heat through the water based heating system in several rooms, and it is possible to regulate the heat transfer individually in each room.

Compared to air based systems, this type typically has a higher annual COP as the ground is warmer than the ambient air during the heating season.

A disadvantage is that the ground-source involves digging or other arrangements to retrieve the necessary heat. This increase investment costs compared to air based solutions but will to some extend be counterbalanced by the reduced costs of energy. A ground-source heat pump will be approximately 15 % more efficient than an air-to-water heat pump.

There are no noise problems when the heat pump is running, which can make it the only possible solution in densely built areas.

Ventilation heat pumps

This heat pump is only applicable in houses with a ventilation system. In old houses with large, uncontrolled ventilation due to air infiltration, this technology will not be suitable. In new and more airtight houses ventilation systems are often applied meaning that ventilation heat pumps could be a suitable solution.

A disadvantage of ventilation heat pumps is that the heat capacity is limited by the heat that can be drawn from the exhaust air.

Environment

The environmental impact of heat pumps relates mainly to power consumption, leaking of synthetic refrigerants and noise.

The environmental impact due to the use of electricity will depend on the way the electricity is produced.

Today all heat pumps for individual heating on the Danish market use synthetic refrigerants. These are known HFC's (hydrofluorocarbons) which are fluorinated gases (F-gases), which possess a potent greenhouse effect and are covered by the Kyoto Protocol.

There are many different refrigerants based on HFCs. The most important are HFC-134a (R134a) and HFC mixtures: R404A, R410A and R407A. The most common refrigerants based on HFCs have Global Warming Potentials (GWP) of about 1,500 to 4,000 compared to CO2 which has a GWP of 1.

Danish Legislation bans the use of HFC's in heat pumps with more than 10 kg of refrigerant. Heat pumps for individual heating typically contain less than 2 kg's of refrigerant meaning that the ban does not affect this segment.

There are, however, some heat pumps working with natural refrigerants (including R290 – propane), but this is a minority. It is expected that there will be a transition towards natural refrigerants or other less harmful refrigerants. The European F-gas regulation from 2015 states that F-gases will be phased out towards 2030 and banned in many applications where less harmful alternatives are available, which will likely lead to an increased use of natural refrigerants in heat pumps.

Research and development perspectives

Research and development primarily concerns new layouts and energy efficiency, where more efficient part load characteristics and control strategies for water based systems are in focus.

It is expected that an air-to-air heat pump that also heats domestic hot water will be introduced in the near future. Other layouts as for instance air-to-air heat pumps with several indoor units are also possible.

Efficient control strategies are particularly important when heat pumps interact with other systems such as ventilation, domestic hot water production, boilers or solar thermal systems. Interaction with the electricity system is also an issue.

There is a development perspective for better installations of particularly air-to-water and ground-source heat pumps. Because of faulty installations these heat pump types often performs worse than their potential. It can be complicated to detect poor performance, which means that it is not discovered by all end users. Higher educational requirements of installers and better monitoring of heat pump performance will reduce this issue. However, if an increased performance of installing heat pumps is achieved, this can reduce both installation costs and operation performance of the heat pump.

Examples of market standard technology

The best air-to-air heat pumps utilize compressors with permanent magnet motors and variable speed drive fans on heat exchangers for high efficiencies, especially during part load.

The best water-based heat pumps also utilize compressors with variable speed drives for increasing the efficiency at part load operation. Electronically controlled expansion valves increase the overall efficiency, while additional heat exchangers are applied for effective heating of tap water.

Hybrid gas heat pumps are configured with advanced controls that enable environmental or economical optimization, as the control unit dynamically calculates an optimal heat production strategy utilizing both heat pump and gas boiler according to parameters determined by the user e.g. fuel prices.

Prediction of performance and costs

Regarding development in cost, it is assumed that, the air to air heat pumps belong to Category 4 as "Commercial Technologies, with large deployment so far". While it is assumed that the other types belongs to Category 3 "Commercial Technologies, with significant deployment potential".

For heat pumps in Denmark it must be assumed that the operation and installation dimensions have larger potentials for improvement than the technologies themselves.

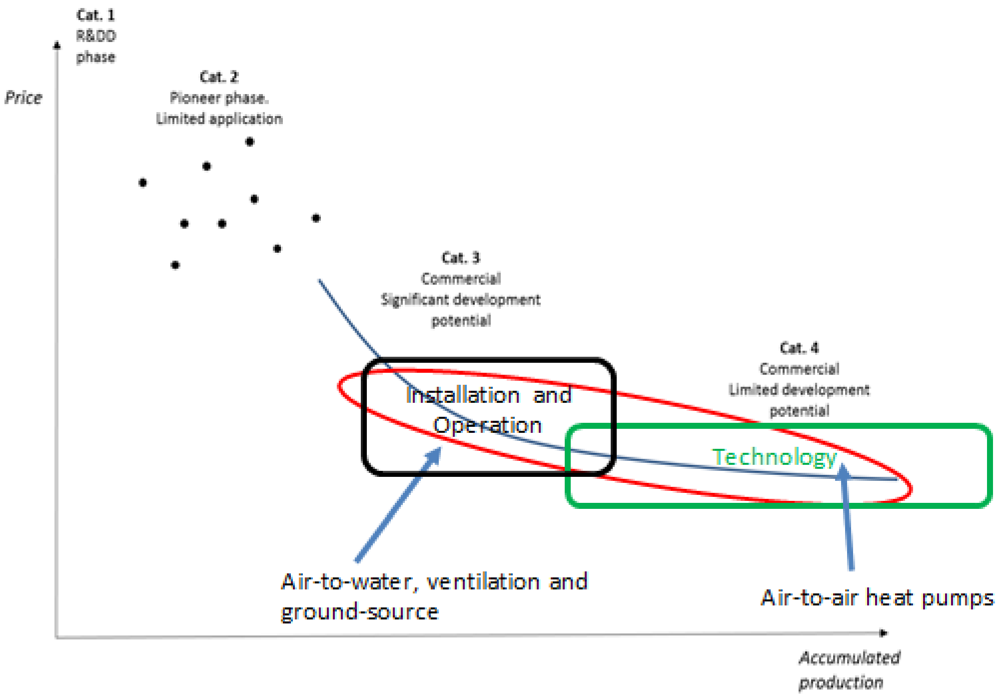

Figure 6: Learning curves of heat pumps for individual heat production. There is a learning curve for the technology itself (marked with green) and for the installation and operation (marked with black).

For the technology itself, it can be categorized in category 3 and 4 as indicated on the figure. For the installation and operation there is a potential for improvement – although this will probably not result in lower price, but rather in better installation implying better performance of the heat pumps. The development could thus be towards fewer and more qualified installers of heat pumps.

Air-to-air heat pumps are produced in far more numbers than the other types of heat pumps for individual space heating. Air-to-air heat pumps are very similar to split air conditioners (often the same appliance can deliver both heating and cooling) meaning that the production numbers are immense and the production plants are highly efficient therefore it must be assumed that the price development is slower than for the other types of heat pumps. Hence, air-to-air heat pumps are in category 4, whereas ventilation-, air-to-water- and ground-source heat pumps are in category 3. The production numbers for these types are much smaller, therefore the doubling time is assumed to be shorter and the costs can be reduced faster. Reduced installation costs require that markets with-in geographical regions are increased. Installation and operation is in category 3 for all types of heat pumps, implying that there is a potential for improvement regarding installation and operation.

A study [18] of the development in Sweden and Switzerland has investigated the learning curves for heat pumps. In Switzerland the number of units sold increased from 2,500 to 20,000 in the period 1985 to 2008, while the costs was reduced by 20 % in the same period. In Sweden the number of units sold increased from 2,500 in 1992 to 40,000 in 2006, while the costs reduced by approximately 30%. Hence, the development has on average resulted in a cost-reduction of 7% every time the number of sold units doubled in Switzer-land, while the doubling of sold units has resulted in an 8% cost-reduction in Sweden. It is considered likely that the cost for installation has decrease more than the cost for the technology because the "doubling" for the technology should be seen in an international perspective, while the installation should be seen in national perspective. The installation rate has been much slower in Switzerland (approx. 8 year between every doubling) than in Sweden (approx. 4 year between every doubling) and if no measures have been used to catalyze the process, it is assumed that the doubling time has been shorter in the first part of the period than in the last.

Based on the above mentioned the following assumptions regarding accumulated volume and cost reduction for investment and maintenance for heat pumps are introduced.

Table 27: Assumed increase in the accumulated produced units in the different time periods

Increase in accumulated produced units	2015-2020	2020-2030	2030-2050
Brine-to-water	0,9	1,25	1,25
Air-to-water	0,9	1,25	1,25
Ventilation	0,9	1,25	1,25
Air-to-air	0,6	0,75	0,75

Table 28: Resulting reduction in cost in the different time periods, it is for both types it is assumed that the cost is decreased 7-8% for every doubling.

Reduction in cost	2015-2020	2020-2030	2030-2050

Brine-to-water	6%	10%	10%
Air-to-water	6%	10%	10%
Ventilation	6%	10%	10%
Air-to-air	4%	6%	6%

The cost reductions over time observed can be expressed as capital or investment costs as a function of cumulative deployment. There is a characteristic declining cost profile, as is the contingency of the rate of decline and stabilization on market conditions (e.g., Swiss and Swedish differences) and technological maturity. In Danish, European and also global context, there is increased focus on energy efficiency (Danish Energy Policy, European Energy Union and Energy Efficiency Directive). Heat pumps can be a tool to increase the energy efficiency. Therefore, a significant market-pull can be expected regarding heat pumps.

Uncertainty

Prices of fuels affect the competitiveness of heat pumps. E.g. expensive biomass, gas or oil will imply that heat pumps will be better alternatives. Alternatively, if the fuel prices drops relative to the electricity prices then heat pumps will become less competitive.

Economy of scale

Economy of scale especially applies to air-to-water and ground-source heat pumps as installation and auxiliary equipment accounts for a considerable amount of the total in-vestment. Within the typical capacity range for single family houses, a capacity increase of 100 % will typically only increase investment cost for these systems by 20-35 %. Typical investment costs for 5, 10 and 15 kW air-to-water and ground source heat pumps are shown in the table below [1] [2] [3].

Table 29: Typical investment costs demonstrating economy of scale [1] [2] [3].

Size (heat production capacity)	5 kW	10 kW	15 kW
Air-to-water, Investment (€/unit)	7.500	10.000	12.000
Ground-source, Investment (€/unit)	12.500	16.000	19.000

As installation cost for air-to-air heat pumps only form a small part of the investment, economy of scale effects are very limited within the ranges for domestic households. A capacity increase of 100 % will typically increase cost by 80-100 %.

As air-to-air and ventilation heat pumps typically only applies heat to a single location, the maximum size of such units is limited to around 6 kW. Within this limited size range an increase of capacity of 50 % will typically add around 25 % to the price.

Additional remarks

A key point regarding application of the data in the data sheet is that e.g. the COP may vary considerably depending on the specific temperature parameters.

Application of the data in the data sheet for concrete calculations of a project should be evaluated according to the specific local conditions. Some guidelines based on experience from existing applications of heat pumps are provided in the data sheets.

Data sheets

The following data sheets are presented consecutively below in tables:

1. Air-to-air, existing one family house
2. Air-to-air, new one family house
3. Air-to-water, existing one family house
4. Air-to-water, new one family house
5. Air-to-water, existing apartments
6. Air-to-water, new apartments
7. Brine-to-water (ground source), existing one family house
8. Brine-to-water (ground source), new one family house
9. Brine-to-water (ground source), existing apartments
10. Brine-to-water (ground source), new apartments
11. Ventilation, new one family house
12. Ventilation, new apartments

Table 30: Heat pump, air-to-air – existing one-family house

Technology	**Heat pump, Air-to-air, existing one family house**									
Energy/technical data	**2015**	**2020**	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
					Lower	**Upper**	**Lower**	**Upper**		
Heat production capacity for one unit (kW)	4	4	6	6	2	10	2	10		1,2,5
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	60	60	60	60	50	70	40	80	F	1,2,7
Expected share of hot tap water demand covered by unit (%)	0	0	100	100	0	100	0	100	F	1.2
Heat efficiency, annual average, net (%)	500	510	410	420	400	550	350	600	C H I	4,5,7,8
Total efficiency, annual average, net (%)	500	510	410	420	400	550	350	600	C H J	4,5,7,8
Auxiliary Electricity consumption (kWh/year)	0	0	0	0	0	0	0	0		
Technical lifetime (years)	12	12	12	12	10	15	10	15		
Regulation ability										
Change in capacity within 1 minute (%)	100	100	100	100	50	100	50	100		1,2,7
Warm start-up time (hours)	0	0	0	0	0	0	0	0		1,2,7
Cold start-up time (hours)	0	0	0	0	0	0	0	0		1,2,7
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	1.8	1.7	1.9	1.8	1.4	2	1.2	2	K	1,2,3,14
- hereof equipment (%)	85	85	75	75	60	90	60	90		1,2,7
- hereof installation (%)	15	15	25	25	10	40	10	40		1,2,7
Possible additional specific investment (1000€/unit)										
Fixed O&M (€/unit/year)	170	162	146	132	150	250	100	150		
Variable O&M (€/GJ)	0	0	0	0	0	0	0	0		1,2,7

Table 31: Heat pump, air-to-air – new one-family house

Technology	Heat pump, Air-to-air, new one family house									
Energy/technical data	**2015**	**2020**	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
					Lower	**Upper**	**Lower**	**Upper**		
Heat production capacity for one unit (kW)	2.5	2.5	3.5	3.5	2	5	2	5		1,2,5
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	60	60	60	60	50	70	40	80	F	1,2,7
Expected share of hot tap water demand covered by unit (%)	0	0	100	100	0	100	0	100	F	1.2
Heat efficiency, annual average, net (%)	480	490	340	360	330	510	330	520	C G H I	4,5,7,8
Total efficiency, annual average, net (%)	480	490	340	360	330	510	330	520	C G H J	4,5,7,8
Auxiliary Electricity consumption (kWh/year)	0	0	0	0	0	0	0	0		
Technical lifetime (years)	12	12	12	12	10	15	10	15		
Regulation ability										
Change in capacity within 1 minute (%)	100	100	100	100	50	100	50	100		1,2,7
Warm start-up time (hours)	0	0	0	0	0	0	0	0		1,2,7
Cold start-up time (hours)	0	0	0	0	0	0	0	0		1,2,7
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	1.2	1.1	1.8	1.7	0.8	2	0.8	2	K	1,2,3,14
- hereof equipment (%)	75	75	70	70	50	80	50	80		1,2,7
- hereof installation (%)	25	25	30	30	20	50	20	50		1,2,7
Possible additional specific investment (1000€/unit)										
Fixed O&M (€/unit/year)	170	162	146	132	150	250	100	150		
Variable O&M (€/GJ)	0	0	0	0	0	0	0	0		1,2,7

Table 32: Heat pump, air-to-water – existing one-family house

Technology	Heat pump, Air-to-water, existing one family house									
Energy/technical data	**2015**	**2020**	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
					Lower	**Upper**	**Lower**	**Upper**		
Heat production capacity for one unit (kW)	10	10	10	10	5	15	5	15		1,2,5
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	70	100	70	100	A F	1,2,7
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	70	100	70	100	A F	1.2
Heat efficiency, annual average, net (%), floor heating	400	410	430	450	380	450	380	500	C I	4,5,7,8
Total efficiency, annual average, net (%), floor heating	390	400	420	440	370	440	370	490	C J	4,5,7,8
Heat efficiency, annual average, net (%), radiators	330	340	360	380	310	370	310	400	C I	4,5,7,8
Total efficiency, annual average, net (%), radiators	325	335	355	370	300	360	300	390	C J	4,5,7,8
Auxiliary Electricity consumption (kWh/year)	100	100	100	100	80	120	80	120	L	4
Technical lifetime (years)	18	18	18	18	15	20	15	20		
Regulation ability										
Change in capacity within 1 minute (%)	100	100	100	100	50	100	50	100		1,2,7
Warm start-up time (hours)	0	0	0	0	0	0	0	0		1,2,7
Cold start-up time (hours)	0	0	0	0	0	0	0	0		1,2,7
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	10	9.4	8.5	7.6	8	12	6	12		1,2,3,14
- hereof equipment (%)	70	70	65	60	50	85	50	85	B	1,2,7
- hereof installation (%)	30	30	35	40	15	50	15	50		1,2,7
Possible additional specific investment (1000€/unit)										
Fixed O&M (€/unit/year)	291	278	255	239	256	328	188	295		
- of which is electricity costs (€/unit/year)	6	7	10	17	6	8	13	20	L	
- of which is other O&M costs (€/unit/year)	285	271	245	222	250	320	175	275		
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		1,2,7

Table 33: Heat pump, air-to-water – new one-family house

Technology	Heat pump, Air-to-water, new one family house									
Energy/technical data	**2015**	**2020**	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
					Lower	**Upper**	**Lower**	**Upper**		
Heat production capacity for one unit (kW)	4	4	4	4	2.5	6	2.5	6		1,2,5
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	70	100	70	100	A F	1,2,7
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	70	100	70	100	A F	1.2
Heat efficiency, annual average, net (%), floor heating	345	355	365	380	330	365	330	400	C I	4,5,7,8
Total efficiency, annual average, net (%), floor heating	325	335	345	365	315	345	315	390	C J	4,5,7,8
Heat efficiency, annual average, net (%), radiators	300	320	340	355	290	330	290	375	C I	4,5,7,8
Total efficiency, annual average, net (%), radiators	285	305	320	335	280	315	280	365	C J	4,5,7,8
Auxiliary Electricity consumption (kWh/year)	100	100	100	100	80	120	80	120	L	4
Technical lifetime (years)	18	18	18	18	15	20	15	20		
Regulation ability										
Change in capacity within 1 minute (%)	100	100	100	100	50	100	50	100		1,2,7
Warm start-up time (hours)	0	0	0	0	0	0	0	0		1,2,7
Cold start-up time (hours)	0	0	0	0	0	0	0	0		1,2,7
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	7	7	6	5	6	9	4	8		1,2,3,13,14
- hereof equipment (%)	60	60	50	50	45	85	40	85	B	1,2,7
- hereof installation (%)	40	40	50	50	15	55	15	60		1,2,7
Possible additional specific investment (1000€/unit)										
Fixed O&M (€/unit/year)	291	278	255	239	256	328	188	295		
- of which is electricity costs (€/unit/year)	6	7	10	17	6	8	13	20	L	
- of which is other O&M costs (€/unit/year)	285	271	245	222	250	320	175	275		
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		1,2,7

Table 34: Heat pump, air-to-water – existing apartment complex

Technology	Heat pump, Air-to-water, existing apartments									
Energy/technical data	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	400	400	400	400	300	500	300	500		5,6
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	70	100	70	100	F	
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	70	100	70	100	F	
Heat efficiency, annual average, net (%), floor heating	430	440	450	480	430	460	440	500	C, I	11,12,15
Total efficiency, annual average, net (%), floor heating	410	420	430	460	410	450	420	480	C, J	4,11,12,15
Heat efficiency, annual average, net (%), radiators	380	390	400	415	380	420	390	450	C, I	11,12,15
Total efficiency, annual average, net (%), radiators	365	375	390	405	370	410	375	430	C, J	4,11,12,15
Auxiliary Electricity consumption (kWh/year)	10000	10000	10000	10000	8000	12000	8000	12000	L	4,7
Technical lifetime (years)	20	20	20	20	15	25	15	25		7,12
Regulation ability										
Change in capacity within 1 minute (%)	50	50	50	50	10	100	10	100		7,11
Warm start-up time (hours)	0	0	0	0	0	0	0	0		11
Cold start-up time (hours)	0	0	0	0	0	0	0	0		11
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	150	141	127	114	130	160	100	150		12,15
- hereof equipment (%)	70	70	70	70	50	85	50	85	B	12
- hereof installation (%)	30	30	30	30	15	50	15	50		12
Possible additional specific investment (1000€/unit)										
Fixed O&M (€/unit/year)	1640	1650	1866	2411	1070	2850	1820	3980		
- of which is electricity costs (€/unit/year)	640	710	1020	1650	570	850	1320	1980	L	
- of which is other O&M costs (€/unit/year)	1000	940	846	761	500	2000	500	2000		12
Variable O&M (€/MWh)	0.50	0.47	0.42	0.38	0.2	1.0	0.2	1.0		12

Table 35: Heat pump, air-to-water – new apartment complex

Technology	**Heat pump, Air-to-water, new apartments**									
Energy/technical data	**2015**	**2020**	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
					Lower	**Upper**	**Lower**	**Upper**		
Heat production capacity for one unit (kW)	160	160	160	160	140	200	140	200		5,6
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	70	100	70	100	F	
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	70	100	70	100	F	
Heat efficiency, annual average, net (%), floor heating	440	450	460	480	440	470	450	520	C I	11,12,15
Total efficiency, annual average, net (%), floor heating	390	400	405	410	390	410	400	490	C J	4,11,12,15
Heat efficiency, annual average, net (%), radiators	420	430	440	460	420	460	430	500	C I	11,12,15
Total efficiency, annual average, net (%), radiators	370	380	390	405	370	400	380	480	C J	4,11,12,15
Auxiliary Electricity consumption (kWh/year)	10000	10000	10000	10000	8000	12000	8000	12000	L	4,7
Technical lifetime (years)	20	20	20	20	15	25	15	25		7,12
Regulation ability										
Change in capacity within 1 minute (%)	100	100	100	100	20	100	20	100		7,11
Warm start-up time (hours)	0	0	0	0	0	0	0	0		7,11
Cold start-up time (hours)	0	0	0	0	0	0	0	0		7,11
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	75	71	63	57	60	100	50	100		12,15
- hereof equipment (%)	60	60	60	60	50	85	50	85	B	12
- hereof installation (%)	40	40	40	40	15	50	15	50		12
Possible additional specific investment (1000€/unit)										
Fixed O&M (€/unit/year)	1640	1650	1866	2411	1070	2850	1820	3980		
- of which is electricity costs (€/unit/year)	640	710	1020	1650	570	850	1320	1980	L	
- of which is other O&M costs (€/unit/year)	1000	940	846	761	500	2000	500	2000		12
Variable O&M (€/MWh)	0.50	0.47	0.42	0.38	0.2	1.0	0.2	1.0		12

Table 36: Heat pump, ground-source – existing one-family house

Technology	Heat pump, ground source, existing one family house									
Energy/technical data	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	10	10	10	10	5	15	5	15		1,2,5
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	80	100	80	100	F	1,2,7
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	80	100	80	100	F	1,2
Heat efficiency, annual average, net (%), floor heating	440	450	460	485	420	480	420	500	C I	4,5,7,8
Total efficiency, annual average, net (%), floor heating	430	440	450	475	410	460	410	480	C J	4,5,7,8
Heat efficiency, annual average, net (%), radiators	370	380	390	405	360	400	360	420	C I	4,5,7,8
Total efficiency, annual average, net (%), radiators	360	370	380	395	350	380	350	405	C J	4,5,7,8
Auxiliary Electricity consumption (kWh/year)	100	100	100	100	80	120	80	120	L	4
Technical lifetime (years)	20	20	20	20	15	25	15	25		1,2,7
Regulation ability										
Change in capacity within 1 minute (%)	100	100	100	100	50	100	50	100		1,2,7
Warm start-up time (hours)	0	0	0	0	0	0	0	0		1,2,7
Cold start-up time (hours)	0	0	0	0	0	0	0	0		1,2,7
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	16	15	14	12	13	17	10	16	D	1,2,3,14
- hereof equipment (%)	65	65	65	65	55	75	55	85	B	1,2,7
- hereof installation (%)	35	35	35	35	25	45	15	45		1,2,7
Possible additional specific investment (1000€/unit)										
Fixed O&M (€/unit/year)	291	278	255	239	256	328	188	295		
- of which is electricity costs (€/unit/year)	6	7	10	17	6	8	13	20	L	
- of which is other O&M costs (€/unit/year)	285	271	245	222	250	320	175	275		
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		1,2,7

Table 37: Heat pump, ground-source – new one-family house

Technology	Heat pump, ground source, new one family house									
Energy/technical data	**2015**	**2020**	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
					Lower	**Upper**	**Lower**	**Upper**		
Heat production capacity for one unit (kW)	4	4	4	4	2.5	6	2.5	6		1,2,5
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	80	100	80	100	F	1,2,7
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	80	100	80	100	F	1,2
Heat efficiency, annual average, net (%), floor heating	355	365	375	390	335	385	335	410	C, I	4,5,7,8
Total efficiency, annual average, net (%), floor heating	335	345	360	375	325	375	325	400	C, J	4,5,7,8
Heat efficiency, annual average, net (%), radiators	310	320	330	345	300	340	300	380	C, I	4,5,7,8
Total efficiency, annual average, net (%), radiators	295	305	315	330	285	325	285	370	C, J	4,5,7,8
Auxiliary Electricity consumption (kWh/year)	100	100	100	100	80	120	80	120	L	4
Technical lifetime (years)	20	20	20	20	15	25	15	25		1,2,7
Regulation ability										
Change in capacity within 1 minute (%)	100	100	100	100	50	100	50	100		1,2,7
Warm start-up time (hours)	0	0	0	0	0	0	0	0		1,2,7
Cold start-up time (hours)	0	0	0	0	0	0	0	0		1,2,7
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	12	11	10	9	9	13	8	14	D	1,2,3,13,14
- hereof equipment (%)	55	55	55	55	45	65	45	75	B	1,2,7
- hereof installation (%)	45	45	45	45	35	55	25	55		1,2,7
Possible additional specific investment (1000€/unit)										
Fixed O&M (€/unit/year)	291	278	255	239	256	328	188	295		
- of which is electricity costs (€/unit/year)	6	7	10	17	6	8	13	20	L	
- of which is other O&M costs (€/unit/year)	285	271	245	222	250	320	175	275		
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		1,2,7

Table 38: Heat pump, ground-source – existing apartment complex

Technology	Heat pump, Ground source, existing apartments									
Energy/technical data	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	400	400	400	400	300	500	300	500		5,6
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	70	100	70	100	F	
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	70	100	70	100	F	
Heat efficiency, annual average, net (%), floor heating	470	480	490	510	470	500	470	550	C I	11,12,15
Total efficiency, annual average, net (%), floor heating	450	460	470	490	450	480	450	530	C J	4,11,12,15
Heat efficiency, annual average, net (%), radiators	420	430	440	460	420	450	420	500	C I	11,12,15
Total efficiency, annual average, net (%), radiators	400	410	420	440	400	430	400	480	C J	4,11,12,15
Auxiliary Electricity consumption (kWh/year)	10000	10000	10000	10000	8000	12000	8000	12000	L	4,7
Technical lifetime (years)	20	20	20	20	15	25	15	25		7,12
Regulation ability										
Change in capacity within 1 minute (%)	50	50	50	50	10	100	10	100		7.11
Warm start-up time (hours)	0	0	0	0	0	0	0	0		7.11
Cold start-up time (hours)	0	0	0	0	0	0	0	0		7.11
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	265	249	224	202	235	265	200	265		12,13,15
- hereof equipment (%)	60	60	60	60	50	85	50	85	B	12.13
- hereof installation (%)	40	40	40	40	15	50	15	50		12.13
Possible additional specific investment (1000€/unit)										
Fixed O&M (€/unit/year)	1640	1650	1866	2411	1070	2850	1820	3980		
- of which is electricity costs (€/unit/year)	640	710	1020	1650	570	850	1320	1980	L	
- of which is other O&M costs (€/unit/year)	1000	940	846	761	500	2000	500	2000		12
Variable O&M (€/MWh)	0.50	0.47	0.42	0.38	0.2	1.0	0.2	1.0		12

Table 39: Heat pump, ground-source – new apartment complex

Technology	Heat pump, Ground source, new apartments									
Energy/technical data	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	160	160	160	160	140	200	140	200		5,6
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	70	100	70	100	F	
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	70	100	70	100	F	
Heat efficiency, annual average, net (%), floor heating	500	510	520	540	500	530	500	580	C I	11,12,15
Total efficiency, annual average, net (%), floor heating	430	440	450	460	430	490	430	530	C J	4,11,12,15
Heat efficiency, annual average, net (%), radiators	480	490	500	520	480	510	480	560	C I	11,12,15
Total efficiency, annual average, net (%), radiators	420	430	440	455	420	470	420	520	C J	4,11,12,15
Auxiliary Electricity consumption (kWh/year)	10000	10000	10000	10000	8000	12000	8000	12000	L	4,7
Technical lifetime (years)	20	20	20	20	15	25	15	25		7,12
Regulation ability										
Change in capacity within 1 minute (%)	100	100	100	100	20	100	20	100		7,11
Warm start-up time (hours)	0	0	0	0	0	0	0	0		7,11
Cold start-up time (hours)	0	0	0	0	0	0	0	0		7,11
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	95	89	80	72	80	100	60	100		12,13,15
- hereof equipment (%)	50	50	50	50	40	80	40	80	B	12.13
- hereof installation (%)	50	50	50	50	20	60	20	60		12.13
Possible additional specific investment (1000€/unit)										
Fixed O&M (€/unit/year)	1640	1650	1866	2411	1070	2850	1820	3980		
- of which is electricity costs (€/unit/year)	640	710	1020	1650	570	850	1320	1980	L	
- of which is other O&M costs (€/unit/year)	1000	940	846	761	500	2000	500	2000		12
Variable O&M (€/MWh)	0.50	0.47	0.42	0.38	0.2	1.0	0.2	1.0		12

Table 40: Heat pump, ventilation – new one-family house

Technology	Heat pump, ventilation, new one family house									
Energy/technical data	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	2	2	3	3	2	3	2	3		1,2,5
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	70	80	85	100	40	100	40	100	F	1,2,7
Expected share of hot tap water demand covered by unit (%)	90	90	100	100	0	100	0	100	F	1,2
Heat efficiency, annual average, net (%)	320	330	350	370	320	350	320	400	C, I	1,2,7
Total efficiency, annual average, net (%)	315	325	345	365	315	345	315	395	C, J	1,2,7
Auxiliary Electricity consumption (kWh/year)	30	30	30	30	20	40	20	50	L	7
Technical lifetime (years)	15	15	15	15	10	20	10	20		1,2,7
Regulation ability										
Change in capacity within 1 minute (%)	100	100	100	100	50	100	50	100		1,2,7
Warm start-up time (hours)	0	0	0	0	0	0	0	0		1,2,7
Cold start-up time (hours)	0	0	0	0	0	0	0	0		1,2,7
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	2	1.9	1.7	1.5	1.5	2	1	2	B, E	3,9,10,14
- hereof equipment (%)	90	90	90	90	80	90	80	90		1,2,7
- hereof installation (%)	10	10	10	10	10	20	10	20		1,2,7
Possible additional specific investment (1000€/unit)										
Fixed O&M (€/unit/year)	202	190	172	157	151	253	153	258		
- of which is electricity costs (€/unit/year)	2	2	3	5	1	3	3	8	L	
- of which is other O&M costs (€/unit/year)	200	188	169	152	150	250	150	250		1,2,7
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		1,2,7

Table 41: Heat pump, ventilation – new apartment complex

Technology	Heat pump, ventilation, new apartments									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	160	160	160	160	140	200	140	200		5,6
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	70	100	70	100	F	
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	70	100	70	100	F	
Heat efficiency, annual average, net (%)	550	560	570	590	550	580	550	620	C I	11,12,15
Total efficiency, annual average, net (%)	530	540	550	570	530	560	530	600	C J	4,11,12,15
Auxiliary Electricity consumption (kWh/year)	3000	3000	3000	3000	2000	4000	2000	4000	L	4,7
Technical lifetime (years)	15	15	15	15	12	20	12	20		7,12
Regulation ability										
Change in capacity within 1 minute (%)	100	100	100	100	20	100	20	100		7,11
Warm start-up time (hours)	0	0	0	0	0	0	0	0		7,11
Cold start-up time (hours)	0	0	0	0	0	0	0	0		7,11
Environment										
SO_2 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NO_X (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
CH_4 (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
N_2O (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Particles (g per GJ fuel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Financial data										
Specific investment (1000€/unit)	75	71	63	57	60	100	50	100		12,15
- hereof equipment (%)	70	70	70	70	50	85	50	85	B	12
- hereof installation (%)	30	30	30	30	15	50	15	50		12
Possible additional specific investment (1000€/unit)										
Fixed O&M (€/unit/year)	1195	1150	1151	1256	640	2285	830	2660		
- of which is electricity costs (€/unit/year)	195	210	305	495	140	285	330	660	L	
- of which is other O&M costs (€/unit/year)	1000	940	846	761	500	2000	500	2000		12
Variable O&M (€/MWh)	0.50	0.47	0.42	0.38	0.2	1.0	0.2	1.0		12

Notes

A In gas hybrid installations the heat pump will cover around 70 % of the total heat demand.
B Including domestic hot water storage tank and auxiliary equipment.
C Weighted by seasonal heat demand of average climate zones according to EN14825 and domestic hot water production according to EN16147.
D The replacement cost of a worn out ground source heat pump will usually only be around 30 % of the initial investment as some components are reused.
E Add on price compared to ventilation unit without heat pump, cost includes domestic hot water storage tank and auxiliary equipment.
F The share of heating demand and hot tap water demand covered depends on how the heat pump is operated in the total heat energy system in the house.
G The reason for lower COP values compared to air-to-air heat pumps in existing buildings, is lower efficiency due to the small capacity of these heat pumps.
H The reason for the drop in COP values in 2030 and 2050, is hot tap water production from 2030 and onwards.
I Heat efficiency values refers to the COP of the heat pump.
J Total efficiency values are including auxiliary electricity consumption.
K Uncertainties on the investment costs are highly dependent on the expected share of hot tap water demand covered by the heat pump
L The cost of auxiliary electricity consumption is calculated using the following electricity prices in €/MWh: 2015: 64, 2020: 71, 2030: 102, 2050: 165. These prices include production costs and transport tariffs, but not any taxes or subsi-dies for renewable energy.

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208 Gas driven heat pumps

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8.1 General qualitative description of gas driven heat pumps

The following section is an introduction to gas driven heat pumps in general and contains an introduction to the technology. This introduction is then succeeded by three sections each describing a unique heat pump technology including a data sheet for each technology.

Introduction - General Information about gas driven heat pumps

“Gas driven heat pumps” or “gas fired heat pumps” are mostly named more simply “gas heat pumps” [2]. For simplification, we have mostly also opted for this last designation in this document.

Note that there are no air-to-air gas heat pumps on the market today for residential heating, but the technology exists for gas driven engine heat pumps (Aisin, Sanyo, etc.) (2012)[12].

In principle, all gas heat pump technologies are reversible and can also be used for cooling/air conditioning, but not all products on the market may be designed for cooling also.

Main differences to electrical heat pumps

The energy efficiency of gas heat pumps is usually expressed in percent and not in "Coefficient of Performance" (COP factor), as for the electrical heat pumps. The highest net efficiency measured for a gas heat pump in heating mode has today reached approximately 170% (COP = 1.7) (value obtained on absorption heat pump), which seems considerably lower than for electric heat pumps. One method to compare the performances of the two types of heat pump is to calculate the efficiencies based on primary energy use.

Due to the lower efficiency of gas heat pumps (compared to electric heat pumps), less energy from the outside air, ground etc. will be collected to the heat pump. Therefore, the design of gas heat pumps is different from that of electrical heat pumps (EHP). This means smaller heat exchangers for the energy source, fewer bore holes, shorter tubes in the ground. As a result, gas heat pumps have potentially lower installation costs compared to electric heat pumps. Another consequence is that gas heat pumps are less dependent on variations in the energy source temperature compared to the electric heat pumps.

Input

The input is the heat from e.g. ambient air collected by the outdoor heat exchanger or ground collector (vertical or horizontal). Gas is needed to drive the process. The heat can also be combined with other "free" energy sources like solar or waste water.

Gas heat pumps can be used with natural gas and LPG (Liquefied Petroleum Gas), but also with new "green gases" like biogas. Appliances that are certified for natural gas can cope with a large variation of natural gas specifications; including natural gas/upgraded biogas mix as long as the specifications of the mixture conform to specifications of the natural gas. Note that upgraded biogas mostly contain methane and will therefore also be able to be used directly (without mixing with natural gas = 100%).

For natural gas/hydrogen mixture, the technologies using fully premix burners (absorption and adsorption heat pumps) should be able to cope with mixtures containing up to 10 to 20% hydrogen (vol.); but no test results are available at this stage.

Output

The output is thermal energy for space heating and hot water. In case of reversible heat pumps, the output is also cooling.

Gas heat pumps can deliver water temperatures above 55 ˚C, and so deliver domestic hot water and use lower radiator size designed for high water temperature. Note, however, the efficiency may decrease when the water temperature in the heating system increases.

Advantages/disadvantages

Advantages

- Because gas heat pumps rely less on the free renewable heat source, compared to electrical heat pumps, gas heat pumps also have a capacity that is less depending on the heat source temperature and as a results have a more constant heat delivery profile compared to electrical heat pump.
- Thus, gas heat pumps generally do not need a backup system to produce heat for low external temperatures) as they are not affected to the same extent by losing capacity with low outdoor temperatures, as electric heat pumps do [12].
- Another consequence is that, the ground source can be 40% smaller on average for gas heat pumps using brine-to-water (and therefore less expensive) compared to an electrical heat pump based on brine-to-water [2].
- Finally, most of the gas heat pumps offer the possibility of higher outlet water temperature (enabling domestic hot water and less radiators when needed);

Disadvantages

- The gas heat pump is already a mature product for the apartment block market and users with a large heat demand (shops etc.), but there are only a few market-ready appliances for the domestic sector, and there is a lack of experience (especially for the adsorption technology).
- Compared to a gas boiler, a larger installation space in the building may be necessary, especially if a wall-hung boiler is replaced by a floor-standing gas (or electrical) heat pump and heat storage unit.
- Gas heat pumps can only be installed where a natural gas grid is present or where biogas is available.

The cost of gas heat pumps and installation is much higher than the cost of a simple condensing gas boiler. As a result, the present (2013) costs are making the investment in such technology more relevant in case of high heating need/larger installation (domestic or collective) and less feasible in low-energy single-family houses.

Advantages/ Disadvantages for brine-to-water heat pump

For brine to water gas heat pumps, a disadvantage is that the ground heat source involves additional investment in piping to retrieve the necessary heat. The most common solution, which is horizontal ground collectors, needs available ground area corresponding to a maximal consumption of 40 kWh/m2 per year where the area is the horizontal area. The investments can be counterbalanced by the reduced costs of energy. However, there is no outdoor noise problems when the heat pump is running, which can make it the only possible solution in densely built-up areas.

Advantages/ Disadvantages for air-to-water heat pump

Noise may pose a problem since the noise level has to be below 35 dB(A) on the boundary to other properties.

As for electrical heat pumps, in densely built-up areas it is sometimes not possible to install air-to-water heat pumps due to this. The air exchanger placed outside may generate other issues for some users (space available, proximity to neighbours, noise, architectural and esthetical aspects).

Finally, air-to-water heat pumps have lower efficiency compared to brine-to-water appliances.

Ground water and vertical pipes can be used instead of horizontal pipes if there is not enough available ground area. This is a more expensive solution, but is now being used more often than previously, which may lower the prices in the future.

8.2 Gas driven absorption heat pumps, air-to-water and brine-to-water

Brief technology description

Gas absorption heat pumps are the so-called “thermally driven heat pumps” using gas both as source of heat to be upgraded and as energy source to drive the heat pump process. This differentiates them from engine-driven heat pumps. The heat from gas is typically produced with a full premix burner. In the basic absorption process, ammonia is evaporated by the free energy (e.g. outside air) and flows to an absorber, where it forms a solution with water. Heat is generated and is transferred from the absorber to the heating system. The ammonia-water solution is pumped at increased pressure to the generator where heat is added through for example a gas burner. The ammonia vapour formed in the generator flows to the condenser, where it is condensed and energy is transferred to the heating system. A lean ammonia-water solution recirculates from the generator to the absorber. Liquid ammonia flows after a pressure reduction from the condenser to the evaporator where it is vaporized again. Other refrigerants are possible in the absorption process, but ammonia-water is used in heat pumps for space heating. The basic absorption cycle is shown in Figure 1.

The heat which the burner produces triggers various physical processes in the closed circuit of the gas heat pump - in contrast to an electric heat pump or gas engine driven heat pump, no compressor is needed.

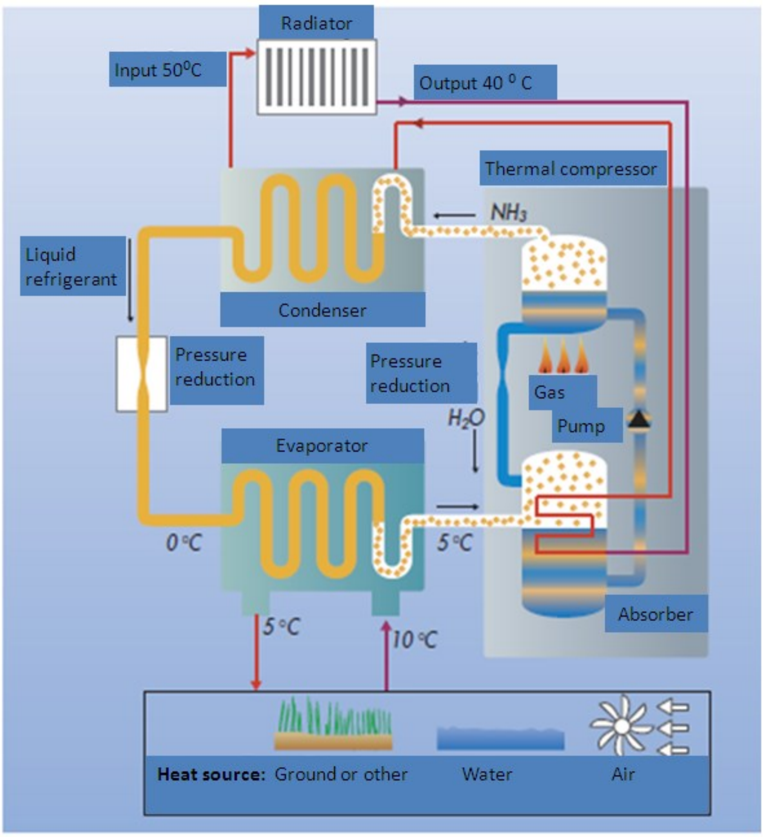

Figure 1 Operating principle for gas absorption heat pump [10]

Market data

The number of installations in Denmark with absorption heat pumps is still limited. Since the first installation of a 35 kW absorption heat pump from Robur in 2009, approximately 10 additional installations have been done. Natural gas, city gas (Bygas2) and LPG are used. The installations range from space heating without a boiler back up (Gl. Holtegaard museum) to a combination of absorption heat pump, solar collectors and gas boiler (Avedøre Stadion) with a large share of hot water production. Both air-to-water and ground source options are used. In the EU, there are already about 45,000 gas absorption heat pumps installed [2].

Typical capacities

The practical capacity range of absorption heat pumps for space heating has increased since the introduction of the Robur appliance around 2009. The limit is further lowered when absorption heat pumps, currently in field test, enter the market in 2013-2015. The heat pumps will then be suitable for single-family houses as well as apartment blocks. For single-family houses will the output capacity be 10-15 kW, and for larger heating demands in for example apartments blocks and the commercial sector, one or several 35 kW Robur heat pumps in a cascade configuration can be used. Absorption heat pumps technology could be suitable for houses with very low heat demand but, due to the present costs of the technology and installation, the market for passive houses or low-energy houses is rather limited. However, it is reported that one challenge for the technology is to further reduce the lower capacity limit.

Currently, <35 kW for a single appliance, earlier technologies of absorption heating and cooling models had up to several MW heating capacity. Larger absorption machines up to MW size that have been produced for several years are not considered to be relevant for the applications in this document and are not further described.

The above indicates the most common capacities. There are also on the market more specific technologies having their own characteristics.

Regulation ability

Different types of regulation (for the load control) exist for heat pumps. Appliances can either work in on/off mode or in modulating mode. The typical modulation range from current technologies of gas absorption heat pumps is 50-100%.

Advantages/disadvantages

Advantages

- The absorption gas heat pump technology is already a mature product with high efficiency.
- It is adapted for the replacement of existing boilers (minimal change of existing system) and suitable for buildings with radiators that might require higher temperatures.

Disadvantages

- The domestic version is not yet available.
- There is basically only one product on the market (Robur; note that it is sold on the market under different names).

Environment

Gas absorption heat pumps use a refrigerant that is not harmful for the ozone layer, and they have an environmental advantage in this respect.

Research and development perspectives

The gas absorption heat pumps are still in an early stage of development. Gas absorption heat pumps are currently available from approx. 40 kW output. Field tests of smaller units are planned to begin in 2013.

Examples of market standard technology

Robur gas absorption heat pump

The Robur E^3 appliances are gas-fired absorption heat pumps with modulating output and flue gas condensation. They have an output in the range of 18 – 44 kW (modulating) depending on the version of the model. The burner is a premixed burner of the same basic design as in modern condensing gas boilers.

The heat pump is available in two options, as an air-to-water or ground-to-water heat pump.

Figure 2 Robur E3 heat pump. Air-to-water (left) and ground source (right) options.

Additional remarks

The Robur heat pump mentioned is presently sold on the market under several brand names, including Buderus, Remeha, Oertli.

Data sheets

Data sheets are available for existing one-family houses and apartment complexes.

Absorption heat pumps technology could be suitable for houses with very low heat demand but, due to the present costs of the technology and installation, the market for passive houses or low-energy houses is limited. As a consequence the data for new one-house families and apartment complexes are not included in the data sheets.

Table 42: Gas driven absorption heat pump, air-to-water – existing one-family house

Technology	Air-to-water heat pump absorption gas driven, one family house, existing buildings									
Energy/technical data	2015	2020	2030	2050	Uncertainty (2020) Lower	Uncertainty (2020) Upper	Uncertainty (2050) Lower	Uncertainty (2050) Upper	Note	Ref
Heat production capacity for one unit (kW)	18	30	30	30	10	50	10	50	J K M N Q	
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	-	-	-	-		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	-	-	-	-		
Heat efficiency, annual average, net (%)	-	-	-	-	-	-	-	-		
Total efficiency, annual average, net (%)	135	145	170	170	-	-	-	-	B	2,16
Auxiliary Electricity consumption (kWh/year)	-	-	-	-	-	-	-	-		
Technical lifetime (years)	20	20	20	20	-	-	-	-	D	
Regulation ability										
Change in capacity within 1 minute (%)	-	-	-	-	-	-	-	-		
Warm start-up time (hours)	-	-	-	-	-	-	-	-		
Cold start-up time (hours)	-	-	-	-	-	-	-	-		
Environment										
SO_2 (g per GJ fuel)	-	-	-	-	-	-	-	-		
NO_X (g per GJ fuel)	15	10	5	5	-	-	-	-		14
CH_4 (g per GJ fuel)	2	1	0.5	0.5	-	-	-	-	L	
N_2O (g per GJ fuel)	0	0	0	0	-	-	-	-	L	
Particles (g per GJ fuel)	0	0	0	0	-	-	-	-	L	
Financial data										
Specific investment (1000€/unit)	13	12	11	10	-	-	-	-	A E	
- hereof equipment (%)	77	75	70	70	-	-	-	-		
- hereof installation (%)	23	25	30	30	-	-	-	-		
Possible additional specific investment (1000€/unit)	2	2	2	2	-	-	-	-	I	
Fixed O&M (€/unit/year)	235	235	235	235	-	-	-	-	C	
Variable O&M (€/MWh)	0	0	0	0	-	-	-	-	D	

Table 43: Gas driven absorption heat pump, ground-source – existing one-family house

Technology	Brine-to-water (ground-source) heat pump absorption gas driven, one family house, existing buildings									
					Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data	**2015**	**2020**	**2030**	**2050**	**Lower**	**Upper**	**Lower**	**Upper**		
Heat production capacity for one unit (kW)	18	30	30	30	10	50	10	50	J K M N Q	
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	-	-	-	-		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	-	-	-	-		
Heat efficiency, annual average, net (%)	-	-	-	-	-	-	-	-		
Total efficiency, annual average, net (%)	135	145	170	170	-	-	-	-	B	2,16
Auxiliary Electricity consumption (kWh/year)	-	-	-	-	-	-	-	-		
Technical lifetime (years)	20	20	20	20	-	-	-	-	D	
Regulation ability										
Change in capacity within 1 minute (%)	-	-	-	-	-	-	-	-		
Warm start-up time (hours)	-	-	-	-	-	-	-	-		
Cold start-up time (hours)	-	-	-	-	-	-	-	-		
Environment										
SO_2 (g per GJ fuel)	-	-	-	-	-	-	-	-		
NO_X (g per GJ fuel)	15	10	5	5	-	-	-	-		14
CH_4 (g per GJ fuel)	2	1	0.5	0.5	-	-	-	-	L	
N_2O (g per GJ fuel)	0	0	0	0	-	-	-	-	L	
Particles (g per GJ fuel)	0	0	0	0	-	-	-	-	L	
Financial data										
Specific investment (1000€/unit)	15.6	14.7	13.2	11.9	-	-	-	-	A E F G H P	
- hereof equipment (%)	64	61	55	55	-	-	-	-	O	
- hereof installation (%)	36	39	45	45	-	-	-	-	O	
Possible additional specific investment (1000€/unit)	6.4	6.4	6.4	6.4	-	-	-	-	I J	
Fixed O&M (€/unit/year)	235	235	235	235	-	-	-	-	C	
Variable O&M (€/MWh)	0	0	0	0	-	-	-	-	D	

Notes

A The cost "Specific investment" is split as following: Appliance + Installation of appliance + Heat collectors brine (when relevant). The cost of appliance in 2015 is difficult to appreciate as the technology is not yet on the market. However, considering the cost of the same technology sold today to commercial users (see next table) it is fair to think that the cost of the appliance alone will be around 10.000€ to start with; the target price once the appliance is on the market would be about 7-9000 € decreasing with time as production increases.

B The Efficiency of the domestic version of Robur is not yet public, but it is announced in the same range as for the larger version of the heat pump (see also comments given next table). Efficiency given here is estimates of annual efficiency based on the data from manufacturers corrected from field test experience and literature. Higher efficiency may be obtained by using low-temperature distribution system (floor heating). The improvement of efficiency foreseen is both due to better technologies and a better interaction between the appliance and the heating installation.

C Same as for gas boilers [1]. The most recent information for boilers service contract is about 135 without VAT. A similar cost is expected to apply to gas heat pumps. Note however, that the service is not mandatory for all appliances

D Supposed to be the same as for gas boilers [1].

E Electrical heat pump (air/water) installation cost is about 2000 € (15% of 13.000 €) according to [1] (table 5.18), a gas boiler installation is about 2500 € [1]. We consider that a gas heat pump air-water installation will cost about 3000 € once installers have learned the technology specificity. Most of the installation is not very different from a boiler installation apart from the air inlet.

F The authors consider that a gas heat pump brine-water installation will cost the same as the air-water version (3000 €). This cost doesn't include the heat collection (see G).

G For the brine version the cost of the heat collection (horizontal) is 4000€ for single-family houses according to source such as (http://www.renvarme.dk/produkter/jordvarme-boringer.aspx?language=da-dk). The data is conform to the figure given for EHP in [1] (based on a 10 kW (capacity) heat pump). The gas heat pumps require less heat collectors, the cost compared to the electrical counterpart will be lower. (40% [2] to 50% [3] of the drilling of the corresponding ground source EHPs; similar figures will also apply for horizontal pipes). The authors expect this to result in a heat collection cost that is about 20% lower. So it will be 3200 € for a 10 kW heat pump (the authors keep 10 kW for comparison purpose with EHP). The initial cost is given with VAT, so the final figure for a 10 kW gas heat pumps is 2600 €.

H The above figure will need to be validated with market data once the technology is on the market.

I Possible installation of a new gas service line grid connection= 1600 €; for new installation only

J In case of vertical drilling for electric heat pumps; there is the "additional cost" of a vertical heat collector of 6000 Euros (hardware + labour) compared to the price of an horizontal heat collector. See [1] The authors have considered that corresponding costs for gas heat pumps would be 20% lower (so 4800 Euros)

K Based on Robur prototype.

L Same as for boiler (the burner is a premix burner as for gas boilers).

M The present capacity will probably be extended in both ends of the range.

N The appliance can modulate between two values of the capacity. Here, we give the maximum capacity.

O For the % calculation; "equipment %" is the cost of the heat pump, and "installation %" is all other cost (labour cost for installation + labour and hardware for the heat collector installation).

P 100% of the investment cost is here given per unit and thus not depending on kW (cost based on one appliance on the market; so it is not possible to make a linear cost model).

Q The solution most commonly used to cover larger heat demand is to use several units in cascade when needed.

Table 44: Gas driven absorption heat pump, air-to-water – existing apartment complex

Technology	Air-to-water heat pump absorption gas driven, apartment complex, existing buildings									
Energy/technical data	**2015**	**2020**	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
					Lower	**Upper**	**Lower**	**Upper**		
Heat production capacity for one unit (kW)	44	80	80	80	-	-	-	-	J,N	
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	-	-	-	-		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	-	-	-	-		
Heat efficiency, annual average, net (%)	-	-	-	-	-	-	-	-		
Total efficiency, annual average, net (%)	135	145	170	170	-	-	-	-	B	2.16
Auxiliary Electricity consumption (kWh/year)	-	-	-	-	-	-	-	-		
Technical lifetime (years)	20	20	20	20	-	-	-	-	D	
Regulation ability										
Change in capacity within 1 minute (%)	-	-	-	-	-	-	-	-		
Warm start-up time (hours)	-	-	-	-	-	-	-	-		
Cold start-up time (hours)	-	-	-	-	-	-	-	-		
Environment										
SO_2 (g per GJ fuel)	-	-	-	-	-	-	-	-		
NO_X (g per GJ fuel)	15	10	5	5	-	-	-	-		14
CH_4 (g per GJ fuel)	2	1	0.5	0.5	-	-	-	-	K	
N_2O (g per GJ fuel)	0	0	0	0	-	-	-	-	K	
Particles (g per GJ fuel)	0	0	0	0	-	-	-	-	K	
Financial data										
Specific investment (1000€/unit)	18	17	15	14	-	-	-	-	A,E	
- hereof equipment (%)	78	78	78	78	-	-	-	-		
- hereof installation (%)	22	22	22	22	-	-	-	-		
Possible additional specific investment (1000€/unit)	1.6	1.6	1.6	1.6	-	-	-	-	I	
Fixed O&M (€/unit/year)	235	235	235	235	-	-	-	-	C	
Variable O&M (€/MWh)	0	0	0	0	-	-	-	-	D	

Table 45: Gas driven absorption heat pump, ground-source – existing apartment complex

Technology	**Brine-to-water (ground-source) heat pump absorption gas driven, apartment complex, existing buildings**									
Energy/technical data	**2015**	**2020**	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
					Lower	**Upper**	**Lower**	**Upper**		
Heat production capacity for one unit (kW)	44	80	80	80	-	-	-	-	J,N	
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	-	-	-	-		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	-	-	-	-		
Heat efficiency, annual average, net (%)	-	-	-	-	-	-	-	-		
Total efficiency, annual average, net (%)	135	145	170	170	-	-	-	-	B	2.16
Auxiliary Electricity consumption (kWh/year)	-	-	-	-	-	-	-	-		
Technical lifetime (years)	20	20	20	20	-	-	-	-	D	
Regulation ability										
Change in capacity within 1 minute (%)	-	-	-	-	-	-	-	-		
Warm start-up time (hours)	-	-	-	-	-	-	-	-		
Cold start-up time (hours)	-	-	-	-	-	-	-	-		
Environment										
SO_2 (g per GJ fuel)	-	-	-	-	-	-	-	-		
NO_X (g per GJ fuel)	15	10	5	5	-	-	-	-		14
CH_4 (g per GJ fuel)	2	1	0.5	0.5	-	-	-	-	K	
N_2O (g per GJ fuel)	0	0	0	0	-	-	-	-	K	
Particles (g per GJ fuel)	0	0	0	0	-	-	-	-	K	
Financial data										
Specific investment (1000€/unit)	33	31	28	25	-	-	-	-	A,E,F,H,M	
- hereof equipment (%)	42	42	42	42	-	-	-	-	L	
- hereof installation (%)	58	58	58	58	-	-	-	-	L	
Possible additional specific investment (1000€/unit)	24.6	24.6	24.6	24.6	-	-	-	-	G,I	
Fixed O&M (€/unit/year)	235	235	235	235	-	-	-	-	C	
Variable O&M (€/MWh)	0	0	0	0	-	-	-	-	D	

Notes

A Costs are based on a 44 kW unit. The cost “Specific investment” is split as following: Appliance + Installation of appliance + Heat collectors brine (when relevant). The cost for the appliance alone in 2015 is stable as the technology is already present for a number of years. Maybe the price will decrease a bit thanks to the higher production numbers.

B Efficiency given here is estimates of annual efficiency based on the data from manufacturers corrected from field test experience and literature. Higher efficiency can be obtained when using low-temperature distribution system (floor heating). The improvement of efficiency foreseen is both due to better technologies and a better interaction between the appliance and the heating installation. Test results available from [18] are claiming 142 to 149% annual efficiency.

C Same as for gas boilers [1]. The most recent information for boilers service contract is about 135 without VAT. A similar cost is expected to apply to gas heat pumps. Note however, that the service is not mandatory for all appliances.

D Supposed to be the same as for gas boilers [1].

E Note that only very few appliances are installed in Denmark and the figures are, therefore, only rough approximates. The authors consider here that the installation of a single air-water gas heat pump will cost about 4000 € (same as for single-family house + 1000€) once installers have learned how to do the job. The installation of several units in cascade will be different, but there are no references in Denmark that allow us to make a correct assessment of this.

F Same as E for the brine/water gas heat pump the authors believe that the installation cost of a single 44 kW appliance will be as for the air-water version (4000 €) And again, the installation of several units in cascade will be different, but there are no references in Denmark that allow us to make a correct assessment of this. This cost doesn’t include the heat collection (see G &H).

G For the brine version the additional cost of the heat collection (vertical) is 670 €/kW for an apartment complex [1]. Because gas heat pumps require less heat collectors, the cost compared to the electrical counterpart will be lower. (40% [2] to 50% [3] of the drilling of the corresponding ground source EHPs was already mentioned. We expect this to result in a heat collection cost that is about 20% lower. So this figure will be 536 €/kW for an apartment complex. This will result in approx. 23.000 € for a 44 kW heat pump.

H The cost of the horizontal heat collection for a 44 kW gas heat pump is not very clear to the authors (not much existing data) at the present time (and EHP data of [1] are not specific for larger installations. But, considering it is about 40% of a vertical collection in general for EHP, and that additional cost for vertical are given as below, we end up with a total cost for vertical of 38.000 Euro (=23/0,6). So the horizontal heat collection would be 15.000 Euros (38.000 -23.000) based on a 44 kW heat pump.

I Possible installation of a new gas service line grid connection= 1600 €; for new installation only.

J 2015 size is based on Robur information.

K Same as for boiler (the burner is a premix burner as for gas boilers).

L For the % calculation; “equipment %” is the cost of the heat pump, and “installation %“ is all other cost (labour cost for installation + labour and hardware for the heat collector installation).

M 100% of the investment cost is here given per unit and thus not depending on kW (cost based on one appliance on the market; so it is not possible to make a linear cost model).

N The appliance can modulate between two values of the capacity. Here, we give the maximum capacity.

References

See the end of chapter 8.4

8.3 Gas engine driven heat pumps, air-to-water and brine-to-water

Brief technology description

A gas engine heat pump uses the same heat pump process as the electric heat pump, but the compressor is operated by a gas engine instead of an electric motor. Heat is also recovered from the engine cooling and the flue gases. In principle, any gas can be used in the gas engine. Natural gas, upgraded (or not) biogas, LPG and hydrogen are possible.

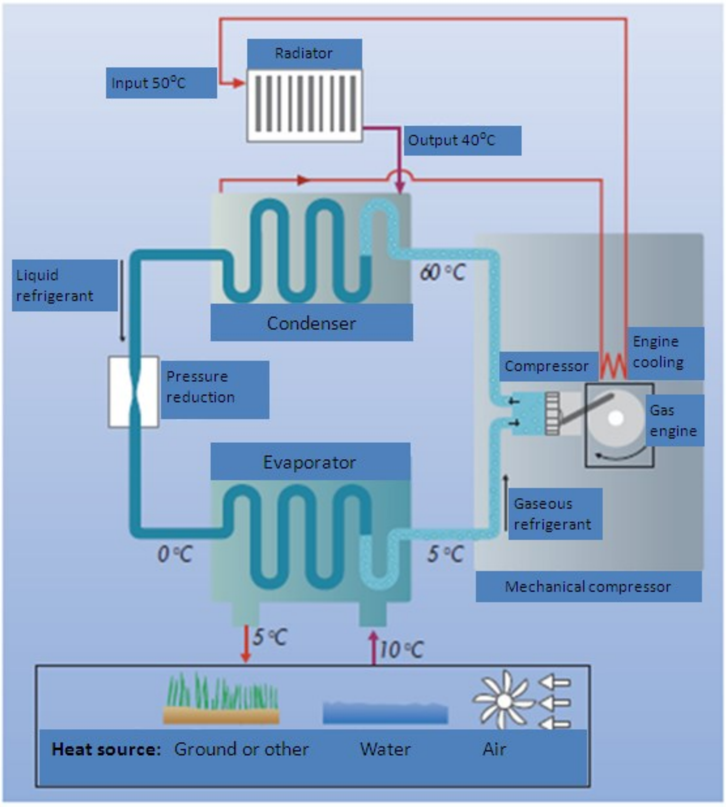

Figure 1: Operating principle for gas engine driven heat pump [10]

Essentially, the heat pump comprises four components: the compressor, the condenser, the expansion valve and the evaporator.

In general, the gas engine driven heat pump will need an ordinary maintenance every 10,000 running hours or so.

Market data

The number of installations in Denmark with gas heat pumps is limited. Accurate data is not available; but for the whole EU, the number of installed appliances is about 10,000 [17].

Even though this technology exists for larger heat/cooling demand (e.g. engine driven Aisin and Sanyo), there are no engine based gas air-air heat pumps on the market for residential heating at the moment (2012).

Typical capacities

A range of capacities is available, typically from 10 kW up to a few MW heat for a single appliance. Appliances are often combined in cascade in order to obtain the needed capacity and achieve better efficiencies.

For gas engine driven heat pump, the scale ranges from a few kW to a few MW mechanical capacity. Heat pumps on the scale of MW are usually specially designed for a specific situation. The capacity range of multi-split units is 30 kW to 90 kW for heating and 20 kW to 70 kW for cooling. The technology of outdoor units based on gas engine-driven compression heat pumps is now fully mature. Outdoor units can easily be connected in cascade to achieve larger capacities (up to 1,000 kW) [2].

Regulation ability

Different types of regulation (for the load control) exist for heat pumps. Appliances can either work in on/off mode or in modulating mode. The percentage of the maximum capacity depends on the technology and model considered.

The typical modulation ranges for gas engine driven heat pumps is approx. 30-100%.

Advantages/disadvantages

Advantages

- The gas engine driven gas heat pump technology is already mature.
- Gas engine heat pumps are preferable (to other gas driven heat pumps) when cooling is the main requirement because of their higher efficiency when cooling [2].

Disadvantages

- There are only few market-ready appliances for the domestic sector. (The appliances are mostly designed for offices, hostels, hospitals and not for the domestic sector).
- Noise from the engine may be an issue; but manufacturers (Sanyo, etc.) are making an effort to produce more silent appliances.
- The investment and maintenance cost of the product are higher than electrical heat pumps (2012) [17].
- The technology is not very well known by users or professionals and standards not yet ready (2012) [17].

Environment

Engine based heat pumps are using the same refrigerants as electrical heat pumps [1]. The heat pumps use F-gases as refrigerants. F-gases are fluorinated gases and include HFCs, PFCs and SF6, which are potent greenhouse gases. They are covered by the Kyoto Protocol.

The HFCs (HydroFluoroCarbons) are the most important, and they are frequently used in the refrigeration industry as the working fluid in the refrigeration cycle. There are many different refrigerants based on HFCs. The most important ones are HFC-134a (R134a) and HFC mixtures: R404A, R410A and R407A. The most common refrigerants based on HFCs have Global Warming Potentials (GWP) of about 1,500 to 4,000 compared to CO2 which has a GWP of 1.

There are, however, some heat pumps working with natural refrigerants (including R290 – propane), but this is a minority. In the future, it will be possible to replace F-gases by natural refrigerants or other less harmful refrigerants.

Natural refrigerants are substances that can be found in nature's own cycle, e.g. ammonia, hydrocarbons, CO2, water and air. None of the refrigerants in the group of natural refrigerants are perfect, and they all have technical limitations. Therefore, natural refrigerants have to be chosen with care, and one fluid cannot cover all applications.

Different types of heat pumps use the same types of refrigerants. The above description is therefore representative for all types of heat pumps.

Engine based heat pumps have higher NOx emissions compared to thermally driven heat pumps. However, catalysts can be used to reduce the emissions.

Research and development perspectives

One of the issues of engine based heat pumps are the NOx emissions. R&D to decrease those would help the technology to better penetrate the market.

Examples of market standard technology

A typical gas heat pump air conditioner from Aisin is a gas engine driven air-to-water heat pump, which provides both cooling (22-71 kW) and heating (26-80 kW). Air-to-air and air-to-water technologies are commercially available. Cascade solutions are possible for up to 6 units.

Figure 2 Aisin is a gas engine driven air to water heat pump

Additional remarks

Note that there are no actual products adapted for existing single-family houses and new single-family houses. Therefore, only existing apartment blocks and new apartment blocks are treated for this technology.

Data sheets

Data sheets are available for existing apartment complexes.

Gas heat pumps technology could be suitable for smaller houses or buildings with very low heat demand but, due to the present costs of the technology and installation, the market for low-energy houses is limited. As a consequence the data for new apartment complexes are not included in the data sheets.

Table 46: Gas-engine driven heat pump, air-to-water – existing apartment complex

Technology	Air-to-water heat pump gas-engine driven, apartment complex, existing buildings									
	2015	**2020**	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data					**Lower**	**Upper**	**Lower**	**Upper**		
Heat production capacity for one unit (kW)	50	50	50	50	20	80	20	80	A,E,L	5
Electricity generation capacity for one unit (kW)	-	-	-	-	-	-	-	-		
Expected share of space heating demand covered by unit (%)	100	100	100	100	-	-	-	-		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	-	-	-	-		
Heat efficiency, annual average, net (%)	-	-	-	-	-	-	-	-		
Total efficiency, annual average, net (%)	150	155	155	160	-	-	-	-		14
Auxiliary Electricity consumption (kWh/year)	-	-	-	-	-	-	-	-		
Technical lifetime (years)	15	20	20	20	15	20	15	20	B	
Regulation ability										
Change in capacity within 1 minute (%)	-	-	-	-	-	-	-	-		
Warm start-up time (hours)	-	-	-	-	-	-	-	-		
Cold start-up time (hours)	-	-	-	-	-	-	-	-		
Environment										
SO_2 (g per GJ fuel)	0	0	0	0	-	-	-	-		
NO_X (g per GJ fuel)	120	80	50	50	20	150	10	100	C	15
CH_4 (g per GJ fuel)	5	5	5	5	-	-	-	-	D	
N_2O (g per GJ fuel)	-	-	-	-	-	-	-	-		
Particles (g per GJ fuel)	-	-	-	-	-	-	-	-		
Financial data										
Specific investment (1000€/unit)	4	4	3	3	-	-	-	-	F,G,O	
- hereof equipment (%)	83	83	83	83	-	-	-	-	P	
- hereof installation (%)	17	17	17	17	-	-	-	-	P	
Possible additional specific investment (1000€/unit)	1.6	1.6	1.6	1.6	-	-	-	-	H,K	
Fixed O&M (€/unit/year)	235	235	235	235	-	-	-	-	I	
Variable O&M (€/MWh)	0	0	0	0	-	-	-	-	J	

Table 47: Gas-engine driven heat pump, ground-source – existing apartment complex

Technology	Brine-to-water (ground-source) heat pump gas-engine driven, apartment complex, existing buildings									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	50	50	50	50	20	80	20	80	A J	5
Electricity generation capacity for one unit (kW)	-	-	-	-	-	-	-	-		
Expected share of space heating demand covered by unit (%)	100	100	100	100	-	-	-	-		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	-	-	-	-		
Heat efficiency, annual average, net (%)	-	-	-	-	-	-	-	-		
Total efficiency, annual average, net (%)	150	155	155	160	-	-	-	-		14
Auxiliary Electricity consumption (kWh/year)	-	-	-	-	-	-	-	-		
Technical lifetime (years)	15	20	20	20	15	20	15	20	B	
Regulation ability										
Change in capacity within 1 minute (%)	-	-	-	-	-	-	-	-		
Warm start-up time (hours)	-	-	-	-	-	-	-	-		
Cold start-up time (hours)	-	-	-	-	-	-	-	-		
Environment										
SO_2 (g per GJ fuel)	0	0	0	0	-	-	-	-		
NO_X (g per GJ fuel)	120	80	50	50	20	150	10	100	C	15
CH_4 (g per GJ fuel)	5	5	5	5	-	-	-	-	D	
N_2O (g per GJ fuel)	-	-	-	-	-	-	-	-		
Particles (g per GJ fuel)	-	-	-	-	-	-	-	-		
Financial data										
Specific investment (1000€/unit)	19	18	16	14	-	-	-	-	F G O	
- hereof equipment (%)	51	51	51	51	-	-	-	-	P	
- hereof installation (%)	49	49	49	49	-	-	-	-	P	
Possible additional specific investment (1000€/unit)	24.6	24.6	24.6	24.6	-	-	-	-	H K	
Fixed O&M (€/unit/year)	235	235	235	235	-	-	-	-	I	
Variable O&M (€/MWh)	0	0	0	0	-	-	-	-	J	

Notes

A Based on model by Aisin & Sanyo air-to-air & air-to-water technologies.

B The authors consider that GHP has a similar lifetime as engine based mCHP, even though this may be conservative, as the technology has been on the market for many years and is mature. Lifetime should improve in the future.

C Emission can be strongly reduced by using catalyst reduction technologies that may be a standard in products for larger appliances in the future.

D The authors consider that CH4 emissions are in the same range as those for “MicroCHP gas engine”.

E Although the 80 kW is not very suitable to single-family houses, the appliances are generally built as series of the same models of different power (here from 20 to 80 kW). Those last and larger appliances are of course more suitable to commercial buildings and multiple apartments heating.

F Specific investment (1000€/unit) (installations) is given here as X+Y where X = installation of the appliances itself; and Y is the cost of the brine heat collectors (installation and hardware). For the costs of air/water heat pumps, the air exchanger is considered as part of the appliance. The authors consider here that the installation of a single air-water & brine -water gas heat pump will cost the same as absorption heat pumps. Here the costs are based on a 44kW unit.

G The authors consider here that the horizontal heat collection for a 44 kW will cost the same as for absorption heat pumps. (15.000 Euros). Here the costs are based on a 44kW unit.

H The authors consider here that the additional cost for the vertical heat collection will cost the same as for absorption heat pumps. (23.000 Euros). Here the costs are based on a 44kW unit.

I Same as for gas boilers [1]. The most recent information for boilers service contract is about 135 without VAT. A similar cost is expected to apply to gas heat pumps. Note however, that the service is not mandatory for all appliances.

J Supposed to be the same as for gas boilers [1].

K Possible installation of a new gas service line grid connection= 1600 €; for new installation only.

L The solution most commonly used to cover larger heat demand is to use the end range of technologies from the table (80 kW) and possibly use them in cascade when needed. Single appliances of over 80 kW exists, but are less common.

M 0.5 (for 80 kW) and 1.4 (for 25 kW).

N See also www.asue.de; www.berndt-enersys.de ; www.prognos.com

O The values in % are given for the example of an appliance of 20,000 Euros

P For the % calculation; “equipment %” is the cost of the heat pump, and “installation % “ is all other cost (labour cost for installation + labour and hardware for the heat collector installation).

References

See the end of chapter 8.4

8.4 Gas driven adsorption heat pumps, brine-to-water

Brief technology description

Gas adsorption (as absorption) heat pumps are part of the so-called “thermally driven heat pumps”, which use gas both for source of heat to be upgraded and energy source to drive the heat pump process. This differentiates them from engine-driven heat pumps. The heat from gas is typically produced with a full premix burner.

In adsorption processes, the water, which is mainly used as the refrigerant, evaporates, and in this process it absorbs the ambient heat. The water vapor is adsorbed on the surface of a solid substance, such as active charcoal, silica gel (glass-like silicates) or zeolite, (such as the Viessmann and Vaillant appliances). Alternative solid-sorption systems such as solid-ammonia, salt-ammonia, LiCl-H_2O are also used [2]. Thus, heat is released at a higher temperature. Once the zeolite is saturated, the water is driven out of the zeolite again in the desorption phase. Heat from a gas burner is used for this purpose.

The adsorption heat pump process is a non-continuous regenerative and periodic process. The figure below illustrates the process. The adsorption heat pump consists of an adsorbent, a heat exchanger and a heat generator (burner). In the desorption phase, heat from the gas burner vaporizes water adsorbed in the adsorbent. The water vapor condenses in the heat exchanger, which in this phase is connected to the heating system. Heat is released during the adsorption and transferred to the heating system.

The heat which the burner produces triggers various physical processes in the closed circuit of the gas heat pump - in contrast to an electric heat pump or gas engine driven heat pump, no compressor is needed.

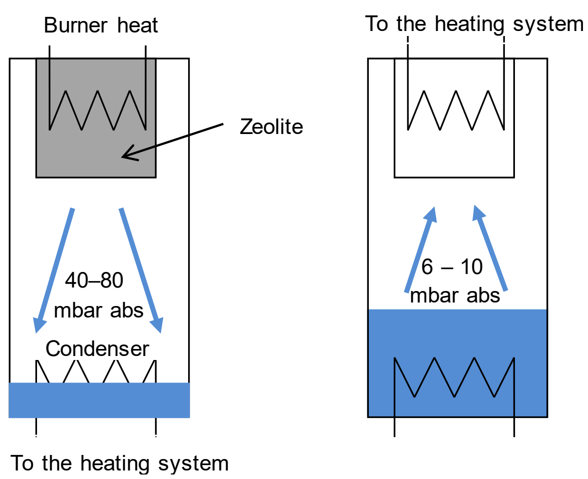

Figure 1: Sketch of the basic adsorption process [16], Residential gas-fired sorption heat pumps. Test and technology evaluation, DGC 2008

Market data

Adsorption heat pumps are very new, and there are no known installations in Denmark yet. The best known manufacturers are Vaillant and Viessmann.

Typical capacities

Gas adsorption heat pumps that will come on the market are designed for the domestic market, so currently < 15 kW for a single-family house in the residential sector.

Regulation ability

Different types of regulation (for the load control) exist for heat pumps. Appliances can either work in on/off mode or in modulating mode. The modulation range for gas adsorption driven heat pumps is approx. 20-100%.

Advantages/disadvantages

Advantages

- Today gas adsorption driven heat pumps are designed by the gas boiler manufacturers, so the one-to-one replacement with existing gas boiler is simple and easy.
- The "package" solution will probably help the introduction on the market.
- Gas adsorption heat pumps use refrigerants with no global warming impact (ammonia/water refrigerant). Current gas adsorption heat pumps use zeolites and water.
- There are no outdoor noise problems, which makes it a possible solution in densely built-up areas.

Disadvantages

- The source energy is limited to ground or solar collectors due to the lower temperature limit of approximately 2°C. This is the reason why it is often combined with solar energy. If not, the piping must be deep enough to guarantee that this requirement is respected.
- Currently, the technology seems to have slightly lower efficiency compared to the two other gas heat pump technologies.
- The technology is very new with the disadvantages that this implies, e.g. few solutions available on the market and lack of knowledge on reliability.
- Today, the appliance is only for the domestic sector.
- The technology is not very well known by users or professionals.

Environment

Gas absorption heat pumps use a refrigerant, which is not harmful for the ozone layer, and they have an environmental advantage in this respect.

Research and development perspectives

As mentioned, adsorption heat pumps with zeolites/water require a source temperature above 2-3 °C. A wider temperature range will increase the market potential. Adsorption heat pumps for the commercial sector are not available today.

Examples of market standard technology

The currently only (market-available) adsorption heat pump for residential use in Europe is the Vaillant ZeoTherm. It is delivered in a package with a storage tank and solar collectors as seen in the figure below. The technical data from the manufacturer [11] describes a standard package system including 1.16 m^2 solar collector. The system can also be used with more options and up to 2.4 m^2 of solar collectors in alternative packages. The water tank volume is 390 l. The solar collectors not only add energy to the heat pump, but also to hot water and heating in the same manner as a boiler and solar collector combination. Zeolites/water requires a source temperature above 2-3°C; if not achievable with solar gas will be used. Vaillant claims an overall efficiency of 135% (nominal net efficiency) for a 40/30°C heating system and additional 10% solar energy contribution, resulting in the overall system efficiency around 145% [11]. The heat pump is modulating in the 1.5-10 and 1.5-15 kW ranges, depending on the model. The maximum supply temperature is 75 °C, but a maximum of 40 °C is recommended. Test results available from [17] are claiming 113 to 122% annual efficiency (without solar) and 133 to 144% annual efficiency (with solar). It is not clear whether this is with or without hot water.

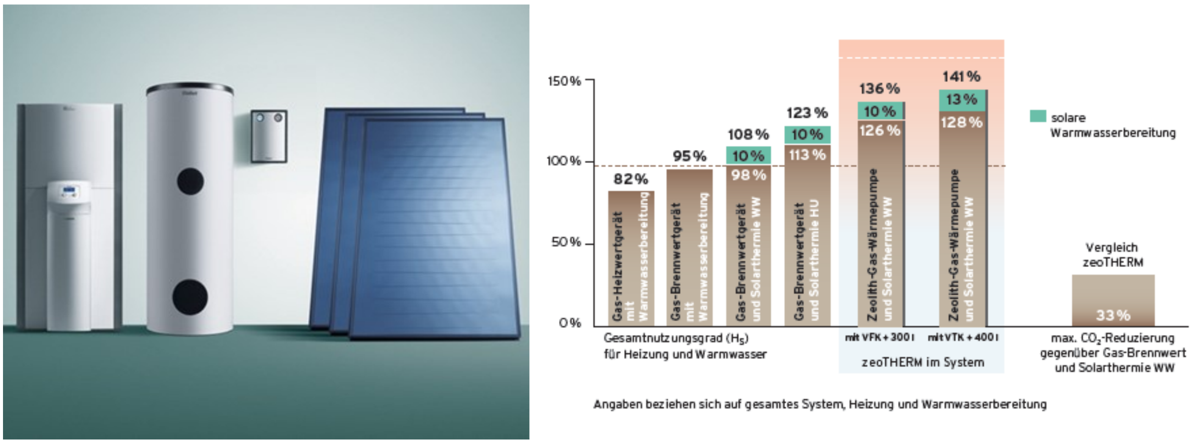

Figure 2 Vaillant Zeolite adsorption heat pump (left) and Vaillant Zeolite adsorption heat pump efficiency - based on lower calorific value (right) [11]

Data sheets

Data sheets are available for existing one-family houses.

Since gas adsorption heat pumps on the market are designed for the domestic single-family houses only, no data is included for apartment complexes. Additionally very limited data is available on adsorption heat pumps designed for low-energy houses, hence no data is presented on new one-family houses.

Table 48: Gas driven adsorption heat pump, ground-source – existing one-house family

Technology	Brine-to-water (ground-source) heat pump, adsorption gas driven, one family house, existing buildings									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	10	10	10	10	1.5	15	1.5	15	F G H I	
Electricity generation capacity for one unit (kW)	-	-	-	-	-	-	-	-		
Expected share of space heating demand covered by unit (%)	100	100	100	100	-	-	-	-		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	-	-	-	-		
Heat efficiency, annual average, net (%)	-	-	-	-	-	-	-	-		
Total efficiency, annual average, net (%)	135	135	135	135	-	-	-	-	B	5,17
Auxiliary Electricity consumption (kWh/year)	-	-	-	-	-	-	-	-		
Technical lifetime (years)	20	20	20	20	-	-	-	-	G	
Regulation ability										
Change in capacity within 1 minute (%)	-	-	-	-	-	-	-	-		
Warm start-up time (hours)	-	-	-	-	-	-	-	-		
Cold start-up time (hours)	-	-	-	-	-	-	-	-		
Environment										
SO_2 (g per GJ fuel)	0	0	0	0	-	-	-	-	E	
NO_X (g per GJ fuel)	20	10	5	5	-	-	-	-	E	
CH_4 (g per GJ fuel)	2	1	0.5	0.5	-	-	-	-	E	
N_2O (g per GJ fuel)	0	0	0	0	-	-	-	-	E	
Particles (g per GJ fuel)	0	0	0	0	-	-	-	-	E	
Financial data										
Specific investment (1000€/unit)	14	13	12	11	-	-	-	-	A I J	
- hereof equipment (%)	71	71	71	71	-	-	-	-		
- hereof installation (%)	29	29	29	29	-	-	-	-		
Possible additional specific investment (1000€/unit)	1.6	1.6	1.6	1.6	-	-	-	-	H	
Fixed O&M (€/unit/year)	235	235	235	235	-	-	-	-	C	
Variable O&M (€/MWh)	0	0	0	0	-	-	-	-	D	

Notes

A Appliance cost = 10.000 Euros. Manufacturer data from www.glo24.eu, confirmed by E.ON Ruhrgas. The prices are, however, for the German market and include the appliance, a hot-water tank, the solar collectors and the system control. The authors consider that the installation cost will be similar to the other heat pumps technologies (4000 Euros).

B The efficiency of 135 % is given for nominal conditions (by the manufacturer). More recent annual efficiency figure was found and is lower as expected. Test results available from [17] are claiming 113 to 122% annual efficiency (without solar) and 133 to 144% annual efficiency (with solar). It is not clear whether this is with or without hot water.

C Same as for gas boilers [1]. The most recent information for boilers service contract is about 135 without VAT. A similar cost is expected to apply to gas heat pumps. Note however, that the service is not mandatory for all appliances.

D Supposed to be the same as for gas boilers [1].

E No test data available at this stage, but it is expected to be the same as boilers because the burner technology is the same as the one used for condensing boilers (fully premix).

F The appliance we know today is targeting the domestic market and the range covered will probably increase to 40/50 kW for appliances dedicated to the commercial market.

G There are no data available for the lifetime as the technology is very new. To be competitive with other technologies the targeted lifetime is to be about 20 years.

H Possible installation of a new gas service line (grid connection= 1600 €); for new installation only.

I Modulating appliance: between 1.5 and 15 kW.

J 100% of the investment cost is here given per unit and thus not depending on kW (cost based on one appliance on the market; so it is not possible to make a linear cost model).

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215 Solar heating

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Date	Ref.	Description
	-	
	-	

Qualitative description

Brief technology description

Solar energy for domestic hot water and space heating is usually based on the principle of pumping a heat transfer liquid (typically a mixture of water and propylene glycol) from an array of roof mounted solar collectors to one or more storage tanks. Solar heating for dwellings has mainly been developed for coverage of the entire hot water demand during the summer period, and to a minor degree for space heating. Because of the mismatch between demand for space heating and available solar heat, there is a need of seasonal energy storage if solar energy should be the only supply. Such storage systems are only feasible at very large scale, and therefore solar heating for single-family houses must be combined with other heating systems, e.g. gas boilers or heat pumps. Small-scale long-term storages based on heat of fusion (heat of melting – the heat used when a substance melts) are theoretically possible, but they are not on the market today.Main components: Flat plate or vacuum tube solar collector, storage tank with heat exchangers, pump and control unit. Self-circulating systems work without pump and control.

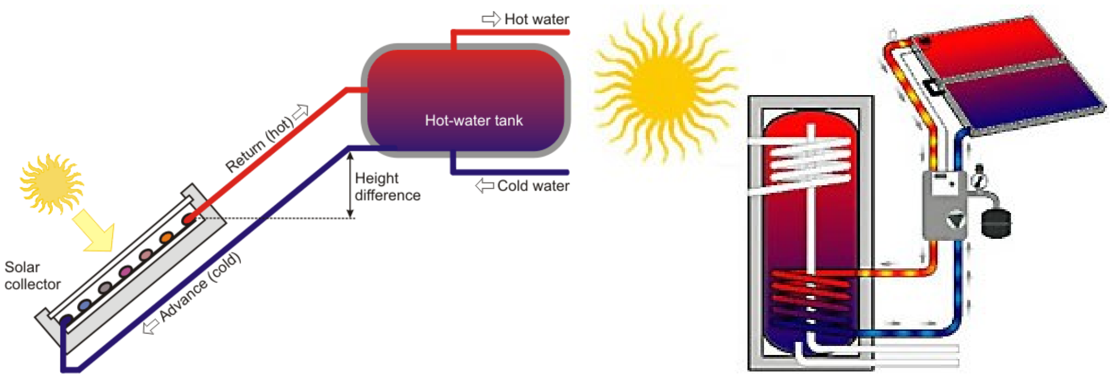

Figure 15: Small solar heating system for domestic hot water. To the left a pumped system where auxiliary heat is supplied to the upper heat exchanger coil. To the right a thermosyphon system without pump. In such a system the circulation of the heat transfer fluid is driven by natural convection rather than a mechanical pump.

Input

The primary energy input is solar radiation, of which a part can be converted to thermal energy in the absorber plate. The amount of energy reaching the solar collector depends on geographical site and orientation of the collector as well as possible shadows and ground reflectance. The only non-solar energy input to a solar heating system is the electric energy needed for the pump, controller and optional electric back-up heater. This amounts to up to 5 % of the delivered energy in a typical system, not including electric backup heater.

Output

The output is thermal energy at medium temperature, typically 20-80 °C, depending on operation conditions and collector type. Higher temperatures are possible with special double-glazed solar collectors for district or industrial heating, but they are hardly relevant for domestic hot water (DHW) and space heating. In combination with heat pumps, it is possible to use very simple and inexpensive solar collectors operating at low temperature. These are typically made of polymers without any cover or insulation. It is very important to mention that the actual performance of a solar heating system is highly dependent on the energy consumption and its distribution on time. A high consumption per m^2 collector is favourable for the efficiency, because it tends to lower the operational temperature, but it also results in a low solar fraction i.e. the part of the heating demand that is covered by the solar heating system.

Typical capacities

Traditionally, the system size is given in m^2 collector surface. For single-family homes the typical range is from 4 m^2 in case of a small DHW system to 15 m^2 for a combined space heating and DHW system. In order to compare with other technologies, IEA has estimated that 0.7 kW of nominal thermal power can be used as an equivalent to 1 m^2 collector surface [5].

Regulation ability

The thermal effect is largely determined by the solar irradiance and the actual operating temperature relative to ambient temperature. As the temperature increases, efficiency drops, so in a sense solar collectors are self-regulating and will stop producing heat when it reaches the so-called stagnation temperature. The regulation system in a solar heating plant can switch the available solar energy to be used for hot water or space heating and in some cases to a heat dump (typically the ground circuit in a solar/heat pump combi-system), in order to avoid boiling or temperature-induced damages. Boiling can happen in case of a power failure during periods with bright sunshine. A safety valve will open and it will be necessary to refill the system.

Advantages/disadvantages

Advantages

- No pollution during operation.
- The solar collector can be integrated in the urban environment and will then substitute a part of the building envelope.
- Large energy savings are often possible if the existing heater can be completely switched off during the summer so that standby losses can be substantially reduced.
- No dependency on fuels

Disadvantages

- Relatively expensive installation, except for large systems.
- Mismatch between heating demand and solar availability.

- Requires sufficient area on the roof with appropriate orientation.
- May compete with photovoltaic systems for the same area.

Environment
A solar heating system mainly contains metals and glass that require energy in manufacturing. It is estimated that the energy payback time is 1-3 years [4] for a well-functioning system in Denmark. Almost all the materials can be recycled. The special selective surface used on most solar collectors is made in a chemical process that in some cases involves chromium. It is important that the process control is adequate to avoid any pollution from this process. The fluid used in most solar heating systems shall be disposed as low-toxic chemical waste.

Research and development perspectives
The most relevant R&D needed for further development of solar thermal systems is:

- Advanced and cost effective storage systems for thermal energy.
- More cost-effective solar collectors, mainly through improved low-cost manufacturing processes.
- Self-adjusting control systems that is easily adapted to the existing heating system.
- Completely new system designs, e.g. air-based wall solar collectors combined with heat pump.
- Improved architectural design and smooth integration in buildings.
- Integration with solar photovoltaic and heat pumps (PVT – Thermal PV).
- Cost- effective mounting and installation methods

Examples of market standard technology
The sector is characterized by step-by-step improvements, and the most important improvements in the last 10 years are:

- Perfection of stratified storage tanks.
- Vacuum tube collectors with high power/cost ratio
- Hot water heat exchanger modules for Legionella prevention.
- Large-scale solar collectors for district heating and other applications.
- Energy saving pumps for less electricity consumption.
- Flexible and pre-insulated installation pipework with fast-connectors.
- Improved design and integration in facades or roof windows (e.g. Velux).

Prediction of performance and costs
Today, solar heating covers a minute part of the Danish energy supply (less than 1 % of the total heating), but the potential is enormous [2]. In recent years, the dominating market has shifted from individual systems to large-scale systems for district heating due to economy of scale benefits. However, with the increasing demand for energy efficiency of new buildings, individual solar heating plants could become more and more common. The international (European) solar thermal industry was growing rather quickly up to 2008 but has been decreasing since then. It has probably to do with the fact that solar photovoltaic has been growing very quickly in the past years. The major challenge for solar thermal energy is to develop low cost manufacturing and installation processes, which is very difficult in a situation where the markets in Europa end Denmark are declining [2]. A logical way

to cope with this challenge is to merge solar thermal with solar photovoltaic into one system or module. There are also many attempts in this respect presently. It should be noticed that compact self-circulating DHW systems are far cheaper than the traditional pumped system, but are not much used in Denmark for aesthetical reasons and risk of freezing. If the cost of solar collector systems or PVT systems does not decrease fast enough, the combination of PV and heat pump or electric boiler could become a competitive alternative to individual solar systems. Solar heating systems are a mature and commercial technology with a large deployment (a category 4 technology).

Uncertainty

Small solar systems for DHW are a category 4 technology. It is expected that this technology will continue to develop on market conditions with gradually reduced prices and increased performance.

The future of larger systems for space heating is more uncertain. The competition about roof space with photovoltaic will be a challenge and it could therefor happen that pure solar heating plants will continue to be a declining market.

Economy of scale effects

The scale effect for solar heating systems for buildings mainly comes from installation costs that will be smaller per area for larger plants. The rational mounting or building integration has been the key issue to address for solar thermal heating systems.

Additional remarks

This technology description is limited to traditional (pumped) solar heating systems without exchange of energy with other buildings than the one where the solar collectors are installed. Only domestic hot water and space heating are considered, not solar cooling.

Data sheets

Table 49: Solar heating system – one-family house, existing building

Technology	Solar heating system - One-family house, existing building.									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	4.2	4.2	4.2	4.2	3	6	3	6	A, I	1
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	5	5	5	5	0	10	0	10	B, I	1
Expected share of hot tap water demand covered by unit (%)	65	65	65	65	40	70	40	70	B, I	1
Electric efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Heat efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Total efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Auxiliary Electricity consumption (kWh/year)	150	140	130	110	100	200	75	150		
Technical lifetime (years)	20	25	30	30	20	30	25	35	C	1
Regulation ability										
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	NA	NA	NA	NA	NA	NA	NA	NA		
Minimum load (% of full load)	NA	NA	NA	NA	NA	NA	NA	NA		
Warm start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Cold start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Environment										
SO_2 (g per GJ fuel)	0	0	0	0	0	0	0	0		
NO_X (g per GJ fuel)	0	0	0	0	0	0	0	0		
CH_4 (g per GJ fuel)	0	0	0	0	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0	0	0	0	0		
Particles (g per GJ fuel)	0	0	0	0	0	0	0	0		
Financial data										
Specific investment (1000€/unit)	4.0	3.6	3.4	2.7	3.2	4.4	2.1	3.0	D	6
- hereof equipment (%)	65	65	65	65	60	70	60	70		
- hereof installation (%)	35	35	35	35	30	40	30	40		
Possible additional specific investment (1000€/unit)	0	0	0	0	0	0	0	0		
Fixed O&M (€/unit/year)	69	68	69	63	47	94	49	98		
- of which is electricity costs (€/unit/year)	9	10	13	13	7	14	9	18	F	
- of which is other O&M costs (€/unit/year)	60	59	56	50	40	80	40	80	E, H	
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		
Technology specific data										
Solar collector area , m²	6.0	6.0	6.0	6.0	4.0	9.0	4.0	9.0	I	1
Output, kWh pr. m² collector pr. year	400	425	450	500	300	450	400	550	J	1

Table 50: Solar heating system – one-family house, Energy renovated.

Technology	Solar heating system - One-family house, Energy renovated.									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	4.2	4.2	4.2	4.2	3	6	3	6	A, I	1
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	10	10	10	10	0	15	0	15	B, I	1
Expected share of hot tap water demand covered by unit (%)	65	65	65	65	40	70	40	70	B, I	1
Electric efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Heat efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Total efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Auxiliary Electricity consumption (kWh/year)	150	140	130	110	100	200	75	150		
Technical lifetime (years)	20	25	30	30	20	30	25	35	C	1
Regulation ability										
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	NA	NA	NA	NA	NA	NA	NA	NA		
Minimum load (% of full load)	NA	NA	NA	NA	NA	NA	NA	NA		
Warm start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Cold start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Environment										
SO_2 (g per GJ fuel)	0	0	0	0	0	0	0	0		
NO_X (g per GJ fuel)	0	0	0	0	0	0	0	0		
CH_4 (g per GJ fuel)	0	0	0	0	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0	0	0	0	0		
Particles (g per GJ fuel)	0	0	0	0	0	0	0	0		
Financial data										
Specific investment (1000€/unit)	3.4	3.4	2.7	2.4	2.7	3.7	1.9	2.7	D	6
- hereof equipment (%)	65	65	65	65	60	70	60	70		
- hereof installation (%)	35	35	35	35	30	40	30	40		
Possible additional specific investment (1000€/unit)	0	0	0	0	0	0	0	0		
Fixed O&M (€/unit/year)	69	68	69	63	47	94	39	88		
- of which is electricity costs (€/unit/year)	9	10	13	13	7	14	9	18	F	
- of which is other O&M costs (€/unit/year)	60	59	56	50	40	80	30	70	E, H	
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		
Technology specific data										
Solar collector area , m²	6.0	6.0	6.0	6.0	4.0	9.0	4.0	9.0	I	1
Performance, kWh pr. m² collector per year	400	425	450	500	300	450	400	550	J	1

Table 51: Solar heating system – one-family house, new building

Technology	Solar heating system - One-family house, new building

	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	4.2	4.2	4.2	4.2	3	6	3	6	A, I	1
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	0	0	0	0	0	0	0	0	B, I	1
Expected share of hot tap water demand covered by unit (%)	65	65	65	65	40	70	40	70	B, I	1
Electric efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Heat efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Total efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Auxiliary Electricity consumption (kWh/year)	150	140	130	110	100	200	75	150		
Technical lifetime (years)	20	25	30	30	20	30	25	35	C	1
Regulation ability										
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	NA	NA	NA	NA	NA	NA	NA	NA		
Minimum load (% of full load)	NA	NA	NA	NA	NA	NA	NA	NA		
Warm start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Cold start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Environment										
SO_2 (g per GJ fuel)	0	0	0	0	0	0	0	0		
NO_X (g per GJ fuel)	0	0	0	0	0	0	0	0		
CH_4 (g per GJ fuel)	0	0	0	0	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0	0	0	0	0		
Particles (g per GJ fuel)	0	0	0	0	0	0	0	0		
Financial data										
Specific investment (1000€/unit)	2.7	2.4	2.1	1.9	2.1	3.0	1.5	2.1	D	6
- hereof equipment (%)	65	65	65	65	60	70	60	70		
- hereof installation (%)	35	35	35	35	30	40	30	40		
Possible additional specific investment (1000€/unit)	0	0	0	0	0	0	0	0		
Fixed O&M (€/unit/year)	69	68	69	63	47	94	39	88		
- of which is electricity costs (€/unit/year)	9	10	13	13	7	14	9	18	F	
- of which is other O&M costs (€/unit/year)	60	59	56	50	40	80	30	70	E, H	
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		
Technology specific data										
Solar collector area , m²	6	6	6	6	4	9	4	9	I	1
Performance, kWh pr. m² collector per year	425	450	475	500	300	450	400	550	J	1

Table 52: Solar heating system – apartment complex, existing building

Technology	**Solar heating system - Apartment complex, existing building**							
	2015	2020	2030	2050	Uncertainty	Uncertainty	Note	Ref

					(2020)		(2050)			
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	140	140	140	140	100	200	100	200	A, I	1
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	0	0	0	0	0	0	0	0	B, I	1
Expected share of hot tap water demand covered by unit (%)	65	65	65	65	40	70	40	70	B, I	1
Electric efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Heat efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Total efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Auxiliary Electricity consumption (kWh/year)	3000	2800	2500	2000	2000	4000	1500	3000		
Technical lifetime (years)	20	25	30	30	20	30	25	35	C	1
Regulation ability										
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	NA	NA	NA	NA	NA	NA	NA	NA		
Minimum load (% of full load)	NA	NA	NA	NA	NA	NA	NA	NA		
Warm start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Cold start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Environment										
SO_2 (g per GJ fuel)	0	0	0	0	0	0	0	0		
NO_X (g per GJ fuel)	0	0	0	0	0	0	0	0		
CH_4 (g per GJ fuel)	0	0	0	0	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0	0	0	0	0		
Particles (g per GJ fuel)	0	0	0	0	0	0	0	0		
Financial data										
Specific investment (1000€/unit)	86	81	74	67	69	94	54	74	D	6
- hereof equipment (%)	65	65	65	65	60	70	60	70		
- hereof installation (%)	35	35	35	35	30	40	30	40		
Possible additional specific investment (1000€/unit)	0	0	0	0	0	0	0	0		
Fixed O&M (€/unit/year)	389	388	438	404	268	536	256	551		
- of which is electricity costs (€/unit/year)	189	193	253	234	138	276	176	351	F	
- of which is other O&M costs (€/unit/year)	200	195	185	170	130	260	80	200	E, H	
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		
Technology specific data										
Solar collector area, m²	200	200	200	200	140	290	140	290	I	1
Performance, kWh pr. m² collector per year	400	425	450	500	300	450	400	550	J	1

Table 53: Solar heating system – apartment complex, new building

Technology	**Solar heating system - Apartment complex, new building**							
	2015	2020	2030	2050	Uncertainty (2020)	Uncertainty (2050)	Note	Ref

Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	140	140	140	140	100	200	100	200	A, I	1
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	0	0	0	0	0	0	0	0	B, I	1
Expected share of hot tap water demand covered by unit (%)	65	65	65	65	40	70	40	70	B, I	1
Electric efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Heat efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Total efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Auxiliary Electricity consumption (kWh/year)	3000	2800	2500	2000	2000	4000	1500	3000		
Technical lifetime (years)	20	25	30	30	20	30	25	35	C	1
Regulation ability										
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	NA	NA	NA	NA	NA	NA	NA	NA		
Minimum load (% of full load)	NA	NA	NA	NA	NA	NA	NA	NA		
Warm start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Cold start-up time (hours)	NA	NA	NA	NA	NA	NA	NA	NA		
Environment										
SO_2 (g per GJ fuel)	0	0	0	0	0	0	0	0		
NO_X (g per GJ fuel)	0	0	0	0	0	0	0	0		
CH_4 (g per GJ fuel)	0	0	0	0	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0	0	0	0	0		
Particles (g per GJ fuel)	0	0	0	0	0	0	0	0		
Financial data										
Specific investment (1000€/unit)	81	74	67	60	64	89	48	66	D	6
- hereof equipment (%)	65	65	65	65	60	70	60	70		
- hereof installation (%)	35	35	35	35	30	40	30	40		
Possible additional specific investment (1000€/unit)	0	0	0	0	0	0	0	0		
Fixed O&M (€/unit/year)	389	388	438	404	268	536	256	551		
- of which is electricity costs (€/unit/year)	189	193	253	234	138	276	176	351	F	
- of which is other O&M costs (€/unit/year)	200	195	185	170	130	260	80	200	E, H	
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		
Technology specific data										
Solar collector area , m²	200	200	200	200	140	290	140	290	I	1
Performance, kWh pr. m² collector per year	425	450	475	500	300	450	400	550	J	1

Notes

A Fixed average size but increasing efficiency is assumed. Typical range is from 3-15 m2 in one-family houses. 1 m2 is equivalent with 0.7 kW.

B Annual yield from 400 to 500 kWh/m2. Highest figures for new buildings. General improvements and better storage technology assumed.

C Increase due to better materials/fluids.

D Depends on existing heating system. Savings if tank should be changed anyway. For new buildings solar system costs are lower because it is being installed during renovation/construction.

E Service checks, liquid etc., 60 EUR/year in average for small systems and 200 EUR/year for large systems.

F Electricity for solar pump and control. The cost of auxiliary electricity consumption is calculated using the following electricity prices in €/MWh: 2015: 64, 2020: 71, 2030: 102, 2050: 165. These prices include production costs and transport tariffs, but not any taxes or subsidies for renewable energy.
G Pollution associated with the small amount of electricity needed for operation is neglected.
H Assuming a cost-reduction of 0.5 % p.a., which in turn is assumed equivalent to the typical improvement of mature technologies.
I The size of the solar heating units are usually determined by the hot water demand so the full load hours are maximized. The size of the units will therefore not be very dependent of the room heating demand.
J In new buildings the unit along with the piping system can be optimised which will result in a more efficient system in new buildings compared with existing buildings.

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216 Electric heating

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Date	Ref.	Description

Qualitative description

Brief technology description

Electric radiators are mounted in each room. The bathrooms are sometimes equipped with electric floor heating systems. The hot tap water is made by a hot water tank with an electric heating coil. In case the distance to a secondary tapping point is large, more than one water heater can be installed. The radiators are equipped with internal thermostats, but more advanced systems are available, making it possible to programme a temperature schedule individually for each room. Electric heating can be a supplement or a complete system. Electric heating can be controlled by external systems, as an example Lauritz Knudsens IHC system including night set back. Also remote internet control is becoming popular, particular in vacation houses. The installation will normally include a group switch per one or two rooms, making central control very simple to install.

Input

The input is electricity.

Output

The output is room heating and hot water.

Typical capacities

Typical capacities for one-family buildings and apartment complex are 5 to 400 kW.

Regulation ability

The control is very flexible and the capacity can be regulated fast from 0 to 100 % and vice versa. It should be noted that the heat output is only dependent on the installed nominal power. In most cases, use of night setback or other forms of periodic heating is very efficient, as the reheating of the rooms can be very rapid. Furthermore, adding extra capacity is cheap.

Electric radiators can be built as storage heaters with some energy storage. For such radiators, electricity can be turned off for a period but heat is still emitted from the radiator. This ability can be used to e.g. fit time varying electricity tariffs in future.

Advantages/disadvantages

Advantages

- Low investment and installation costs [4]
- Very high flexibility
- Very efficient reheating after night setback
- Very precise room temperature control
- Easy possibility of remote control
- Periodic sanitation of the hot tap water is done by heating the water in the hot water tank without any loss of energy.
- Furthermore, distribution heat losses are saved compared to water based heating systems.
- It is expected that electricity will become increasingly important in the future energy supply. With increasing penetration of renewable electricity, the ability to consume electricity flexible becomes increasingly interesting. Large scale demonstration of smart grid technologies on Bornholm has demonstrated that households with direct electric heating are more flexible than households with heat pumps [5].

Disadvantages

- High energy price
- High loss of exergy when converting electricity to heat
- If widespread used, the peak load power demand can prove a challenge for both power production units and the electricity grid.
- A household or indeed an apartment complex heated by electric heating often requires reinforcement of the electricity connection compared to households heated by boilers or district heating

Environment

The environmental impact due to the use of electricity will depend on the way the electricity is produced.

Research and development perspectives

Research concerning the future use of direct electrical heating in a smart grid may lead to positive results for this technology. It shall be taken into account that electrical heating historically often showed unexpected low energy consumptions [2].

Examples of market standard technology

A modern electric heating system is an intelligent system, see [3]. Each room can be controlled individually, and the consumption per room can be displayed for the consumer. The bathrooms are heated with floor heating and the rooms with panels. The hot water tank is a 'smart tank' including self-learning controls to maintain the lowest average temperature, while still controlling the risk of Legionella. Storage heaters are used in case of varying electricity tariffs.

Prediction of performance and costs

The deployment of electric heating systems is expected to be limited to housings were the demand of space heating is considerably reduced, such as vacation houses, where water based heating systems are too costly.

Electric heating systems are a mature and commercial technology with a large deployment (a category 4 technology).

Uncertainty
With increasing focus on energy efficiency the future of direct electric heating solutions may be extremely limited.

Economy of scale effects
Investment cost is very low and economy of scale is not relevant / not existing.

Additional remarks
The prices below include a complete system for space heating and domestic hot water in each living unit.

Data sheets

Table 54: Electric heating – one-family house, new building

Technology	Electric heating - One-famely house, new building									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	3	3	3	3	2	7	2	7		
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Heat efficiency, annual average, net (%)	100	100	100	100	100	100	100	100		
Total efficiency, annual average, net (%)	100	100	100	100	100	100	100	100	A	
Auxiliary Electricity consumption (kWh/year)	0	0	0	0	0	0	0	0		
Technical lifetime (years)	30	30	30	30	25	30	25	30		
Regulation ability										
Primary regulation (% per 30 seconds)	100	100	100	100	100	100	100	100		
Secondary regulation (% per minute)	100	100	100	100	100	100	100	100		
Minimum load (% of full load)	0	0	0	0	0	0	0	0		
Warm start-up time (hours)	0	0	0	0	0	0	0	0		
Cold start-up time (hours)	0	0	0	0	0	0	0	0		
Environment										
SO_2 (g per GJ fuel)	For electric heating, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socioeconomic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk).									
NO_X (g per GJ fuel)										
CH_4 (g per GJ fuel)										
N_2O (g per GJ fuel)										
Particles (g per GJ fuel)										
Financial data										
Specific investment (1000€/unit)	3.0	2.9	2.8	2.5	2.4	3.3	2.0	2.8	D, E, F	4
- hereof equipment (%)	70	70	70	70	70	70	70	70		4
- hereof installation (%)	30	30	30	30	30	30	30	30		4
Possible additional specific investment (1000€/unit)	0	0	0	0	0	0	0	0		
Fixed O&M (€/unit/year)	25	24	23	21	20	40	15	30	C, E	
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Table 55: Electric heating – apartment complex, new building

Technology	Electric heating - Apartment complex, new building									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	160	160	160	160	100	250	100	250	B	
Electricity generation capacity for one unit (kW)	0	0	0	0	0	0	0	0		
Expected share of space heating demand covered by unit (%)	100	100	100	100	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	100	100	100	100		
Electric efficiency, annual average, net (%)	NA	NA	NA	NA	NA	NA	NA	NA		
Heat efficiency, annual average, net (%)	100	100	100	100	100	100	100	100		
Total efficiency, annual average, net (%)	100	100	100	100	100	100	100	100	A	
Auxiliary Electricity consumption (kWh/year)	0	0	0	0	0	0	0	0		
Technical lifetime (years)	30	30	30	30	25	30	25	30		
Regulation ability										
Primary regulation (% per 30 seconds)	100	100	100	100	100	100	100	100		
Secondary regulation (% per minute)	100	100	100	100	100	100	100	100		
Minimum load (% of full load)	0	0	0	0	0	0	0	0		
Warm start-up time (hours)	0	0	0	0	0	0	0	0		
Cold start-up time (hours)	0	0	0	0	0	0	0	0		
Environment										
SO_2 (g per GJ fuel)	For electric heating, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socioeconomic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk).									
NO_X (g per GJ fuel)										
CH_4 (g per GJ fuel)										
N_2O (g per GJ fuel)										
Particles (g per GJ fuel)										
Financial data										
Specific investment (1000€/unit)	106	103	98	89	85	117	71	98	D, E, F	4
- hereof equipment (%)	70	70	70	70	70	70	70	70		4
- hereof installation (%)	30	30	30	30	30	30	30	30		4
Possible additional specific investment (1000€/unit)	0	0	0	0	0	0	0	0		
Fixed O&M (€/unit/year)	50	49	46	42	40	80	30	60	C, E	
Variable O&M (€/MWh)	0	0	0	0	0	0	0	0		

Notes

A Annual efficiency based on 100 % space heating efficiency and hot water efficiency. In addition, distribution heat losses compared to water based heating systems are saved, typically in the range of 5-10 %.

B Assuming 150 apartments.

C Assuming change of heating elements in the hot water tank every 10 years.

D The price includes the complete system including room heaters and hot tap water preparation.

E Assuming a cost-reduction of 0.5 % p.a., which in turn is assumed equivalent to the typical improvement of mature technologies.

F Including costs of wiring and procurement and installation of radiators

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217 Solid Oxide Fuel Cell (SOFC) micro-CHP - Natural gas / Biogas

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Date	Ref.	Description
-	-	-
-	-	-

Qualitative description

Brief technology description

Solid oxide fuel cell micro combined heat and power systems (SOFC mCHPs) typically use natural gas or biogas as fuel and, therefore, they can simply be connected to the gas grid like conventional natural gas boilers. Alternatively, SOFC CHPs can utilise hydrogen, syngas, propane/LPG or diesel as fuel. However, because the fuel cell needs hydrogen and/or CO as input, a natural gas SOFC mCHP system must include a reformer (either separate component or internal reforming) which produces hydrogen or CO from the inlet gas. The system can either produce heat and electricity only to the household and/or export excess electricity to the electricity grid - possibly for grid balancing. The system can be assisted with a peak load boiler and/or heat storage (hot water tank) to balance heat production and demand. The secondary heat source might be integrated in the mCHP system.

Figure 1 shows a sketch of a typical SOFC mCHP installed in a household, including the fuel cell unit, a top-up boiler (peak-demand boiler) and hot water storage. It also visualizes that excess electricity can be fed into the electricity grid [1]. The emissions are predominantly limited to CO_2 from the reforming process of natural gas (methane) to hydrogen. In addition to this, water is produced from the electrochemical reaction between hydrogen and oxygen.

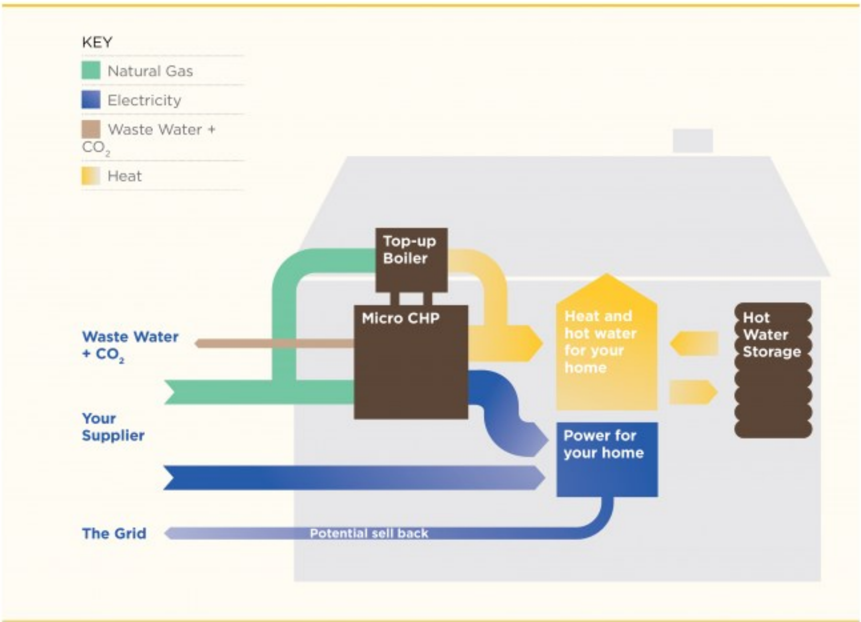

Figure 1: Typical installation of a mCHP in a domestic household [1].

Figure 2 shows the current structure of the XellPower FC heating unit, which is an example of a market standard technology.

Figure 2: Structure of the current XellPower FC heating unit: the fuel cell system with the auxiliary units is in the bottom, the auxiliary condensing gas boiler heater is on top. © Vaillant (left picture). Vaillant micro CHP (right picture) [17].

Input

Natural gas or biogas.

Output

Electricity and heat (for hot water and for space heating).

Typical capacities

Typical capacities for SOFC mCHP units are 0.6 - 25 kW heat (including supplementary heater/boiler) and 0.7-5 kW electricity [1]. In a typical residential installation, the actual fuel cell unit produces only a small part of the heat demand and a supplementary peak demand boiler is the main contributor. Not including the peak demand boiler leads to heat production capacities between 0.3 and 3 kW reflecting the ratio between heat and electricity presented in the energy balance. Units installed in Japan are most often in a lower range of electrical output, typically 0.2-0.7 kW electricity [11].

Electrical efficiency of the FC mCHP system is expected to drop during its lifetime; the energy is converted to heat instead.

Regulation ability

The FC mCHP system can modulate and can be operated in various modes, for example: constant power output [3], or it can be operated to follow the heat- or the power demand of the building. The chosen mode varies for different manufacturers.

SOFC systems can be designed to regulate below 30% of nominal load without any significant loss of efficiency. The response time can be very short (a few seconds) when the system is in standby mode. The cold start-up time is several hours.

Advantages/disadvantages

The main advantages include:

- Produce both electricity and heat in cogeneration and with a higher electrical efficiency than for other cogeneration technologies in the same power range fuelled with natural gas.
- The decentralised cogeneration of electricity and heat minimises grid losses and the need for infrastructural investments.
- Natural gas fuelled SOFC mCHPs can be operated from the national natural gas grid even if the natural gas is exchanged with synthetic natural gas (SNG).
- The required gas quality is less strict compared to e.g. gas engines. SOFC mCHP units are more flexible in relation to utilisation of fuels and can run on different types of gasses (methane, syngas, hydrogen, biogas) without them being upgraded to SNG.

The main disadvantages include:

- Currently, lifetime of the stacks is relatively short. Several replacements of stacks may be needed during the lifetime of the plant.
- Long start-up times from a cold start.

Environment

The emissions from natural gas fuelled SOFCs are relatively low compared to electricity produced at central power plants. The emission of SO_2, NO_x and particles is absent. Additionally, there is no noticeable noise pollution related to the operation of the SOFC mCHP. If the gas is produced from fossil free sources, the operation of the unit is carbon neutral. Today, the most common used material for the anode in SOFCs consists of nickel mixed with YSZ. In the production / end of life disposal, the use of e.g. nickel / nickel oxide is a concern as it is carcinogenic.

Research and development perspectives

SOFC mCHP units are still under development. The development is concentrated on reducing the costs of the units, increasing the lifetime and increasing the reliability.

In a later phase, the research and development activities may be more concentrated on how to use the units in a smart grid context so that SOFC mCHP can optimize their operation according to dynamic electricity prices. Several European manufacturers of SOFC mCHP systems are currently demonstrating their units in field trials [1] and [2]. Apart from units installed in field trials, a few international companies have entered the European market with commercially available products. Today, most installations are taking place in Japan as a part of the ENE-FARM project.

Examples of market standard technology

The following products are examples of market standard technologies:

- Vaillant xellPOWER fuel cell heater (electrical output of 0.8 kW, thermal output of 1.5 kW).
- BlueGEN system from SOLIDpower.
- ENGEN 2500 system from SOLIDpower.
- Galileo 1000 N from Hexis.

Prediction of performance and costs

The technology is classified between Category 1: Research and development and Category 2: Pioneer phase, demonstration.

The investment cost is expected to decrease from 21,000 $€_{2015}$/unit in 2020 to 11,000 $€_{2015}$/unit in 2050. Since the technology is classified between category 1 and category 2 and still needs development, the cost of investment is subject to significant uncertainties. The uncertainty in 2050 is within the interval from 5,000 $€_{2015}$/unit to 16,000 $€_{2015}$/unit. The lower uncertainty is based on 'The cost of domestic fuel cell micro-CHP systems', London Business School.

Uncertainty

The uncertainty related to the cost projection is significant and is affected by challenges such as life time improvements, improved operational flexibility and reduction of investment costs. It is also worth noticing that in Contini, V., Eubanks, F. & Jansen, M., Stationary and Emerging Market Fuel Cell System Cost Analysis - Auxiliary Power Units, Batelle, 06/19/2014, Washington D.C., the capital cost of stacks are relatively small compared to the system cost and the sales mark-up.

Additional remarks

No additional remarks.

Data sheets

Table 56: SOFC (microCHP) – natural gas / biogas, new and existing one-family house

Technology	SOFC (microCHP) - natural gas / biogas One-family house existing and new building									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat generation capacity for one unit (kW)	0,67	0,56	0,56	0,56					A	
Electricity generation capacity for one unit (kW)	0,70	0,70	0,70	0,70					B	
Typical share of space heating demand covered by unit (%)	0,11	0,08	0,08	0,08					A	
Typical share of hot tap water demand covered by unit (%)	1	1	1	1					A	
Electric efficiency, annual average, net (%)	46	50	50	50	46	57	48	60	C	20
Heat efficiency, annual average, net (%)	44	40	40	40					C, J	
Total efficiency, annual average, net (%)	90	90	90	90					C	
Auxiliary Electricity consumption (kWh/year)	-	-	-	-						
Technical lifetime (years)	10	20	20	20					D	
Regulation ability										
Primary regulation (% per 30 seconds)										
Secondary regulation (% per minute)										
Minimum load (% of full load)	0,7	0,7	0,7	0,7						
Warm start-up time (minutes)	1,5	1,5	1,5	1,5						
Cold start-up time (minutes)	360	240	240	240					E	
Environment										
SO2 (g per GJ fuel)	0	0	0	0						
NOX (g per GJ fuel)	NA	2	2	2						
CH4 (g per GJ fuel)	NA	1.25	1.25	1.25						
N2O (g per GJ fuel)	NA	0	0	0						
Particles (g per GJ fuel)	0	0	0	0						
Financial data										
Specific investment (1000€/unit)	27	21	16	11	17	27	5	16	F, G	18, 21
- hereof equipment (%)	80	80	80	80						
- hereof installation (%)	20	20	20	20						
Fixed O&M (€/unit/year)	1350	1050	800	550					I	19
Variable O&M (€/GJ)	0	0	0	0						

Notes

A The heat output is 0.6 kW. The system is also combined with a peak demand boiler (up to 25 kW thermal power), this is to match the heat demand for a household. The value presented in the table does not include the contribution from a peak demand boiler. Assumed 6000 full loads hours per annum for fuel cell. Assumed that supplying hot tap water is given priority.

B The electrical output of this system is up to 0.7 kW, but varies between 0.2 – 5 kW when evaluating European and Japanese systems. [1,7,11, 13-15]

C Looking at listed values for more manufacturers the electrical efficiency ranges from 35 to 60 %. Large variations in the electrical / heat efficiency as different manufacturers run their units in different modes, e.g. optimized for either heat or power production. Heat efficiency increases as the electrical efficiency decreases. Heat efficiency refer to the SOFC micro CHP alone, e.g. any production from peak demand boiler is excluded as this differs between different technologies.

D The techno economical lifetime is the lifetime of the whole system. The stack lifetime is shorter and the stack is expected to be exchanged during this period. The stack life-time is expected to be app. 10 years in 2020 [5].

E Start up from an outdoor or room temperature is slow as the units contain ceramics. If the system is at operating temperature the stack can be started faster, assuming that gases are supplied and help systems are active. Also shut down can be performed quickly, not counting in the time required to cool the system.

F Price in Japan 19,400 Euro. Cost of modification for European market plus installation is estimated by DGC to add up to 27,000 Euro/unit

G The specific investments for 2020, 2030 and 2050 are estimated from [16]. The major price reduction factor between 2020 and 2050 is mass production of units (50,000 units/year assumed in 2050).

H The uncertainties for specific investment costs reflect variations in the level of mass production based on figures given in [16].

I Fixed O&M costs assumed to be 5% of the specific investment based on [17]. In [17], the fixed O&M is estimated to be 5% of investment for Alkaline and PEM FC. The same is assumed for SOFC.

J The heat efficiency, which can be derived, depends on the return temperature of the cooling circuit and the size of the heat exchanger.

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218 Low Temperature PEM Fuel Cell micro-CHP - hydrogen

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-	-	-
-	-	-

Qualitative description

Brief technology description

The fuel cell performs electrochemical conversion of fuel into electricity and heat. Generally, the conversion efficiency from fuel to electricity is high in a fuel cell and the technology is scalable without loss of efficiency.

The small power and heat generation units, mCHP, are arranged for integration in decentralized applications in private households and small enterprises. The mCHPs will primarily be installed to cover the household heat demand; the generated power can be utilised by the house and/or exported to the grid. The mCHP must be combined with another heating technology to cover the heat demand in older buildings. The hydrogen can either be supplied from a central electrolyser (figure 1, left) or by a household electrolyser (Figure 1, right).

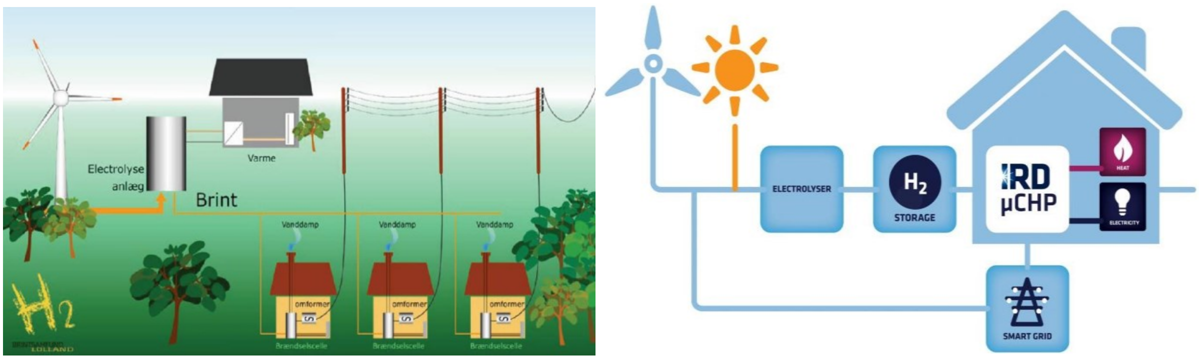


Figure 1: The Vestenskov village hydrogen (left) supply model & the open area hydrogen supply model (right).

Input
Hydrogen.

Output
Electricity and heat (for hot water and for space heating).

Typical capacities
The capacity of the mCHP units are typically around 1 kW to 5 kW of electrical power. Demonstration of mCHP units started in 2006 in Denmark as part of an ambitious 6 year plan; the demonstration involved the following Danish enterprises: EWII Fuel Cells A/S (former IRD), Topsoe Fuel Cell, DONG Energy, Syd Energi, SEAS-NVE, DGC, COWI and Ballard Power Systems (former Dantherm Power).

More than 150,000 mCHP units are in demonstration in Japan and heavily subsidised units have been sold to private households for the last year.

Regulation ability and other power system services
Larger number of mCHP units in the grid can support the grid companies in the efforts to balance the grid and reduce the need for new cables. In a Danish context, the potential for mCHP is outside the district heating areas and where gas is available. In 2015 there were approx. 430,000 conventional gas boilers in operation Denmark.

Within the Danish mCHP demonstration project it has been proven that the hydrogen fuelled mCHP has a fast start-up time (presently ≈2 mins, can be lowered to ms), and can cope with >2,500 start/stop cycles without degradation. Furthermore, the hydrogen fuelled mCHP is efficient over a large power interval (Figure 3).

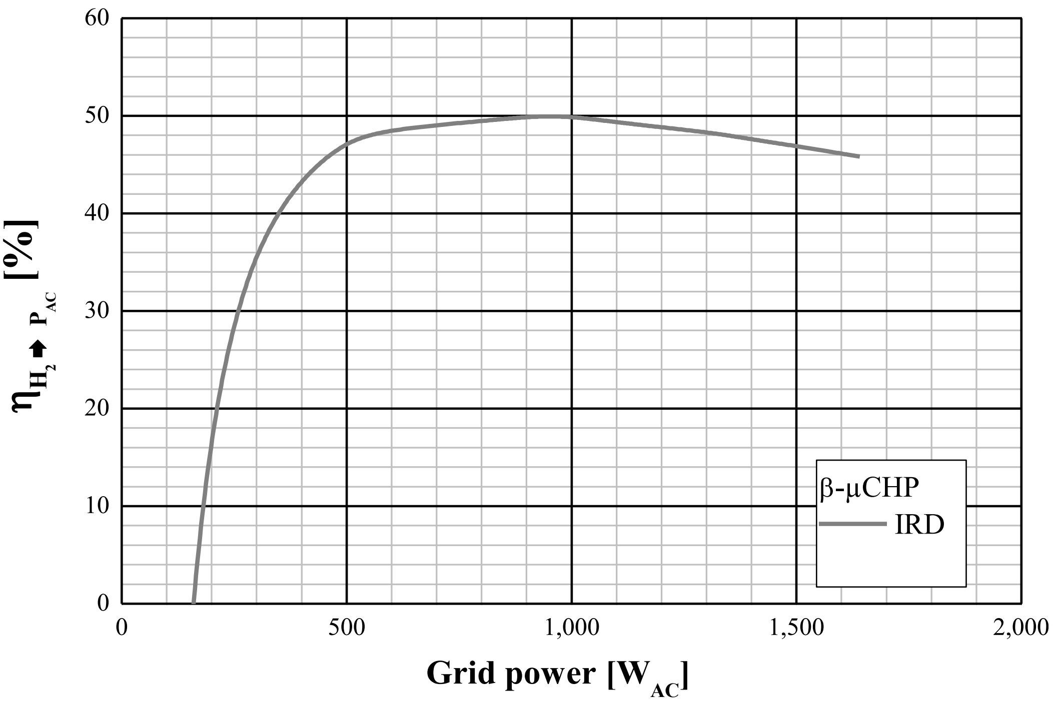


Figure 3: Efficiency versus grid power measured on an EWII hydrogen fuelled β-micro CHP.

Advantages/disadvantages

Advantages include:

- The PEM mCHP utilises the scalability of the fuel cell technology to produce electricity locally with efficiencies equal to or higher than for conventional power plants.
- Lower CO_2 footprint (high efficiency)
- The grid balancing property of the PEM mCHP contributes to reduced additional investments in infrastructure e.g. cables.
- Cost competitiveness for the user.
- Decentralised cogeneration of electricity and heat minimises grid losses and the need for infrastructural investments.

Disadvantages include:

- Relatively high production costs due to expensive materials (platinum).
- Lifetime of current technology needs to be improved.

Environment

The emissions from hydrogen are zero if the hydrogen is produced by surplus power from renewable energy sources. A single family hydrogen fuelled mCHP will if the hydrogen is produced from surplus power typically save the environment for 5-7 tons CO_2 emissions per year compared to today's individual fossil fuel heating devices e.g. gas boilers.

Research and development perspectives

The Danish mCHP units are today on an advanced prototype level where the main developing topics are focussed on reducing cost while simultaneously increasing lifetime, durability, and reliability. In Denmark, an Overall Plan for Development of Fuel Cell based mCHP (Dansk Plan for Markedsmodning af mikrokraftvarme [5]) was issued in 2011 by the stakeholders of Hydrogen Denmark (former The Danish Partnership for Hydrogen and Fuel Cells). Recent analyses within the project "Analysis for Commercialization of Hydrogen Technologies" under the Danish Energy Technology Development and Demonstration Program (EUDP)" [7] showed that it would be very difficult for mCHP technologies to compete with other technologies for individual heating, including for example electric heat pumps. Today, the Danish hydrogen industry does not expect a significant market for mCHP technologies in Denmark [8]. The fuel cell technology has shown high electrical efficiency above competing power generation technologies. However, the fuel cell technology still needs to be matured on lifetime and cost.

Examples of market standard technology

The market for LT-PEMFC using natural gas is extremely limited. The technologies presented below are LT-PEMFC using natural gas as input [9].

- Toshiba, 700 W unit, Size (mm): W780 x D300 x H1000
- Panasonic, 700 W unit, Size (mm), H1750 x W400 x D400

Exclusive of the natural gas reformer, the same technologies could be used with hydrogen as fuel. The absence of the reformer leads to a lower investment cost and a higher electric efficiency.

Prediction of performance and costs

Category 2: Pioneer phase, demonstration

A recent study on advancing Europe's energy systems with stationary fuel cell for distributed generation was published by Roland Berger Strategy Consultants [10]. A significant growth of the European market for fuel cell mCHP was envisioned. The concluding expectations were that the technology will play a significant role in the future distributed generation of heat and power.

Approximately 150,000 fuel cell based mCHP units (mainly PEM technology) have been installed in private Japanese houses since 2009 [9]. The three Japanese suppliers are now making inroads to the European market by allying with European manufactures and distributes of natural gas boilers. This may accelerate the European market introduction of fuel cell mCHP.

The decrease of equipment cost is closely linked to the production volume. The estimated price development is inspired by the learning curves from the ENE-FARM project cf. Figure 4 [1], [2] and the results of the recent Delta-ee survey cf. Figure 5 [3], [4]. The latter has concluded that over two thirds of European homeowners would be willing to invest in mCHP, following a survey carried out in the UK, Germany and the Netherlands, but the price would have to be halved. Delta-ee furthermore concluded that householders are willing to pay a premium price for fuel cell mCHP over engine-based - but just how much of a premium varies by country (cf. Figure 5).

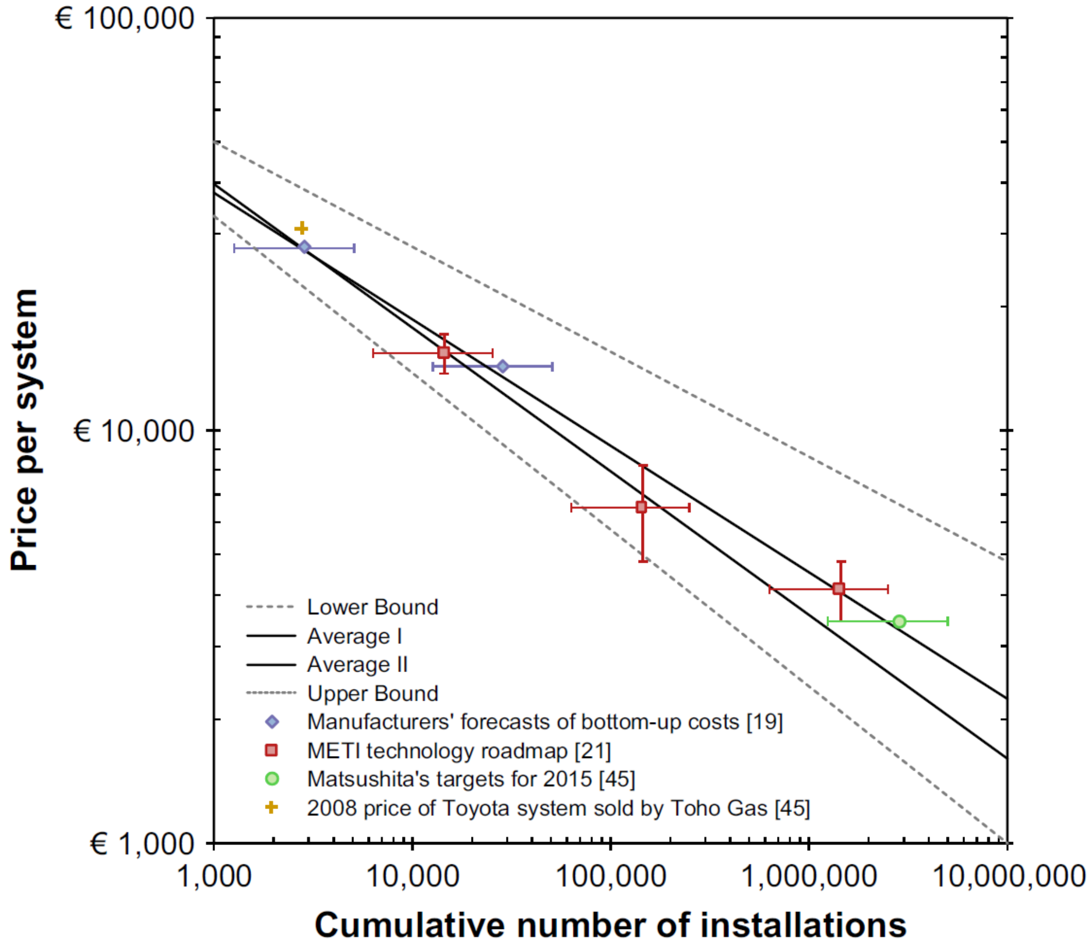
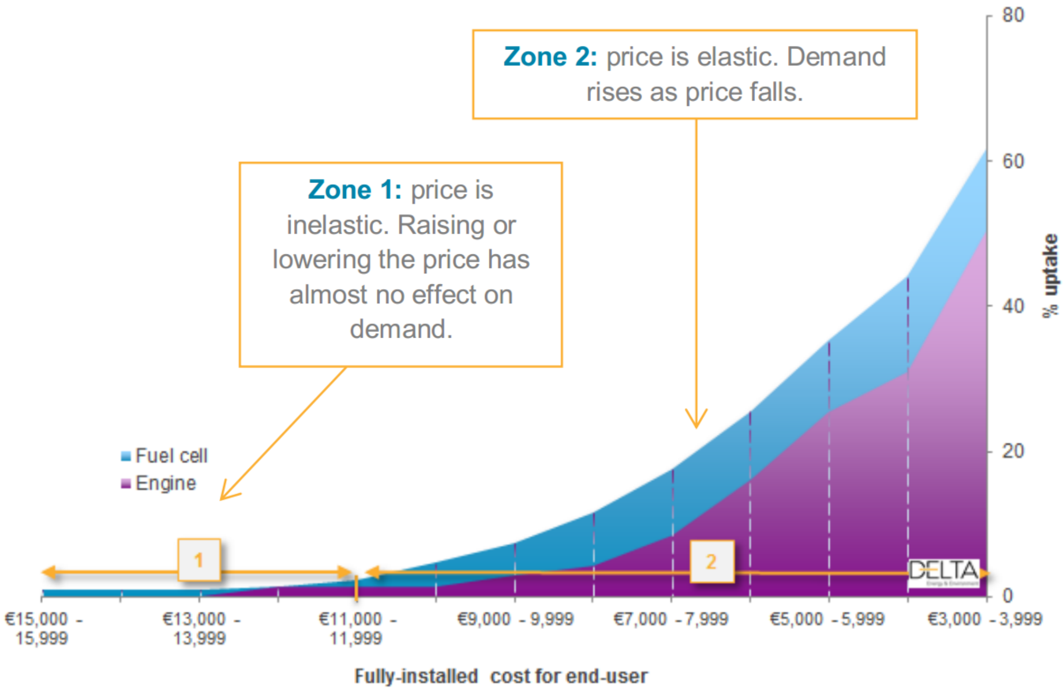


Figure 4: The experience curves, which account for additional experience gained, plotted against projected and target prices for ENEFARM systems (Staffel & Green 2009).



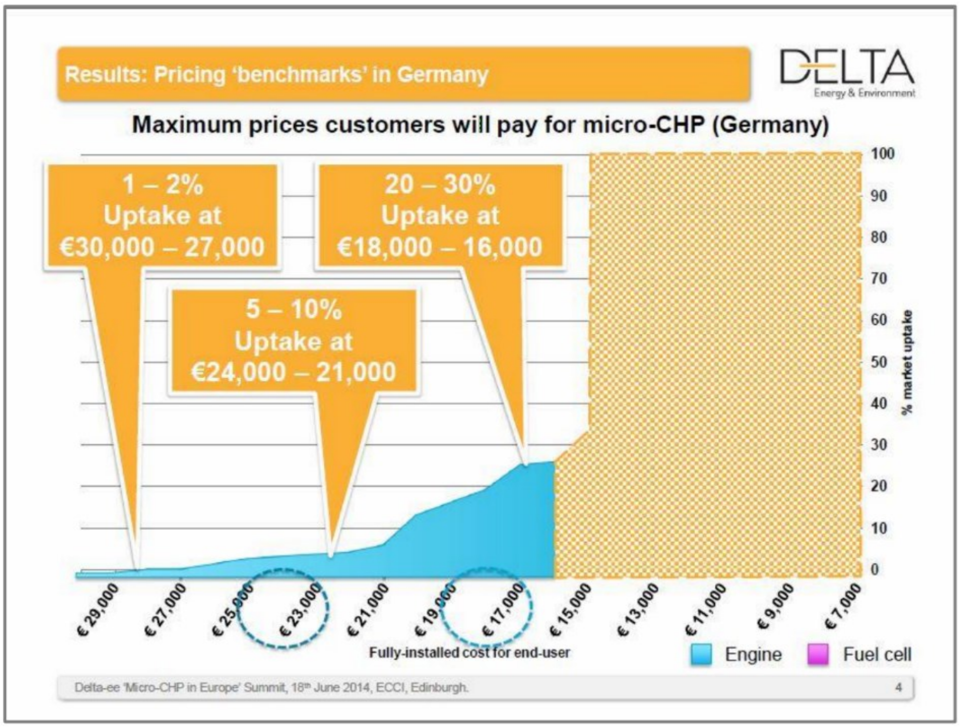


Figure 5: Maximum prices (2014) household owners are willing to pay for mCHP.
Top figure: Netherlands (n = 216) [3]. Lower figure: Germany [4].

According to [9] new units were sold at a price of €12,500 in Japan in 2016, the price is excluding installation costs.

Uncertainty

The uncertainty related to the cost projection is significant and is affected by challenges such as life time improvements, introduction of cheaper materials and improved market share resulting in economy of scale synergies.

According to Lawrence Berkeley National Laboratory (UC Berkeley) [6], the total costs for a low temperature backup power system PEM fuel cell varies with the annual production volume. The Laboratory estimates that with an annual production volume of 100 units/year a 1 kW_e system costs approximately 16,300 $€_{2015}$/kW. Assuming an annual production volume of 50,000 units per year, the total cost decreases to about 2,400 $€_{2015}$/kW. Note that the estimates are for a power producing unit only, but a CHP system fuelled on hydrogen is estimated to cost roughly the same. To these costs should be added non-manufacturing corporate costs such as general and administrative, and sales and marketing as well as installation cost. The Lawrence Berkeley National Laboratory suggests that corporate mark-up will increase the price to the costumer by 50-100 %. Adding a 75 % mark-up the price at an annual production volume of 50,000 units reaches 4,200 $€_{2015}$/kW, plus installation costs.

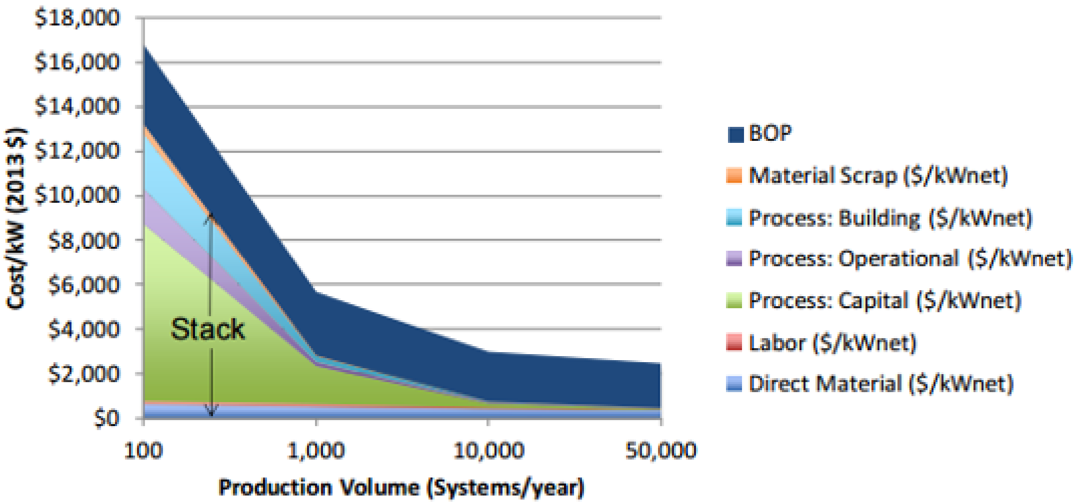


Figure 6: Total costs and cost distribution for a 1 kW_e PEM backup power system as a function of annual production volume.

Additional remarks

No additional remarks.

Data sheets

Table 57: SOFC (microCHP) – natural gas / biogas, new and existing one-family house

Technology	**LT-PEMFC (microCHP) - hydrogen**									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat generation capacity for one unit (kW)	0,78	0,70	0,70	0,70					A, B	
Electricity generation capacity for one unit (kW)	0,70	0,70	0,70	0,70					A	
Typical share of space heating demand covered by unit (%)	0,15	0,12	0,12	0,12	20	70	20	70	B	
Typical share of hot tap water demand covered by unit (%)	1	1	1	1					B	
Electric efficiency, annual average, net (%)	45	47	50	50					C	
Heat efficiency, annual average, net (%)	50	47	46	48					C, I	
Total efficiency, annual average, net (%)	94	94	96	98						
Auxiliary Electricity consumption (kWh/year)										
Technical lifetime (years)	7	10	20	20					D	
Regulation ability										
Primary regulation (% per 30 seconds)										
Secondary regulation (% per minute)										
Minimum load (% of full load)										
Warm start-up time (minutes)	2	2	2	2						
Cold start-up time (minutes)	2	2	2	2					E	
Environment										
SO2 (g per GJ fuel)	0	0	0	0						
NOX (g per GJ fuel)	0	0	0	0						
CH4 (g per GJ fuel)	0	0	0	0						
N2O (g per GJ fuel)	0	0	0	0						
Particles (g per GJ fuel)	0	0	0	0						
Financial data										
Specific investment (1000€/unit)	11,7	11	8	6	9	13	4	10	B, I	6,9,11
- hereof equipment (%)	71	64	48	50					H	
- hereof installation (%)	29	36	52	50					F	
Fixed O&M (€/unit/year)	700	700	500	400	600	1300	200	1000	D, G, J	*
Variable O&M (€/GJ)	0	0	0	0						
Technology specific data										
Shut down time (minutes)	0.1	0,1	0.1	0.1						

Notes

A A µCHP is up to 5 kWAC in power

B An additional heating device is not considered, but probably necessary for older heat demanding buildings. A combined heat storage and 15 kW electrical boiler will increase the equipment cost of 1,300 € (2015). Several 'plug & play' boilers are available, the increase in installation cost will only be marginal, Assumed 6000 full loads hours per annum for the fuel cell. Assumed that supplying hot tap water is given priority.

C A degradation rate of 3.5 µV/h has been proven in the Danish µCHP project. This indicates a technical stack lifetime of 20,000 operational hours (10% voltage decay). The degradation rate of 3.5 µV/h (corresponding to 0.5% per 1,000 h's) will result in an electrical efficiency loss of 5% over 20,000 hours. A BoL electrical efficiency of 47% has been proven by DGC in the Danish µCHP-project. An average electrical efficiency over the 20,000 h' is entered. The loss in electrical efficiency is converted to heat! A BoL heat efficiency of 47% has been measured by DGC in the Danish µCHP-project. The heat efficiency is also entered as an average lifetime efficiency (2015). (The latest IRD µCHP is 50% electrical and 41% heat efficient at BoL), please note that increased electrical efficiency is obtained on behalf of heat efficiency)

D One stack exchange is included in the O&M for 2015. The official Danish heating season is 1-oct to 30-apr (5,064 h's). The summer operation (5 month per year) includes only domestic hot water production, which typically is 2,500 kWh/year per family. The accumulated need for domestic hot water during the summer month is therefore around 1,050 kWh and will be covered by 1,050 operational hours with the µCHP. The estimate yearly operation is therefore considered to be around 6,100 h's given the SoA stack a lifetime of 3-4 years.

E Proven in the Danish µCHP-project. For the post-2015 µCHP versions a supercapacitors or batteries will be included (fast start-up as UPS-systems)

F Based on the installation cost in the Danish µCHP project

G Assuming one annual service inspection

H The decrease of equipment cost is closely linked to the production volume. The estimated price development is inspired by the learning curves from the ENE-FARM 'project cf. Fig. 17.4 [Ref. 1-2] and the results of the recent Delta-ee survey cf. Fig. 13.5 [Ref. 3-4]. The latter has concluded that over two-thirds of European homeowners would be willing to invest in µCHP, following a survey carried out in the UK, Germany and the Netherlands, but the price would have to be halved. Delta-ee furthermore concluded that householders are willing to pay a premium price for fuel cell µCHP over engine-based - but just how much of a premium varies by country (cf. Fig. 17.5)

I 2015 pries is based on today's prices observed in Japan for systems using natural gas as input. We assume a cost reduction of EUR 2000 to account for the cost of the reformer. Installation cost are estimate to be EUR 1000 (higher in demonstration projects). Estimation of uncertainties for specific investment costs based on [5].

J See section 'Uncertainty' for FC-LT PEM microCHP hydrogen.

K The heat efficiency, which can be derived, depends on the return temperature of the cooling circuit and the size of the heat exchanger.

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* An asterisk in the reference indicate high uncertainty or "guesstimate", where more certain data was not available

219 Low Temperature PEM Fuel Cell micro-CHP - methane / natural gas

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-	-	-
-	-	-

Qualitative description

Brief technology description

Methane fuel cell mCHPs use natural gas as fuel and therefore they can simply be connected to the gas grid like e.g. natural gas boilers. However, because the fuel cell needs hydrogen as input, a methane fuel cell mCHP must include a reformer (either separate component or internal reforming) which produces hydrogen from methane. The system produces electricity and heat for the household, the electrical grid is used to balance electricity production and it requires a secondary heat source, e.g. a peak load boiler and/or heat storage to balance heat production and demand. The secondary heat source might be integrated in the mCHP system.

Figure 1 show several methane fuel cells installed as mCHPs in individual households. The emissions are predominantly limited to CO_2 from the reforming process of methane to hydrogen. In addition to this, some water production takes place from the electrochemical reaction between hydrogen and oxygen (which comes from intake of atmospheric air).

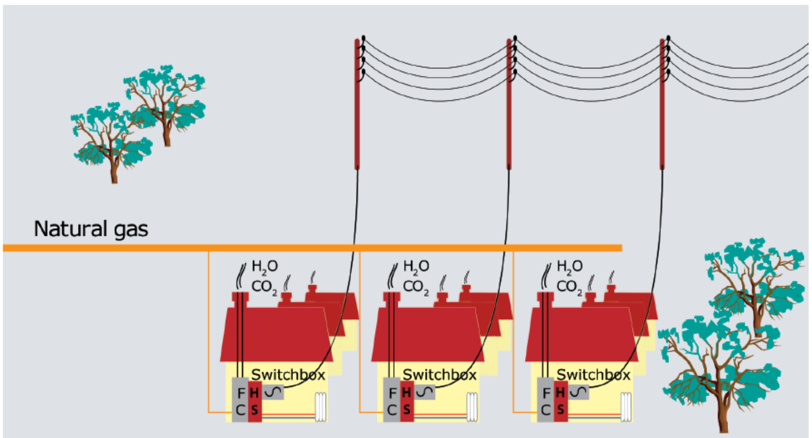

Figure 1: Several methane fuel cells installed as mCHPs in individual households.

Input
Methane

Output
Electricity and heat (for hot water and for space heating).

Typical capacities
Typical capacities for methane fuel cell mCHP units are 1.5-20 kW heat (including supplementary heater/boiler) and 0.7-2.5 kW electricity. In the data sheet a 700 W_e mCHP system from Toshiba is used as reference. The Danish company Ballard Power Systems (former Dantherm Power) is introducing a 2 kW mCHP unit with similar specifications. Increasing the power range from 0.7 kW to 2 kW increases the system cost by a factor of approximately 1.5. This will reduce the cost pr. kW by nearly a factor of 2. Electrical efficiency of the fuel cell mCHP system is expected to drop approximately 20% during its lifetime, by which the energy is converted to heat instead.

Regulation ability and other power system services
The fuel cell mCHP system can modulate, and can run in heat following mode to supply as much heat as possible or in a power following mode according to what is preferred. The electrical production follows the thermal production, unless a complete switch to secondary heat source and heat only is produced.

Advantages/disadvantages
The main advantages include:

- Producing both electricity and heat in cogeneration and with a higher electrical efficiency than for other cogeneration technologies in same power range fuelled by methane.
- Possible to supplement individual gas boilers with methane fuel cell mCHPs.
- Decentralised cogeneration of electricity and heat minimises grid losses and the need for infrastructural investments in the electricity grid.
- Methane fuelled mCHPs can be operated from the national natural gas grid even if the gas grid is converted to supply synthetic natural gas.

Disadvantages include:

- Relatively high production costs due to expensive materials (platinum).
- Lifetime of current technology needs to be improved.

Environment
The emissions from methane fuel cells are relatively low compared to electricity produced at central power plants. If methane is from fossil free sources the emission is CO_2 neutral.

Research and development perspectives
Methane fuel cell mCHP units are still under development. The development is concentrated on reducing the costs of the units, increasing the lifetime and increasing the reliability. In a later phase, the research and development activities may be concentrated on how to use the units in a smart grid context so that methane fuel cells can optimize their operation according to dynamic electricity prices.

Examples of market standard technology

- Toshiba, 700 W unit, Size (mm): W780 x D300 x H1000, Electric efficiency: 39 %
- Panasonic, 700 W unit, Size (mm): H1750 x W400 x D400 Electric efficiency: 39 % [3]

Within the EU research project ene.field (enefield.eu) up to 1,000 residential fuel cell Combined Heat and Power (mCHP) plants were installed across 11 European countries. The manufacturers involved in ene.field are Baxi Innotech, Bosch, Ballard Power Systems (former Dantherm Power), Elcore, Hexis, RBZ, SOLIDpower, Vaillant and Viessmann [7].

Prediction of performance and costs

Category 2: Pioneer phase, demonstration

The recent study by Roland Berger Strategy Consultants sponsored by EU "Advancing Europe´s Energy Systems: Stationary fuel cell in distributed generation" [1] envisions a significant growth of the European market for mCHP and expects the technology to play a significant role in the future distributed generation of heat and power.

Recent analyses within the project "Analysis for Commercialization of Hydrogen Technologies" under the Danish Energy Technology Development and Demonstration Program (EUDP)" showed that it would be very difficult for mCHP technologies to compete with other technologies for individual heating, including for example electric heat pumps. Today, the Danish hydrogen industry does not expect a significant market for mCHP technologies in Denmark.

Scenario analyses of the long term development of the Danish energy system by the Danish Energy Agency do not foresee an appreciable market and role for mCHP in a Danish context [4].

In Japan, already 150,000 mCHP units based on fuel cells are installed and running on methane [3]. The three Japanese suppliers are making inroads to the European market by allying with European manufactures and distributes of natural gas boilers. This may accelerate the European market introduction of fuel cell mCHP.

Uncertainty

The uncertainty related to the cost projection is significant and is affected by challenges such as lifetime improvements, introduction of cheaper materials and improved market share resulting in economy of scale synergies.

According to Lawrence Berkeley National Laboratory (UC Berkeley) [2], the total costs for a LT-PEMFC mCHP system varies with the annual production volume. The Laboratory estimates that with an annual production volume of 100 units/year a 1 kW_e system costs approximately 23,000 $€_{2015}$/kW. Assuming an annual production volume of 50,000 units per year, the total cost decreases to about 7,400 $€_{2015}$/kW.

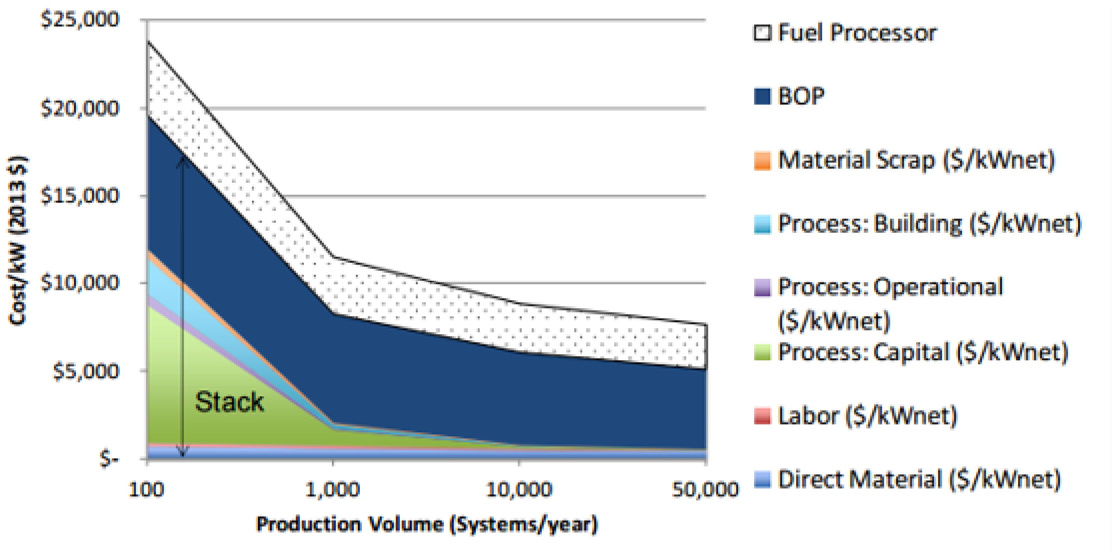

Figure 2: Total costs and cost distribution for a 1 kWe PEM CHP system as a function of annual production volume.

It should be stressed that production cost (ab factory) are often significantly lower than prices paid by consumers.

Additional remarks

No additional remarks.

Data sheets

Technology	LT-PEMFC (mCHP) - methane/natural gas									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat production capacity for one unit (kW)	1,20	1,19	1,21	1,21					A	8
Electricity generation capacity for one unit (kW)	0,70	0,70	0,70	0,70						8
Typical share of space heating demand covered by unit (%)	0,29	0,29	0,29	0,29					J	
Typical share of hot tap water demand covered by unit (%)	1	1	1	1					J	
Electric efficiency, annual average, net (%)	34,2	35,1	35,1	35,1	31	39	31	39	G	8, 13
Heat efficiency, annual average, net (%)	58,8	59,9	60,9	60,9					I	8
Total efficiency, annual average, net (%)	93	95	96	96						8
Auxiliary Electricity consumption (kWh/year)	-	-	-	-						
Technical lifetime (years)	20	20	20	20					B	8
Regulation ability										
Primary regulation (% per 30 seconds)										
Secondary regulation (% per minute)										
Minimum load (% of full load)										
Warm start-up time (minutes)	7	5	5	5					E	9
Cold start-up time (minutes)	45	40	30	30					E	9
Environment										
SO2 (g per GJ fuel)	0	0	0	0					C	11
NOX (g per GJ fuel)	2	2	2	2						11
CH4 (g per GJ fuel)	2	2	2	2						12
N2O (g per GJ fuel)	0	0	0	0						
Particles (g per GJ fuel)	0	0	0	0						11
Financial data										
Specific investment (1000€/unit)	13,7	12	9	7	10	14	5	11	D, F	2
- hereof equipment (%)	68	67	65	60					D	
- hereof installation (%)	32	33	35	40					D	
Fixed O&M (€/unit/year)	800	800	550	450	350	1000	250	800	H	10, *
Variable O&M (€/GJ)	-	-	-	-						
Technology specific data										
Shut down time (minutes)	5	5	5	5						9

Notes

A Without peak load boiler, however a (natural gas fired) condensing peek boiler is included in the cost considerations
B Stack lifetime specified for 80.000h by Toshiba
C Fuel cleaned for sulphur to avoid damage of fuel cell system
D Estimate based on price in Japan by Panasonic/Tokyo Gas 1.630.000YEN in 2016 (=€12.700). To this is added €1000 in installation cost (may be higher for the first units or demonstration projects) . The European market requires installation indoor and adoption to a different gas and power quality. The European requirements results in higher cost than in Japan. The cost reduction is estimated based on increased integration and increased volume advantages. Introduction costs in the European market can be expected to be significantly higher, approx. €20,000 by 2017.
E Up/down regulation will vary with seasonal heat load
F Estimation of uncertainties for specific investment costs based on [6].
G Uncertainties for electric efficiencies estimated from [6]. Efficiency takes into account, a 20 % drop in electrical efficiency during the life-time of the fuel-cell.
H See section 'Uncertainty' for FC-LT PEM microCHP natural gas.
I The heat efficiency, which can be derived, depends on the return temperature of the cooling circuit and the size of the heat exchanger.
J Assumed 6000 full loads hours per annum. Assumed that supplying hot tap water is given priority.

References

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[5] Dansk Energi, 2016. Brint i fremtidens energisystem. Slutrapport for analyser af brintteknologier. Del af arbejdspakke 2 og 3. Rapporten opsamler og konkluderer samlet på projektets analyser.
[6] Personal communication with Tejs Lausten Jensen, director, Brintbranchen, 17. August 2017.
[7] http://enefield.eu/category/about/ , accessed 8 Dec 2017
[8] Toshiba Japan in IEA Annex 25 presentation Oct. 2014
[9] No data available from Toshiba. Results from tests of Dantherm Power µCHP in the project "Dansk Mikrokraftvarme”
[10] Maintenance cycle 3,5 years specified from Toshiba for 2014
[11] EUR 20681 Rapport, 2003/2010 "Fuel Cells"
[12] Lowest value found in www.asue.de
[13] Technology Roadmap - Hydrogen and Fuel Cells, 2015, International Energy Agency
* An asterisk in the reference indicate high uncertainty or "guesstimate", where more certain data was not available