Analysis of Energy Efficiency of Domestic Electric Storage Water Heaters

Study for the Directorate General for Energy (DGXVII)
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FINAL Report

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Contractor:
Energieverwertungsagentur (EVA)
the Austrian Energy Agency
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EC Project Manager:
Paolo Bertoldi
DGXVII

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Study group members

EVA	Austria	H. Lechner (co-ordinator) G. Simader
ADEME	France	B. Lebot
CCE	Portugal	C. Lopes
CECED	Belgium	P. Le Devehat
ECU	UK	M. Hinnells
EMP+Inestene	France	J. Adnot, A. Riahle, M. Orphelin
ENEA	Italy	B. Mebane, M. Presutto
IDAE	Spain	C. Angel Galan
PW Consulting	France/UK	P. Waide
Technical University of Graz	Austria	M. Sakulin, E. Schmautzer, M. Hölblinger, C. Kawann
Wuppertal Institute	Germany	S. Thomas

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Summary

Background of the study

This report summarises the results of a study on the energy efficiency of **D**omestic **E**lectric **S**torage **W**ater **H**eaters (DESWHs) in the European Union (EU). The study is supported by the SAVE programme. It continues the EU initiative to explore the potentials and development of implementation strategies to increase the energy efficiency of electric appliances in the domestic sector, and complements analyses on the energy efficiency of cold appliances (refrigerators and freezers), wet appliances (washing machines, dishwashers and dryers) and brown goods (televisions and video recorders).

The results, conclusions and recommendations presented are based on five technical reports.

Electric water heating in Europe

The total EU electricity consumption by DESWHs in 1997 was 87 TWh. Standing losses accounted for 22% or 19 TWh of this total, about the total electricity consumption of Ireland. DESWHs account for 15% of household electricity consumption and are thus the second most important group of domestic appliances.

About 30% (43.5 million) of the EU's 142 million households use electric water heating systems. The percentage of households in each country using electricity to heat water is more than 40% in Luxemburg, Austria, France and Germany, between 30 and 40% in Italy, Belgium and Finland, just over 20% in the UK, between 10 and 20% in Portugal, Sweden, the Netherlands, Ireland, Denmark and Spain, and less than 10% in Greece.

Measuring energy efficiency of DESWHs

The best single parameter to describe the energy efficiency of a DESWH is a quantification of its standing losses. The IEC 379/HD500 S1 standard defines the most appropriate reference method for the measurement of standing losses. It is already used in all European countries to define and describe 24-hour standing losses and to impose a measurement protocol.

Based on the data supplied by CECED for 1995, which covers about 80% of the European DESWH market, the average (standard) standing losses have been calculated and are used to define the 'base case' for the following technical/economical analyses. The base case for standing losses ($L_{St,BC}$) is the approximated mean of weighted (with the number of models)/unweighted averages and can be described as shown in the following table.

Average DESWH standing losses ('base case') as a function of rated capacity (V)

Type of DESWH	Capacity (litres)	Base case for standing losses (LSt,BC)
Vertical	> 50-1000	$0.2 + 0.051 * V2/3$
Horizontal	> 50-300	$0.75 + 0.008 * V$
Small	5-50	$0.13 + 0.0553 * V2/3$

In order to identify the relevant parameters influencing standing losses, a sensitivity analysis was conducted. It clearly shows that the main influence on standing losses results from the ratio of insulation thickness at the side to thermal conductivity. Using the thermal conductivity of PU foam (0.035 W/m K) and using average values for all physical parameters of DESWHs, an insulation thickness of 4-5 cm for 'base case DESWH models' has been found.

Optimal insulation thickness

Life-cycle cost analysis considers the total costs for hot water supply during the life-span of a DESWH. In this study life-cycle costs were calculated as the sum of the cost for the insulation of a DESWH and its discounted real standing losses costs during the lifetime of the DESWH. All price components related to thicker insulation were included in a specific insulation price of 0.6 ECU/litre.

Three configurations for hot water supply situations - based on a 3-person household - were chosen for the economic (life-cycle cost (LCC)) analyses. It shows an optimal insulation (related to the lowest life-cycle costs) between 5 cm and 11cm, depending on the electricity tariffs in the different EU member states. For the 'EU case' (average of electricity tariffs) the optimal insulation thickness is between 6.4 and 9.3 cm. Compared

to real storage losses, it can be shown that increasing insulation thickness decreases not only standing losses but also life-cycle costs.
The main factors influencing the level of optimal insulation are the additional insulation costs and the price of electricity. The discount rate, ambient temperature and usage conditions are of minor importance.
The technical/economic analysis indicates that the country-specific optimal insulation thicknesses vary widely but are greater than the insulation thickness of the base case within each EU member state. On the other hand there are a series of DESWH models with poorer performance in comparison with the base case. Therefore an energy policy mix based on two main strategies seems the most appropriate approach: setting a minimum energy efficiency standard and introducing a labelling scheme.

Minimum energy efficiency standard and its effects

For the determination of a minimum energy efficiency standard, the effects of variations in real life conditions (e.g.usage profile, lifetime of the appliances, additional costs of insulation, country-specific electricity tariffs) on optimal insulation thickness have to be taken into account. For this reason the base case Lst,BC was selected to define the minimum energy efficiency standard. Choosing this moderate performance level limits the price increase of improved DESWHs, avoids negative effects on manufacturers, and at the same time guarantees benefits for consumers.
The proposed minimum energy efficiency standard can be expected to have the effects:

Societal effect of the proposed minimum efficiency standard

	Year			
Data not accumulated	**2000**	**2005**	**2010**	
Consumers				
Savings (million ECU)	54	173	259	
Manufacturers				
Return on equity (change in %)	-0.4	0.0	0.0	
Environment/society				
CO2 reduction (Mt CO2)	0.22	0.73	1.10	
Environment/society				
Reduction of electricity consumption (GWh)		452	1 445	2 158

Labelling

Of the proposed information activities, labelling of DESWHs is the most important measure. Labelling provides a language for all stakeholders. Consumers suffer from a large information deficit. Even if persons (e.g. plumber) other than the user choose the DESWH, the label will provide them with information that is not currently available. In accord with the existing EU-labelling schemes, classes A to G are proposed.

Other measures

Additional information activities should be carried out to promote the label and give advice on the economic benefits to potential buyers, plumbers and traders of buying a more efficient DESWH, especially to encourage households - if they make their purchase decision - to address the responsibility of third parties (e.g. installers) on operating costs. Furthermore 'good practice' in DESWH selection (e.g. capacity, type, tariff), installation (e.g. location, dimensions, placing and insulation of pipes) and usage (e.g. water-saving devices, time controllers) to self-installers and plumbers should be demonstrated. R&D activities are required to attain further improvements in the performance of DESWHs. Those include better insulation materials, intelligent control systems and armatures for avoiding/reducing heat bridges.

I.Introduction

This report summarises the results of a study on the energy efficiency of **D**omestic **E**lectric **S**torage **W**ater **H**eaters (DESWHs) in the European Union (EU). The study is supported by the SAVE programme. It continues the EU initiative to explore the potentials and development of implementation strategies to increase the energy efficiency of electric appliances in the domestic sector, and complements analyses on the energy efficiency of cold appliances (refrigerators and freezers), wet appliances (washing machines, dishwashers and dryers) and brown goods (televisions and video recorders).

The study was contracted in December 1995 between the European Commission and EVA, the Austrian Energy Agency, which subcontracted the study group members ADEME (France) with its consultants Ecole des Mines/EMP, INESTENE and PW Consulting, CCE (Portugal), ECU (UK), ENEA (Italy), IDAE (Spain), Technical University of Graz (Austria), Wuppertal Institute (Germany), and the manufacturers' association CECED. An interim report was prepared in August 1996.

The results, conclusions and recommendations presented here are based on five technical reports covering the following tasks (the responsible subcontractor is given in brackets).

1. Legal and technical framework, definition of terminology and data collection (ADEME).
2. Statistical analysis and validation (ADEME).
3. Engineering analysis of energy efficiency improvements of DESWHs (Technical University of Graz).
4. Investigation of energy efficiency policy options and definition of scenarios (ECU).
5. Impact analysis (ENEA).

I.Electric water heating in Europe: An overview

A.Relevance of electric water heating for households

The total EU electricity consumption by DESWHs in 1997 was 87 TWh. Standing losses accounted for 22% or 19 TWh of this total, about the total electricity consumption of Ireland. DESWHs account for 15% of household electricity consumption and are thus the second most important group of domestic appliances.

About 30% (43.5 million) of the EU's 142 million households use electric water heating systems. The percentage of households in each country using electricity to heat water is shown in Table 1 and amounts to:

- more than 40% in Luxemburg, Germany, Austria and France
- between 30 and 40% in Italy, Belgium and Finland
- just over 20% in the UK

- between 10 and 20% in Portugal, Sweden, the Netherlands, Ireland, Denmark and Spain
- less than 10% in Greece.

Table 1: Penetration of electric water heating in European households

Country	Total no. of households (thousands)	No. of households using DE(S)WHs [thousands (%)]
Luxemburg	100	45 (45.0)
Germany	34600	15200 (43.9)
Austria	2960	1290 (43.6)
France	21000	8800 (41.9)
Finland	1700	650 (38.2)
Belgium	3900	1287 (33.0)
Italy	25021	8257 (33.0)
UK	22600	4755 (21.0)
Portugal	2710	515 (19.0)
Sweden	2800	530 (18.9)
Spain	11300	1900 (16.8)
Netherlands	6000	1000 (16.7)
Ireland	1070	170 (15.9)
Denmark	2420	320 (13.2)
Greece	3100	160 (5.2)
EU total	**141281**	**44879 (31.8)**

When speaking about domestic electric water heating systems a distinction should be made between:

- **pure electric systems, e.g.:**
  - storage heaters (DESWHs)
  - instantaneous heaters
  - heat pumps

- **mixed energy systems using electricity - in parallel or alternating - with other energy sources, e.g.:**
  - combination boilers ('combis') also supplying the space-heating system
  - solar collectors

and

- **'multi point' versus 'single-point', that means**
  - hot water production for the household from one central heating source or
  - point of use water heating with several independent systems.

Mains-pressure storage systems are the most common type of electric water heating systems in European households. However, there is considerable national variation, as follows.

The main exception is **Germany**, which has 7.2 million households with instantaneous systems and only 4million households that use electric storage water heaters as their main hot water source. Germany is also an exception in that while households in other EU member states have just one electric water heater (centralised system), in the typical German household with electric water heating a few smaller units are installed (decentralised system). Only 4 million of the 15.2million German DESWHs are principal units. Another 11.2 million small DESWHs are used as secondary water heating sources. Altogether there is a high share of electric water heaters in Germany.

For former Eastern Germany it is thought that about 90% of those on district heating also derive their hot water from district heating systems. Most of the rest, who are on the gas network, use instantaneous gas water heaters. Elsewhere, electric water heaters are widely used, including instantaneous single point up to 6 kW and storage models (both single-point and 80 litre multi-points). It is thought that the use of single-point configurations will increase.

There has traditionally been a high share of electric water heating in **France**, complementing the high incidence of electric resistance space heating. However, the trend is towards 'combis' and indirect water heating, although many dwellings combine wet system central heating with electric water heating.

The **UK** has a unique pattern of plumbing. Until 1989, water by-laws forbade the storage of more than 15 litres of hot water under direct mains pressure. The basis of water heating in the UK is the single-walled open-vented copper cylinder. These are mostly indirectly heated by the central heating boiler (usually supplemented by an electric immersion heater for use when the boiler is not running), but copper cylinders are also used in conjunction with off-peak electricity. With the change in the by-laws, unvented versions are now appearing, as are other hybrid versions. Copper cylinders have lost ground to combis, and instantaneous gas water heaters are vanishing.

Italy has been very much an electric water heater market, but is moving increasingly towards combis and cylinders heated indirectly by the central heating boiler. The number of families with water heating linked to central heating rose from 6.2 million in 1989 to 9.8 million in 1995.

Water heating in **Spain** is based first and foremost on gas water heaters using LPG, but there is also a significant use of electric water heaters. Combi boilers are gaining share both in new buildings and existing dwellings that are being connected to the natural gas network.

In **Portugal**, the number of households with hot water is increasing very fast: in 1988, 38% of households had no hot water, but in 1994 this had dropped to only 14%. Instantaneous gas water heaters are most commonly used, but DESWHs are common in the north of Portugal, especially in Oporto, where cheap electricity was available until some years ago. The new natural gas network will encourage the

change from electric water heaters to gas appliances, mostly by way of financial incentives and advertising campaigns.
In both **Belgium** and the **Netherlands,** instantaneous gas water heaters have traditionally been used. In the Netherlands, combis have gained a large share of the stock, but have proved less popular in Belgium. Dwellings connected to the gas network have tended to stay with dedicated gas water heaters, while those without gas have opted either for electric water heaters or for indirect heating (which in Belgium is associated far more with oil-fired boilers than with gas boilers).
Finally, electric water heating is the norm in **Austria**, with gas being confined mainly to Vienna.
The total number of installed DESWHs in the EU in 1992 was 45.2 million. Four countries - Germany with 15.2 million (33.6%), Italy with 9.5 million (21.1%), France with 8.8 million (19.5%) and the UK with 4.8 million (10.5%) - account for 85% of the total stock (see Figure 1).

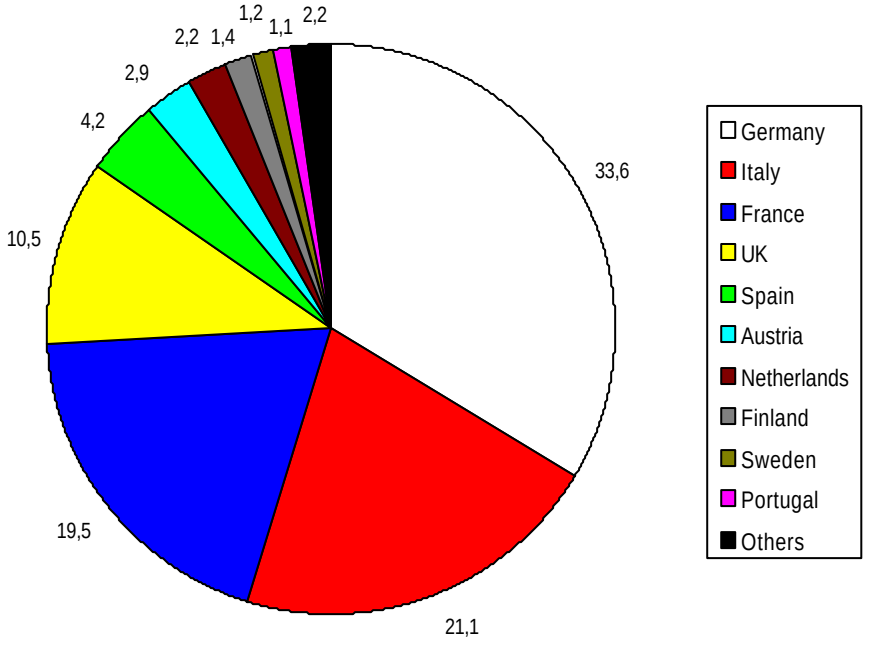

Figure 1: Distribution of DESWH stock among European Union member states

A.DESWH capacity and electricity consumption

There is a wide variation between European countries in the distribution of the water storage capacity of the DESWH stock (see Table 2). For example, whereas 73% of Germany's DESWHs have a capacity below 15 litres (since households use several small units), in France 65% of DESWHs have a capacity greater than 150 litres (partly as a result of promotion campaigns).

Table 2: Distribution of DESWHs according to capacity

Country	Distribution of DESWHs by capacity (%)			
	<15 litres	**16-50 litres**	**51-149 litres**	**>150 litres**
Austria	45	19	18	18
France	5	10	20	65
Germany	73	11	11	5
Italy 24	20	49	7	
Netherlands	38	18	42	2
Portugal			100	
Spain	20	55	25	
UK	50	50		

Analysis of the average consumption of DESWHs in four countries yielded the results shown in Table 3.

Table 3: Average consumption of DESWHs in Austria, France, Germany and Portugal

Country	Storage capacity (litres)	Consumption (kWh/year)
Austria (1990)	<15	1017
>15	2183	
France (1995)	Mean	2402
Germany (1991)	<15	968
15-200	1968	
>200	2416	
Portugal (1991)	15-20	3112
>200	3071	

The data in Table 3 confirm the importance of electric hot water production, which accounts for 14-19% of the total electricity consumption by households in Austria, France, Germany and Portugal.

A.Sales trends for hot water producing appliances

Aggregated sales trends (excluding the smaller electric water heaters) are shown in Figure 2. Details of estimated sales by capacity in 1995 are given in Appendix 8.3 (the pattern of sales shows quite different characteristics between countries). Some general European trends are masked by particular circumstances in individual countries:

- the decline in sales of instantaneous gas water heaters in most countries was temporarily hidden by the rapid increase in demand from the former Eastern Germany, where sales peaked in 1992 before falling dramatically from the end of 1993 onwards

- the underlying growth in sales of indirect cylinders (which are usually heated by a primary hot water circuit from the boiler) is masked by the decline in the large copper cylinder market in the UK (which includes some types other than indirect cylinders) and the peaking of the German market following the exceptional demand in 1991.

Sales of DESWHs are declining slightly with time. This is because the DESWH market is increasingly becoming a 'replacement business'. Since the average lifetime of small-capacity DESWHs is less than that of larger DESWH units, relatively more small-capacity DESWHs are sold.

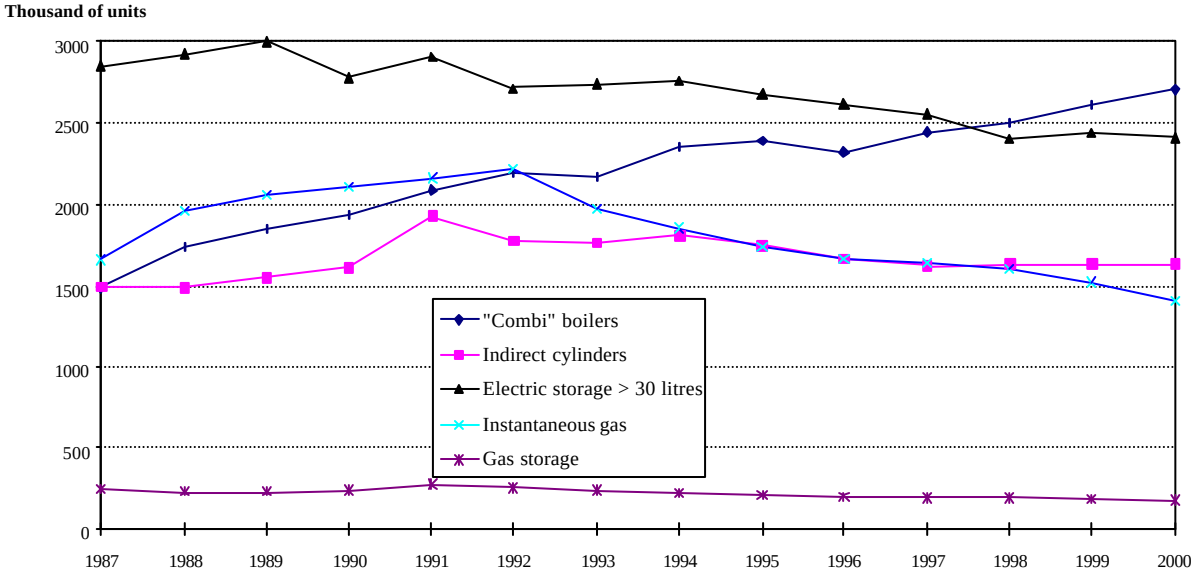

Figure 2: Sales trends for principal water heating products from 1987 to 2000 for 10 European countries

Manufacturers sell the same water heaters under different trade marks. It seems that the number of heaters sold per trade mark is a quasi-constant. The supply structure of DESWHs varies significantly between countries. One manufacturer dominates in Austria with a market share of 52%, while the Portuguese market is characterised by many small producers who manufacture small quantities by manual production processes. All in all, the European picture shows an oligopolistic market structure. Italy, Germany and France are the main manufacturing and exporting countries. The number of imports increased slightly from 1990 to 1994, mainly in Germany (from Italy). Imports from non-EU countries come mainly from Slovenia, Croatia, Switzerland and the USA; however, their share of total EU imports is low (being important only for local markets in neighbouring countries, such as Slovenian DESWHs in Austria). In 1994, only 7% of total DESWH imports to EU countries (960000 units) were delivered by non-EU countries.

As a result of a significant expansion of shipments to non-EU countries - mainly the Arab region - exports of DESWHs had a stronger growth than imports.

I.Technical Framework of the Study

A.Users' hot water needs

The total consumption of hot water depends on the size of the house, the number of inhabitants, their habits and standard of living, and the type and number of end-use appliances and climatic conditions (see Table 4).
As a consequence of the diversity of habits and end-use appliances, it would be too complicated to consider each type of hot water use. The needs of the user can be expressed by certain quantities, MWI, of warm water at temperature TWI appropriate to use (e.g. 35-40 °C for showering or bathing; up to 60 °C for cleaning). The definition of needs expressed in terms of MWI and TWI is independent of the cold water temperature TC. However, the energy content Qn of the required hot water (energy needs) depends on the cold water temperature. Further, in the case of mixing, the cold water temperature determines the amount of warm water that can be gained from a given amount Mhot of hot water.
The average European consumes 36 litres of hot water each day (standardised to a temperature of 60 °C, starting from cold water at 10 °C).
While the consumption of hot water can be expected to increase with a higher standard of living, the decreasing number of persons per household may also have an impact.

Table 4: Volume of hot water required per person per day in Europe, and corresponding energy consumption

	Volume of hot water required (litres/day per person) (Th = 60 °C)	**Hot water energy needs (kWh/day per person)**
Minimum	10-20	0.6-1.2
Mean	20-40	1.2-2.4
Maximum	40-80	2.4-4.8

A.Test standards

Electric water heater test standards are issued by:

- the IEC (International Electrotechnical Commission), which is the relevant international standards authority
- CENELEC (Comité Européen de Normalisation Electrotechnique), the European standards organisation.

The relevant IEC energy measurement standard is IEC379 (3rdedition1987, replacing the 2ndedition of 1982), 'Methods for measuring the performance of electric storage water heaters for household purposes'.
This standard is covered at the European level in the CENELEC standard HD500S1(1987), 'Methods to be used for measuring energy consumption of thermal storage water heaters and for the purpose of informing consumers on it'.

There are no significant differences between these two standards (for a more detailed description, see Appendix 8.2).

A.Database

For the detailed analysis of the DESWH market, three main sources of information were used.

1. The CECED database, which comprises more than 2700 models of water heaters and represents about 80% of models available on the market. It is important to note that the CECED database includes only the number of models, and no sales data. As a member of the study group, CECED made the database available to the working groups.
2. Results of a questionnaire established by Ecole des Mines and prepared by the study group members. This questionnaire provides quantitative and qualitative data and can be used as a complementary source (for countries not covered by the CECED database, i.e. Austria, Ireland, Germany, Portugal and the UK) as well as a source of further information (e.g. electricity tariffs, prices of DESWHs, plumbers' wages) necessary for engineering and impact analyses.
3. Catalogue data regarding the dimensions of DESWHs on the Austrian/German market.

The structure of the CECED database is as follows:

- source (manufacturing) country of the DESWH
- countries in which the DESWHs are distributed
- brand (up to 4 different brand names)
- commercial reference
- capacity (in litres)
- rated capacity (in litres)
- mixed water quantity (in litres)
- standing losses per 24 h (in kWh).

In the CECED database, storage water heaters are assigned to seven groups:

- horizontal (575; 21.0%)
- mixed horizontal (72; 2.6%)
- mural vertical (926; 33.8%)
- pedestal vertical (328; 12.0%)
- mixed pedestal vertical (155; 5.7%)
- mixed vertical (203; 7.4%)
- small capacity, 5-50 litre (482; 17.6%).

Mural vertical, horizontal and small-capacity DESWHs account for nearly three-quarters of existing models (see Figure 3). Figure 4 shows the basic technical designs of these three most important types of DESWHs (together with a simplified drawing of pedestal vertical DESWHs).

A more detailed analysis of the CECED database was carried out to define DESWH categories, groups of water heaters that can be considered homogeneous with respect to their technical characteristics and therefore comparable regarding their standing losses/energy efficiency. This led to the following conclusions:

i) vertical DESWHs are more efficient than horizontal ones (water stratification is better for vertical units)

ii)high-capacity DESWHs are more efficient than small ones
iii)mixed horizontal DESWHs consume more electricity than horizontal ones and mural vertical DESWHs consume less than other types of vertical DESWH; however, these differences are negligible
iv)there is no significant difference in the performance of mural and pedestal DESWHs, although it can be expected that the way of fixing a boiler has an influence on losses as a result of thermal bridges
v)according to the database analysis there is no difference in energy efficiency between mixed DESWHs and other DESWHs.

On the basis of these conclusions, the seven DESWH groups in the CECED database can be assigned to the following three categories:

- small DESWHs, with a capacity of 5-50 litres (representing 20% of all models)
- horizontal DESWHs, with a capacity of more than 50 litres (22% of all models)
- vertical DESWHs, with a capacity of more than 50 litres (58% of all models).

Within these categories a distinction is made according to DESWH capacity.

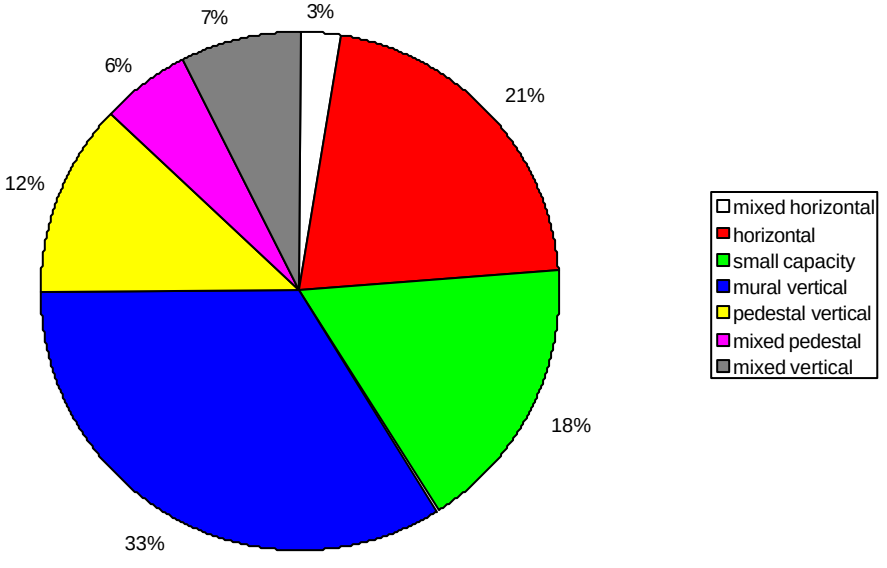

Figure 3: Distribution of types of DESWH comprising the CECED data base