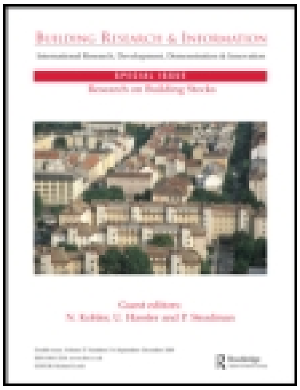

Building Research & Information
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/rbri20

Comparing European residential building stocks: performance, renovation and policy opportunities

Frits Meijer [a] , Laure Itard [a] & Minna Sunikka-Blank [b]

[a] OTB Research Institute for Housing, Urban and Mobility Studies, TU Delft, PO Box 5030, Delft, NL-2600GA, the Netherlands E-mail:

[b] Department of Architecture, University of Cambridge, 1 Scroope Terrace, Cambridge, CB2 1PX, UK E-mail:

Available online: 02 Dec 2010

To cite this article: Frits Meijer, Laure Itard & Minna Sunikka-Blank (2009): Comparing European residential building stocks: performance, renovation and policy opportunities, Building Research & Information, 37:5-6, 533-551

To link to this article: http://dx.doi.org/10.1080/09613210903189376

Building Research & Information (2009) **37**(5-6), 533–551

Routledge
Taylor & Francis Group

RESEARCH PAPER

Comparing European residential building stocks: performance, renovation and policy opportunities

Frits Meijer[1], Laure Itard[1] and Minna Sunikka-Blank[2]

[1]OTB Research Institute for Housing, Urban and Mobility Studies, TU Delft, PO Box 5030, NL-2600GA Delft, the Netherlands
E-mails: F.M.Meijer@tudelft.nl and L.C.M.Itard@tudelft.nl

[2]Department of Architecture, University of Cambridge, 1 Scroope Terrace, Cambridge CB2 1PX, UK
E-mail: mms45@cam.ac.uk

Greater potential energy savings can be achieved in the large stock of existing dwellings than in the relatively small proportion of newly built dwellings. Although the energy performance of existing dwellings is much poorer than new dwellings, the stock of existing dwellings is very large in a 'mature' built environment of most developed countries. In the past decade, awareness of the potential energy savings has spread widely among the many stakeholders involved. Nonetheless, most regulations and instruments are still aimed at achieving sustainable newly built construction. An evidenced-based overview of the current state of the residential building stock is provided for eight northern European countries along with current renovation data. Comparisons are made on the characteristics, physical quality and developments of the residential building stock. Existing policies and incentives to reduce energy use and CO_2 emissions are analysed for their impacts on the existing building stock as well as the barriers preventing successful sustainable renovation. Common denominators in the current state of renovation of residential building stock are used to identify possible future instruments and incentives that are needed to overcome current barriers.

Keywords: building quality, building stock, energy performance, energy policy, energy savings, housing policy, renovation, sustainability, thermal quality

C'est dans le parc important des logements existants plutôt que dans le pourcentage relativement faible des logements de construction récente qu'il y a le plus de possibilités de réaliser des économies d'énergie. Bien que la performance énergétique des logements existants soit bien moindre que celle des logements neufs, le parc des logements existants est très important dans un cadre bâti parvenu « à maturité », tel que celui de la plupart des pays développés. Dans la dernière décennie, la sensibilisation aux économies d'énergie pouvant être réalisées s'est largement répandue parmi les nombreuses parties prenantes impliquées. Néanmoins, la plupart des réglementations et des textes réglementaires visent encore à obtenir une durabilité dans des constructions neuves. Un panorama, fondé sur des données probantes, de l'état actuel du parc bâti résidentiel est fourni pour huit pays d'Europe du Nord, accompagné des données actuelles en matière de rénovation. Des comparaisons sont faites concernant les caractéristiques, la qualité physique et les évolutions du parc bâti résidentiel. Les politiques existantes et les mesures incitatives destinées à réduire l'utilisation d'énergie et les émissions de CO_2 sont analysées quant à leurs effets sur le parc bâti existant, ainsi que les obstacles qui empêchent de réussir une rénovation durable. Les dénominateurs communs propres à la situation actuelle en matière de rénovation du parc bâti résidentiel sont utilisés afin d'identifier les futurs textes réglementaires et les futures incitations possibles qui sont nécessaires pour surmonter les obstacles actuels.

Mots clés: qualité des bâtiments, parc bâti, performance énergétique, politique énergétique, économies d'énergie, politique du logement, rénovation, durabilité, qualité thermique

Building Research & Information ISSN 0961-3218 print/ISSN 1466-4321 online © 2009 Taylor & Francis
http://www.informaworld.com/journals
DOI: 10.1080/09613210903189376

Introduction

Energy use in the residential sector accounts for 23% of the total energy use at the European level (International Energy Agency (IEA), 2004). There is increasing recognition for new policies to limit energy consumption and increase energy efficiency. Although the last few decades have seen growing policy attention for the existing residential stock (Kohler and Hassler, 2002; Thomsen and van der Flier, 2002; EuroACE, 2004; Kohler, 2006; Sunikka, 2006; Thomsen and Meijer, 2007; European Insulation Manufacturers Association (EURIMA), 2007), building regulations and other instruments are still mainly focused on newly built dwellings. Existing dwellings exceed the number of newly built dwellings in most developed countries. The existing stock will continue to dominate for the next 50 or more years. In the Netherlands the annual newly built production is roughly 1% of the existing residential building stock (Meijer and Thomsen, 2006). Awareness of the CO_2 reduction potential of the existing stock is widespread among stakeholders; the European Union, national governments, constructors, building owners, and housing associations have vested interests in trying to achieve a more sustainable existing building stock (EuroACE, 2004; EURIMA, 2007; IEA, 2009).

When the high energy-saving potential identified in ambitious policy targets is examined more closely, it appears difficult to find well-founded data on the estimated energy-saving potentials at either the European or the national levels. Many predictions seem relatively disjointed. To create a more specific picture of the situation in Europe, this paper presents an inventory of data on the existing housing stock in eight European countries: Austria, Finland, France, Germany, the Netherlands, Sweden, Switzerland, and the UK (Itard and Meijer, 2008). The aim of the current paper is to give an evidence-based and realistic image of what is really known about the current characteristics and physical quality of the residential building stock in the selected European countries, the type of renovation activities undertaken, and currently implemented policies. Two main questions form the basis of the research project. The first focuses on the available data on the characteristics and physical quality of the existing residential stock in the selected European countries and tries to identify the gaps. The second aims to gain insight into the available data on the content and effects of the policies and incentives implemented to improve the environmental performance of the residential stock and tries to determine if these policies address the characteristics of the existing stock.

The second section presents the scope and methodology of the paper. The third section presents the main characteristics of the residential sector in the eight countries. The physical quality of the residential building stock is addressed in the fourth section. The fifth section gives insight into the actual renovation activities in the eight countries and includes data on the construction and demolition rates. The sixth section focuses on the barriers and incentives for sustainable renovation. The paper concludes with conclusions and recommendations in the seventh section.

Scope and methodology

The focus of this paper is on (1) the environmental quality of the building stock in terms of energy performance and (2) the possibilities for improving energy performance through renovation. The term 'renovation' is used generally to cover modernization, retrofit, restoration, rehabilitation, and renovation, actions that go beyond mere maintenance. As political, supply side and social recognition has increased over the need to reduce the use of energy and CO_2 emissions, the application of energy-saving techniques in dwellings has increased. The data collected focus on the physical quality of the residential building stock that affects energy performance: insulation, space and hot water heating, and ventilation systems, supported by other relevant performance data. The research focuses on how buildings that can support environmentally sound performance, but not on long lifespans of buildings as such. Data on the age and typology of the stock are considered as essential factors with regard to the energy performance of dwellings. As stakeholders are of primary importance in the achievement of renovation measures and the uptake of policies, the tenure characteristics are presented. Current renovation activities are mapped in order to determine the extent to which the established development already contributes to the better energy performance of the building stock. The characteristics of the building stock are presented in tables and figures. Some countries are highlighted as examples of the main trends. Due to limitations of space, all the barriers and individual policy incentives from each country cannot be described in detail. Therefore, the paper focuses on the policy analysis results that are common to all eight countries in order to describe how the current policies respond to the statistical data and the established renovation activities.

The results are limited to the eight countries set as the focus of the research project. The project was carried out as a part of the Erabuild programme; representatives of the eight countries joined their efforts towards the creation of a sustainable building stock and felt they had comparable governance cultures and climatic circumstances (northern and western parts of Europe). The bulk of the information collected is based on a literature review using key policy documents, the scientific literature, national and international reports and databases. When information was available from official European databases and statistics, it was used as the main source of information. In the absence of European data, national statistics, censuses and reports were used. When information was not directly available, other literature sources (research reports and papers) were used. Table 1 summarizes the main sources of information per country.

In addition, expert interviews were conducted in each country. The questions were structured in a questionnaire more than 40 pages long; but only the relevant parts were sent to contact persons in ministries, government agencies, universities, and consultancy firms. The questionnaire addressed the key factors of the residential building stock that were identified on the basis of the literature, statistical and policy overview. Based on the questionnaire, 25 additional in-depth expert interviews were held. Information was gathered in a structured way about building typology and involved stakeholders, renovation activities, barriers and opportunities in the renovation process, current policies at national and European levels, and additional sources of information.

If information sources could not be found in the international and national literature (or on the Internet) and were not known to the experts, the information was considered not operationally available. The data used are based on the results of national censuses or various European or national housing surveys and statistics. Notably, even basic data are difficult to compare between countries because of the different usages of units, definitions, or varying years of measure. In order to make a comparison between countries possible, less recent but more harmonized data from European surveys were sometimes used. Also remarkable is that in most studies of housing statistics no data are available on energy use. Data on energy usage are found in statistics from Eurostat or from the IEA. Therefore, discrepancies between these sources sometimes occur. The aim of this paper is to identify the main needs of and trends towards better energy performance of the residential stock in Europe. Although the data were gathered as thoroughly as possible, this paper does not claim to be exhaustive. The intention is to provide an overview of the current state in part of Europe and enable comparisons between countries to be made, resulting in general recommendations for European statistics and policies.

Main characteristics of the residential building stock

This section gives an overview of characteristics that have an impact on the sustainability of building stock in terms of energy use. Besides categorizing buildings by their physical typology, it is necessary to categorize them by their stakeholder structure too, because non-technical barriers to the realization of more sustainable building stock will be partly related to the stakeholders as they are expected to have a great influence on renovation decision-making (Meijer, 1993; Thomsen and

Table 1 Main sources of information per country

European sources	Austria	Finland
Ministry of Infrastructure of the Italian Republic and Federcasa Italian Housing Federation (2006), Department of the Environment, Heritage and Local Government of Ireland (2004), European Insulation Manufacturers Association (EURIMA) publications, EuroACE reports, United Nations Economic Commission for Europe (UNECE) (2002), Eurostat publications, International Energy Agency (IEA)	Statistik Austria (2001, 2007), Kreutzer & Fischer und Partner (2004), Institute for Real Estate, Construction and Housing (IIBW) reports	Statistics Finland (2005, 2006), Institute of Construction Economics (ICE) (2005), Ministry of Trade & Industry, Finland (2006), reports from VTT and HUT
France	**Germany**	**The Netherlands**
INSEE (1999, 2001 – 2002), Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME) (2006), Ministère de l'écologie, du developpement et de l'aménagement durables, Economie & Statistiques (n.d.), Centre Scientifique et Technique du Bâtiment (CSTB) reports, ENPER-EXIST project, ADEME, French Environment and Energy Management Agency	Statistisches Bundesamt (2006), Gebäudebestand WestEuropa (1999), Institut Wohnen und Umwelt reports	Centraal Bureau voor de Statistiek (CBS) (2006, 2007), Ministerie van VROM reports
Sweden	**Switzerland**	**UK**
Statistics Sweden (2005, 2007), Nässen and Holmberg (2005), Botta (2005)	Bundesamt für Statistik (2004), Bundesamt für Energie (BFE) (2002, 2006), Bundesamt für Wohnungswesen (BWO) (2005)	Department for Communities and Local Government (DCLG) (2007), Department of Trade and Industry (DTI) (2002), EuroACE (2004)

Note: VTT, Technical Research Centre of Finland; HUT, Helsinki University of Technology.

Meijer, 2007) and, in many cases, on building operation. A division is made between owner-occupied, social-rented (owned by housing associations who operate on a non-profit basis) and privately rented dwellings (owned by property/real estate investors or private owners). Because energy performance, technical characteristics and quality, and possible renovation measures are also expected to depend on the typology of the building, they were divided into single-family dwellings and apartment buildings, and the authors discriminated between the construction periods.

The total useful floor area of the residential stock in the eight countries studied amounts to nearly 10 billion m^2, accounting for around 70% of the total building stock (based on floor area) in these countries. On average, the residential useful floor area is 39 m^2 per inhabitant, with only small differences between the various countries. Basic data on the number of dwellings and useful[1] floor area are given in Table 2. Data are sometimes given in the number of dwellings, the number of buildings, useful area (m^2) or heated area (m^2). For instance, the data for Finland from the *Regular National Report on Housing Developments in European Countries* (Department of the Environment, Heritage and Local Government of Ireland, 2004) are consistent with the data from *Housing Statistics in the European Union* (National Board of Housing, Building and Planning of Sweden and the Ministry for Regional Development of the Czech Republic, 2004), but not with the data from *Building Stock 2006* (Statistics Finland, 2006), which give a much lower number of dwellings. This is due to the type of dwellings accounted for differently in the different statistics. For more details, see Table 2.

Energy use

The sustainability of the building stock is strongly related to the energy performance of the stock itself, but also to the sustainability of energy sources. Statistical surveys by the IEA (2004) show that on average the residential stock is responsible for 30% of the total final energy consumption in the countries studied. There are large differences between countries, however, with the lowest share found in Finland with 19% and the highest in Germany with 34%. Data on the energy sources are given in Figure 1.

Despite the increase in the use of renewable energy sources, the energy supply still relies largely on fossil fuels. The use of combustible renewable and waste sources is high with more than 20% in Austria, Finland and France. District heating, where the waste heat of electricity production is used as a heat source, has a high degree of penetration in Finland, Sweden and Germany. Electricity as an energy source has a high share in all countries. However, the sustainability of electricity production (Figure 2) differs per country. In Austria, Sweden and Switzerland hydropower accounts for more than 50% of production. France,

Table 2 Basic data on the residential building stocks

	Population[a]	Residential buildings		
		Useful area (millions of metres)[b]	Number of dwellings	Percentage of total (residential plus non-residential) useful area (m^2)
Austria	8 206 500	300	3 863 000	n.a.
Finland	5 236 600	212	2 478 000	43
France	60 561 200	2135	25 800 000	72
Germany	82 500 800	3301	35 800 000	63
Netherlands	16 305 500	724	6 969 931	81
Sweden	9 011 400	312	4 404 059	66
Switzerland	7 418 400	330	3 581 000	96
UK	60 034 500	2236	26 200 000	71
European stock[c]		9858	113 876 000	69

Notes: [a]Data are from Eurostat Statistics (2004).

[b]Useful area is the floor space of dwellings measured inside the outer walls, excluding cellars and non-habitable attics; in multi-family dwellings common spaces are excluded.

[c]Data are only for buildings in the cold and moderate climatic zones: they are the sum of all eight countries in the present study, minus Switzerland, plus Belgium, Denmark, Ireland and Luxembourg. Data are from European Insulation Manufacturers Association (EURIMA) (2007) and EuroACE (2007).

Sources: Austria: Statistik Austria (2007), statistics for 2001. Non-residential data are from Census 1997. Finland: Statistics Finland (2006) and Department of the Environment, Heritage and Local Government of Ireland (2004): number of dwellings. Secondary homes are excluded from these statistics. There are about 470 000 secondary and holiday homes. France: Ministère de l'écologie, du developpement et de l'aménagement durables, Economie & Statistiques (n.d.), residential: statistics for 2002 (m^2) and 2005 (number). The number of dwellings is the number of main homes. In addition, there are 3 million secondary homes and 1.9 million unoccupied dwellings. Non-residential: statistics for 2004 (heated area). Germany: Statistisches Bundesamt (2006); statistics for 2004 for residential (Department of the Environment, Heritage and Local Government of Ireland, 2004). For non-residential, no official statistics; data from Euroconstruct (1999) were extrapolated to 2004. The Netherlands: Ministerie van VROM (2002), for residential. For non-residential, from ENPER-EXIST (2007). Sweden: Statistics Sweden (2005) with projection to 2006, and Department of the Environment, Heritage and Local Government of Ireland (2004). For non-residential, estimation of heated floor area for 2000 from Nässen and Holmberg (2005). Switzerland: Bundesamt für Statistik (BFS) (2004). UK: Department for Communities and Local Government (DCLG) (2007), statistics from 2005 – residential data are for England only. Data scaled to the UK with a population fraction of 60.6/50.8, data for non-residential are for England and Wales, scaled as well.

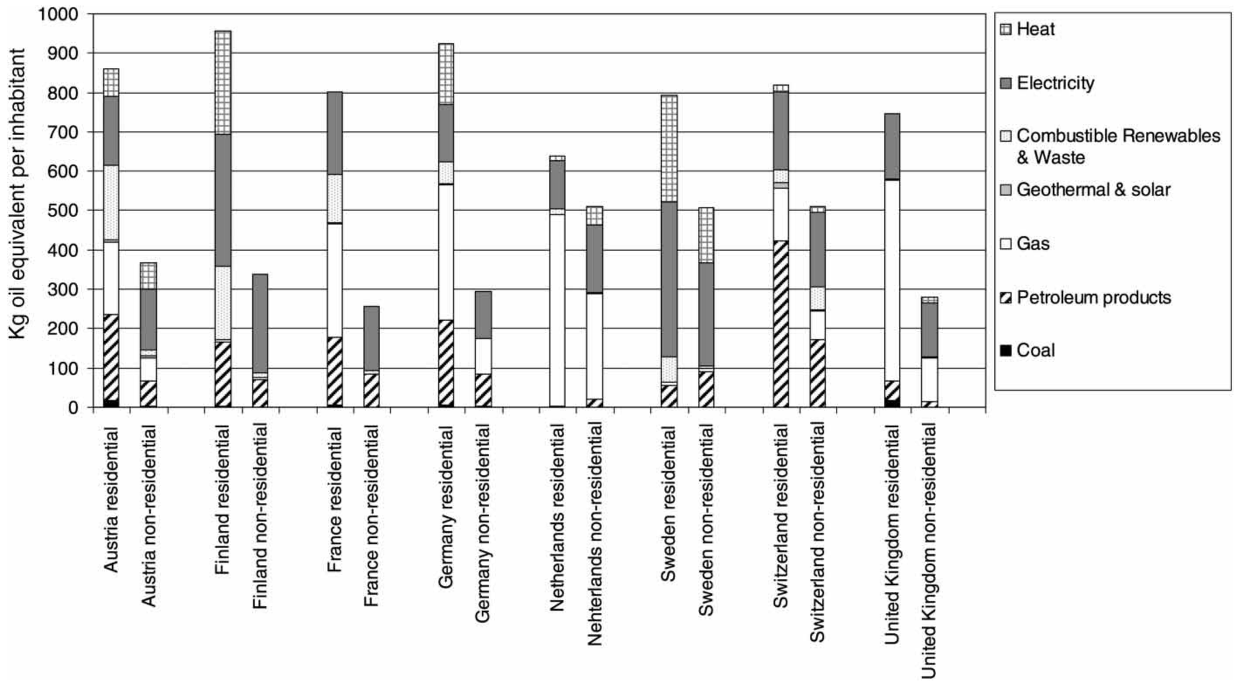

Figure 1 Share of energy sources for the residential and non-residential building stock per inhabitant, 2004. Source: International Energy Agency (IEA) (2004).

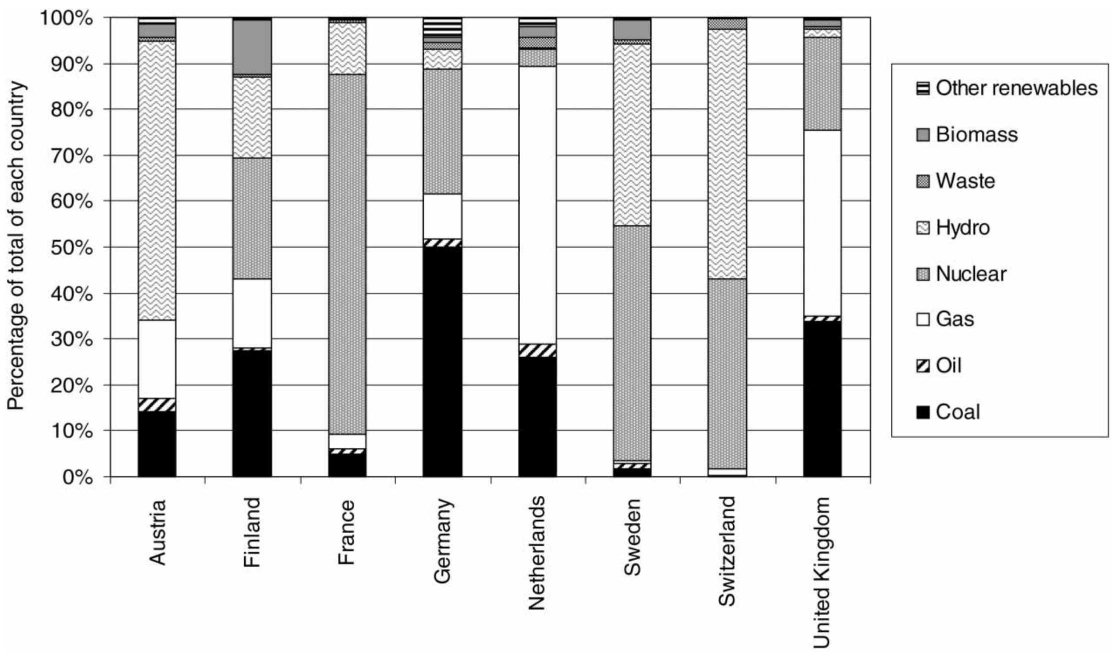

Figure 2 Energy sources for electricity production, 2004. Source: International Energy Agency (IEA) (2004)

Sweden and Switzerland rely largely on nuclear power. Apart from hydropower, renewable energy sources are used in a very limited way for electricity production. Biomass and waste are the most used renewable energy sources. Wind power is the fastest growing source (Eurostat Yearbook, 2007).

Detailed data on the end use of energy in dwellings are lacking in the current statistics and breakdowns are different in each country, from the specification of heat sources and heat losses by type of building (*e.g.* Finland) to the specification of gas and electricity consumption per household (*e.g.* the Netherlands). It can be stated,

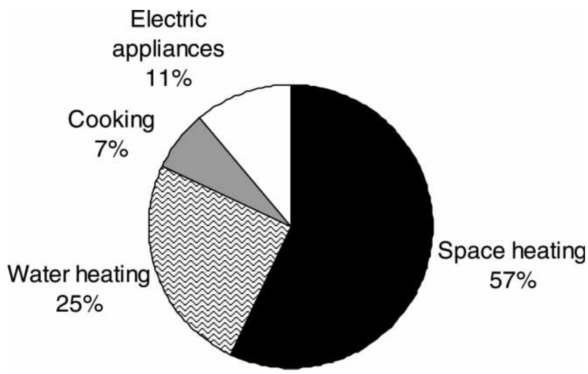

Figure 3 Final energy consumption in the residential sector in European Union countries: breakdown in end-use. Source: EuroACE (2004). 'Electric appliances' includes lighting and white goods, but excludes brown goods.

however, based on the compiled data (EuroACE, 2004; Balaras *et al.*, 2007; Eurostat Yearbook, 2007; IEA 2004; Statistik Austria, 2007; Institute of Construction Economics (ICE), 2005; Statistics Sweden, 2007; Ministerie van VROM, 2002) and the expert estimates that water and space heating are, on average, responsible for a very large part of the final energy consumption in the residential stock; space heating accounts for around 60% (EuroACE, 2004) (Figure 3) and domestic hot water for 25% of the energy used in the residential sector in European Union countries.

Electricity use for major household appliances (white goods) and lighting represents 11% of household energy consumption. Small electrical appliances (brown goods) not included in Figure 3 and in the percentages given above consume about 40% of the total electricity used by European households, with white goods and lighting taking the remaining 60%. Even if all this used electricity is not related to building characteristics, a dwelling could play a role in reducing the environmental burden: the optimization of natural light, for example, or using a building as an energy or electricity generator (*e.g.* solar thermal or photovoltaic cells).

Building types

Figure 4 shows the breakdown of residential building stock into single- and multi-family dwellings according to national statistics and reports. Austria, Finland, France, and Sweden have approximately the same share of single- and multi-family dwellings, both around 50% of the total residential stock. The Netherlands and the UK have a large number of single-family homes, up to 80% in the UK. The UK has less than a 20% share in apartment buildings, whereas the share in Germany and Switzerland is more than 70%.

Ownership structure

The ownership categories are relatively well documented in official sources. The data are summarized in Figure 5.

Owner-occupied dwellings generally represent 35–62% of the total stock, with a high share of 70% in England. Germany and Switzerland have large privately rented sectors that account for 50% of their total stock. Sweden and the Netherlands have very large social-rented sectors. The social-rented sector is organized differently in the eight countries studied,

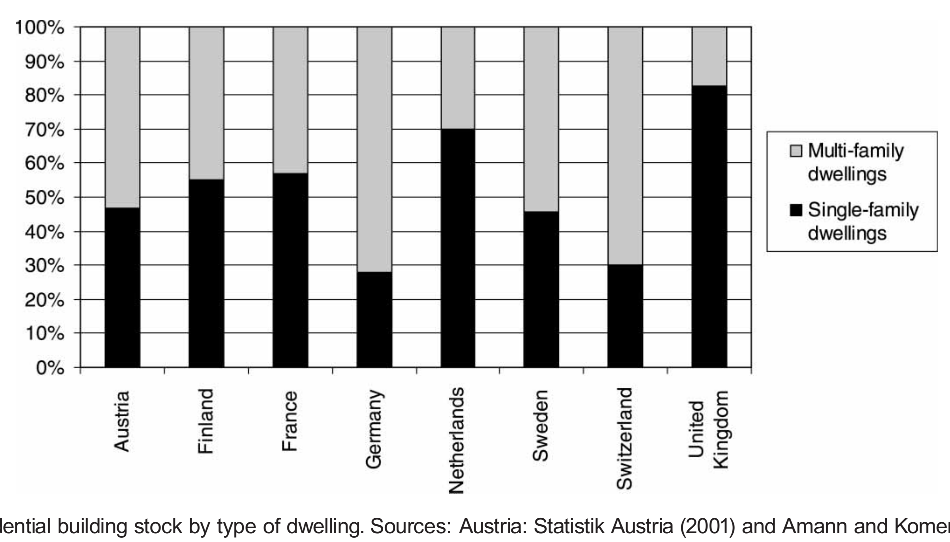

Figure 4 Residential building stock by type of dwelling. Sources: Austria: Statistik Austria (2001) and Amann and Komendantova (2007). Finland: Ministry of Infrastructure of the Italian Republic and Federcasa Italian Housing Federation (2006). France: Centre Scientifique et Technique du Bâtiment (CSTB) (2005, 2006). Germany: Ministry of Infrastructure of the Italian Republic and Federcasa Italian Housing Federation (2006). The Netherlands: Ministerie van VROM (2000) and Centraal Bureau voor de Statistiek (CBS) (2005, 2006). Sweden: Statistics Sweden (2005, 2007). Switzerland: Bundesamt für Statistik (BFS) (2004); two-family dwellings were put into the category single-family dwellings, whereas 'more than two-family dwellings' was put into the category multi-family dwellings. UK: Department for Communities and Local Government (DCLG) (2007), statistics from 2005 – data for England only. Percentages for the UK are assumed to be the same.

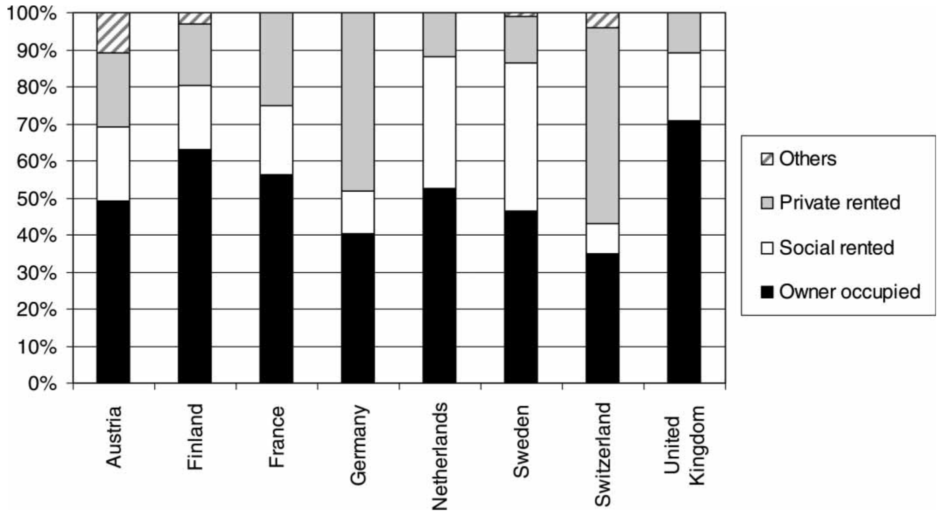

Figure 5 Residential building stock: breakdown in tenure type. Sources: Austria: Statistik Austria (2001, 2007). Finland: Statistics Finland (2005) and Ministry of Infrastructure of the Italian Republic and Federcasa Italian Housing Federation (2006). France: Ministère de l'écologie, du developpement et de l'aménagement durables, Economie & Statistiques (n.d.). Germany: Ministry of Infrastructure of the Italian Republic and Federcasa Italian Housing Federation (2006). The Netherlands: Ministerie van VROM (2000). Sweden: Statistics Sweden (2007) for 1990. Note that some discrepancy was found between the data from Statistics Sweden and those from Department of the Environment, Heritage and Local Government of Ireland (2004), which gives different figures: 38% owner-occupied in 2002 and 46% rented, of which 52% is social rented. It is not known whether this shift is real or whether it comes from the method used. Switzerland: Bundesamt für Statistik (BFS) (2004). UK: Department for Communities and Local Government (DCLG) (2007), statistics from 2005 – data for England only. Percentages for the UK are assumed to be the same.

although all have a high level of regulation and a close relationship with local or national governments.

The owner-occupied and rental sector each share roughly 50% of the residential market. Both sectors are important in achieving a sustainable residential building stock. Opportunities for and barriers to reaching a sustainable dwelling stock differ according to the type of tenure (see the sixth section). Table 3 shows the distribution of the dwelling types per ownership category. A large share of single-family dwellings is owner-occupied. For multi-family dwellings this varies: in Sweden, 68% of the multi-family dwellings are social-rented compared with only 6% in Switzerland.

Table 3 Distribution of dwelling types per ownership category (%)

		Owner-occupied	Social rented	Private rented	Total
Austria	Single-family dwellings	96	2	1	100
	Multi-family dwellings	63	29	7	100
Finland		n.a.	n.a	n.a	
France	Single-family dwellings	80	8	12	100
	Multi-family dwellings	25	35	40	100
Germany		n.a	n.a	n.a	
The Netherlands	Single-family dwellings	66	26	8	100
	Multi-family dwellings	21	58	21	100
Sweden	Single-family dwellings	91	8	1	100
	Multi-family dwellings	13	68	19	100
Switzerland	Single-family dwellings	86	14		100
	Multi-family dwellings	20	80		100
UK	Terraced dwellings	69	18	13	100
	Detached dwellings	84	9	7	100
	Multi-family dwellings	32	45	23	100

Sources: Austria: from Statistik Austria (2001, 2007). For the social rented sector, an additional breakdown for multi-family dwellings is available in housing associations (16%) and municipalities (13%). France: Centre Scientifique et Technique du Bâtiment (CSTB) data, INSEE (1999), Comptes du logement (2007) and CSTB (n.d.). The Netherlands: Ministerie van VROM (2000). Sweden: Statistics Sweden (2007). For the social rented sector, an additional breakdown is available in public social housing (3/38%, respectively), municipalities and state (1/2%, respectively) and private corporations (4/28%, respectively). Switzerland: from Bundesamt für Wohnungswesen (BWO) (2005). For the social rented sector, an additional breakdown is available in housing cooperatives (1/3%, respectively), municipalities, cantons and state (2/3%, respectively) and corporate housing by employers (0/4%, respectively). UK: Department for Communities and Local Government (DCLG) (2007). For the social rented sector, an additional breakdown is available in housing associations (9/4/20%, respectively) and municipalities (9/5/25%, respectively).

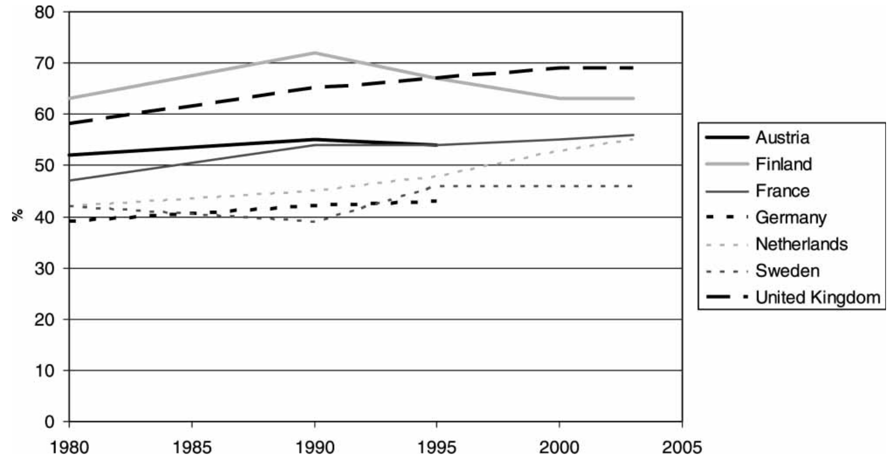

Figure 6 The share of owner-occupied dwellings in the residential dwelling stock, 1980–2003. Source: Ministry of Infrastructure of the Italian Republic and Federcasa Italian Housing Federation (2006). No data are available for Switzerland.

Figure 6 shows the evolution of tenure type between 1980 and 2003. In all countries, apart from Finland, the share of owner-occupied dwellings has increased, while the share of rented dwellings decreased.

Age of the stock

The age of the dwelling stock relates to its physical characteristics, including thermal performance. Performance also depends on the extent to which these dwellings have been renovated (see the discussion in the fifth section). The periods used in the statistics in each country vary. Figure 7 classifies the data according to the shortest common periods that could be identified in the various countries.

Pre-war dwelling stock accounts for 20–39% of the total dwelling stock in the countries studied, with the exception of Finland where this figure is only 10%. From the expert interviews, it seems that the pre-war residential stock is reasonably homogenous in terms of national construction characteristics. Dwellings built after the Second World War and before the oil crisis in the 1970s account on average for almost

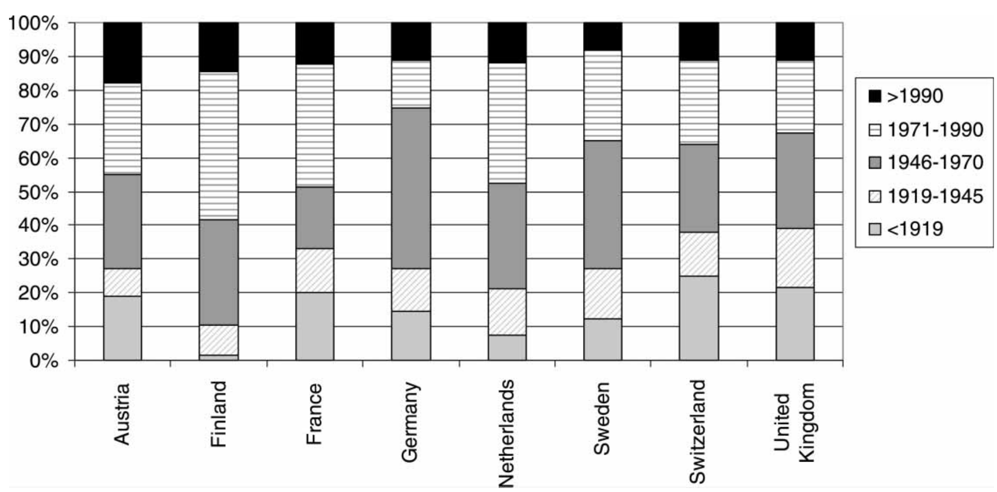

Figure 7 Age of the residential building stock in percentage dwellings. Sources: Austria: Statistik Austria (2007), data are from 2003. These data are similar to those in National Board of Housing, Building and Planning of Sweden and the Ministry for Regional Development of the Czech Republic (2004), data for 2002. Finland: Ministry of Infrastructure of the Italian Republic and Federcasa Italian Housing Federation (2006), data are for 2002. France: Ministry of Infrastructure of the Italian Republic and Federcasa Italian Housing Federation (2006), data are for 2002. Germany: Ministry of Infrastructure of the Italian Republic and Federcasa Italian Housing Federation (2006), data are for 2002. The Netherlands: National Board of Housing, Building and Planning of Sweden and the Ministry for Regional Development of the Czech Republic (2004), data are for 2002, and from Ministerie van VROM (2000). Sweden: Ministry of Infrastructure of the Italian Republic and Federcasa Italian Housing Federation (2006), data are for 2005. Switzerland: Bundesamt für Statistik (BFS) (2004). UK: Department for Communities and Local Government (DCLG) (2007). Data are from Ministry of Infrastructure of the Italian Republic and Federcasa Italian Housing Federation (2006), data for 2004/2005 give a slightly different share (before 1919, 17.0%; 1919–1945, 17.0%; 1946–1970, 21.0%; 1971–1990, 41.8%; and after 1990, n.a.)

one-third of the total stock and are, generally speaking, less homogenous than pre-war buildings. A common characteristic is that the buildings were generally poorly insulated at the time of construction and show a relatively high need for renovation.

In most countries, dwellings built between 1970 and 1990 account for approximately one-quarter of the total stock. Exceptions are France and the Netherlands with shares of more than 35% for this building period, and Finland with more than 43%. In general, the dwellings built after the oil crisis and the introduction of mandatory thermal regulations are reasonably well insulated, but already need some basic renovation.

The average percentage of newly built dwellings since 1990 is 14% of the total stock, varying from 8% to 22% in the eight countries studied.

Some countries have collected data relating the age of the building stock to the type of dwelling: single- or multi-family dwellings. In Austria and Switzerland, multi-family dwellings account for approximately 60% of the pre-1919 building stock, whereas this share is only 40% in the building stock built after 1990.

In France, a large proportion (more than 89%) of single-family dwellings is owner-occupied with only small differences in relation to the building period. Pre-war apartments are predominantly owner-occupied (82%). For post-war apartment buildings owner-occupancy decreases to 50–55% and social rented increases from very low to 35–42%. Privately rented apartments have a constant share across all the building periods, varying between 3% and 7%.

In Germany, the oldest building stock is found primarily in detached dwellings and multi-family dwellings. In both categories, 13% of the dwellings were built before 1918. For terraced dwellings this is only 5%.

In the Netherlands, 66% of the single-family dwellings are owner-occupied and 26% social-rented. This is rather unusual for Europe. Half the social-rented single-family dwellings are post-war and were built before the first oil crisis of the 1970s. Almost no social-rented single-family dwellings have been built since 1990. Half the owner-occupied single-family dwellings were built before the oil crisis. More than 50% of multi-family dwellings are social-rented, whereas owner-occupancy and privately rented have an equal share of 21%. One-third of the multi-family dwelling stock was built between the war and the oil crisis, and another third between 1970 and 1990.

Energy performance of the existing stock

This section addresses the technical factors that affect the energy efficiency of the residential stock. The energy used for space heating is a significant factor of the energy performance of the building stock (see the third section). The energy use for space heating is mainly determined by heat transmission losses (proportional to the insulation degree), by ventilation and air infiltration losses (determined by the ventilation system, building fabric and build quality), and by the efficiency of the heating system used (Clarke, 2001). The survey is focused on these three aspects and the systems for hot water; its heating demand is seen to be a non-negligible part of the energy end-use.

Insulation

Data on the number of insulated dwellings are essential to determining the potential for energy saving in residential building stock. There are, however, nearly no statistical data available on the degree of insulation in existing dwellings.

Insulation of external walls differs for cavity walls (a masonry wall with cavity space) or solid walls (no air cavity). The insulation of cavity walls is relatively easy. The cavity is injected with insulating material, but the insulation value may be low if the cavity is small. Solid walls can only be insulated by adding material to the outside or the inside. External insulation can prevent moisture problems and mould risks that may occur with indoor insulation (*e.g.* Al-Homoud, 2005; Melville *et al.*, 1997). External insulation is expensive and has an impact on the facade. This is especially problematic in countries that have historical housing stock (*e.g.* France and the UK); in some cases municipal regulations may not allow for alterations to the facade alignment (or change in external appearance). Indoor insulation may cause a loss of internal space and condensation problems may occur. It is important to assemble sufficient data on the typology of solid walls to determine which kinds of standard technical solution may be applied and to estimate the possible energy savings. Table 4 summarizes the data collected in the different countries.

France has a high percentage of solid walls (up to 90%), whereas only 4% of the Dutch dwelling stock has solid walls. In the UK the percentage totals around 30%. Cavity walls are insulated more frequently than solid walls. Note that the data in Table 4 do not reveal the quality of insulation. Possibly a high percentage of insulated walls are insulated only poorly, but unfortunately there is no statistical evidence for that fact. Estimations on the thermal quality (heat transfer coefficients) have been made (EURIMA, 2007), but the coefficients are based on mere guesswork in the absence of empirical evidence.

Flat roofs, representing only a small share of all roofs (except for the Netherlands), are usually insulated. Loft insulation beneath sloping roofs is easy to implement and has been done in approximately 70%

Table 4 Type and insulation of walls, roofs, floors and glazing

	Solid walls as a percentage of total walls	Percentage insulated solid walls	Percentage insulated cavity walls	Percentage insulated roofs	Percentage insulated floors	Percentage double-glazing	Percentage triple-glazing
Austria	n.a.	20	about 100	50–70	30–60	90	5
Finland	about 100	90–98	–	98	50–100	25	75
France	84	n.a.	n.a.	n.a.	n.a	n.a	n.a
Germany	n.a.	n.a.	n.a.	n.a.	n.a	n.a	n.a
The Netherlands	4		59	>71	43	80–85	about zero
Sweden	n.a.	high		high	high	average	high
Switzerland	n.a.	n.a.	n.a.	n.a.	n.a	90–96	
UK	31	about 0	about 40	72–95	n.a.	71	about zero

Sources: Austria: estimate from the Institute for Real Estate, Construction and Housing (IIBW), based on projects, reports and literature, and Demohouse (2005). Finland: Statistics Finland (2006) and expert estimation. France: French Agency for Quality in Construction (AQC). The Netherlands: Ministerie van VROM (2000, 2002). Sweden: Expert estimation. Switzerland: Gerheuser (1998) and Jakob and Jochem (2003). UK: Department for Communities and Local Government (DCLG) (2007), Department of Trade and Industry (DTI) (2002), and EuroACE (2004).

of dwellings. Floor insulation (30–60% of dwellings) is less common than loft insulation. The penetration of double-glazing is high in all countries, but apart from Finland and Sweden (with colder climate conditions), the penetration of triple-glazing and high energy-efficient glazing is still low.

Systems for space heating

Figure 8 shows the heating systems for single- and multi-family dwellings in the studied countries. In single-family dwellings, central heating is typically based on either fossil fuel or biomass. District heating is used mainly in multi-family dwellings and has a very large share in Finland and Sweden. Local heating appliances (stoves) still represent 5–17% of the heating systems in Austria, Germany, the Netherlands and Switzerland. Local heating is generally less efficient than central heating, but if installed in only a small number of rooms it may consume less energy than central heating because only a small part of the dwelling is heated.

Heat pumps have already been installed in 5% of single-family dwellings in Switzerland. Electrical heating is used widely in Finland and France with shares up to 30%. Direct use of electricity for heating

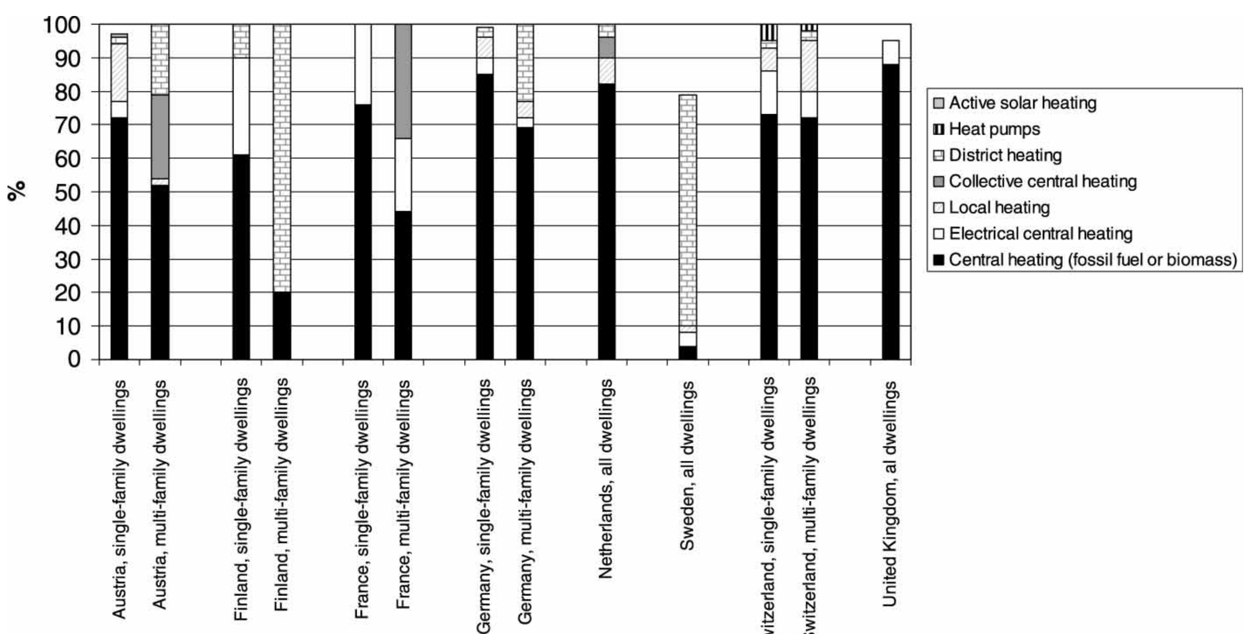

Figure 8 Types of space heating systems (%) used in each country. Sources: Austria: Statistik Austria (2001). Finland: Institute of Construction Economics (ICE) (2005). France: Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME) (2006). Germany: IWU estimates based on micro-census 2002. The Netherlands: SenterNovem (2007) and Ministerie van VROM (2000). Sweden: Statistics Sweden (2005). Switzerland: Bundesamt für Statistik (BFS) (2004). UK: CAR Ltd estimates and Department of Trade and Industry (DTI) (2002)

applications (without the additional use of a heat pump) might be considered sustainable only if the electricity production is low-carbon and environmentally friendly, which is currently not the case in most countries (Figure 2).[2] In terms of rational energy use, the use of relatively low temperature waste heat, as in district heating, is the most sustainable option (Schmidt, 2004; Shukuya and Hammache, 2002).

The share between fossil fuel and biomass in central heating is not known for all countries. It seems, however, that more than 70% of single-family dwellings' central heating systems are driven by fossil fuels. In multi-family dwellings, this is about 50–65% (data are from Austria, Germany, Switzerland and the UK; see the references in Figure 8).

France has data on the age of boilers for central heating (see the references in Figure 8). The older the boiler, the lower its efficiency: 22% were more than 20 years old, 67% less than 14 years, and 53% were less than nine years old. In the Netherlands, central heating boilers were mostly gas-driven. Some 12% of households had a conventional boiler, 49% a high-efficiency boiler, and 39% a high-efficiency condensing boiler. In Switzerland, 80% of central heating systems in single-family dwellings are fossil fuel-driven (65% in multi-family dwellings). In the UK, central heating runs mainly on gas or oil, the latter being mainly restricted to rural areas.

Systems for hot water

In the European Union residential sector, domestic hot water is responsible for 25% of energy use. Based on Bertoldi *et al.* (2001) and expert estimates, around 30% (43.5 million) of the 142 million households in the European Union use electric water-heating systems. The share of households using electricity to heat water is more than 40% in Austria, France and Switzerland, between 30% and 40% in Finland, just over 20% in the UK, and between 10% and 20% in Sweden, the Netherlands and Germany. Boilers (whether or not combined with space heating) are used to various degrees. Local gas-fuelled water heating (also known as combustion boilers) are still in use in many countries, particularly in France, where they have a share of 53% despite their disadvantages for indoor air quality.[3] When district heating is used for space heating, it is often combined with water heating. Table 5 sums up the data on hot tap water systems.

Ventilation systems

The aim of ventilation is to provide a continuous rate of fresh air by operating openings or mechanical fans. Ventilation rates must be high enough to remove indoor pollutants and finishing (decoration materials) and to prevent humidity problems such as mould growth. From the viewpoint of energy conservation, however, the air change rate should be kept as low as possible. Indoor health and energy use are very sensitive to ventilation, both in opposite ways.

Three main ventilation systems are used in dwellings (*e.g.* American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), 2009). The first is natural ventilation, which covers airing through windows and continuous ventilation through window grilles. It is often combined with a fan in the bathroom and/or kitchen. The second is a mechanical exhaust ventilation system whereby the air supply is fed naturally through window grilles and a ventilator in an exhaust duct ensures that air is continuously expelled outside. The main advantage is that it ensures minimal air flow, but its disadvantages are the electricity consumption of the ventilator and possible noise. The third system is heat recovery with mechanical ventilation, also called balanced ventilation or 'mechanical supply and exhaust heat recovery' ventilation. In this system outdoor air is mechanically supplied to a heat exchanger that transfers heat from the exhaust hot air

Table 5 Hot water equipment (%)

<table>
<tr><th></th><th>Gas/oil boiler (%)</th><th>Local gas heater (%)</th><th>Electrical boiler (%)</th><th>District heating (%)</th><th>Solar boiler (%)</th><th>Total</th></tr>
<tr><td>Austria</td><td>55</td><td>n.a.</td><td>35</td><td>n.a</td><td>1.5</td><td>91.5</td></tr>
<tr><td>Finland</td><td colspan="5">n.a</td><td></td></tr>
<tr><td>France</td><td>47</td><td colspan="2">53</td><td>n.a.</td><td>n.a.</td><td>100</td></tr>
<tr><td>Germany</td><td colspan="2">79</td><td>18</td><td>n.a.</td><td>n.a</td><td>97</td></tr>
<tr><td>The Netherlands</td><td>63</td><td>22</td><td>8</td><td>n.a.</td><td>0.6</td><td>93.6</td></tr>
<tr><td>Sweden</td><td>n.a.</td><td>n.a.</td><td>about 15</td><td>about 69</td><td>n.a.</td><td>84</td></tr>
<tr><td>Switzerland</td><td colspan="2">51</td><td>40</td><td>1.3</td><td>1</td><td>93.3</td></tr>
<tr><td>UK</td><td colspan="2">80</td><td>20</td><td>n.a.</td><td>n.a.</td><td>100</td></tr>
</table>

Sources: Austria: Estimate from the Institute for Real Estate, Construction and Housing (IIBW), based on projects, reports and literature. France: Estimate from the Centre Scientifique et Technique du Bâtiment (CSTB) and the Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME) (2006). Germany: Estimate from IWU. The Netherlands: Ministerie van VROM (2000). Sweden: Expert estimation and Bertoldi *et al.* (2001). Switzerland: Bundesamt für Statistik (BFS) (2004) and Bundesamt für Energie (BFE) (2002). UK: Building Research Establishment (BRE) (1998) and Bertoldi *et al.* (2001).

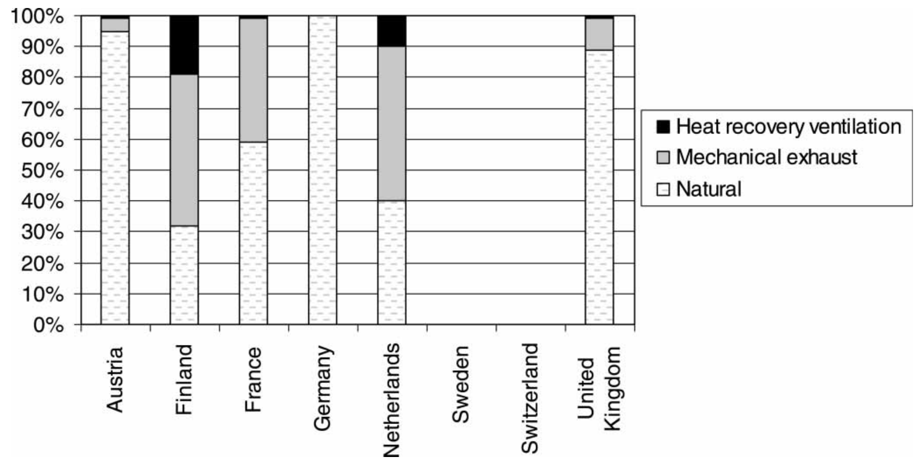

Figure 9 Penetration of the three main types of ventilation system. Sources: Austria: expert estimate, 2006. Finland: Dean and Bernard (2007). France: Dean and Bernard (2007). Germany: expert estimate, 2006. The Netherlands: Dean and Bernard (2007), expert estimates, 2007. Sweden: not available. Switzerland: not available. UK: Dean and Bernard (2007)

to the incoming cold air. Outside air is preheated before being supplied to the room, thus drastically reducing the heating demand of the building.

Apart from in Finland (18%) and the Netherlands (10%) (Figure 9), mechanical supply and exhaust systems with heat recovery are not widely used. These systems are increasingly being applied in newly built dwellings in the Netherlands, having had a share of 39% in 2001 (Beerepoot, 2007). Natural ventilation of dwellings through windows and sometimes grilles as well as kitchen or bathroom fans is still the most common form of ventilation in the residential sector. In Austria, Germany, the UK and Switzerland natural ventilation accounts for nearly 100% of all systems. In Finland, France and the Netherlands its share is approximately 30%, 40% and 60%, respectively. Mechanical exhaust systems are used largely in Finland (50%), France (40%) and the Netherlands (40%).

Renovation activities

Current renovation activities are described in order to understand the actual rate of renovation activities and what these can contribute to the energy performance of residential stock.

New construction and demolition rates

In 2003 (Ministry of Infrastructure of the Italian Republic and Federcasa Italian Housing Federation, 2006; Bundesamt für Statistik (BFS), 2008) the annual rate of new construction (the number of new constructions as a percentage of the number of existing constructions) was between 0.5% and 2%. Of the countries studied, Austria had the highest rate of new construction and Sweden the lowest. In most countries the rate of new construction is around 1% of the total stock. An analysis of the developments in the eight countries over the past five years shows declining construction rates (Itard and Meijer, 2008). Therefore, the relative importance of renovation can be expected to increase.

The annual demolition rate in the European Union varied between 0.025% and 0.23% of the total stock in 2003. Of the countries studied, the Netherlands had by far the highest demolition rate and Switzerland the lowest. Demolition mostly occurs in the context of urban renewal and low occupancy rates in Austria, Germany, France and the Netherlands. Apart from the Netherlands, these areas have a high proportion of prefabricated concrete housing. Demolition is often due to lack of market demand. In some areas of the Netherlands the high demand for dwellings is poorly matched with existing dwellings; demolition is followed by new construction. The decision to demolish, however, is often influenced by land prices and market demand instead of the technical quality.

Current renovation activities

As reliable information about renovation activities is very limited, expert interviews were carried out in the eight countries. The interviews show the investments in renovation activities is lower than or at most equal to the money invested in new construction in the residential sector. The UK, Sweden and Germany seem to be the exceptions to this rule. Although investments in renovation are generally lower than in new construction, the number of renovated buildings exceeds the number of newly built dwellings in most of the countries.

In Austria, the Institute for Real Estate, Construction and Housing (IIBW) estimates that around 100 000 dwellings undergo refurbishment every year compared with around 45 000 new dwellings built annually.

The Austrian government's expenditure on housing subsidies in 2005 was €1.55 billion in new residential construction and €0.53 billion in renovation. In Austria twice as many dwellings are renovated than are built new each year, involving roughly 25% of the total investment.

In Finland (2006), renovation investment was estimated to be roughly half of the total construction investment. Residential buildings account for half of the renovation activities and their share is expected to increase as the stock built in 1960–1970 will soon come to an age requiring renovation. In Finland, the renovation investments for 2006–2015 are estimated to be around €1.8 billion per year. Due to subsidies and ownership structures, renovation activities in the rental sector are likely to be higher than in the owner-occupied sector.

In France, €67.4 billion were invested in the acquisition of new housing in 2005 compared with €38.1 billion in renovation; the cost of renovation represents a little more than half of the acquisitions of new housing (Comptes du logement, 2007). This is very different in Germany where €84 billion were invested in renovation of residential buildings (62%) compared with €52 billion in new construction (38%) (Schaetzel, 2005). In Sweden, twice as many renovations occur compared with new construction: 120 000 apartments were renovated whereas 61 300 new dwellings were built in 2000–2004 (Statistics Sweden, 2005).

In Switzerland, €29.5 billion were invested in construction in 2005 with two-thirds spent on new construction and one-third on renovation and refurbishment (BFS, 2006). The number of buildings renovated each year, however, exceeds the number of newly built housing and the unit costs per renovation are lower than for newly built buildings.

In the Netherlands, no statistical data are available about the ratio of newly built dwellings to renovated dwellings. The authors' estimation (based on experience) is that each year twice as many dwellings are renovated than newly built.

The modernization of kitchens and bathrooms are the most common renovation activities in all the countries studied. Mostly these modernization activities take place before the end of the components' service life is attained (expert estimates). The need to replace building components at the end of their service life and to solve comfort problems are the most frequently named reasons for renovation in all countries. Specifically mentioned were mould and moisture problems in Finland and the upgrading of social neighbourhoods in the Netherlands, the UK and Sweden. In the Netherlands, a reduction in maintenance and operational costs begins to play a role in the decision to renovate. Energy-saving targets are important, especially for housing associations and municipalities.

Each year heating systems are replaced in 4% of Austrian (Amann and Komendantova, 2007), 9% of French (Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME), 2006), 5% of German (expert estimate by the IWU), and 18% of Finnish (Vaino *et al.*, 2002) dwellings. In Finland, new electrical wiring is installed in 8% of dwellings each year. In France, 11% of households (2.9 million dwellings in total) undertake renovation activities aimed at achieving energy savings, in particular the installation of double-glazing and shutters, and floor or roof insulation. In Switzerland, ground-floor insulation is installed in 2.5% of the housing stock each year (Bundesamt für Energie (BFE), 2005).

In Finland, an annual estimate of €1.75 billion is invested in the renovation of the dwelling envelope, 51% spent on detached dwellings, 20% by housing companies, 6% on office and commercial buildings, and 14% on public buildings. Another €1.4 billion were invested in the renovation of heating, mechanical ventilation and air-conditioning (HVAC) systems, of which 37% was spent on detached dwellings, 16% by housing companies, 10% on office and commercial buildings, and 22% on public buildings. In the Netherlands, the majority of the renovation investment goes on maintenance and structural repairs.

Natural renovation moments that provide a cost-effective opportunity to replace components with more efficient ones are relocation, replacement renovation of defective components, and such modernization activities as changing kitchens and bathrooms. These natural moments are related to maintenance cycles, especially for housing associations and other professional actors. For the owner-occupied market this implies that information on sustainable products and activities should be available at the time of these interventions.

None of the countries studied maintained national monitoring of renovation effects. Monitoring projects are short-term (often related to complaints about indoor air quality) and limited to the neighbourhood level and demonstration projects. Due to this lack of systematic monitoring, little is known about the long-term performance of equipment or the influence of inhabitant behaviour on possible energy savings aimed at by some renovation activities.

Barriers and incentives for sustainable renovation

Barriers

As indicated in previous research on sustainable building (Sunikka, 2006; Klunder, 2005), the policy analysis and expert interviews in this research confirm that the main barriers to sustainable renovation identified in all eight countries are a lack of knowledge and the unconvincing cost–benefit relation whereby an investor does not always profit from improved performance. Further barriers in the market are inappropriate products that are geared towards new construction, a lack of experience, and few best-practice examples. In urban restructuring projects, knowledge seems to be lacking about centralized district systems and their connection to dwellings. Apart from the social-rental sector, small-scale renovations are often carried out by non-professionals who do not know about energy-saving solutions, as most contractors do not know either. Expert interviews suggest that a new challenge in the Netherlands would be the cost structure applied by energy service companies. When energy companies invest in generating sustainable energy, they want to earn their investment back by using the 'no-more-expensive-than-elsewhere' principle. However, their rates and charges are higher than the actual energy consumed, so they fail to get the inhabitants' support. Integrating sustainable renovation and fuel switch with urban restructuring objectives (an opportunity recognized in the expert interviews) calls for more specific examples of organizational and financial solutions than are currently available.

Barriers and opportunities differ according to the type of tenure and dwelling type; large-scale renovations may be difficult to implement in owner-occupied multi-family dwellings (a large portion of the Swiss building stock) as the decision to renovate is shared among several households. For owner-occupants, the expert interviews and policy analysis identified high investment costs, long payback times, and other competing investment priorities as barriers. In the rental sector, with about a 50% share of the market and equally important in sustainable renovation, while the owner invests, the occupant profits from the investment – unless there is a considerable rental increase, which is only possible in the privately rented sector.

Incentives for sustainable renovation

The housing policy in European Union Member States is affected by European Union legislation, policy documents and research programmes (Sunikka, 2006). In Member States, sustainable renovation is currently directed by the European Union Construction Products Directive and the European Union Energy Performance of Buildings Directive (EPBD, 2002/91/EC) and more indirectly by the Air Quality Directive, the Energy End-Use Efficiency and the Energy Services Directive. The Member States modify their legislation to conform to the EPBD and Construction Products Directive.

The expert interviews stress the need for incentives for technical innovation, educational programmes, practical renovation concepts (France), and demonstration projects (the UK, the Netherlands, Austria) as ways to overcome the barriers to sustainable renovation. Opportunities can be generated by the national government (pushing for energy targets and legislative adaptations) and the market. Urban restructuring projects in such countries as the Netherlands and the UK are also considered as intervention opportunities.

The survey of policy documents and the expert interviews indicate that all eight countries studied use a mix of policy instruments to improve the sustainability of the residential stock. All main policy instruments were identified in the research; regulatory, economic, communicative (information dissemination along the lines of publicity campaigns), and organizational instruments. The main applied incentives for sustainable renovation seem to be subsidies, tax reductions and publicity campaigns (Itard and Meijer, 2008). Environmental platforms that set environmental aims for specific sectors have been established. However, the interviews with the stakeholders indicate that the route to achieving policy targets is difficult and therefore attainment of (often very high) policy targets is expected to be problematic.

The policy overview shows that all countries studied have adapted their building regulations in recent years in order to promote energy efficiency. In principle, energy requirements for new buildings need to be met when dwellings are drastically renovated, *e.g.* in Germany and the Netherlands. The implementation of this principle varies from a requirement at the component level (*e.g.* insulation values) to performance agreements for buildings. In Germany, when more than 20% of a component (wall, roof or window) is changed, the dwelling needs to meet building regulations comparable with those for new construction. In Sweden, a component must meet the equivalent requirements for the newly built. In the UK, any work on existing buildings is expected to meet minimum energy-efficiency standards. For specified major improvements in buildings with floor areas exceeding 1000 m^2, where there is a potential to increase energy intensity, for example, by extending a building or installing air-conditioning, there are further energy-efficiency requirements, taking into account the consideration that these requirements are technically, functionally and economically feasible.

In some countries (*e.g.* Germany, England) owners are obliged to provide a 'dwelling passport' to potential purchasers that contains information about the quality of the dwelling including its energy performance. The information could induce a new owner to undertake action.

In order to address the main barrier (long payback times) to energy improvements, the main incentives used to promote sustainable renovation are subsidies (usually in the owner-occupied sector), tax reduction and publicity campaigns. All countries have introduced demonstration projects where the feasibility of sustainable techniques is tested, often within the framework of European Union-funded research projects. As a lack of knowledge is often mentioned as a barrier in the interviews and policy documents, it seems as if information either fails to be put into practice or it is not sufficiently factored into the cost-based decision-making process.

According to the statistical survey, the share of electric appliances in the total household energy consumption is equally high in all countries studied. If the households' energy consumption is to be reduced, policies need to target the energy efficiency of household appliances as part of the sustainability policy in the residential sector.

There is little evidence that the effectiveness and efficiency of these incentives, regulations, and communication projects are measured in a robust and systematic manner. There is little impact monitoring and if there is it is often based on simple indicators such as the numbers of heat pumps or solar boilers installed. These numbers may give an idea of the uptake resulting from a policy measure, but such limited monitoring ignores the operational stage and user behaviour and, therefore, the actual effect on energy use. Monitoring in the Netherlands actually shows that due to a lack of continuous and automated system control, office buildings with heat pumps are on average no more energy efficient than those that use a boiler (Elkhuizen *et al.*, 2006). The same trend can be observed with heat recovery-balanced ventilation systems that work suboptimally and in the end may use more energy than they save (Soldaat and Itard, 2007). The more efficient the building services are, the greater the influence of occupant behaviour on the environmental performance of buildings. Yet, the expert interviews and policy survey indicate that few models can with any reasonable accuracy predict the effect of user behaviour, thus making energy savings and predicted pay-back times very uncertain.

Conclusions

This paper has presented an overview of the characteristics of the residential stock, current renovation activities and incentives in the Netherlands, Germany, Finland, Sweden, the UK, France, Switzerland, and Austria. Based on a statistical survey, key technical and policy documents and expert interviews, the research aimed to identify gaps in data, knowledge, and public policy in sustainable renovation. Knowledge of the technical performance of the residential stock is needed in order to evaluate the efficiency of renovation measures and to set feasible policy targets.

Firstly, the statistical survey that aimed to clarify what data are available on the characteristics and physical quality of existing residential stock shows that despite the importance given to energy saving on the policy agenda, there are serious gaps in the monitoring of the physical residential stock. Apart from the data from the IEA (2004), Eurostat Yearbook (2001, 2007), and Eurostat Statistics (2004), definitions and data-collection methods used in national statistics differ in each country studied, despite the fact that, except for Switzerland, all the studied countries are European Union Member States. The breakdown of energy use differs per country: energy consumption data, for example, are not related to the age of the stock, which is a key factor in recognizing energy-saving potential (only in relation to single/multi-family dwellings in France, Germany, and the Netherlands). It is not always given in m^2 and sometimes includes second homes (a large proportion in Finland and Sweden). This makes accurate comparisons between countries difficult. The statistical survey indicates that there is an established rate of energy-efficient improvement in all the countries studied, but is it enough to reach national policy targets? At the moment there are insufficient data on the number of insulated dwellings and the quality of the insulation to answer these kinds of policy questions. In order to make cost-effective policies that can facilitate the improvements beyond the established rate of improvement, it would be useful to have more annual data on the number and quality of energy measures taken in renovation.

While tenure characteristics are generally better documented than the physical quality of the buildings, it should be noted that more official data are available on the residential sector than on the non-residential sector, where consistent statistics are scarce and scattered among many private companies or sector organizations. More accurate data would be useful for policy-making and research purposes. If the European Union aims to address the housing stock in further directives, uniform data between the countries are not available. A common basis set up in the European Union and the development of consistent European Union statistics to assess the built environment should be considered.

Secondly, the research examined which data are available on the contents and effects of the policies and incentives for achieving a more sustainable residential stock. The results indicate that the importance of the existing stock is generally recognized in national building and energy policies in all eight countries studied. The expert interviews and policy documents name costs, a lack of information, and the unprofessional market as the main barriers to sustainable renovation. The lack of money up front and the low investment capacity are particularly problematic in the owner-occupied sector which accounts for 35–70% of the residential building stock in the countries studied (60–96% of the single-family dwellings are owner-occupied).

The capture of benefits between the owner making an investment and the tenant profiting from it is a key barrier in the rental sector. This calls for specific financial and organizational solutions that current policies such as limited subsidy programmes do not manage to address. Some countries, Germany for instance, have begun to set requirements for renovations to comply with new construction, but the role of building control and sanctions remains problematic in the owner-occupied and private rental sectors. An ambition level comparative with new construction is important in terms of ensuring sufficient measures of insulation in a renovation, for example adding 300 mm of loft insulation rather than a minimum of 50 mm.

Besides government policies, the market presents encouraging opportunities. The statistical survey of the renovation activities indicates that common to all countries studied, increased comfort levels are usually the driver behind renovation activities (mostly maintenance, repair and modernization aimed at extending component service life, increasing comfort or replacing components). Renovation statistics indicate that many interventions are focused on a new kitchen or a bathroom. The increased comfort expectations (including for indoor climate) in the ageing European residential stock is an opportunity for sustainable renovation where information and support could be given to households to extend the renovation to include such key energy efficiency measures as insulation, the installation of new windows or heating systems. As reported in the expert interviews, the consultancy process where the contractor also acts as a (non-objective) consultant can be problematic. However, if the decision-makers, mainly owner-occupants and (small) contractors, are well informed on how to integrate environmental improvements into the natural maintenance cycle and also know how to fix technical components, sustainable renovation can become more cost-effective and cause fewer disturbances to the occupants.

The results show that residential stock in European Union Member States is very diverse. The Netherlands and the UK, for example, have a high proportion of one-family dwellings, a high percentage of home ownership, and similar climactic conditions, yet their stock is very different. Social rental is a large sector in the Netherlands and Sweden with professional management and the possibility of being regulated by the government. In Germany and Switzerland, in contrast, the private rental sector is large, with a high proportion of apartment buildings and low investment capacity.

In France, 90% of the stock has solid walls (which are difficult to insulate), whereas in the Netherlands this is only 4%. In order to facilitate policy exchange and recognize common priority areas, it may, however, be useful to cluster the countries thematically based on the characteristics of the building stock. Based on energy data, Finland and Sweden seem to have a more upgraded residential stock (mostly built after the energy crisis) than the other countries studied. They also have a high proportion of dwellings equipped with district heating. In Finland, Sweden and the Netherlands, 10–20% of dwellings are estimated to have heat recovery driven by stringent thermal regulations where the energy performance target is no longer attainable by insulation measures only. Among these forerunners policy should be oriented towards renewable energy sources. Apart from Switzerland, where 5% of dwellings have heat pumps, solar heating, heat pumps or district heating have been demonstrated in many projects, but scaling-up of these projects seems a difficult task that calls for sustainable leadership in technically and process-wise complex projects. In the UK, for example, most local building regulations require 10% of the energy to be generated with renewable sources on site, but this rather successful policy measure (known as 'the Merton rule') applies only to new buildings. What also can be observed in the forerunner countries is that many 'easy' energy renovation measures have already been adopted in response to the emergence of indoor air quality problems.

The statistics and interviews indicate that in countries such as France and the UK basic energy measures (*e.g.* thermal insulation) continue to be a challenge in the older residential stock, often complicated by high investment costs, preservation of architectural values, and the absence of best-practice examples. In countries that also have a large proportion of solid walls, the common barrier continues to be lack of practical knowledge of cost-effective technical solutions. Extra insulation can radically change the appearance of the building if installed internally or externally.

The statistical survey shows that natural ventilation is still very common in the residential sector, but the experience of the forerunner countries indicates that it may be insufficient in thermally renovated buildings. In Finland, for example, most mould problems are caused by thoughtless renovation of older dwellings where thermal performance was improved by extra insulation without the adaptation of ventilation systems. This is an example of an area where knowledge transfer would be valuable for other countries. The policy overview shows an increasing number of research projects related to the indoor climate, ventilation, material emissions, and health in all the countries studied, but these should be linked more to renovation.

Surprisingly little data are available on the actual impact of policy instruments, whether regulatory or economic, raising the question of what current policy initiatives on sustainable renovation are based on. It became evident in the policy overview that in all eight countries studied there is a serious lack of quantitative data on policy effects. On the other hand, there are no precise statistics on energy performance of the stock. Compared with new construction, some renovations do not require the building authorities to be notified, which hampers the collection of data. Furthermore, occupant behaviour is not addressed in policies. Current policy instruments focus on the adoption of measures, not on what happens after measures have been installed. The expert interviews recognized the further development of the European Union Energy Performance of Buildings Directive (EPBD) as a specific policy that could be helpful to gather information and enable comparisons between European Union Member States. At the moment, however, the methods used and the data gathered for the EPBD differ greatly in the various European Union Member States. If the EPBD is to be used for monitoring and statistics, harmonization between countries is necessary.

Acknowledgements

This research was undertaken under the umbrella of Erabuild. Many Erabuild members contributed actively to this research and gave useful comments. The authors would like to thank, in particular, Stephan Jenniskens and Barbara Leenen (Senter Novem, the Netherlands), Peter Whittington and Terry Boniface (BERR, UK), Charles Filleux and Petra Karlstrom (BZH, Switzerland), Jan Sandelin (Formas, Sweden), Julien Hans and Luc Bourdeau (CSTB, France), Christian Hageneder and Herbert Greisberger (Ögut, Austria), and Klaus Stroing and Ludgera Klinke-Haberman (TÜV Rheinland, Germany). In addition, the authors would also like to thank especially Rofaïda Lahrech from the CSTB (France), Wolfgang Amann and Alexis Mundt from Institute for Real Estate, Construction and Housing (IIBW) (Austria), Rainer Greiff from IWU, Institute for Housing and Environment (Germany), and Evert Vrins and Harry Hoiting from W/E Consultants (the Netherlands), who helped in gathering the data. Additionally, many experts were consulted in the different countries and the authors like to thank them as well: Georg Benke (Energy Agency, Austria), Günter Lang (IG Passivhaus, Austria), Margareta Mahidi (Statistik Austria), Robert Stefenelli (Baustoffindustrie, Austria), Andrea Stockinger (Wirtschaftskammer Österreich), Mr Airaksinen (VTT, Finland), Haari Hakaste (Ministry of the Environment, Finland), Olli Seppanen (Helsinki University of Technology, Finland), Nathalie Weiss and Patrick Elias (CSTB, France), INSEE (France), Orjan Svane (KTH Environmental Strategies Resarch-fms, School of Architecture and the Built Environment of Stockholm, Sweden), Marianne Berger (BFS, Switzerland), Mr Hauri (BWO, Switzerland), Mr Jakob (CEPE, Switzerland), Michel Schorer (Nuklearforum Schweiz, Switzerland), William Fawcett (CAR Ltd, UK), Allan Brown (Sustainable Buildings, Communities and Local Governments, UK), and Tim Yates (BRE, UK).

References

Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME) (2006) *Les chiffres clés du bâtiment*, ADEME, Paris.

Al-Homoud, M.S. (2005) Performance characteristics and practical applications of common building thermal insulation materials. *Building and Environment*, **40**(3), 353–366.

Amann, W. and Komendantova, N. (2007) *Sanierungsoffensive gegen den Klimawandel*, Institute for Real Estate, Construction and Housing (IIBW), Vienna.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (2009) *ASHRAE Handbook – Fundamentals*, ASHRAE, Atlanta, GA.

Balaras, C.A., Gaglia, A.G., Georgopoulou, E., Mirasgedis, S., Sarafidis, Y. and Lalas, D.P. (2007) European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings. *Building and Environment*, **42**, 1298–1314.

Beerepoot, M. (2007) Public energy performance policy and the effect on diffusion of solar thermal systems in buildings: a Dutch experience. *Renewable Energy*, **32**, 1882–1897.

Bertoldi, P., Waide, P. and Lebot, B. (2001) Assessing the market transformation for domestic appliances resulting from European Union policies. in *Proceedings of ECEE 2001 Summer Studies*, pp. 191–202.

Botta, M. (2005) Towards sustainable renovation, three research projects. Dissertation, Royal Institute of Technology, Stockholm.

Building Research Establishment (BRE) (1998) *Estimates of Hot Water Consumption from the 1998 EFUS. Implications for the Modelling of Fuel Poverty in England*, BRE, Watford (available at: http://www.berr.gov.uk/files/file16568.pdf).

Bundesamt für Energie (BFE) (2002) *Marktpotentiale und Markthindernisse für die thermische Solarenergie. Forschungsprogramm energiewirtschaftliche Grundlagen*, BFE, Bern.

Bundesamt für Energie (BFE) (2005) *Mobiliesierung der Energetische Erneuerungspotenziale im Wohnbaubestand, Schlussbericht*, BFE, Bern.

Bundesamt für Energie (BFE) (2006) *Grenzkosten bei forcierten Energie-Effizienz-Massnahmen und optimierter Gebäudete chnik bei Wirtschaftsbauten*, BFE, Bern.

Bundesamt für Statistik (BFS) (2004) *Eidgenössische Volkszählung 2000. wohnversorgung und wohnverhältnisse Entwicklungen 1990–2000*, BFS, Bern.

Bundesamt für Statistik (BFS) (2006) *Wohnungzählung 2006*, BFS, Bern.

Bundesamt für Statistik (BFS) (2008) *Wohnungzählung 2008*, BFS, Bern.

Bundesamt für Wohnungswesen (BWO) (2005) *Detailauswertung der Gebäude- und Wohnungserhebung, Schriftreihe Wohnungswesen, Band 75*, BWO, Bern.

Centraal Bureau voor de Statistiek (CBS) (2005) *Statistics Netherlands*, CBS, The Hague (available at: http://statline.cbs.nl).

Centraal Bureau voor de Statistiek (CBS) (2006) *Statistics Netherlands*, CBS, The Hague (available at: http://statline.cbs.nl).

Centraal Bureau voor de Statistiek (CBS) (2007) *Statistics Netherlands*, CBS, The Hague (available at: http://statline.cbs.nl).

Centre Scientifique et Technique du Bâtiment (CSTB) (2005) *Le parc des logements existants*. Laboratoire économie et statistique, June, CSTB, Paris.

Centre Scientifique et Technique du Bâtiment (CSTB) (2006) *Le parc des logements existants*. Laboratoire économie et statistique, First Results, CSTB, Paris.
Centre Scientifique et Technique du Bâtiment (CSTB) (n.d.) *Database COMMbat*, CSTB (available at: http://boutique.cstb.fr/dyn/cstb), Paris.
Clarke, J.A. (2001) *Energy Simulation in Building Design*, Butterworth-Heinemann, Oxford.
Comptes du logement (2007) *Rapport de la commission des comptes du logement*. DAEI/SESP et DHUHC, comptes du logement 2005 tet résultats 2006, Ministère de l'Ecologie, de l'Energie, du Développement durable et de la Mer en charge des technologies vertes et des négociations sur le climat, Paris.
Dean le, P. and Bernard, A. (2007) Survey of ventilation systems in Europe, in *Proceedings of the International Conference CLIMA 2007 Wellbeing Indoors*, Helsinki, Finland, 10–14 June 2007.
Demohouse (2005) *Report State of the Art*, Demohouse, Budapest (available at: http://www.demohouse.net/reports).
Department for Communities and Local Government (DCLG) (2007) *English House Condition Survey*, DCLG, London.
Department of the Environment, Heritage and Local Government of Ireland (2004) *Regular National Report on Housing Developments in European Countries*, Stationery Office Dublin.
Department of Trade and Industry (DTI) (2002) *Energy Consumption in the United Kingdom*, DTI, London.
Elkhuizen, P., Scholten, J., Rooijakkers, E., de Knegt, J. and Deutz, L. (2006) *Kwaliteitsborging van installaties – Evaluatie van bestaande instrmenten en een visie voor de toekomst*, TNO, Delft.
ENPER-EXIST (2007) *Final Report, Building Stock Knowledge*, June, ENPER-EXIST, Danish Building Research Institute, Aalborg University, Hørsholm.
EuroACE (2004) *Towards Energy Efficient Buildings in Europe*. Final Report, June, EuroACE, Brussels (available at: http://ec.europa.eu).
EuroACE (2007) *Mitigation of CO_2 Emissions from the Building Stock Based on Housing Statistics in the European Union*, EuroACE, Brussels.
Euroconstruct (1999) *EUROPARC – Der Bestand an Gebäuden in (West-) Europa (Deutschland, Frankreich, Großbritannien, Italien und Spanien)*, Euroconstruct, Munich.
European Insulation Manufacturers Association (EURIMA) (2007) *Sensitivity Analysis of Cost Effective Climate Protection in the EU Building Stock*. Ecofys Report No. VI (available at: http://www.eurima.org).
Eurostat Statistics (2004) *Energy Balance Data 2004*. Report, Eurostat, Luxembourg (available at: http://www.eurostat.org).
Eurostat Yearbook (2007) *Europe in Figures, 2006–07*, Eurostat, Luxembourg.
Gebäudebestand WestEuropa (1999) *Ausgewählte Ergebnisse der Studie 'EUROPARC – Der Bestand an Gebäuden in Europa'*, in ifo Schnelldienst (1999) H.12, IFO Institute, Munich.
Gerheuser, F.W. (1998) *Mietbelastung und Wohnverhältnisse. Ergebnisse der eidgenössische Verbrauchserhebung 1998, Schriftenreihe Wohnunwesem Band 73*, Bundesamt für Wohnungswesen (BWO), Grenchen.
INSEE (1999) *General Census*, INSEE, Paris (available at: http://www.recensement.insee.fr).
INSEE (2001–2002) *Housing Inquiry*, INSEE, Paris (available at: http://www.recensement.insee.fr).
Institute of Construction Economics (ICE) (2005) *Rakennusten energiankulutus ja CO_2-ekv päästöt Suomessa*. EKOREM Report No. 4, VTT (Technical Research Centre of Finland), Espoo.
International Energy Agency (IEA) (2004) *Statistics for 2004/Energy Balances for 2004*, IEA (available at: http://www.iea.org).
International Energy Agency (IEA) (2009) *World Energy Outlook (WEO) Policy Databases, 2009*, IEA, Paris (available at: http://www.iea.org).
Itard, L.C.M. and Meijer, F. (2008) *Towards a Sustainable Northern European Housing Stock Figures, Facts and Future*, IOS Press (TUD), Amsterdam.
Jakob, M. and Jochem, E. (2003) *Erneuerungsverhalten im Bereich Wohngebäude*, Auftrag des Forschungsprogamms EWG des Bundesamts für Energie (BFE), Zurich.
Klunder, G. (2005) *Sustainable Solutions for Dutch Housing. Reducing the Environmental Impacts of New and Existing Houses*, SUA Series, OTB Thesis, Delft University Press, Delft.
Kohler, N. (2006) A European perspective on the Pearce Report: policy and research. *Building Research & Information*, **34**(3), 287–294.
Kohler, N. and Hassler, U. (2002) The building stock as a research object. *Building Research & Information*, **30**(4), 226–236.
Kreutzer & Fischer und Partner (2004) *Bauen und Wohnen in Österreich*, 3 bände, Kreutzer & Fischer und Partner, Vienna.
Meijer, F. (1993) Maintenance and improvement activities of homeowners in the Netherlands. *Journal of Housing and the Build Environment*, **8**(3), 327–346.
Meijer, F. and Thomsen, A. (2006) *Kwaliteit van de particuliere woningvoorraad*, Report, Habiforum, Gouda.
Melville, I.A., Gordon, I.A. and Stephenson, E.M. (1997) *The Repair and Maintenance of Houses*, Estates Gazette, London.
Ministère de l'écologie, du developpement et de l'aménagement durables, Economie & Statistiques (n.d.) *Homepage* (available at: http://www.statistiques.equipement.gouv.fr).
Ministerie van VROM (2000) *Kwalitatieve woonregistratie*, Ministerie van VROM, The Hague.
Ministerie van VROM (2002) *Kwalitatieve woonregistratie*, Ministerie van VROM, The Hague.
Ministerie van VROM (2003) *De kwaliteit van de Nederlandse woning en woonomgeving rond de milleniumwisseling, Basisrapportage Kwalitatieve woningregistratie 2000*, Ministerie van VROM, The Hague.
Ministerie van VROM (2005) *Dossier Energy Saving and Insulation*, Ministerie van VROM, The Hague (available at: http://www.vrom.nl).
Ministerie van VROM (2006) *Cijfers over wonen*, Ministerie van VROM, The Hague (available at: http://www.vrom.nl).
Ministry of Infrastructure of the Italian Republic and Federcasa Italian Housing Federation (2006) *Housing Statistics in the European Union 2005/2006*, Ministry of Infrastructure, Rome (available at: http://www.federrcasa.it).
Ministry of Trade & Industry, Finland (2006) *Energy Review*, Ministry of Trade & Industry, Helsinki.
Nässen, J. and Holmberg, J. (2005) Energy efficiency – a forgotten goal in the Swedish building sector? *Energy Policy*, **33,** 1037–1051.
National Board of Housing, Building and Planning of Sweden and the Ministry for Regional Development of the Czech Republic (2004) *Housing Statistics in the European Union*, National Agency for Enterprise and Housing, Copenhagen.
Schaetzel, L. (2005) Investitionsprozesse im Wohnungsbestand. *Bundesbaublatt*, **7–8,** 20–23.
Schmidt, D. (2004) Design of low exergy buildings– method and a pre-design tool. *International Journal of Low Energy and Sustainable Buildings*, **3**, 1–47.
SenterNovem (2007) *Cijfers and Tabellen 2007*, SenterNovem, Utrecht (available at: http://www.senternovem.nl).
Shukuya, M. and Hammache, A. (2002) *Introduction to the Concept of Exergy – For a Better Understanding of Low-Temperature Heating and High Temperature Cooling Systems*. Report IEA Annex 37, International Energy Agency (IEA), Helsinki (available at: http://www.lowex.net).

Soldaat, K. and Itard, L. (2007) Influence of occupants on the energy use of balanced ventilation systems, in *Proceedings of the International Conference CLIMA 2007 Wellbeing Indoors*, Helsinki, Finland, 10–14 June 2007.
Statistics Finland (2005) *Housing 2005*, Statistics Finland, Helsinki.
Statistics Finland (2006) *Building Stock 2006*, Statistics Finland, Helsinki.
Statistics Sweden (2005) *Yearbook of Housing and Construction Statistics*, Statistics Sweden, Stockholm.
Statistics Sweden (2007) *Yearbook of Housing and Construction Statistics*, Statistics Sweden, Stockholm.
Statistik Austria (2001) *GWZ 2001: Gebäude- und Wohnungszählung*, Statistik Austria, Vienna.
Statistik Austria (2007) *Statistische Jahrbuch (ISIS database)*, Statistik Austria, Vienna.
Statistisches Bundesamt (2006) *Statistical Yearbook for the Federal Republic of Germany*, Statistisches Bundesamt, Wiesbaden.
Sunikka, M. (2006) *Policies for Improving Energy Efficiency in the European Housing Stock*, SUA Series, OTB Thesis, Delft University Press, Delft.
Thomsen, A. and Meijer, F. (2007) Sustainable housing transformation; quality and improvement strategies of the ageing private housing stock in the Netherlands, in *Annual Bulletin of Housing and Building Statistics for Europe & North America*, *Proceedings of the International Conference on Sustainable Areas*, ENHR Congress, Rotterdam, The Netherlands.
Thomsen, A. and van der Flier, K. (2002) Updating the housing stock; the need for renovation-based approaches, in *Proceedings of the International Research Conference on Housing Cultures – Convergence and Diversity*, ENHR & Europaforum Wien, Vienna [CD-ROM].
United Nations Economic Commission for Europe (UNECE) (2002) *Annual Bulletin of Housing and Building Statistics for Europe & North America*, UNECE, Geneva (available at: http://www.unece.org).
Vaino, T., Jaakkonen, L., Nippala, E., Lehtinen, E. and Ikaksson, K. (2002) *Korjausrakentaminen 2000–2010*. Tiedotteita 2154, VTT, Espoo.

Endnotes

[1]Useful floor area is net internal area: the usable floor area of a dwelling with certain specified areas (such as internal structural walls, stairwells and atria, areas with a headroom less than 1.5 m and shafts) excluded from the overall gross extents.

[2]It would be better to use electricity for applications only when really necessary (*e.g.* for lighting).

[3]Oxygen in the room is used for combustion, and combustion gases are released into the room as well.