Technology Collaboration Programme
by iea

Technology Collaboration Program on Heat Pumping Technologies (TCP-HPT)

HPT-Annex 46
Domestic Hot Water Heat Pumps

Annex 46

Calculation models for Domestic Hot Water Systems

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Phetradico

December 2019

Report Annex 46 HPT-AN46-07

Published by Heat Pump Centre
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Production Heat Pump Centre, Borås, Sweden

Report No. HPT-AN46-07

Preface

This project was carried out within the International Energy Agency Technology Collaboration Program on Heat Pumping Technologies (HPT TCP).

The IEA

The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Program. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a Program of energy technology and R&D collaboration, currently within the framework of over 40 Implementing Agreements.

Disclaimer

The HPT TCP is part of a network of autonomous collaborative partnerships focused on a wide range of energy technologies known as Technology Collaboration Programs or TCPs. The TCPs are organized under the auspices of the International Energy Agency (IEA), but the TCPs are functionally and legally autonomous. Views, findings and publications of the HPT TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

The Technology Collaboration Program on Heat Pumping Technologies (HPT TCP)

The Technology Collaboration Program on Heat Pumping Technologies (HPT TCP) forms the legal basis for a Program of research, development, demonstration and promotion of heat pumping technologies. Signatories of the TCP, called participating countries, are either governments or organizations designated by their respective governments to conduct. The Program is governed by an Executive Committee (ExCo), which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

Annexes

The core of the TCP are the “Annexes”. Annexes are collaborative tasks conducted on a cost-sharing and/or task-sharing basis by experts from the participating countries. Annexes have specific topics and work plans and operate for a specified period, usually a number of years. The objectives range from information exchange to the development and implementation of heat pumping technologies. An Annex is in general coordinated by an expert from one country, acting as the Operating Agent (manager). This report presents the results of one Annex.

Triennial Heat Pump Conference

The IEA Heat Pump Conference is one of the three major products of the Technology Collaboration Program on Heat Pumping Technologies. The Executive Committee supervises the overall organization and its quality and selects from a tender procedure the host country to organize the Conference and establishes an International Organization Committee (IOC) to support the host country and the ExCo.

The Heat Pump Centre

The Heat Pump Centre (HPC) offers information services to support all those who can play a part in the implementation of heat pumping technologies. Activities of the HPC include the publication of the quarterly Heat Pumping Technologies Magazine and an additional newsletter three times per year, the HPT TCP website, the organization of workshops, an inquiry service and a promotion Program.
The HPC also publishes results from the Annexes under the TCP-HPT.

For further information about the Technology Collaboration Program on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:
Heat Pump Centre
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Disclaimer

The information and analysis contained within this summary document has been developed to inform policy makers. Whilst the information analysed was supplied by representatives of National Governments, a number of assumptions, simplifications and transformations have been made in order to present information that is easily understood by policy makers, and to enable comparisons with other countries. Therefore, information should only be used as a guidance.

The market is developing fast and at the moment of publication some information can already be overtaken by new developments.

In compiling, editing and writing this report I would like to thank Kashif Nawaz (Oakridge National Laboratories – USA), Cordin Arpagaus (NTB-Interstaatliche Hochschule für Technik Buchs - CH), Roberto Sunyé (CanmetÉNERGIE/CanmetENERGY – Can), the Japanese National Team under Kyioshi Saito (Waseda University – Japan) and Neil Hewitt (Ulster University – UK).

Disclaimer

The views expressed in this report do not necessarily reflect those of the individual project participants.

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1. Introduction

As new buildings become more energy efficient, CO_2 emissions from hot water preparation start to exceed those from space heating. This effect is exaggerated by the fact that because the total space heating demand is lower, the usefulness of 'losses' from the hot water system decreases. As we move towards more energy efficient houses, a similar level of detail should be applied to hot water system design as to the building envelope and ventilation systems. The way in which most current building energy models and energy standards consider hot water system losses is too simplistic for new build and deep renovation dwellings.

General available models calculate hot water consumption on the basis of the living area and a standard occupancy depending on the surface of the housing. In comparison with real life, these methods lead very often to an oversizing of the DHW production and storage. In retrofit, the simplest way is to replace the old DHW equipment with a new one having the same capacities. Thus, the DHW remains oversized and the real performance is usually lower than the theoretical one.

Calculation models can be defined in (at least) four categories:

- Specific physical calculations on detailed parts of the heat pump and the storage tank itself, designing the configuration of the heat pump, like the model developed by EDF (reference?);
- Calculation for the energy performance of a building in relation to legislative procedures, like the Standard Assessment Procedure (SAP) and Reduced Data SAP (RdSAP) models in the UK with which the EPC for the building is calculated or the Dutch EPC calculation (NEN 7120).
- Calculation for designing the optimal system, used by consultants, building constructors, architects, installers, etc. These models are often 'owned' by and developed by consulting companies and commercially available.
- Advanced complex simulation models, like TRNSYS.

These models have a number of characteristics:

- With the model it is often not possible to compare different system concepts;
- Innovative technologies and concepts are often not included in the model;
- The focal point of the model is space heating/cooling, DHW is often a secondary part of the energy system, based upon flat rate/default values, often leading to over-dimensioning of the system;
- Models for developing a system are often based upon Economical models;
- Models often don't use the chain efficiency as basis for the calculation, except those which have a relation to legislative procedures.

A number of models like RETScreen and Expert developed by NRCan use Seasonal Performance and base their calculation of weighted average performance during a specific period (mostly annual) based on certified testing data of the heat pump itself.

Climate, location and building specific components, often traditional for certain regions are the basis of these models. Thus it is difficult to make clear comparison between the available models as systems differ much. Moreover many models are thus not usable for policy makers at local level to make the right long-term choices for the support of developments in building projects for new buildings or renovation.

On the other hand, although a number of existing and new models go into depth, we do not recommend micro-component modelling of hot water use as part of this, especially for single family buildings and individual systems since it is a behavioural variable rather than one that is suited to incorporating in plumbing system design models.

2. Calculation tools for efficiency

A basis for a good choice for an energy efficient system is an objective calculation model in which different concepts of systems can be juxtaposed. In the energy market many calculation models, often on commercial basis, are available.

There are governmental communication programs available like the US 'Selecting a new water heater', which is a broad program developed by the US Department of Energy to support the customer to make the right choices. On the other hand the website by the UK Energy Saving Trust and their pages on Saving Water and the Water Energy Calculator by don't even mention DHW Heat Pumps as option.

Some of these models, although commercial, are part of the legislative process in these countries, used for getting building permits. It proves that energy is an important aspect in this and that with the decreasing demand for space heating/cooling the focus 'must' be on optimizing the models for domestic hot water.

2.1 Models for the Energy Performance

Energy models from Netherlands, France United Kingdom and United States are discussed here.

2.1.1 Netherlands

The EPC calculation is usually not made by an installation consultant or installer. The architectural characteristics of the house such as the Rc values are decisive, after which the installations are chosen to fill the 'hole'. Products with good quality declarations score high and are frequently used. The result of designing on the EPC outcome is that this architecturally skilled designer is often unaware of which installations he has ultimately chosen, and how they are valued by the resident in terms of comfort and health, ease of use, maintenance and energy consumption.

In recent years there has been a strong advance of very energy-efficient new construction, anticipating the tightening of the EPC requirements that will take effect in 2020 and are now known under the name BENG (Nearly Energy Neutral Buildings). The energy consumption for hot water used to account for 10% of the total building-related energy consumption in the distant past. This has now risen to 25% for a current new-build home, which rises to 33% and more at BENG.

EPC - Calculation models

A large number of calculation models are available for determining the energy performance of a building, part of a building or a residential area. The starting point for determining the Energy Performance in the Netherlands is the Dutch Technical Agreement 8800 (NTA 8800) which is under development.

In EPC calculations use can be made of flat-rate values. These calculation values are generally a safe assumption, to which the majority of applications present on the market meet. The Buildings Decree allows for more favourable calculation values under certain conditions. This may be done when it can be demonstrated that the product achieves a higher return at the same starting points as in the standard and under representative conditions. The developments in the construction world are not standing still. Regularly, innovative techniques and methods come on the market. These can then not simply be used in the EPC calculations, because it is not yet known which (energy) performance these new technologies deliver and how this is valued in the building regulations. The Building Decree offers the possibility to apply innovative techniques through Declaration of Quality and Declaration of Conformity statements.

Heat pumps that have been and are being used in the new building and / or within the EPA method have been rated in terms of performance at a relatively low fixed value in the applicable regulations, unless a quality or equivalence declaration from an independent organization can be used demonstrate that the performance of the relevant heat pump (s) is above the fixed value. From the Buildings Decree, the quality and equivalence declarations are checked by the 'College for Checked Equivalence Statements' (https://www.bcrg.nl/). This seems unnecessary for heat pumps, because both the quality and equivalence declarations for heat pumps have been issued by independent test laboratories accredited by the Dutch Accreditation Council.

The energy performance of the innovative devices is determined on the basis of test procedures and / or calculation procedures that are often set internationally, but also often have a national perspective imposed by additional requirements. For innovative devices or combinations, a number of calculation and test procedures have been developed over the past decade for such things as the Hybrid Heat Pump, the Booster Heat Pump and the combination of Thermal Solar Energy and the Heat Pump. Quality and equivalence statements have been drawn up for this.

Calculation methods for EPC

The calculation of the EPC must be done according to NEN 7120. Various calculation programs are available that can be used for an EPC calculation according to this standard. Suppliers of EPG software are:

- Bink
- DGMR
- De Twee Snoeken
- Uniec
- Vabi

With the EPCheck program it is easy to check whether an EPC calculation contains no major errors. This is possible for EPC calculations of residential construction, non-residential construction and combined buildings. EPCheck is intended to check calculations made according to the NEN 7120.

Domestic Hot Water in the EPC models

NEN7120 and in the future the NTA 8800 and the related commercial models are not suitable for designing a home installation, they are key instruments. And to be able to test you need standardized rules so that you can compare apples with apples.

For hot water, its use in homes is determined with a formula that depends on the area of use. No account is taken of the actual composition of households, which varies from 1 person to 6 people (large families) or more. And no account is taken of differences in behaviour such as, for example, the shower frequency and duration. Logical is then that the outcome does not correspond to the actual energy consumption. But that is also not necessary, because in order to be able to compare properties on energy performance, it is useful to start from normalized consumption. It is therefore a mystery why in the housing sector the EPC is embraced as broadly as a design tool

In the Netherlands there is also a number of additional requirements for tap water that deviate from international standards. These additional requirements have an effect on the EPC result and the choices made for the final concept. The national choices also have an effect on the test procedures for domestic hot water heat pumps.

For example, an important aspect in the assessment that the values for tap water use used in the calculation methods do not correspond to the practice. The use of 11GJ hot water in the EPC standard and 14 GJ for test procedures gives a totally wrong picture. The actual use is not yet on 9GJ and sometimes even on 6GJ. All in all, tap water use is still an unknown area; research via monitoring is necessary for more clarity.

Furthermore, the Dutch requirements for legionella impose obstacles on energetically sound solutions. The Netherlands is an island in this area: it is time to take over the 'European Technical Guidelines for the Prevention, Control and Investigation, or Infections Caused by Legionella species' from June 2017 onwards.

Calculation models for energetic / economic optimization

With the calculation of the EPC for a building no objective choice is made between different energy concepts for a building and group of buildings. These models are often used by consultants and / or suppliers / manufacturers. These models are often 'owned' by and developed by themselves.

ITHO-Daalderop has, for example, a calculation platform: https://platform.ithodaalderop.nl/

In addition, a number of models are public and an interesting overview is given by Netbeheer Nederland: https://www.netbeheernederland.nl/dossiers/rekenmodels-21 with an underlying Keuzehulp Energietransitie Rekenmodellen. Netbeheer states that: 'To achieve the goals from the Energy Agreement and to be able to overcome the consequences, new insights are needed'. The toolkit 'Energy transition calculation models' helps municipalities, housing corporations and energy cooperatives to solve their energy problems faster and more effectively by using proven models.

Calculation models and tap water

It is unclear to what extent the choices for an optimal tap water system in the energy calculation models are possible. In the context of Annex 46, a calculation model was set up under Task 2 that, as a basis, looks at the system and environmental factors in addition to an energy-efficient device. This is especially important for

A number of models and model calculations can be found to determine the use of tap water and the required generator:

- Boiler info gives very nice practical information about tap water usage and the dimensioning of storage vessels
- Warmtepomp info provides information about heat pumps and the specific component of tap water
- BINK Software provides a package with a DHW calculation according to VEWIN, ISSO 30 and 55

KWR The basis for all calculations is the use of tap water that is relatively unknown.

KWR conducted a study in 2015 into the efficiency of hot water preparation. Here the stochastic calculation model SIMDEUM® is combined with returns according to the NEN7120 to SIMDEUM-HW (Hot Water). With SIMDEUM, tap profiles can be simulated and refined on resident numbers and characteristics, such as age and gender. SIMDEUM uses statistical data. The result SIMDEUM-HW is a model that can give installers and consumers more insight into the actual expected energy consumption. It enables installers to make a well-founded choice for the type of domestic hot water preparation, and also to predict the effect of energy-saving measures on energy use. The context in which energy-saving measures, such as a WTW shower, are applied plays a role in the extent to which these measures have an effect.

Where NEN7120 comes to a fixed value, SIMDEUM shows a spread of the 10-90 percentile, ie the spread between economical and inefficient users, the 10% lowest and 10% highest consumers omitted. SIMDEUM also shows the difference between the number and type (age) of the resident. The spread is really big. The SIMDEUM-HW calculation model further uses the generation efficiencies in accordance with the NEN7120, which means that the primary energy consumption in both calculations would be equal in case of equal input (demand). In the equation it is striking that the determination with NEN7120 is calculated within the 10-90 percentile with SIMDEUM, but at the same time it also shows that there can be a factor 2 difference. When we consider that hot water accounts for 33% or more of the primary energy consumption of a modern home, a factor of 2 is of great influence and deserves much more attention than it has received so far.

Extension of the SIMDEUM® model to calculate energy-use bandwidth

We applied SIMDEUM® to six standard household situations to determine the daily primary energy demand for hot water heating under different circumstances (season, hot water temperature, use of shower heat exchangers). In a supplementary step, the model was extended to become SIMDEUM-HW (SIMDEUM Hot Water), which, together with quality declarations of different types of hot water heaters and the NEN7120 standard, establishes the system's energy efficiency, annual energy costs and annual CO2 emissions. The new model also takes account of the energy losses that occur during the transport of hot water and the subsequent cooling of the pipes.

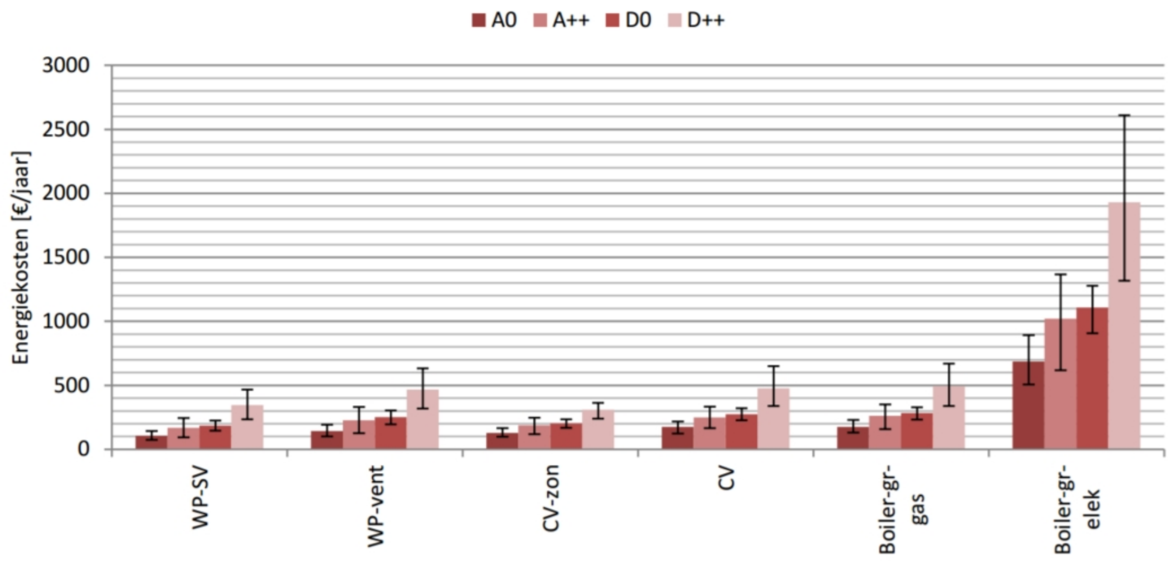


Fig. 2.1 - SIMDEUM® model outcome for different DHW technologies and different categories of DHW usage

Based on the consumption patterns from SIMDEUM®, the annual energy costs for hot water heating can be calculated for different standard household situations. A0 stands for a household with a simple drinking water installation (0) and 1-2 people (A); D++ stands for a household with a top-quality drinking water installation and 3-4 people.

On the basis of the consumption patterns from SIMDEUM®, we developed a model that shows how different types of hot water heaters (heat pumps, central-heating boilers, solar boilers) perform in terms of: (1) energy efficiency, (2) annual energy costs and (3) annual CO2 emissions. The model allows installers and consumers, for a specific household situation, to make a well-founded decision when choosing a hot water heater. It also gives them insight into the impact of energy-saving measures on energy use.

Model studies of standard household situations show that heat pumps, and the combination of a central-heating boiler with a solar boiler, produce the best performances. A shower heat exchanger usually produces an inferior performance, but because of the absolute saving involved, it does nevertheless cut energy costs. The research also indicated that the context in which the energy-saving measures are taken plays a role in the extent of their impact.

2.1.2 United Kingdom

The Standard Assessment Procedure (SAP) was developed by the Building Research Establishment (BRE) for the former Department of the Environment in 1992, as a tool to help deliver its energy efficiency policies. The SAP methodology is based on the BRE Domestic Energy Model (BREDEM), which provides a framework for calculating the energy consumption of dwellings.

SAP works by assessing how much energy a dwelling will consume, when delivering a defined level of comfort and service provision. The assessment is based on standardised assumptions for occupancy and behaviour. This enables a like-for-like comparison of dwelling performance. Related factors, such as fuel costs and emissions of carbon dioxide (CO2), can be determined from the assessment.

SAP quantifies a dwelling's performance in terms of: energy use per unit floor area, a fuel-cost-based energy efficiency rating (the SAP Rating) and emissions of CO2 (the Environmental Impact Rating). These indicators of performance are based on estimates of annual energy consumption for the provision of space heating, domestic hot water, lighting and ventilation. Other SAP outputs include estimate of appliance energy use, the potential for overheating in summer and the resultant cooling load.

RdSAP 2012 is used to produce Energy Performance Certificates for existing dwellings and applies in all parts of the UK from 8 December 2014. With the SAP and RdSAP the EPC for the building is calculated. Approved software for calculation is available:

- SAP 2012 document (October 2013, updated June 2014 and with minor corrections December 2014)
- RdSAP 2012 v9.93 (in use from 19th November 2017)
- Current list of approved SAP 2012 software
- Current list of approved RdSAP 2012 software
- Current list of approved ECO software using RdSAP 2012

Development of SAP and RdSAP will be timed to meet the demands of users. A formal review is currently underway, which is expected to be completed in 2016. In the longer term it is anticipated that further changes will be needed in line with the requirements of European legislation.

Each technique relies on different levels of input information, different calculation or simulation techniques, and provides results with different applicability. A critical review of each technique, focusing on the strengths, shortcomings and purposes, is provided along with a review of models reported in the literature.

Commercial Buildings

Simplified Building Energy Model (SBEM) is a software tool developed by BRE that provides an analysis of a building's energy consumption, especially for non-domestic buildings in support of the National Calculation Methodology (NCM), the Energy Performance of Buildings Directive (EPBD) and the Green Deal.

The tool is currently used to determine CO_2 emission rates for new buildings in compliance with Part L of the Building Regulations (England and Wales) and equivalent Regulations in Scotland, Northern Ireland, the Republic of Ireland and Jersey. It is also used to generate Energy Performance Certificates for non-domestic buildings on construction and at the point of sale or rent.

SBEM was developed by BRE for the Department for Communities and Local Government. The latest version of the SBEM tool and its accompanying user interface, iSBEM, can be downloaded free of charge from the dedicated National Calculation Methodology website. A special version – cSBEM – was created to accompany the recent consultation on the 2013 revision of Part L of the Building Regulations in England.

The BRE Domestic Energy Model (BREDEM) is a methodology for calculating the energy use and fuel requirements of dwellings based on their characteristics. It is suitable for use in research work, such as stock modelling. It shares some features with the SAP methodology, but allows users to adjust inputs which are fixed in SAP, making it better suited to certain analysis tasks. The current version is BREDEM 2012. The link below provides a document describing how to carry out a BREDEM calculation, step-by-step. Notices describing any changes or updates will be posted on this page.

The BREDEM methodology is owned by BRE, but we allow it's use freely for research and non-commercial purposes. If you wish to make use of the methodology on a commercial basis please contact us and we'll be happy to discuss.

Calculation tool for design of low temperature domestic heating systems

The Community Domestic Energy Model (CDEM) has been developed to explore potential routes to reduce carbon dioxide (CO2) emissions and the model is used to predict the CO2 emissions of the existing English housing stock. The average dwelling CO2 emissions are estimated as 5827 kgCO2 per year, of which space heating accounts for 53%, water heating for 20%, cooking for 5%, and lights and appliance for 22%. Local sensitivity analysis is undertaken for dwellings of different age and type to investigate the effect on predicted emissions of uncertainty in the model's inputs. High normalized sensitivity coefficients were calculated for parameters that affect the space heating energy use. The effects of the input uncertainties were linear and super-posable, so the impact of multiple uncertainties could be easily determined. The results show that the accumulated impact on national CO2 emissions of the underperformance of energy-efficiency measures could be very large. Quality control of the complete energy system in new and refurbished dwellings is essential if national CO2 targets are to be met. Quality control needs to prioritize detached dwellings because their emissions are both the greatest and the most sensitive to all energy-efficiency measures. The work demonstrates that the uncertainty in the predictions of stock models can be large; a failure to acknowledge this can lead to a false sense of their reliability.

2.1.3 France

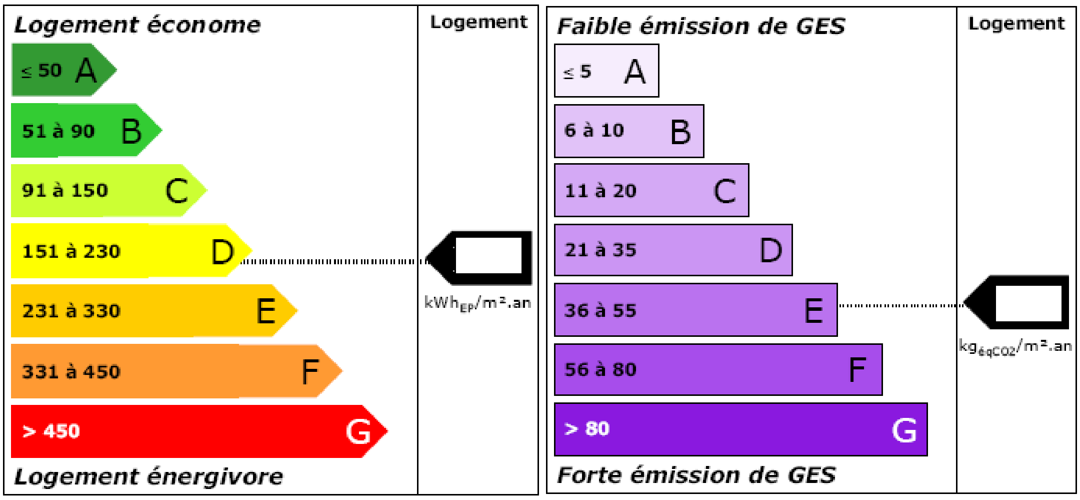
Energy Performance of Buildings Calculation

Ministère de la Transition écologique et solidaire is together with the energy agency ADEME is responsible for maintaining the energy performance of buildings through regulation and the introduction of energy labels. A large number of calculation modules have been developed for this purpose to support this policy. The Ministry gives extensive information on their website.

The energy performance diagnostic (EPD) provides information on the energy performance of a home or building, by assessing its primary energy consumption and its impact in terms of greenhouse gas emissions. It is part of the energy policy defined at European level to reduce the energy consumption of buildings and limit greenhouse gas emissions.

The content and modalities for establishing the DPE are regulated. The DPE describes the building or housing (surface, orientation, walls, windows, materials, etc.), as well as its heating, domestic hot water, cooling and ventilation equipment's. It indicates, depending on the case, either the quantity of energy actually consumed (on the basis of invoices), or the energy consumption estimated for a standardized use of the building or housing.

The Energy Performance Diagnosis (EPD) has been recognized as a device of first importance by the Grenelle Environment Forum and will be at the heart of public policies to reduce energy consumption and greenhouse gas emissions. As a result, the Ministry of Ecology has engaged a reliability plan for the entire system.



Fi. 2.2 Illustration of an Energy label (left) and a Climate label (right)

The reading of the DPE is facilitated by two labels with 7 classes from A to G (A corresponding to the best performance, G to the worst):

- the energy label to know the primary energy consumption;
- the climate label to know the amount of greenhouse gas emitted.

This system is part of a set of measures aimed at both limiting the impact of rising energy costs on the French purse and also preserving the environment. This energy label is a great progress in the information of the users: it allows in particular every French household which buys or rents a property to better measure the impact on the greenhouse effect of its energy choices and to have an evaluation of its energy bill.

The actual consumption of buildings depends very directly on the conditions of use and the actual heating temperature; the estimated consumption is not a contractual guarantee, but it allows an objective comparison of the quality of housing and buildings offered for sale or rented.

The diagnosis also includes recommendations that enable the acquirer, owner, lessor or lessee to know the most effective measures to save energy: advice on the proper use and management of the building, building and its equipment, as well as recommendations for works. This recommended work is not mandatory: the aim of the DPE is to encourage improvements in the energy performance of the building, not to force work to be carried out.

Table 2.1 - Software evaluation monitoring table incorporating the 3CL-DPE calculation method

Editor	Software	Version	Transmission of DPE to Ademe	pdf
ATLANTE DEVELOPMENT	ATLANTE XPERT	2.0	yes	
Atlibitum	Analysimmo DPE 3CL-2012	2.1.1.2	yes	
BCTI	simetric			
BBS Development	Eco-Diag	1.0	yes	
C2Partner				
Cardonnel	Bati-cube			
Diagamter	W-TAB	21	yes	

Erecie				
FAUCONNET Engineering SAS	Fisa-ECD	Fisa-DPE 2013	yes	
HPC-SA	ArchiWIZARD			
ITGA	Imm'PACT DPE module	7.0.4	yes	
Impartial Software	Diagnosis Suite	7		
Valley of the Kings	ECD-Building	0.3	yes	
LICIEL Environment	LICIEL Diagnostics	4	yes	
Software Perrenoud	DPEWin	4	yes	
OBBC Development	WINDPE		yes	
Office Expert	Expertec PRO	2.0	yes	
PAP				
Qualiconsult	QualiDPE		yes	
Tekimmo				
Deveko	Domofit DPE	1.1	yes	
Deveko	Domofit DPE	2.0	yes	

Another overview can be found on XPair and at ADEME.

Numerous software programs make it possible to evaluate the energy consumption of buildings. On a case-by-case basis, the project manager or the design office must choose the most appropriate tool.

Compulsory software evaluation is one of the main orientations of this reform which was formalized by the decree of January 27, 2012 and which requires that all the software integrating the method of calculation 3CL-DPE in its version 2012 are validated by the Minister of Ecology before they can be used, within the framework of the provisions laid down for this purpose.

This mandatory approach comes as a result of a voluntary initiative that began in 2008 and whose evaluation was favourable for the 10 software mentioned in the table below.

This new evaluation procedure, which you will find here, is mandatory for everyone, even those who have successfully passed the 2008 voluntary procedure and will start in the coming weeks. It consists of two successive stages:

- an admissibility phase allowing publishers to develop their software;
- an evaluation phase allowing publishers to obtain an opinion on the technical quality of their software.

Indicator calculations are evaluated by the different methods (conventional "existing buildings" method, conventional "new buildings" method and "invoices" method) and the respect of the methodologies for the development of ECDs.

Many of the methods calculate hot water consumption on the basis of the living area and a standard occupancy depending on the surface of the housing. In comparison with real life, these methods lead very often to an oversizing of the DHW production and storage. In retrofit, the simplest way is to replace the old DHW equipment with a new one having the same capacities. Thus, the DHW remains oversized and the real performance is usually lower than the theoretical one.

Building energy Performance Regulation for new buildings: RT2012

The **2012 buildings regulation** reinforces the requirements regarding the thermal performances of **new buildings**, starting from 2013: they may not consume more than **50 kWh of primary energy per square meter** for space and water heating, space cooling, ventilation and lighting. This reference value depends on climate zone, altitude, type of use of the building and the average area of housing. This is a significant tightening compared with previous legislation, which modulated the energy consumption allowance by type of heating system. This new regulation has strong impact on insulation requirements and guides strongly the space heating modes. In particular, the reference to primary energy without any consideration for CO_2 emission levels leads to promote indirectly gas heating systems at the expense of electrical solutions (for which a conversion coefficient final/primary energy of 2.58 is applied). This aspect is partly offset by another rule included in this thermal regulation: among the energy consumed in a new built house, 5 kWh/m^2.yr have to come from renewables.

In the framework on this regulation, it is needed to calculate, for each new building project, the forecasted annual energy consumption for the 5 uses described above. A calculation model called "moteur RT" is used for that. This model integrates algorithms to calculate consumption impact of commun heating, cooling, ventilation, DHW production systems.

For DHW performance calculation: heat pump water heaters performance data according to EN 16147 (which is also the European standard to become harmonised for ErP regulations) is required. From this performance data, a simulation tool is used to identify the 3 values for: COP and power input at standard heat source temperature, heat loss coefficient from the storage tank (UA).

In the building regulation computation tool, the last value is used in the description of the storage tank with its volume.

Heat pump water heaters performance (COP and power input) is described by a matrix according to the heat source and sink temperature ranges. The calculated COP and power input are corresponding to the "centre" of the matrix; all other values for other temperatures being calculated using conventional correction factors.

In the computation tool, a load profile according to the size and use of the building is defined and the annual energy consumption for DHW preparation is calculated on an hourly basis using this load profile.

Building energy Performance Regulation for existing buildings: RT existent

The **building regulation for retrofitted buildings** is based on minimal performance requirements for installed or replaced equipment. It deals with equipment of insulation, space heating/cooling and hot water production. This is called the "element by element" building regulation. No computation tool is needed for this regulation.

On the opposite, for major refurbishment[1] of residential buildings of more than 1000 m2, the regulation imposes a maximum value of yearly energy consumption for heating, cooling and domestic hot water, from 80 kWh/m2.an to 165 kWh/m2.an, depending on the climate and the type of installations. This last regulation is based on the same computation tool than the RT2012.

2.1.4 United States

The most widely used building energy model in the US is EnergyPlus™ (E+). Its development and distribution are supported by the US DOE Building Technologies Office (BTO).

EnergyPlus™ is DOE's open-source whole-building energy modelling (BEM) engine, the successor to DOE-2.1E. Under development since 1997, EnergyPlus embodies the state-of-the-art in BEM knowledge in a comprehensive

[1] The cost of works is higher than 25% of the value of the building.

and robust engine that is continuously maintained, thoroughly documented and fully supported. BTO releases two annual updates to EnergyPlus.

EnergyPlus implements detailed building physics for air, moisture, and heat transfer including treating radiative and convective heat-transfer separately to support modelling of radiant systems and calculation of thermal comfort metrics; calculates lighting, shading, and visual comfort metrics; supports flexible component-level configuration of HVAC, plant, and refrigeration systems; includes a large set of HVAC and plant component models; simulates sub-hourly timesteps to handle fast system dynamics and control strategies; and has a programmable external interface for modelling control sequences and interfacing with other analyses. EnergyPlus is tested according to ASHRAE Standard 140 methodology, which is currently being extended with measured data from well-characterized, highly instrumented test facilities.

Historically focused on commercial buildings, EnergyPlus has been expanded with modeling capabilities relevant to residential buildings and data centers. Residential enhancements include an improved ground heat transfer model, an improved infiltration model, models for residential equipment like integrated water-heating/air-conditioning heat-pumps (IHP), and a new model for duct heat loss. Other recent additions include new physics-based models for variable refrigerant flow (VRF) air conditioning systems, expanded modeling of dedicated outdoor air systems (DOAS), and support for HVAC fault modeling and urban-scale modeling.

EnergyPlus supports a variety of used cases including integrated design of new buildings and retrofits, design guide development, development of and compliance with energy-efficiency codes like ASHRAE 90.1, asset ratings like DOE’s Commercial Energy Asset Score, green certificates like USGBC’s LEED, performance documentation for financial incentives from utilities and governments, and dynamic applications like automated fault-detection and diagnostics (AFDD) and model-predictive control (MPC). Arguably, the use case that contributes most directly to energy efficiency is integrated design. DOE tracks the use of EnergyPlus in integrated design via the American Institute of Architects (AIA) 2030 Commitment. The open source software can be downloaded from www.energyplus.net

EnergyPlus™ is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for heating, cooling, ventilation, lighting and plug and process loads—and water use in buildings. Among the users are ASHRAE’s committees responsible for development/maintenance of the ASHRAE building energy efficiency standards (90.1 and 90.2) and green building standard (189.1). They use E+ to evaluate improvements in building energy efficiency for each new release of these standards. Dr. Amir Roth is the BTO building energy modeling leader.

Another modeling tool used in the US is BEopt™ (Building Energy Optimization Tool). This software provides capabilities to evaluate residential building designs and identify cost-optimal efficiency packages at various levels of whole-house energy savings along the path to zero net energy. BEopt™ was developed by the National Renewable Energy Laboratory in support of the DOE Building America program (Bringing Building Innovations to Market) goal to develop market-ready energy solutions for new and existing homes. The BEopt™ (Building Energy Optimization Tool) software provides capabilities to evaluate residential building designs and identify cost-optimal efficiency packages at various levels of whole-house energy savings along the path to zero net energy.

BEopt can be used to analyze both new construction and existing home retrofits, as well as single-family detached and multi-family buildings, through evaluation of single building designs, parametric sweeps, and cost-based optimizations.

BEopt provides detailed simulation-based analysis based on specific house characteristics, such as size, architecture, occupancy, vintage, location, and utility rates. Discrete envelope and equipment options, reflecting realistic construction materials and practices, are evaluated.

BEopt uses EnergyPlus, the Department of Energy's flagship simulation engine. Simulation assumptions are based on the Building America Housing Simulation Protocols.

The sequential search optimization technique used by BEopt:

- Finds minimum-cost building designs at different target energy-savings levels
- Identifies multiple near-optimal designs along the path, allowing for equivalent solutions based on builder or contractor preference

BEopt has been developed by the National Renewable Energy Laboratory in support of the U. S. Department of Energy Building America program goal to develop market-ready energy solutions for new and existing homes.

DOE-2 and eQUEST are building energy use and cost analysis software. DOE-2 software (latest version is DOE-2.2) software was developed by James J. Hirsch & Associates in collaboration with Lawrence Berkeley National Lab (LBNL). **eQUEST**® is a freeware building energy use analysis tool. It was designed to perform detailed comparative analysis of building designs and technologies by applying building energy use simulation techniques but without requiring extensive experience in the "art" of building performance modeling. This is accomplished by combining schematic and design development building creation wizards, an energy efficiency measure (EEM) wizard and a graphical results display module with a complete up-to-date DOE-2 (version 2.2) building energy use simulation program. The eQUEST Overview to get a more complete summary of the features and capabilities of the program. These are private sector software tools (not sponsored or endorsed by either the US DOE or LBNL).

Other US Calculation models are:

- DOE-2 is a widely used and accepted freeware building energy analysis program that can predict the energy use and cost for all types of buildings. DOE-2 uses a description of the building layout, constructions, operating schedules, conditioning systems (lighting, HVAC, etc.) and utility rates provided by the user, along with weather data, to perform an hourly simulation of the building and to estimate utility bills.
- The Life-Cycle Costing (LCC) analysis method is recognized to reliably identify cost optimal building design solutions yet it is not widely used with confidence. The National Institute of Standards and Technology (NIST) and ANSI have suggested standardized LCC nomenclature and conventions so that the entire buildings industry can speak one "language" when performing LCC analysis. NIST's LCC procedures are embodied in the Building

The TRNSYS (http://www.trnsys.com/) software is also used somewhat in the US for simulating the behavior of buildings and building systems. It must be ordered through the web site.

Directly focusing on the end user is the US Department of Energy website Selecting a new water heater developed to support the customer to make the right choices.

3. System Efficiency

3.1 Introduction

Objective comparison of systems from a policy point of view has to be based upon the chain efficiency where the overall efficiencies for the complete chain from primary (fossil) energy to the end user are compared and the weakest links in the chain are analyzed. The following aspects for hot water production then have to be taken into account:

- Energy transition from primary energy into heat, i.e. gas/oil/wood/coal etc into heat or 'indirect' by electricity into heat with the electricity generation efficiency (including fossil and renewable generated power)
- Energy losses during starting and stopping of the heat production at the level of the end user
- Energy losses in energy storage, i.e. the hot water storage tank
- Transport and distribution losses in collective as well as individual systems
- Energy use of auxiliary/utility equipment (fans and pumps)
- Auxiliary heating (solar system and collective systems)

These aspects of the chain efficiency are of importance at the macro level of policy decisions. Two levels lower is the micro level of decision for the end user. It is important to mention that when the time comes to replace the existing installation, the end user often bases his decision on the initial cost of the DHW generator, the energy efficiency being often overlooked. Between those levels is the installer, consultant, designer of the hot water heating system, whereas housing corporations and house rental companies can belong to this group.

For these three categories system efficiency can be explained differently.

3.2 SEPEMO Definition of Performance

For heat pumps the efficiencies are related to the SEPEMO structure – this structure is described first. Annex 46 focusses on DHW-application, so we excluded space heating from the standard SEPEMO-structure.

Basically the Energy Performance of the domestic hot water generator, the COP of the heat pump for DHW HPs, is the starting point of any calculation and thus of every decision. Under the European SEPEMO project[2] the definition of COP for heat pumps in buildings has been broadened to four levels of performance definition, being:

- SPF1 - contains only the heat pump unit. It evaluates the performance of the refrigeration cycle and allows a calculation of the SPF of the heat pump without the auxiliary drives to show the efficiency of the refrigerant cycle
- SPF2 - contains the heat pump unit and the equipment needed to make use of the source energy available for the heat pump. This level of system boundary responds to the European RES-Directive[3] requirements for calculating the used renewable energy by the heat pump. SPFH2 allows the calculation of the SPF including auxiliary drives for the heat source, but without back-up heater
- SPF3 - contains the heat pump unit, the equipment to make the source energy available and the backup heater. It represents the heat pump system and thereby can be used to compare heat pump systems with conventional heating systems e.g. oil or gas fired systems.

[2] SEPEMO project: http://sepemo.ehpa.org/

[3] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

- SPF4 - allows a calculation of the SPF with the total produced thermal energy divided by the total energy consumption. This system boundary contains the heat pump unit, the equipment to make the source energy available, the backup heater and all auxiliary drives including the auxiliary of the heat sink system. SPFH4 represents the heat pump heating system including all auxiliary drives which are installed in the heating system.

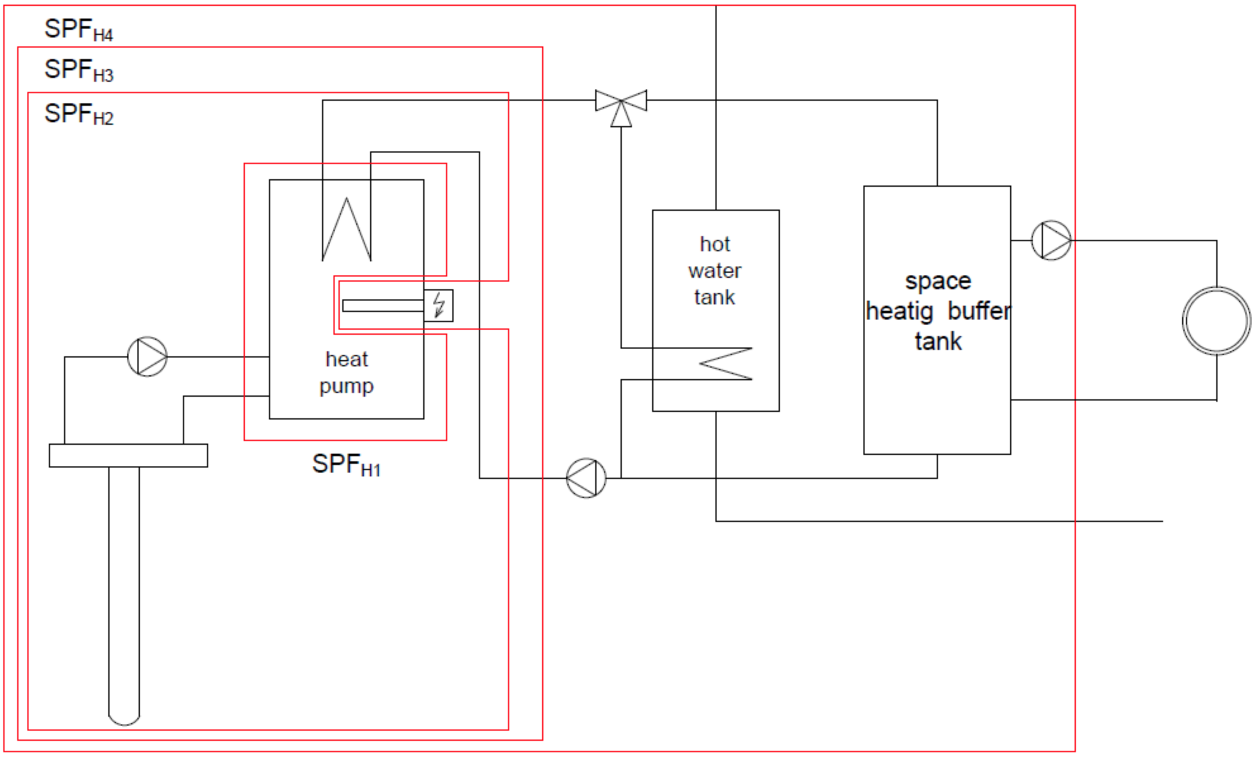


Fig 3.1 – SEPEMO definition of Seasonal Performance [

This definition of SPF has been taken over by the European Commission in the European Commission Decision 2013/114/EU from March 2013[4] (establishing the guidelines for Member States on calculating renewable energy from heat pumps from different heat pump technologies pursuant to Article 5 of Directive 2009/28/EC of the European Parliament and of the Council) [08].

This SEPEMO definition describes the overall performance of a heating system taking into account a number of energy losses in the system. In fact it does not describe the definition of a domestic hot water heat pump and the various systems of hot water heating with heat pumps, like solar assisted heat pumps, booster heat pumps and fresh water systems, nor gas driven systems.

Focusing on stand-alone domestic hot water heat pumps the SPF definition becomes different.

- SPF1 - contains only the heat pump unit. It evaluates the performance of the refrigeration cycle and allows a calculation of the SPF of the heat pump without the auxiliary drives to show the efficiency of the refrigerant cycle

[4] In cases where several climate conditions are existing within the same Member State, the Member States should estimate the installed capacity of heat pumps in the respective climate condition area

- SPF2 - contains the heat pump unit, the storage tank and the equipment needed to make use of the source energy available for the heat pump. Including the storage tank mean that the specific technology and following aspects are taken into account
    - Cold water temperatures supplied to storage tank of the DHW HP and the hot water temperature setting, often as a consequence of legionella legislation, defining the energy needed to heat the tank and the condenser temperatures for the heat pump, i.e. ΔT and thus the bare COP.
    - Heat transfer system, especially the condenser in relation to the storage tank, wrap around, internal spiral or auxiliary plate heat exchanger.
    - Heat losses of the storage tank;
    - Control strategy of the stored hot water and the characteristics of the thermostat (ΔT in the on/off control).

  In this part the source can be:

    - Outside air source, which is very dependent on the climatic conditions
    - Inside air source, which ventilation air and has an effect on the overall energy usage for space heating
    - Low temperature heat distribution from a waste heat source or from another generator like a collective heat pump for space heating (this is for a booster type of heat pump – see Addendum 2)
    - Solar thermal, which is fluctuating source dependent on incoming sunshine (this is for a solar supported heat pump – see addendum 2)

  In all cases auxiliary drives for the heat source are needed which is included in the SPF2.

- SPF3 - contains the heat pump unit, the equipment to make the source energy available and the storage tank including any auxiliary heating, such as an electric resistance heater or an additional thermal solar heat exchanger. This represents the overall domestic hot water heat pump and can as such be used to compare with other domestic hot water generators, such as electric storage water heaters, gas fired storage water heaters, solar water heaters etc..

- SPF4 - allows a calculation of the SPF of the overall system including in house distribution losses and taking into account the effects on the overall space heating system. This SPF4 is discussed in the Task 2 report as it contributes to the calculation of the overall energy performance of the building.

3.3 Chain Efficiency

To be able to compare the different generating technologies with different energy sources, it is of importance to look at the chain efficiency from primary energy to the energy content delivered in the hot water at the tapping point.

The calculation of the chain efficiency is based upon, starting at the demand:

A. Net demand at the taps with the end-user
B. DHW-Input in the piping system of the individual dwellings (terraced house/apartment)
C. Energy-input at the dwelling or at a collective generator of DHW
    1. Individual generation
    2. Collective generation
D. Primary Energy needed to provide the energy input at the dwelling or collective generating system.

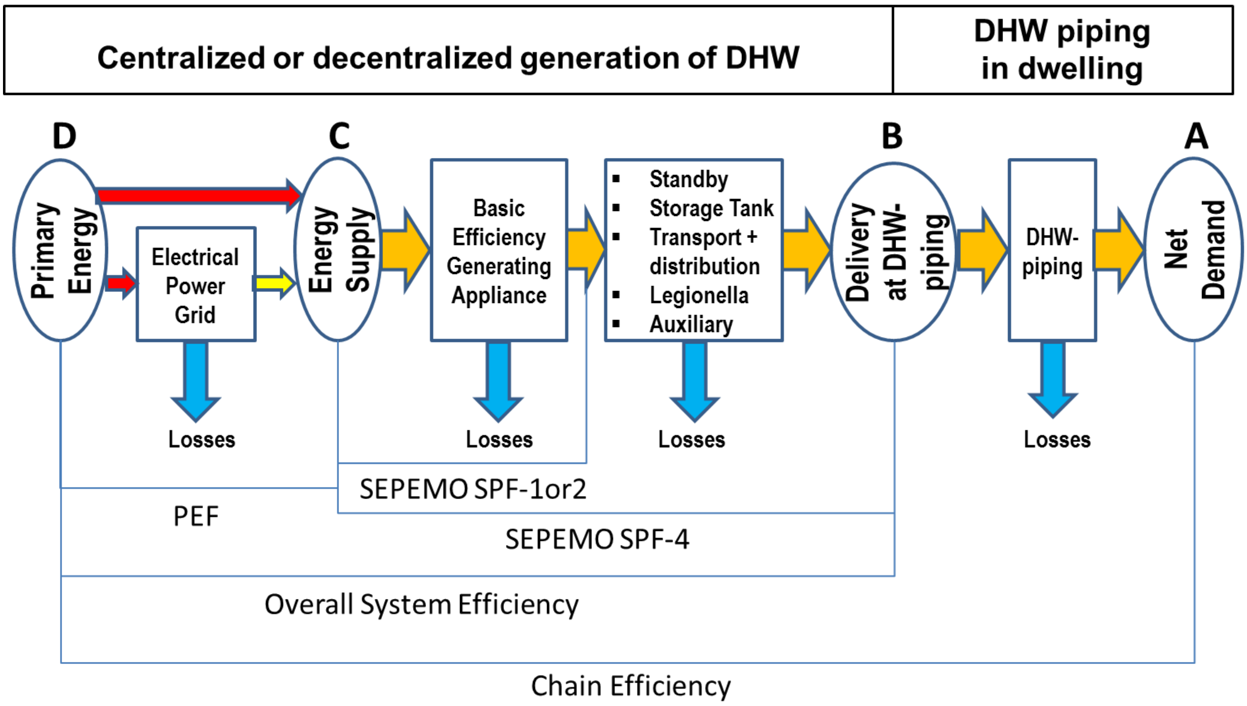


Fig 3.2 - Chain Efficiency [25]

The occurring losses between A and B and between B and C will be discussed in the next paragraphs.

3.4 In House losses

In house losses are strongly related to the distance between the DHW-generating device (and storage vessel) and the location of the taps in the house (bathroom and kitchen).

There are two types of energy losses for in house piping:

- Draw off losses between generator and tap point typically in single family houses
- Distribution losses in collective systems

These two types distribution losses are different and have different solutions. The best practice standard is that the hot water supply pipe-work is insulated throughout its length.

3.4.1 Individual systems in single family houses

In single family houses the location of the generator in relation to the storage tank and the location of the storage tank to the tapping points. The kitchen tap is generally supposed to be the most susceptible to draw off losses since typically it is used for short bursts of hot water, compared to the bath tap where a long draw off is more common and an initial cold flow can still be utilized'.

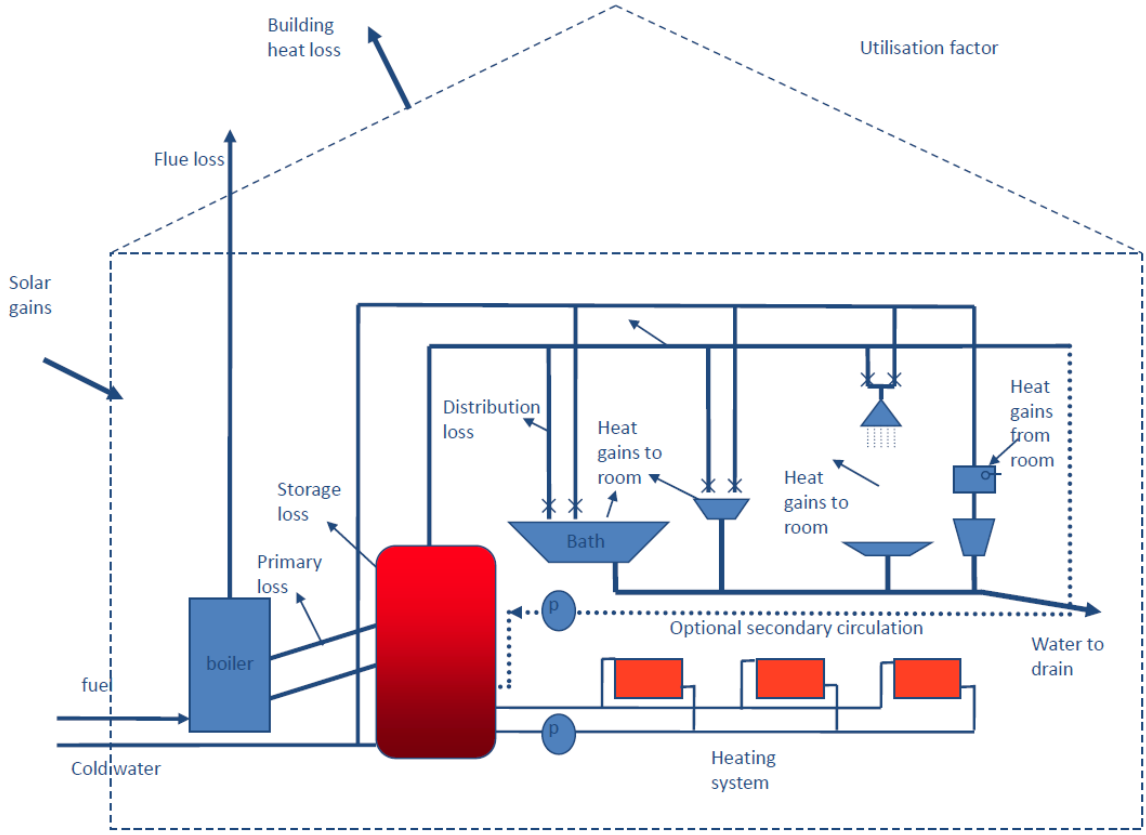
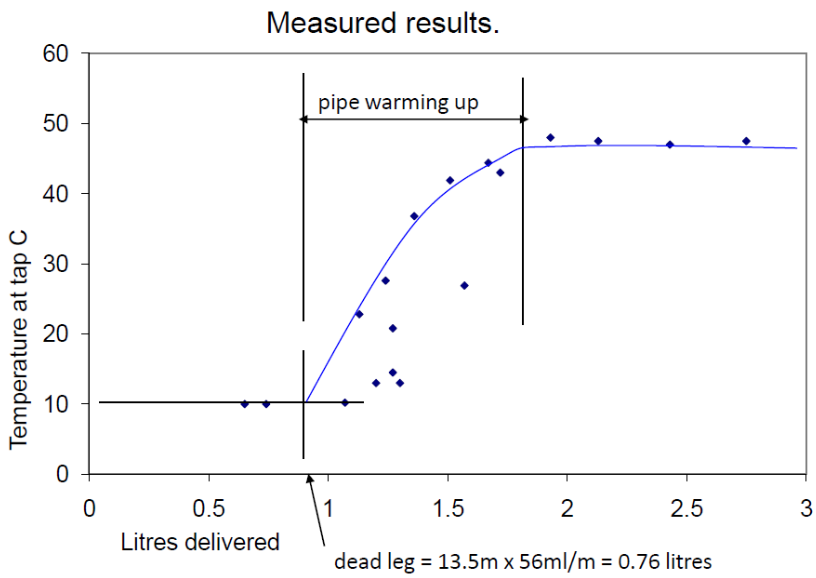


Fig 3.3 Overview of in house distribution system and its losses [37]

Example (from the authors private house): In the case of a high efficiency gas boiler installed in the attic at the top of the house 5 liters of water is tapped of before the hot water reaches the required maximum temperature at the kitchen tap based at the first floor. Then 5 – 7 liters is used and the tap is closed and the hot water says in the pipe. This contributes a bit to the space heating in wintertime but can most of the year be counted as heat loss. This is nicely illustrated in fig 3.3.



- Draw-off lag, especially occurring with instantaneous water heaters like gas boilers and electric resistance heaters where the generator has to heat up from cold to the level of hot water temperature
- Waste of water while waiting for hot
- Hot water left in pipe cools down, which occurs after
- Depends on volume = length x area

Fig 3.4 - Water losses related to the length of the in house piping - typical for small tubes (approx.. 10 mm copper tube or ¼” threaded steel tube).

The losses in a typical Dutch terraced house vary from 2 to 4,5 GJ (550-1250 kWh-th) per year. These losses are based on the assumption that the hot water in the pipe has cooled so far, that it cannot be used for the intended purpose of the next tapping.

The heat lost from the unit itself and its in-feed pipework during post-shower cool down is lost within the heated space of the dwelling. This will be of some use during the heating season by contributing to internal gains. At present this benefit is ignored on the basis that it is insignificant. However, this is technically incorrect, especially in low energy houses, energy zero houses or Passivhaus

Install the generator or water storage tank as close to the tap with numerous small amounts of water use. In the kitchen, where a lot of small amounts of water are used during the day, the impact of the length of the water piping there is the greatest. Compared with generator located in the attic (and a kitchen on the ground floor) approximately 3.5GJ (net) may be saved (at 9GJ net DHW requirement). For newly built houses with a low demand for space heating it is the challenge for the architect and building constructor to realize this option. All newly built homes are designed from the drawing board. It is sensible to take into account the distance between the source(s) of hot water and the taps at this stage already. This allows the user of the house the saving of a lot of energy (and cost) during the operating life of the house.

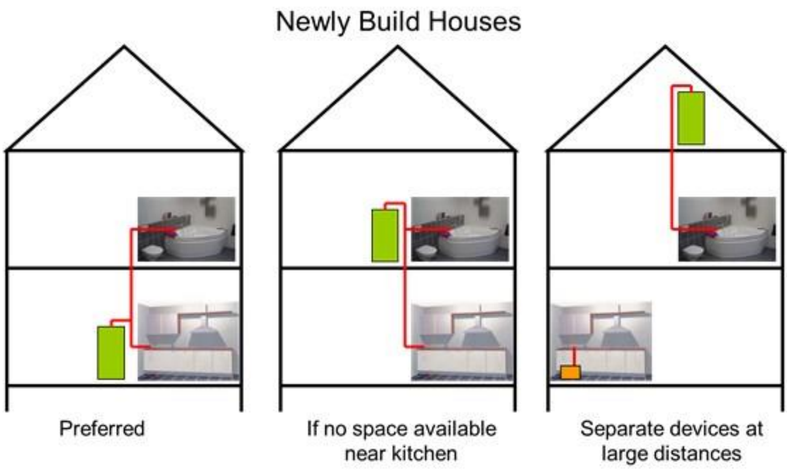


Fig 3.5 – Typical configuration in a Dutch house [25]

Ideally the hot water storage cylinder should be sited to minimise “dead leg” distances especially to the point of most frequent use. The UK Water Energy Model (WEM), used for SAP calculations [15], indicates that optimised hot water system design in new houses (primary pipe work, boiler location, controls, cylinder sizing, insulation and hot water distribution) could provide significant CO_2 emission reduction, as well as water and cost savings. The model also indicates how commonly applied bad practice (e.g. long primary pipes, poorly insulated secondary circulation and long un-insulated dead legs) can lead to very significant losses. Whilst future research could quantify the impacts of regulatory improvements in this area, many of these measures result in cost effective savings and better performance and so should be implemented anyway.

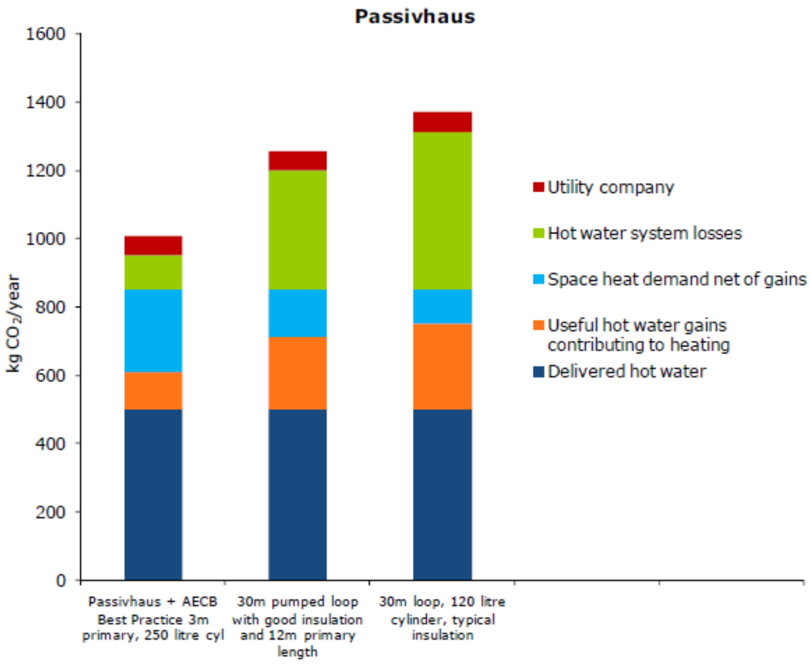


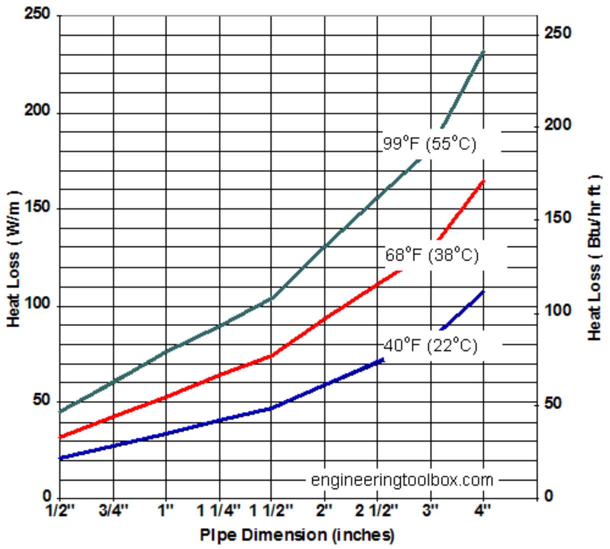
Fig 3.6 - Three different approaches to plumbing system design in a very well insulated house. A short primary loop is the most efficient configuration [15].

3.4.2 Collective systems in Multi Family Buildings

In collective concepts the largest energy loss is in the transport and distribution of the heat (DHW is produced inside the dwelling with a plate heat exchanger). The low efficiency of DHW systems is well known by field practitioners. Experts complain about the lack of research to quantify time, water, and energy waste of different DHW systems. Most disturbing of all is that hot water delivery times and water waste have been getting steadily worse with newer buildings. The sources of inefficiency can be found in every one of the diverse phases entailed by DHW systems: from the design of the piping structure and the sizing of equipment to the selection of the applied control strategies. Nowadays, such designs usually trust in generic, vague constants and assumptions published in official directives and recommendations. The usual result is oversized, low-efficient installations [21].

Collective DHW is usually integrated within the central heating system of the building, using the same furnace room to provide all thermal services. Thus water is heated by general boilers and later distributed to the consumption points by means of a dedicated network of pipes.

A straightforward calculation of the heat losses between the generator and the end user can be done assuming a steady state circulation pattern of a two pipe or four pipe distribution system.



Example - Required Circulation Volume in a Hot Water Return Pipe Line: The length of a pipeline inclusive the circulation line is 100 m. With water at temperature 50°C the average specific heat loss from the pipe line is estimated to 30 W/m. The total heat loss from the whole pipe line can be calculated as q = (100 m) (30 W/m) = 3000 W. Required water flow to limit the temperature drop to 10°C can be calculated as: Q = (3000 W) / ((988 kg/m3) (4182 J/kg°C) (10 °C)) = 7.2 10^{-5} m3/s = (7.2 10^{-5} m3/s) (1000 liter/m^3) = 0.072 liter/s

Fig 3.7 Heat losses vs pipe dimensions (Source: Engineering Toolbox)

Nominal bore		Heat loss for the fluid inside pipe (W/m)			Heat loss for the fluid inside pipe (Btu/hr ft)		
		Temperature difference (°C)			Temperature difference (°F)		
(mm)	*(inches)*	22	38	55	40	68	99
15	1/2	21	32	45	22	34	47
22	3/4	28	43	60	29	45	64
28	1	34	53	76	36	56	79
35	1 1/4	41	64	89	43	67	93
42	1 1/2	47	74	104	49	77	108
54	2	59	93	131	62	97	136
67	2 1/2	71	111	156	74	116	162
76	3	83	129	181	87	135	189
108	4	107	165	232	111	172	241

Nominal bore		Heat Loss	
(mm)	*(inches)*	*(W/m)*	*(Btu/hr ft)*
22	3/4	8	8
28	1	10	10
42	1 1/2	11.5	12
54	2	14.5	15
67	2 1/2	16	17
76	3	19	20

Table 3.2 heat loss from insulated copper pipes or tubes to surrounding air.

The heat loss is based on a temperature difference of 55°C (99°F) with insulation thickness 25 mm (1 inch) and conductivity coefficient k = 0.043 W/m°C (0.3 Btu in/ft hr°F).

However simple this calculation this losses can be reduced by 'simple' design alternatives an adequate control mechanism. Thus the losses calculated in this manner can be considered as maximum losses.

The design of the system for Multi Family Buildings have been extensively studied by Bernhard Vetsch et. al [01] and Jukka Yrjölä et.al. [10]. In practice alternatives from the two/four pipe systems occur

In general, one creates with a circulation system additional heat losses due to the doubling of the line lengths (return to the store) and the constant flow with domestic hot water. In addition, a pump circulates the circulation circuit, which means a direct electrical energy reference. In addition, a domestic hot water system with a heat pump as an energy producer reacts particularly sensitive to the circulation. This is justified by three points. On the one hand, the circulation return has a strong influence on the stratification of the domestic hot water tank. If the stratification is disturbed, the coefficient of performance of the heat pump is reduced by the increased return temperature in the condenser. In addition, as a result of the mixing, the temperatures in the storage decreases rapidly, which causes more frequent recharge. Thirdly, the domestic hot water temperature must be adapted to the "least favorable" recipient. The rule of thumb from Hubacher et al. (2009) attests a reduction of the annual work rate (SCOP) by up to 2.5% per Kelvin temperature increase.

Yrjölä describes different GSHP arrangements and compares computationally. A two-stage heat pump arrangement is introduced in which water tanks of the heating system are utilized for warming up the DHW in two stages. It is shown that the electricity consumption with this two-stage system is approximately 31% less than with the single-stage heat pump and 12% less than with the cascade system. Further, both low temperature (LT) and HT heat pumps can run alone, which is not common in cascade or other two-stage heat pumps. This is advantageous because the high loads of the space heating and DHW production are not simultaneous. Proper insulation of the DHW and recirculation pipe network is essential when aiming for a high efficiency.

A study by the City of Vienna [11] clearly concludes that in terms of the sum of all losses, decentralized solutions (hot water is produced where it is needed) are the best choice. However collective systems have their advantages mainly because these systems can be optimized and controlled centrally.

Depending on how DHW is produced, there are on-demand systems and storage systems. The design of on-demand systems is conditioned by the moment of maximum demand, requiring heaters capable to work at higher power rates than average. To reduce such high power levels and obtain more homogeneous performances, storage systems use tanks to accumulate hot water and flatten the power demand. Both instantaneous and storage systems are common nowadays. Demand systems are usually more energy efficient as they eliminate standby heat losses from the tank, but the energy differences tend to be reduced in scenarios where the demand of DHW is high and frequent [21]. Demand recirculation systems point to be the ideal, optimal solution. Profile-based control becomes a fair evolution with regard to the introduced strategies. It manages the operation of heating and recirculation systems by means of predictive algorithms. Therefore, controllers deploy DHW habit patterns to obtain context awareness and forecasting capabilities.

An excellent example of such a demand pattern control can be found in the project of DUWO student accommodation in Leiden, Netherlands. This is a renovation of the sanitary hot water supply in a student home

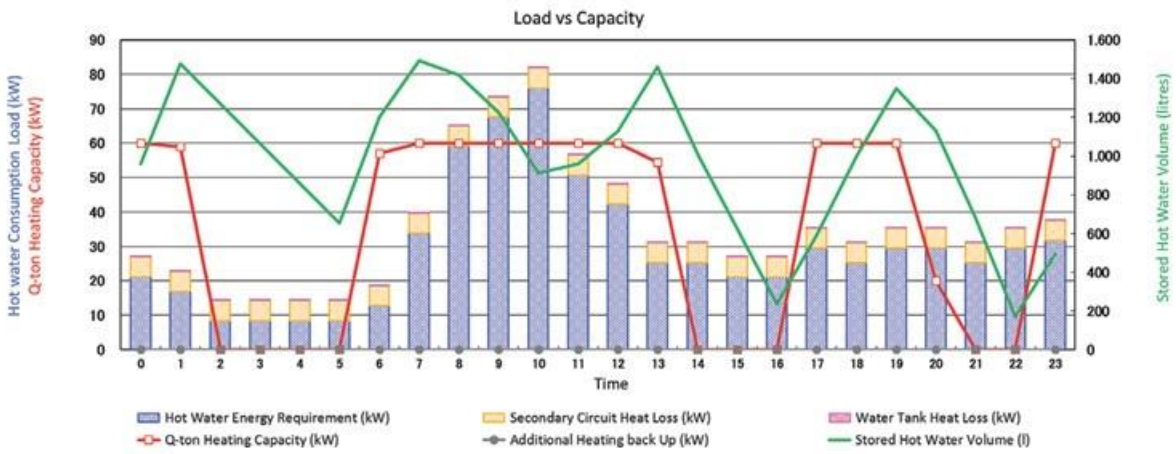


Fig 3.8 – Hot water use in DUWO Student house in Leiden (Annex 46 Example project)

Another example for a Multi Family Building shows clearly that the hot water usage per end user can vary over a broad spectrum

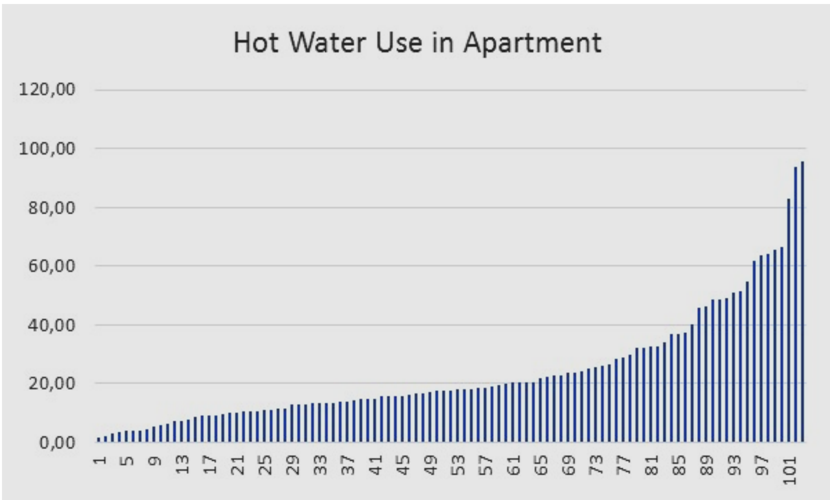


Fig 3.9 Energy usage in 100 apartments (Annex 46 Example project)

In managing a collective system for an apartment building the capacities of heat supply for DHW can be controlled based upon the demand. Thus the heat losses in the circulation system can be decreased significantly.

Félix Iglesias et. al [21] conclude that the review of the DHW use database discloses that, as a general rule, hot water demand of single flats is mostly located during daytime and distributed in very short periods. Limiting to the location of the available data, official simultaneity coefficients seem to be oversized and require better calculations more realistic and tailored to the specific region. Note that the performance detriment of oversized systems is actually strong. Hence profiling techniques are useful for control but also for design phases. The spread collection of building profiles would allow to optimize the design of pipe structures and equipment, but also other smart home and building services.

3.5 Energy supply to generator

3.5.1 Efficiency related to the HP source

Air source is the main source for the DHW HP occurring in the market as stand-alone heat pump for hot water production. With the generation of hot water more and more combined with space heating other sources are found. Six types of sources are distinguished – with main characteristics:

- Outside air
  - In cold climates low fluctuating supply temperature
  - In cold climates auxiliary energy may be needed
  - Outside fan noise
- Ventilation exhaust air
  - High temperature source (at indoor room temperature of approx. 20 °C)
  - Effect on load for space heating/cooling
- Low Temperature Solar Thermal (water or air cooled collectors/PV-panels)
  - High source temperature possible
  - Possibility of reducing auxiliary energy by use of natural convection
- LT- Distribution: Either collective source in a MFB of LT District Heating
  - Stable and high source temperature (20 - 40°C supply)
  - Collective source systems only
- Brine (GSHX: Ground Source Heat Exchanger)
  - Stable source temperature
  - Individual systems and collective systems
  - Passive cooling option
  - No maintenace
- ATES: Aquifer Thermal Energy Storage
  - Stable source temperature
  - Collective source systems only for individual houses or apartments
  - Need of regeneration of the source
  - Substantial cooling demand needed / obligatory source regeneration
  - Need of large surface area
  - Need for an Energy Service Company (i.e. high costs)
  - High service costs

In the table below the source's characteristics are qualified.

	New	Existing
Single Family Houses	Air	Air
	LT Distribution	LT Distribution
	District Heating	District Heating
	GS Hex	GS Hex
	ATES	ATES
Multi Family Building	Air	Air
	LT Distribution	LT Distribution
	District Heating	District Heating
	GS Hex	GS Hex
	ATES	ATES

Fig 3.10 In the schedule on the left the possible application of these sources is shown in each of the situations the Heat Pump Water Heaters can be applied.

- Green: preferable source
- Orange: possible application if preferable option is not available
- Red: Not likely or application not to be preferred

For DHW Heat Pumps the source is a very important parameter as the temperature for the evaporator is a measure for the final COP. A number of sources are characterized by their temperatures in the standards as:

Heat source	Outdoor air	Indoor air	Exhaust air	Brine	Water	LT Distribution
Temperature	+ 7 °C (+ 6 °C)	+ 20 °C (maximum + 15 °C)	+ 20 °C (+ 12 °C)	0 °C (inlet)/ – 3 °C (outlet)	+ 10 °C (inlet)/ + 7 °C (outlet)	+20 – 40°C (inlet) +10 – 30°C (outlet)

Especially for air source DHW HP the climatic conditions have significant effect on the performance. And in US as well as European standards fixed at a temperature that is not reflecting the application in practice where the outside temperature is fluctuating and can be 'very low'. The temperature and humidity at the evaporator is one of the main determinants of the performance of an air-source DHW HP.

3.5.2 Heat losses of storage vessels

Hot water storage cylinders are recommended to be kept at 60°C, based on the risk of legionella. The temperature of hot water required at the appliance varies (e.g. shower 40°C, bath 44°C, kitchen sink 55°C). We therefore mix cold water with the hot water from the cylinder in order to get the desired temperature. This therefore begs the question of what effect hot water cylinder temperature has on CO_2 emissions (because higher storage temperatures will result in higher heat losses).

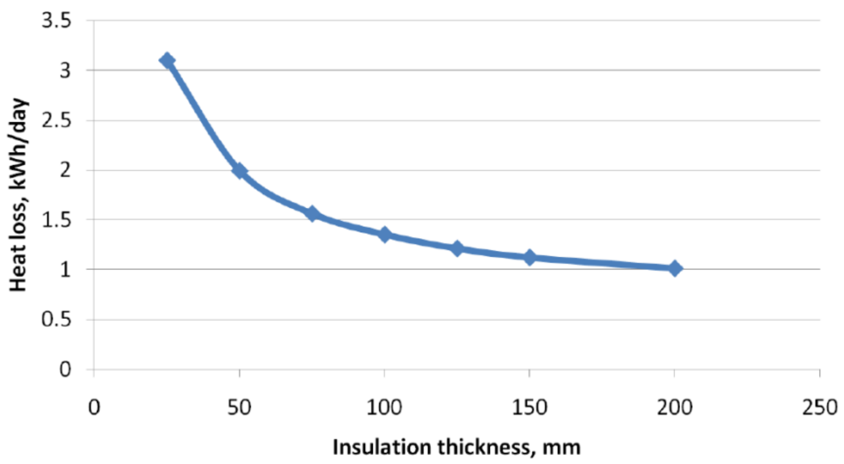
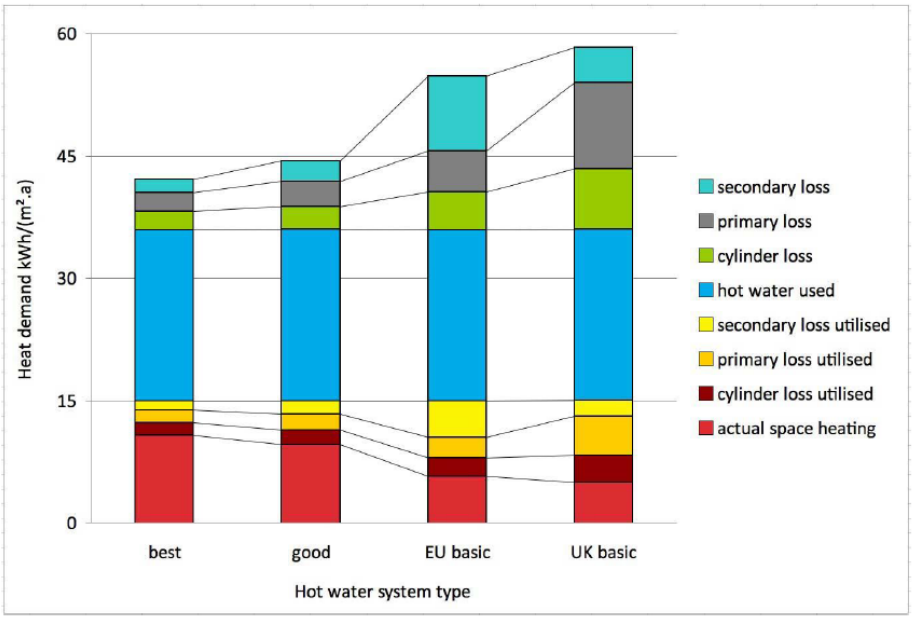


Fig 3.11 Heat losses of storagetanks



Thermal Stratification has impact on the thermal performance of DHW systems[5].

Building of stable thermocline in time and space implies that the mixing should be minimised. Stable thermal stratification or thermocline within the tank can be achieved by various means.

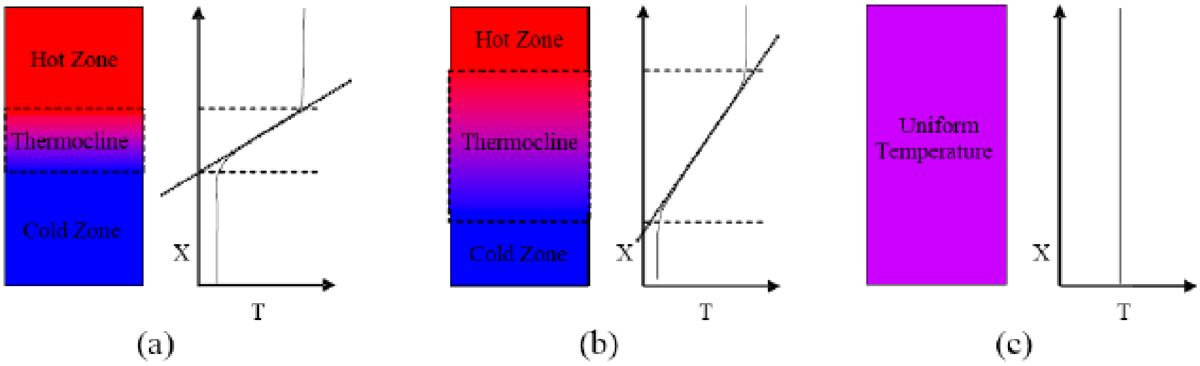


Fig 3.13 Three types of stratification [20]

Losses of the storage tank are part of the testing procedure. Typical losses vary from 30 W to 200 W continuously, resulting in 270-1800 kWh/yr extra heating demand for the generator.

For separate storage vessels the EU has classified the following values related to the Energy Label:

Storage losses [W]		**Storage vesselsize [ltr]**		
		80	150	300
EU E-label				
A+/A	very good	24	29	36
A/B	good	33	40	50
B/C	acceptable	46	56	70
C/D	average	65	78	98
D/E	below average	81	98	122
E/F	poor	105	127	160
F/G	very poor	127	155	194

[5] A high degree of thermal stratification increases the thermal performance of solar hot-water systems because the return temperature to the solar collector is lowered. A lower return temperature to the solar collector will increase the efficiency of the solar collector (Furbo)

RdSAP uses the following calculation of storage vessel losses:

Table 2 (RdSAP v9.92) – Hot water storage loss factor

Insulation thickness, mm	Cylinder loss factor (L) kWh/litre/day	
	Factory insulated cylinder thermal store store in combi boiler	Loose cylinder jacket
0	0.1425	0.1425
12	0.0394	0.0760
25	0.0240	0.0516
35	0.0191	0.0418
38	0.0181	0.0396
50	0.0152	0.0330
80	0.0115	0.0240
120	0.0094	0.0183
160	0.0084	0.0152

Notes:

1. Alternatively the heat loss factor, L, may be calculated for insulation thickness of t mm as follows: Cylinder, loose jacket: L = 0.005 + 1.76/(t + 12.8) Cylinder, factory insulated: L = 0.005 + 0.55/(t + 4.0)
2. The data for factory insulated cylinder apply to all cases other than an electric CPSU where the insulation is applied in the course of manufacture irrespective of the insulation material used, e.g. the water store in a storage combi or a gas CPSU.
3. For an electric CPSU, the loss is 0.022 kWh/litre/day.

The term 'cylinder' includes thermal stores and other similar water storage vessels.

Table 2a (RdSAP v9.92) - Volume factor for cylinders and storage combinations

Volume V_c	Volume Factor VF	Volume V_c	Volume Factor VF
40	1.442	180	0.874
60	1.259	200	0.843
80	1.145	220	0.817
100	1.063	240	0.794
120	1.00	260	0.773
140	0.950	280	0.754
160	0.908	300	0.737

RdSAP				
Storage losses [W]		**Storage vesselsize [ltr]**		
		80	150	300
insulation thickness [mm]				
160		32	48	77
120		36	55	87
80		44	67	106
50		58	88	140
38		69	105	167
35		73	111	176
25		91	139	221

Notes:

1. When using the data in Table 2, the loss is to be multiplied by the volume factor.
2. Alternatively, the volume factor can be calculated using the equation $VF = (120 / Vc)^{1/3}$

To compare the RdSAP calculation with the EU Energy Directive classification, the RdSAP formulas were used to calculate the continuous loss in [W] for factory insulated cylinders – the values cannot be the same because the EU Energy label categories are not related to an insulation thickness. However the order size and the trends are comparable.

In Switzerland the SIA 385/1 standard [1] defines maximum allowed heat losses of storage tanks in kWh per 24 hours at a temperature difference of 45 K between the stored fully mixed hot water and the ambient air. The maximum allowed thermal losses must not exceed the critical values. There are storage tanks with and without factory-made insulation. The requirements are summarized in Table 8. In similar manner, the insulation of the tubing is defined. (Calculation example: 80 L storage tank ⍰ critical value = 0.98 kWh in 24 h ⍰ 0.98 kWh / 24 h = 40.8 W).

Table 1: Heat loss requirements for storage tanks according to SIA 385/1 [1].

factory-insulated

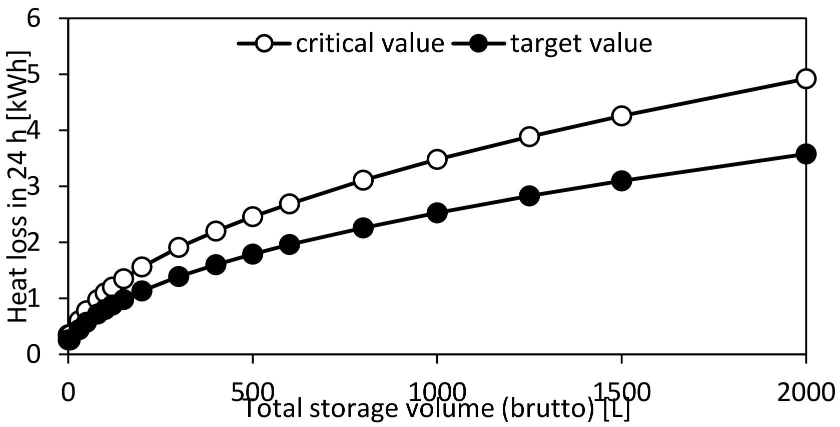


Figure 1: Heat loss vs. total volume of storage tank (data from SIA 385/1 [1])

not factory insulated

	λ-Value for calculation [W/m·K]	Minimum insulation thickness d_{sto}	
		critical value	target value
Material	*λ*	$d_{sto} \geq \lambda/U_0$	$d_{sto} \geq \lambda/U_0$
- Glass wool, rock wool	0.045	200 mm	300 mm
- Polyurethane	0.035	150 mm	230 mm
- Nano gel (high performance insulation)	0.020	90 mm	130 mm

λ: Conductivity of the insulation material at 40°C
U_0 = 0.225 W/(m²·K) for the calculation of the critical value and 0.15 W/(m²·K) for the calculation of the target value, respectively.

4 Calculation model results

4.1 Introduction

The steps of the calculation model are described in Addendum 1 and elaborated in a separate XL-sheet. In this sheet specific values for each country can be applied. The results below are calculated with typical boundary conditions for the Dutch situation.

First we discuss calculation results related to the source type of the heat pump. These results represent the HP system performance according to the system borders of SPF-4.

In the second part of the chapter we discuss the chain efficiency of the total system including the influence of the DHW demand and the losses of the in house piping by varying both parameters.

4.2 Chain Efficiency

The following systems are involved in the comparison of the chain efficiency. They are divided in systems for individual application per dwelling (terraced house or apartment) and in collective systems for a series of dwellings.

Individual systems, mostly applied in single family houses:

Combined systems that provide DHW as well as SH:

- High efficiency condensing gas boiler providing instantaneous DHW (no storage) and space heating (SH)
- Heat pump storage water heater by a gas fired diffusion absorption heat pump, with Ground Source Heat Exchanger (BTES) as heat pump source
- Hybrid outside air source heat pump with high efficiency gas boiler for peak load in space heating and instantaneous DHW without storage
- Heat pump storage water heater, with outside air as heat pump source
- Heat pump storage water heater, with BTES as heat pump source

Separate systems which only provide DHW:

- Gas fired storage water heater
- Storage heater on a high efficiency gas boiler
- Electric storage water heaters, a small one in the kitchen and a large one for the bathroom
- Electric instant flow heaters, two separate devices for bathroom and kitchen
- Solar storage water heater with high efficiency gas boiler (water tank is on available solar energy temperature, if necessary, water is reheated to the right temperature in a separate HX just before use)
- Heat pump storage water heater on ventilation exhaust air as source

Collective systems:

- Gas fired central heating boiler for space heating and DHW in a multifamily apartment building.
- Collective solar storage water heater in multifamily building with gas fired auxiliary back up heating
- Ground source (BTES) gas fired absorption heat pump in a multifamily apartment

building.

- Aquifer Thermal Energy Storage (ATES) - open ground source electric heat pump with heat distribution to the individual domestic (terraced) houses at 70°C supply and 40°C return ("mini" district heating).
- District heating with central heat generation by gas fired boilers.
- District heating on a gas fired electricity generating steam cycle by means of a gas and steam turbine combination (CHP); electrical efficiency decreases caused by heat extraction on steam cycle.
- District heating based on incineration rejected heat of electricity generating steam cycle; electrical efficiency decreases caused by heat extraction on steam cycle
- Hybrid system [01], [04], [05], based upon a low temperature district heating (45°C supply and 30°C return) and a small heat pump with DHW storage tank in each dwelling

4.3 Results

Overview of SPF definition in paper presented on 11th HPC [01]

Figure 4.1 shows the basic efficiency of the DHW generating device. For heat pumps this is the SCOP according to SEPEMO-SPF 4. This means that losses of in house piping are not included and that the origin of electricity (the Primary Energy Factor) is not taken into account. For gas appliances storage losses or distribution losses (e.g. district heating) are not included.

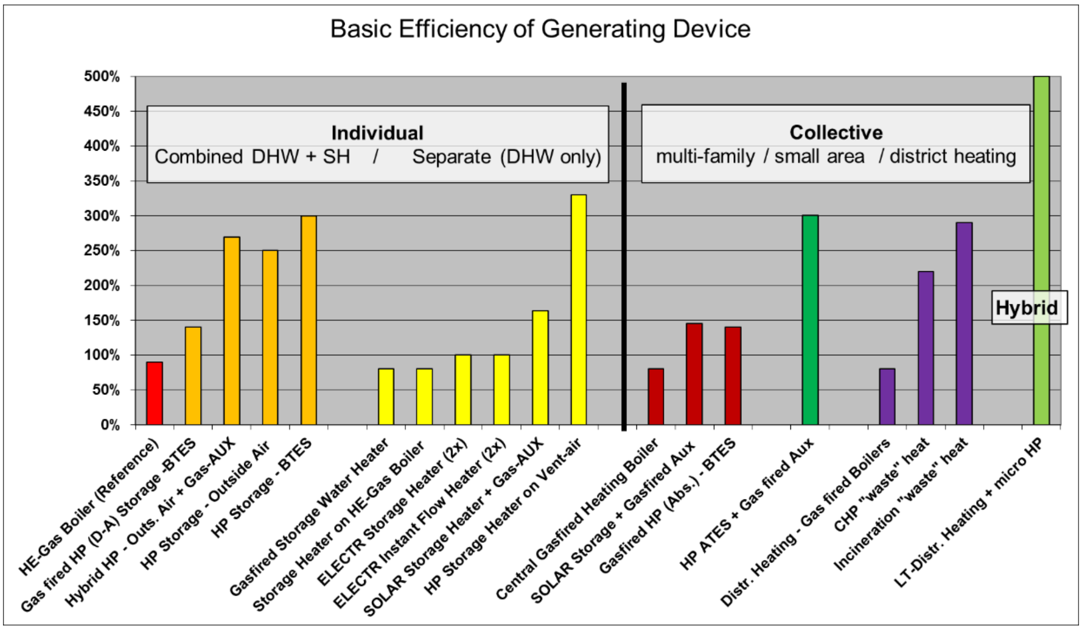


Figure 4.1: Basic generation efficiencies at a demand of DHW of 9 GJ/year [25]

In combined and separate concepts the main energy loss is caused by the water storage tank. In collective concepts is the largest energy loss is in the transport and distribution of the heat (DHW is produced inside the dwelling with a plate heat exchanger). Only a part of the distribution system between the location of the heat production and the dwellings is allocated to DHW production. These are the losses outside the heating season to keep the network up to temperature and the additional losses during the heating season because the use of an outside temperature-dependent supply temperature is not possible[6].

There are a number of standard available heat pump water heaters developed by Dutch manufacturers with special attention to minimizing the downtime losses of the storage tank by optimizing the insulation of the water

[6] *All losses are related to a net demand of DHW of 9 GJ/year.*

storage tank, highly stratified tapping curves, pipe connections and a smart control. This results in average heat losses lower than 40W and COP's as high as 4.0. In such cases the volume of the storage can be as small as 150 liters giving sufficient DHW during the day. Solar water heaters from the same manufacturers have a high efficiency because the high efficiency gas boiler is outside the storage tank giving instantaneous back up when tapping. The storage tank is thus only used for storing solar thermal energy which can be at a lower temperature than needed at the tap.

An overview of main energy losses per concept is shown in Figure 4.2.

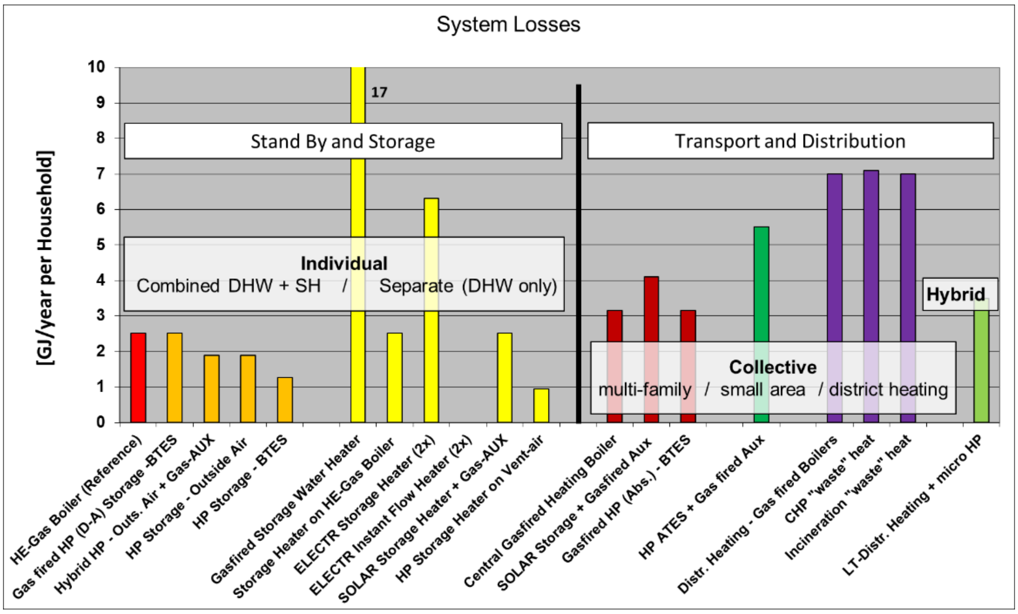


Figure 4.2: Stand By and Distribution Losses (excluding start/stop losses) [25]

The overall system efficiency of DHW production is given in Figure 4.3. These values include all aspects of the production from primary energy to the beginning of the DHW piping in the dwellings. The efficiency of electrical power generation is also included. In house piping losses are not included.

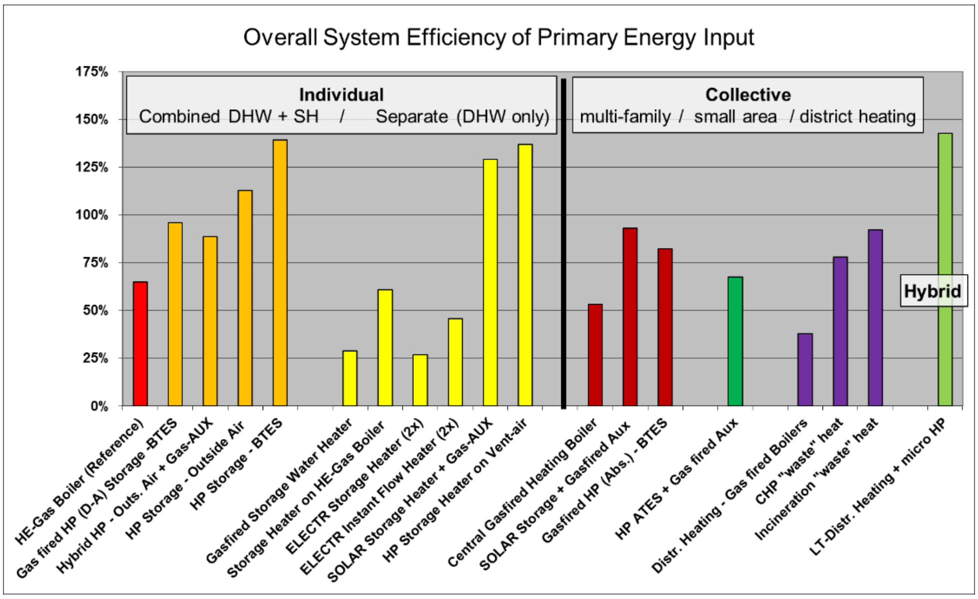


Figure 4.3: Overall System Efficiency [25]

These results show that:

- Within the separate concepts, the heat pump water heater and solar water heater with gas fired backup result in significantly higher efficiencies than the other systems; within the combined concepts, heat pumps achieve the highest results;
- Within the district heating concepts the residual heat from a waste incineration (AVI) has the highest efficiency
- The hybrid concept gives the best efficiency of all systems, this is mainly due to the preheating of the water using waste heat.

The high efficiencies of heat pumps, solar water heaters and AVI waste heat are, of course, all due to the share of renewable and / or ambient energy that is used in these concepts.

New results

The model used in [1] has been further elaborated and fine-tuned. Figure 4.4 shows the results for the same range of systems assuming a PEF of 2,0 and including all system losses until the in-house piping system (these losses are not included).

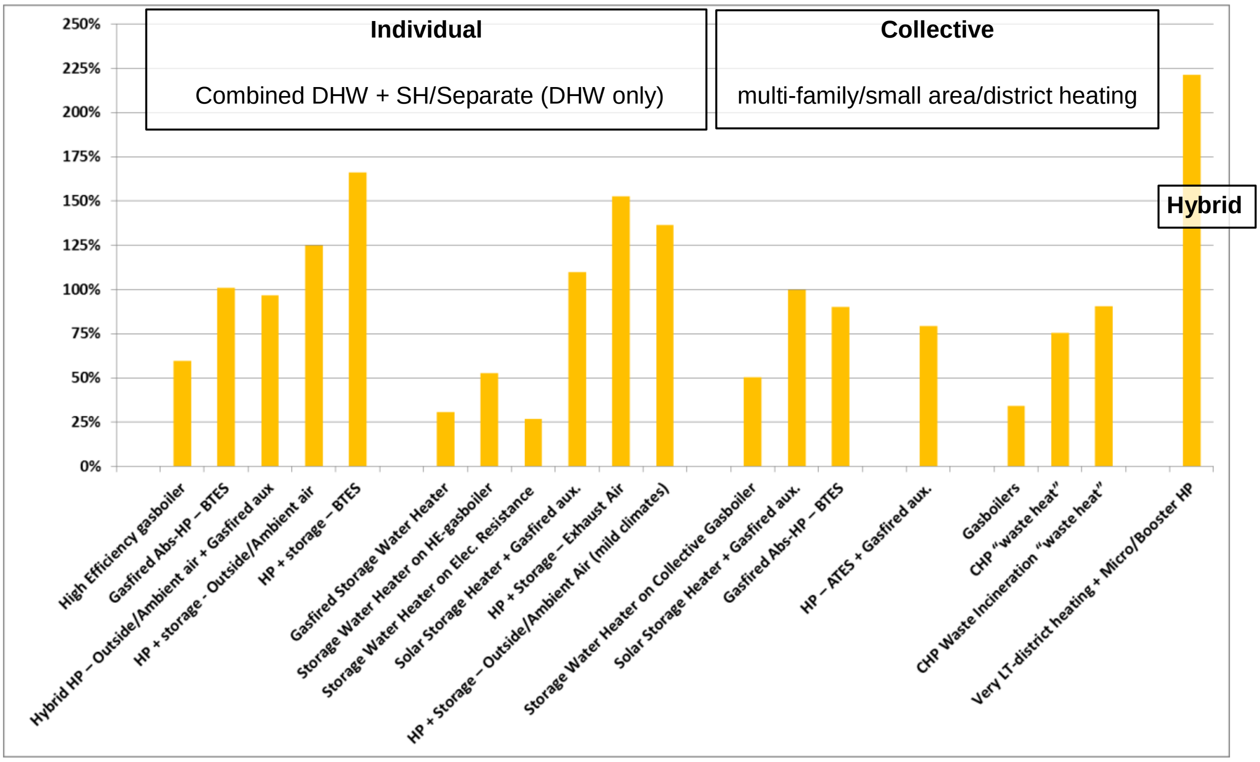


Figure 4.4: Primary energy system efficiency (PEF = 2,0) at 7,7 GJ/yr net demand; according to SEPEMO 4 (internal losses DHW-piping not included) [25]

When we include a yearly in-house piping loss of 3,5 GJ (almost 1000 kWh) the complete chain efficiency for DHW is decreasing of course. The results are shown in fig. 4.5.

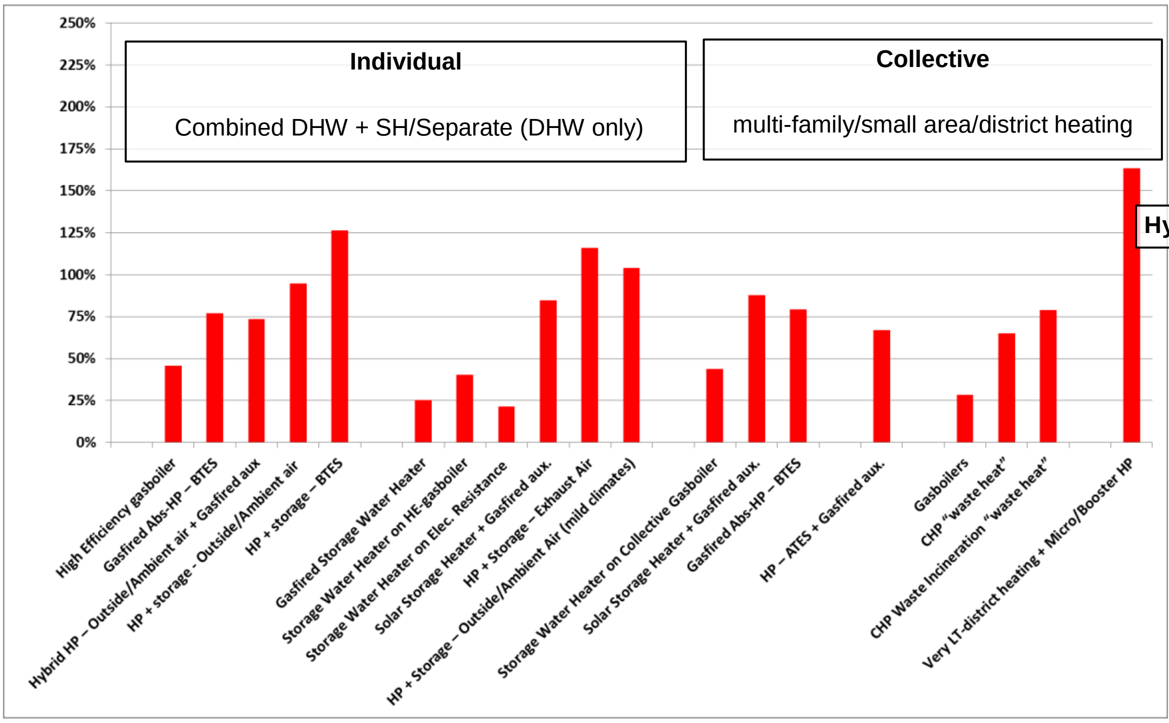


Figure 4.5: Primary energy system efficiency at 7,7 GJ/yr net demand; according to SEPEMO 4 and including internal losses DHW-piping of 3,5 GJ/yr [25]

Figure 4.6 shows the system efficiency (SEPEMO SPF-4) for different amounts of net DHW demand.

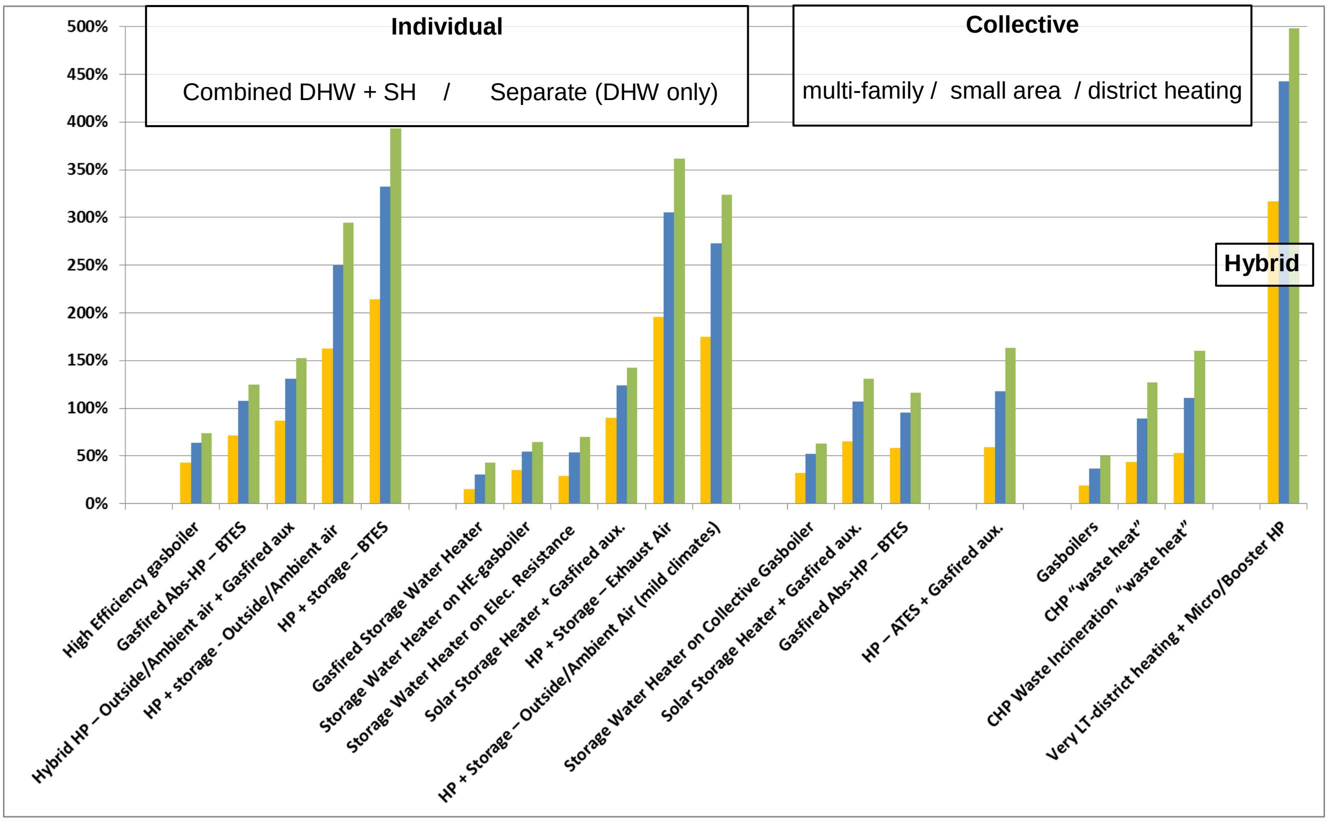


Figure 4.6: System efficiency (according to SEPEMO SPF-4) for three different DHW-demands without conversion factor for primary energy to electricity and in-house DHW-piping losses are not included. [25]

The colors are related to the following DHW-demands:

- Orange: 770 kWh/yr (demand pattern S of the EU-directive)
- Blue: 2130 kWh/yr (demand pattern M of the EU-directive)
- Green: 4260 kWh/yr (demand pattern L of the EU-directive)

It is very clear that the amount of DHW-use has a large impact on the system efficiency. For individual systems the storage losses, and for collective systems the transport and distribution losses, are relatively high at small DHW-demands. This influence is also found in field tests as described by Firth et al. [09].

5 Designing a hot water system

The design of a hot water service system may follow the procedure below:

- Determine the demand of hot water from the consumers - quantity and temperature
- Select the type, capacity and heating surface of the calorifier - or heat exchanger
- Select the DHW generator
- Design the pipe scheme and the size of the pipes

Hot water is normally supplied to fittings and their consumers at 50 - 60°C. For canteens and professional kitchen temperatures of 65°C are often required to satisfy hygienic standards. Hot water should not be stored at temperatures below 60°C (140°F) to avoid the risk of legionella contamination.

Where lower temperatures are necessary for safety reasons - as in kindergartens, centres for disabled etc. - the hot water temperature should not exceed 40 - 50°C. Special care should be taken - like regular disinfection of fittings - to avoid legionella infections.

Note! Hot water can be stored at higher temperatures and reduced to lower supply temperatures by mixing in cold water in blender valves. Storing the hot water at a higher temperatures increases the system overall capacity and reduces the need of storage volume.

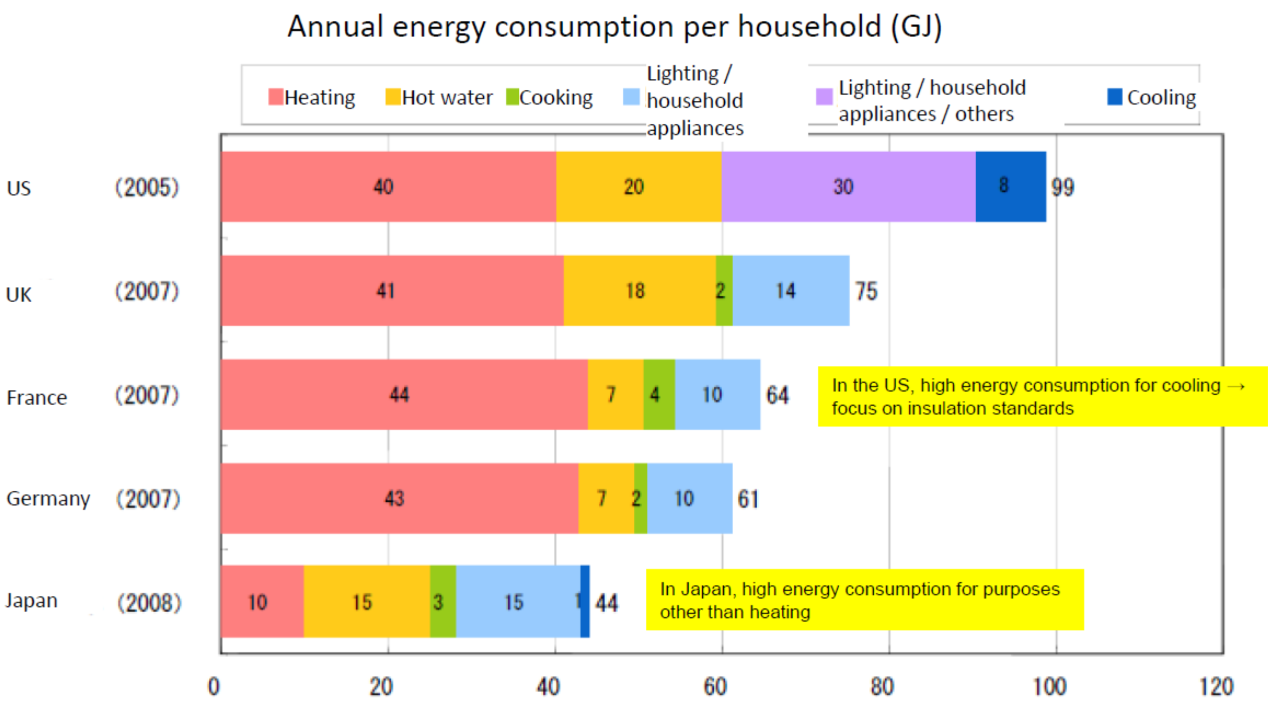
During the design of a hot water heating system for a one family dwelling the following average values can be used for estimating the hot water consumption. Depending on the appliances in the household, the following average consumption values per person can be calculated.

- Low Consumption 20-30 liters
- Average Consumption 30-50 liters
- High Consumption 50-70 liters

However there are great differences up to a factor 20 due to factors such as end user behavior, age (younger people tend to use the shower for a longer time[7] than elderly people) and culture (for example, the bathing culture in Japan) as well as showers versus bathtubs.

The method to determine hot water consumption in many calculation models does not take account an important factor affecting hot water use – shower type. It is therefore proposed to introduce a new procedure which calculates the amount of hot water used by showers according to their flow rates, as well as for baths and 'other' uses of hot water. This makes for a more transparent calculation as well as allowing a detailed consideration of the effect of shower type [17]. The proposed changes will more accurately reflect the performance of the dwelling than the present calculation, which should help encourage better (e.g. lower carbon) decisions to be made by those building or retrofitting homes.

[7] Shower Waste Water Heat Recovery is more profitable with long-term use (50% with a short shower and 65% with a long shower) and halves energy use during showering. The energy consumption thus runs less fast when using excessive showers.



*Source: Jyukankyo Research Institute, Inc. (prepared on the basis of statistical data for each country) / September 2010
*Note: The years in brackets represent the most recent data for each country.
For the US, cooking is included in the value for lighting / household appliances / others.
For Japan, the data are for households consisting of two or more people. Cooking represents the use of gas / LPG other than for heating and hot water and does not include electricity used for cooking.
There are no cooling data for European countries.

Fig 5.1 – Energy Consumption in some large economies [22]

Although the average usage of hot water is almost the same in US, UK, Germany and France, the overall energy use for hot water is remarkably different as US and UK are using almost three times the amount of energy than France and Germany. In UK this can 'partly' be explained by the overall bad insulation of existing old storage tanks and the fact that electric showers which heat water instantaneously from cold to a comfortable shower temperature are found in around 45% of homes (according to MTP figures).

6 Discussion

A number of guidelines for designing and engineering an optimal DHW heating system can be drawn, starting with the awareness that there is a number of different target groups:

- Macro-level of policy decisions focusing on technology solutions to support in R&D for the longer term and where the overall chain efficiency and the changing landscapes of energy supply security are of importance in the future energy systems until 2050.
- Meso-level, with the installer, consultant, designer of hot water heating systems, whereas housing corporations and house rental companies also belong to this group. At this level the acceptability in legal procedures to acquire permits for new building and/or large scale renovation is more important than the chain efficiency. Local government can play an important role in this process. As we move towards more energy efficient houses, calculating methodologies for hot water system design with a level of detail to similar to the ones for building envelope and ventilation systems (incorporating the latest innovative technological developments[8]) is needed.
- Micro-level of private house owners, i.e., the end user. The leading concern here is the replacement of the existing installation, where the main driver for the end user is the cost of the DHW generator, energy efficiency being often overlooked. Governmental information programs as well as educational programs for installers would support a 'better choice' for the end user. Legislation is another instrument for the government which is marketed through informative labelling of DHW generators and even ban on sales of specific less efficient generators (as an example, high efficiency gas boilers are banned in specific applications in Denmark).

Overall it is important to think in terms of complete system concepts. Even if the heat is produced with a high energy efficiency, high storage and/or distribution losses still remain unnecessary and eventually will cause a low overall system efficiency to the best generating apparatus. It is therefore important to consider the heat generators not only individually but to design a complete DHW concept with a critical view on performance, comfort and legionella prevention.

Choose generating devices with a high efficiency. A hot water unit with high efficiency (for example, a heat pump storage water heater or solar storage water heater) consumes less primary energy than a device with a low efficiency (for example, a gas fired storage water heater). A hybrid outside air source heat pump with high efficiency gas boiler for peak load in space heating and instantaneous DHW without storage, although not having the best available efficiency, is a very good option in renovation situations.

Install the generating apparatus or water storage tank as close to the tap with numerous small amounts of water use. In the kitchen, where a lot of small amounts of water are used during the day, the impact of the length of the water piping there is the greatest. Compared with generator located in the attic (and a kitchen on the ground floor) approximately 3.5GJ (net) may be saved (at 9GJ net DHW requirement). For newly built houses with a low demand for space heating it is the challenge for the architect and building constructor to realize this option. All newly built homes are designed from the drawing board. It is sensible to take into account the distance between the source(s) of hot water and the taps at this stage already. This allows the user of the house the saving of a lot of energy (and cost) during the operating life of the house.

Choose a (device with a) very well insulated storage tank. Do not compromise on the insulation of the water storage tank not only in thickness but also in design where pipe connections at the side or top of the storage tank should be avoided as much as possible. In addition, a smart control depending on the tapping patterns and

[8] The way in which most current building energy models and energy standards consider hot water system losses is too simplistic for new build and deep renovation dwellings.

volumes (lowering the storage temperature during night and / or certain daytimes) reduces the standby losses, without decreasing the comfort level.

Limit unnecessary consumption of auxiliary energy. Auxiliary power is usually only needed during heat production. Choose a control system or adjust set points in such a way that pumps, fans and other auxiliary equipment is not continuous and / or unnecessary in operation.

Insulate hot water pipes optimally. The moment outlet pipes and connections are well insulated, line losses are reduced and the overall efficiency benefits. Potable water pipes have a lifespan of about 50 years. Insulation of the pipes afterwards, in existing situations, often cost a lot of money and time. For this reason, it is wise to install well-insulated pipes right away in difficult to reach spaces and ducts in new houses.

Allocate space for the location of a water storage tank. Several devices that generate hot water have a storage tank in order to have a small capacity generator designed on the need for space heating. Examples include solar water heater, electric water heater, combined heat pump and the heat pump water heater. When the location of a storage vessel is allocated in the design phase, later discussion regarding the placement is prevented.

Separate unit for the kitchen at large distances. In existing domestic housing the heat generator is far from the kitchen. When many small amounts of water are used there throughout the day, the hot water must often travel long distances to the kitchen. This is accompanied by unnecessary waiting, wasting water and lots of energetic line losses. A solution to this is to place a separate DHW heater in the kitchen, for example, by placing an small electric storage water heater (see figure 9 and 10). This immediately raises the discussion that the ECO standard for efficiency of water heaters (Lot 2) [Ref. 3] which labels electric storage water heaters in the category E is the right standard for this case. It moreover proves the statement made that it is important think in terms of complete system concepts rather than to look at the apparatus only!

Combine collective heat supply with individual generation of DHW. Hot water is to be moved over a distance as short as possible. Collective heat supply and district heating for space heating often, however, is combined with the heating for DHW. This results in large distribution and line losses up to 50% (particularly in the transport and distribution pipelines that must be kept at DHW temperatures in the summer) and leads to a low overall system efficiency. Often it is argumented that collective heating systems are of interest for multifamily buildings and apartment blocks having a high and concentrated heat demand at one delivery point, making it an interesting economic solution. However after the collective heat exchanger point the distribution losses inside the building are enormous for which in the end the customer has to pay using actually twice the amount of GJ’s for DHW as in an optimal solution.

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ADDENDUM 1 – Calculation model

A. Net demand of DHW

There are substantial differences between cultures and countries. For each three levels of detail are recognized:

1. Detailed amounts, capacities and temperatures per tapping
2. Amount of energy per tapping
3. Net energy demand per day, or per year (= daily demand times 365)

The present model uses the yearly energy demand as basic input value – more details can be added in later versions of the calculation model. Especially for larger areas of dwellings the SIMDEUM-model is equipped to make dynamic calculations of the collective DHW-demand during the day.

B. DHW-input in home-system

1. In this part of the calculation the in house piping losses are taken into account. Every time a tapping takes place, the pipe from the DHW storage (or generator) to the tap has to be filled completely with hot before the water at the tap can be defined as useful. In the model it is assumed that the contents of the piping is not useful anymore at the next tapping.

   These losses differ strongly depending on the extensiveness of the piping system. To avoid complex calculations, three categories of losses were defined:

   i. Small
   ii. Intermediate
   iii. Large
2. Loss of circulation systems (this could apply to MFB)
   For reasons of comfort (mainly to avoid long waiting times at the taps) DHW circulation systems are applied in multifamily buildings. The amount of energy losses depends on the specific situation; default values can be selected for each category:
   i. Small
   ii. Intermediate
   iii. Large

C. Energy input at generating device

1. Individual
   i. Production/conversion efficiency
   ii. Standby losses (storage vessel)
   iii. Legionella prevention (thermal disinfection)
   iv. Auxiliary energy (pumps/fans/control)
2. Collective
   i. Production/conversion efficiency
   ii. Standby losses (individual/collective storage/HX to district heating system)
   iii. Transport and distribution
   iv. Auxiliary energy (pumps/fans/control)

   In the production/conversion efficiency of heat pumps the following components are included: compressor efficiency

   - design and construction of source heat exchanger
   - design and construction of HX to hot water storage vessel
   - application of flash injection
   - internal pressure and temperature losses of the refrigerant lines
   - inverter technology

These parameters all have strong influence on the overall efficiency of the "bare" heat pump

D. Primary Energy needed

The Primary Energy Factor (PEF) is used for this final step of the calculation. The PEF which differs per country, has to be obtained for:

1. Fossil > electricity
2. Fossil > thermal
3. Renewable

Calculation model

In the calculation model average values can be used for the in-house losses of the DHW piping system for terraced/single family houses could be:

- Small: 550 kWh
- Average: 900 kWh
- Large: 1250 kWh

For circulation systems in multifamily buildings average values per apartment are suggested:

- Small: 500 kWh
- Average: 750 kWh
- Large: 1000 kWh

When any tap is not directly near the circulation system, extra losses have to be added for MFB.

PEF (average per country/EU)

Fossil/Nuclear/Renewable > electricity

For each country this will be a different mix of these components

In the Netherlands for a long time (about 20 years) a PEF of 2,56 (eta = 39%) has been applied. This is not realistic since the average efficiency of "fossil" electricity generation is above 45% for some years. The new PEF to be applied in NL from 2020 is 2,14. The government even wants to apply a lower figure – this is under discussion.

The EU has planned to reduce the PEF from 2,5 to 2,1 in 2020.

ADDENDUM 2 - Sources

System classification for HP water Heaters would lead to a multidimensional matrix. The possible application of a HP source depends also on the outdoor climate. For the calculation of the chain efficiency, system classification is based on the situation of the HP's application; this is divided in newly built and existing dwellings and in terraced house and multi-family buildings.

Six types of sources are distinguished – with main characteristics:

- ATES: Aquifer Thermal Energy Storage
  - Stable source temperature
  - Collective source systems only
  - Substantial cooling demand needed / obligatory source regeneration
  - High costs to the end user because of intermediary party
- GSHX: Ground Source Heat Exchanger (or BTES – Borehole Thermal Energy Storage)
  - Stable source temperature
  - Individual and collective systems
  - Passive cooling option
- Outside air
  - Limited application in cold climates
  - Relatively high amount of auxiliary energy
  - Point of attention: fan noise
- Ventilation exhaust air
  - High temperature source (at indoor room temperature of approx. 20 °C)
  - The creation of extra and unnecessary ventilation is very simple (and leads to higher demands of space heating energy)
- Low Temperature Solar Thermal (water or air cooled collectors/PV-panels)
  - Higher source temperature than outside air
  - Possibility of reducing auxiliary energy by use of natural convection
- LT-DH: Low Temperature District Heating (40°C supply)
  - Excellent source temperature
  - Collective source systems only

In the table below the source's characteristics are qualified.

Source	COP	Aux Energy	Invest-ment	Maint-nance
ATES (aquifer storage)	-	0	++	-
BTES (Ground Source Heat Exchanger)	++	0	0/-	++
Outside Air	+	--	++	-
Ventilation Exhaust Air	++	-	+	-
Low-Temperature District Heating	+++	+	+/++	+

In the schedule below the possible application of these sources is shown in each of the situations the Heat Pump Water Heaters can be applied.

	New	Existing
Single Family Houses	Air (green)	Air (green)
	LT Distribution (red)	LT Distribution (red)
	District Heating (orange)	District Heating (orange)
	GS Hex (green)	GS Hex (orange)
	ATES (red)	ATES (red)
Multi Family Building	Air (green)	Air (green)
	LT Distribution (green)	LT Distribution (orange)
	District Heating (orange)	District Heating (orange)
	GS Hex (green)	GS Hex (green)
	ATES (orange)	ATES (red)

- Green: preferable source
- Orange: possible application if preferable option is not available
- Red: Not likely or application not to be preferred

In the next part, the different types of Heat Pump Water Heaters will be described based on the classification shown above.

General Efficiency (SCOP) related to SEPEMO-4 for heat pump systems:

Source type/climate	Cold	Average	Warm
ATES [1]		3.6	
GSHX	3.3	3.3	
Outside Air	2.0	2.7	3.5
Ventilation Exhaust Air [2]	3.1	3.1	
LT District Heating	4.4	4.4	

New Single Family Houses

Mostly double function (space heating and DHW) HP's are used. Because of the new building area that is developed, application of GSHX is very easy. If GSHX's are not possible, outside or ambient air as a source can be used. For large area's (big number of new houses) ATES could be an option, when the heating demand is very low and a substantial amount of cooling is needed. Nevertheless ATES requires an area network of piping and special attention must be payed to the control strategy and control equipment to avoid high loads of pumping energy for the distribution network.

If a low temperature heat source is available (provided by a collective heat pump for space heating, cascaded geothermal heat or industrial waste heat), a Booster Heat Pump Water Heater can be applied very profitably. Same remarks as made for ATES apply here also.

Options for <u>new</u> (well insulated) single family houses per climate type:

	DHW only				Double Function		
Climate:	Cold	Average	Warm		Cold	Average	Warm [4]
ATES [1]	[red]	[red]	[red]		[red]	[orange]	[red]
GSHX	[orange]	[orange]	[red]		[green]	[green]	[red]
Outside Air	[red]	[orange]	[green]		[orange]	[green]	[red]
Ventilation Exhaust Air [2] [6]	[red]	[red]	[red]		[red]	[red]	[red]
Solar Thermal (LT)	[orange]	[green]	[green]		[orange]	[green]	[red]
LT District Heating [3]	[green]	[green]	[red]		[red]	[red]	[red]

[1] ATES is not applicable for DHW only
[2] Ventilation Exhaust Air is not likely to be applied as a source in new houses
[3] Low temperature district heating requires no HP for space heating\
[4] No space heating demand assumed in warm climates
[6] Not applicable for double function without additional heating

Existing Single Family Houses

In existing residential areas the construction of a distribution network for ATES or for low temperature (waste) heat is rather difficult and therefore expensive (if even possible). Also the construction of a GSHX in an existing garden is a radical measure.

The most obvious heat pump source for existing dwellings is air. This can be outside air (in intermediate and warm climates) or ventilation exhaust air and ambient air. Another aspect is that existing dwellings usually need high (or intermediate) supply temperatures for space heating. Hybrid heat pumps (source: outside air) deliver a major part of the space heating demand, and some types will also deliver a part of the demand for DHW (e.g. pre-heating the water).

Ventilation exhaust air has an excellent temperature for heat pump water heaters and application results in re-use of energy content of the exhaust air. Nevertheless, if the need for ventilation air is low, the production of DHW will lead to an extra heating demand for space heating. In that case the high COP for the ventilation exhaust air heat pump water heater is decreasing.

Options for <u>existing</u> single family houses per climate type:

	DHW only				Double Function		
Climate:	Cold	Average	Warm		Cold	Average	Warm [4)]
ATES [1)]							
GSHX							
Outside Air [5)]							
Ventilation Exhaust Air [6)]							
Solar Thermal (LT)							
LT District Heating [3)]							

[1)] ATES is not applicable for DHW only
[3)] Low temperature district heating requires no HP for space heating
[4)] No space heating demand assumed in warm climates
[5)] Additional heating required depending on climate and HP technology
[6)] Not applicable for double function without additional heating

New Multifamily Buildings

For multifamily buildings, collective systems become more interesting because one connection can serve a large amount of users without the need for an extensive distribution network. Therefore the application of a low temperature supply from a collective heat pump for space heating to several individual booster heat pump water heaters can be very attractive. Also individual double function HP with GSHX or outside air as HP-source are good applications. A special option is the application of one HP for the space heating of 4 to 8 apartments with an individual DHW storage tank for each apartment which is heated by the semi-collective HP (called Multi-Storage)

Options for <u>new MFB</u> per climate type:

	DHW only				Double Function		
Climate:	Cold	Average	Warm		Cold	Average	Warm [4)]
ATES [1)]							
GSHX							
Outside Air [5)]							
Ventilation Exhaust Air [2)]							
Solar Thermal (LT)							
LT District Heating [3)]							

[1)] ATES is not applicable for DHW only
[2)] Ventilation Exhaust Air is not likely to be applied as a source in new MFB
[3)] Low temperature district heating requires no HP for space heating

4) No space heating demand assumed in warm climates
5) Additional heating required depending on climate and HP technology

Existing Multifamily Buildings

In existing MFB normally high temperature systems are used for space heating (unless substantial insulation measures have been carried out afterwards – then these MFB's can be regarded as new built). Three types of systems:

a. Central heating by boilers and DHW-circulation system
b. Central heating by gas boilers only for space heating and individual electrically heated water storage tanks
c. Individual double function gas boilers

Type a.: central HT-HP with a combined source of outside air (autumn and spring) and ATES or BTES (winter) assisted by traditional HE gas boiler for peak heating.

Type b. individual HP ventilation exhaust air

Type c. Individual DF-HP on outside air or mixed outside and ventilation exhaust air.

Options for <u>existing</u> *m*ultifamily buildings per climate type:

	DHW only				Double Function		
Climate:	Cold	Average	Warm		Cold	Average	Warm [4)]
ATES [1), 7)]							
GSHX							
Outside Air [5)]							
Ventilation Exhaust Air [6)]							
Solar Thermal (LT)							
LT District Heating [3)]							

1) ATES is not applicable for DHW only
3) Low temperature district heating requires no HP for space heating
4) No space heating demand assumed in warm climates
5) Additional heating required depending on climate and HP technology
6) Not applicable for double function without additional heating
7) ATES to be applied combined with outside air and HT heat pump

New development:

Double function HP can be equipped with a two-stage compression system: The first stage delivers system water of 40-45 °C for space heating and showering. The second stage uses the 40 °C system water as source for the heating of a small amount of DHW for cleaning purposes up to 60 °C. The sanitary water for the shower is heated instantly by a plate HX so there is no storage of sanitary water at 40 °C (which would be an ideal temperature for Legionella multiplication).

ADDENDUM 3 - Effect of the Type of Shower on DHW efficiency [17]

A. Number of showers per day

The number of showers per day is in practice highly occupant dependant, but for SAP some kind of average or typical behaviour must be assumed, for a given number of (assumed) occupants. A relationship based on occupancy has been developed. This was

derived by converting data in the form of showers per person per day based on UU/LJMU data into a SAP “AN+B” style of equation by scaling the A and B coefficients to predict an identical number of showers for an average number of occupants (2.36). Data was only available to do this for homes which also had a bath (since all the homes in the sample had a bath), but it was possible to rescale the coefficients again to cover cases where no bath is present based on the equations for shower total water use in DCLG’s water calculator. These assume showers are used 0.78 times as often where a bath is also present.

Showers per day = 0.45 N + 0.65 (if bath also present)4

Or = 0.58 N + 0.83 (if no bath is present)

Where multiple showers are present, it is assumed they are all used equally5, so the number of shower uses per day for all showers is divided by the number of showers present in the home to get the use for a particular shower unit.

B. Shower flow rate

The most important physical factors affecting flow rate are the hot water pressure and the presence of any flow restrictors, since these determine the maximum flow rate that can be achieved. The former depends most strongly on the plumbing characteristics of the hot water system. However occupant behaviour is also a factor so we have based the assumed flow rates in table 1 on averages associated with each plumbing arrangement taken from field data6,7, assuming no flow restrictors are fitted. A correction can then be made where limiters are fitted.

Table 1 - Proposed shower flow rates (l/min) by plumbing arrangement:

Vented hot water system	7
Vented hot water system + pump[8]	12
Unvented hot water system	11
Instantaneous electric shower (vented or unvented)	0[9]

If a permanent flow restrictor10 is known to be fitted (i.e. one requiring the use of tools to remove), the restricted flow rate should be used in place of these figures, down to a lower limit of 6 l/min11. Part G of the building regulations requires that showers fitted to new homes have their flow rates restricted to no more than 8l/min, so the highest unrestricted flow rates in the table are only likely to be used for existing dwellings.

In practice SAP assessors may not find these categories intuitive to use, so a series of questions and logic is provided in Appendix A to assist in choosing the correct category.

C. Total water use per shower

Showers are assumed to last 6 minutes, thus total water use per shower (l) = 6 * flow rate

D. Proportion of shower water that is hot

Showers are assumed to be delivered at 41°C, made up of a mixture of cold and hot water. The proportions of hot and cold water required depend on the temperature of the hot and cold components relative to the desired shower temperature, denoted T_{hot}, T_{cold} and T_{shower} respectively (all in°C). The temperature of cold water varies by month of the year. This is taken from the existing table G2 in SAP 2012:

Table 2 - Cold water feed temperature, Tcold, in °C (SAP table G2)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
11.1	10.8	11.8	14.7	16.1	18.2	21.3	19.2	18.8	16.3	13.3	11.8

This data was based on EST field trials in 2008, which also revealed that the average temperature of hot water, Thot, provided was 52°C, with no significant monthly variation.

The proportion of hot is calculated based on the requirement to provide shower temperature water, Tshower, at 41°C: Proportion hot = (T_{shower} - $T_{cold,m}$) / (T_{hot} - T_{cold},m)

This gives the following proportions of hot water for each month:

Table 3 - Proportion of hot water required for showers in each month

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.731	0.733	0.726	0.705	0.694	0.675	0.642	0.665	0.669	0.692	0.716	0.726

E. Daily hot water use for shower

This is the product of the volume of water per shower, the proportion of that which is hot and the number of showers per day taken using shower outlet X:

$V_{d,showerX,m}$ (litres/day) = Total water per shower * Proportion hot * Showers per day

Finally, the monthly figure obtained for each shower type is multiplied by an additional monthly behavioural variation factor, as described in section 2.2 (table 8).

Having calculated this for each shower present in the dwelling the figures are summed to give the total daily showering hot water volume for each month.

$V_{d,shower,m}$ (litres/day) = $V_{d,shower1}$ + $V_{d,shower2}$ + etc…

F Conclusions

The method to determine hot water consumption in SAP 2012 does not take account of an important factor affecting hot water use – shower type. It is therefore proposed to introduce a new procedure which calculates the amount of hot water used by showers according to their flow rates, as well as for baths and 'other' uses of hot water. This makes for a more transparent calculation as well as allowing a detailed consideration of the effect of shower type.

Overall, these changes should improve the accuracy of SAP's predictions of hot water energy consumption significantly. The only potential negative consequence identified is that this change could encourage housebuilders to install showers in new homes which have flow rates that are unacceptably low to occupants, who might then replace them with types with higher flow rates; hence an attempt has been made to avoid this.

The main impacts of the changes proposed are as follows:

- The volume of hot water required will vary considerably with shower type.
- Consequently the predicted energy consumption associated with water heating will vary far more from home to home. Two homes which currently have the same DER or SAP rating, but have different shower types, would receive different ratings in future.
- The savings from SWH and WWHR will be either higher or lower than at present due to their performances being highly dependent on the hot water demand. Savings from WWHR will usually be higher (since they are used with higher than average flow rate showers)20. Saving from SWH will be higher than at present if showers with high flow rates are used and lower if lower flow rate showers are used.

The proposed changes will more accurately reflect the performance of the dwelling than the present calculation, which should help encourage better (e.g. lower carbon) decisions to be made by those building or retrofitting homes.

(This Appendix is an extract from: [17] – Consultation Paper: CONSP:08, Amendments to SAP's hot water methodology, Issue 1.0, Building Research Establishment Ltd (BRE), 2016

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Report no. HPT-AN46-06