ANALYSIS OF ENERGY EFFICIENCY OF DOMESTIC ELECTRIC STORAGE WATER HEATERS

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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/HD 500 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 ($L_{St,BC}$)
Vertical	> 50–1000	$0.2 + 0.051 * V^{2/3}$
Horizontal	> 50–300	$0.75 + 0.008 * V$
Small	5–50	$0.13 + 0.0553 * V^{2/3}$

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[1] 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 11 cm, 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

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[1]

LT-200 C	200 litre DESWH, located in the cellar, low electricity tariff
LT-150 B	150 litre DESWH, located in the bathroom, low electricity tariff
LT-75 B	75 litre DESWH, located in the bathroom, high electricity tariff

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 $L_{st,BC}$ 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 CO_2 reduction (Mt CO_2)	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.

RESUMÉ

Présentation de l'étude

Ce rapport contient les résultats d'une étude effectuée sur l'efficacité énergétique des ballons d'eau chaude électriques pour utilisation domestique dans l'Union européenne. Cette étude a été subventionnée dans le cadre du programme SAVE. Elle fait partie de l'initiative européenne ayant pour but d'explorer le potentiel et le développement des stratégies destinées à améliorer l'efficacité énergétique des appareils électriques domestiques. Elle complète les analyses sur l'efficacité énergétique des réfrigérateurs et congélateurs, des machines à laver le linge et la vaisselle, des sèche-linge ainsi que des téléviseurs et magnétoscopes.

Les résultats, conclusions et recommandations présentés sont basés sur cinq rapports techniques.

Préparation d'eau chaude électrique en Europe

La consommation d'électricité totale par les ballons d'eau chaude électriques en Europe s'élevait en 1987à 87 TWh. Les pertes en attende représentaient 22% ou 19 TWh de ce total, à peu près l'équivalent de la consommation totale d'électricité en Irlande. Les ballons d'eau chaude électriques pour utilisation domestique représentent 15% de la consommation électrique domestique et forment ainsi le second groupe le plus important des appareils électriques domestiques.

Environ 30% (43,5 millions) des 142 millions des foyers de l'Union européenne utilisent les systèmes électriques de préparation d'eau chaude. Le pourcentage des foyers dans chaque pays qui utilisent l'électricité pour chauffer l'eau est de plus de 40% au Luxembourg, en Autriche, en France et en Allemagne, entre 30% et 40% en Italie, en Belgique et en Finlande, légèrement supérieur à 20% au Royaume-Uni, entre 10% et 20% au Portugal, en Suède, aux Pays-Bas, en Irlande, au Danemark et en Espagne, et inférieur à 10% en Grèce.

Mesurage de l'efficacité énergétique des ballons d'eau chaude électriques pour utilisation domestique

Le meilleur paramètre individuel pour définir l'efficacité énergétique des ballons d'eau chaude électriques est une quantification de leurs pertes en attente. Le standard CIE 379/ HD S-1 définie la méthode de référence la plus appropriée pour mesurer les pertes en attende. Il est déjà utilisé dans tous les pays européens pour définir et décrire les pertes en attente sur 24h ainsi que pour mettre en place un protocole de mesure.

Sur la base des données fournies par la CECED pour 1995, qui couvrent environ 80% du marché européen des ballons d'eau chaude électriques, les pertes en attente moyennes (standard) ont été calculées et sont utilisées pour définir le « cas de base » pour les analyses techniques/économiques suivantes. Le cas de base pour les pertes en attente ($L_{ST,BC}$) est approximativement la valeur estimative des moyennes pondérées et non pondérées (avec le nombre des modèles) et peut être décrit de la façon suivante (voir tableaux ci-dessous) :

Moyenne des pertes en attente des ballons d'eau chaude électriques (cas de base) comme fonction de la capacité nominale (V)

Type de ballons d'eau chaude électriques	**Capacité en litres**	**Cas de base pour les pertes en attente ($_{ST,BC}$)**
vertical	> 50-1000	0.2 +0,051 *$V^{2/3}$
horizontal	> 50-300	0.75 + 0/008 *V
petit	5-50	0.13 + 0.553 *$V^{2/3}$

Afin d'identifier les paramètres qui exercent une influence sur les pertes en attente, une analyse de sensibilité a été effectuée. Elle montre clairement que le principal facteur d'influence dépend de la relation entre l'épaisseur de l'isolation et la conductivité thermale. En utilisant la conductivité thermale de la mousse PU (0,0035 W/m K) et en utilisant des valeurs moyennes pour tous les paramètres physiques des ballons d'eau chaude électriques, on a trouvé une épaisseur d'isolation de 4-5 cm pour les modèles des ballons d'eau chaude électriques considérés comme cas de base (c.à.d. ayant les mêmes pertes en attente que le cas de base).

Epaisseur optimale d'isolation

L'analyse du coût du cycle de vie prend en considération les coûts totaux pour l'approvisionnement en eau chaude pendant la durée de vie d'un ballon d'eau chaude électrique. Dans cette étude, les coûts du cycle de vie ont été calculés comme la somme du coût pour l'isolation d'un ballon d'eau chaude électrique et le coût de ses pertes en attente réelles escomptées pendant sa durée de vie. Toutes les composantes du prix relatif à une plus grande isolation[2] ont été inclues dans un prix d'isolation spécifique de 0,6 ECU/litre.

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[2] par ex., coût supplémentaire de matériaux, transformation de la chaîne de production

Trois configurations[3] pour l'approvisionnement en eau chaude - sur la base d'un foyer de 3 personnes - ont été choisies pour les analyses économiques (coût du cycle de vie). Il en ressort une isolation optimale (en relation avec les coûts du cycle de vie les plus bas) entre 5 cm et 11 cm, selon les tarifs d'électricité dans les différents Etats membres de l'UE. Pour le « cas UE » (tarifs d'électricité moyens), l'épaisseur d'isolation optimale se situe entre 6,4 et 9,3 cm. En se référant aux pertes réelles d'emmagasinage, on peut démontrer qu'une plus grande épaisseur d'isolation permet de diminuer non seulement les pertes en attente mais aussi les coûts du cycle de vie.

Les principaux facteurs qui influencent le niveau d'isolation optimale sont les coûts d'isolation supplémentaires et le prix de l'électricité. Le taux d'escompte, la température ambiante et les conditions d'utilisation sont d'importance mineure.

L'analyse économique/technique indique que les épaisseurs d'isolation optimales dans les différents pays varient largement les uns par rapport aux autres, mais sont supérieurs à l'épaisseur d'isolation du cas de base à l'intérieur de chaque pays membre de l'UE. D'autre part, il y a des séries de modèles de ballons d'eau chaude électriques avec une performance inférieure à celle du cas de base. C'est pourquoi une politique énergétique basée sur deux stratégies principales semble être l'approche la plus appropriée: à savoir définir un standard minimum de l'efficacité énergétique et mettre en place un système de labels.

Standard minimum pour l'efficacité énergétique et ses effets

Pour déterminer un standard minimum de l'efficacité énergétique, il faut tenir compte des variations potentielles des facteurs ayant un effet sur l'épaisseur optimale d'isolation (par ex. le profil d'utilisation, la durée de vie des appareils, les coûts additionnels d'isolation, les tarifs d'électricité en vigueur dans les différents pays). C'est pourquoi le cas de base $L_{ST,BC}$ a été sélectionné pour définir le standard minimum de l'efficacité énergétique.

Le fait de choisir un niveau de performance modéré limite les augmentations de prix des ballons d'eau chaude électriques perfectionnés, évite les effets négatifs pour les fabricants, et présente en même temps des avantages pour les consommateurs.

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[3] 200 litres, installé dans la cave, tarif de nuit

150 litres, installé dans la salle-de-bains, tarif de nuit

75 litres, installé dans la salle-de-bains, tarif standard

On peut s’attendre à ce que le standard minimum d’efficacité proposé ait les effets suivants:

Répercussions sur la société du standard minimum d’efficacité proposé

Données non accumulées	**2000**	**2005**	**2001**
Consommateurs Epargnes (million ECU)	54	173	259
Fabricants Rendement en capital propre (changement en %)	-0,4	0,0	0,0
Environnement/société Réduction de CO_2 (Mt CO_2)	0,22	0,73	1,10
Environnement/société Réduction de la consommation d’électrité (GWh)	452	1 445	2 158

Label

L’octroi d’un label pour les ballons d’eau chaude électriques est la mesure d’information la plus importante parmi toutes celles proposées. Le label est une aide pour toutes les personnes concernées. Les consommateurs souffrent d’un grand déficit d’information. Même si les personnes autres que l’utilisateur (par ex. les plombiers) choisissent le ballon d’eau chaude électrique, le label fournira des informations qui ne sont pas disponibles actuellement. En accord avec les programmes de label propres à l’UE, une classification allant de A à G est proposée.

Autres mesures

Il faudrait mettre en place des mesures d’information supplémentaire pour promouvoir le label, conseiller les acheteurs potentiels, les plombiers et les vendeurs sur les avantages économiques de l’achat d’un ballon d’eau chaude électrique avec une meilleure efficacité énergétique. Il serait aussi souhaitable d'encourager les foyers - s'ils prennent la décision d'achat - à demander aux tierces personnes (par ex. les installateurs) d'assumer leur responsabilité par rapport aux coûts de fonctionnement.

De plus, on devrait exposer aux acheteurs qui s’occupent eux-mêmes de l'installation et aux plombiers la meilleure façon de choisir un ballon d’eau chaude électrique (par ex. par rapport à la capacité, le modèle, le tarif), de l’installer (par ex. l’emplacement, les dimensions, l’installation et l’isolation des tuyaux) et de l’utiliser (appareils permettant d’économiser de l’eau, les thermostats). Des mesures de R&D sont nécessaires pour continuer à améliorer la performance des ballons d’eau chaude électriques. Cela veut dire de meilleurs matériaux d’isolation, des systèmes de contrôle intelligents et des armatures permettant d’éviter/de réduire les ponts thermiques.

Executive Summary

Hintergrund der Studie

Dieser Bericht faßt die Ergebnisse einer Studie über die Energieeffizienz von elektrischen Warmwasserspeichern für Haushalte in der EU zusammen. Die Untersuchung wurde von der Europäischen Kommission beauftragt und durch das SAVE-Programm gefördert. Sie setzt die Initiative der EU zur Analyse der Potentiale und Entwicklung von Umsetzungsstrategien zur Verbesserung der Energieeffizienz von elektrischen Haushaltsgeräten fort. Bisher wurden bereits Studien zur Energieeffizienz von Kühlgeräten, Waschmaschinen, Geschirrspülern und Trocknern sowie für Fernseher und Videorecorder erarbeitet. Die vorgestellten Ergebnisse, Schlußfolgerungen und Empfehlungen basieren auf fünf Teilberichten.

Elektrische Warmwasserbereitung in Europa

Der gesamte Stromverbrauch für elektrische Warmwasserspeicher für Haushalte in der EU betrug 1997 87 TWh. Die Bereitschaftsverluste machten 22% oder 19 TWh davon aus, was in etwa dem Stromverbrauch von Irland entspricht. Mit einem Anteil von 15% am Stromverbrauch der Haushalte sind elektrische Warmwasserspeicher die zweitwichtigste Gruppe von Haushaltsgeräten.

Etwa 30% (43,5 Mio.) der 142 Mio. EU-Haushalte verwenden elektrische Warmwasserbereitungssysteme. Der Prozentanteil der Haushalte, die Wasser elektrisch erwärmen, liegt in Luxemburg, Österreich, Frankreich und Deutschland über 40%, in Italien, Belgien und Finnland zwischen 30 und 40 %, in Großbritannien knapp über 20 %, in Portugal, Schweden, den Niederlanden, Irland, Dänemark und Spanien zwischen 10 und 20%, und in Griechenland unter 10 %.

Messung der Energieeffizienz von elektrischen Warmwasserspeichern

Der beste Einzelparameter, um die Energieeffizienz eines elektrischen Warmwasserspeichers zu beschreiben, ist die Quantifizierung seiner Bereitschaftsverluste. Der IEC 379/HD 500 S1-Standard definiert die geeignetste Methode zur Messung der Bereitschaftsverluste. Er wird bereits in allen europäischen Ländern verwendet, um die 24 Stunden-Bereitschaftsverluste zu definieren und zu beschreiben und um ein Meßprotokoll zu erstellen.

Basierend auf den Daten, die von CECED[4] für 1995 zur Verfügung gestellt wurden, und die etwa 80% des europäischen Marktes abdecken, wurden die durchschnittlichen (Standard-) Bereitschaftsverluste ermittelt. Diese werden verwendet, um den ”base case” für die folgende technisch-ökonomische Analyse zu definieren. Der „base case“ der

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[4] Europäischer Verband der Weißwarenerzeuger.

Bereitschaftsverluste ist die Regressionskurve aus den ungewichteten und - mit der Anzahl der Modelle - gewichteten Durchschnitten der Bereitschaftsverluste und kann folgendermaßen beschrieben werden (s. Tabelle).

Durchschnittliche Bereitschaftsverluste („base case“) von elektrischen Warmwasserspeichern als Funktion des Nenninhalts (V)

Art	Nenninhalt in Liter	„Base case“ der Bereitschaftsverluste
Vertikal	> 50 – 1000	$0,2 + 0,051 * V^{2/3}$
Horizontal	>50 – 300	$0,75 + 0,008 * V$
Klein	5 – 50	$0,13 + 0,0553 * V^{2/3}$

Um die relevanten Parameter zu identifizieren, die die Bereitschaftsverluste beeinflussen, wurde eine Sensitivitätsanalyse durchgeführt. Sie zeigt deutlich, daß der Haupteinfluß auf die Bereitschaftsverluste aus dem Verhältnis Isolierungstärke zu Wärmeleitwert resultiert. Unter Verwendung des Wärmeleitwerts für PU Schaum (0,035 W/m K) und unter Verwendung von Durchschnittswerten für alle physikalischen Größen von elektrischen Warmwasserspeichern wurde eine Isolierungsstärke von 4 – 5 cm für die „base case-Modelle“[5] errechnet.

Optimale Isolierungsstärke

Die Lebenszyklusanalyse berücksichtigt die gesamten Kosten der Warmwasserbereitung während der Lebensdauer des elektrischen Warmwasserspeichers. In dieser Studie wurden die Lebenszykluskosten als die Summe der Kosten für die Isolierung eines elektrischen Warmwasserspeichers und seiner diskontierten realen Bereitschaftsverluste während der Lebensdauer des Speichers definiert. Alle Preiskomponenten im Zusammenhang mit einer stärkeren Isolierung[6] wurden in einen spezifischen Isolierungspreis von 0,6 ECU/Liter eingerechnet.

Drei Konfigurationen[7] für die Warmwasserbereitung, basierend auf einem 3-Personen Haushalt, wurden für die ökonomische Analyse der Lebenszykluskosten (LCC) gewählt. Daraus ergibt sich eine optimale Isolierung (im Bezug auf die niedrigsten Lebenszykluskosten) zwischen 5 und 11 cm, abhängig von den Stromtarifen in den verschiedenen EU-Mitgliedsländern. Für den EU-Durchschnitt (durchschnittliche Stromtarife) beträgt die optimale Isolierungsstärke zwischen 6,4 und 9,3 cm. Bezogen auf die

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[5] Das sind jene, die die Bereitschaftsverluste des „base case“ aufweisen.

[6] Z. B. zusätzlicher Materialaufwand, Umbau der Fertigungsstraße.

[7] 200 Liter, im Keller installiert, Nachttarif
150 Liter, im Badezimmer installiert, Nachttarif
75 Liter, im Badezimmer installiert, Standardtarif.

tatsächlichen Speicherverlusten läßt sich aufzeigen, daß sich mit zunehmender Isolierungsstärke nicht nur die Bereitschaftsverluste sondern auch die Lebenszykluskosten verringern.

Die Hauptfaktoren, die die optimale Isolierstärke beeinflussen, sind die zusätzlichen Isolierungskosten und der Stromtarif. Die Diskontrate, die Umgebungstemperatur und die Nutzungscharakteristik sind von geringerer Bedeutung.

Die technisch/ökonomische Analyse zeigt auf, daß die länderspezifischen optimalen Isolierungsstärken stark voneinander abweichen, aber größer sind als die Isolierungsstärke des „base case“ innerhalb jedes EU-Mitgliedslandes. Andererseits gibt es eine Reihe von Warmwasserspeichern, die noch schlechter (isoliert) sind als jene des „base case“. Daher scheint ein energiepolitischer Mix, basierend auf zwei Hauptstrategien, die geeignetste Vorgangsweise: einen ***Mindeststandard für die Energieeffizienz*** vorzusehen und ein ***Kennzeichnung*** (Labelling) von elektrischen Warmwasserspeichern einzuführen.

Effekte des Mindeststandards

Bei der Festlegung eines Mindeststandards für elektrische Warmwasserspeicher müssen die möglichen Schwankungen der wesentlichen Einflußfaktoren (z.B. Nutzungsprofil, Lebensdauer der Geräte, zusätzliche Kosten der Isolierung, länderspezifische Stromtarife) berücksichtigt werden. Aus diesem Grund wurde der „base case“ ausgewählt, um den Mindeststandard zu definieren. Die Wahl dieses moderaten Effizienzniveaus beschränkt den Preisanstieg für die verbesserten Warmwasserspeicher, vermeidet negative Effekte für die Gerätehersteller und führt zugleich zu Vorteilen für die Konsumenten.

Der vorgeschlagene Mindeststandard läßt folgende Effekte erwarten[8]:

	Jahr		
	2000	**2005**	**2010**
Konsumenten Einsparung bei Stromrechnung (Mio. ECU)	54	173	259
Hersteller Eigenkapitalrendite (Veränderung in %)	-0,4	0,0	0,0
Umwelt, Gesellschaft CO_2 Reduktion (Mt CO_2)	0,22	0,73	1,10
Umwelt, Gesellschaft Reduktion des Stromverbrauchs (GWh)	452	1.445	2.158

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[8] Werte sind nicht kumuliert.

Energieverbrauchskennzeichnung - Labelling

Von den vorgeschlagenen Informationsaktivitäten ist das Labelling von elektrischen Warmwasserspeichern die wichtigste Maßnahme. Labelling „bietet eine Sprache“ für alle Beteiligten. Konsumenten haben einen großen Informationsbedarf. Auch wenn andere Personen als der Benutzer (z.B. Installateure) den Warmwasserspeicher auswählen, bietet die Kennzeichnung Informationen, die jetzt nicht verfügbar sind. In Übereinstimmung mit den existierenden EU-Kennzeichungsschemata bei anderen Geräten, wird eine Klassierung von A bis G vorgeschlagen.

Andere Maßnahmen

Zusätzliche Informationsaktivitäten sollten durchgeführt werden, um das Label zu verbreiten und potentiellen Käufern sowie den Installateuren und Händlern Beratung über die ökonomischen Vorteile von elektrischen Warmwasserspeichern mit verbesserter Energieeffizienz zu bieten. Speziell die Haushalte sollten darauf aufmerksam gemacht werden, daß bei einer Delegation der Kaufentscheidung an Dritte (z.B. Installateure) diese damit auch über ihre künftigen Betriebskosten entscheiden. Weiters sollte die ”beste Vorgangsweise” bei der Auswahl (Kapazität, Typ, Tarif), eines elektrischen Warmwasserspeichers, seiner Installierung (Aufstellung, Dimensionierung, Montage und Isolierung der Rohre) und Benutzung (Wasserspar-Anleitungen, Zeitkontrollen) für Heimwerker und Installateure demonstriert werden. F&E-Aktivitäten sind erforderlich, um weitere Verbesserungen der Energieeffizienz von elektrischen Warmwasserspeichern zu erzielen. Dazu gehören bessere Isoliermaterialien, intelligente Steuerungssysteme sowie Armaturen zur Vermeidung bzw. Reduzierung von Wärmebrücken.

1 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[9]. 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).

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[9] CECED is the European Committee of Manufacturers of Domestic Equipment.

2 ELECTRIC WATER HEATING IN EUROPE: AN OVERVIEW

2.1 Relevance of electric water heating for households

The total EU electricity consumption by DESWHs in 1997 was 87 TWh[10]. 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[11].

About 30% (43.5 million) of the EU's 142 million households[12] use electric water heating systems[13]. 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.

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[10] Result of stock model used in task 4.

[11] Based on 1994 data sets.

[12] Including the new member states Austria, Finland and Sweden.

[13] Based on data sets from 1992 to 1995.

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	34 600	15 200 (43.9)
Austria	2 960	1 290 (43.6)
France	21 000	8 800 (41.9)
Finland	1 700	650 (38.2)
Belgium	3 900	1 287 (33.0)
Italy	25 021	8 257 (33.0)
UK	22 600	4 755 (21.0)
Portugal	2 710	515 (19.0)
Sweden	2 800	530 (18.9)
Spain	11 300	1 900 (16.8)
Netherlands	6 000	1 000 (16.7)
Ireland	1 070	170 (15.9)
Denmark	2 420	320 (13.2)
Greece	3 100	160 (5.2)
EU total	**141 281**	**44 879 (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 4 million 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 15.2 million 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%[14] of the total stock (see Figure 1).

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[14] Countries directly involved in this study represent more than 95% of the EU stock.

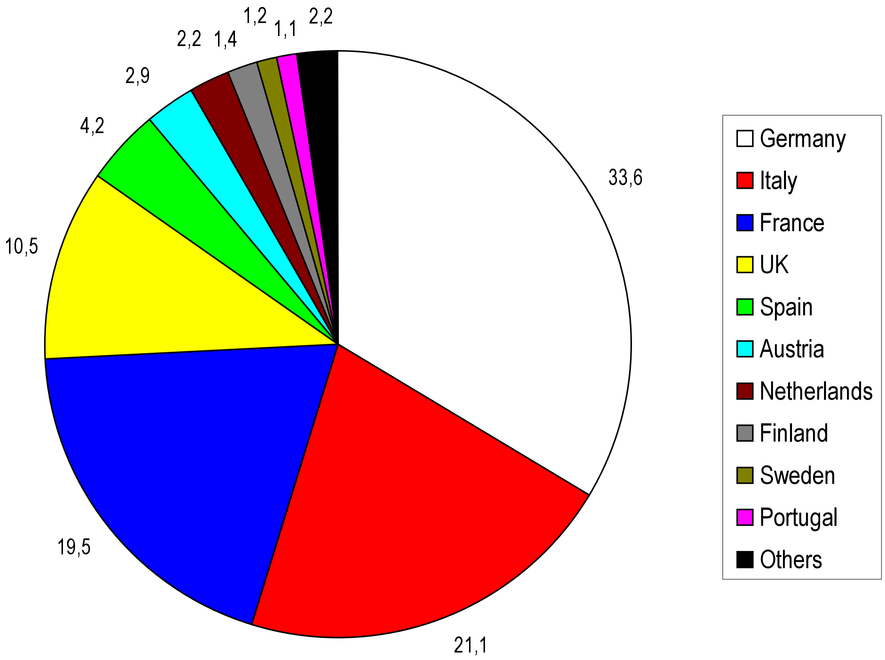

Figure 1: **Distribution of DESWH stock among European Union member states**

2.2 DESWH capacity and electricity consumption

There is a wide variation between European countries in the distribution of the water storage capacity[15] 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).

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[15] This term refers to the IEC 379 standard, which uses 'rated capacity', meaning the water capacity (volume in litres) assigned to the DESWH by the manufacturer.

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[16] yielded the results shown in Table 3.

Table 3: Average consumption of DESWHs in Austria, France, Germany and Portugal[17]

Country	Storage capacity (litres)	Consumption (kWh/year)
Austria (1990)	<15	1 017
	>15	2 183
France (1995)	Mean	2 402
Germany (1991)	<15	968
	15–200	1 968
	>200	2 416
Portugal (1991)[18]	15–20	3 112
	>200	3 071

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[16] In which the appropriate information was available.

[17] Average consumption of stock in reference year, reference year in brackets.

[18] Average consumption of sales in reference year, reference year in brackets.

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.

2.3 Sales trends for hot water producing appliances

Aggregated sales trends[19] (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.

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[19] Including France, Germany, the UK, Italy, Spain, Portugal, Belgium, the Netherlands, Austria and Switzerland.

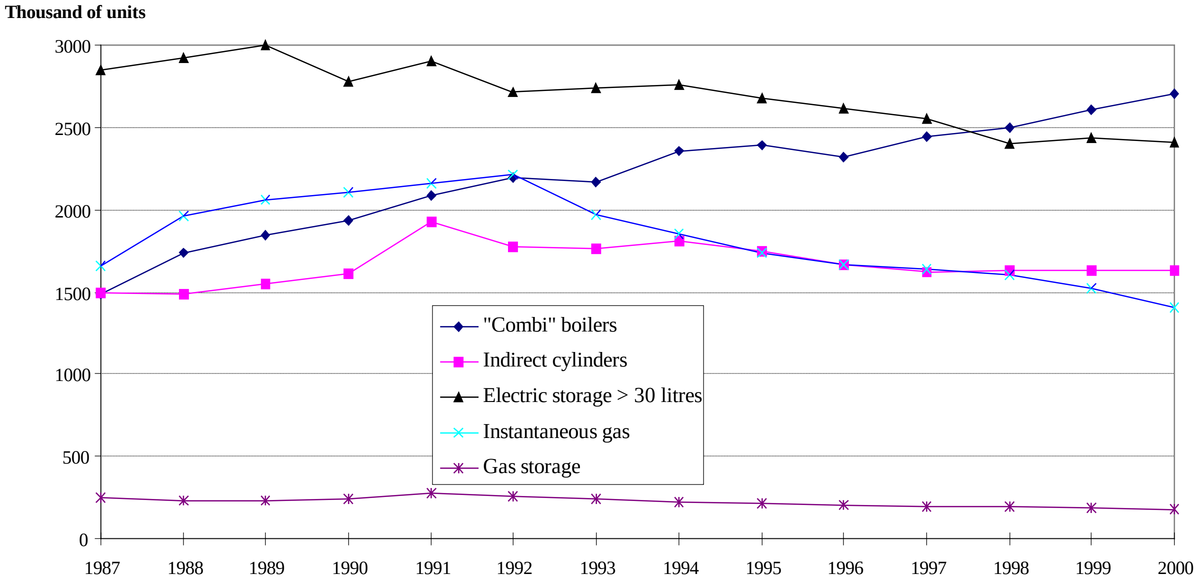

Figure 2: Sales trends for principal water heating products from 1987 to 2000 for 10 European countries[20]

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 (960 000 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[21] of DESWHs had a stronger growth than imports[22].

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[20] Including France, Germany, the UK, Italy, Spain, Portugal, Belgium, the Netherlands, Austria and Switzerland.

[21] About 2.5 million DESWH units were exported in 1994.

[22] Between 1990 and 1994.

3 TECHNICAL FRAMEWORK OF THE STUDY

3.1 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[23]. The needs of the user can be expressed by certain quantities, M_{WI}, of warm water at temperature T_{WI} 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 M_{WI} and T_{WI} is independent of the cold water temperature T_C. However, the energy content Q_n 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 M_{hot} 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.

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[23] Typical use of hot water includes: a) kitchen: washing, cooking, cleaning, washing machine, dishwasher (supply of these machines with warm water is frequent in the USA, the UK and Ireland); b) bathroom: basin (hand and body washing), shower, bath, hand-washing of clothes.

Table 4: Volume of hot water required per person per day in Europe, and corresponding energy consumption[24]

	Volume of hot water required (litres/day per person) (T_h = 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

3.2 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 IEC 379 (3rd edition 1987, replacing the 2nd edition 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 HD 500 S1 (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).

3.3 Database

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

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[24] Recknagl, Sprenger, Schramek (1995): Taschenbuch für Heizung und Klimatechnik. Oldenburg Verlag, München.

1. The CECED database, which comprises more than 2700 models of water heaters[25] 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[26], 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[27] of the DESWH
- countries in which the DESWHs are distributed
- brand (up to 4 different brand names)
- commercial reference[28]
- capacity[29] (in litres)
- rated capacity[30] (in litres)
- mixed water quantity (in litres[31])
- standing losses per 24 h (in kWh[32]).

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[25] Some models appear several times under different brand names.

[26] Germany is included in the CECED database, but some information is not included, and hence information from the questionnaire was used to complement the database.

[27] Includes Belgium, France, Germany, Italy, Spain and Switzerland.

[28] According to the seven groups described in the next paragraph.

[29] Actual thermal storage volume (excluding dead zones). Most models in the CECED database have a capacity equal to rated capacity.

[30] Water capacity assigned by the manufacturer.

[31] Quantity of hot water (40 °C) that can be obtained by mixing cold water (15 °C) and hot water (65 °C) from the DESWH.

In the CECED database, storage water heaters are assigned to seven groups[33]:

- horizontal (575; 21.0%)
- mixed[34] 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[35], 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

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[32] The standard test (IEC 379) is performed with a ΔT of 45 °C and a room temperature of 20 °C.

[33] The numbers in brackets refer to the number of models in the group and the model distribution share, respectively.

[34] 'Mixed' means mixed energy source (e.g. electricity/gas or electricity/solar).

[35] In a given appliance category a DESWH is defined by its rated capacity and its standing losses per 24 hours. DESWH energy efficiency can be assessed by comparing the standing losses of any two models in the same category and with the same capacity.

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[36] (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.

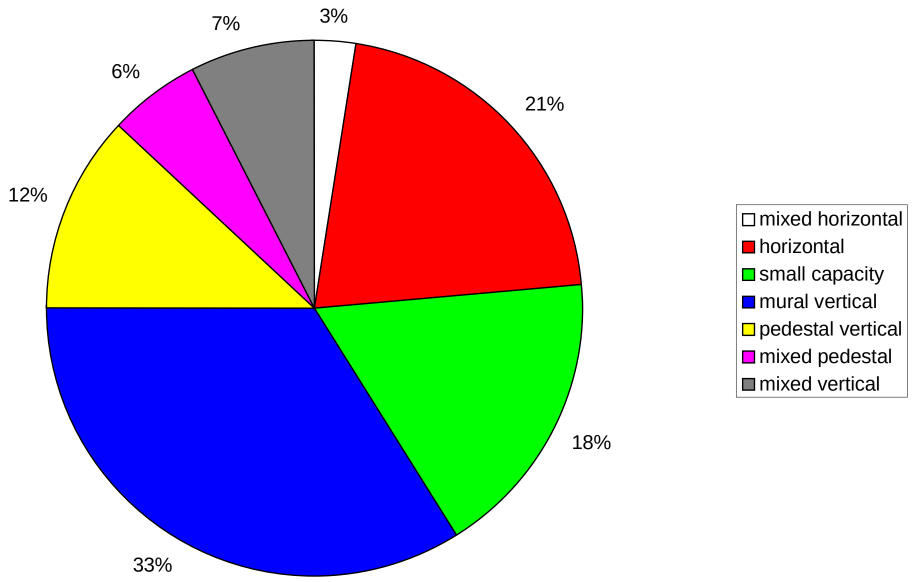

Figure 3: Distribution of types of DESWH comprising the CECED data base

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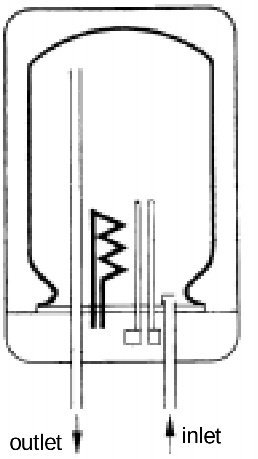
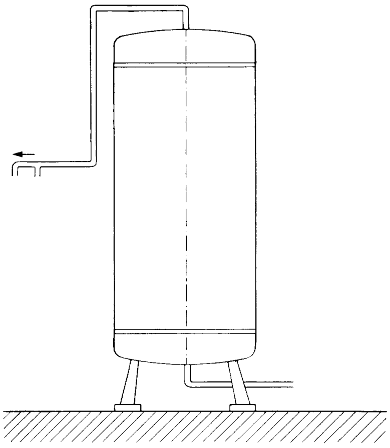
[36] This category includes DESWH models of 5–50 litres capacity from all groups.

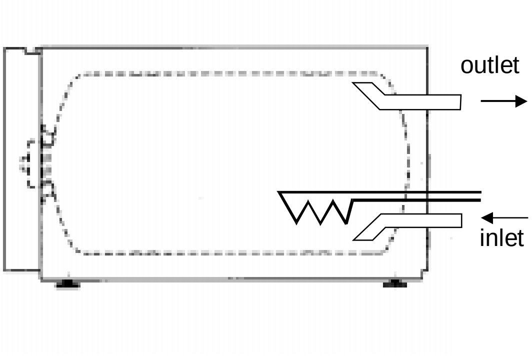
Mural vertical
(>50–1000 litres)



Pedestal vertical
(>150–1000 litres)



Horizontal (>50–300 litres)



Small
(5–50 litres)

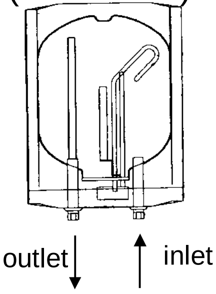


Figure 4: **Basic design of mural vertical, pedestal vertical, horizontal and small-capacity DESWHs**

4 OPTIONS FOR DESWH ENERGY EFFICIENCY IMPROVEMENTS

4.1 Definition of the base case

The best single parameter to describe the energy efficiency of a DESWH is a quantification of its standing losses. The IEC 379/HD 500 S1 standard defines the most appropriate reference method[37] 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)[38] 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[39]/unweighted averages and can be described as shown in Table 5 (V = rated capacity of the DESWH in litres).

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[37] There are also a number of national testing standards:

- UK: BS 5615, BS 699 and BS 1566; also requirements defined by the electricity industry for making use of the off-peak Economy 7 tariff.
- France: NF C 73-221 is used to classify DESWHs into two classes (A and B).
- Switzerland: performance requirements in the decrees from 22/1/92 and 7/7/93.
- Germany: DIN 44532 is fully consistent with IEC 379.

[38] According to the energy measurement standard IEC 379 (3rd edition, 1987). The term 'standing losses' will actually be used for 'standard standing losses' from here on.

[39] Weighted with the number of models.

Table 5: Average DESWH standing losses as a function of rated capacity[40]

Type of DESWH	Capacity (litres)	Base case for standing losses ($L_{St,BC}$)
Vertical	> 50–1000	$0.2 + 0.051 * V^{2/3}$
Horizontal	> 50–300	$0.75 + 0.008 * V$
Small	5–50	$0.13 + 0.0553 * V^{2/3}$

The base case standing losses for vertical, horizontal and small-capacity DESWHs are shown in Figures 5, 6 and 7 (derived from CECED data base).

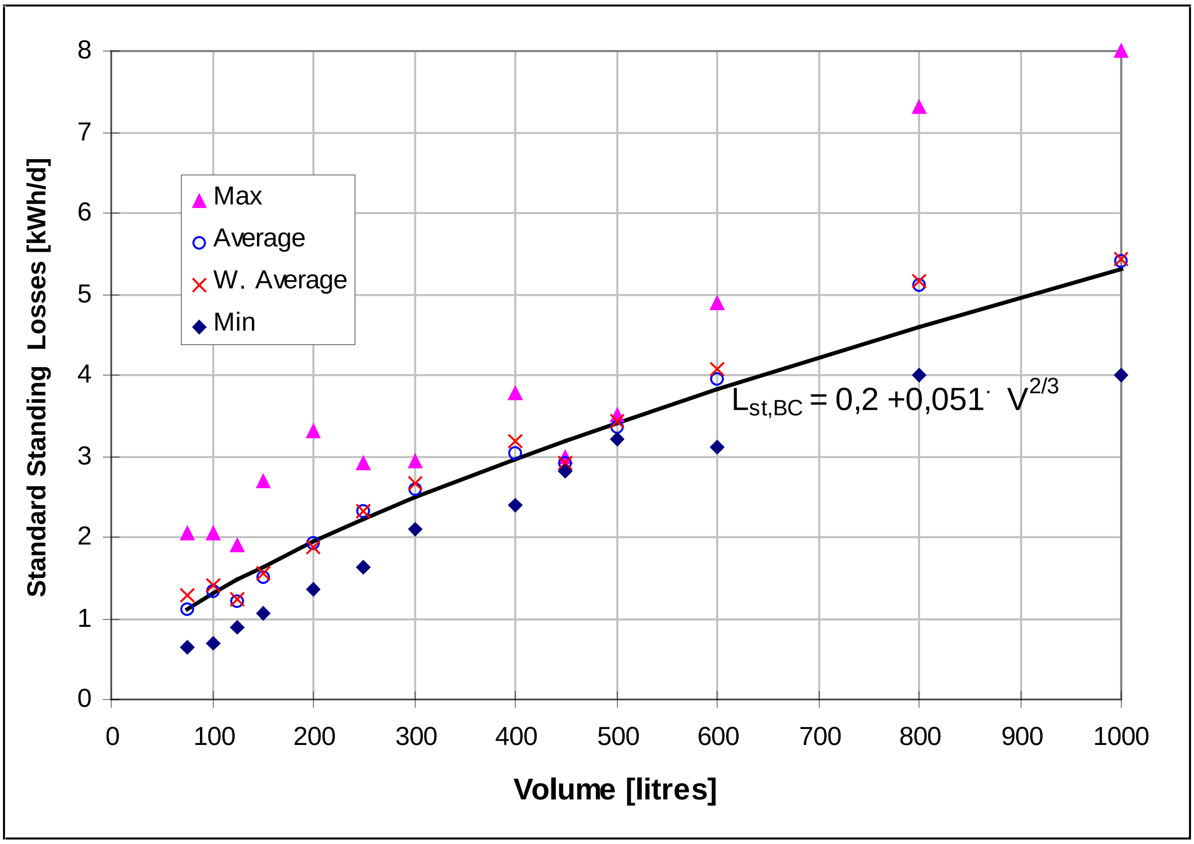

Figure 5: Base case standing losses for vertical DESWHs (50–1000 litres)

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[40] V = rated capacity in litres.

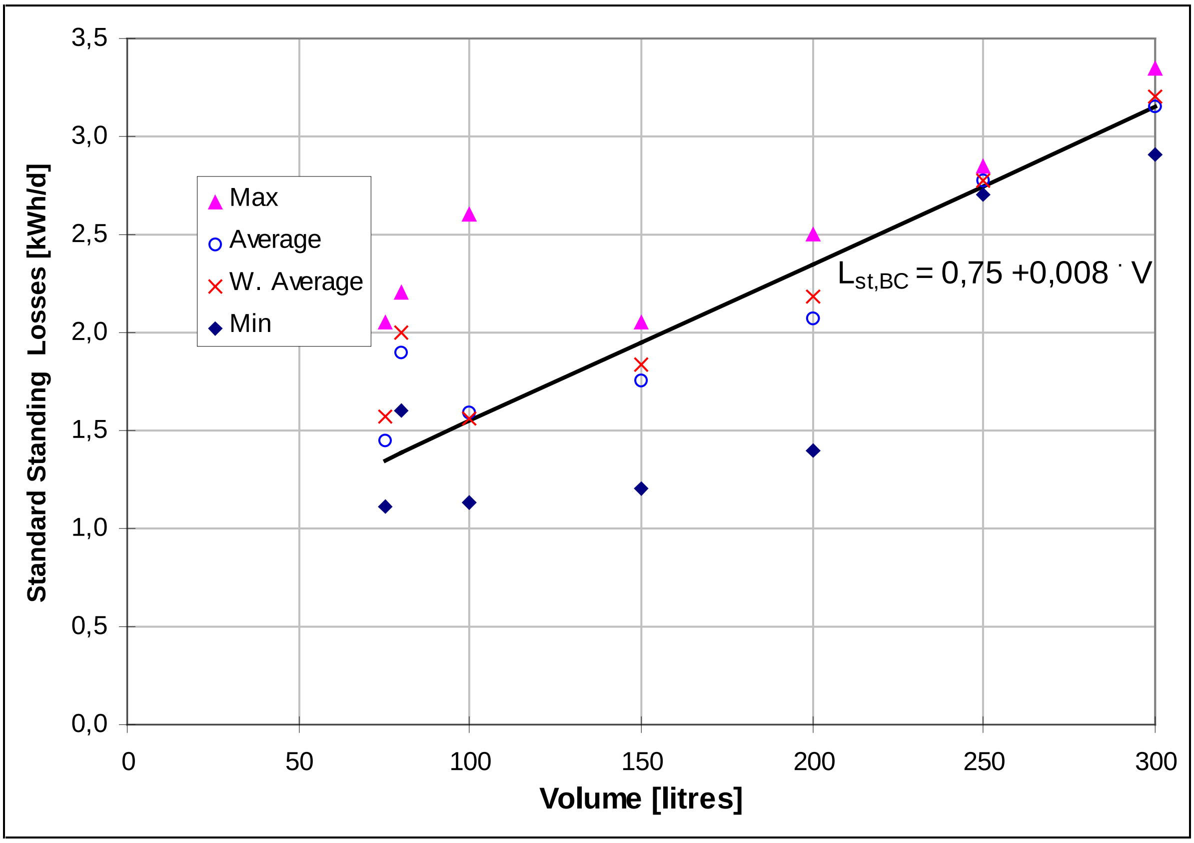

Figure 6: Base case standing losses for horizontal DESWHs (50–300 litres)

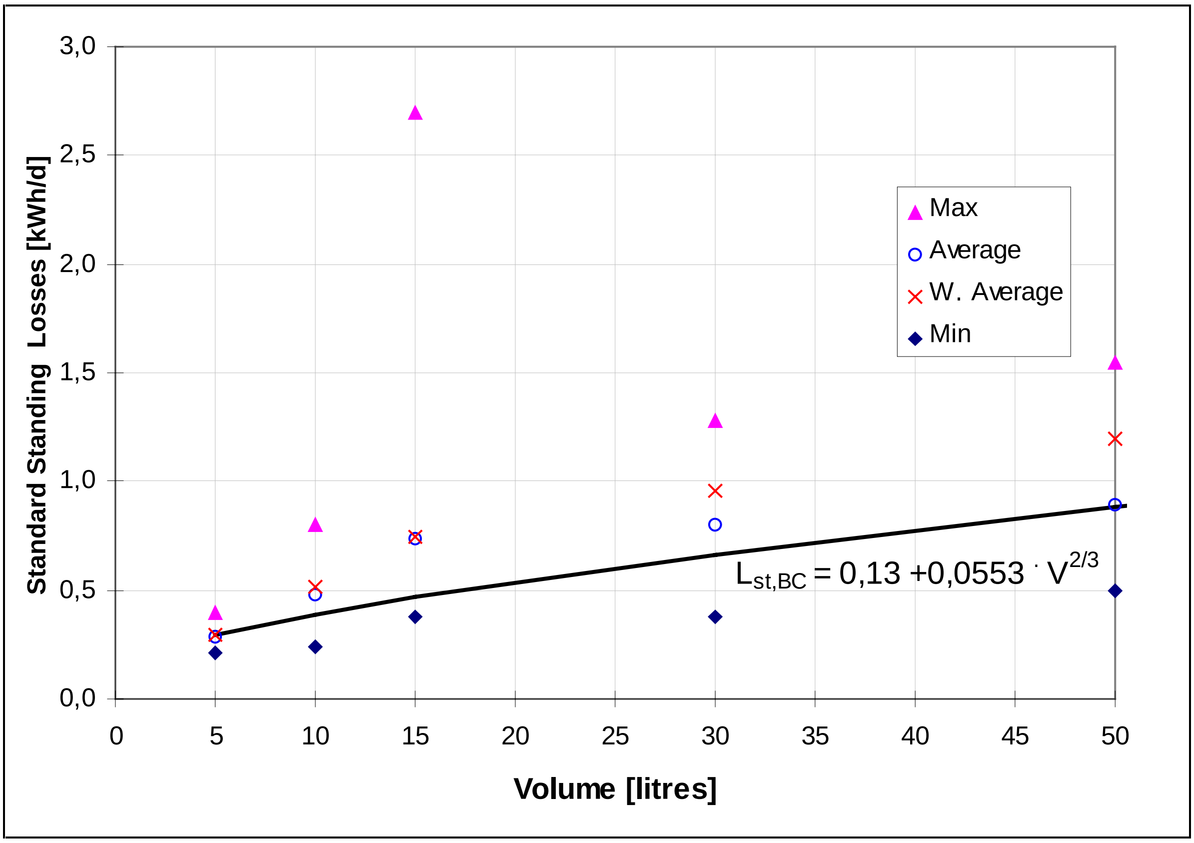

Figure 7: Base case standing losses for small DESWHs (5–50 litres)

4.2 Energy-saving potential

Analyses show a large range of standing losses for the same rated capacity and type of DESWH on the market[41]. The ratio of maximum to minimum standing losses is between 1.9 and 7.1 for small-capacity DESWHs (5–50 litres), between 1.06 and 3.15 for vertical DESWHs (>50 litres) and between 1.06 and 2.3 for horizontal ones (>50 litres). These indicate that there is a high energy-saving potential using existing DESWH technology.

Under the assumption that all models with higher standing losses than the base case are improved until they equal the base case standing losses (Potential 1), the energy-saving potential for small DESWHs is up to 55%, for vertical DESWHs up to 25% and for horizontal DESWHs up to 37%.

If all models were upgraded to the standing losses of the best available models on the market (Potential 2), the energy-saving potential is up to 88% for small DESWHs, up to 59% for vertical DESWHs and up to 47% for horizontal DESWHs.

Figures 8–10 present a more detailed picture of the energy-saving potentials against rated capacity.

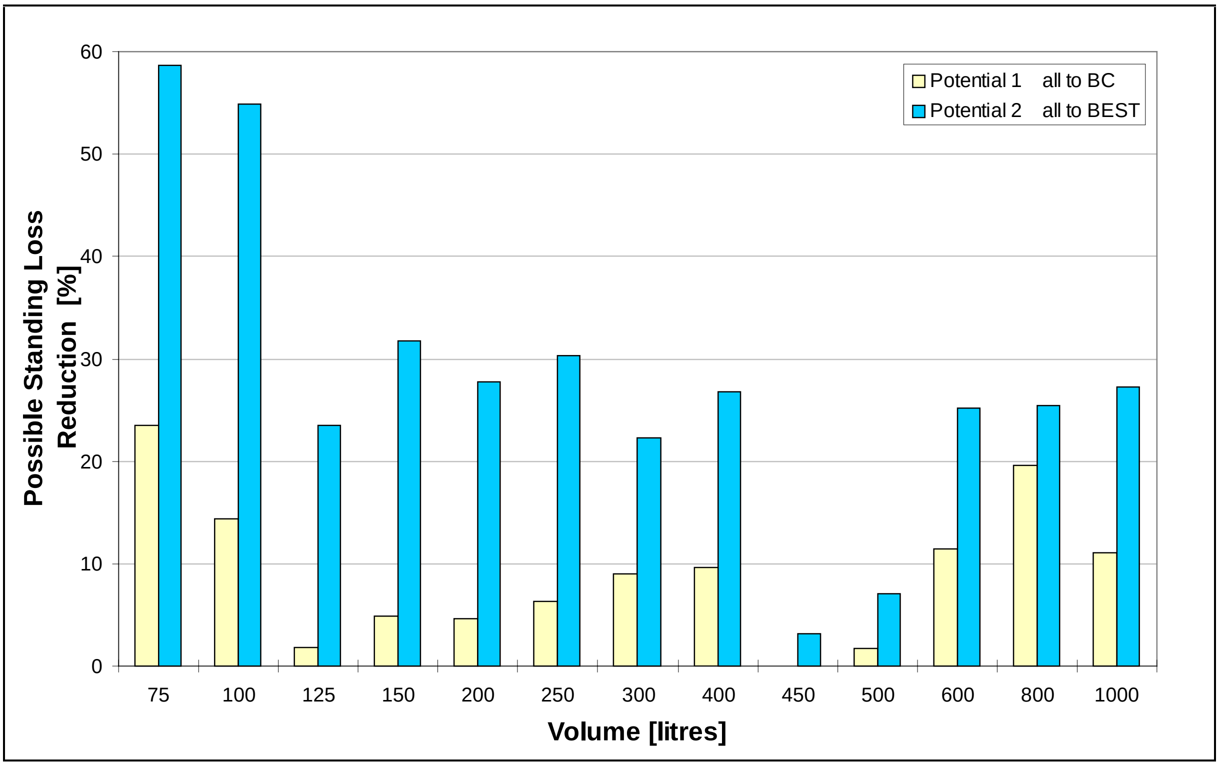

Figure 8: Energy-savings potentials (% of base case) for vertical DESWHs

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[41] Calculations are related to models because sales numbers were not available.

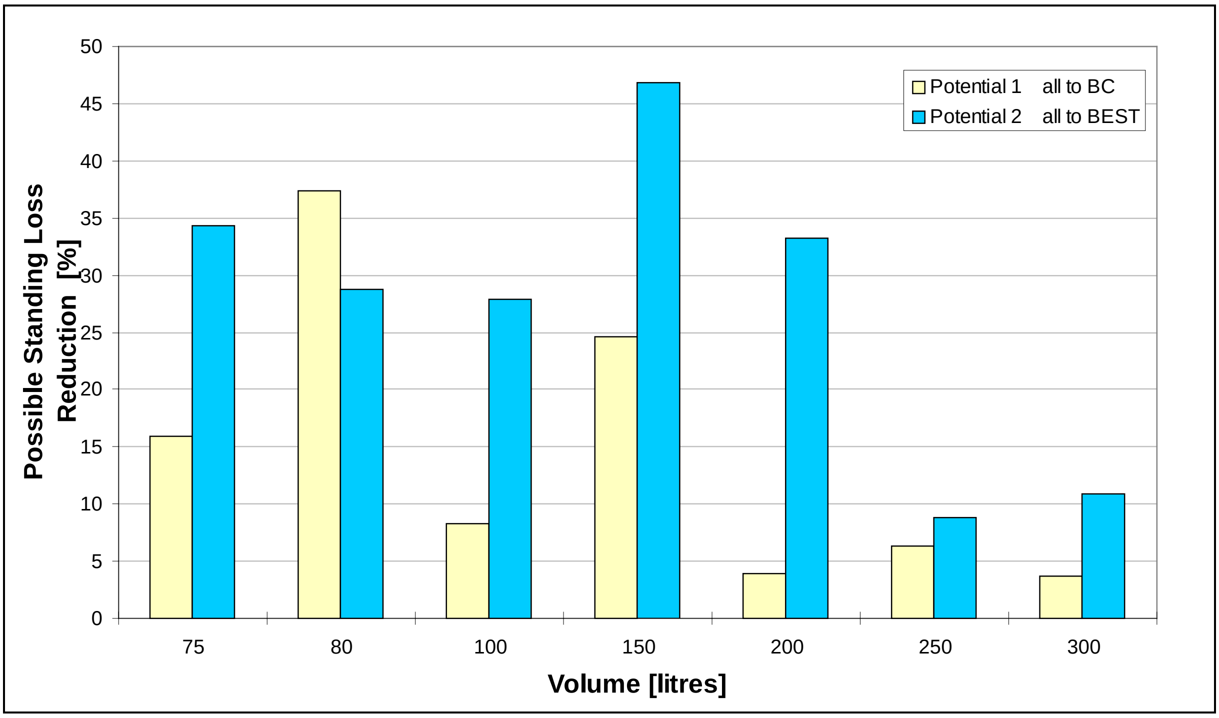

Figure 9: **Energy-savings potentials (% of base case) for horizontal DESWHs**

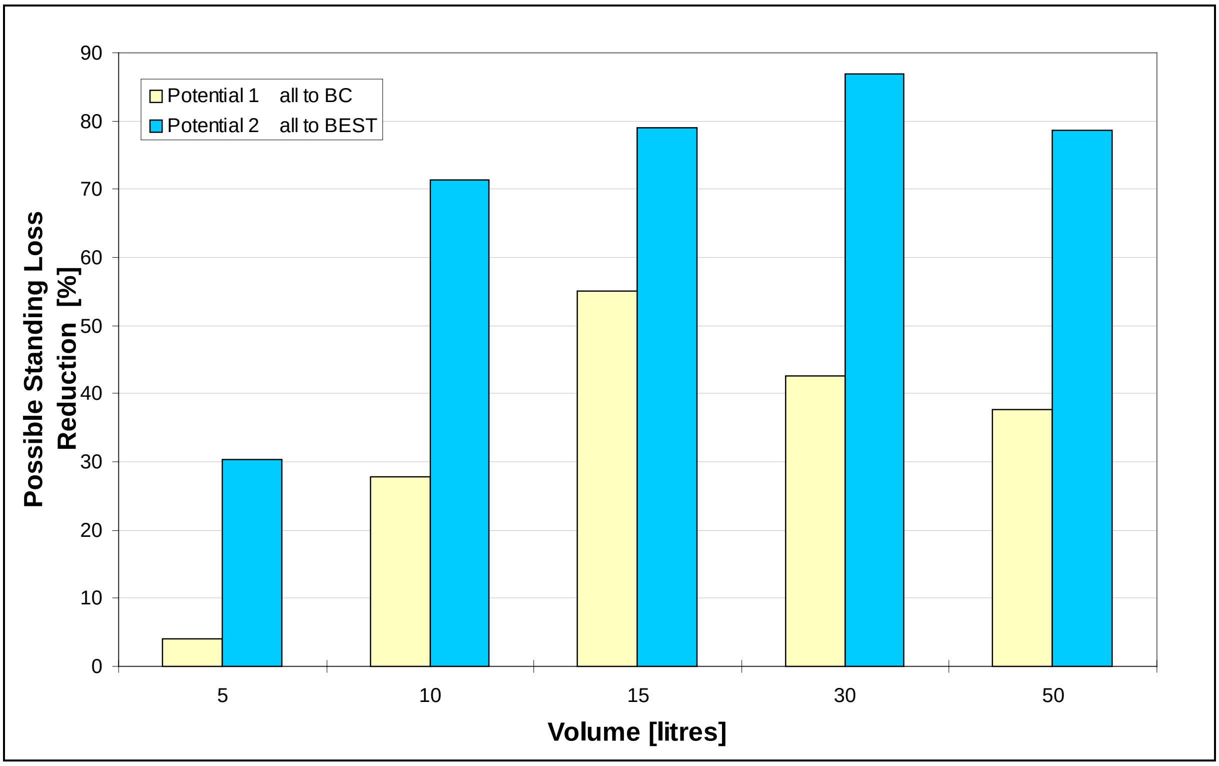

Figure 10: **Energy-savings potentials (% of base case) for small DESWHs**

4.3 Insulation thickness: the most important parameter influencing standing losses

In order to identify the relevant parameters influencing standing losses, a sensitivity analysis was conducted[42]. For this reason a mathematical simulation model[43] was developed that describes the standing losses of DESWHs with a series of physical parameters:

H:R	the boiler’s height:radius ratio
s, s_t	insulation thickness of the boiler: on the side and top, respectively
λ	thermal conductivity of the insulation material
$s:\lambda$	ratio of insulation thickness at the side to thermal conductivity
$s_t:s$	ratio of insulation thickness on top and at the sides
P_{fix}	fixed losses due to heat bridges (connections, flanges, etc.).

The variation in the magnitude of these parameters (see Figure 11[44]) likely to be found on the market shows that the main contributor is $s:\lambda$. No other parameter – single or combined – can explain the large differences in standing losses.

Using the thermal conductivity of PU foam (0.035 W/m K) and using average values for all parameters, the simulation model gives an insulation thickness of 4–5 cm[45] for

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[42] Since the CECED database did not contain all the necessary information, catalogue data were also used for 67 models.

[43] For more detail, see report on Task 3. This model was tested and showed realistic results that will be described in greater detail later.

[44] Variations for the example of a 200 litre vertical DESWH were carried out for following parameters/ranges:

$s = 0.02 \ldots 0.044 \ldots 0.1$ m

$\lambda = 0.02 \ldots 0.035 \ldots 0.06$ W/m K

$P_{fix} = 5 \ldots 10 \ldots 20$ W

$h_i:R_i = 3 \ldots 5 \ldots 6$

$s_t:s = 1 \ldots 3$

[45] This is valid for the whole capacity range from 50 to 1000 litres for vertical DESWHs. If fixed losses exist, the insulation thickness must be increased to reach the base-case standing losses.

the base-case standing losses. To verify the results of the simulation model, the results were compared with experimental values for 100- and 200-litre DESWH prototypes measured according to IEC 379. This showed good agreement between measured and simulated results for a realistic range of insulation thicknesses[46].

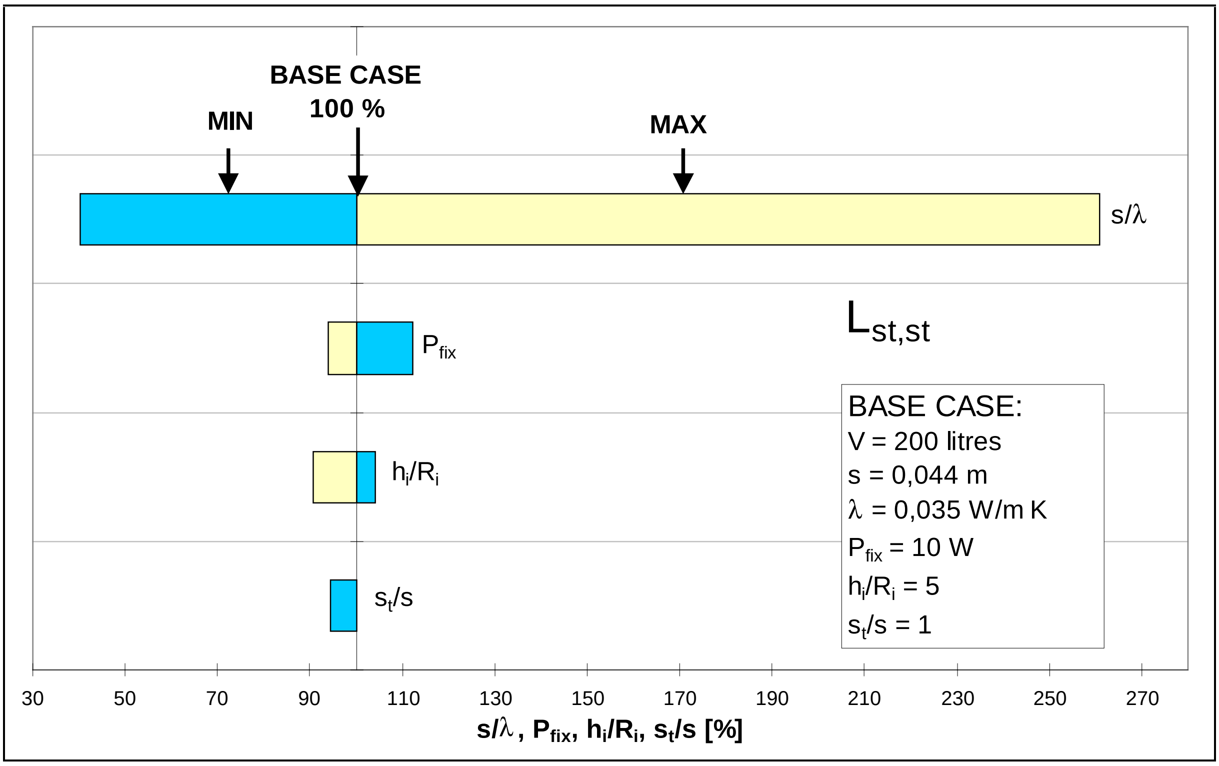

Figure 11: Influence of DESWH design parameters on standing losses

4.4 Life-cycle cost analysis for improved insulation

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

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[46] Measurements and simulations were carried out for mural vertical DESWHs with different thicknesses of insulation. Essential differences between measurement and simulation appeared only in the case of an insulation thickness of 33.5 cm. For such thick insulation the testing method of IEC 379 is not sufficient to reach steady-state conditions because of the long time constant (see report on Task 3).

cost for the insulation of a DESWH and its discounted real standing losses costs[47] during the lifetime of the DESWH[48].

To adjust for how actual usage patterns influence *in situ* standing losses, a correction factor f_{real} was used in the life-cycle cost analysis. Factor f_{real} depends on:

- the number of persons in the household
- the tariff used (high tariff (HT) corresponds to day tariff, and low tariff (LT) corresponds to night tariff (between 22:00 and 6:00))
- the usage profile
- the location of the storage tank (bathroom or cellar, with different distribution losses and ambient temperatures).

All price components related to thicker insulation were included in a specific insulation price (p_{ins}) of 0.6 ECU/litre[49] (additional purchase price $\Delta PP = p_{ins} * \Delta V_{foam}$). p_{ins} is based on the following costs[50]:

---

[47] No other costs for the equipment and the operation of the DESWH (energy costs) were included, i.e. only cost components which change with the variation of standing losses were considered.

[48] A rather cautious 10-year life-span was assumed for the calculations.

[49] The total additional costs of 0.6 ECU per litre for the additional foam volume are relatively high compared with other studies. In an Australian study, 0.17 ECU per litre was used, and in a US report 0.1 ECU per litre was used (in both cases this was for additional foam costs only). This demonstrates that in the framework of the current study a rather cautious approach was used. The impact of the additional insulation costs on optimal insulation is described in the sensitivity analysis later in this chapter.

[50] The additional purchase price can be calculated as:

$$\Delta PP(s,\Delta s) = \left[\left(p_{foam} + p_{trans}\right)\cdot \Delta V_{foam} + p_{sur}\cdot \Delta A_{sur} + \Delta PP_{tool}\right]\cdot c_m \approx p_{ins}\cdot \Delta V_{foam}$$

For detailed information see report on Task 3.

0.25 ECU/litre	foam plus transport ($p_{foam} + p_{trans}$)
25 ECU/m^2	additional surface (p_{sur})
3 ECU per unit	retooling (ΔPP_{tool})
2 (100%)	manufacturer's mark-up (c_m).

Three configurations for hot water supply situations – based on a 3-person household – were chosen for the economic (life-cycle cost (LCC)) analyses:

LT-200 C	200 litre DESWH, located in the cellar, low electricity tariff
LT-150 B	150 litre DESWH, located in the bathroom, low electricity tariff
LT-75 B	75 litre DESWH, located in the bathroom, high electricity tariff.

The life-cycle cost analysis[51] shows an **optimal insulation**[52] between **5 cm and 11 cm**, depending on the electricity tariffs[53] in the different EU member states (see Figures 12–14, for numerical information see appendix 8.5). 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 (see Figures 15–17).

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 (f_{real}) are of minor importance.

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[51] Calculations were carried out using $\lambda = 0.035$ W/m K. For more detailed information see report on Task 3.

[52] Related to the lowest life-cycle costs.

[53] Since the Italian tariff structure offers no low tariff, the calculations for this country shown in Figures 12–17 are based on high tariffs only.

Looking at so-called ‘poor’ models (insulation thickness 2 cm, or even less[54]), pay-back periods for reaching the optimal insulation thickness are extremely short and range from 0.5 to 3 years.

A sensitivity analysis[55] was performed to quantify how the optimal insulation thickness was influenced by variations in:

- ambient temperature (T_{amb})
- discount rate (i_r)
- lifetime of DESWH (LC)
- usage pattern (f_{use})
- insulation costs (p_{ins})
- electricity tariff (p_{el}).

The range in values for the sensitivity analysis covers the range in values found across Europe. As can be seen in Figures 18 and 19, the main impact is from the prices p_{ins} and p_{el} and from life-span LC. Climatic conditions, the usage pattern and the discount rate have minor impacts.

Figures 18 and 19 emphasise that assuming lower insulation costs (e.g. 0.2 ECU/litre, which is still twice the value used in the US DESWH study) would result in a significant increase in the optimal insulation thickness, rising from 7 to 11 cm for the 200 litre model and from 9 to 14 cm for the smaller, 75 litre DESWH in calculations using the average European electricity price (high tariff situation).

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[54] Especially copper tanks without insulation, as found in the UK. These models are not included in the CECED database.

[55] The reference data for the sensitivity analysis are the same as those used for the life-cycle cost analysis.

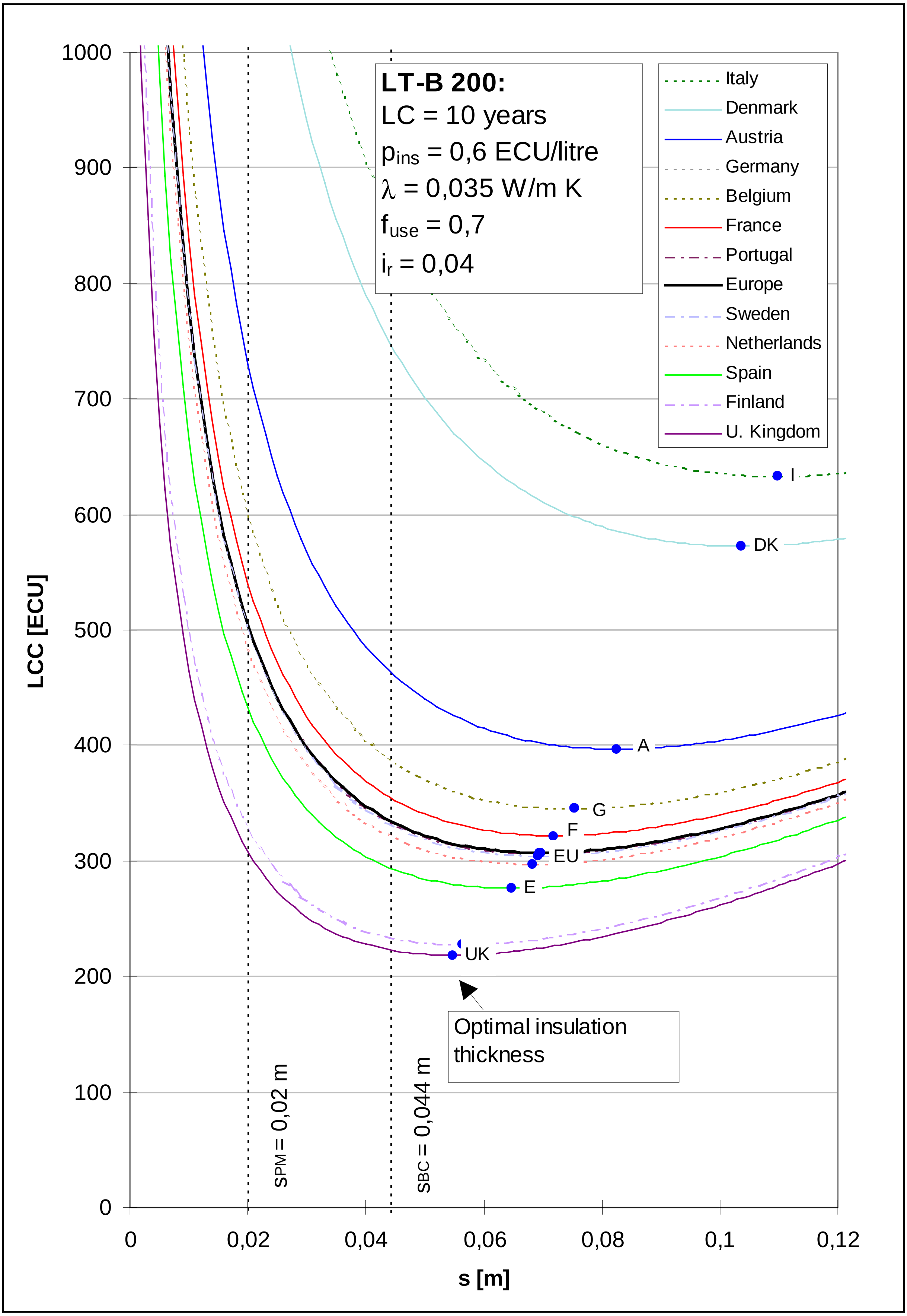

Figure 12: Life-cycle costs for configuration LT-C 200 (10-year life-span)

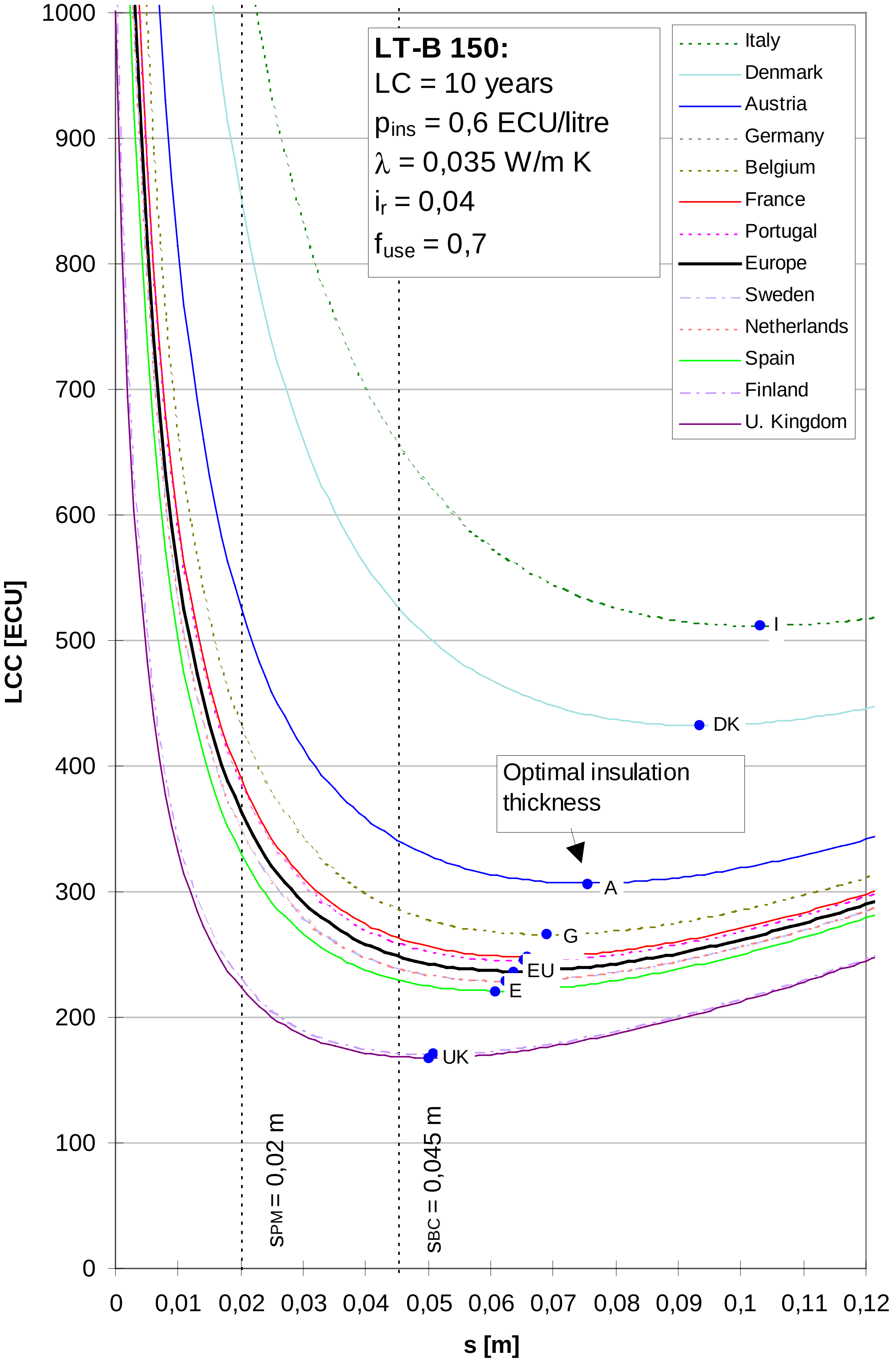

Figure 13: Life-cycle costs for configuration LT-B 150 (10-year life-span)

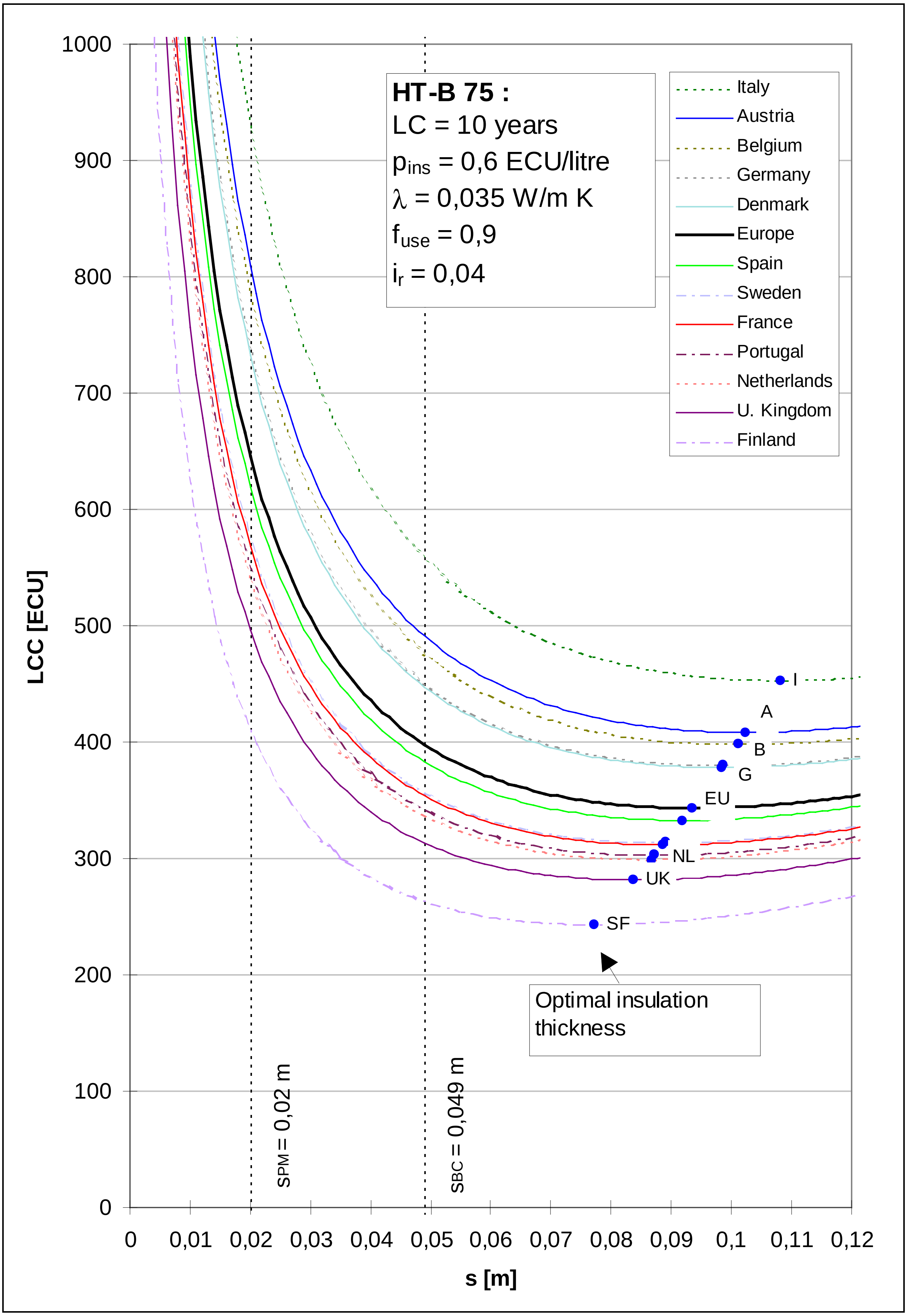

Figure 14: Life-cycle costs for configuration HT-B 75 (10-year life-span)

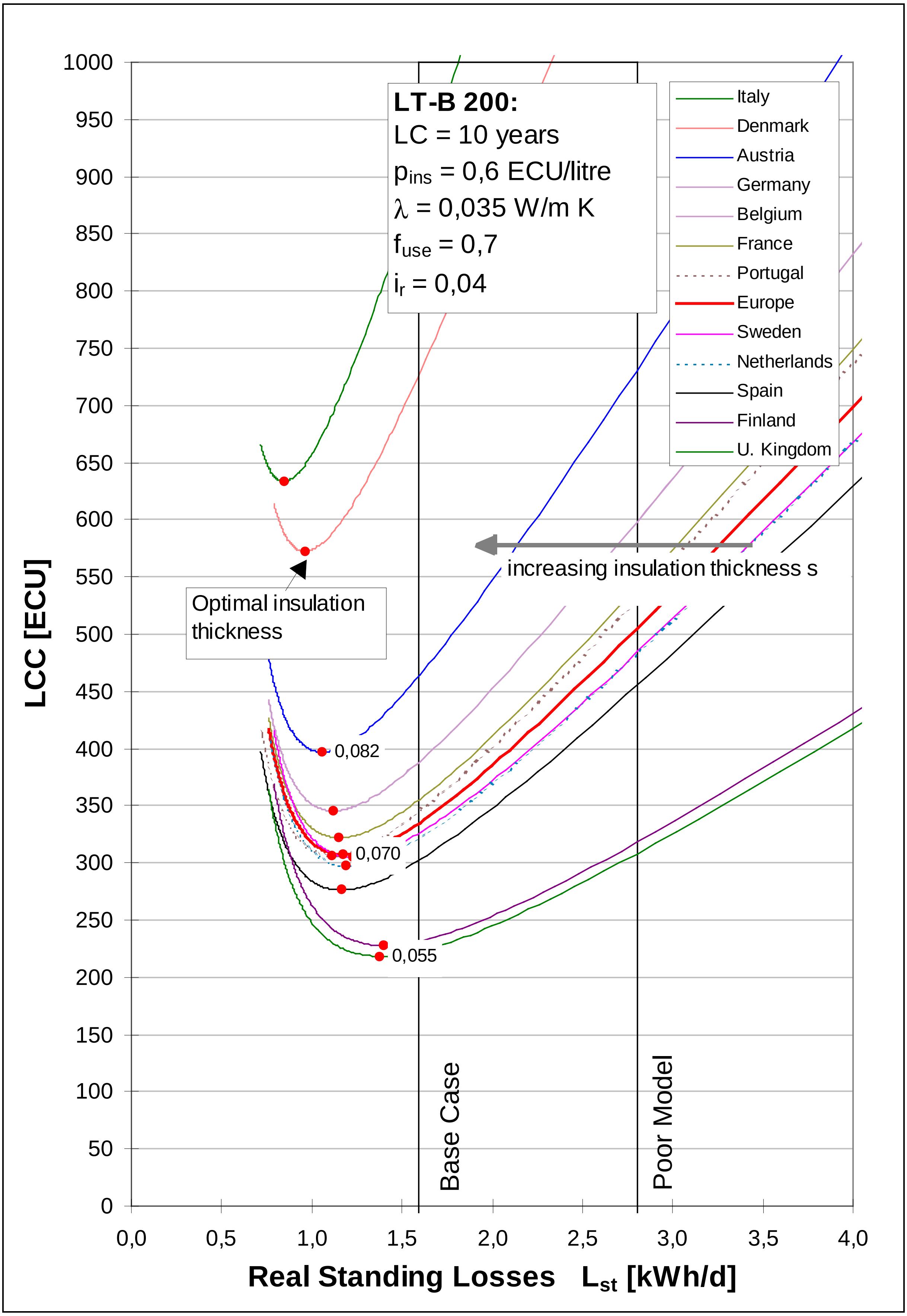

Figure 15: **Standing losses versus LCC for configuration LT-C 200 (10-year life-span)**

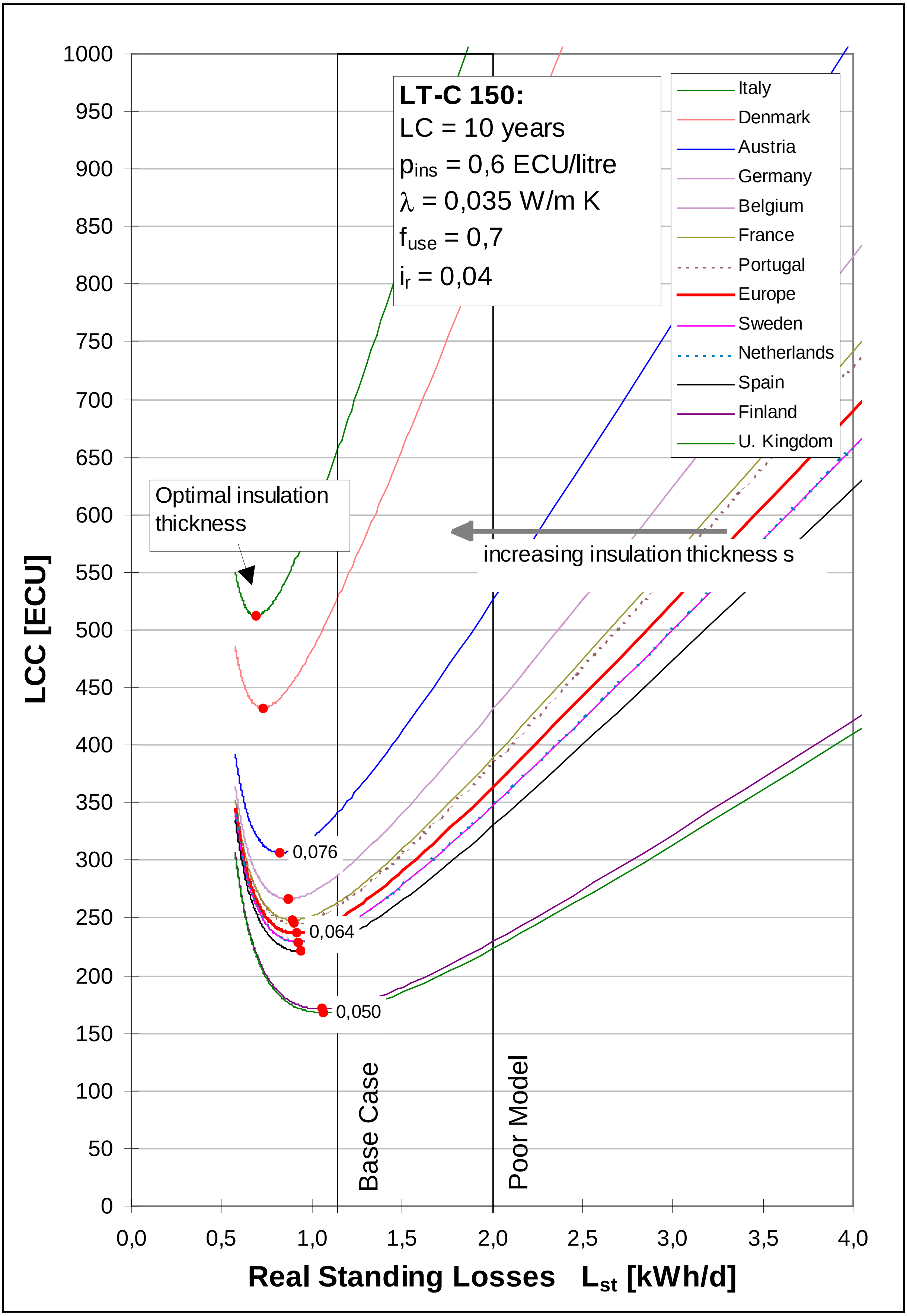

Figure 16: Standing losses versus LCC for configuration LT-B 150 (10-year life-span)

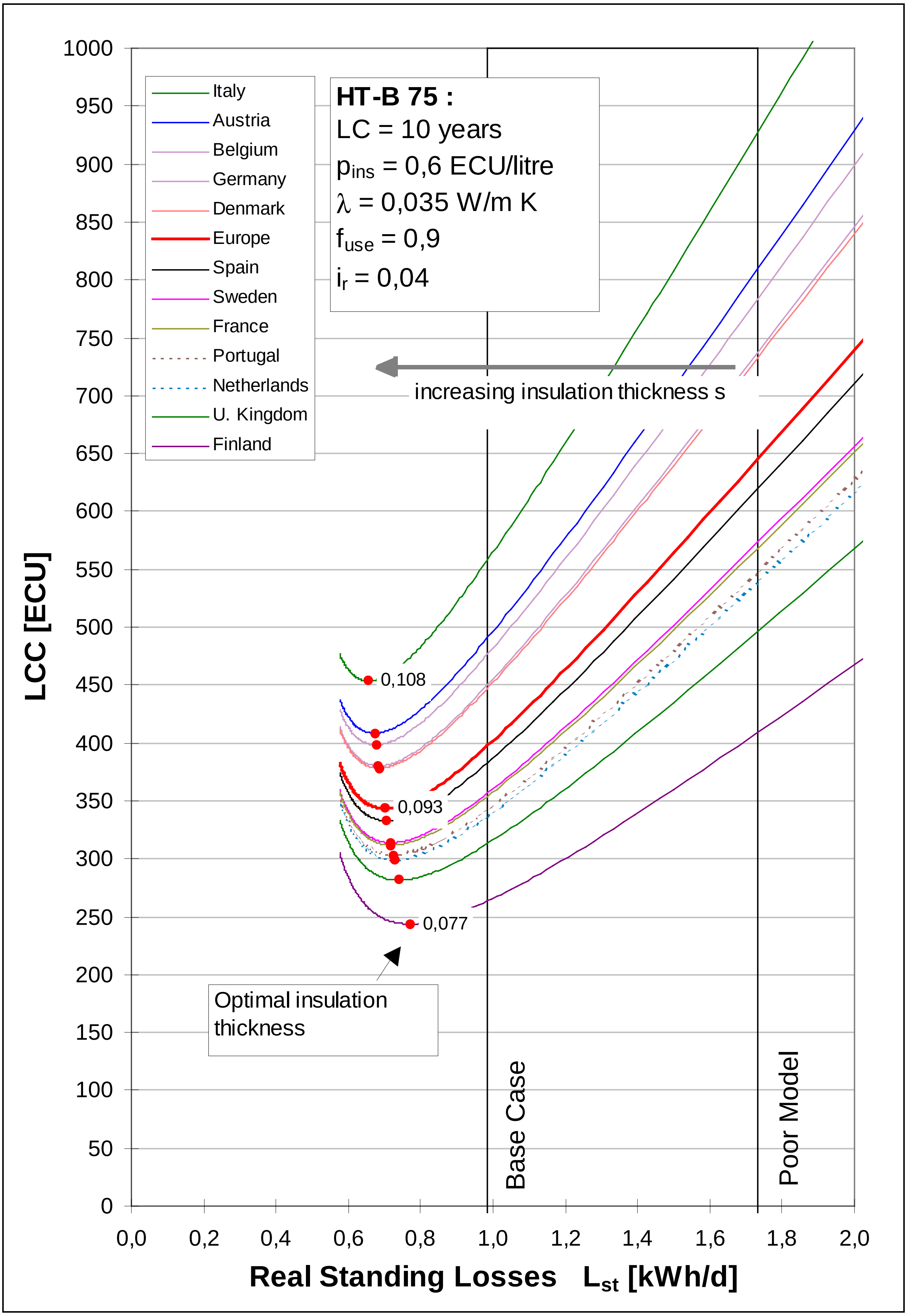

Figure 17: Standing losses versus LCC for configuration HT-B 75 (10-year life-span)

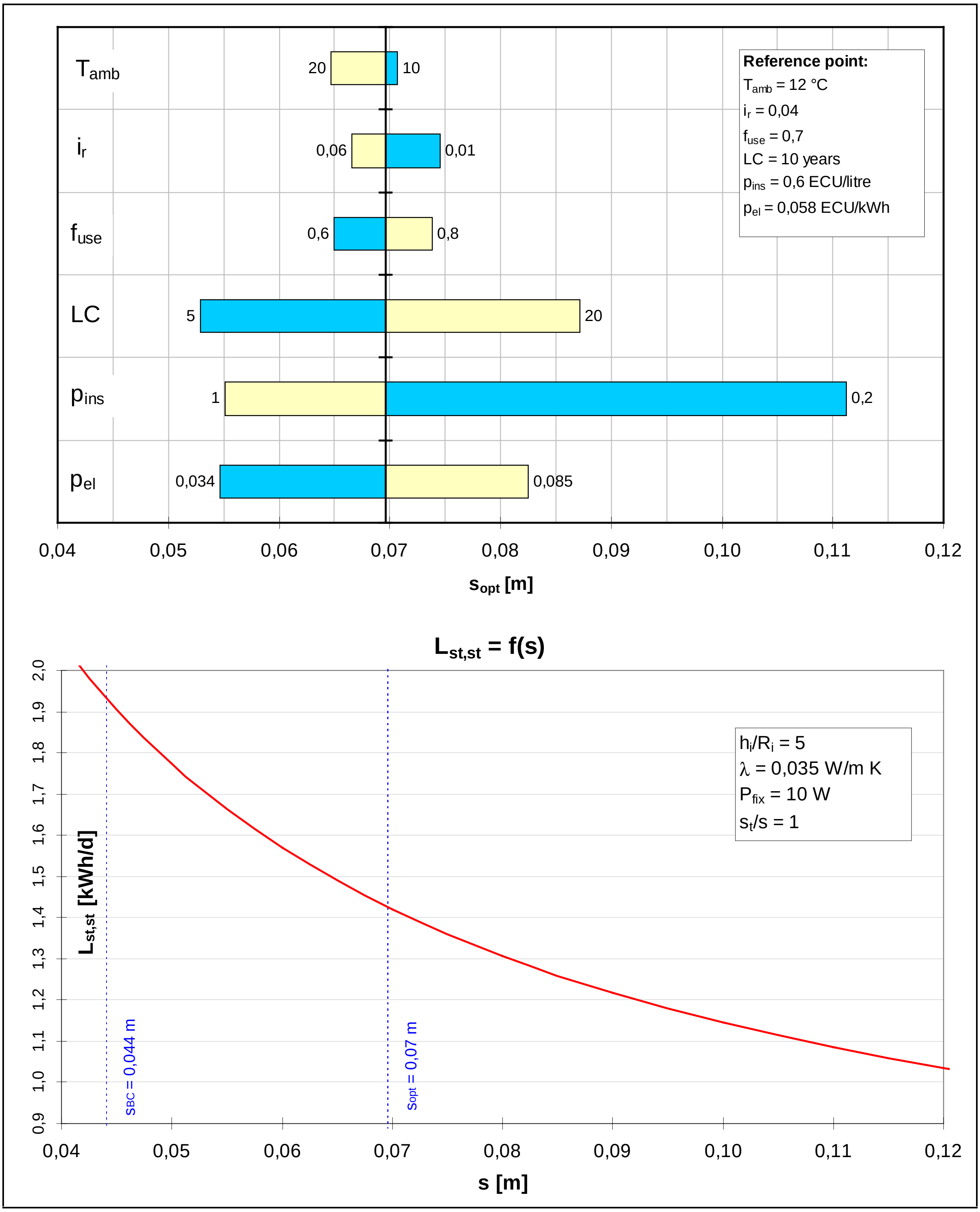

Figure 18: **Sensitivity analysis of optimal insulation thickness, EU average conditions, configuration LT-C 200 (top: variation in cost-relevant parameters; bottom: corresponding standing losses)**

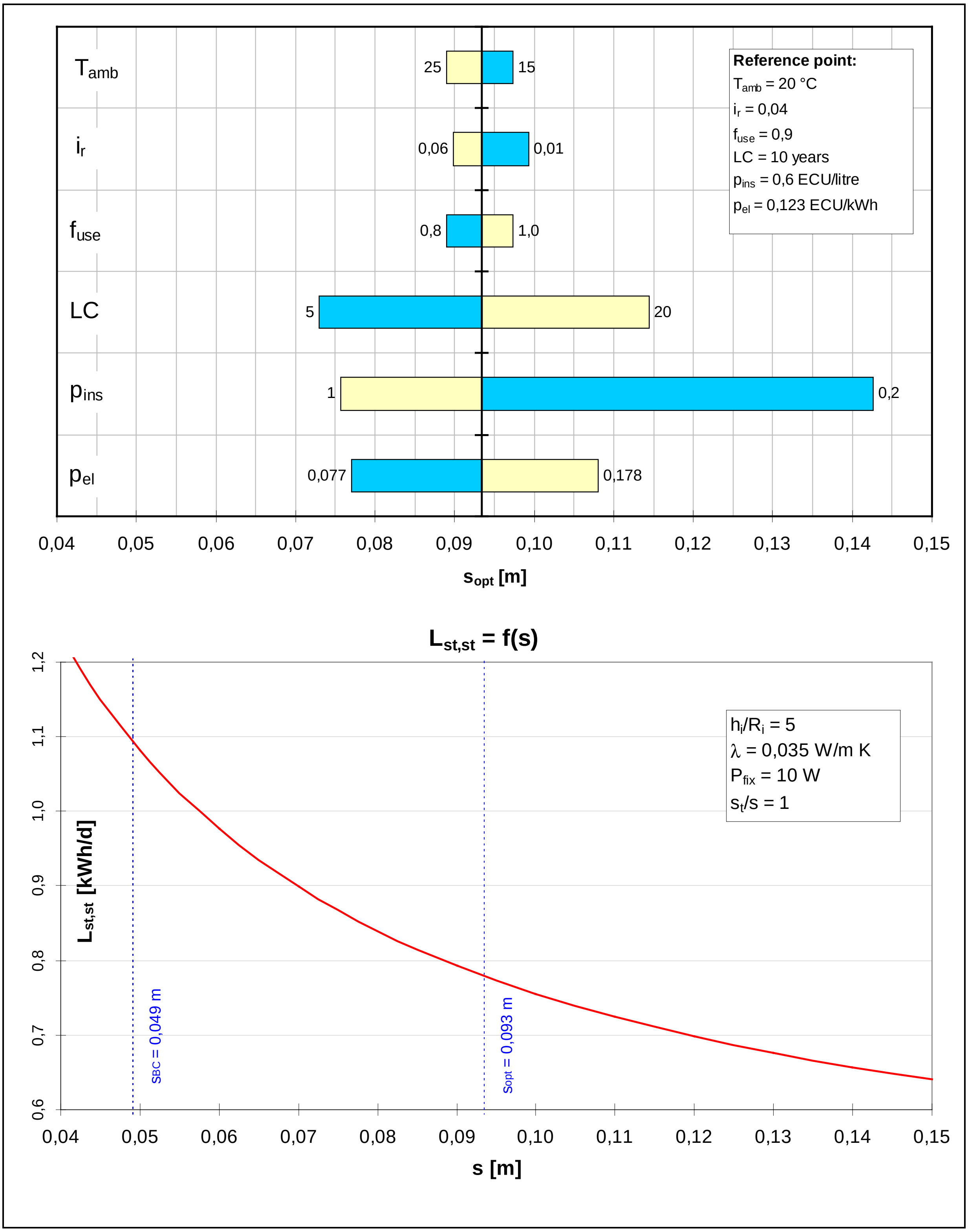

Figure 19: Sensitivity analysis of optimal insulation thickness, EU average conditions, configuration HT-B 75 (top: variation in cost-relevant parameters; bottom: corresponding standing losses)

4.5 Further options for improving DESWH efficiency

Beside increasing the insulation thickness of DESWHs, other options[56] have been evaluated, as outlined in the following sections.

4.5.1 Improvement of insulation material

Materials with a lower heat conductivity λ would have a significant effect on decreasing standing losses. Using such materials would be more or less as effective as varying the insulation thickness. At present, however, no insulation materials better than PU foam, for which λ decreases some months after manufacture, are available on the market. Vacuum-insulated panels have recently been developed for cooling appliances, and the adaptation of this innovative technology for insulating DESWHs should be considered in future R&D activities[57].

Measurements of DESWH prototypes, produced by the manufacturers especially for checking the simulation model results, show that it is possible to achieve a heat conductivity of $\lambda = 0.027$ W/m K with PU foam. However, there is no evidence, nor have the manufacturers stated, that these values are stable over the lifetime of the DESWH.

In the life-cycle cost analysis, a conventional value of $\lambda = 0.035$ W/m K was used together with a relatively high price of $p_{ins} = 0.6$ ECU/litre for insulation improvements. Figure 20 shows the impact of λ improvements and insulation price changes on the optimal insulation performance $L_{st,opt}$ and the optimal insulation thickness s_{opt} with regard to a 200 litre DESWH.

For example, if the price is unchanged, a higher performance (lower standing losses) can be reached with a lower insulation thickness s_{opt} if λ has been improved.

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[56] Fuel-switching would be also an option but was not analysed in the framework of this study (only the two-source use of energy as with heat pumps or solar collectors).

[57] A reliable price level for such a new technology was not available. Therefore a reverse cost analysis was applied to calculate a tolerable additional purchase price for the improved material. For a DESWH of 200 litres capacity, the additional costs for this type of insulation can be 35–90 ECU if a pay-back time of 2–5 years is guaranteed.

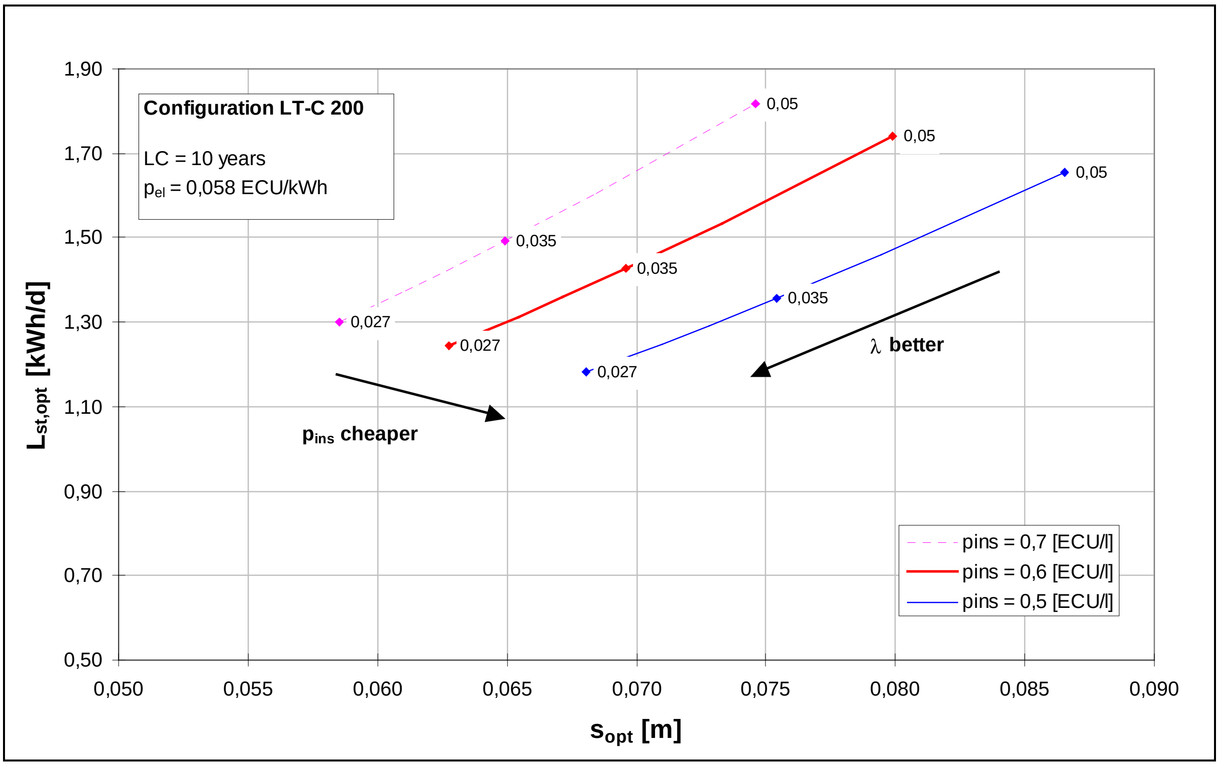

Figure 20: Impact of heat conductivity and insulation price on optimal insulation performance for a 200 litre DESWH

4.5.2 Changes in DESWH shape (height:radius (H:R) ratio)

Lower H:R values reduce the optimal insulation thickness by approximately 2%, reducing standing losses by up to 7%.

4.5.3 Changes in insulation thickness at sides/top of the boiler

An increase in the top:sides insulation ratio results in an economic optimum with slightly higher standing losses (2%) and less insulation on the side[58].

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[58] Total foam volume is increasing.

4.5.4 Avoidance of heat bridges

The occurrence of heat bridges is related to the connection of pipes, heating elements, flanges, mounting armatures, etc. They depend on the construction of the DESWH and result in the need for special armatures with insulated interconnections or other special insulation and installation measures (heat traps, thermo syphon, etc.). Depending on the electricity tariff, extra costs for such measures in the range of 10–20 ECU are cost-effective in reducing fixed losses by 50%. R&D efforts should explore the potential for low-cost solutions for avoiding heat bridges.

4.5.5 Use of optimal hot water temperature for a given DESWH capacity

Depending on the number of persons in a household, the hot water temperature of a DESWH can be reduced to the optimal temperature to supply exactly the amount of hot water needed, thereby reducing standing and distribution losses. However, the reduction of temperatures to <50 °C[59] should be avoided in order to prevent potential serious health problems caused by *Legionella* (critical temperature range 32–42 °C).

4.5.6 Use of DESWHs with capacity adapted to household size

The use of smaller-capacity DESWHs in households with fewer inhabitants reduces standing losses as the hot surface of the smaller DESWH is smaller. However, DESWHs that are too small for the household´s demand need to be operated at higher temperatures or need to be reheated during the day[60].

4.5.7 Increasing insulation but keeping outside dimensions constant

In this case water temperature must be raised to supply the same volume of hot water required. The higher water temperature would lead to higher standing losses, but the thicker insulation compensates for this effect to some extent. When the

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[59] Furthermore, it is well known that this bacterium is killed only at temperature above 60 °C.

[60] In countries with night tariffs (low tariffs) exists, operating cost will increase as a result of the use of the more expensive day tariff (high tariff) at certain times.

additional distribution losses, the increase in calcification and heat conductivity of the foam, and the reduction in the life-span of the DESWH are considered, the total effect of this measure is to increase energy losses.

4.5.8 Use of intelligent control devices

Programmable control systems capable of ‘learning‘ the daily course of hot water demand may contribute to significant reductions in standing losses, especially when used to ‘upgrade’ existing inefficient appliances. Some European research projects are based on this strategy. The purchase price for such a device should not be higher than 30 ECU in a low-tariff situation or 150 ECU in a high-tariff situation if a pay-back time of 3–5 years is to be attained.

4.5.9 Use of water-saving devices

The installation of water-saving faucets, e.g. water-saving shower roses or time-controlled taps, can achieve a 10–15% reduction in hot water needs. In order to be cost-effective the price difference between devices such as these and standard faucets should be in the range of <50 to 100 ECU.

4.5.10 Reduction of distribution losses

Low distribution losses can be achieved with small pipe volumes, short heating times and long cooling periods. These require short pipe lengths, good pipe insulation and small pipe diameters.

4.5.11 Use of heat pumps for hot water production in DESWHs

Heat pumps utilise the surrounding heat sources (earth, air, water) and thus only 25–50% of their heating effect is supplied through electricity. The integration of heat pumps in DESWH systems does not appear to be cost-efficient in low-tariff situations but could be advantageous under high-tariff conditions. Further investigations are necessary to confirm this.

4.5.12 Use of solar collectors

The analysis of a bivalent (electric/solar) hot water supply system with a DESWH capacity of 200 litres results - considering Central European solar radiation levels - in costs for the ’substituted kWh’[61] which are in the higher range and above the average European high-tariff situation. The situation might be different in Southern European countries such as Portugal, Spain, Italy and Greece as well as southern parts of France, all of which have high solar radiation levels and some have also high electricity tariffs. Further investigations are required in this area.

4.6 Comparison of hot water supply systems

For the comparison of the different hot water supply systems an overview of the Austrian market was prepared (see Figure 21). In order to get comparable results, the costs for investment, installation, operation and maintenance as well as energy consumption (needs, input from environment, distribution losses, storage losses) must be taken into account. Because the life-cycle costs of the various hot water production technologies differ, the total annual costs for each system were used.

Figure 21 assumes the same warm water needs for all systems and allows the identification of the system with the lowest energy consumption or the lowest total cost. The impact of system improvements on cost and energy demand are also illustrated. While energy consumption (*x* axis) can be determined very exactly, cost (*y* axis) can vary widely, depending on market prices.

As can be seen for DESWHs, increasing insulation performance reduces costs up to a minimum consistent with very low energy consumption. Water-saving devices achieve further cost and energy reductions[62].

In summary, centralised, low-tariff systems (if located in the cellar) have higher distribution losses, while systems near the principal point of water consumption have lower distribution losses. High-tariff systems use smaller-capacity DESWHs; these have a lower investment cost, but a higher total cost related to the high price of electricity.

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[61] It is assumed that in Central Europe about 70% of the electricity demand for hot water production can be substituted by solar collectors. When relating the investment costs for the solar plant to the avoided electricity consumption, costs for ’substituted kWh’ (0.1 - 0.24 ECU/kWh) can be calculated.

[62] As would be the case for all other hot water supply systems.

Total electricity input can be reduced below hot water (energy) needs with the use of water-savings devices as well as the utilisation of heat pumps and solar collectors[63].

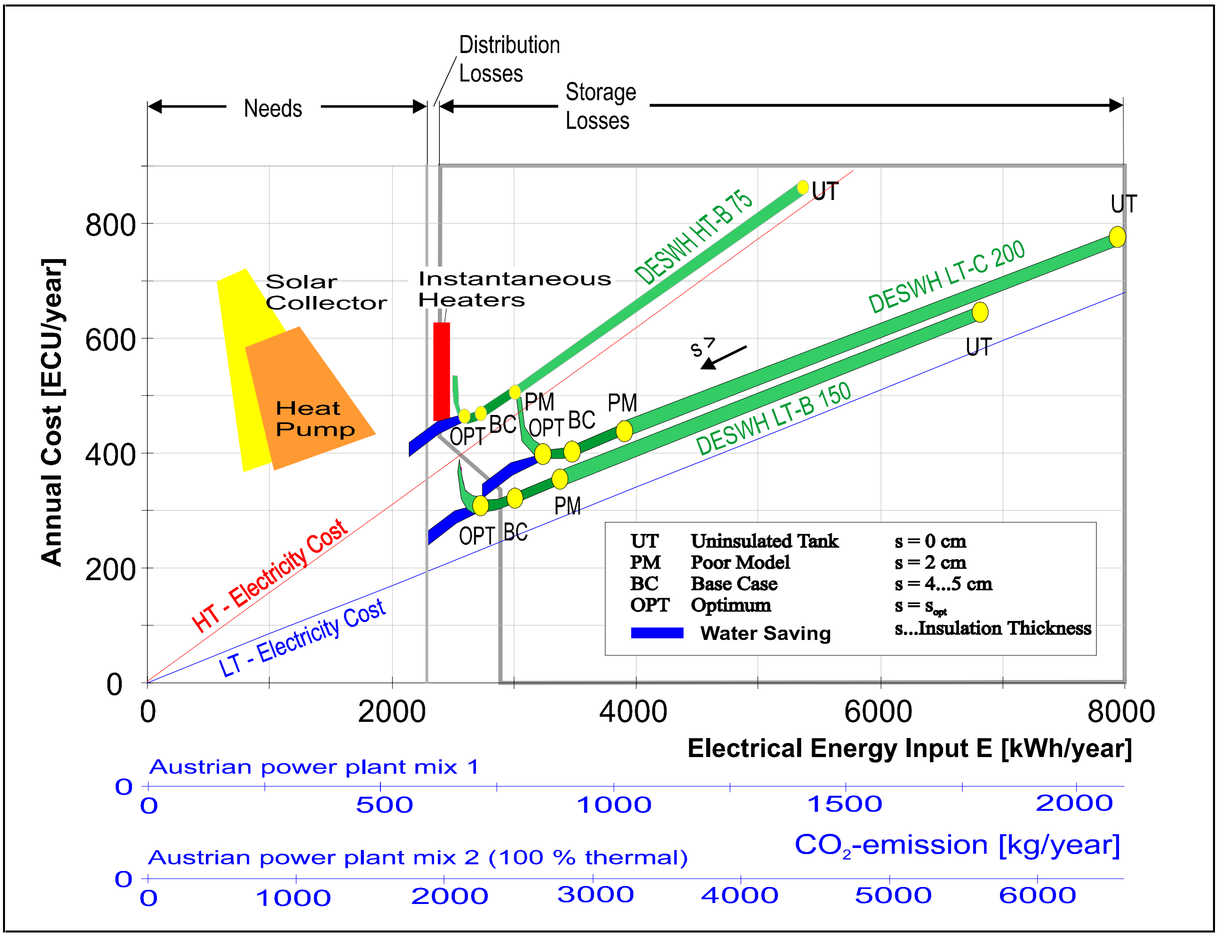

Figure 21: Comparison of cost and energy efficiency of electric water heating systems[64]

The optimal insulated LT[65]-DESWH (point 'OPT') is the cheapest and most efficient electric hot water supply system. Locating it in the bathroom helps to keep distribution losses low and, furthermore, allows utilisation of the heat losses for heating the room. Intelligent regulation – timing of water heating to immediately before hot water use or before the end of the LT period – and optimised operation of the DESWH (lowest allowed temperature) further reduce both annual costs and electricity consumption.

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[63] This is especially important for countries with high solar radiation levels, such as Portugal, Spain, Italy, Greece and southern parts of France.

[64] Based on Austrian mix of hydro-thermal electricity supply.

[65] Low tariff = night tariff.

5 EFFECTS OF POLICY INTERVENTIONS ON ENERGY SAVINGS AND CO_2 REDUCTION

5.1 Definition of scenarios

The effect of policy interventions on energy savings and CO_2 reduction was examined with the DECADE[66] model.

Total EU electricity consumption by DESWHs, including both used hot water and standing losses, is shown in Figure 22. DESWHs were projected to consume 87 TWh in 1997, with consumption declining only marginally to 78 TWh in 2020 under the ‘business as usual’ (BAU) scenario. The data show that ownership is declining in 6 major countries, which account for 82%[67] of current total electricity consumption of DESWHs in the EU. Thus, overall, EU consumption is in decline[68].

In the BAU-scenario no further technical changes in DESWH energy efficiency were assumed for the period 1995–2020.

In 1997, standing losses accounted for 22% of total DESWH electricity consumption. Standing losses declined from a peak of 33 TWh in 1978 to 19 TWh in 1997 (see Figure 23).

The development of standing losses depends on the assumptions taken for average standing losses in each country, taking into account typical capacities at any one time. The three countries for which historical, new-model consumption data are available (the UK, France and Germany), each show similar historical improvements

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[66] Domestic Equipment and Carbon Dioxide Emissions, developed by ECU, Oxford. This stock model needs a series of exogenous variables as inputs (e.g. number of households, ownership level, lifetime of DESWHs, usage patterns), described in detail in a technical appendix to this study.

[67] UK 14%, Italy 21%, Germany 15%, France 24%, Spain 6%, Portugal 2%.

[68] Also due to improved efficiency of DESWHs, see the comment on standing losses below.

from relatively poorly insulated (or uninsulated) tanks as a result of government policy measures in 1976, 1984 and 1990. Other countries are assumed to follow these basic trends, because there is some import/export of water heaters between countries.

However, since it takes some 10 years in Europe and 20 years in the UK for water heaters to be replaced, improvements made 10 years ago to new models are still working through the stock, and will continue to do so for a few years yet, but this effect will saturate by 2005.

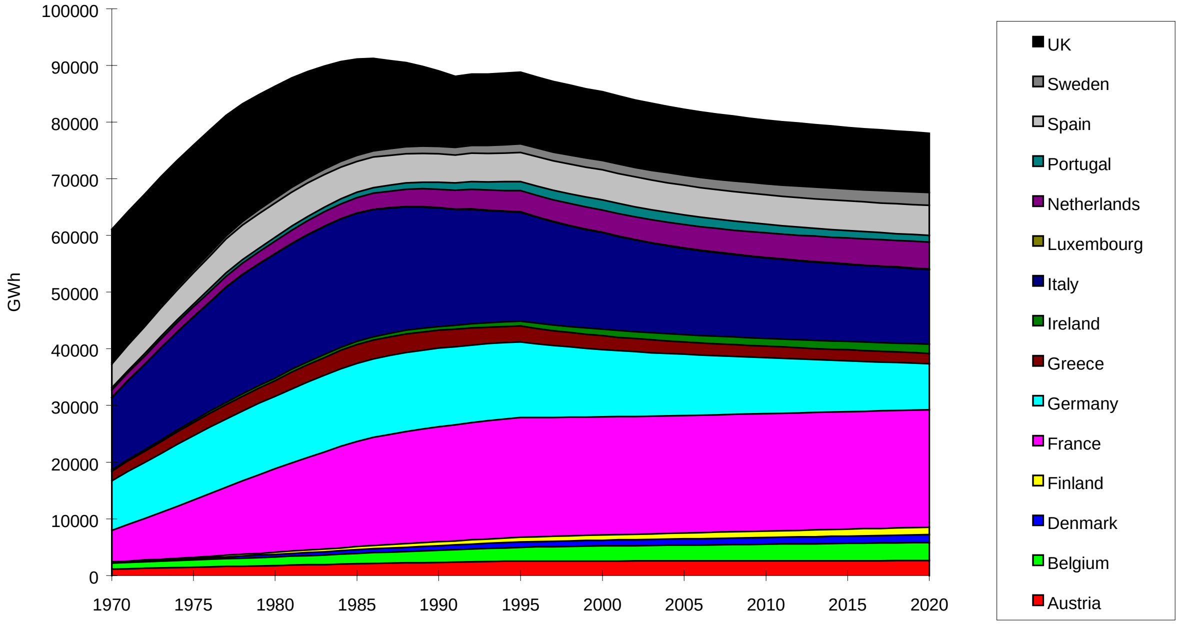

Figure 22: Total DESWH electricity consumption in the European Union, historical and projected

Five scenarios of policy options were designed and compared with the BAU scenario. These scenarios are as follow:

1. **EtoBc2000** Every DESWH on the market with standing losses worse than the base case in the technical/economic analysis moves up to the base case by the year 2000.

2. **csETP2000** Every DESWH in each country moves to the country-specific standing losses optimum[69] and utilises the full economic and technical potential in the different countries by the year 2000.
3. **EUbest2000** Every DESWH on the market moves to the best (with regard to standing losses) on the EU market by the year 2000.
4. **csETP2005** Same as scenario csETP2000, except the date is assumed to be 2005.
5. **EUbest2005** Same as scenario EUbest2000, except the date is 2005.

5.2 Energy savings and CO_2 reduction

Table 6 and Figure 23 summarise the results of the comparison between the BAU scenario and the five scenarios of policy options. If all new models were to move to the average on the market by 2000 (scenario EtoBc2000), savings would amount to 2.623 GWh by 2020, or 17% of the projected consumption attributable to standing losses, i.e. the value of savings would be 315 million ECU to consumers and 0.37 Mt of carbon[70] (= 1.36 Mt of CO_2).

If every DESWH were to move to the best on the market by 2000 (scenario EUbest2000), savings would amount to 6.426 GWh by 2020, or 41% of projected consumption attributable to standing losses, i.e. the value of savings would be 771 million ECU to consumers and 0.90 Mt of carbon (= 3.3 Mt of CO_2).

It can also be seen from Table 6 that the effect of delaying the implementation date from 2000 to 2005 disappears by 2020[71], but the difference in savings is significant in the early years.

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[69] Represents those technical improvements that are already available and are cost-effective with regard to each country's electricity prices.

[70] As C, not CO_2.

[71] Difference in % savings between scenarios 2 and 4, and scenarios 3 and 5.

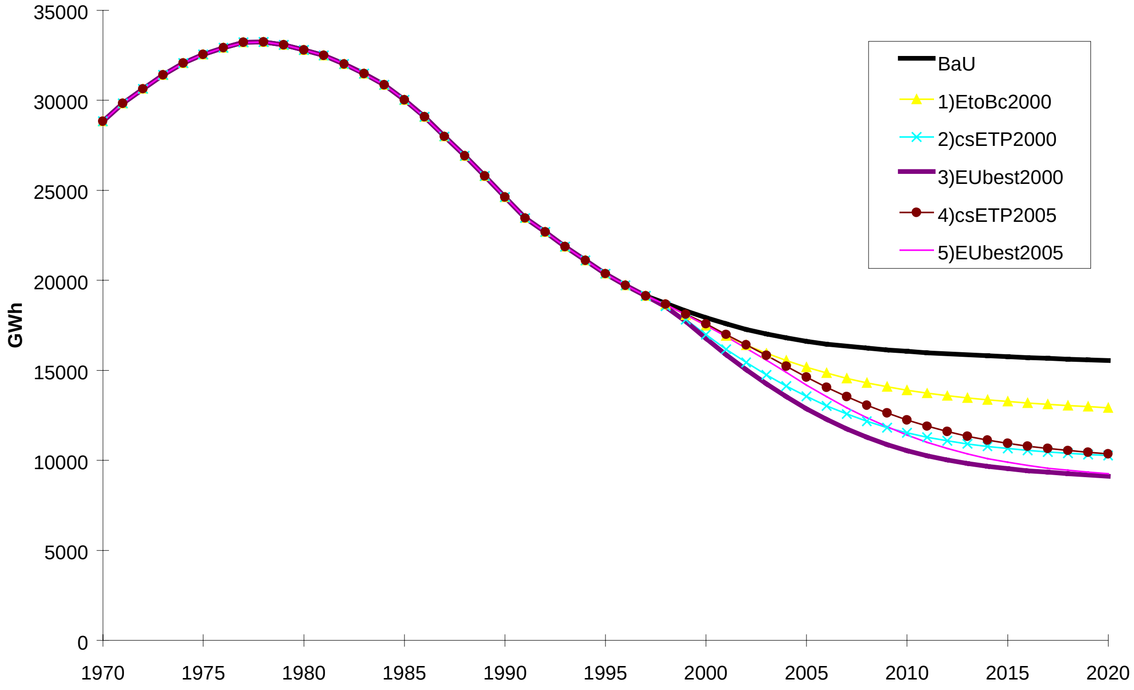

Figure 23: **DESWH standing losses for the EU stock according to five scenarios of policy options**

Savings vary widely between the different member countries. The effect of moving everything to the average on the market (scenario EtoBc2000; see Figure 24) will clearly have a much greater effect in the 'least efficient' countries[72], and little or no effect in the 'most efficient' countries. Thus, with this scenario, the UK achieves the greatest savings (25% of all savings), followed by Italy (22%) and Spain (15%); however, no savings are achieved in Germany.

If every DESWH moves to the best on the EU market (scenario EUbest2000; see Figure 25), savings will be more evenly distributed, with 22% of all savings being accounted for by France, 18% by Italy, 16% by the UK, 10% by Spain and 7% by Germany.

The effect of reaching country-specific optima (scenario csETP2000) is that countries with higher energy prices tend to make higher savings; thus France and Italy account for 23% and 22% of savings, respectively, while the UK accounts for a lower share of 15%.

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[72] With respect to DESWH standing losses.

Table 6: **Standing losses, electricity savings and CO_2 reductions according to five scenarios of policy options (*vs* BAU scenario) in the EU**

Data related to year 1995, 2000, ect.[73]	**BAU**	**EtoBC 2000**	**csETP 2000**	**EUbest 2000**	**csETP 2005**	**Eubest 2005**
Standing losses (GWh)						
1995	20367					
2000	17935	17482	16979	16770	17576	17500
2005	16618	15172	13551	12873	14623	14184
2000	16053	13895	11533	10538	12244	11411
2020	15549	12927	10268	9123	10369	9253
Electricity savings (GWh)						
2000		452	955	1164	358	434
2005		1445	3067	3745	1995	2433
2010		2158	4520	5514	3809	4641
2020		2623	5281	6426	5181	6297
% savings (*vs* standing losses)						
2000		3	5	6	2	2
2005		9	18	23	12	15
2010		13	28	34	24	29
2020		17	34	41	33	40
Savings (millions of ECU)						
2000		54	115	140	43	52
2005		173	368	449	239	292
2010		259	542	662	457	557
2020		315	634	771	622	756
Carbon reductions (Mt CO_2)						
2000		0.22	0.48	0.59	0.18	0.22
2005		0.73	1.58	1.94	1.03	1.25
2010		1.10	2.35	2.86	1.98	2.38
2020		1.36	2.71	3.30	2.68	3.26

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[73] Not accumulated.

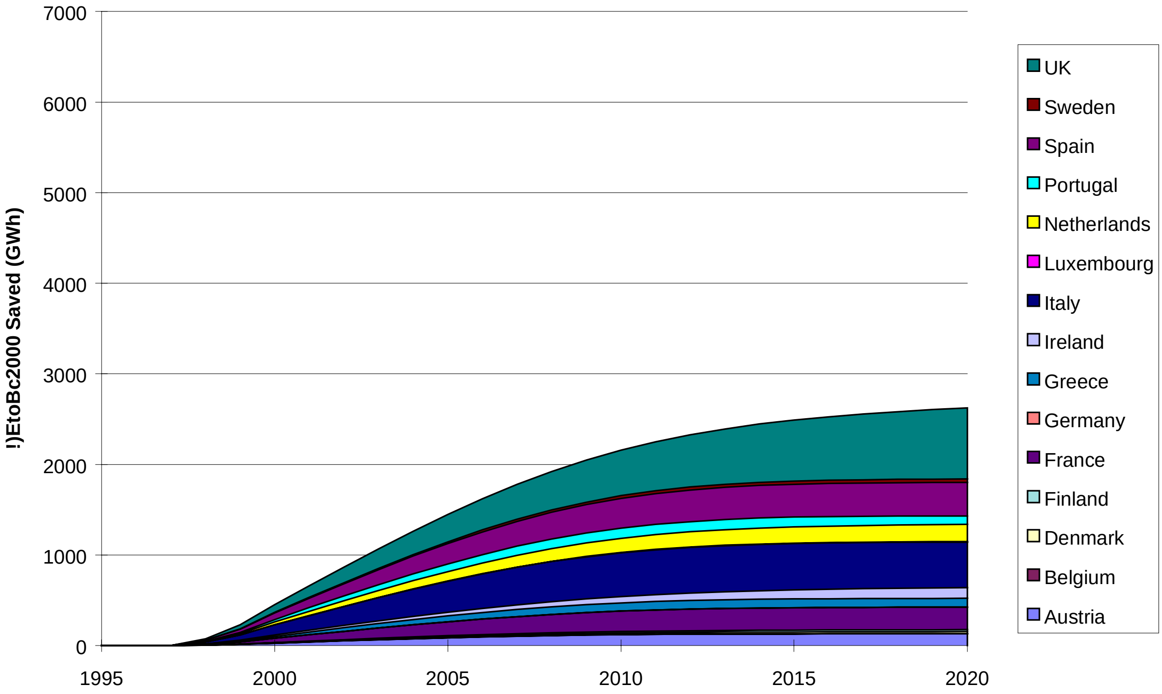

Figure 24: Electricity savings achieved by European Union countries under scenario EtoBc2000

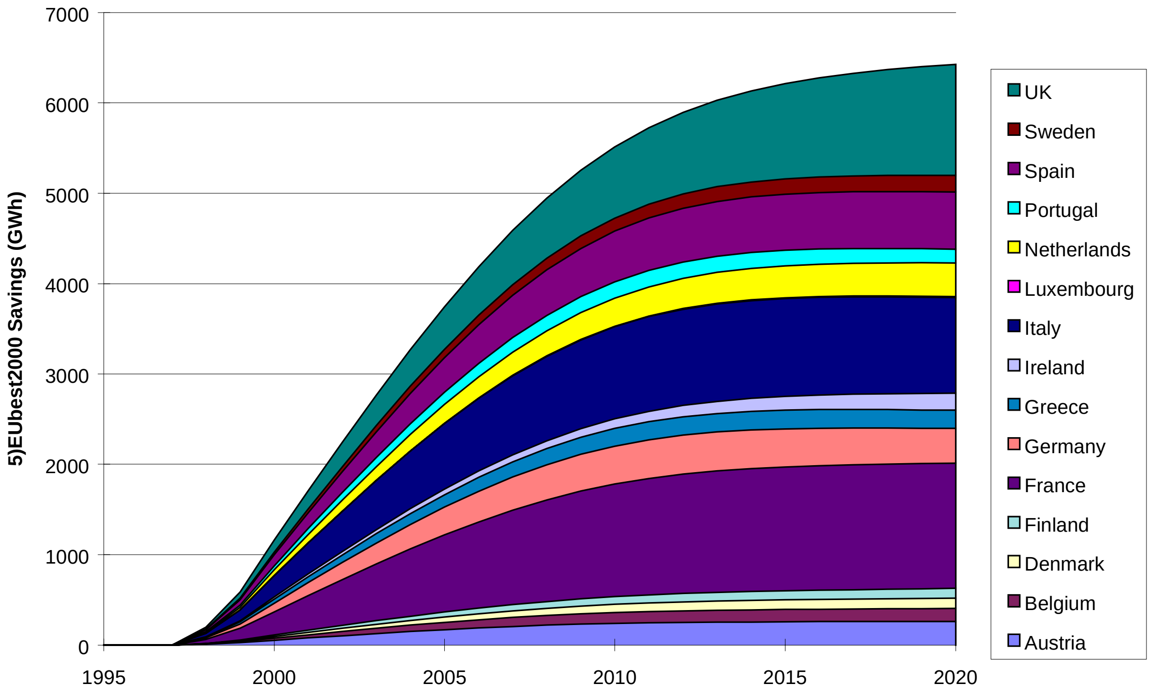

Figure 25: Electricity savings achieved in European countries under scenario EUbest2000

6 IMPACT ON CONSUMERS AND MANUFACTURERS

6.1 Impact on consumers

The analysis of the impact of improved energy efficiency on consumers concentrated on an empirical evaluation[74] of consumer behaviour in Italy[75]. Even if the results for one country are not representative of 'the European market' they provide some interesting indications of consumer preferences.

One important question consumers were asked concerned their reasons for purchasing their water heater; the results are summarised in Table 7[76]. The greatest influence on consumer choice (32% on average) was 'suggestion' by third parties (installers, sales staff, friends, etc.). 'Suggestion' had greater impact when buying a gas water heater (42%) than choosing a DESWH (30%).

Another important reason was 'convenience' (19% on average), with the sales price[77] of the water heater (14% on average) being the dominant factor. Other reasons mentioned were 'heating efficiency'[78] (13%), 'safety' (12%) and 'promotion' (11%).

Only a few consumers (2%) described the reason for their purchase choice as 'economic in use (energy efficient)'.

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[74] Eighty percent of the interviews were with owners of DESWHs and twenty percent with owners of gas systems.

[75] ENEA tried to obtain results from all 15 member states through an *ad hoc* questionnaire to national consumers´ associations, but no response was received; analysis therefore focused on Italy.

[76] Nearly one-quarter (23%) could not remember why they chose to buy their particular water heater. In addition, 13% of consumers said they had no specific reasons.

[77] For buyers who remembered why they chose their water heater, ranking of single factors shows that 'sales price' was the most important reason, approximately equal to 'advice by installers'.

[78] Time needed to bring water to the desired temperature.

Table 7: Reasons behind water heater purchase choices in Italy (by % of questionnaire respondents)

Reason	All water heater types				Total	
	Region in Italy				Electric water heater	Gas water heater
	North	Centre	South	Total		
SUGGESTION	**69**	**34**	**27**	**32**	**30**	**42**
installer's advice	*27*	*2*	*13*	*13*	*12*	*20*
installer's choice	*33*	*–*	*4*	*6*	*5*	*10*
sales staff advice	*3*	*23*	*6*	*8*	*8*	*8*
friend's advice	*6*	*9*	*4*	*5*	*5*	*4*
CONVENIENCE	**3**	**28**	**20**	**19**	**19**	**16**
price	*3*	*13*	*16*	*14*	*14*	*16*
quality/price	*–*	*15*	*4*	*5*	*5*	*0*
NONE	**6**	**6**	**15**	**13**	**14**	**4**
HEATING EFFICIENCY	**12**	**4**	**14**	**13**	**13**	**12**
SAFETY	**18**	**4**	**12**	**12**	**12**	**12**
PROMOTION	**6**	**2**	**12**	**11**	**11**	**12**
popular brand name	*6*	*–*	*10*	*9*	*9*	*8*
advertising/information	*–*	*2*	*2*	*2*	*2*	*4*
OTHERS	**9**	**2**	**6**	**5**	**5**	**12**
modern system	*6*	*2*	*2*	*2*	*2*	*6*
energy efficient/ economic in use	*3*	*–*	*3*	*2*	*2*	*2*
low maintenance	*–*	*–*	*1*	*1*	*1*	*4*
I DON'T REMEMBER	**12**	**34**	**22**	**23**	**23**	**24**

The low relevance of energy efficiency in buyers' decision-making must be considered together with the fact that when consumers were asked whether they were satisfied with their hot water system in terms of safety, operating costs related to energy efficiency, time to achieve the desired hot water temperature, maintenance and environmental impact, they were least content with the energy efficiency of water heaters. If a distinction is made between electric and non-electric water heaters (see

Figure 26), satisfaction with the energy efficiency of DESWHs was lower than for other hot water systems (e.g. gas water heaters) [79].

This indicates that consumers are aware that the energy efficiency of DESWHs is not good enough. Bearing in mind that in the Italian empirical survey 73% of the owners of a DESWH installed the appliance themselves[80], and that 69% of these 'self-installers' directly purchased their DESWH in a shop (65% decided on the type and 62% on the brand), the importance and effectiveness of providing sufficient information to consumers is evident.

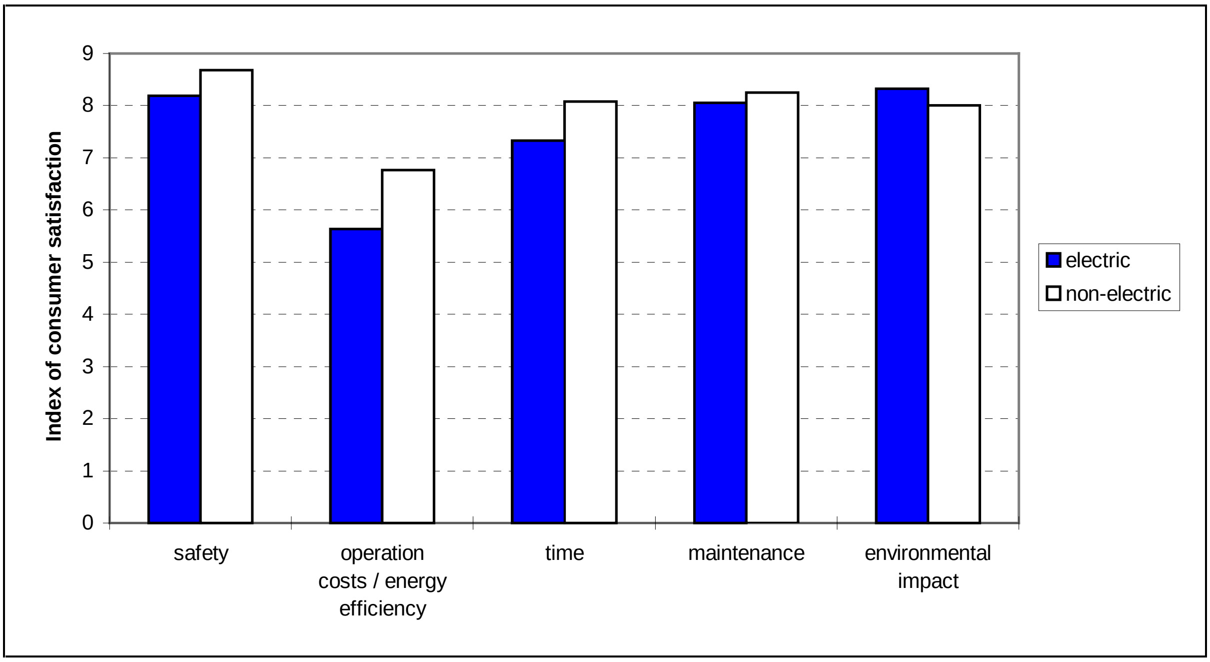

Figure 26: Consumer satisfaction with hot water systems in Italy[81]

12% of the interviewed consumer sample stated that they needed to buy a new DESWH, of which 8% wanted to substitute an old one and 4% to install an additional one. Interest in a more energy efficient DESWH was then explored in those families willing to buy a new DESWH through asking another specific question focusing on

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[79] In other words, although buyers were not satisfied with the energy efficiency of their DESWH, they had enough other convincing reasons for choosing a DESWH.

[80] This results differ from that of other member states, e.g. UK and France, where most DESWHs are installed by plumbers and the decision on type and brand is not made by the owner of DESWH.

[81] 10 points as the highest mark for very good performance, 2 points as the lowest mark for negative performance.

measuring the trade-off between savings on operational costs on the one hand and a higher sales price on the other hand. The following cases[82] were evaluated:

A) 15 000 lire (7.5 ECU) saving on the total energy bill and price increase of 30 000 lire (15 ECU)

B) 25 000 lire (12.5 ECU) saving on the total energy bill and price increase of 50 000 lire (25 ECU)

C) 35 000 lire (17.5 ECU) saving on the total energy bill and price increase of 70 000 lire (35 ECU).

As shown in Figure 27, the willingness to buy a more efficient DESWH was strongly related to the performance of the new DESWH, with the percentage of willing respondents doubling when expected savings move from 7.5 to 12.5 ECU (from case A to B) and increasing more than 10 times[83] when savings change from 12.5 to 17.5 ECU (from case B to C). These results support the expectation that the market potential for more efficient DESWHs might grow significantly if consumers are aware that they can realise considerable savings concerning operational costs with only slightly increased investments for a new more energy-efficient DESWH. Of course, buyers´ decisions are influenced by the costs of other usable[84] and possibly more satisfying competing systems for hot water production.

The calculations in the technical/economic analysis show that the potential savings achieved by increasing insulation thickness are much higher than the benefits required by consumers (7.5, 12.5 and 17.5 ECU, respectively, per year; see cases A, B and C) as compensation for higher DESWH purchase prices.

By spending an additional 23 ECU[85] on their purchase, Italian buyers could save about 39 ECU per year[86] if they choose a base-case DESWH (with about 4.7 cm

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[82] Without specific savings/price information, 60% were positively oriented towards buying a more efficient product (20% certainly yes; 40% probably yes); 15% would definitely not accept any price increase.

[83] Compared with case A.

[84] There are various restrictions for competing technologies, e.g. gas availability, limitation in electrical capacity demand of households through electric fuse.

[85] Based on a 100 litre DESWH which is most frequently used in Italy the foam volume for the insulation of the ’poor’ model (35.7 litre) has to be increased by 37.8 litre to get a base-case model. With the specific insulation price of 0.6 ECU/litre (see chapter 4.4) this amounts to 22.7 ECU.

[86] Standing losses of the ’poor’ 100 litre model are 1.95 kWh/day, for the base-case model 1.29 kWh/day. This results in savings of 38.7 ECU (217 kWh) per year: 0.66 kWh/day x 365 days x 0.178 ECU/kWh x 0.9 (influence of ambient temperature and usage conditions, see chapter 4.4). Using the average European

insulation) instead of a ’poor’ model (with approximately 2.5 cm insulation)[87]. With an additional purchase price of 107 ECU the annual savings will increase to about 67 ECU when a ’poor’ model is replaced with the ’optimal’[88] model. This results in pay-back periods of 0.6 and 1.6 years, respectively, much less than assumed in cases A, B and C as used in the consumer survey.

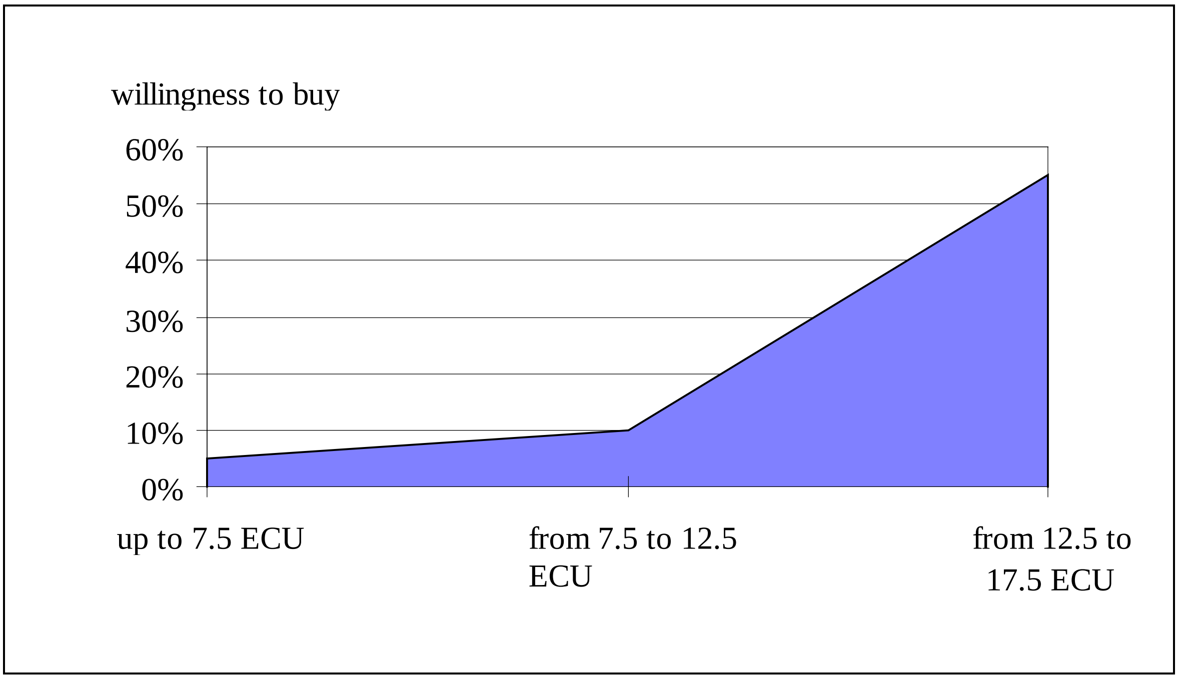

Figure 27: Trade-off between savings on operational costs and higher sales prices

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electricity high tariff amounts in annual savings of 26.7 ECU (with average European low tariff savings are 12.6 ECU).

[87] DESWHs with 75 litre and 100 litre capacity are most commonly used in Italy. The CECED data base contains 4 ’poor’ and 3 base-case vertical models in each case.

[88] The 100 litre vertical model with the least life-cycle cost related to Italian conditions (electricity tariffs) would have an insulation thickness of 11 cm. The foam volume of the ’poor’ model has to be increased by 178.5 litre to get an ’optimal’ model. With the specific insulation price of 0.6 ECU/litre (see chapter 4.4) this amounts to 107.1 ECU.
Standing losses of the ’poor’ 100 litre model are 1.95 kWh/day, for the ’optimal’ model 0,81 kWh/day. This results in savings of 66.7 ECU (374 kWh) per year: 1.14 kWh/day x 365 days x 0.178 ECU/kWh x 0.9 (influence of ambient temperature and usage conditions, see chapter 4.4). Using the average European electricity high tariff amounts in annual savings of 46.1 ECU (with average European low tariff savings are 21.7 ECU).

A more general picture[89] of pay-back periods (PBP) is presented in Figures 28 and 29. If insulation thickness is increased, the pay-back time for opting for optimum insulation thickness s_{opt} depends on the initial insulation thickness s_0 and the electricity price (for a given configuration and user profile). As shown in both Figures 28 and 29, the thinner the initial insulation, the shorter the pay-back period.

Uninsulated tanks (as they have occurred in the UK) could be improved to the optimum with pay-back periods of less than half a year. ‘Poor’ Italian models (HT-B 75 litre, s_0 = 0.025 m) (see Figure 29) could be improved within less than 1.5 years, while the same ‘poor’ UK models would require pay-back periods of at least 2.25 years because the electricity price is lower there.

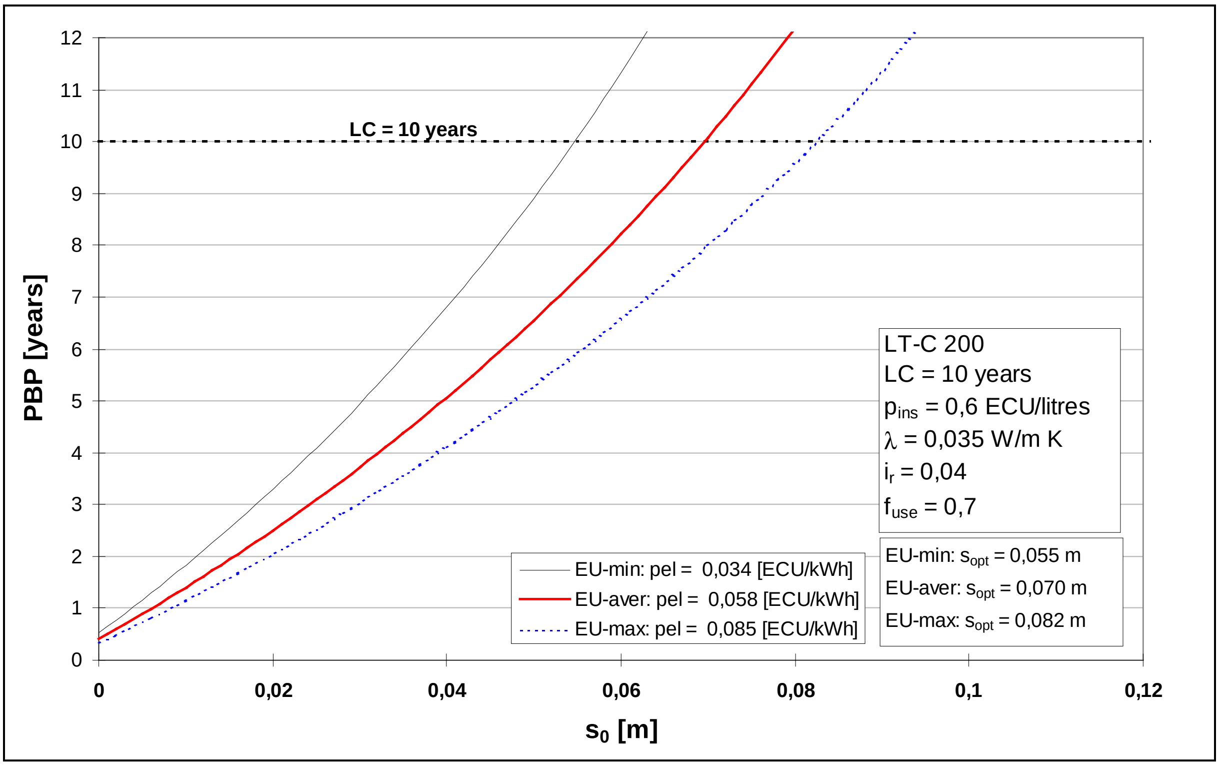

Figure 28: Pay-back period for improving insulation thickness from s_0 to s_{opt}, configuration LT-C 200

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[89] Taken from the technical/economical analysis. Costs for improving insulation thickness - used in the calculation - are roughly the same as in the impact analysis.

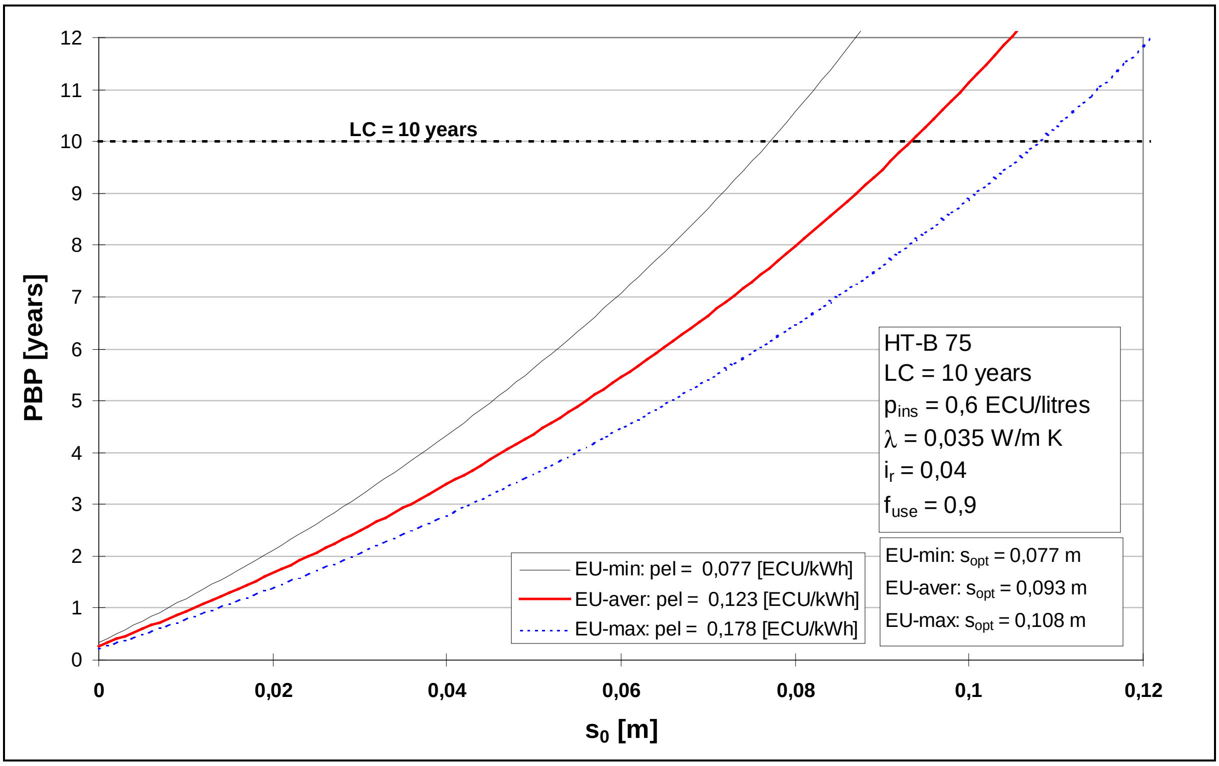

Figure 29: Pay-back period for improving insulation thickness from s_0 to s_{opt}, configuration HT-B 75

A comparison of consumer opinions and energy efficiency potential from an economic point of view leads to the following conclusions. Since consumers are not satisfied with the energy efficiency of their water heaters, they consider energy efficiency one of the less important factors in determining their purchase decision. ‘Suggestion’[90] is the most important influence in their purchase decision, while ‘sales price’ is the most important single economic issue. However, DESWHs that realise much higher savings than expected by consumers are available on the market. Thus it is evident that there is an information deficit. Raising consumer awareness could result in energy savings as long as possible price increases for more efficient appliances are accepted by the majority of consumers willing to buy a new DESWH.

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[90] This includes several factors, such as advice from installers, sales staff, etc.

6.2 Impact on manufacturers

The evaluation of the effects of policy interventions on manufacturers utilised the results of a questionnaire that was distributed to DESWH producing companies. Six enterprises responded[91]; together they employ more than 6 000 people and sell around 2 million product units per year – collectively their turnover was 916 billion ECU in 1996 and they had a European market share of slightly less than 70%[92].

The breakdown of average water heater unit production costs, as taken from the questionnaire, is shown in Table 8. The mean total per-unit production cost (for a 100 litre vertical unit) is 105 ECU. Energy, non-energy raw materials, distribution and marketing, and royalties are considered as variable costs and account for 67.1% of the total unit costs[93].

With reference to the assumptions for additional costs in the technical/economic analysis (0.6 ECU per litre, including additional transport costs, etc.; see section 4.4), adding 2 cm of insulation to a 100 litre 'poor' DESWH model costs about 20 ECU[94]. Improving the 100 litre 'poor' model with additional 6 cm insulation would cost about 70 ECU[95].

These figures are close to the data set provided by manufacturers (see the fixed and variable incremental costs per unit given in Table 9) for an additional 2 cm of insulation and about 15% lower than the estimates of the producers for an additional insulation of 6 cm.

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[91] Three big groups and three small/medium enterprises.

[92] Industry structure is an oligopoly, three major firms supplying 70% of the market, 30% of supply is represented by smaller enterprises.

[93] These figures are a weighted average of the cost structures of the single companies which appear, strangely enough, quite different among themselves: this is particularly true for machinery costs, which vary between 3.5 and 30%, and for total production costs, which range between 53 and 165 ECU.

[94] The ’poor’ model needs an insulation foam volume of 35,7 litre. Additional 2 cm insulation would require an additional foam volume of 33,8 litre. With the specific insulation price of 0,6 ECU/litre this amounts to 20,3 ECU.

[95] Additional 6 cm insulation would require an additional foam volume of 116,1 litre. With the specific insulation price of 0,6 ECU/litre this amounts to 69,7 ECU.

Table 8: Breakdown of average unit production costs for 100-litre vertical DESWHs

Cost component	Share of total costs (%)
Machinery	14.7
Energy	3.1
Non-energy raw materials	55.8
Labour	18.2
Distribution, marketing	7.3
Royalties, know-how	0.9
TOTAL	100.0

All six of the responding manufacturers shared a common and quite straightforward opinion regarding the effects of policy measures: in the short-term, EU market shares for DESWHs are projected to rise between 2% and 4%, but the producers expect that this trend will definitely be reversed if energy efficiency policy imposes the introduction of thicker insulation.

In this case the manufacturers estimate that market shares will decrease by as much as 3% in the short term (1–2 years) and 10% in the long term (1–5 years) for the small DESWHs (≤15 litres), and by 5% in the short term and 10% in the long term for the vertical bigger models (50–200 litres).

The reasons for this development are provided in qualitative terms and focus primarily on the assumption that consumers do not give much attention to energy efficiency and that any cost increase in this ‘mature’ market will therefore induce demand shifts to collateral products (e.g. gas water heaters). At first glance, manufacturer opinion is backed up by the results of the Italian empirical survey on consumer preferences which shows that price is the crucial factor influencing their purchase, while energy efficiency is one of the less important reasons given.

However, the same survey also revealed that users are not only aware that DESWHs are not as energy efficient as they might be but are also willing to pay a higher product price; calculations showed that the benefits to consumers resulting from the higher prices are considerably higher than assumed in the consumer poll (see section 6.1). Thus one can expect perceptible demand shifts to alternative products only in cases where increases in purchase price are disproportionate to savings in operation costs or where consumers are unaware or unsure that they will benefit in the long run from paying a higher sales price, and where the alternative technology for hot water production is usable and competitive.

Furthermore, manufacturers indicated that an increase in insulation thickness may create installation problems as a result of the increase in overall product size[96], and may consequently add to transportation costs. The first argument depends clearly on the definite thickness, and both these factors would present only marginal problems. Installation problems will most certainly not occur where insulation thickness of improved DESWHs stays in the range already available on the market, but difficulties could arise if the required insulation is significantly thicker than existing values. Such problems could become more important if insulation thickness is increased to a level approaching the country-specific insulation optimum.

To analyse the effects of an increase in insulation thickness the cost structure of one major manufacturer concerning the 100 litre vertical water heater with an insulation thickness of 2.5 cm (’poor’ model) was used. If another 2 cm of insulation is added[97], unit manufacturing variable cost will increase by 13%.

If, however, 6 cm of insulation is added, unit manufacturing variable cost will increase by 42%. Table 9 reports these data[98], together with other input variables for an aggregated European market of DESWHs that were necessary to run the Lawrence Berkeley Laboratory Manufacturer Impact Model (LBL-MIM) simulation.

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[96] E.g., the boiler would be too big to fit in a bathroom.

[97] To give approximately the same insulation thickness as in the base case used in the technical/economic analysis (4–5 cm).

[98] The data in table 9 refer to the year 1996 and to an aggregate European market of DESWHs. Data are weighted averages of the different answers obtained from the responding companies. Incremental costs are related to the ‘poor model’ and describe selected possible cost increases resulting from the introduction of insulation thickness standards by the EU Commission for the same base model. The 100 litre vertical water heater is considered the ‘proxy’ product for the entire market. The industry average cost structure is that described in table 8, representing the cost breakdown of large companies only; the data collected for small and medium-sized companies operating in the DESWH industry were poor and unsuitable for modelling purposes.

Table 9: Insulation thickness improvement scenario (1996 data)

Variables	**'Poor' model 2.5 cm insulation**	**'Base case' model, 4.5 cm insulation (+ 2 cm)**	**'Efficient' model, 8.5 cm insulation (+6 cm)**
Demand price elasticity (%)		-0.22	-0.22[99]
Consumer discount rate on energy savings (%)	5		
Unit manufacturing variable cost[100] ($US)	84	11	35
Incremental cost per unit fixed capital costs[101] ($US)		12	48
Appliance annual operating costs ($US per year)	150	150	144
Ratio of highest to lowest mark-up	1.12		
Typical manufacturer mark-up over unit variable costs (%)	28.5		
Size of firm as % of total industry (%)	30		
Industry shipments (thousands of units)	5 131		
Shipments by product class (thousands of units)	770		
Tax rate (%)	33		
After tax equity cost of capital (long term average bond yield) (%)	6.5		

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[99] Plus the correction for operating costs. This, in agreement with LBL, is due to the fact that the elasticity that is obtained from the consumer survey is for a specific product improvement with an explicit hypothesis on energy savings. Instead the LBL model normally uses a general elasticity for the industry. To include again, for the 'base case' model, a correction for the energy savings would be double counting. Instead for the 'efficient' model (which is not covered in the survey) a decrease in DESWH operating costs is considered.

[100] Include costs which vary with the level of production such as materials, labour, etc.

[101] Include „one-time" costs, e.g. costs for retooling.

LBL-MIM collects into one spreadsheet all the calculations necessary to determine the impact of a change in appliance minimum efficiency limits on an industry’s profitability and scale of operation. Appliance manufacturers may be affected by a change in minimum efficiency limits, depending on the interaction of three factors:

1) the costs imposed by the change in the efficiency limits (e.g. additional investments, retooling)
2) the price elasticity of a single firm
3) the industry’s price and operating cost elasticities of demand.

LBL-MIM integrates and analyses these three factors as they apply to a single typical firm.

Table 10 summarises the basic outcomes of the model simulations (using inputs presented in Table 9). In the long term[102] the results indicate that an energy efficiency policy requiring at least 4.5 cm of insulation for DESWHs (which is comparable to the base case in the technical/economic analysis) results in a 2.8% decline in shipments but has positive effects on revenues (+10.0%) and net income (+6.7%).

Return on equity[103] as a key indicator of industries´ profitability remains unchanged, the product price rises by 13.2%.

A further increase of insulation thickness (improving the ‘poor’ model to an ‘efficient’ model with 8,5 cm of insulation) results in a decrease of 7.1% in sales and a slight reduction of the return on equity (-0.5%)[104] in the long run. Revenues (+31.5%), net income (+17.0%) and market price (+41.5%) will rise.

The difference between short term[105] and long term figures is negligible in both cases, with the exception of net income, which increases a small amount in the short

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[102] Effect after about 5 years.

[103] Net profits after taxes divided by stockholders´ equity.

[104] The model does not provide an estimate of layoff of the work force due to a decline in shipments. However, if the return on equity is to be maintained and profits increased, the cost of labour must be curtailed.

[105] Effect within about 2 years.

term and then stabilises around 7% in the first case (+ 2cm insulation), about 17% in the second case (+ 6cm insulation).

The sensitivity analysis confirms that demand price elasticity (-0.22[106]) is a crucial factor of such simulations (in the US study on DESWHs the lower value of -0.12 was chosen).

A 10% increase in elasticity reduces revenues by 0.3% in case 'poor model plus 2cm insulation' and by about 1% in case 'poor model plus 6 cm insulation', whereas net profits are reduced by about 0.8% and 2.2% respectively. Return on equity will decline only slightly.

A 10% decrease in elasticity, however, will have a corresponding positive impact on revenues and net income, almost symmetric to the previous figures as shown. More details concerning the sensitivity analysis are shown in appendix 8.6.

In interpreting and assessing the accuracy of Table 10, it should be kept in mind that in a recently published paper the authors[107] stated that engineering estimates like LBL-MIM overestimates the effects on manufacturers[108]. It is also known that manufacturers of DESWHs act in a much broader segment (e.g. all sorts of sanitary equipment). This means that even under the assumption of a decrease in DESWH sales as a result of higher purchase prices, manufacturers will benefit from a rise in the demand for 'substitute' technologies.

Considering these facts, it can be taken for granted that improving 'poor' models to the 'base case' performance will result in no negative effects on manufacturers[109].

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[106] Elasticity is calculated from the potential new demand determined in the empirical evaluation of consumer behaviour in Italy (see chapter 6.1 and task 5 report). Established a sample of 120 000 units and using the upper portion of the saving curve (Figure 27), the number of new DESWH units is 94 286, equal to 78% of the total. The complement with the respect to one is -0.22.

[107] Jim McMahon, Mark Hinnells (1997): Stakeholders and Market Transformation: An Integrated Analysis of Costs and Benefits. In: Proceedings of the European Council for an Energy Efficient Economy. Summer Study in Energy Efficiency, June 9-13, Spindleruv Mlyn, Czech Republic, published by Danish Energy Agency, Copenhagen.

[108] With other products (refrigerators, cars, etc.) manufacturers do not pass cost increases resulting from stronger regulation on to consumers. To fulfil their obligation, manufacturers often make investments that increase productivity, and these productivity gains compensate the increase in a single cost component.

[109] This also means that it is unnecessary to recalculate the five scenarios for energy policy intervention (see chapter 5) on energy consumption and CO_2 reduction. Taking into consideration that other hot water technologies are more energy-efficient than DESWHs (using less primary energy, e.g. direct use of natural gas for gas water heaters versus fuel input for electricity generation for DESWHs), these outcomes represent the minimum effects of the investigated policy measures.

Even if insulation is increased to 8,5 cm - which is approximately the ‘optimal’ insulation thickness (see chapter 4.4 and 8.5) of a 100 litre DESWH in a series of EU member countries - only small negative effects on manufacturers will arise according to LBL-MIM results.

Table 10: Percentage changes in manufacturer costs related to increasing DESWH insulation thickness by 2 cm (‘poor’ model to ‘base case’ model) and by 6 cm (‘poor’ model to ‘efficient’ model), according to LBL-MIM

Variables	**‘poor’ to ‘base case’ (2,5 cm to 4,5 cm)**		**‘poor’ to ‘efficient’ (2,5 cm to 8,5 cm)**	
	Short term	Long term	Short term	Long term
Shipments	-2.7	-2.8	-6.8	-7.1
Market price	12.7	13.2	40.0	41.5
Revenues	9.7	10.0	30.5	31.5
Net income	1.7	6.7	2.9	17.
Return on equity	-0.4	0.0	-1.4	-0.5

7 RECOMMENDATIONS

7.1 Basic approach

The technical/economic analysis indicates that the country-specific[110] 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.

The proposed energy policy framework was designed to fulfil the following conditions, with the aim of achieving an equilibrium between consumers and manufacturers, the two principal stakeholders:

a) to ensure energy savings without transaction costs at least up to an extent where consumers benefit in any case and to reduce the possibility of negative effects on manufacturers to a minimum.

b) to provide information on the energy efficiency of the DESWH for all other cases where certain consumers could face financial disadvantages[111] and manufacturers could be affected negatively to a noticeable extent if a general, more rigorous performance standard were set.

The best way to realise these demands in a cost-effective way is to have an energy policy mix based on two main strategies:

1) Set a **minimum energy efficiency standard** (covering condition *a* above). DESWHs are different from other domestic electric appliances as the user is often not the buyer. Therefore recommending only a label is not sufficient.

2) Introduce a **labelling scheme** (covering condition *b* above).

Figure 30 demonstrates these two main strategies and shows the area of labelling from 100% down to around 50% of the standing losses of the base case, covering all calculated national economic optima and existing best models.

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[110] Depending on electricity tariffs.

[111] See the different country-specific optimal insulation thicknesses.

Some other measures (e.g. information on ‘good practice‘ with respect to hot water production) are discussed at the end of this chapter (section 7.4) to complete the recommendations.

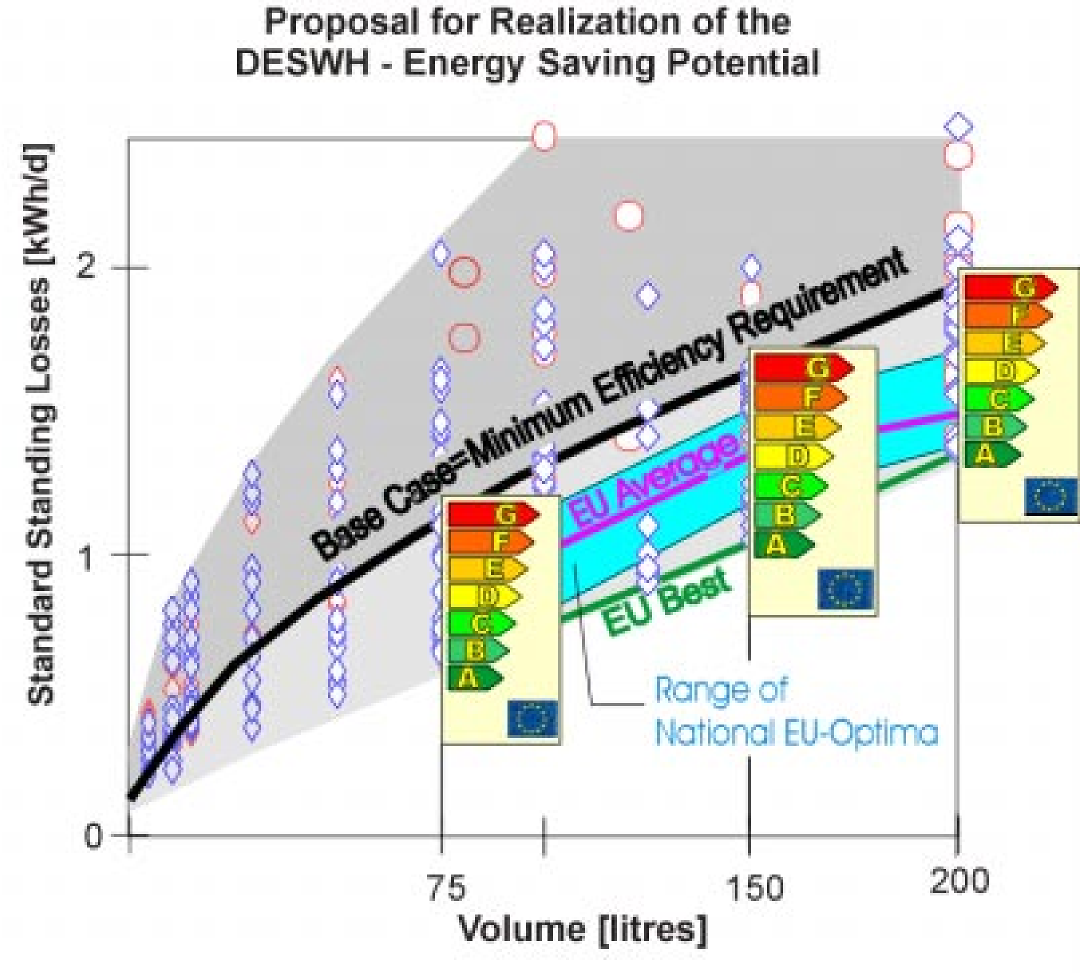

Figure 30: Basic approach for increasing energy efficiency of DESWHs

7.2 Minimum energy efficiency standard

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 $L_{st,BC}$ 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[112], and at the same time guarantees benefits for consumers. It should be underlined that the life-cycle analysis in chapter 4 indicates clearly that the lowest country-specific optimal insulation thickness is in any case slightly higher than that of the base case. Keeping in mind that the life-cycle cost analysis was performed using very ‘conservative’ assumptions[113] (i.e. with respect to the additional insulation costs), it can be claimed that using the base case as a minimum energy efficiency standard is an extremely cautious approach.

The minimum energy efficiency standard can be set in the framework of a Directive or a negotiated agreement, concluded between the Commission and manufacturers (through CECED, the manufacturers’ association).

Standing losses[114] $L_{st,st}$ (in kWh/day) (measured according to the energy measurement standard in IEC 379 (3rd edition, 1987), which is sufficient to impose the proposed regulation) of the particular DESWH with rated capacity V (in litres) must not exceed $L_{st,mes}$, the minimum efficiency standard: $L_{st,st} \leq L_{st,mes}$ with $L_{st,mes} = L_{st,BC}$.

This means minimum energy efficiency requirements ($L_{st,mes}$) for standing losses as shown in Table 11.

Table 11: Minimum energy efficiency requirements as a function of rated capacity

Type of DESWH	Capacity (litres)	Minimum energy efficiency requirements[115] ($L_{st,mes} = L_{st,BC}$)
Vertical	> 50–1000	$0.2 + 0.051 * V^{2/3}$
Horizontal	> 50–300	$0.75 + 0.008 * V$
Small	5–50	$0.13 + 0.0553 * V^{2/3}$

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[112] See results of LBL-MIM in chapter 6.2. The model is not formulated to simulate a situation where one producer has no investment to perform and another producer must retool for all his products of a certain class. But in addition it has to be taken into account that implementing a standard which requires such investments is only one part of the proposed policy and that labelling will effect more/other manufacturers in an additional/different way.

[113] But the savings are still very high; see the results in chapter 4.

[114] Using standard standing losses ensures flexibility in selecting the combination of insulation thickness and heat conductivity λ for insulation quality.

[115] V = rated capacity in litres.

Functions for $L_{st,mes}$ were derived by a curve-fitting procedure through the points of unweighted and weighted averages from the CECED database. The relative standing losses, i.e. the losses related to the existing average, range from 57% to 579% in the case of small DESWHs, from 60% to 168% in the case of horizontal DESWHs, and from 54% to 185% in the case of the vertical ones (see Appendix 8.4).

Figure 31 compares the proposed minimum energy efficiency standard with existing efficiency thresholds in various European countries (France, the UK, Germany/Switzerland).

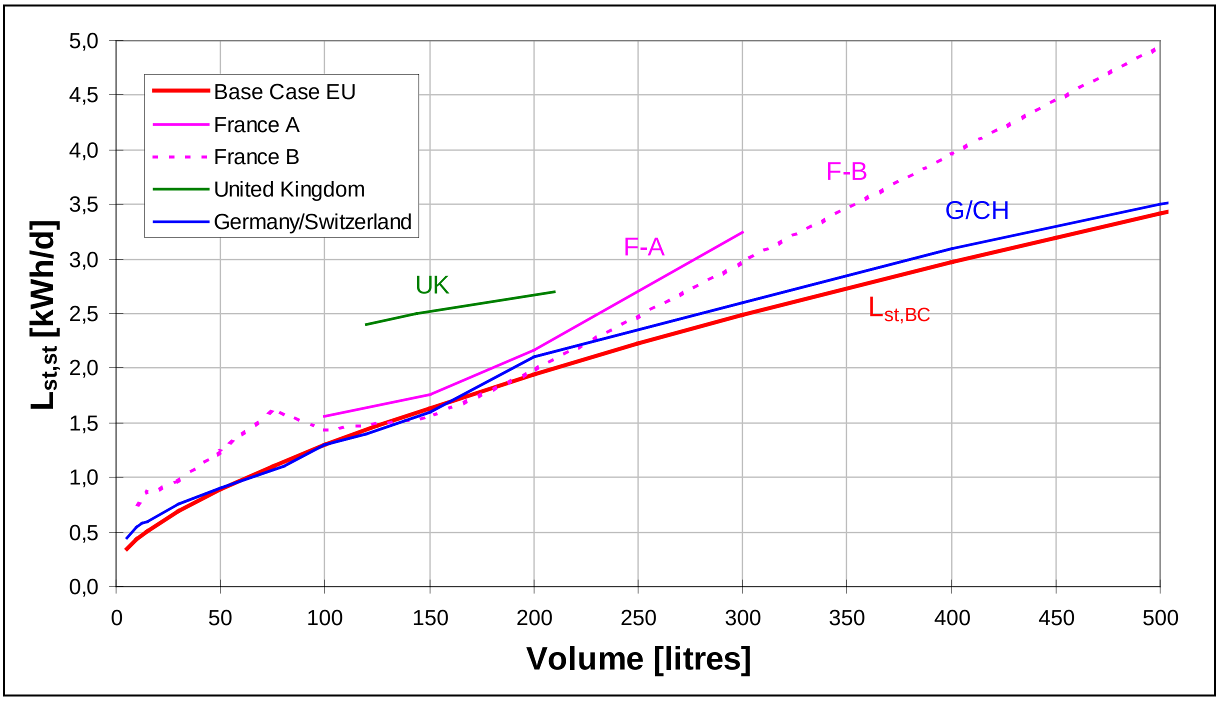

Figure 31: Existing efficiency thresholds for small and vertical DESWHs in France, the UK and Germany/Switzerland

7.2.1 Effect of a minimum energy efficiency standard on DESWH models

Tables 12–14[116] include information (based on the available CECED data[117]) on the percentage of models that would have to be improved after implementation of the proposed minimum energy efficiency standard.

Table 12: Vertical DESWHs that would need to be improved after implementation of the proposed minimum energy efficiency standard

	Models by manufacturing country (% of CECED)	Models not fulfilling the efficiency standard (% of manufacturing country)
France	77.9	45.8
Italy	2.0	59.4
Spain	9.5	100.0
Germany	5.6	19.1
Switzerland	2.4	26.3
Belgium	2.6	85.4
CECED	100.0	50.3

Table 13: Horizontal DESWHs that would need to be improved after implementation of the proposed minimum energy efficiency standard

	Models by manufacturing country (% of CECED)	Models not fulfilling the efficiency standard (% of manufacturing country)
France	66.7	21.1
Italy	1.2	50.0
Spain	29.6	99.0
Germany	–	–
Switzerland	0.6	0.0
Belgium	1.9	25.0
CECED	100.0	44.4

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[116] The first column shows the countries which are included in the CECED data base. The second column contains the manufacturing structure, e.g. Table 12 indicates that 5.6% of all vertical models in the CECED data base are produced in Germany, 77.9% in France. The third column shows how many of the models are not fulfilling the proposed minimum energy efficiency standard, e.g. Table 13 indicates that 21.1% of horizontal models which are manufactured in France are not fulfilling the proposed standard.

[117] See description in section 3.3.

Table 14: Small DESWHs that would need to be improved after implementation of the proposed minimum energy efficiency standard

	Models by manufacturing country (% of CECED)	Models not fulfilling the efficiency standard (% of manufacturing country)
France	54.5	77.2
Italy	11.8	100.0
Spain	17.6	100.0
Germany	14.3	30.4
Switzerland	0.4	0.0
Belgium	1.4	100.0
CECED	100.0	77.2

7.2.2 Effects of a minimum energy efficiency standard on society

Based on the results of chapter 5 ('Effects of policy interventions on energy savings and CO_2 reduction') and on estimates of key financial data of the DESWH industry, the proposed minimum energy efficiency standard can be expected to have the effects shown in Table 15[118].

Table 15: Societal effect of the proposed minimum efficiency standard

	Year[119]		
	2000	2005	2010
Consumers Savings (million ECU)	54	173	259
Manufacturers Return on equity (change in %)	-0.4	0.0	0.0
Environment/society CO_2 reduction (Mt CO_2)	0.22	0.73	1.10
Environment/society Reduction of electricity consumption[120] (GWh)	452	1 445	2 158

---

[118] Assuming that the standard is in effect in the year 2000. Other unquantified effects include the reduced demand for electricity generation and a reduction in 'conventional' emissions (SO_2, NO_x, etc.)

[119] Data related to year 2000, 2005 and 2010 (not accumulated!)

7.3 Labelling

Of the proposed information activities, labelling of DESWHs is the most important measure. As described in the previous chapters, 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. Additional information measures (see section 7.4) can strengthen the effect of labelling.

Labelling provides a language for all stakeholders. One can imagine that plumbers take advantage of A or B labels in their offers to customers, establishing in that way a direct influence of consumers on the choice of products.

Two options are proposed for labelling DESWHs. The **first option (O1)** should be selected if only a part of the DESWH market is covered by $L_{st,mes}$ (if only a few manufacturers sign a voluntary agreement). The **second option (O2)** should be selected if all models are covered by a minimum energy efficiency standard (no labelling above the base case is necessary).

Labelling focuses on $L_{st,st}$ (the measured 'standard' standing losses of the specific DESWH according to IEC 379) excluding fixed losses $L_{st,fix}$, set[121] at 0.12 kWh/day (corresponding to 5 W) for vertical and horizontal DESWHs, and to 0.072 kWh/day (corresponding to 3 W) for small DESWHs. Thus the remaining amount, $L_{st,var}$, can be calculated as $L_{st,var} = L_{st,st} – L_{st,fix}$.

$L_{st,var,100}$, the 100% bench-mark of the label, is $L_{st,BC}$ minus $L_{st,fix}$. This leads to a percentage x of measured standing losses $L_{st,st}$ of a DESWH compared to $L_{st,var,100}$ of:

$$x = (L_{st,var}/L_{st,var,100}) \times 100 = ((L_{st,st} - L_{st,fix}) / (L_{st,BC} - L_{st,fix})) \times 100$$

In accord with the existing EU-labelling schemes, classes A to G are proposed[122]. The definition of classes for vertical, horizontal and small DESWHs is as shown in Table 16.

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[120] Through reduction of standing losses.

[121] In accordance with experience gained in the technical/economical analysis.

[122] As Figure 21 shows, DESWHs are only one technology to provide the energy service „hot water". It should be considered to expand labelling to other options for hot water supply and to include information on the relative energy efficiency (e. g. gas/electricity, but also electric vertical/electric horizontal) of different appliances.

Table 16: Definition of proposed energy label classes for DESWHs

Class	Option 1 (O1)	Option 2 (O2)
G	$x > 100$	$100 \geq x > 90$
F	$100 \geq x > 90$	$90 \geq x > 82$
E	$90 \geq x > 80$	$82 \geq x > 74$
D	$80 \geq x > 70$	$74 \geq x > 66$
C	$70 \geq x > 60$	$66 \geq x > 58$
B	$60 \geq x > 50$	$58 \geq x > 50$
A	$x \leq 50$	$x \leq 50$

Figure 32 shows the labelling classes for vertical DESWHs, and Figures 33 and 34 illustrate the proposal for small and horizontal DESWHs (all related to O1), respectively.

Within 2 years after implementation of minimum efficiency requirements and labelling, a study should be carried out to evaluate the effect of these measures, to improve a European DESWH database, supplemented with sales data sets (preferably in co-operation with CECED), and to investigate benefits of further improvements in the performance of DESWHs.

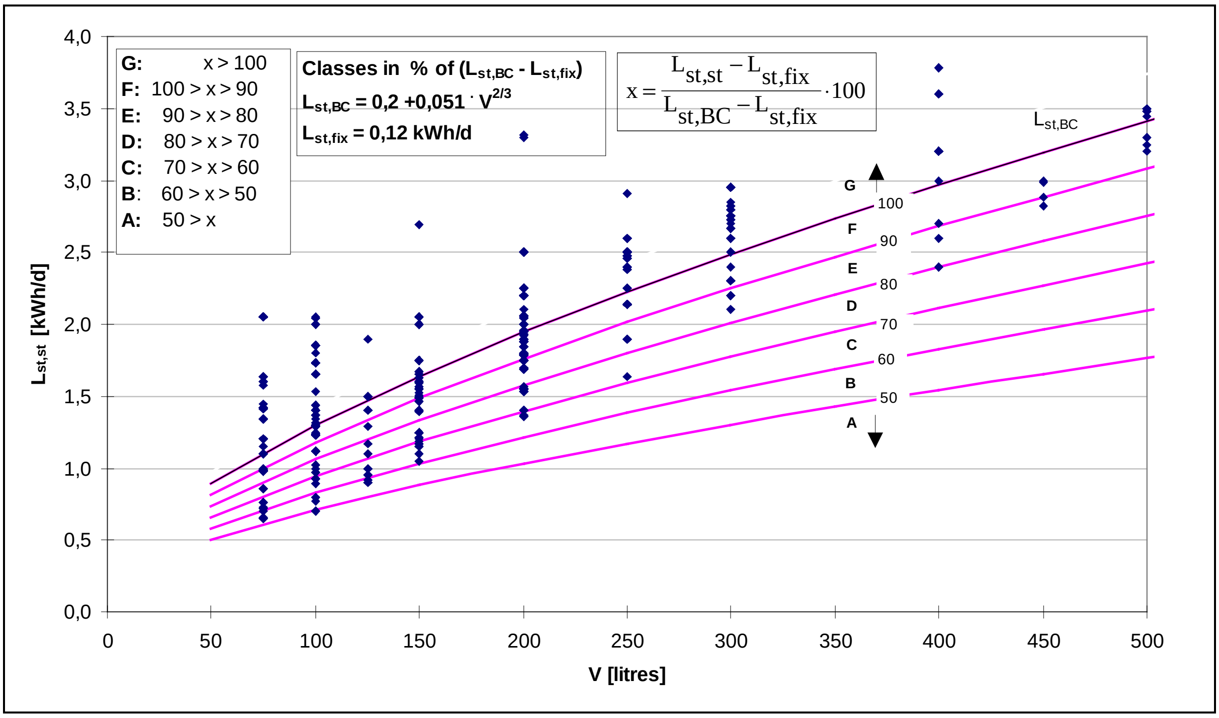

Figure 32: Classification of vertical DESWHs for labelling (O1)

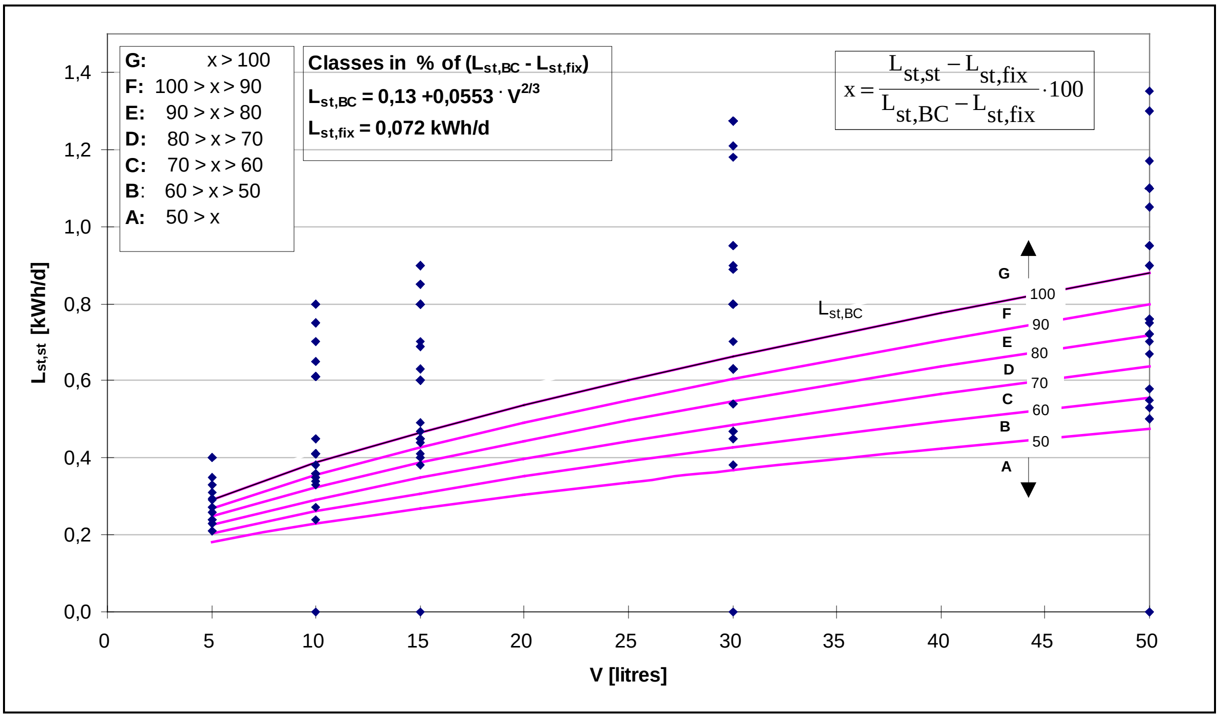

Figure 33: Classification of small DESWHs for labelling (O1)

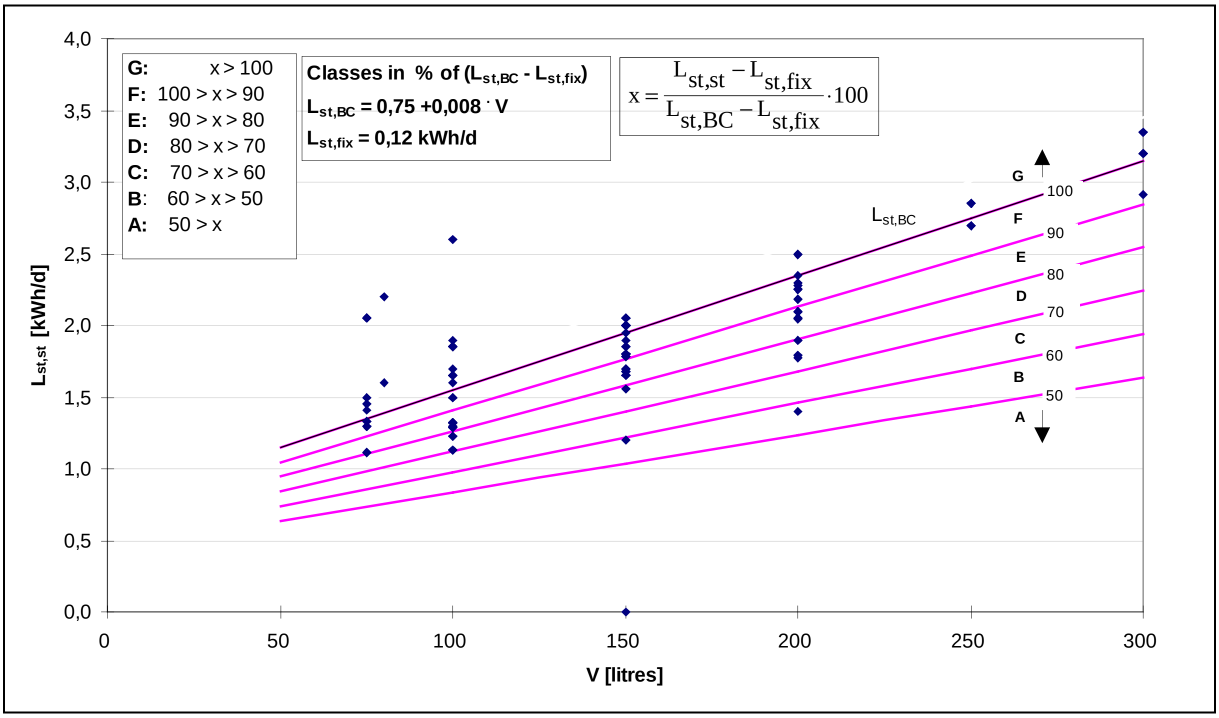

Figure 34: Classification of horizontal DESWHs for labelling (O1)

7.4 Other measures[123]

1. 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
   - **demonstrate '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.

   The SAVE programme is an appropriate tool for initiating and supporting such activities in co-ordination with member states on a European level. It also looks for opportunities and economic limits to supplement hot water production with solar heating, and it performs an economic environmental (CO_2) cost–benefit analysis of different technologies with respect to systems for hot water production.
2. In order to create a 'level playing field' and to evaluate cost-effective measures for utilising energy saving potentials, other appliances for hot water production (especially gas water heaters) should be investigated.
3. R&D activities are required to attain further improvements in the performance of DESWHs. These activities focus particularly on the development of:
   - better insulation materials (e.g. vacuum panels)
   - intelligent control systems (e.g. to 'upgrade' already installed DESWHs)
   - armatures for avoiding/reducing heat bridges.

   Manufacturers can take advantage of the existing EU programmes in the field of R&D if their R&D projects contain exceptionally technical and economic risks.
4. A procurement strategy on a European level should be taken into account in order to launch R&D activities that have the perspective of broad market penetration opportunities and the utilisation of large-scale economies.
5. Utilities should provide incentives to shift hot water production to periods with lower electricity demand. Offering night tariffs together with remote control of DESWHs by utilities are 'classic' load-management measures, are beneficial to both consumers and utilities, and 'save' electricity-generation capacity.

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[123] Manufacturers suggested the following alternative measures to increase energy efficiency of DESWHs:

- Funding of R&D projects aimed at developing insulation materials more efficient and environmentally sound.
- Improving coherence and co-ordination among EU projects related to the industry: i.e. projects for HCFC elimination versus projects for increasing insulation.
- Implementing provisions of appropriate Demand-Side Management measures.
- Favouring the development of electric water heaters with two circuit systems using two different power tariffs.
- Promoting decentralised hot-water systems, i.e. installation of small water heaters at the point of use.
- Promoting heat pumps and solar systems (reduction of primary energy consumption and reduction of emissions).
- If efficiency limits are established they must have an adequate system of control to provide absolute adherence to the established requirements.

8 APPENDICES

8.1 Description of energy flow in water supply systems

8.1.1 Energy flow

Figure 35 shows the scheme of the energy flow in hot water supply systems (from the energy input, the heating system, the storage tank and the distribution system to the hot water needs of the user).

8.1.2 DESWH heating systems

DESWH heating systems consist of one or two electrical heating elements and thermo-sensors, situated directly in the storage tank. For this case, heating losses L_h can be neglected, i.e. the heat input Q_h into the storage tank equals the end energy E. Neither other fuels nor input from environment need to be considered for the energy consumption of the DESWH. The electrical power of the heating element depends on the capacity of the storage tank, the desired heat-up time and the tariff situation.

High-tariff (HT) systems are powered the whole day, heating up immediately after each draw-off or after dropping below the lower temperature limit of the sensor.

Low-tariff (LT) systems have a limited power-on time of 4–8 hours per day, following demand-side management considerations of the utility. Normal LT periods are overnight, with start times between 10 pm and 2 am and end times at 6 am or 7 am.

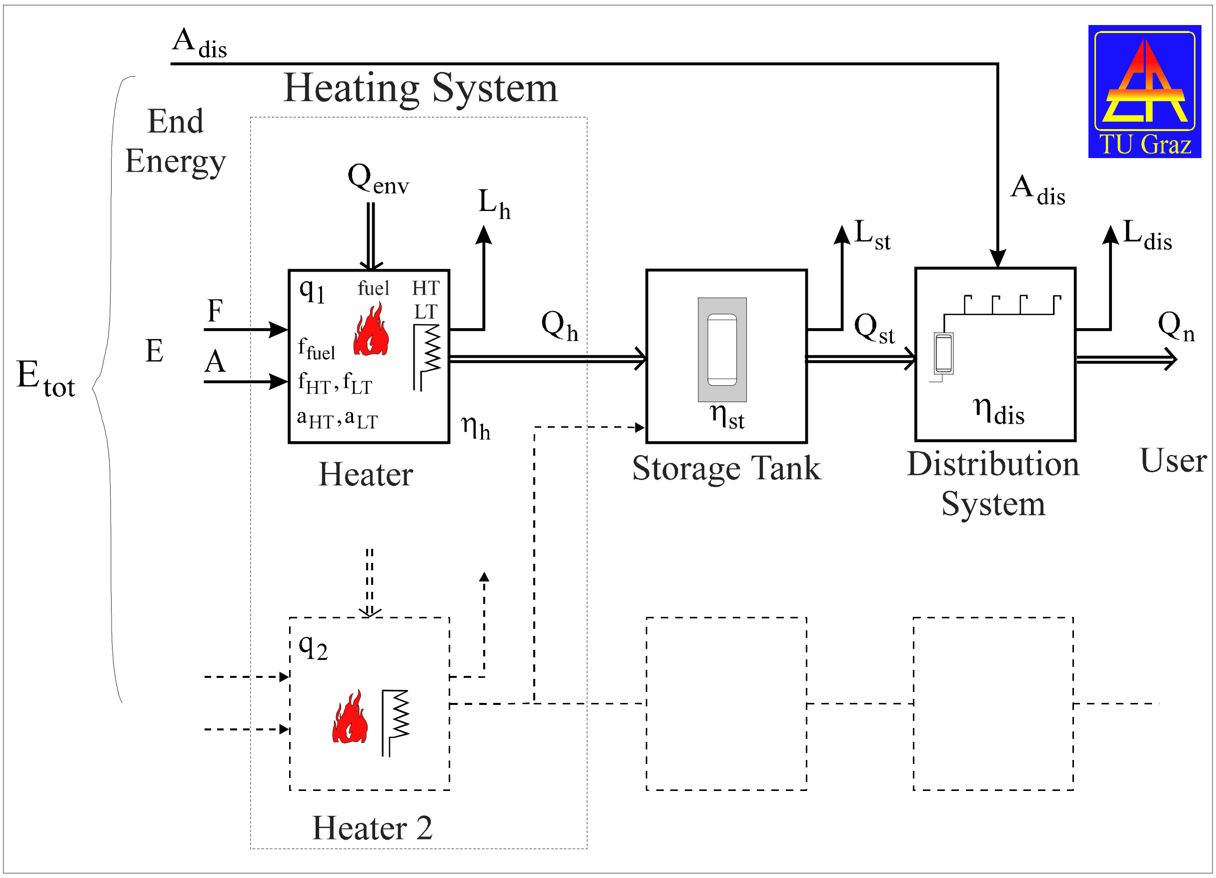

Figure 35: Energy flow in warm water supply systems

PE	Primary energy
E_{tot}	Total end energy input (heating plus auxiliary)
E	End energy input for hot water needs
F	Fuel input (including electricity for electric heating)
A	Auxiliary electricity for pumps, oil burner, heat pumps, etc.
A_{dis}	Auxiliary electricity for distribution (e.g. circulation pump, trace heating)
Q_{env}	Environmental heat input (solar, surrounding)
Q_h	Heat input into the storage tank
Q_{st}	Hot water output of the storage tank, input into the distribution system
Q_n	Hot water energy needs supplied through the outlets to the user
L_{st}	Storage losses (at real conditions)
$L_{st,st}$	Storage losses at standard conditions (standard standing losses)
L_{dis}	Distribution losses
L_{PE}	Losses of energy conversion between primary and end energy
q_i	Portion of hot water needs in the case of several heat sources
η_h	Efficiency of the heating system
η_{st}	Efficiency of the storage tank
η_{dis}	Efficiency of distribution
η_{PE}	Efficiency of energy conversion between primary and end energy

8.1.3 Storage tank

The heat input Q_h into the storage tank, which is supplied by the heating system, must cover the used hot water Q_{st} (needs plus distribution losses) and the storage losses (standing losses) L_{st} of the tank itself. As already described in section 1.2, the standing losses depend on a number of constructional conditions of the tank (tank dimensions, performance of heat insulation, etc.) and operational conditions. Real operational conditions can differ from those defined in the standards. Both Q_{st} and Q_h depend on the temperature difference between hot water T_h and cold water T_c, whereas the losses L_{st} only depend on the temperature difference between T_h and ambience T_{amb}.

Single-powered storage tank

The single-powered storage tank (see Figure 36) is described by the following equations:

$$Q_h = Q_{st} + L_{st} = \frac{Q_{st}}{\eta_{st}} \qquad \eta_{st} = \frac{Q_{st}}{Q_h} = \frac{Q_{st}}{Q_{st} + L_{st}}$$

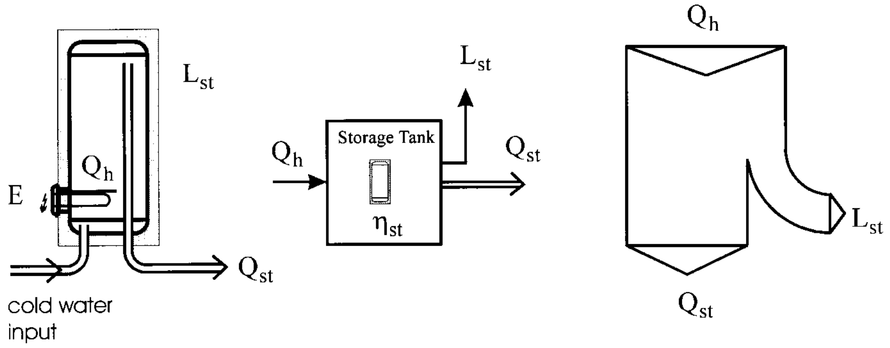

Figure 36: Single-powered storage tank

Multi-powered storage tank

One storage tank can be supplied by more than one heater (multi powered, see Figure 37). For example, there can be two electric heating elements for HT and LT electricity, or there can be only one electric heating element plus heat exchangers – so-called ‘combis’ – for the use of solar energy or heat pumps, or for connection with the room heating systems, etc.

These heating sources may be used alternately, so that only one source is in use at any one time of the year (e.g. LT electricity in summer, oil in winter), or they may be used in **parallel** (e.g. solar plus LT or HT electricity as supplementary energy during the same day). It must be taken into account that for the specific operation modes with several heating sources the storage losses from the same tank can differ according to the positions of the heating elements in the tank, heated volumes, hot water temperatures and operating times. Furthermore, also distribution losses can be different in the case of various water temperatures supplied by the storage tank.

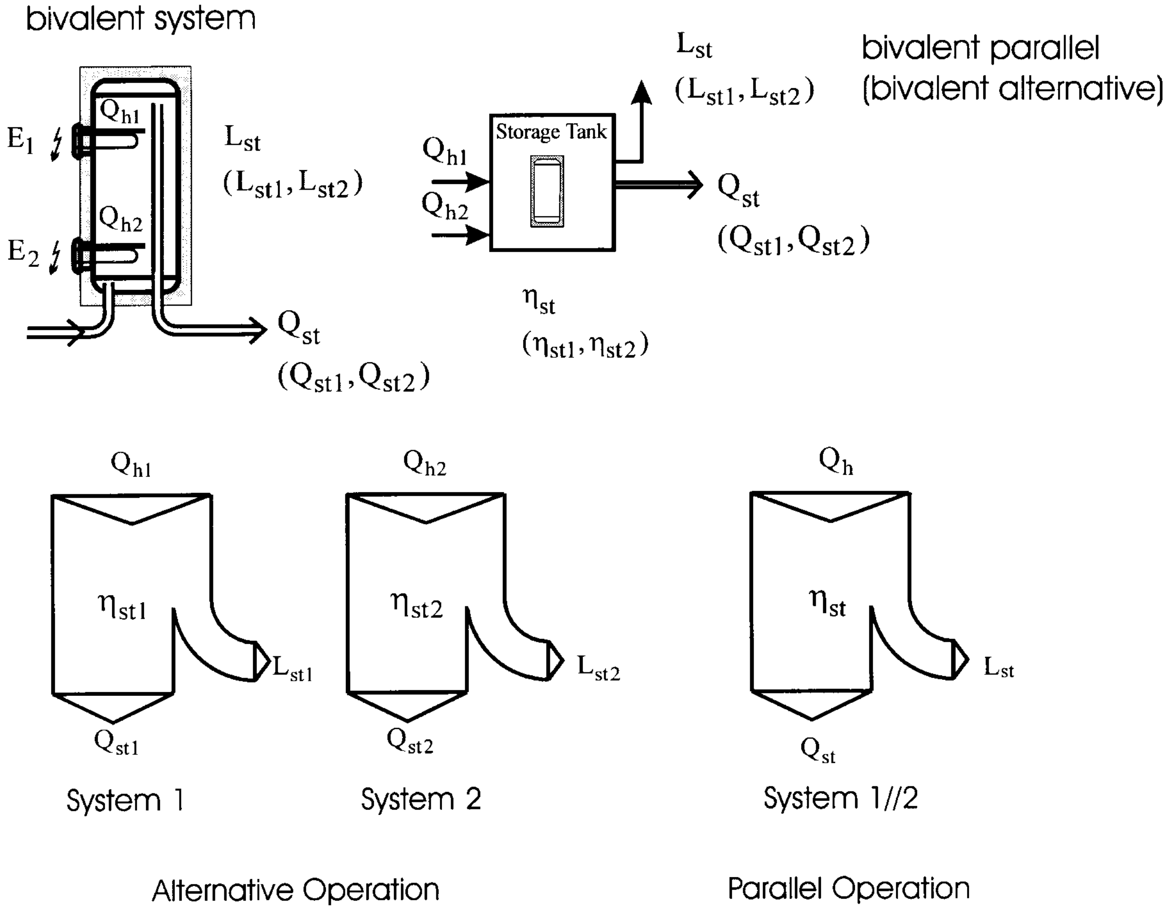

Figure 37: Multi-powered storage tank

Types of DESWH

With regard to mechanical construction, a distinction should be made between DESWH systems which are operating under pressure (unvented) of the cold water supply system with taps in each of several outlets, and pressureless (vented) systems where the tap is situated in the cold water inlet pipe, thus allowing only one outlet.

Copper tanks that are mechanically enforced by a steel surface are normally used in the UK. As reported, most of these systems are not heat insulated, or the heat insulation contains large heat bridges.

8.2 IEC 379

The purpose of this standard is to define the principal performance characteristics of electric storage water heaters and to describe the standard methods for measuring these characteristics.

8.2.1 Verification of the rated capacity

The water heater is filled in the normal way and then the water supply is cut off. It is then emptied through the water inlet or if it is not possible, through the drain plug opening[124]. The water withdrawn is measured and the result stated in litres, to the nearest one-tenth litre.

8.2.2 The energy test

Starting and ending at the period the thermostat cuts out, the energy E_1 consumed during time t_1 (hours) is measured over a period of not less than 48 hours. The water temperatures θ_{Ei} at each thermostat cut-in and θ_{Ai} at each thermostat cut-out are measured.

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[124] Water in the feed cistern of a cistern water heater is excluded from the quantity withdrawn.

The energy consumption E per 24 hours is calculated:

$$E = \frac{E_1.24}{t_1}$$

The mean water temperature[125] θ_M is calculated:

$$\theta_M = \frac{\theta_A + \theta_E}{2}$$

Standing losses per 24 hours, Q_{pr}, are calculated according to[126]:

$$Q_{pr} = \frac{45}{\theta_M - \theta_{amb}}.E$$

Q_{pr} is expressed in kilowatt-hours per 24 h related to a temperature rise of 45 K and expressed to the nearest 0.1 kWh[127].

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[125] The thermostat of water-heaters where adjustment is provided is set so that the mean water temperature θ_M is 65 ± 3 $^{\circ}$C.

[126] Ambient temperature has to be 20 ± 2 $^{\circ}$C, temperature θ_C of cold water supply 15 ± 2 $^{\circ}$C.

[127] The electrical energy consumed is measured by means of a watthour meter and recorded in kilowatt-hours to the nearest 0.01 kWh.

8.3 Market trends by country in 1995

Table 17: Estimated sales of electric storage water heaters by capacity, 1995 (thousands of units)

Capacity (litres)	**F (1991)**	**UK**	**D ?**	**I**	**E**	**P (!)**	**B**	**NL**	**A**	**CH**
5 ≤ 10	45		906	-		-		72	40	
10 ≤ 15		25		250	18	-	64		14	9
15 ≤ 30	82		30	45					13	
30 ≤ 50				125	100	12				4
50 ≤ 75				115	144					
75 ≤ 80	174		170	455	51	22	29			14
80 ≤ 100		45 (°)			44			53	74	
100 ≤ 150				80			26			
150 ≤ 200	482				12	10	24			16
> 200	78		30		11		22		7	21
(°) + 90 –100 000 copper cylinders (electric)										

Source: GB Consult Group Ltd, UK.

(?) in **Germany** figures are very much estimated.

(!) for **Portugal** data are estimated, and might include also DESWHs used in the tertiary sector (i.e. hotels).

8.4 Range of standing losses for small, vertical and horizontal DESWHs, from the CECED database

Table 18: Small DESWHs

V	Nr.	Min	Max	Max/Min	Avg.	W. Avg.	$L_{st,BC}$	Min/Avg	Max/Avg	Most frequent model	
[l]					kWh/d			(%)	(%)	Nr.	kWh/d
5	22	0.21	0.40	1.90	0.29	0.30	0.29	72	137	5	0.4
10	67	0.24	0.80	3.33	0.47	0.52	0.39	62	207	18	0.61
15	95	0.38	2.70	7.11	0.74	0.75	0.47	81	579	30	0.8
30	162	0.38	1.28	3.37	0.80	0.96	0.66	57	193	60	0.8
50	199	0.5	1.55	3.10	0.89	1.19	0.88	57	176	82	1.1
Sum	**545**										
n. u.	7										
Total	**552**										

n. u. = not usable, incomplete data sets V = volume in litre Nr. = number of models

Table 19: Horizontal DESWHs

V	Nr.	Min	Max	Max/Min	Avg.	W.Avg.	$L_{st,BC}$	Min/Avg	Max/Avg	Most frequent model	
[l]					kWh/d			(%)	(%)	Nr.	kWh/d
75	94	1.11	2.05	1.85	1.45	1.57	1.35	82	152	39	1.3
80	3	1.60	2.20	1.38	1.90	2.00	1.39	115	158	2	2.2
100	126	1.13	2.60	2.30	1.59	1.56	1.55	73	168	37	1.85
150	126	1.20	2.05	1.71	1.76	1.84	1.95	62	105	38	1.8
200	162	1.40	2.50	1.79	2.07	2.18	2.35	60	106	52	2.25
250	48	2.70	2.85	1.06	2.78	2.78	2.75	98	104		
300	25	2.91	3.35	1.15	3.15	3.20	3.20	92	106		
Sum	**584**										
n. u.	1										
Total	**585**										

n. u. = not usable, incomplete data sets V = volume in litre Nr. = number of models

Table 20: Vertical DESWHs

V	Nr.	Min	Max	Max/Min	Avg.	W.Avg.	$L_{st,BC}$	Min/Avg	Max/Avg	Most frequent model	
[l]					kWh/d			(%)	(%)	Nr.	kWh/d
75	241	0.65	2.05	3.15	1.12	1.29	1.11	59	185	60	0.98
100	310	0.70	2.05	2.93	1.32	1.41	1.30	54	158	60	1.12
125	19	0.90	1.90	2.11	1.21	1.25	1.48	61	129	4	1.4
150	287	1.05	2.69	2.56	1.50	1.55	1.64	64	164	60	1.25
200	395	1.36	3.32	2.44	1.94	1.88	1.94	70	171	60	1.55
250	142	1.64	2.91	1.77	2.33	2.31	2.22	74	131	60	2.14
300	119	2.10	2.95	1.40	2.60	2.65	2.49	84	119	30	2.75
400	40	2.40	3.78	1.58	3.04	3.19	2.97	81	127	25	3.2
450	4	2.82	3.00	1.06	2.92	2.92	3.19	88	94		
500	18	3.20	3.50	1.09	3.36	3.44	3.41	94	103	8	3.5
600	6	3.10	4.90	1.58	3.96	4.07	3.83	81	128	2	4.6
800	3	4.00	7.30	1.83	5.12	5.17	4.60	87	159		
1000	7	4.00	8.00	2.00	5.40	5.44	5.30	75	151	2	5.7
Sum	**1591**										
n. u.	13										
Total	**1604**										

n. u. = not usable, incomplete data sets V = volume in litre Nr. = number of models

8.5 Optimal insulation performance of DESWH

The following table 21 gives the results of the optimal insulation thickness and the corresponding standard standing losses for the different European countries.

The range of the economical optima, expressed by the corresponding standing losses, is between the base case and the existing best models. For the ‘high tariff’ (HT) configuration the optimal insulation performance is better (higher insulation thickness, lower standing losses) than for the ‘low tariff’ (LT) situation.

Table 21: Optimal insulation thickness sopt based on l = 0,035 W/m K and corresponding optimal standard losses Lst,opt in kWh/day

	s_{opt} [m]			$L_{st,opt}$ [kWh/d]		
Country	**LT-C 200**	**LT-B 150**	**HT-B 75**	**LT-C 200**	**LT-B 150**	**HT-B 75**
Austria	0,082	0,076	0,102	**1,28**	**1,18**	**0,75**
Belgium	0,075	0,069	0,101	**1,36**	**1,24**	**0,75**
Denmark	0,104	0,093	0,098	**1,12**	**1,04**	**0,76**
France	0,072	0,066	0,089	**1,40**	**1,28**	**0,80**
Finland	0,056	0,051	0,077	**1,64**	**1,51**	**0,86**
Germany	0,075	0,069	0,099	**1,36**	**1,24**	**0,76**
Italy	0,110	0,103	0,108	**1,09**	**0,99**	**0,73**
Netherlands	0,068	0,062	0,087	**1,45**	**1,32**	**0,81**
Portugal	0,069	0,065	0,087	**1,43**	**1,29**	**0,80**
Spain	0,065	0,061	0,092	**1,49**	**1,35**	**0,79**
Sweden	0,069	0,062	0,089	**1,43**	**1,32**	**0,80**
U. Kingdom	0,055	0,050	0,084	**1,67**	**1,52**	**0,82**
Europe	0,070	0,064	0,093	1,28..**1,43**..1,67	1,18..**1,31**..1,52	0,73..**0,78**..0,86
% of base case				66..**74**..86	72..**80**..93	66..**70**..78
Best on market				**1,36**	**1,05**	**0,65**
% of base case				**70**	**64**	**59**
Base case	0,044	0,045	0,049	**1,94**	**1,64**	**1,11**

8.6 Results of sensitivity analysis

Table 22: Long-term Multipliers

Variables	**Demand Elasticity + 10%**		**Demand Elasticity - 10%**	
	‘poor’ to ‘base case’	**‘poor’ to ‘efficient’**	**‘poor’ to ‘base case’**	**‘poor’ to ‘efficient’**
Shipments	-0.25	-0.65	0.30	0.70
Market price	-	-	-	-
Revenues	-0.30	-0.95	0.35	0.95
Net Income	-0.75	-2.20	0.70	2.50
R.O.E.	-0.05	-0.10	0.04	0.24

Table 23: Price elasticity -0.22 +20% = -0.264

Variables	**‘poor’ to ‘base case’ (2,5 cm to 4,5 cm)**		**‘poor’ to ‘efficient’ (2,5 cm to 8,5 cm)**	
	Short Term	**Long Term**	**Short Term**	**Long Term**
Shipments	-3.2	-3.3	-8.0	-8.4
Market price	12.7	13.2	39.7	41.5
Revenues	9.0	9.4	28,5	29.6
Net Income	-0.7	5.2	-4.3	12.6
R.O.E.	-0.6	-0.1	-1.9	-0.7

Table 24: Price elasticity -0.22 -20% = -0.176

Variables	**‘poor’ to ‘base case’ (2,5 cm to 4,5 cm)**		**‘poor’ to ‘efficient’ (2,5 cm to 8,5 cm)**	
	Short Term	**Long Term**	**Short Term**	**Long Term**
Shipments	-2.2	-2.2	-5.5	-5.7
Market price	12.8	13.2	40.3	41.5
Revenues	10.4	10.7	32.5	33.4
Net Income	4.2	8.1	10.3	21.
R.O.E.	-0.3	0.04	-1.0	-0.23

8.7 Comparison Measurement - Simulation

Table 25, Table 26, Figure 38 and Figure 39 show the comparison between measurement and simulation results. Measurement data were supplied by CECED (GIFAM), simulation was performed by TU Graz.

Table 25: Comparison between Measurement and Simulation: Standard Standing Losses of the 200 litres Prototypes with different Insulation Thickness

200 litres		**Measurement**	**Simulation Results for $\lambda \pm 10$ %**
Prototypes	**s [m]**	**$L_{st,st}$ [kWh/d]**	**$L_{st,st}$ [kWh/d]**
No. 1:	0,026	2,09	2,01...**2,23**...2,43
No. 2:	0,035	1,69	1,60...**1,78**...1,94
No. 3:	0,055	1,29	1,14...**1,28**...1,39
No. 4:	0,335	0,84	0,50...**0,54**...0,58

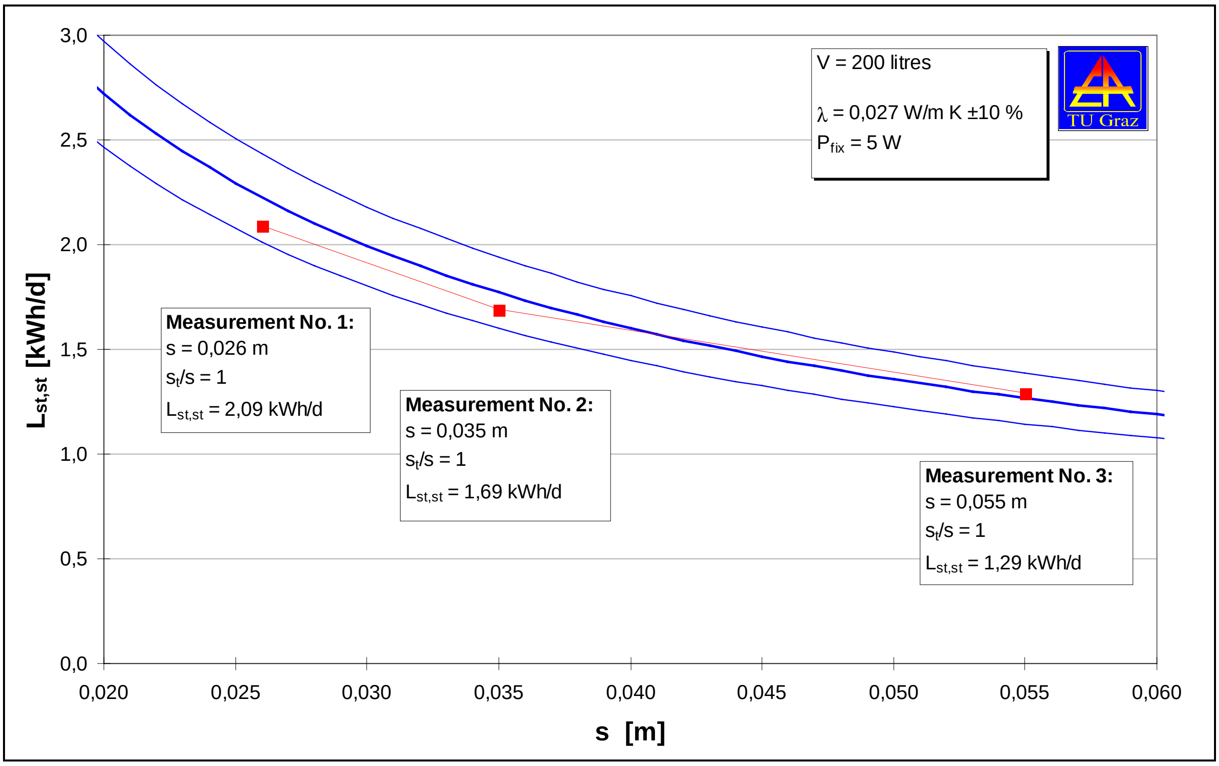

Figure 38: Comparison between Measurement and Simulation: V = 200 litres

Table 26: Comparison between Measurement and Simulation: V = 100 litres Standard Standing Losses of the 100 litres Prototypes with different Insulation Thickness

100 litres			Measurement	Simulation Results for different λ [W/m K]			
				0,027	0,030	0,033	0,036
Prototype	s [m]	s_t/s	$L_{st,st}$ [kWh/d]	$L_{st,st}$ [kWh/d]			
No. 1:	0,0275	1,5	1,27	1,17	1,28	1,38	1,48
No. 2:	0,055	1	0,84	0,76	0,83	0,90	0,97

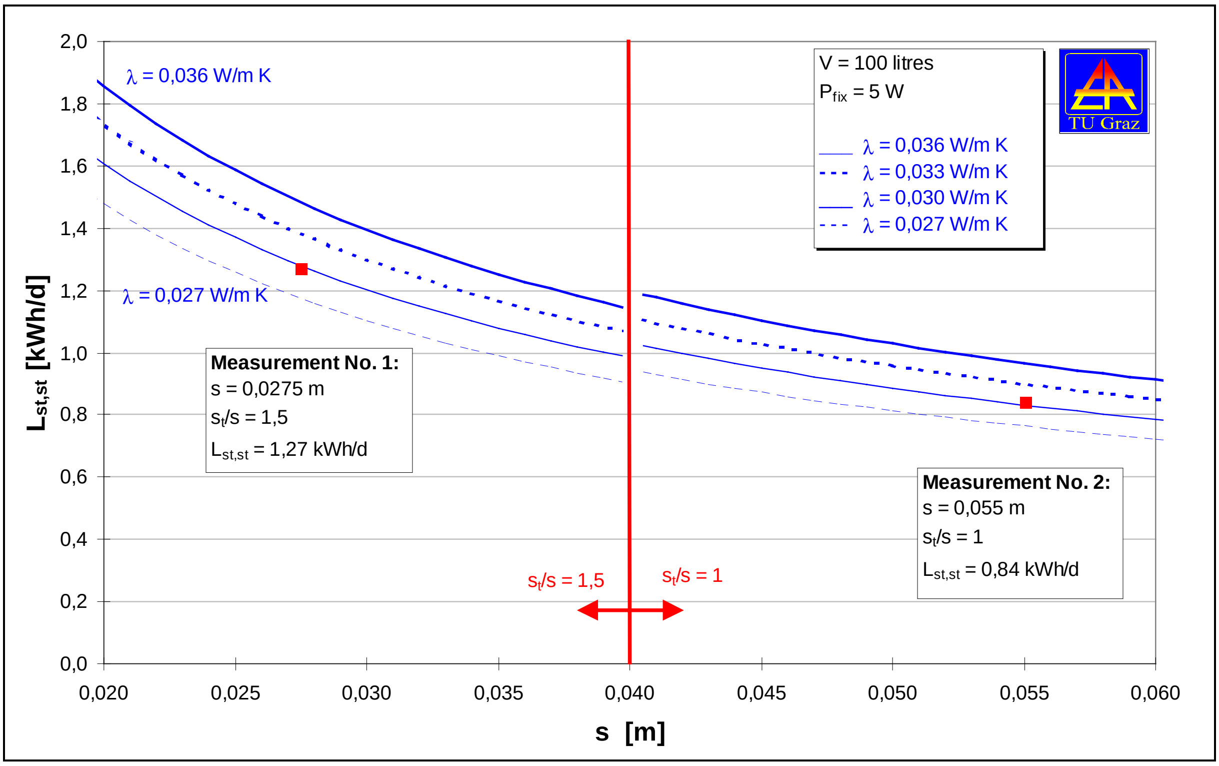

Figure 39: Comparison between Measurement and Simulation: V = 100 litres

The results show a very good accordance between measurement and simulation with differences less than 5%. Only the 200 litres-prototype 4 with an insulation thickness of 33,5 cm (very unrealistic for normal use) brings a larger difference - simulation shows only 65 % of standing losses compared to measurement. This difference can be explained by the large time constant of heat flow due to the extreme thick insulation. In this case the IEC 379 measuring procedure is not appropriate.