Title
Residential Electricity Use: A Scandinavian Comparison

Journal
Energy, 15(10)

Authors
Tyler, S.
Schipper, Lee

Publication Date
1989-09-01

LBL-27276
Preprint

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

Submitted to Energy – The International Journal

Residential Electricity Use: A Scandinavian Comparison

S. Tyler and L. Schipper

September 1989

APPLIED SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

DISCLAIMER

RESIDENTIAL ELECTRICITY USE: A SCANDINAVIAN COMPARISON

LBL-27276

Stephen Tyler and Lee Schipper

International Energy Studies, Energy Analysis Program, Lawrence Berkeley Laboratory,
University of California, Berkeley, California 94720, U.S.A.

SEPTEMBER, 1989

Abstract — We compare changes in the structure of residential electricity use in Denmark, Norway, and Sweden since the early 1970s. A major distinguishing feature among these countries has been consistent differences in the average residential price of electricity. We reach three important conclusions: (1) When the saturation of household appliances reaches maturity, it is only changes in space and water heating uses of electricity which can cause significant change in the intensity of electricity use in the residential sector. (2) The efficiency of household electricity use is strongly influenced both by domestic technologies and policies (e.g., housing standards), as well as by international manufacturers (e.g., of lighting equipment, windows, and household appliances). (3) The behavior of household occupants plays a key role in determining the intensity of electricity use, both through their demand for the services electricity provides and through their choices of equipment. Relative electricity prices have strongly influenced the choices of policy makers, consumers and equipment manufacturers in this sector. These conclusions suggest that pricing policies and improved technology offer potential for reducing residential electricity use in Scandinavia through greater efficiency and fuel substitution.

This work was supported by the Swedish Council for Building Research and Oslo Lysvaerker. Stephen Tyler also acknowledges the support of the Social Sciences and Humanities Research Council of Canada. We acknowledge the contributions of A. Ketoff, D. Hawk, N. Hirt, and C. Campbell to the collection and analysis of data used in our project on Household Electricity Use. J. Harris and R. Diamond provided constructive comments on an initial draft of this paper. Opinions are solely those of the authors. **Please address all comments to the authors at LBL Berkeley, fax 415 486 5172, e-mail ljschipper@lbl.gov.**

1 Introduction

Considerable uncertainty exists about the development of electricity markets in OECD countries. After unprecedented rapid growth in the 1960s and 1970s, demand growth for electricity in the 1980s has slowed. A wide divergence of views exists about the direction of future electricity demand in different markets. This work examines the dynamics of electricity consumption in the residential market from the perspective of changing technology and behavior which affect patterns of end use in individual households.[1]

The Scandinavian countries of Sweden, Norway and Denmark form a particularly interesting comparison because among them they exemplify each of three types of residential electricity markets found in OECD countries: 1) a market dominated by the very high penetration of electric space heating (Norway); 2) a market in which electricity has recently become important, but not dominant, as a primary and secondary source of space heat (Sweden); and 3) a market in which electric space heating plays only a small role in the residential sector (Denmark). All three countries share a similar standard of living, comparable patterns of household formation, and a similar climate, although winters are both colder and darker in the less-populated northern regions of Sweden and Norway. All have technically sophisticated construction industries and (recently, at least) similar national housing standards. They share a common market for most types of energy-intensive household electrical appliances. The comparison of residential electricity use among these countries may therefore yield results of broader interest in illustrating the range of influence that other factors, such as energy markets, technological change, and public policy can have on the demand for electricity in this sector.

The comparison is also of specific interest in the Scandinavian context of continuing growth in electricity demand and mounting concern about the environmental and economic costs of new electricity supply within the region. By comparing household electricity use in these countries, we hope to provide insights into the principal factors affecting the evolution of consumption patterns in each country, and the potential for further gains in end-use efficiency. This type of analysis is a useful initial step in considering electricity policy options on both the supply and demand side.

2 Residential Energy and Electricity Use

The total consumption of electricity in the residential sector can be considered as a function of the size of the sector (number of households, total population), the saturation of electricity for particular residential uses, and the intensity of each type of use (per capita or per household). Intensity depends on the efficiency of end-use technologies and the amount of service provided, often measured as the hours of use or the size and features of the device. The size of the sector can be readily determined. Saturation of electrical equipment is also available from survey data. However, the intensity of each energy use is less easy to evaluate.

In the case of residential end uses for which alternative fuels exist, the intensity of electricity use depends on the local availability of specific alternative fuels, their relative prices, and the technological and behavioral factors modifying consumer choice (such as the existing capital stock, and acceptable patterns of dwelling use and indoor comfort). For appliances and lighting, where there is usually no alternative to electricity, the intensity of electricity use depends on technical efficiency, and on consumer behavior in terms of both selecting and using appliances.

Our goal in this study is to understand differences in patterns of residential electricity use based on variations in these fundamental factors, in order to identify implications for the evolution of electricity demand and the potential for conservation of electricity in this sector. To explore differences in residential energy use patterns requires paying close attention to prices, technologies and behavior to construct a "bottom-up" picture of sectoral energy use.[2] In this comparison, we devote special attention to differences in domestic technologies or policies to explain differences in energy use patterns.*

* In the text we cite references for important and specific points. Appendix 1 contains some definitions of key terms. In Appendix 2 we describe our main data references in general, followed by descriptions of sources and assumptions for each Scandinavian country. Our original work on OECD residential electricity use (Ref. 1) has been updated and will be published.

3 Residential Energy Use Compared

The shares of each energy source in aggregated household energy use in Denmark, Norway and Sweden are shown in Fig. 1. This shows the dominance of electricity in Norway, of oil in Denmark, and the mixture of fuels — oil, district heating, electricity and wood are all important — for residential energy needs in Sweden. Most of the differences in fuel shares can be attributed to different choices of fuels for space and water heating, which dominate household energy use in these climates. The most obvious feature of comparison is the paramount role played by electricity in Norway. Note that while the comparative role of electricity in Sweden lay closer to that of Denmark in 1972, it evolved towards the Norwegian mix by 1986. Growth in electricity and district heat dominates changes in household energy use in Sweden in the 1970s and 1980s.

By comparison with other OECD countries, Sweden has a relatively large electrical share in aggregate sectoral energy use. France and Canada are the only other OECD countries for which electricity plays such an important role in household energy use. While natural gas does not play a significant role in residential sector energy use in Scandinavia, district heating in Denmark and Sweden can be considered in many respects to fill the market niche in the densely populated urban areas where the high cost of laying pipes is repaid by the high density of customers.

Fig. 2 shows the disaggregation of total residential energy use into different types of end use. The dominance of space heating in this northern climate is no surprise. However, while the relative shares of appliance and domestic hot water energy use are much smaller, per capita levels are large when compared with most other OECD countries (1). The Scandinvian countries have comparatively high levels of energy use for all purposes in the residential sector, reflecting their standard of living and levels of consumer spending.

4 Electricity Use Intensity in Denmark, Norway and Sweden

Table 1 presents comparative information on the residential sector of each country. In most important respects, conditions appear very similar in each country. Climate data, population-weighted to reflect the sparse population in northern Norway and Sweden, show that there are approximately 33 percent more heating degree days in Sweden or Norway than Denmark.

The differences in total electricity use among these countries can be illustrated by comparisons of the intensity of electricity consumption for different end uses. Electricity consumption per capita is illustrated in Fig. 3 for each country, by type of end use.* These great differences arise both because of differences in the penetration of electricity uses and because of differences in intensity of electricity uses, which we explore below.

While the largest absolute differences are in the space and water heating categories, it is important to recognize the relative variation in other electricity end use categories as well. Differences among countries in electricity use for cooking, refrigeration, lighting and appliances are substantial, in spite of the fact that these functions might be presumed to be relatively standardized in modern Scandinavian households at similar standards of living. For example, Norway and Sweden share a very similar level of appliance energy use per dwelling, but Denmark's appliance energy use appears to be almost 35 percent lower on a unit basis.

To explain these differences requires an appreciation of the differences in context and in evolution of residential energy use in each country. In particular, we consider the historical growth of the housing stock, housing regulations and construction standards, energy prices, and behavior.

* This figure shows total consumption by end use, divided by total population. We discuss other more sophisticated data normalization procedures and unit intensity estimates below when describing each separate end use market.

Table 1: THE CONTEXT OF SCANDINAVIAN RESIDENTIAL ENERGY USE*

	Denmark	Norway	Sweden
Population (thousands)			
1972	4990	3960	8130
1986	5120	4167	8370
GDP/Capita (US$)			
(1980 prices and exchange rates)			
1972	11376	10165	13000
1986	15235	17000	16400
Degree Days			
(base 18C)	3122	4069	4154
Dwellings (thousands)			
1972/3	1880	1380	3295
1986:	2307†	1645	3863‡
• Pre 1940	39%	24%	26%
• 1940 -1975	45%	54%	61%
• 1975-1986	16%	21%	13%
Single-family dwelling Share	59%	79%	47%
Persons per Dwelling			
1972/3	2.65	2.90	2.47
1986	2.28	2.61	2.23
Dwelling Size - m^2			
(average, all types)			
1972	99.9	89.0	81.2
1986	104.6	101	95.3
Share of Housing Stock Heated Principally by Electricity			
1972/3 Total	1.6%	31.8%	6.6%
Single-family	2.0%	27.6%	13.9%
Multi-family	1.2%	47.2%	1.4%
1986 Total	6.7%	57.0%‡	27.0%
Single-family	9.4%	53.3%	52.6%
Multi-family	2.7%	70.9%	4.6%

† 1987; ‡ 1985

* **Sources:** Statistisk Centralbyraan, *Bostads- och byggnadsstatistisk aarsbok 1988,* Stockholm, 1988; Nordic Council, *Nordisk Statistisk aarsbok, 1988;* International Monetary Fund, *International Financial Statistics Yearbook 1988.* The share of single-family dwellings (SFD), which includes detached, semidetached, and row-houses, was taken from each country's housing survey. Dwelling size is taken from BBR (Denmark) Energidata, based on unpublished material from SSB (Norway), and, for Sweden, from Carlsson, L. G., 1984; **Energianvaendning i Bostaeder och Lokaler**. (r132:1984, Stockholm: Byggforskningsraadet). People per dwelling, or household size, was obtained by dividing total population by the number of occupied dwellings or households. This overestimates household size since as much as 5% of the population lives in military barracks, care homes, institutions, etc.

5 Context of Residential Energy Use in Each Country

The distribution of the housing stock by type and age is suggested by the figures in Table 1. Housing built since 1975 has been subject to more stringent energy efficiency regulations in all three countries. In Sweden homes built after 1975 were predominantly single-family: almost 20 percent of the single family housing stock in 1986 did not exist prior to 1975, while less than 2 percent of the multi-family stock is of this recent vintage. This one-sided evolution of the Swedish housing sector in the period since 1975 is much more marked than in either of the other two countries, and is largely a response to the previous over-dominance of multi-family housing in Sweden. In spite of the rapid addition of single-family stock in this period, multi-family housing still comprises over 50 percent of the total housing stock, a much higher proportion than in either of the other two countries.

Proportionately, Denmark has added slightly more to its 1975 housing stock than has Sweden, so that in 1986 almost 20 percent of single family homes and 15 percent of multi-family homes were of recent vintage. The trend towards a greater share of single family housing is also important in Denmark, but is weaker than in Sweden. We estimate that Norway has made the largest proportionate contribution to its housing stock in the period since 1975. In 1986, over 21% of Norway's total housing stock had been built since 1975, but the proportions of single- and multi-family dwellings have been relatively constant.

Average dwelling area has increased in all countries since 1973 (Table 1), the increase in Sweden caused by the dominance in new construction of large single family dwellings. Household size (persons/household) has declined steadily in all three countries, but most rapidly in Denmark. Swedish households have fewer people, on average, than in either of the other countries, while average dwelling size (floor area) is largest in Denmark.

New, more stringent thermal requirements in the building regulations of each country have helped to change patterns of residential energy use in Scandinavia. In this regard, Sweden took the lead, introducing comprehensive new thermal requirements in 1975 to what were already arguably the most energy efficient homes in the OECD.[3] As Fig. 4 shows, Denmark and Norway followed Sweden's regulatory lead with similar standards. Since 1977, each country has increased its requirements, but Swedish thermal standards remain the most stringent.

A crucial element of the context within which residential fuel choices and consumption patterns took shape is that of relative fuel prices. Prices provide important signals to consumers and to household equipment manufacturers and thereby influence consumer choices both directly and indirectly. The clearest price effects can be seen in those markets for which there is competition between fuels. This is the heating market, although the degree of actual competition between electricity and fuel oil (the principal alternative fuel) is sharply modified by the effects of government policies supporting other forms of heating (e.g. district heating in large cities) and by the existing capital stock in domestic heating equipment.*

Fig. 5 illustrates the trends in consumer prices for electricity (heating rates) and fuel oil, compared in terms of useful energy equivalent at an assumed efficiency for fuel oil of 66 percent. The chart shows average residential electricity prices (allocating fixed charges at the mean consumption level). Prices are consistently higher in Denmark than in the other countries. Fig. 6 presents the ratios of the prices of heat from the two fuels for each country (again assuming heat is obtained from oil with 66% efficiency), showing the generally increasing price attractiveness of electricity relative to fuel oil in all three countries over the period.†

There have been sharp and consistent differences among the three countries in the average residential price of electricity. In Norway, electricity prices in the early 1970's were the lowest in the region (possibly in the world). They have steadily increased in real terms since then, but at a slow rate. As a result, in the 1970's when fuel oil prices were climbing, the price of electricity relative to that of fuel oil continued to fall, reaching a ratio of less than 60 percent in 1981. Recent petroleum product price reductions (in spite of increased taxation) have once again

* The role of the capital stock (installed heating equipment) is explored further below in specific discussion of the electric space heating market. Because consumers must have two kinds of heating equipment to be able to use different fuels, there is often a substantial capital investment involved in the fuel substitution decision. The situation is particularly relevant in any decision to switch to fuel oil in an electricity-only home, for which a very costly central furnace and heating system would have to be installed.

† Note that while the comparison is made in terms of relative price ratios, there are a variety of non-price reasons (flexibility, low first costs, convenience) why electricity might be preferred to fuel oil as a heating fuel anyway.

made these products more attractive.

In Sweden, real electricity prices fell steadily between 1978 and 1986. Indeed, the difference between fuel oil and electricity prices grew steadily in Sweden up until 1986, due to increased taxation of fuel oil.

For Denmark, residential electricity prices were well above the prices in Sweden throughout this period. Within the country, electricity prices have remained at least 50 percent higher than fuel oil, on an energy equivalent basis. This situation in Denmark is partly the result of the source of electricity, which is entirely thermally-generated (unlike Norway, where electricity is hydro-based, or Sweden, where hydro and nuclear provide most of the base load). But it is reinforced by very high rates of taxation on both fuel oil and electricity (in the range of 50%), which increases the absolute retail price differential between the fuels. While it can be argued that these taxes support fiscal policy, they are also a clear indication of the Danish commitment to discouraging the use of imported energy sources.[4]

The evolution of fuel shares in total residential use of delivered energy since 1973 was shown in Fig. 1. The share of oil as a residential fuel has dropped in each country, and the share of electricity has increased, unsurprisingly. In Sweden and Denmark, impressive gains in share have been made by district heating, which has been strongly favored by explicit government policy, financial support, and even regulatory provisions.* In Sweden, district heat, wood, and electricity substituted directly for oil in the heating market; in Norway, wood and electricity played the same role. These substitutions forced oil use down by more than 50 percent in Sweden and Norway. In Denmark, by contrast, district heating was already widespread in 1973, while electricity has been expensive and wood scarce. Electricity thus played a key role in reducing the oil heating share in Norway and Sweden, but only a small role in Denmark.

While the share of electricity in residential energy use has increased in all countries, it has done so in a different fashion, and in response to different factors, in each. To examine where the gains in electricity use have come from in each country, we examine each of the major end use markets in turn: space heating, water heating, cooking, appliances and lighting.

6 The Major Electricity End Use Markets Compared in Detail †

The differences in electricity use intensity between Sweden, on one hand, and Denmark and Norway on the other, are well illustrated in Fig. 3. The differences among the three countries are concentrated in the space and water heating markets: virtually the entire difference between Sweden and Norway is made up of use for water and space heating and lighting. Similarly, most of the difference between Sweden and Denmark is made up by the same two markets. This pattern of differentiation has remained consistent throughout the period of study. Finally, most of the *growth* in electricity use in Norway and Sweden arose in space and water heating as well. While there are other differences in the cooking and lighting/appliances markets, space/water heating account for *both* most of the differences among countries as well as the changes in use/capita over time.

* For example, in Sweden when an urban neighborhood has been designated as a future recipient of district heat due to system expansion, the utility company can refuse to upgrade residential electrical service to handle electrical heating loads. In Denmark, new residential buildings are not permitted to have primary electrical space heating unless they meet especially stringent thermal requirements.

† The intensity of electricity use may be expressed using either population or households as a base. It is most sensible to use per capita terms when the service is one which can be provided flexibly in relation to individual demand, such as hot water use or cooking. When the service is provided for the entire household, such as space heating or even lighting, its intensity is more reasonably measured on the basis of the dwelling unit or relative to floor area. Unfortunately, data limitations can restrict the adoption of this common sense guideline. The problem comes when trying to modify estimates of electricity use for specific end uses per dwelling to the more intuitive per capita measure. While per dwelling measures can be calculated from equipment saturation and housing stock data (see main report) there is no reasonable way of translating this into a per capita figure without the average household size for households using electricity for this specific use (it may differ from the national average). Therefore, when we are limited in information to the saturation of specific uses within the total household stock, we can only derive indicators for these uses on a per household basis. When comparing total household electricity use among countries, we have adopted the convention of normalizing according to population.

When these data are compared with our figures for other OECD countries for 1986 (Fig. 7), it can be seen that the three Scandinavian countries encompass much of the range of variation among all countries: Norway has by far the highest per capita use of any major country, while Denmark has a relatively low electricity intensity, particularly in markets where other sources compete, and Sweden lies intermediate to these cases. The Scandinavian comparison therefore represents a picture of where other OECD countries lie or may be headed in terms of electricity use. The comparison also illustrates the dynamics of a market for space heating which is dominated by electricity, a fuel whose suitability to the residential market has been strongly contested by powerful utility and environmental interests. In the following sections of the paper, we review each of the major end-use markets represented in Figs. 3 and 7. We focus on the implications of our findings for Sweden and Norway.

6.1 Space Heating.

Electric space heating represents the most important distinctive element in comparing the pattern of residential electricity use in Scandinavia. In 1986, electricity was the main heating source for about 60 percent of the Norwegian housing stock, 32 percent of the Swedish stock, but less than 10 percent of homes in Denmark. Additionally, about 30 percent of homes in Norway, 20 percent in Denmark, and 25 percent in Sweden used significant amounts (ie., >500 kWh/year) of electricity as a supplement to other main heating systems. The pattern of electricity use for principal and secondary space heating differs, so we discuss these two uses separately.

6.1.1 Principal Space Heating with Electricity

Homes with electric space heat in Scandinavia have the lowest heat losses, on average, of such homes anywhere in the world. Fig. 8 compares the annual use of electricity for principal space heating per (electrically-heated) dwelling unit for each country since 1973.* It is difficult to compare electricity use for space heating among countries or over time because of the changing role of secondary heating (see below). The figures we show in Fig. 8 represent only the contribution of electricity to space heating in homes where electricity is the principal source. Changes in unit consumption can reflect changes in efficiency (insulation, air tightness), changes in indoor temperature, a switch from direct, baseboard heating to hydronic heat (as has occurred in Sweden), or changes in the role of secondary fuels. The area of homes heated with electricity has increased during this period, for example because of extension and the addition of newer, larger homes to the electrically heated stock. Nevertheless, the differences in the evolution of unit consumption in the three countries is striking: in Sweden and Norway, unit consumption varied only slightly, while in Denmark unit consumption fell markedly.

In all three cases, the principal factors which explain the evolution of these electricity use intensities are behavioral (changes in indoor comfort), policy-related (building standards and conservation incentives), or technological (new construction and heating techniques). In each case, these factors have been influenced by relative prices for secondary fuels which are a function both of natural resource endowments in each country, *and* of energy taxation policies. The range of effects that differences in electricity price can have is thus illustrated by the variation in the influence and role of each factor among countries.

---

* The main choices of systems in Scandinavia are: 1) a centrally-controlled unit providing heat to the entire house (central boilers, plenum heaters or wall-mounted direct resistance or, increasingly popular in Swedish multi-family buildings, heat pumps); 2) independent wall-mounted radiator units in each of the living spaces in the building; 3) small fixed or portable space heaters to supplement other heating systems and maintain comfort levels in selected areas of the home. The first two types are referred to here as *principal* electric space heating. We acknowledge that this distinction is somewhat arbitrary given the extremely wide variation in conditions of indoor comfort and heating system use to which electric heating can be adapted. This special flexibility, and its relation to the use of secondary electrical space heating is discussed further below. The important principle which we have followed in our analysis (using a variety of data sources for each country) is to separate those dwellings which can be readily identified as using electricity for the dominant space heating fuel, and evaluate their electrical use differently from other dwellings.

The initial dramatic decline in electricity use per dwelling with electric heat in Denmark in the 1970s can largely be attributed to behavioral change. In 1973, average indoor temperatures in Danish homes were in the range of 22° C. Denmark's unit energy intensities for space heating were higher than either of the other two countries. By the end of that decade, indoor temperatures had fallen to 18° C.[5] But other important changes in electric heating gradually took place as a result of deliberate government policy measures.

We have already documented how Danish reliance on thermal generation and the taxation of electricity resulted in much higher relative prices for residential electricity in that country. But Danish energy policy in the late 1970s focused very strongly on reducing space heating energy use in general through the use of retrofit subsidies, tough thermal efficiency standards for new buildings and, after 1981, audit and inspection requirements for older homes.[6] The influence of new construction standards was especially important for electric space heating intensities because fully 29 percent of Denmark's electrically-heated housing stock (in 1987) has been built since 1979, when the standards came into effect.[7]

Along with the tougher new construction standards in Denmark came measures to prohibit the use of electricity for space heating in areas which were served by district heat systems or natural gas. Electrically heated homes also had to meet especially stringent thermal standards after 1983. In spite of these requirements, the proportion of new homes constructed with electrical space heating has not declined since the late 1970's. These requirements have led to major changes in the techniques of new Danish home construction, with the result that "low-energy" new electrically-heated homes (forming a significant portion of the Danish electrically-heated stock) are fully comparable in terms of thermal performance with the extremely high Swedish standards.[8]

In Sweden, as in Denmark, electric space heating is found mainly in single family dwellings. There has been little change in the unit intensity of electricity use for space heating in Sweden, although the general direction of the trend appears to be downward. In the late 1970s, electricity came to dominate other household fuels for space heating installation in both new single family houses and in upgrading older homes. Rigorous thermal requirements for new residential construction, which in Sweden since 1975 has been overwhelmingly single-family and electrically-heated, have compensated for the increase in size of new homes, without sacrificing high indoor temperatures (typically at least 21° C). However, the large number of electric heating retrofits in older, leakier homes meant that the stringent thermal standards for new buildings have not had a dramatic effect on the average unit intensities of electric space heating in Sweden.

In Norway, the trend in unit heating intensity has been opposite to that in Denmark.[9] Intensity has increased steadily, in spite of the introduction of thermal standards for new buildings and widespread energy conservation retrofitting. This phenomenon is attributed to increased levels of indoor comfort and larger homes. Partly because of the multiple fuel tradition of Norwegian home heating, users often heated only portions of the home according to need. Norwegians, on average, lagged behind their Scandinavian neighbors in terms of indoor comfort levels at the beginning of the 1970s and the changes in intensity reflect increases in both the number of rooms heated and average indoor temperatures.[10] Although Norway has also introduced tougher thermal requirements for new buildings, its building codes have been less stringent in this regard than the other two countries and have also been introduced more recently. The higher efficiency of the new housing stock has not yet played a strong role in influencing average unit intensities. The electrically-heated housing stock in Norway has been subject to neither the massive retrofit campaign undertaken in Denmark, nor the standardized, high-quality construction practices of the Swedish building industry. Electricity has been widely available and used for space heating in some form throughout the country for at least two generations. It has been priced at levels that rendered other commercial heating fuels and voluntary conservation retrofits relatively unattractive.

6.1.2 The Role of Secondary Fuels in Space Heating

For the purposes of comparing overall unit intensities, principal electric space heating represents only part of the story describing the differences among countries. At least 1/3 of electrically heated homes in Sweden and Denmark, and 2/3 of those heated with electricity in Norway, also used a second fuel (usually wood or trash, but also oil or kerosene) to some extent.[11] And the electric heating market also includes secondary electric space heating as a supplement to other heating systems (in Scandinavia, either wood or oil).

Indeed, the aggregate shares of different fuels in residential energy use (see Fig. 1) obscure the fact that in all three countries, a significant portion of households (Norway 80%; Sweden, 40%; Denmark, 25%) has the potential to use multiple space heating fuels: often wood and electricity, or oil/kerosene and electricity, or even all three. While in the coldest weather conditions, all fuels might be used, it would be quite possible in these cases for households to select their principal fuel based on competitive prices and convenience for much of the heating season, leading to substantial year-to-year variation in electricity use depending on climate and relative prices. In Norway and Sweden, occupants often switch fuels during the same heating season. Danish households have less flexibility because electricity and oil are so expensive, while wood or other bio-fuels (including trash) are less available than in Norway or Sweden. Note that this same flexibility is **not** available to homes heated exclusively with baseboard resistance electric systems.

Secondary space heating data are weaker than those for principal electric space heating, because it is more difficult to tell how many households use electricity on a supplementary or irregular basis, or estimate how much is used. It may be more realistic to speak of multiple-fuel heating systems, rather than "principal" and "secondary" systems. In Norway, for example, most homes built before the mid-1970s have been equipped with both electric space heating and kerosene or wood systems as well. In 1973, only 10 percent of the dwelling stock relied exclusively on electricity for space heating. By 1983, this figure had almost doubled, but there had been relatively little change in the total proportion of the housing stock which used electricity either alone or in combination with kerosene or wood for heating (67 percent in 1973 compared with 75 percent in 1983). In all three countries, solid fuels (especially in rural areas) have gained importance for residential heating in the past decade, after almost disappearing prior to that period.

In Denmark, the multiple-fuel situation has two important dimensions: the increasing use of solid fuels to supplement costly electric heating in rural areas, and a sharp recent trend to supplement non-electric space heating systems with point source small electric heaters during short-term heating peaks. Our estimate is that this latter secondary space heating electricity use represents almost one-third of total residential space heating electricity use in Denmark for 1987, although it is not reflected in the intensity comparison shown in Fig. 8.

Unit intensities explain only a portion of the difference among countries in the role played by electricity consumption for space heating. The second element for comparison is the proportion of the housing stock heated by electricity in each country. Here the story is most dramatic in Norway, where the proportion of single family housing in the total stock is highest, and where even in urban areas district heating is not an important heat source.* Indeed, electric space heating not only dominates Norway's single-family housing sector, but is also the fuel of choice in about half of the multi-family stock (which is equipped with electric resistance heating in each individual unit).

The explanation for this sharp divergence from the other two cases can be found both in the nature of the housing stock and traditional fuel use, as well as in the relative prices of heating fuels. In the early 1970s, when much of the Norwegian housing stock was being modernized and upgraded to higher comfort levels, oil prices were just beginning to rise. The simplest form of supplementing existing heating systems was with electricity. Its convenience and lower cost made it an easy favorite in Norway.

* Where district heat distribution systems exist in Sweden and Denmark, electricity is no longer a feasible alternative, for either economic or regulatory reasons (Wilson *et al., op.cit.*).

6.1.3 Conclusions: Space Heating

Our examination of electric space heating in the three countries leads to the conclusion that Denmark exhibits the clearest reduction in unit energy intensity over the past 15 years, over all housing categories. This has been due to:

1) high-priced electricity that discouraged heating conversions and forced parsimony on existing electrically-heated homes;
2) sharp reductions in indoor comfort levels in the late 1970s;
3) a high proportion of electrically-heated homes that are new and of high thermal quality;
4) some substitution of principal electricity by secondary solid fuels.

Sweden's case is intermediate: electricity prices were low enough to prompt a large number of conversions to electric heating in the late 1970s and the early 1980s. These conversions of older homes tended to *raise* unit consumption. But housing standards were being sharply tightened to reduce the need for space heating in new electrically-heated homes. As a result, overall unit consumption of electric heating in Swedish single-family dwellings has not changed much.

Norway's very high rates of penetration and high electricity use intensities are the result of:

1) lower electricity prices due to hydro resource endowments and to government policy;
2) steadily increasing indoor temperatures and house size;
3) weaker thermal performance standards for new construction.

The case of Denmark, where all fuel prices were high and there was no practical alternative to expensive fuel oil (outside of district heating and gas distribution areas), suggests the importance of prices *and* standards in compelling more careful use of electricity for space heating. However the Danish example also shows that there can be a market niche for electric space heating even under very high electricity prices, either as a principal source of heat in very efficient homes or as a secondary source of heat for local convenience and comfort in cooler living spaces. By contrast, electricity in Sweden and Norway offered relief from high oil prices and a practical complement to wood, making it particularly attractive in single-family dwellings. But the Swedish case suggests that *standards* can provoke high levels of insulation even when prices are low. Conversations with experts in Norway, however, suggest that the low price of electricity there was used as an argument *against* tightening thermal standards in 1985.

It is not inconceivable that the dominance of electricity in heating, particularly for single-family dwellings, would be reversed if electricity prices increased significantly while oil remained inexpensive or natural gas became available. The flexibility of the secondary heating market and the existence of many older, less efficient homes with multi-fuel equipment suggests the potential for a rapid response by consumers to changing conditions of fuel competition in the space heating market. *Thus, the recent rise in the importance of electricity in Sweden (and to a certain extent in Norway) is* **partly** *reversible.*

6.2 Water Heating.

The importance of electric water heating in Scandinavia varies widely, but generally follows the pattern set by space heating. Yet few studies of electricity use in Scandinavia separate space and water heating, so water heating saturation and energy use is often ignored. From various sources, however, we find that while 95 percent of homes in Norway use electricity for water heating (highest in the OECD), only 11 percent do so in Denmark (close to the lowest in the OECD) and 35 percent in Sweden (See Fig. 9). Virtually all of the systems in Denmark are free-standing tanks, while about 5 percent in Norway are from electric heating elements in central boilers, and the rest tanks. In Sweden, systems are mixed: roughly 10 percent are central electric boilers (most of which can use other fuels), 2 percent are from combinations with heat pumps, and the rest tanks. Since central hot water systems are a long tradition in all three countries, electric instant-water heaters have virtually no niche.

Analysis of the intensity of electricity use for hot water is complicated by several factors. In our global comparisons of end use (cf. Figs. 3, 7) we define hot water to include both water heated electrically in tanks and in water-intensive appliances (for washing clothes and dishes). The overall per capita effects illustrated there include both changes in intensity of use and in saturation of tanks and appliances. We attribute the sharp increases in electricity use per capita for hot water in Sweden and Denmark to increased saturation, which more than offset a slow decline in electricity use per household using electricity for water heating, which we estimated from country sources.

Unit consumption of electricity for water heating is very uncertain. The best estimates put consumption in Norway and Sweden at about 3500 kWh/dwelling in the mid 1980s, down about 12 percent from 1970.* The figures for Denmark are markedly lower than for Sweden or Norway, at about 3000 kWh/dwelling, and have followed a similar downward trend since the early 1970s. This calculation, unlike our per capita figures, excludes water heated in dishwashers and clothes washers, because it is impossible to determine whether homes heating water electrically also have these appliances.

Interpreting these estimates is problematic, however. In all three countries, household size has declined significantly. Any studies of domestic hot water consumption have shown that it varies widely among households but is very strongly related to household size.† In Norway, where high saturation of electric water heating means that it can safely be assumed that the average number of persons per household with electric water heating declined proportionately to the national average, per capita electricity consumption for water heating has changed very little in the past 15 years. In spite of these measurement uncertainties, we believe that the figure for Denmark does lie significantly below those for Sweden or Norway.

There are few data that compare levels of insulation or other measures of efficiency of water heating among Scandinavian countries or over time. However, a comparison of current water heaters[12] shows a clear difference in insulation levels among products offered for sale in Sweden. We suspect that there are significant differences in insulation levels among and within countries, and that the potential for saving electricity through deliberate efforts to improve tank insulation and temperature control merits further attention than it has so far received.

Hot-water heat pumps, particularly those using exhaust air, are popular in Sweden[13] and not unknown in Denmark or Norway. However, we have seen very few studies that document their actual performance or compare electricity use in homes with these heat pumps to that of homes with ordinary water heaters. Therefore, we can offer no firm conclusions about either unit consumption levels or comparative efficiencies.

6.3 Cooking.

The penetration of electricity for cooking in Scandinavia represents an extreme: virtually all homes in Norway, more than 90 percent of homes in Sweden, and close to 85 percent of all homes in Denmark use electricity for cooking in a combined stove/cooktop (See Fig. 9). The principal reason for the high saturation is the lack of natural gas. City gas was popular in Denmark and in larger cities in Sweden[14] and even a few cities in Norway, but has yielded to electricity. More recently, natural gas has begun to attract users in cities in Denmark and southern Sweden.

Unit consumption of electricity for cooking has fallen for many reasons. Households are smaller, and members are eating fewer meals at home because of greater female labor force participation and higher household incomes. Increased labor force participation also means less time for cooking at home, which leads to simpler meals. Technology has served these changes, providing a variety of electricity-using specialty appliances (rice cooker, coffee maker, egg cooker, etc.) that *reduce* electricity needs for specialized cooking purposes. Finally, microwave ovens are popular because of their convenience, and becoming important in Scandinavia, reaching at least 15 percent of

* These figures reflect full year-round use of electricity. Some homes use electricity only in the summer when the main heating/hot water system is turned off.

† If data on the number of persons in households using electricity for water heating were available, it could be determined whether the declining unit intensities were simply an artifact of household size. Such data are not available however, and surprisingly few studies have been undertaken on this particular use of electricity in homes in Scandinavia, especially considering that in households with electric water heating, it represents the second largest consumption of electricity after space heating.

homes in Sweden. These use less electricity for basic processes than ordinary ovens, and can be used for boiling small volumes of water as well. Finally, cooking ovens are better insulated today than in 1973, and cooking elements better designed for transferring heat to pots and pans. But this increased efficiency of electric cooking is probably the *least* significant component of reduced unit consumption of electricity for cooking.

6.4 Lighting.

Indoor lighting is important in Scandinavia because of the long winter nights (mjoerketiden). For lighting there is a dramatic difference in intensity of consumption between Sweden and Denmark (Fig. 10), on the one hand (600 - 800 kWh/dwelling), and Norway (>1500 kWh/dwelling). While the longer winter nights would explain part of the difference between Norway and Denmark, this cannot account for the difference between Norway and Sweden. Certainly the lighting of common spaces in apartments in Sweden (not broken out by end use in our data) accounts for some of the Norway - Sweden difference. Other possible explanations for the high use in Norway are that 1) electricity is cheap so nobody pays any attention to lights; 2) Norwegians have strong cultural preferences for high levels of indoor lighting; 3) a widespread practice in Norway is to purchase more powerful, but less efficient, longer-lasting bulbs; and 4) it is widely believed that since the heat from the lights contributes to space heating anyway, there is no economic loss from such high lighting levels.[15] In all, however, we conclude that there are important differences in electricity use for lighting among Scandinavian countries. We suspect, too, that higher electricity prices make use of fluorescent lighting more attractive in Denmark than in Sweden or Norway.

6.5 APPLIANCES

Electric appliances — devices whose functions are met exclusively by electricity — consume between 2500 kWh and 4000 kWh/home in Scandinavia. Fig. 11 shows the evolution of electricity use for household appliances in Norway, Denmark, and Sweden since 1972. The main appliances include refrigeration equipment (refrigerators, freezers, and combination fridge-freezers, or combis) and "wet goods", or clothes washers, dryers, and dishwashers.*

6.5.1 Refrigeration.

Refrigeration represents the largest single electricity use for appliances. The comparative saturation of household ownership of the three different styles of device found in Scandinavia is shown in Fig. 12 for 1972/3 and 1986. While ownership of refrigerators is growing only slowly, ownership of combination refrigerator-freezers (combis) and of freezers grew significantly since 1972, and these generally increased in size as well. In terms of both saturation and size/features Danish household refrigeration equipment lags behind the trends in Norway and Sweden. The evolution of refrigeration equipment in homes has led to a situation in which both a freezer and refrigerator (or combi) can often be found in the same household. A small number of households have more than one refrigerator.

As Fig. 3 shows, electricity for refrigeration (ie., refrigerators, freezers, and refrigerator-freezers, or "combis") is an important part of total household use, and is highest in Norway and Sweden. This is because there are more appliances, and they are larger, than in Denmark. In Sweden and Denmark, in spite of increased appliance saturation, size and features, electricity use per household for refrigeration has dropped since 1973. Fig. 13 shows the unit consumption of the stock of each kind of refrigeration appliance. The downward trends for Sweden and Denmark are clear. The figures for Norway, while somewhat uncertain, suggest that the trend towards larger appliances has

---

* In appliances we exclude the estimated electricity to heat water in the appliances themselves for cleaning clothes and dishes. In our global per capita comparisons (cf. Figs. 3, 7), this electricity is counted more appropriately with water heating. In Sweden, "appliances" includes a significant quantity of electricity — as much as 500 kWh/dwelling — for "fastighets foervaltning", or common functions in apartments (lights, washers, elevators, fans), as well as some space and water heat. These applications are considerably less important in Norway and Denmark due to less frequent provision of common appliances and smaller multifamily buildings, and are counted in a different category of consumption, "eiendomsdrift".

been more important than reductions in electricity through greater efficiency of new appliances added to the stock.

The reduction in unit consumption of new appliances conceals a persistent wide range of performance in models of comparable size. For example, Fig. 14 shows for Sweden the decline in average electricity use for refrigerators between 1973 and 1987. But it also illustrates the range of consumption levels among new models of size comparable to the average in the stock in 1987. Given a wide range of available equipment, and when high-efficiency appliances usually cost more, consumers do not always choose the most efficient models. Further reductions in refrigerator electricity use therefore cannot be assumed, even though the technical potential for further reductions in energy demand is great.[16]

6.5.2 Washing and Drying

Electricity use for the other main appliances differs among the three countries. Fig. 15 shows changes in household saturation of the main cleaning appliances, or "wet" goods. There has been a dramatic increase in the ownership of these appliances in all three countries since 1973. Denmark has a slightly lower saturation level than either Norway or Sweden, but this difference is not sufficient to explain the apparent differences in electricity consumption. In addition to the lower saturation, Danish appliances tend also to be smaller in size. And according to Moeller,[17] Danish families have modified their use habits somewhat in response to higher electricity prices, which probably reduced electricity use for wet goods more than for other appliances.

Most wet appliances in Norway and Denmark heat their own water. In Sweden, by contrast, 90% of dishwashers use centrally-heated water. Improved controls and reduced water use have lowered average unit energy consumption, but the overall impact of these appliances on residential electricity use has been dominated by the effects of increasing saturation. The growing numbers of appliances have led to aggregate electricity use increases in this end use category. At 80 percent in each of Norway and Sweden, the saturation of washing machines is unlikely to change further, but dishwashers and, to a lesser extent, dryers still may exhibit substantial ownership growth.

6.5.3 Other Appliances

What about electricity use for other appliances? While virtually every home in Scandinavia has radio, T.V., and other electronic devices, the total electricity used for these devices is no more than 200kWh/yr. Thus electronics are *not* a major use of electricity in homes in Scandinavia.

Other miscellaneous heating appliances can be important in specific cases or in relation to peak load coincidence, but do not represent a significant area for growth in electricity use. Examples common to Sweden and Norway include the sauna, the electric car seat heater, and the engine block heater. Vattenfall estimates that these uses combined are spread to as much as 20 percent of homes in Sweden and account for as much as 500 kWh/yr in homes that have them,[18] but averaged over the entire stock, unit consumption is still small, amounting to about 300 kWh/dwelling in Sweden, somewhat less in Norway, and significantly less in Denmark. In Norway and Denmark, waterbeds are now growing in popularity, and are found in around 10 percent of homes. They are almost always heated by electricity, which essentially contributes to indoor space heating, although it is not counted in this category.

Electricity use for appliances also includes that for ventilation and central heating system circulation pumps. Both are significant in Sweden (as much as 300 kWh/yr for ventilation and 500 kWh/yr for the pump), while the latter is also important in Denmark. Neither are significant in Norway.

7 Comparison with the Rest of the OECD.

Fig. 7 showed *per capita* electricity use in 10 OECD countries in 1985/6. The main factors accounting for differences among OECD countries are similar to those we have found in the Scandinavian case: variations in penetration of electricity use for heating and water heating, as well as cooking, and differences in ownership levels of freezers, dishwashers, and clothes dryers. Differences in electricity prices are one factor: in most OECD countries, households pay *more* for a kilowatt-hour than in Sweden or Norway, but less than in Denmark. Japan is an important exception, with very high electricity prices; parts of the U.S. and Canada had very low prices until recently. Differences in income have narrowed since the early 1970s, but are reflected in the size of homes and appliances.[19]

Unit consumption for many uses — particularly space and water heating — varies because of both behavior and efficiency. Unit consumption is typically lower in countries with high electricity prices. There are some differences in the **efficiency** of appliances, but these are minor because production has become international.[20] The most important component of differing unit consumption of appliances is the difference in size or features.

Some highlights of the differences between consumption patterns in Scandinavia and elsewhere in the OECD are as follows.

Space Heating: France has seen a significant penetration of all-electric heating using resistance heat. In Germany and U.K., the dominant heating system for those using electricity (less than 10 percent of homes) is night-time storage heat. In both countries, these systems are losing market share to gas. The importance of electric heating is high in the U.S. because of heat pumps, which are almost always combined with air conditioning. Japan has a large number of secondary heat pumps (nearly 40 percent of homes), almost universal saturation of *kotatsu*, small, under-the-table foot heaters, but almost no penetration of direct electric heating. In all these countries, electric heating has expanded either by capturing a share of new construction, or as a fuel chosen for homes that are being renovated, or as a secondary fuel. Only in Canada have there been significant conversions of homes from oil to electricity, aided by a subsidy program. The wave of conversions of existing homes in Sweden and Norway from other fuels to electricity is thus unique for Europe.

Efficiency varies considerably. While there are many well-insulated homes in Canada and France (and even in the U.S.), the *average* level of insulation in electrically-heated homes in Scandinavia is far better than in other countries. The Swedish thermal integrity is the *highest*.[21]

Water heating: The structure of electric water heating in Europe differs from that in Scandinavia. Because central heating came later to most of Europe than to Scandinavia or even the U.S., hot water is often independent from the heating system. Consequently, electricity is used in as many as 30 percent of homes where electricity is **not** the main heating fuel. Point-of-use tanks are popular in Germany and France. Tanks in France, Italy, and the U.K. are smaller than in Scandinavia, while American tanks are larger. In Japan, the entire 7 percent of homes which have large tanks are charged up at night to take advantage of inexpensive off-peak electricity rates. In France, a small portion of homes with electric tanks uses the night-time rate.

Our comparison shows that unit consumption in the U.S. and Japan is higher than in European countries, except Norway and Sweden. The reasons are related both to the size of the storage tanks, as well as to habits of using hot water. Low electricity prices (in Japan's case, a special night rate for water heating) are a common feature of this group of countries.

Cooking: We noted above that electric cooking is more widespread in Scandinavia than in any other OECD region. Lack of a natural gas network is the main reason. But in OECD countries with gas, electric ovens or cooktops combined with gas are gaining in popularity, as are microwave ovens and small electric appliances that substitute for use of gas. Indeed, microwave ovens have even grown in popularity in France and Italy, countries where more elaborate meals based on gas stoves used to be the rule. The universal reasons are related to reduced household size and higher female labor force participation rates which put a premium on convenience and time savings.

Trends in unit electricity consumption for cooking stoves in all countries are downward, for the same reasons as described above for Scandinavia. In addition, higher electricity prices have promoted greater levels of insulation in ovens, and more controls for cooktops. The relative gas/electricity price has *some* influence on fuel choice, but marketing (by the electricity or gas authorities), and culinary traditions are important as well. Nevertheless the entrance of natural gas into the residential markets of Denmark and Sweden will likely boost interest in gas cooking.

Lighting: Electricity use for lighting varies substantially around the OECD. In the U.S. (and Canada), average annual consumption is more than 1000 kWh/dwelling, high in part because of the large size of homes. In Germany, on the other hand, lighting electricity use per dwelling is much lower, less than 350 kWh/dw. Higher penetration of fluorescent lights in Germany and other countries may be one reason why electricity use for lighting is lower then than in Norway, Sweden, or the United States. The cost of electricity and long-term habits contribute to the differences.

The technology of lighting is changing. New compact fluorescent bulbs reduce electricity consumption per unit of lighting by two-thirds and last 10 times longer than incandescent bulbs. These bulbs are making a slow entrance in homes, however, because of their high initial cost (over 200 NOK, 150 SEK, for example). Philips of Norway pointed out that these new bulbs are "cost effective", yet they are making slow headway, especially in countries with cheap electricity. Promotion by Oslo Lysvaerker and Stockholms Energi, however, show promise for boosting the popularity of these new devices.[22]

Authorities indicate that if new fixtures are developed to utilize these new bulbs, and if consumers become aware of their attractive economics, that the new bulbs will capture an increasing share of the market by substituting for incandescent bulbs.

Electric Appliances: Fig. 16a shows electricity use/capita for appliances and lighting in several countries. The differences arise from variations in the same three factors that vary in Scandinavia (ownership, size/utilization, efficiency). Figs. 16b-e show the differences in ownership for three main appliances and for refrigerators and combis combined. Major differences arise for freezers, dishwashes, and dryers (not shown), all of which are more common in Scandinavia than in Europe. Refrigeration equipment is much *larger* in North America than in Scandinavia, but somewhat smaller in Japan and the rest of Western Europe. Japanese and North American refrigerators have more features (frost free, ice makers, etc.) than those in Europe. In some countries, certain appliances have not been very popular: dryers in Japan and France, freezers in Japan, single door refrigerators in the U.S. Dryers have recently become very popular in France; similar waves boosted the popularity of dishwashers or dryers in other countries. We expect that within a decade, or at most two, the *saturation* of all major appliances will be very similar around the OECD, near the levels in Sweden (or North America) today. Thus a major reason for differences in electricity use for appliances will steadily diminish in importance. But differences in appliance size and features may remain, and with these differences varying levels of unit consumption.

In the past it was possible to identify countries where certain appliances were *more* or *less* efficient. Such differences are disappearing because the manufacturers are making similar models for entire regions. It is still true, however, that Japanese refrigerators are likely to have more advanced compressors, or that European dish- and clothes-washers use significantly less water (and therefore energy) than those made in North America. There is now an intense effort underway to develop a substitute refrigerant for freon, which will have an effect on refrigeration equipment design and performance.

8 ELECTRICITY USE AND LIFESTYLE

So far we have focused on the saturation of electricity uses, the utilization of appliances (and space and water heating), and the efficiencies of each end-using technology. All of these factors evolve over time, causing household electricity use to change. Electricity prices are important to this evolution, but they are not the only factor driving it. In another study we identified *lifestyle* as an important factor causing changes in household electricity use.[23] By *lifestyle*, we mean the set of activities or behaviors in which household members engage during their daily routines.

One reason why activity changes is because the structure of families changes. Schipper *et al.* (see previous footnote) noted that the variation in *per capita* electricity use among families of different sizes and composition is significant. Fig. 17 shows electricity use per household in 1984/5 for subsamples of the American population *not* using electricity for space heating, nor for the most part for water heating. Fig. 18 shows the same distribution, but on a per capita basis. The variation in *per capita* electricity use among family types is significant. Note, for example, that young singles use less electricity than older, retired singles. The older, retired singles are home most of the time; only 10 percent of those in this sample work. By contrast, most of the young singles work, so they are home less and their electricity use is smaller. Thus shifts in the mix of households change electricity use per household.

One important change in "lifestyle" that has affected energy use through changing use of the home is the increased labor force participation rate of women. With both parents working and young children in childcare facilities, homes are vacant for long periods during the day. Functions assumed by household electricity (lighting, cooking, water heating) are carried out in the service sector, or skipped. In Sweden, where the portion of women working is among the highest in the world and childcare is readily available, such changes have had a downward influence on household electricity use. The decline in the utilization of the home — measured by Carlsson as the total time spent at home[24] — may soon change. In a reversal of past trends, increased use of the home for work could *increase* household electricity use, in spite of improved technical efficiencies of domestic energy-using equipment. The progressive aging of the demographic profile in these countries will also affect the way in which energy is used in homes (through changes in occupancy, indoor comfort, size of appliances, etc.).

These changes in lifestyles can cause changes in electricity use, more or less independent of prices and incomes, which could turn out to be greater than efficiency effects. The point is that the magnitude, and even the *sign*, of such lifestyle-induced changes is highly uncertain. What is clear is that behavioral responses to new technologies and to other social and cultural trends can confound simplistic engineering or economic projections of energy savings due to price and technology changes.

9 Appliances of the Future: More or Less Electricity?

Consideration of the high price of electricity in Denmark, the importance of district heating which blocks further expansion of electric space and water heating in Sweden, and the almost universal penetration of electricity into these markets in Norway suggests there will be **no** significant growth in electricity use in the largest markets: space and water heating. Thus only saunas, car heaters, waterbeds etc., can cause significant growth in demand. We do not expect to see such growth.

Growth in ownership of certain appliances will continue. There is room for combis to replace refrigerators. Similarly, more homes may choose freezers, and all of these could get larger. Dishwashers and dryers have not reached saturation. However, the efficiency of these appliances has improved significantly in the past 15 years, and so increased saturation will have a smaller effect on household electricity use. Although we see evidence that the efficiency of new appliances has stopped increasing, today's new appliances are still far from technical or economic potentials for further efficiencies in electricity use. To achieve further gains may require deliberate policy actions due to the low incentives for consumers or manufacturers to pursue socially-efficient appliance technologies.[25] Microwave cooking, halogen cooking tops, and better insulation of ovens (all to enable better control) promise to further reduce electricity use for cooking. New lighting technologies can reduce electricity use for lighting in homes by 75%, although marketing of these lamps remains a challenge.

To be sure, people are buying increasing quantities of electronics and computing equipment. These devices use very little electricity, typically 100 W or less. And the increasing numbers of electronic systems are really only significant if people have time to use them. Thus while the *numbers* of electronic goods will doubtless continue to increase in the future, their electricity consumption will be limited. All together, Malinen estimates that as much as 400 kWh/year may be devoted to electronics and computing. And as Norford *et al.* argue,[26] computers and electronics themselves are getting more efficient. The most important exception may be high resolution T.V., which Japanese manufacturers indicate may require 5 to 10 times as much power (in watts) as the current generation of T.V.

10 Lessons and Comparative Insights: The Potential for Conservation

What do we learn about household electricity use and conservation potential through this international comparison? First, it is clear that space heating and water heating lead growth in residential electricity use, as the high levels of consumption in Norway and Sweden show. These two uses must be addressed carefully and exhaustively if demand reduction becomes an important objective.

Second, there are very sharp differences between the residential electricity use patterns in Norway and Sweden on one hand, and Denmark on the other. Across all end uses, the intensity of electricity use in Denmark's residential sector is clearly lower than in either of the other two countries. Variation due to different intensities (i.e. normalized for differences in saturation of electricity end uses) provides evidence of the potential for conservation.

Third, there appear to be a number of opportunities for further improvements in the efficiency of electricity use in homes, especially in Norway and Sweden. For space heating, the largest end use, the question is where to focus conservation efforts given the considerable effort already devoted to this end use, particularly in Sweden. Our comparative assessment of the electrically heated housing stock suggests two overlapping sets of homes which deserve special attention:

- older homes which have been converted to electricity from other fuels.
- homes which have multiple-fuel potential.

Given economic incentives to reduce electricity use (e.g. higher relative prices), would these households respond by upgrading the thermal efficiency of the building shell or by switching to alternative fuels such as oil or wood? Either response is possible. The latter may well be more attractive: except for modest measures (infiltration reduction or ceiling insulation), conservation retrofits of existing homes are costly and tedious.

The multiple-fuel issue has special implications for the evolution of electricity use in Scandinavian homes. In Sweden, the high proportion of multiple-fuel capability amongst the older single family housing stock (much of this recently converted to electricity) suggests some flexibility in fuel selection which is not available to the new, electric-only single family stock. The trend towards use of secondary point-source electric space heating during peak heating demand periods in Denmark bears negative implications for utility load factors and demand management. Indeed, in all three countries, the existence of substantial flexible heating capacity means that it is difficult for utility authorities to accurately anticipate the coincident peak heating load, and suggests the potential for significant year-to-year variation in fuel selection, particularly if weather patterns or relative prices change sharply.

The proportion of multiple-fueled electrically-heated homes is highest in Norway. However, a shift away from electricity towards oil or wood fuel use in that country, without substantial upgrading of the thermal quality of the housing stock, would be difficult because of the limited penetration of true central heating equipment. Alternatively, a reduction in heated area or indoor comfort levels would likely be strongly resisted.

Considering the importance of electricity use for water heating in single-family homes (all homes in Norway), very little is currently known about the patterns of domestic hot water use. There are also many uncertainties about the nature of current equipment, technical efficiencies, modes of operation and control, and the potential for gains through improved technology or reduced demand (e.g. lower temperatures, reduced flows). These issues deserve thorough investigation, and may well offer potential for significant efficiency improvements.

We expect some growth in ownership of major appliances, particularly in Denmark. But we do not expect much growth in electricity use per home for cooking, lighting and appliances in any of the three countries studied. Scandinavia is part of a larger international market for household appliances, which in Europe is rapidly approaching a point at which it becomes irrelevant to speak of unique domestic technologies. International appliance manufacturers will be making decisions which affect the use of electricity in Scandinavia, and Scandinavian manufacturers will be expected to develop innovations in order to remain competitive in external markets. Given the opposing forces influencing appliance unit intensity (consumers want more features, but household size continues to fall; energy-efficient technologies are feasible but manufacturers are uncertain of the market), the question is how rapidly electricity use intensity in appliances could decline, particularly with policy measures to support improved technologies.

11 Conclusions

This comparison demonstrates the results which economic theory would lead one to expect: higher electricity prices prompt substitution of alternative fuels in the case of uses for which alternatives exist, and encourage the use of more efficient (and costly) technology to reduce the need for electricity. It also demonstrates the potential role of public intervention, particularly in the form of building standards and support for appliance efficiency, in speeding the implementation of energy-efficient technologies.

The systematic differences we have described in residential electricity use among the three Scandinavian countries suggest three important conclusions.

1) When the saturation of household appliances reaches maturity, it is only changes in space and water heating uses of electricity which can cause significant change in the intensity of electricity use in the residential sector. The large differences in intensity of electricity use among the three countries studied can be almost entirely attributed to these uses. Multiple fuel sources and improved thermal integrity offer prospects for reversing the historical trend of rising electricity intensity.

2) The efficiency of household electricity use is strongly influenced both by domestic technologies and policies as well as by international manufacturers. In all three countries, large household appliances have become more efficient due to technological innovations by the manufacturers. Changes in building technology, driven by intense research efforts and by higher thermal requirements in building standards, have reduced the space heating intensity of new homes in Sweden and Denmark.

3) The behavior of household occupants plays an important role in determining the intensity of electricity use, both through their demand for the services electricity provides and through their choices of equipment. For example, Danish households sharply reduced indoor temperatures in response to price increases. The evidence also suggests that consumers in Denmark select consistently smaller and more efficient appliances. In Norway, household lighting use is much higher than in the other countries, primarily due to consumer behavior.

Comparing Denmark with Sweden and Norway leaves little doubt that the former's higher electricity prices (a function of both resource endowment and deliberate policy) encouraged attention to the design, purchase and utilization of electricity-intensive equipment in homes. We expect that higher relative electricity prices would also lead to more careful use in Sweden and Norway. Electricity use for supplementary heating would diminish, and other principal space heating fuels would assume a greater importance with time. Higher prices would provoke users to pay more attention to electricity when buying new appliances, and would also encourage technical innovations by appliance manufacturers. These conclusions suggest that pricing policies and improved technology offer potential for reducing residential electricity use in Scandinavia through greater efficiency and fuel substitution.

REFERENCES

1. For an overview of international residential electricity use patterns, see: Schipper, L., Ketoff, A., Meyers, S., and Hawk, D., 1987. Residential Electricity Consumption in Industrialized Countries: Changes since 1973. **Energy, the International Journal**, Vol. 12, N. 12, 1987.

2. For a summary of intensity measures and end-use approaches to residential energy, see: Schipper, L., Ketoff, A., and Kahane, A., 1985. Explaining Residential Energy Use by Bottom-Up, International Comparisons. **Annual Review of Energy**, Vol. 11. Palo Alto., CA: Ann. Revs. Inc. An earlier summary is availalbe in Schipper., L., 1984a. **Internationell Jaemfoerelse av Bostaedernas Energifoerbrukning..** R131: Stockholm: Byggforskningsraadet. Our analyses of each country are contained in three reports: Schipper, L., 1983. Residential Energy Use and Conservation In Denmark. **Energy Policy**, (Sept.); Schipper, L., 1984. Residential Energy Use and Conservation In Sweden. **Energy and Buildings**, Feb., 1984b; and L. Schipper, R. Howarth, and D. Wilson, 1989. **A Long Term Perspective on Norwegian Energy Use..** LBL-27295. Berkeley: Lawrence Berkeley Laboratory.

3. Schipper, L., Meyers, S., and Kelly, H., 1985. **Coming in From the Cold.** Washington, DC: Seven Locks Press and Am. Council for an Energy Efficient Economy

4. Soerensen, Bent. 1989. "Danish Programs for Efficient Use of Energy", Evaluation Conference Proceedings. Chicago: Argonne National Laboratory (in press).

5. Noergaard, J., 1977. **Boliger og Varme.** Lyngby: Fysisk Laboratorium III, Danmarks Tekniske Hoejskole. see also Schipper, 1983, *op. cit.* A variety of surveys and calculations lead to these temperature estimates.

6. Wilson, D., L. Schipper, S. Tyler and S. Bartlett, 1989. **Residential Energy Conservation Programs: A Comparison of Five OECD Countries**, LBL-27289.

7. Danmarks Statistik, 1988. **Bolig og Bygning Register** [BBR: Danish Housing Statistics] for 1988. Table B.08. Copenhagen: Danmarks Statistik (provided by Erik Nielsen).

8. Grimmig, M., 1987. **Energiforbruget i boliger opfoert efter BR 1977.** Taastrup: Teknologisk Institut.

9. Ljones, A., 1988. **Utvikling av Energiforbruket 1975 - 1985.** Prepared for Olje og Energidepartementet. Flataasen: A/S Energidata.

10. Grinde, B., 1988. **Analyse av energiforbruket 1976 - 1986 i boligsektor. ENOK og reelle forklaringsvaktorer..** Trondheim: Elektrisitetsforsynings Forskningsinstitutt A/S. See also Schipper *et al.* 1985.

11. These figures can be derived from the Omnibus surveys analyzed by Danmarks Elvaerkers Forening, the Swedish **Energistatistik foer Smaahus**, and the Norwegian **Energiundersoekelse 1983.**

12. **Raad och Roenn** (Magazine of the Swedish Consumer Authority), 1986 (August).

13. Schipper, Meyers and Kelly, **op. cit.**.

14. Kaiser, A., *et al.*, 1989. **Att aendra riktningen.** Stockholm: Liber Foerlag. See also Schipper 1984b.

15. The Norwegian estimates represent the mean of all the studies we consulted (see the original report). The figures are derived from examining expenditures for bulbs as well as sales of the most common sizes of

residential bulbs, most of which replace lamps that have burned out. From the sizes and expected lifetimes, electricity use can be determined. Danish references use a similar method. The Swedish State Power Board undertook a detailed survey of lighting in 1971 and has attempted to monitor changes ever since.

The sharp differences in Norwegian lighting practices from those of other Scandinavian countries have never been systematically investigated, to our knowledge. We are indebted to various Norwegian colleagues for their anecdotal contributions to these speculative explanations.

16. Schipper, L., and Hawk, D., 1989. *More Efficient Household Electricity Use: An International Comparison.* LBL-27277. See also the discussion in Bodlund, *et al.*, in Johansson, T., *et al.*, eds., 1989. **Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications.** Lund: Lund University Press. The data for new appliances were assembled by E. Mills, Lund University, as part of the aforementioned study.

17. Moeller, J., 1988. **Elbesparelser i Boligsektorn.**. Lyngby (Denmark): Danmarks Elvaerkers Forenings Udredningsinstitut.

18. Malinen, M., 1989. Private communication based on his 1987 market analysis and current forecast.

19. Schipper *et al.*, 1987. *op cit.*

20. Schipper and Hawk, 1989. **op. cit.**.

21. Schipper, Meyers, and Kelly, **op. cit.**

22. Blomberg, H., and Persson, A., 1988. **Rabbatten paa Watten**. Stockholm: Stockholms Energi.

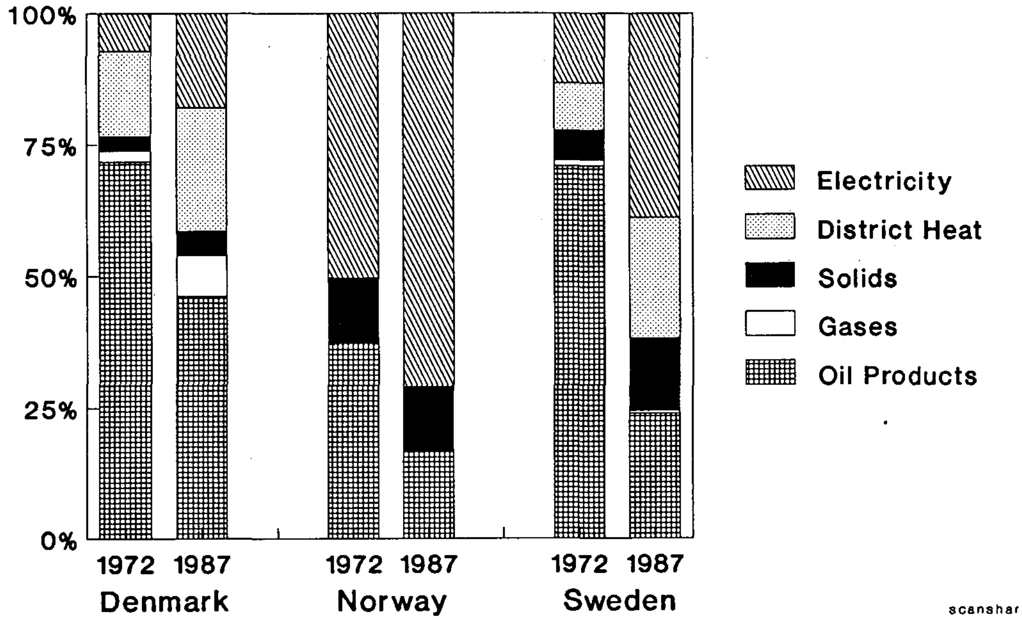
23. Schipper, L., et al. Linking Energy And Lifestyles: A Matter of Time? **Annual Review of Energy**, 14, Oct. 1989 (in press). Palo Alto, CA: Annual Reviews, Inc.

24. Carlsson, L.G., 1989. **Energianvaendning och strukturomvandling i byggnader 1970 - 1985.** R22:1989. Stockholm: Byggforskningsraadet. See also Palmborg, C., 1987. **Hushaallens Energikonsumtion**. Project for Uppdrag 2000. Stockholm: Statens Vattenfall.

25. Schipper and Hawk, *op.cit.*

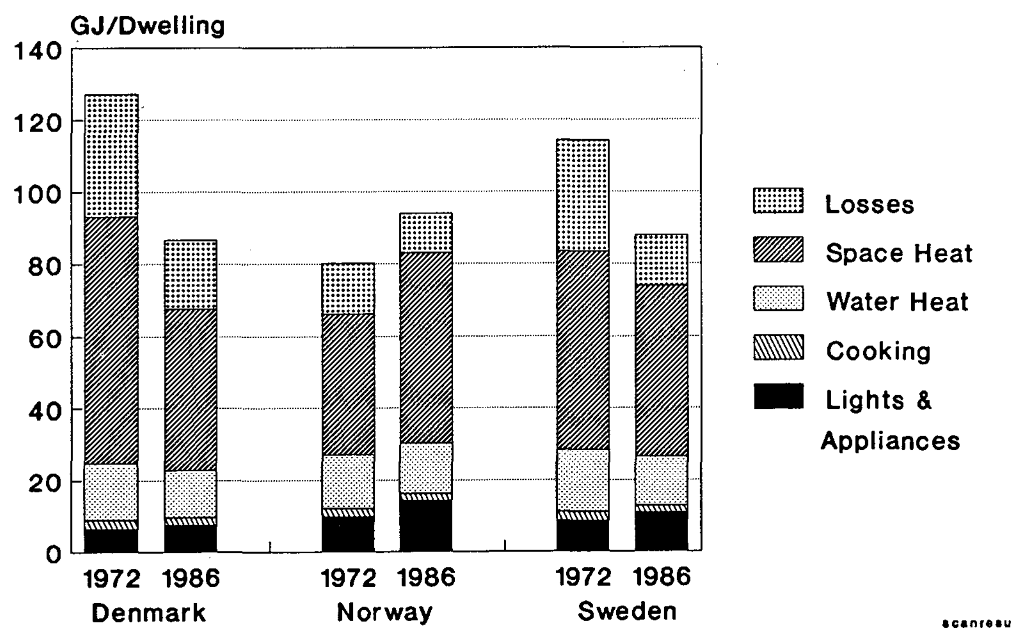
26. Norford, L., Rabl, A., Harris, J., and Roturier, J., 1989. Electronic Office Equipment: The Impact of Market Trends and Technology on End-Use Demand for Electricity. In Johansson, T., *et. al., op. cit.*.

Figure 1. RESIDENTIAL ENERGY USE
Shares of Delivered Energy



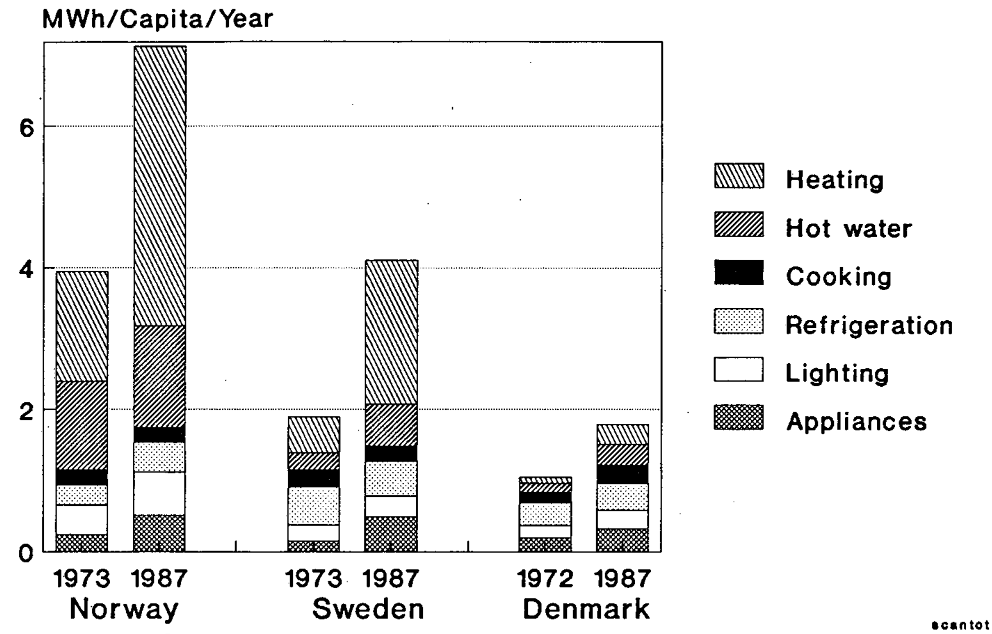
Delivered energy = site energy

Figure 2. RESIDENTIAL ENERGY USE
Scandinavia - All Fuels



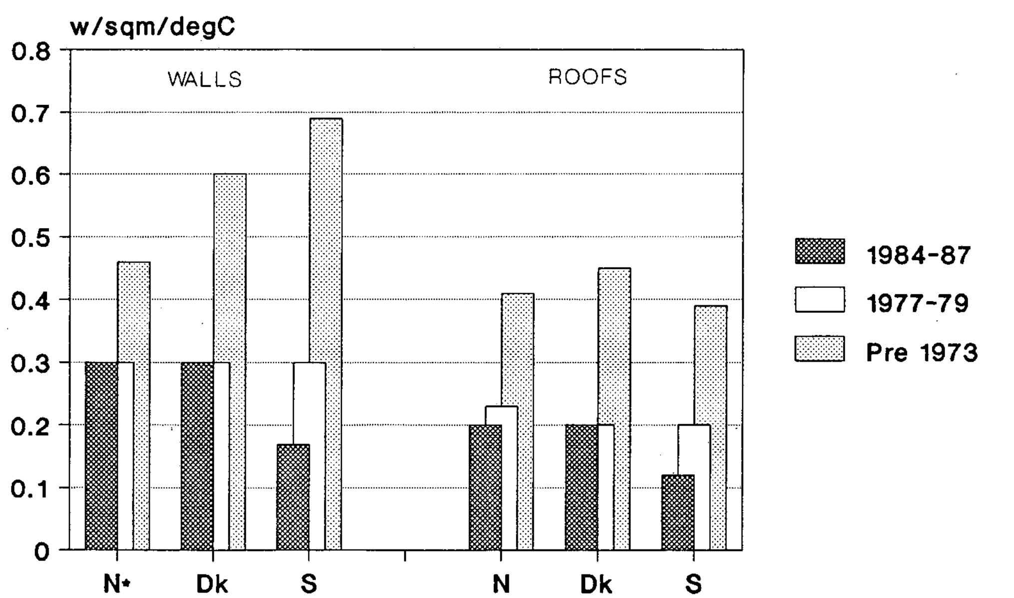
Losses = delivered less useful energy

Figure 3. RESIDENTIAL ELECTRICITY USE
Normalized to Population



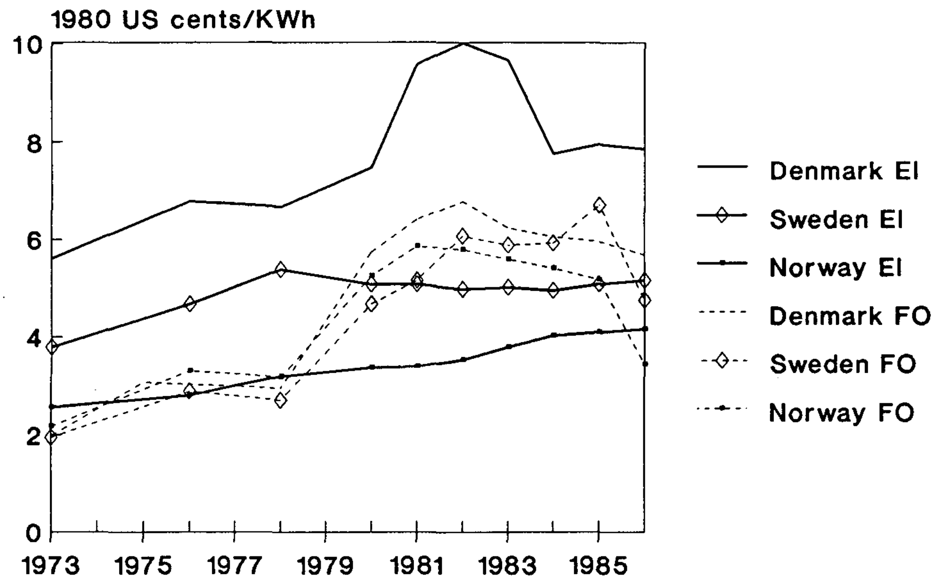
Corrected to Normal Climate
Hot Water includes washers

Figure 4. BUILDING CODES - SCANDINAVIA
Maximum Heat Transmission Values



*1987 Value for entire wall, incl window
1977-9 values valid from 1981

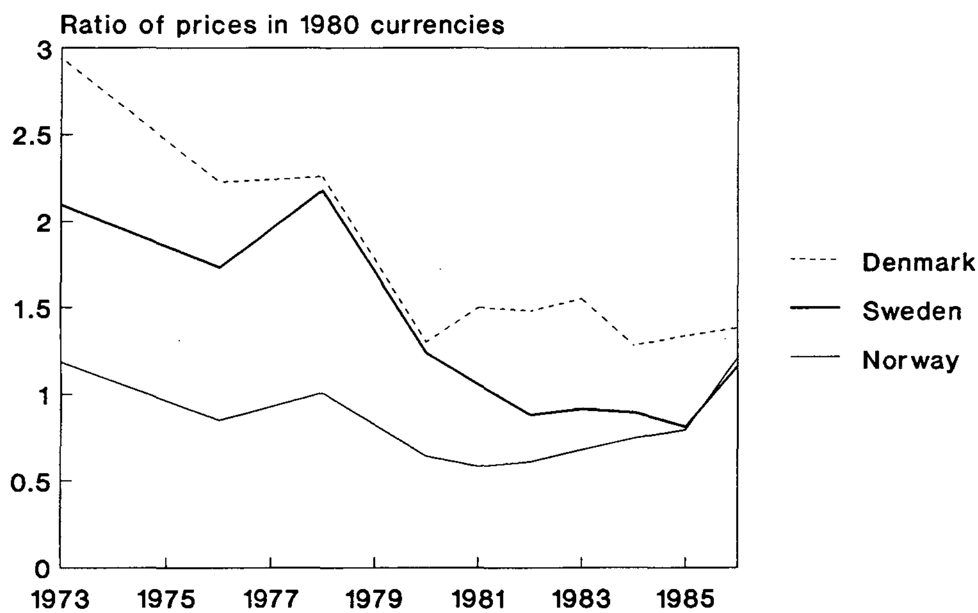
Figure 5. HEATING FUEL PRICES
Electricity and Fuel Oil



prices

Useful energy: fuel oil @ 66% efficiency
1980 exchange rates

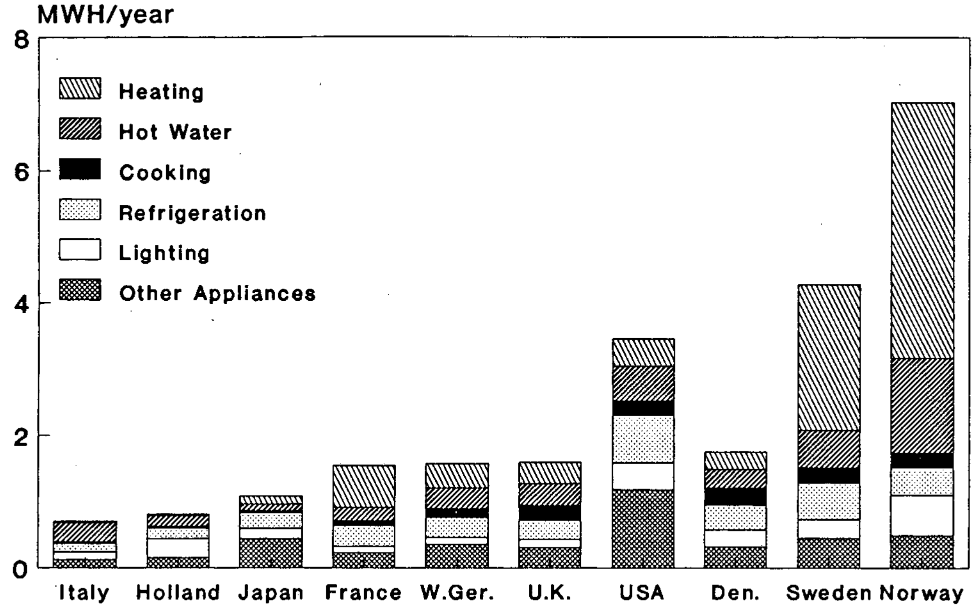
Figure 6. ELECTRICITY / FUEL OIL PRICE
Residential heating



elratio

Useful energy: fuel oil @ 66% efficiency

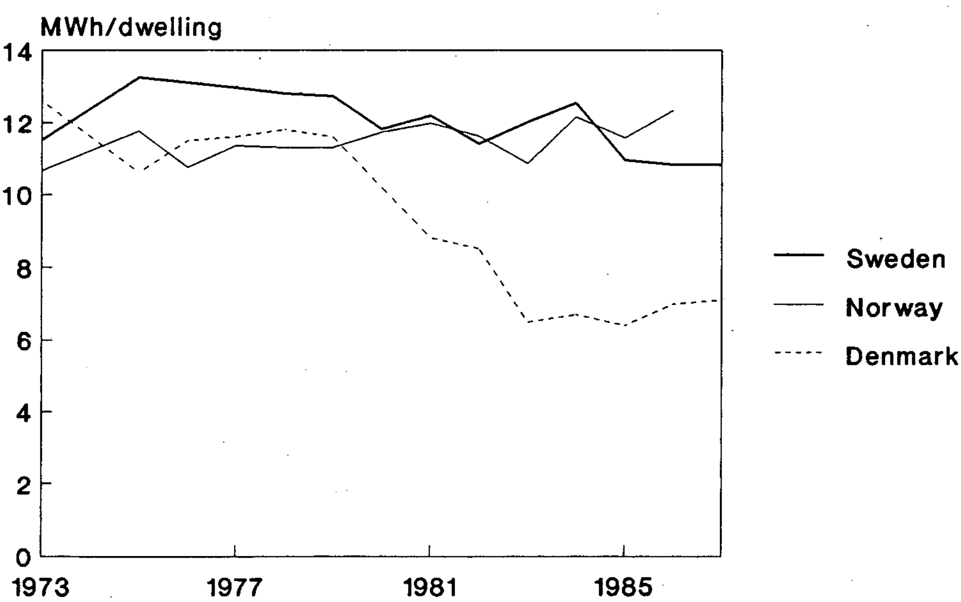
Figure 7. ELECTRICITY USE PER CAPITA
1986 - Corrected To Average Weather



Water Heating Includes washers

elcap86c

Figure 8. ELECTRIC HEATING
Homes With Electricity as Main Source



Corrected to Normal Climate
Reflects homes with electric heat

fig8

Figure 9. ELECTRIC COOKING & WATER HEAT
Saturation in Scandinavia

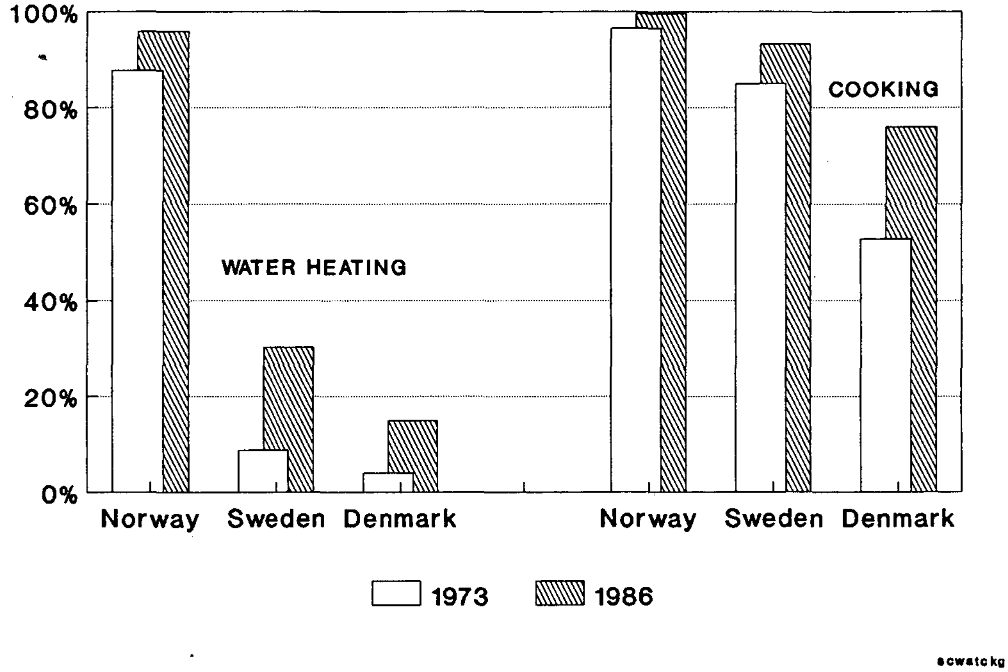


Figure 10. LIGHTING ELECTRICITY USE

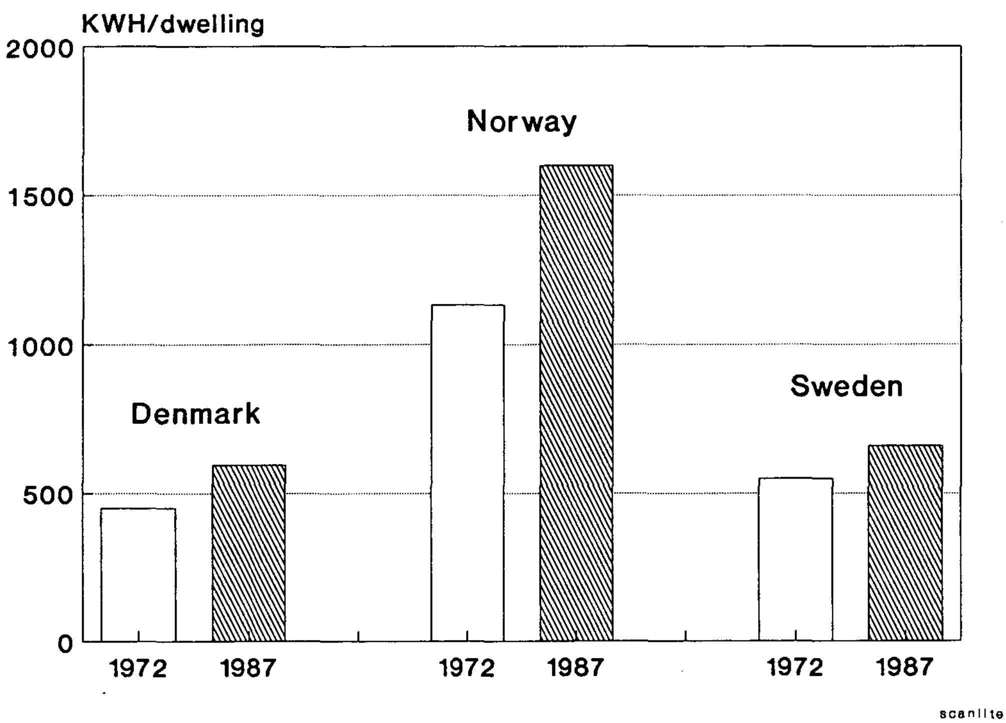
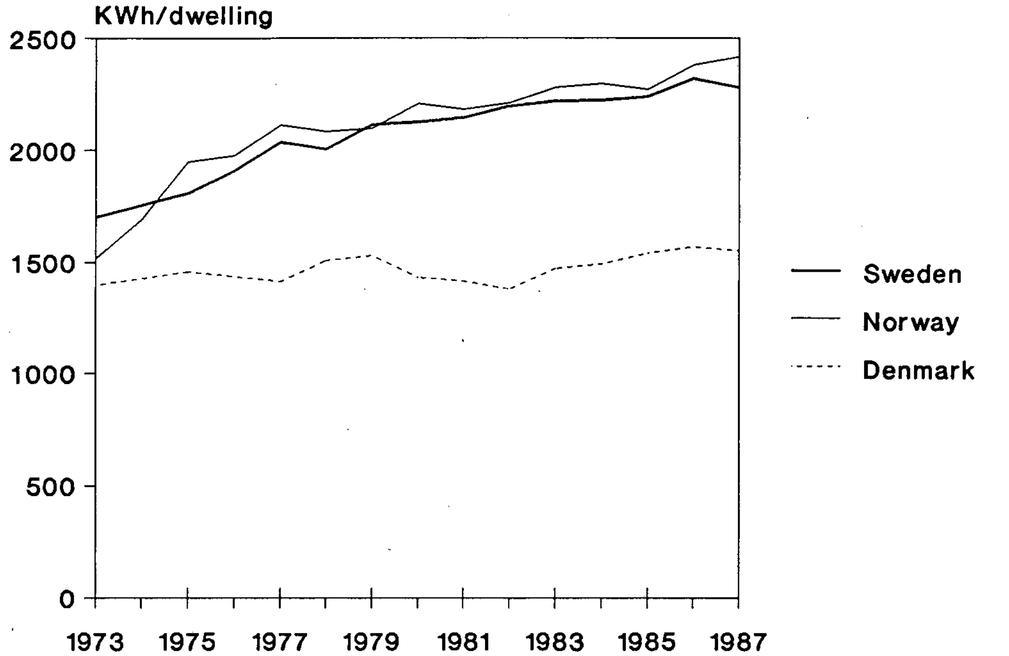
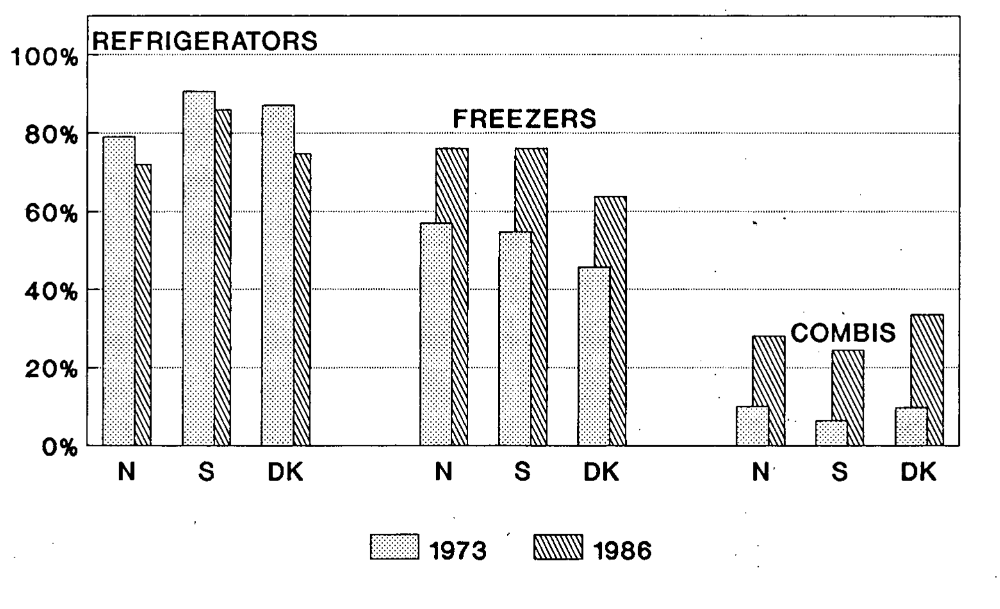


Figure 11. APPLIANCE ELECTRICITY USE



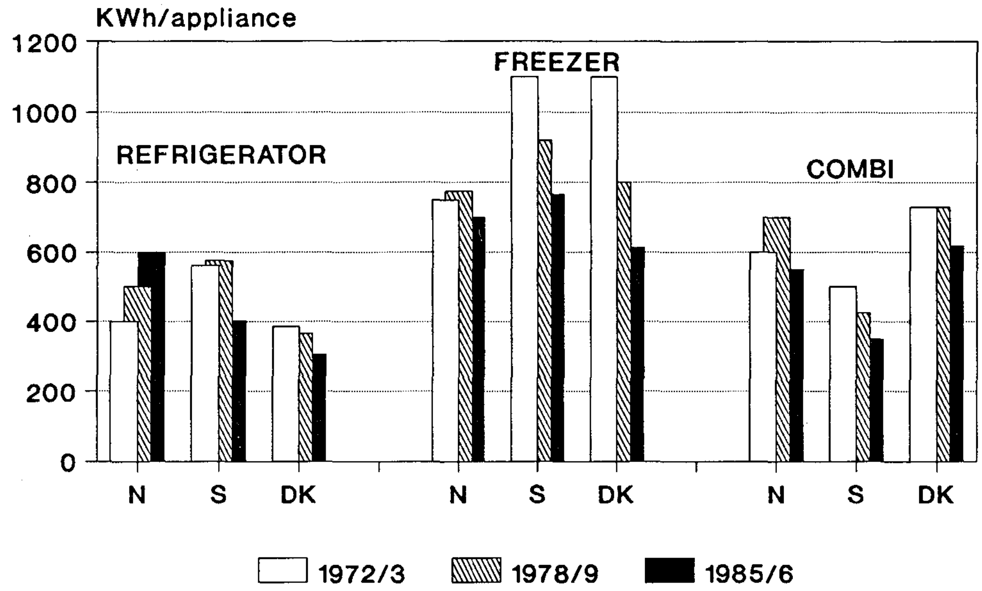
Excludes water in washers

Figure 12. APPLIANCE SATURATION
Refrigeration - 1973 and 1986



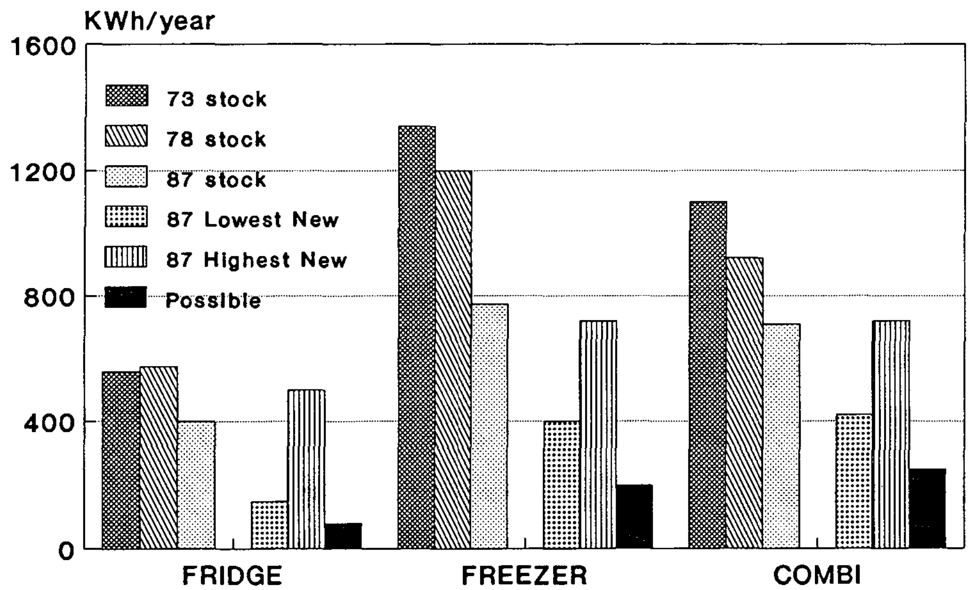
Note: Combi is 2-door refrigerator with freezer

Figure 13. REFRIGERATION
Unit Consumption



Note: Norwegian data uncertain

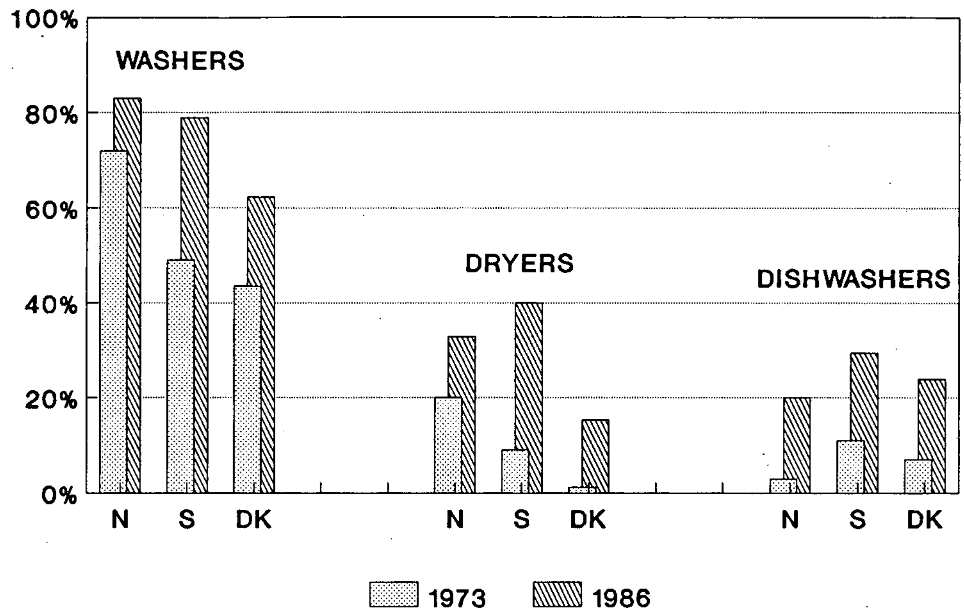
Figure 14. REFRIGERATION - SWEDEN
Appliance-Specific Electricity Use



sources: Konsumentverket, Vattenfall
fr:150-200; frz:250-300; comb:350-375 l.

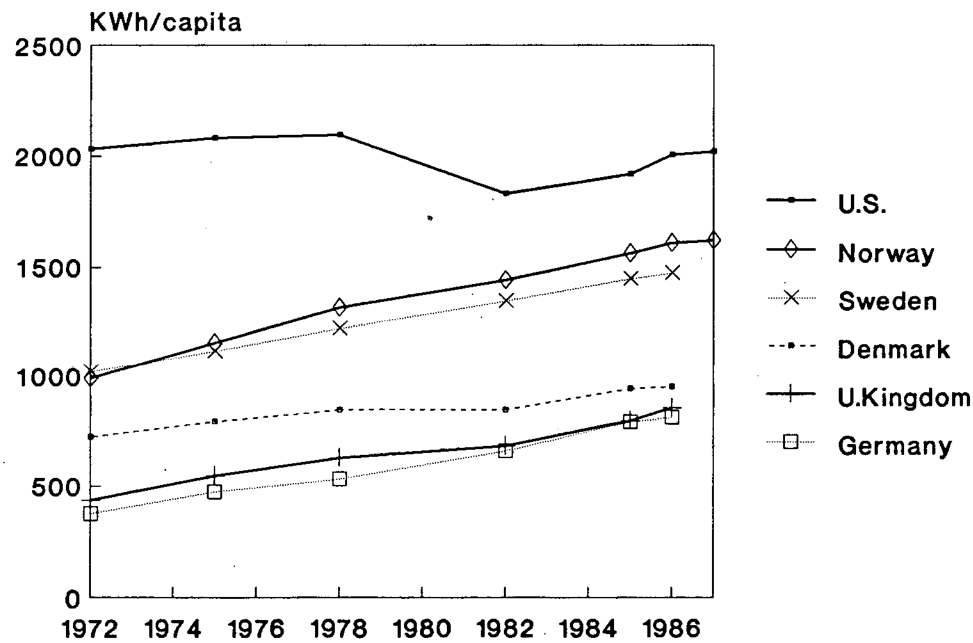
swedapp

Figure 15. APPLIANCE SATURATION
Washers and Dryers - 1973 and 1986



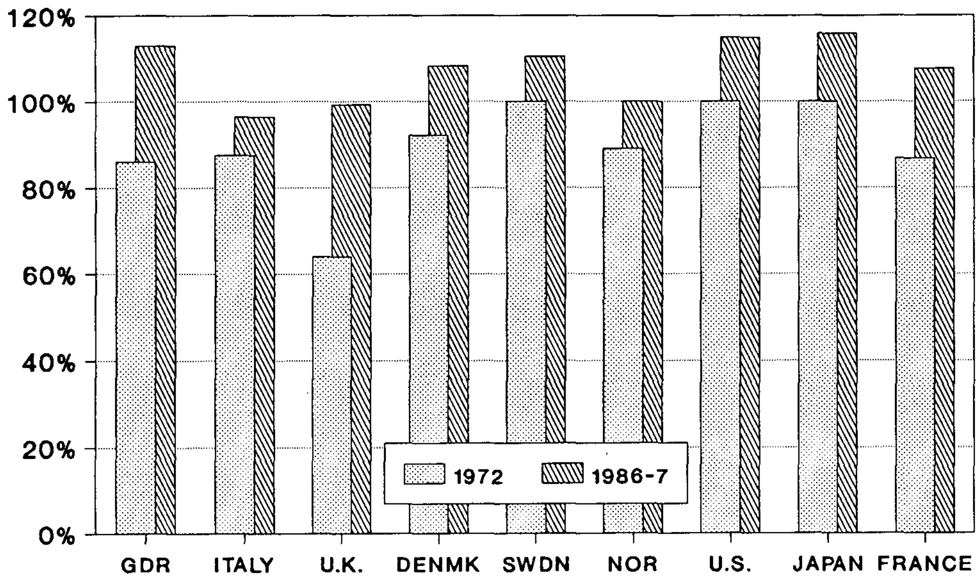
satn1

Figure 16a. APPLIANCES AND LIGHTING
Electricity Use per Capita



applcap6

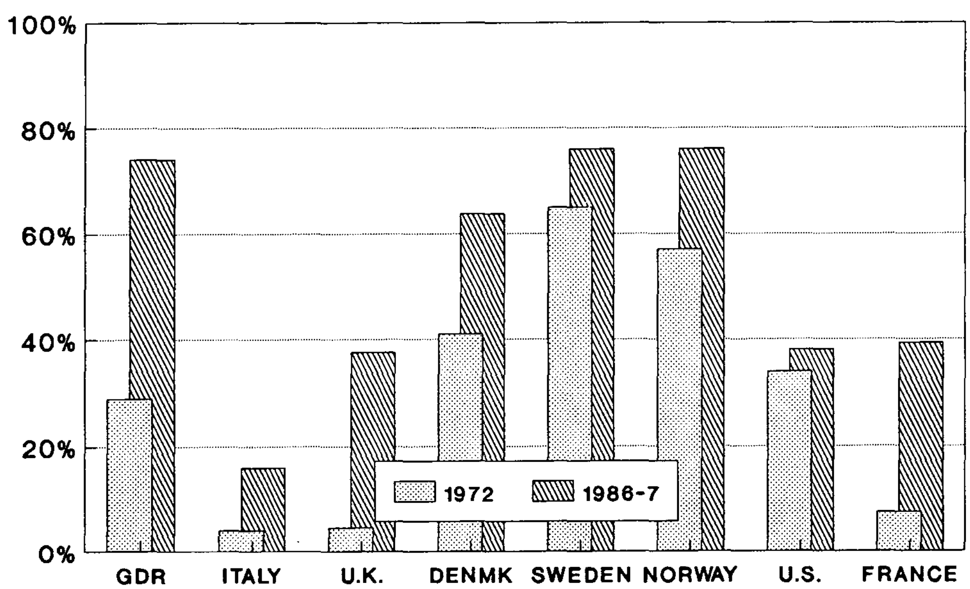
Figure 16b. REFRIGERATORS
OECD Appliance Diffusion



U.S. and France early data is from 1973

ref7287

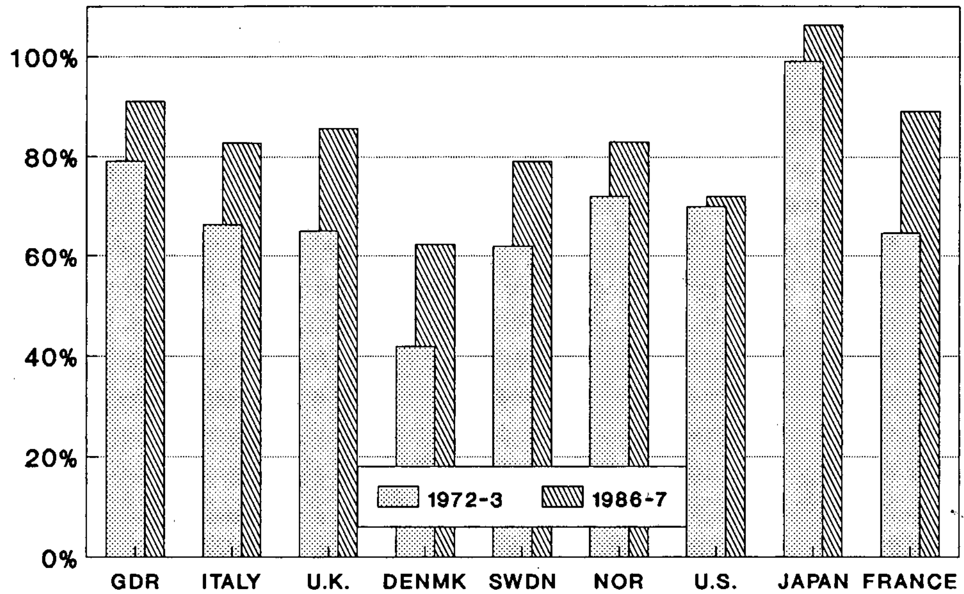
Figure 16c. FREEZERS
OECD Appliance Diffusion



U.S. and France early data is from 1973
Japan is zero

frez7287

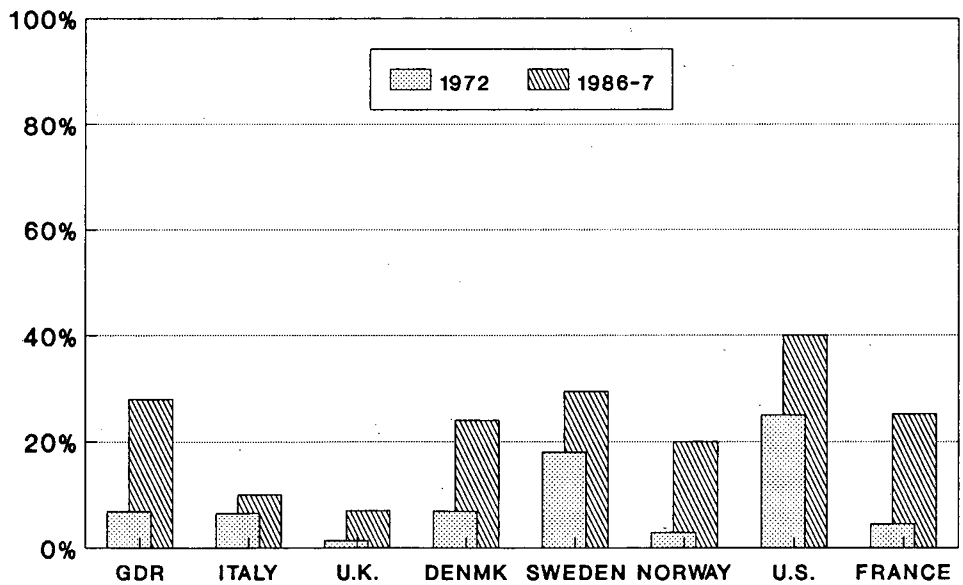
Figure 16d. CLOTHESWASHERS
OECD Appliance Diffusion



clot7287

U.S. figures are for saturation

Figure 16e. DISHWASHERS
OECD Appliance Diffusion

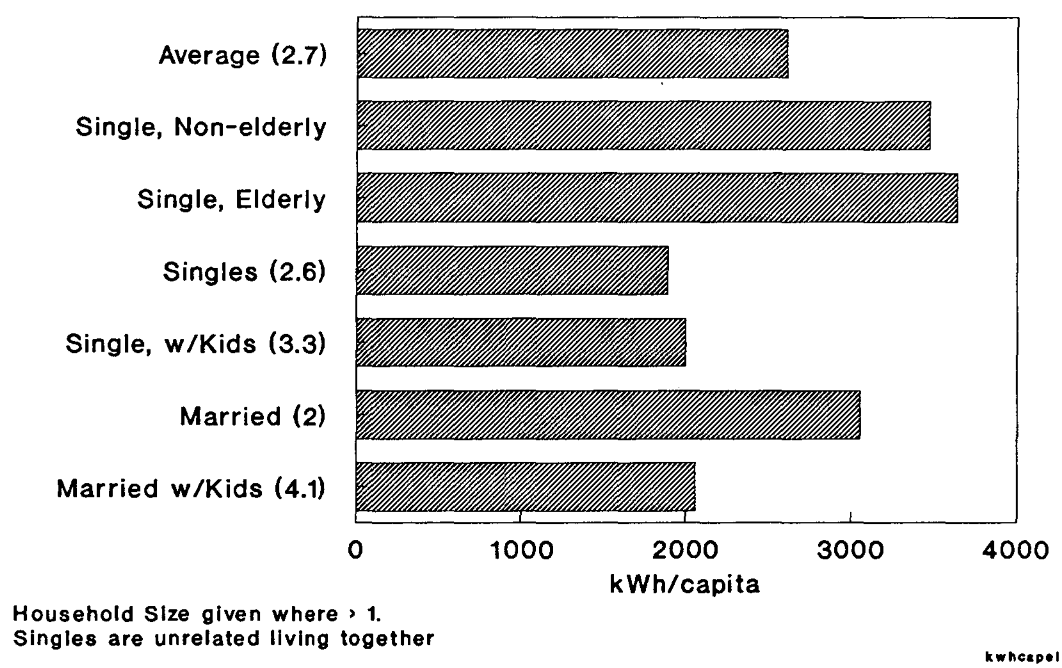


U.S. and France early data is from 1973.
U.S. data are saturation; Japan is zero

dish7286

Figure 17. ELECTRICITY USE PER HOME
U.S. Households with Gas Heating

Figure 18. ELECTRICITY USE PER CAPITA
U.S. Households with Gas Heating



APPENDIX 1: NOTE ON TERMS

From the companion paper (Schipper and Hawk, 1989) we provide a list of important terms used herein. Each term denotes an important parameter that determines household electricity use.

Structure is the pattern of overall electricity use; disaggregated by end-uses and by types of dwellings/households.

Saturation is the fraction of homes or households owning or using a particular appliance or having a certain end-use, such as electric heating.

Utilization expresses the behavioral interaction between appliance users and appliances. Generally, utilization refers to indoor (or hot water) temperature, hours heated (or water used), meals cooked, kg. of clothes washed, etc. The size and features of appliances also measure service. For example, a large, frost-free combination refrigerator freezer delivers more service to a home than a small, single-door manual defrost refrigerator.

Household unit consumption means electricity use per household for a specified end-use.

Appliance unit consumption refers to electricity use per appliance for a specified end-use.

Electricity intensity measures electricity use per unit of energy service for a specified end-use or appliance, such as kWh/(kg of wash), kWh/(liter of refrigeration per day), or kWh/(area heated)x(degree days). Thus, intensity is independent of the amount of service an appliance performs. This is the inverse of efficiency.

Efficiency is the ratio of service performed to energy or electricity consumed. Efficiency can refer to a certain product class of appliances (for example, top-mount, auto-defrost refrigerator freezer) or to individual components of an appliance (for example, a compressor, condensor or fan motor). A large refrigerator may be more efficient than a small one, yet require more electricity per year. A refrigerator with automatic defrost may have more efficient components than one without, yet use more electricity because of the defrost feature. Thus a given improvement efficiency does not always lead to a similar reduction in unit consumption.

Changes over time in total electricity use are the result of changes in the saturation of appliances, building shell efficiency (for space heating only), appliance utilization, appliance size, appliance features/options, and appliance efficiency. Household unit consumption is a function of the number of appliances per household and last five factors in this list. Appliance unit consumption is a function of the last four factors in this list. Appliance intensity is the inverse of appliance efficiency and is independent of the other factors. Since 1973, all of these factors have changed for almost every OECD country, giving rise to important changes in electricity use per household.

APPENDIX 2: DATA SOURCES AND PROCEDURES*

The first goal of this project was to collect and analyze historical and current data on the structure of consumption covering the period 1972/3 through 1986. This meant analyzing the ownership and characteristics of electricity-using systems (space heating, refrigerators, etc.), the use of those systems, and the consumption per system, which we call intensity, or per household, which we call unit consumption. Many of the data problems are summarized in Schipper 1984.[1] This note summarizes sources of data and general rules of analysis.

There are few "official" data that cover both the structure of household electricity consumption and unit consumption as well. However, data from utilities, utility associations, appliance manufacturers, consumer advice and testing groups, researchers, etc. do cover ownership of electricity-using systems, use patterns, and often give *estimates* of unit consumption as well.

Our first task was to adjust various data sources so as to give as correct a picture as possible of the residential sector, ie., including consumption of households not otherwise included in national data, but excluding consumption not clearly related to household purposes. *As a general rule, the national energy balance of a country does* **not** *give the same estimate of total residential electricity use that we use in this study.* (The Federal Republic of Germany, Norway, and the United Kingdom are the exceptions.) This is because the "residential" sector may or may not include farmhouses, farm equipment, mass metered apartments, consumption in the common spaces of apartments, principal residences in buildings used for other purposes, etc. Based on our previous work, we have been able to combine data sources in each country to develop figures for *total* residential electricity use that are both self consistent over time and as comparable between countries as is possible.

For Sweden and Denmark, our figures include the estimated residential part of consumption of electricity counted under "Jordbruk"/"Lantbrugseiendom". For Sweden, we also include 3/4 of "Fastighets Foervaltning" (common spaces in apartments or other residential complexes where consumption is billed to one company rather than individual dwellings). Second homes are excluded, wherever possible, from calculations for each country. For Norway, we count "residential" (boliger") consumption.

Definitions.

The basic consuming unit varies among countries. In some countries (W. Germany, Italy, Japan, U.K.) we count households in occupied principal dwellings. In the U.S., sources count occupied dwellings, while in Sweden sources count principal dwellings, including those that are unoccupied. **We include electricity use in principal dwellings, but exclude electricity use in secondary dwellings, ie., summer homes.** These differences in counting lead to variations in the number of consumers (or individual appliances) of about ± 5%, which can lead to small differences in the absolute *number* of systems, particularly heating systems, often counted from the total number of dwellings in the stock. Finally, residential electricity use is usually counted by adding up the consumption of each residential meter or customer. This procedure usually excludes consumption of households not on residential tariffs. This last uncertainty adds ± 2% to the uncertainty of total residential electricity use.

Climate Correction. Estimated electricity use for space heating is adjusted to eliminate changes in consumption due to annual variations in the average outdoor temperature. To do this, we make an index, derived by taking the ratio of actual annual degree days for each to the long-term average annual degree days (base 18C during the heating months). This ratio is divided into actual heating consumption to estimate "climate corrected " consumption. Failure to make such a first-order correction leads to a serious over- or under- estimate of electricity demand in some countries, particularly in years that were significantly warmer or colder than the average (1985 or 1987 were very cold, 1982 or 1983 were very warm years), and where heating accounts for a significant portion of total consumption (Sweden, Norway) However,

* This appendix gives a broad overview of our definitions and data sources. Detailed notes for each Scandinavian country then follow.

Japanese experts suggested that this correction not be applied to Japan, because virtually all electric heating is used as a backup to heating from other sources: In colder years, less backup and more principal heat is used.

For Denmark, the climate index from Energistyrelsen, which measures half of the yearly variation in degree days, is used to retrieve the full variation. This figure is then used to estimate yearly average degree days to base 18C, without credit for insolation. For Sweden, degree-day figures from Statistiska Central Byraa (SCB) for SFD and MFD, which were previously tabulated by Carlsson, are weighted to provide a single degree-day index. This is multiplied by the estimated 9 month heating average of 4017 DD, base 18C to get the actual yearly figure. For Norway, the actual monthly degree days base 17C (excluding June, July, August) are tabulated from a series provided by Statistiska Sentral Byraa (SSB). These are adjusted upward to 18C by multiplying 1 degree times the length of the heating season.

Space heating. The principal space heating are the systems that survey respondents indicate are their primary heating systems. Secondary systems are usually small portable heaters (with notable exceptions in Sweden and Japan) that provide relatively small amounts of heat to individual rooms in homes otherwise heated by fossil fueled systems.

In the U.S. and Germany, most kWh used for heating are used in principal systems. In Sweden, the distinction is not clear, because almost 1/3 of all homes using electricity as their principal fuel also use some wood or oil as well. Furthermore, as much as 15% of all space heating kWh in Sweden are used for secondary heating, usually in combination with oil or wood. Only 1/3 of those home using electric heat use only electric heat, a fact that must be borne in mind when comparing Sweden with other countries. The same comments apply to the U.K., where the use of small portable heaters is common in almost 3/4 of all homes. In Italy, principal electric space heating use is very minor, while in Japan virtually all electricity used for heating is for secondary heating, commonly with heat pumps.

Water Heating. In homes, water is heated in tanks or other water heating devices (instant heaters, water heating components in central-heating systems), as well as in many dish- and clothes-washers. "Main tanks" includes only the former group of devices, while "hot water" includes water heated in washers. "Other appliances" *excludes* electricity used to heat water in washers. Where hot water is shown in international calculations, it includes water heated in washers.

We assume that in Scandinavia, every home with electric principal heating also has electric water heating. Additional units of electric water heating are found in some homes heated with fuel-based central heating and in homes without central heating, according to surveys of the total penetration of electric water heating. We assume that all washers and dishwashers in Norway and Denmark are cold fill, ie., heat their own water. In Sweden about 90% of dishwashers are warm fill, but clothes washers are cold fill.

Cooking. For most countries, cooking refers to use of electricity for main cooking stoves/ovens. Smaller devices (portable ovens, cookplates) are excluded except in Japan, where a small amount of electricity for smaller kitchen appliances is counted by our source. In Italy, stoves include the majority that use both electricity and gas.

Lighting and Appliances. Refrigeration includes refrigerators, two-door refrigerator/freezers ("combi", "fridge-freezer"), and freezers. Since there is confusion in some countries between a two-door fridge-freezer and a one-door refrigerator with a small compartment, the split between these two devices is only approximate; where ownership figures for only device are given, it is likely that a small number of the other type still remains.

Ownership

We have reviewed a large number of surveys that evaluate *ownership* of electricity-using devices. Ownership data are taken from household surveys carried out regularly in each country. In Japan W. Germany, and G. Britain, such surveys are undertaken by public and private authorities every year; for Italy, surveys of electricity-using systems are undertaken every few years for the national utility ENEL. For the U.S., complete household energy surveys are taken every 3 years, while other surveys of electric appliance ownership are available for most years since 1970.

For Sweden, surveys were carried out in 1971, 1973, 1975, 1978, 1979, 1981, 1982, and 1985. Vattenfall has interpolated and extrapolated these to find smooth values for appliance ownership through 1987. However, for some years, the surveys undercount washers and dryers that are placed in collective rooms ("tvaett stuga"). For Denmark, DEFU has used figures from "Omnibusundersoeggelser", sales figures, and interpolation to do the same. For Norway, we took existing material from 1967, 1973, 1979, 1981, and 1984/6 (**Forbrugsundersoekkelse**), supplemented with some estimates from Philips, and interpolated for various years.

We have compared data sources and resolved problems in definitions, sample population, etc., and believe that the results, expressed as the share of homes owning (or the absolute number owning) are comparable both over time and between countries. Most of our results are shown as the share of households owning/using a given appliance or end-use, called *saturation or penetration*. In a few important cases (refrigerators, freezers), we show the number of devices per 100 households, divided by 100, in order to account for multiple ownership, which we call *diffusion*. Where we have data on both saturation and diffusion, one can calculate the number of devices per home owning at least one device. This figure is especially important for small heating devices, air conditioners, TV, small water heaters, and, as noted above, refrigerators and freezers.

Unit Consumption

Unit consumption refers to the electricity use per household for a given purpose or appliance. Where stated explicitly, unit consumption refers to "use per appliance" in homes with more than one appliance per home. Consumption per capita for a given purpose refers to total consumption in a country for that purpose, divided by total population.

As indicated in our original study, unit consumption data are uncertain for many reasons. Energy consumption surveys are only carried out regularly at the national level in the United States. Electricity-use surveys have been carried out every five years in Germany, and surveys of consumption of energy for space- and water heating are undertaken every year in Sweden. These surveys yield measures of electricity consumption in homes with and without heating, etc. Other end-uses can be found by regression of total consumption against appliance ownership and characteristics, or by comparing the consumption in homes with and without each end use. Unfortunately, few authorities have carried out submetering experiments at the national level that are reliable enough to yield unit consumption estimates of major appliances. Authorities have *estimated* unit consumption of most end-uses on the basis of information from appliance manufacturers, limited load research data, and some comparison (or regression analysis) of consumption in homes with different groups of appliances. Often yearly consumption is estimated by assuming a certain number of uses (or hours of useage) of an appliance.

Unit consumption estimates of electric appliances should be used with caution. Differences between the unit consumptions given for appliances in the U.S., Japan, and European countries as a group are significant, but differences among European countries are not significant relative to uncertainties in differences in the nature of the equipment (size, capacity) or patterns of use (hours, uses/year). For Scandinavia, unit consumption figures were taken from Moeller (1988 and earlier work), Vattenfall (Malinen, priv. comm., 1988), and from various Norwegian sources. We also consulted a Scandinavian comparison.[2]

For new appliances, the situation is somewhat different. Authorities in most countries have established test procedures by which new appliance electricity use can be estimated. While the test results do not translate exactly in to actual consumption in homes, the results do allow a ranking of each appliance according to its electricity use for specific purposes (by washing or drying cycle, for 24 hours of refrigeration to certain temperatures, for heating a given amount of water to a certain temperature and then maintaining the water warm). The estimates of changes in unit consumption of new appliances over time do give a fair measure of improvements in efficiency for a given appliance within each country. Where they have been accurately determined, we give these measures of electricity use in new appliances.

For Sweden, we have used Vattenfall's estimates of unit consumption over time (M. Malinen, priv. comm.), some of which have appeared in published reports. For Denmark, our estimates were made by Jan Moeller of DEFU,[3] and are also found in various publications from DEFU and elsewhere. For Norway, we found no carefully constructed unit consumption estimates, although Poleszynski[4] made some estimates. We also studied unpublished estimates from Statistiska Sentral Byraa.

Estimates of unit consumption for heating in the Nordic countries were made by examining sales to homes with heat in Denmark and Sweden, subtracting estimated consumption for appliances (as measured by unit consumption in homes without heating) and water heating. This procedure was made for single-family dwellings and multi-family dwellings separately. For Norway, we used information from **Energiundersoekelsen** (1985) [5] and some runs from that study provided by the author, A. Ljones, to try to isolate heating in mixed systems, electric-only systems, and systems where electricity was used as the secondary fuel. Earlier figures (1973, 1979) were based on information about the breakdown of the electric heating market into "electric only " and "mixed" systems. Other years were estimated by subtracting consumption for all other purposes. Our results compare well with those of Grinde (EFI, 1988)[6] and recent estimates made by Ljones (Energidata 1988, priv. comm).

Assumptions about unit consumption in water heaters for Denmark were taken from Moeller 1987 (and previous work). We found these low, compared with international experience and other Danish references, so we raised them; we estimate 3300kWh/single-family dwelling in 1986, for example. Estimates of unit consumption for Sweden were based on information from Vattenfall (priv. comm.), Carlsson (1989)[7] and Schipper (1984). Those for Norway were from Ljones (Energidata, priv. comm.) and Soerensen.[8] These authors concur that families in single-family dwellings used approximately 4000kWh/yr and multi-family dwellings close to 2500kWh/year in 1973. In aggregate figures for all countries, we included 75% of the energy consumed in dishwashers and clothes washers (clothes washers only in Sweden) in 1986 (80% in 1972/3) to represent the water heated in these machines.

Estimates of unit consumption for cooking were made by Vattenfall for Sweden and Moeller (1987) for Denmark; for Norway, we tried to assemble a reasonable time series based on various guesses published in literature. In all countries use of stoves/ovens is falling as fewer, simpler meals are cooked at home.

Electricity-Use Efficiency

In general, we defined efficiency as the ratio of service provided to electricity consumed. Intensity is the inverse, electricity per unit of service. Decreases in electricity used per appliance are related to increases in efficiency, although some of the decrease may come about through changes in the way appliances are used.

From the data we have studied, it is possible to say how average consumption of electricity in most new appliances and electric stoves has changed since the early 1970s. Most of these changes are due to increased efficiency. Increased appliance size and greater features have offset the electricity savings from increased efficiency somewhat, while changing patterns of use have both increased and decreased electricity use, depending on the appliance and country. For example, today consumers in Europe wash clothes in considerably cooler water (ie., 60C versus 90C for the majority of washers) than in 1973. This change reduces electricity used to heat the water.

Changes in consumption of electricity for space heating and water heating are much more difficult to break into changes in efficiency and changes in other factors. Sweden is the only country where a detailed survey of electricity use for space heating is carried out regularly (although the water heating component is mixed in with space heating). These surveys show electricity use as a function of the vintage and location of the house *and* how electricity is used in combination with other fuels. Other comparable surveys give detailed data on the housing and heating stock (kinds of heating systems, insulation levels in existing and new homes) exist. Thus, for Sweden it is possible to estimate separately the impact on electricity consumption of improved building shells, changes in heating equipment, and changes in indoor temperatures.

For other countries, far fewer data are available. Instead there are either stock-wide averages of space heating consumption, or estimates of heating use from computer models. For water heating the situation is similar. Thus it is only possible to give rough indication of how electricity efficiency has changed for space heating and water heating. The improvements in building shells, as indicated by increased insulation thicknesses required by building codes, suggest that electric space heating has become more considerably more efficient in the last 15 years in all countries.

REFERENCES

1. Schipper L., 1984. **Internationell jaemfoerelse av Bostaedernas Energifoerbrukning.** R131:1984. Stockholm: Statens Raad foer Byggforskning. See also Schipper, L., 1984. Residential Energy Use and Conservation in Sweden. **Energy and Buildings** (February).

2. Ettesoel, G., and Lund, J., 1981. **Energisparing for Husholdningsapparater.** 1/1981. Oslo: Nordisk Ministerraad.

3. Moeller, J., 1987. **Elbesparelser i Boligesektorn.** Lyngby: DEFU.

4. Poleszynski, D., 1978. **Energibruk i husholdning. Arbeidsrapport april 1978.** Oslo: Statens institutt for forbrugsforskning.

5. Ljones, A., 1985. **Energiundersoekelsen.** Oslo: Statistiska Sentralbyraa.

6. Grinde, B., 1988. **Analyse av energiforbruket 1976 - 1986 i boligsektor. ENOK og reelle forklaringsvaktorer.** Trondheim: Elektrisitetsforsynings Forskningsinstitutt A/S.

7. Carlsson, L.G., 1989. **Energianvaendning och strukturomvandling i byggnader 1970 - 1985.** R22:1989, and Carlsson, L. G., 1984. **Energianvaendning i bostaeder och lokaler.** R132:84. Stockholm: Byggforskningsraadet.

8. Soerensen, S.E., 1977. **Energiforbruk til varmtvann.** Note 501.2W62, 19.4.77. Oslo: NBI.

DENMARK: Derivation of Structure of Electricity Use

Total electricity consumption for Denmark for the residential sector is not defined or recorded unambiguously by any national statistical authority. Statistics from the Utility Association (Elvaerkersforening) form the basis of our work. These reach back to 1977, covering electricity use in farm and non-farm premises, with and without heat.[1] (Previous years consumption patterns were estimated by Dansk Elvaerkers Forening Udredningsinstitut, or DEFU [J. Moeller, 1981].)[2] Additionally consumers are divided into single-family dwellings (SFD), multifamily dwellings (MFD), and farmhouses. Homes with heat are defined as SFD (MFD) with consumption of greater than 10000 (6000) kWh/year. This definition does not capture all homes with electric heat, and includes some without, but the total numbers of SFD and MFD with heat as estimated this way are close to those figures given in the Bygning og Bolig Register (BBR), the official building census. The definition was changed from 1986 onward to reflect homes that really did or did not have electric heat.

To the consumption in these four classes of consumers must be added that for farmhouses. We multiply the number of farmhouses by the average electricity use in SFD without heat to approximate the consumption of farmhouse customers for household purposes. (This procedure follows that of Schipper 1983)[3]

Population is from the Danish Bureau of Statistics. Total number of dwellings were estimated by the Bureau. Total numbers of households are from various analyses by Moeller. Degree days were taken from the figures supplied by Energistyrelsen (base 17C, approximately 9 month heating season) and adjusted upward to the base 18C by multiplying 250 days times one degree.

Schipper 1983 derived detailed energy-use balances for the residential sector for 1972, 1975, 1978 - 1982. These were updated to 1983 - 1986 in the present work. For 1972, the figure in Schipper (1983) was modified to reflect more recent information provided by Moeller For 1978 and 1983, the figures from Schipper were used, with slight modifications based on Moeller (1987).[4] For 1986, the breakdowns were estimated by Moeller 1987.

Space Heating.

We defined "central" space heating to be homes with electric baseboard heating (including those that likely used some wood as well), as well as the small number with electric boilers. It is known from various surveys that a large number of the homes with full baseboard heating also rely on wood or other secondary sources for their heat, particularly in the coldest period.

Total consumption of electricity for main space heating was taken from Schipper 1983, and from Moeller. For homes defined as having electric space heat, we assumed that electric water heating was present. Consumption per home in homes with heat was adjusted by removing estimated consumption for water heating and for appliances, the former estimated for each year (3300kWh/SFD in 1986, for example), the later taken as consumption per home in homes without space heating. (We assume that water heating is paired with space heating.) Unit consumption for each class of customer was multiplied by total number of customers to give total water and space heating for SFD and MFD.

Secondary heating with electricity is not insignificant in Denmark. The combinations of electricity with wood or oil are considered to be secondary use of electricity. But there is almost no quantitative information on the amounts of electricity used; therefore, our estimates are very rough. One omnibus survey suggested that in the mid 1980s as many as 40% of all homes used some kind of back-up electric heating, and that a similar or larger share of homes using electric heat used wood or some other back-up to electricity. Thus the dividing line between electric heat and no electric heat is somewhat uncertain. After discussions with Elvaerkersforening, Energistyrelsen, and Risoe, we set 1986 use of secondary heating at 362GWH.

Correction for climate is made by dividing estimated consumption for space heating by the ratio of the actual number of degree-days base 18C to the long-term average number. The base 18C is derived from Energistyrelsen figures by adjusting from the lower base they give. The long term average for a 9 month heating season is 3316DDC. The words CC or CCORR denote where the correction is applied to heating, or to totals (for calculating shares, etc.).

Water Heating, Cooking, Lighting, and Appliances.

Water heating. Schipper 1983 judged that every home with electricity as its main heating source (and others without electric heating) also derived hot water from an electrical system. The assumed unit consumptions for SFD and MFD were 3700kWh and 2500kWh/yr in 1972, rising somewhat through the mid 1970s, then falling through 1983. The estimates shown are somewhat higher than those given in various reports by Moeller, but not inconsistent with estimates for SFD and MFD, respectively, for Sweden or Norway. The considerably higher price of electricity in Denmark than in these neighboring countries suggests somewhat lower figures, which are reflected in estimates in Moeller (1987; see also Nielsen 1988).[5] Moeller (1987) also gives data on total saturation of electrical water heating tanks. From these we estimate the number of homes with electric water heating but *not* electric space heating. This extra consumption is added to the "water heating" end-use.

Cooking. For cooking, saturations and unit consumption were obtained from Moeller and other surveys from 1972 onward.

Lighting. Moeller gives estimates of consumption of electricity for lighting in his work, which we used.

Electric Appliances. Total electricity use for appliances and electric cooking was obtained from data on consumption of electricity in MFD and SFD without heat, respectively. These data were given by the Utility Association data after 1977, and estimated by Moeller for previous years. From this figure we subtracted the consumption for electric cooking stoves to obtain electric appliances aggregated over all dwelling types. Unit consumption for individual uses was take from Moeller. Finally, consumption electricity for hot water in washing machines and dishwashers was subtracted from electric appliances. We estimated that 80% of the unit consumption of electricity in these machines was for water heating in 1972, falling after 1979 to 75% in 1986. Ownership figures are given as saturation (share of homes owning) except where multiple ownership is important, where we give diffusion, or (appliances per one hundred households)/100.

Energy Conservation.

Moeller and Nielsen both discuss energy conservation in new appliances, and Moeller, in the DEF Yearbook, estimates the average energy consumption in the stock of each appliance sold each year. His estimates reflect the best judgement of both tested unit consumption as well as the mix of sizes and features that represent each year's sales. Both Moeller and Nielsen discuss the "best on the market" and how much less electricity these models used compared with both existing models and all new models.

REFERENCES

1. The Danish Utility Association (Dansk Elvaerkers Forening) publishes a yearly analysis of production and consumption, as well as a yearly "Ti Aaars Oversigt" (Ten Year Overview), from which our data are taken.

2. Moeller, J., 1981. **Danmarks elforbrug frem mod 1990.** Lyngby: DEFU.

3. Schipper, L., 1983. Residential Energy Use and Conservation in Denmark. **Energy Policy**. December.

4. Moeller, J., 1987. **Elbesparelser i Boligsektorn**. Teknisk rapport 258. Lyngby: DEFU.

5. Nielsen, L., 1988. **Elforbrug: Udvikling, sammensaettning, og perspektiver.** Copenhagen: AKFs Forlag.

DENMARK RESIDENTIAL ELECTRICITY USE

	1970	1972	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
POPULATION, 10e3	4910	4990	5060	5090	5100	5120	5120	5120	5110	5110	5110	5110	5120	5120
Households, 10e3	1785	1881	1966	2003	2047	2070	2101	2140	2163	2183	2195	2226	2245	2276
TOTAL ELECTRICITY USE, GWH	4180	5190	6250	6698	7415	7823	7616	7620	7650	7746	8084	8702	8983	9276
Climate index	1.078	0.955	0.901	0.943	0.994	1.087	1.032	1.000	0.948	0.923	0.923	1.113	1.026	1.079
Climate Corrected, GWH	4008	4831	5628	5902	6441	6649	6576	6642	6696	7002	7272	7639	7907	8059
Per Capita, kWh	816	968	1112	1159	1263	1299	1284	1297	1310	1370	1423	1495	1544	1574
Per Household, kWh	2246	2568	2863	2946	3146	3212	3129	3103	3095	3208	3313	3432	3523	3541
END USES, GWH														
Main Heat, GWH, uncorr	170	360	625	798	975	1165	1037	978	961	755	828	1034	1067	1190
Secondary Heat, GWH, unco	25	20	30	39	93	120	109	120	119	126	187	287	308	362
Total Heating, GWH, CCorr	181	398	727	887	1075	1182	1110	1099	1139	955	1099	1187	1341	1439
Water Heating, GWH*	495	644	907	1077	1158	1239	1297	1289	1299	1318	1335	1361	1426	1510
Cooking, GWH	750	750	940	1000	1081	1100	1111	1119	1128	1156	1222	1278	1333	1323
Lighting, GWH	758	846	885	952	1024	1035	1051	1085	1163	1173	1236	1311	1322	1354
Refrigeration, GWH	1353	1592	1772	1923	1954	1989	1991	1945	1928	1896	1860	1873	1865	1891
Other Appliances, GWH **	628	978	1092	910	1130	1176	1020	1083	1052	1322	1415	1558	1661	1645
SHARES, % (C Corr)														
Main Heat	3.9%	7.8%	12.3%	14.3%	15.2%	16.1%	15.3%	14.7%	15.1%	11.7%	12.3%	12.2%	13.2%	13.7%
Secondary Heat	0.6%	0.4%	0.6%	0.7%	1.5%	1.7%	1.6%	1.8%	1.9%	2.0%	2.8%	3.4%	3.8%	4.2%
Water Heating*	4.5%	8.2%	12.9%	15.0%	16.7%	17.8%	16.9%	16.5%	17.0%	13.6%	15.1%	15.5%	17.0%	17.9%
Cooking	12.3%	13.3%	16.1%	18.2%	18.0%	18.6%	19.7%	19.4%	19.4%	18.8%	18.4%	17.8%	18.0%	18.7%
Lighting	18.7%	15.5%	16.7%	16.9%	16.8%	16.5%	16.9%	16.8%	16.8%	16.5%	16.8%	16.7%	16.9%	16.4%
Refrigeration	18.9%	17.5%	15.7%	16.1%	15.9%	15.6%	16.0%	16.3%	17.4%	16.8%	17.0%	17.2%	16.7%	16.8%
Other Appliances **	33.8%	33.0%	31.5%	32.6%	30.3%	29.9%	30.3%	29.3%	28.8%	27.1%	25.6%	24.5%	23.6%	23.5%

AVG ANNUAL GROWTH RATES, %	70-72	72-78	78-83	83-87	72-87
Space Heat (all)	48.3%	18.0%	-2.3%	10.8%	9.0%
Water Heating*	14.1%	10.3%	2.6%	3.5%	5.8%
Cooking	0.0%	6.3%	1.4%	3.4%	3.9%
Lighting	5.6%	3.2%	2.8%	3.7%	3.2%
Refrigeration	8.5%	3.5%	-0.6%	-0.1%	1.2%
Other Appliances **	24.8%	2.4%	3.2%	5.6%	3.5%

	1970	1972	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
PER CAPITA CONSUMPTION, kWh, CC														
Main Heat, kWh, CCorr	32	76	137	166	192	209	196	191	198	160	175	182	203	216
Secondary Heat, kWh,CCorr	5	4	7	8	18	22	21	23	25	27	40	50	59	66
Water Heating, kWh *	101	129	179	212	227	242	253	252	254	258	261	266	279	295
Cooking. kWh	153	150	186	196	212	215	217	219	221	226	239	250	260	258
Lighting,kWh	154	170	175	187	201	202	205	212	228	230	242	257	258	265
Refrigeration, kWh	276	319	350	378	383	388	389	380	377	371	364	366	364	369
Other Appliances, KWh	128	196	216	179	222	230	199	212	206	259	277	305	324	321
PER DWELLING CONS., kWh														
Lighting	425	450	450	475	500	500	500	506.94	537.6	537.6	563.22	588.84	588.84	595
Refrigeration	758	846	901	960	955	961	947	909	891	869	848	841	831	831
Other Appliances **	352	520	555	454	552	568	486	506	486	606	645	700	740	723

* Includes water heated in clothes- and dish- washers

** Excludes water heated in clothes- and dish- washers

DENMARK RESIDENTIAL ELECTRICITY USE

	1970	1972	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
SPACE HEATING CC, GWH	181	398	727	887	1075	1182	1110	1099	1139	955	1099	1187	1341	1439
Climate index	1.078	0.955	0.901	0.943	0.994	1.087	1.032	1.000	0.948	0.923	0.923	1.113	1.026	1.079
SPACE HEATING, GWH	195	380	655	837	1069	1285	1146	1099	1080	881	1015	1321	1376	1553
- Principal, Gwh	170	360	625	798	975	1165	1037	978	961	755	828	1034	1067	1190
Saturation, %	0.8%	1.6%	3.1%	3.8%	4.1%	4.4%	4.7%	5.2%	5.5%	5.8%	6.2%	6.5%	6.7%	6.9%
Use per household, MWh	12.5	12.0	10.2	10.5	11.8	12.7	10.5	8.8	8.0	6.0	6.1	7.1	7.1	7.5
- Secondary, Gwh	25	20	30	39	93	120	109	120	119	126	187	287	308	362
Saturation, %	10.0%	10.0%	10.0%	9.7%	17.9%	21.0%	20.8%	22.5%	22.2%	22.2%	28.9%	35.3%	39.7%	42.1%
Use per household, Kwh	140	106	153	200	254	276	250	250	248	261	295	365	346	378
WATER HEATING,GWH TANKS	190	230	400	464	494	538	589	582	596	624	651	682	740	793
Saturation, %	3.0%	4.0%	6.2%	7.7%	8.4%	9.2%	10.0%	10.7%	11.4%	12.0%	12.5%	13.3%	14.2%	14.9%
Use per household, Kwh	2923	3067	3333	3203	3187	3074	3020	2909	2839	2835	2832	2842	2959	2992
COOKING STOVES, GWH	750	750	940	1000	1081	1100	1111	1119	1128	1156	1222	1278	1333	1323
Saturation, %	45.0%	52.7%	64.1%	67.6%	72.3%	71.0%	74.5%	74.8%	75.1%	75.6%	78.6%	79.1%	80.2%	80.2%
Use per household, Kwh	775	750	746	738	730	720	710	699	694	701	709	726	733	725
LIGHTING, GWH	758	846	885	952	1024	1035	1051	1085	1163	1173	1236	1311	1322	1354
Use per household, Kwh	425	450	450	475	500	500	500	507	538	538	563	589	589	595
APPLIANCES, GWH w Hwater	2287	2984	3370	3444	3748	3866	3719	3736	3683	3912	3960	4110	4212	4253
Use per household, Kwh	1281	1586	1714	1719	1831	1868	1770	1745	1702	1792	1804	1846	1876	1868
of which :														
TOTAL REFRIGERATION	1353	1592	1772	1923	1954	1989	1991	1945	1928	1896	1860	1873	1865	1891
Use per Householdhod, kWh	758	846	901	960	955	961	947	909	891	869	848	841	831	831
REFRIGERATORS, GWH	550	582	578	572	574	578	577	542	540	535	533	534	526	517
Saturation, %	77.0%	80.3%	77.4%	77.1%	76.8%	76.5%	75.2%	74.3%	74.1%	73.9%	74.5%	75.0%	74.8%	74.5%
Use per appliance, Kwh	400	385	380	370	365	365	365	341	337	332	326	320	313	305
FREEZERS, GWH	707	848	879	962	955	958	944	942	928	907	884	886	876	890
Saturation, %	33.0%	41.0%	49.7%	56.5%	58.3%	59.7%	59.9%	59.8%	59.8%	59.8%	60.0%	62.0%	63.7%	65.2%
Use per appliance, Kwh	1200	1100	900	850	800	775	750	736	717	695	671	642	613	600
COMBI, GWH	96.8	162	314	389	426	453	470	461	460	453	444	452	463	483
Saturation, %	7.0%	11.8%	21.9%	26.6%	28.5%	30.2%	31.5%	31.9%	31.8%	31.4%	31.0%	32.0%	33.4%	34.8%
Use per appliance, Kwh	775	730	730	730	730	725	710	675	669	661	652	635	617	610
CLOTHES WASHERS, GWH	344	430	501	555	588	614	621	630	632	631	628	625	632	650
Saturation, %	35.0%	41.9%	48.5%	54.3%	56.3%	58.2%	58.5%	58.6%	58.9%	59.4%	60.0%	60.4%	62.4%	64.2%
Use per appliance, Kwh	550	545	525	510	510	510	505	502	496	487	477	465	451	445.0
Of Which Hot Water	468	463	446	434	434	434	429	427	417	404	391	377	361	356
DISHWASHERS, GWH	15.2	57.3	95.3	166	193	210	212	203	205	205	206	214	227	246
Saturation, %	2.0%	7.0%	10.1%	16.2%	18.0%	19.9%	20.4%	20.5%	20.6%	20.7%	21.0%	22.0%	24.0%	26.0%
Use per appliance, Kwh	425	435	480	510	525	510	495	462	459	454	447	436	421	415
of which Hot Water	361	370	408	434	446	434	421	393	386	377	367	353	337	332
CLOTHES DRYERS, GWH		11.0	29.2	56.4	69.5	79.8	90.0	98.0	104.9	111.4	119.4	137.9	137.7	156.6
Saturation, %		1.3%	3.3%	6.4%	7.9%	9.4%	10.2%	10.9%	11.6%	12.3%	13.2%	15.3%	15.3%	17.2%
Use per appliance, Kwh		450	450	440	430	410	420	420	418	415	412	405	401	400
Hot Water in Washers, TWH	305	414	507	612	664	701	708	707	703	694	684	679	687	717
REMAINING APPLIANCES, GWH	575	692	730	474	663	687	517	628	584	844	927	1047	1139	1094
"" per HH, kwh	322	368	371	237	324	332	246	294	270	387	422	470	507	480

NORWAY

There are no "real" time series for the residential consumption of energy for Norway, only approximations such as those made by Soerensen,[1] who estimated consumption of each fuel back to 1950. Knut Alfsen and Asbjoern Aaheim from Statistiska Sentral Byraa (SSB) also provided estimate of residential energy use. A series for *electricity consumption*, by contrast, exist from 1960 to the present in *Elstatistikk*. Schipper derived detailed energy-use balances for the residential sector for 1973, 1979, and 1983. These were updated to 1983 - 1986 in Schipper, Howarth, and Wilson 1989).[2] The derivation proceeded by estimating homes using electricity, heating oil, kerosene, wood or coal for each end-use, estimating unit consumption for space and water heating (from various partial surveys of energy use, from Energiundersoekkelse 1980 and Energiundersoekkelse 1983), and taking estimates of unit consumption for electric cooking, lighting, and major appliances from the sparse literature. Secondary electric heating was estimated from the 1983 Energiundersoekkelse, and guessed for other years.

Space Heating.

Correction for climate is made by dividing estimated consumption for space heating by the ratio of the actual number of degree-days base 18C to the long-term average number. The base 18C is derived from SSB figures by adjusting from the lower base they give, ignoring June, July, and August. The long term average for a 9 month heating season is 4069DD. The words CC or CCORR denote where the correction is applied to heating, or to totals (for calculating shares, etc.).

Water Heating, Cooking, Lighting, and Appliances.

Water heating.

We believe that in 1970 about 80% of all homes had electricity based water heating systems, 12% had systems based on oil, and 8% had no running hot water. By 1986, electricity captured 95% of all homes, oil only 5%. We estimated unit consumption for electricity for single- and multifamily dwellings separately and averaged the two. In 1970 this average unit consumption was 3673kWh/home; by 1979, 3818kWh/home, and in 1986, 3475kWh/home (as more multi-family dwellings used electricity). To total electricity consumed for water tanks we add the estimated consumption of hot water in washers and dish-washers, 75-80% of unit consumption.

Cooking.

Ownership of electric cooking stoves was estimated at 95% by the 1973 Forbrugsundersoekkelse. We put the figure at 99.7% in 1983 and 99.8% in 1986. Following references in Poleszynski[3] and elsewhere, we put unit consumption at 650kWh/hh in 1970, falling slowly to 554kWh/hh in 1986.

Lighting.

After discussions with Ljones (A/S Energidata, Flataasen) and B. Grinde (EFI, Trondheim), we set the electricity consumption per home for lighting to 1000 kWh/hh in 1970, 1200 kwh/hh in 1973, 1400 kwh/hh in 1979, and 1600 kwh/hh in 1986. The lifetime of bulbs by wattage, combined information with yearly sales (which replace bulbs that burn out), allows estimation of the electricity that was consumed in causing the burnout estimated to occur.

Electric Appliances.

Our electric appliance ownership data are from various **Forbrugsundersoekkelser** (1967, 1973, 1974-6, 1981-3, 1984-6). Estimates of unit consumption were found in Poleszynski (1978), in Energidata (1988)[4] in Grinde (EFI, 1988), [5] and in various published and unpublished material from EFI and SSB. In no case were the various estimates from different sources reconciled. Therefore, we tried to make such a reconciliation. We assumed that refrigeration equipment was getting bigger and, by the early 1980s, somewhat more efficient as well. The first trend increased unit consumption; the second trend reduced it. For washing equipment, we observed the international trend towards lower water use and assume that this affected machines sold in Norway by the late 1970s; additionally, we note that consumers gradually switched to cycles with lower temperatures. Greater centrifuge speeds reduced drying needs somewhat. When our assumptions about unit consumption for the major appliances are multiplied by the estimates of ownership from surveys, we obtain about 1000kWh/hh in 1973 and 2000kWh/hh in 1986. This left a residual of about 600kwh/hh in 1973 and 1000kWh/hh in 1986 or TV, small appliances, ventilation, sauna and other miscellaneous uses.

REFERENCES

1. Soerensen, S-E., 1985. **Boligers Energiforbruk og Energikostnader**. Oslo: Norges byggforskningsinstitutt.

2. Schipper, L., Howarth, R., and Wilson, D., 1989. **A Long Term Perspective on Norwegian Energy Use.** LBL 27295. Berkeley: Lawrence Berkeley Laboratory.

3. Poleszynski, D., 1978. **Energibruk i husholdning. Arbeidsrapport april 1978.** Oslo: Statens institutt for forbrugsforskning.

4. Ljones, A.., 1988. **Utvikling av Energiforbruket 1975 - 1985.** Prepared for Olje og Energidepartement. Flataasen (Norway): Energidata 1988

5. Grinde, B., 1988. **Analyse av energiforbruket 1976 - 1986 i boligsektor. ENOK og reelle forklaringsvaktorer.** Trondheim: Elektrisitetsforsynings Forskningsinstitutt A/S.

NORWAY: RESIDENTIAL ELECTRICITY USE

	1960	1970	1973	1975	1976	1979	1980	1981	1982	1983	1984	1985	1986	1987
POPULATION, 10e3	3581	3880	3960	4010	4030	4070	4086	4100	4115	4128	4140	4153	4167	4175
HOUSEHOLDS, 10e3	1075	1297	1367	1413	1437	1502	1524	1539	1556	1569	1582	1589	1595	1595
TOTAL ELECTRICITY Use, GWH	7528	14394	15722	17406	18931	22344	22525	23878	25081	25775	26878	28911	29917	30833
Climate Index	1.019	1.059	0.989	0.926	1.044	1.085	1.061	1.056	0.982	0.936	0.945	1.107	1.040	1.062
Climate Corrected, GWH	7486	14069	15787	17960	18580	21522	21922	23266	25308	26662	27690	27369	29280	29810
Per Capita, kWh	2090	3626	3987	4479	4610	5288	5365	5675	6150	6459	6688	6590	7027	7140
Per Household, kWh	6963	10847	11549	12710	12930	14329	14385	15117	16265	16993	17503	17224	18357	18689
END USES, GWH		5843	6070	6914	8235	10463	10456	11537	12458	13048	14004	15902	16716	17546
Main Heat, GWH, uncorrecte	2222	3824	4186	4186	4250	6740	6472	6870	7417	7711	8056	9787	10444	11146
Secondary Heat, GWH, uncorr		2232	1884	2727	3985	3722	3983	4667	5042	5337	5948	6115	6271	6400
Total Heating, GWH, CCorr	1349	5517	6135	7468	7885	9640	9853	10925	12686	13935	14816	14360	16080	16515
Water Heating, GWH *	2861	4837	5093	5258	5264	5732	5822	5999	6102	5975	5972	5973	5968	5996
Cooking, GWH	611	780	845	859	868	894	897	902	900	900	892	884	882	890
Lighting, GWH	860	1297	1640	1625	1724	2103	1981	2078	2178	2275	2373	2542	2552	2552
Refrigeration, GWH	290	813	1098	1231	1310	1617	1560	1728	1781	1795	1780	1777	1745	1725
Other Appliances, GWH **	641	825	975	1519	1529	1535	1809	1635	1660	1783	1857	1833	2053	2131
SHARES, % (CCORR)														55.4%
Main Heat	29.7%	24.2%	26.8%	25.2%	21.9%	28.9%	27.8%	28.0%	29.8%	30.9%	30.8%	32.3%	34.3%	34.4%
Secondary Heat	18.03%	15.0%	12.1%	16.4%	20.5%	15.9%	17.1%	19.0%	20.3%	21.4%	22.7%	20.2%	20.6%	20.2%
Water Heating	38.2%	34.4%	32.3%	29.3%	28.3%	26.6%	26.6%	25.8%	24.1%	22.4%	21.6%	21.8%	20.4%	20.1%
Cooking	8.2%	5.5%	5.4%	4.8%	4.7%	4.2%	4.1%	3.9%	3.6%	3.4%	3.2%	3.2%	3.0%	3.0%
Lighting	11.5%	9.2%	10.4%	9.0%	9.3%	9.8%	9.0%	8.9%	8.6%	8.5%	8.6%	9.3%	8.7%	8.6%
Refrigeration	3.9%	5.8%	7.0%	6.9%	7.0%	7.5%	7.1%	7.4%	7.0%	6.7%	6.4%	6.5%	6.0%	5.8%
Other Appliances	8.6%	5.9%	6.2%	8.5%	8.2%	7.1%	8.3%	7.0%	6.6%	6.7%	6.7%	6.7%	7.0%	7.1%
AVERAGE ANNUAL GROWTH RATES %		60-70	70-73			70-79				79-83			83-86	
Space Heat (all)		15.1%	3.6%			6.4%				9.6%			4.9%	
Water Heating*		5.4%	1.7%			1.9%				1.0%			-0.0%	
Cooking		2.5%	2.7%			1.5%				0.2%			-0.6%	
Lighting		4.2%	8.1%			5.5%				2.0%			3.9%	
Refrigeration		10.8%	10.6%			7.9%				2.6%			-0.9%	
Other Appliances**		2.6%	5.7%			7.1%				3.8%			4.8%	
PER CAPITA CONSUMPTION, kWh, CC														
Main Heat	609	931	1068	1128	1010	1526	1493	1587	1835	1995	2059	2128	2411	2513
Secondary Heat	0	543	481	735	947	843	919	1078	1248	1381	1520	1330	1448	1443
Water Heating	799	1247	1286	1311	1306	1408	1425	1463	1483	1447	1443	1438	1432	1436
Cooking	171	201	213	214	215	220	220	220	219	218	215	213	212	213
Lighting	240	334	414	405	428	517	485	507	529	551	573	612	612	611
Refrigeration	81	209	277	307	325	397	382	421	433	435	430	428	419	413
Other Appliances	179	213	246	379	379	377	443	399	404	432	449	441	493	510
PER DWELLING CONSUMPTION, kWh														
Lighting	568	601	618	608	604	595	589	586	578	574	564	556	553	558
Refrigeration	800	1000	1200	1150	1200	1400	1300	1350	1400	1450	1500	1600	1600	1600
Other Appliances	270	627	803	871	911	1077	1024	1123	1145	1144	1125	1118	1094	1082

*Includes water heated in clothes- and dish- washers

** Excludes electricity for water heated in clothes- and dish-washers

NORWAY: RESIDENTIAL ELECTRICITY USE

	1960	1970	1973	1975	1976	1979	1980	1981	1982	1983	1984	1985	1986	1987
SPACE HEATING CC, GWH	2222	5517	6135	7468	7885	9640	9853	10925	12686	13935	14816	14360	16080	16515
Climate index	1.019	1.059	0.989	0.926	1.044	1.085	1.061	1.056	0.982	0.936	0.945	1.107	1.040	1.062
SPACE HEATING, GWH	2264	5843	6070	6914	8235	10463	10456	11537	12458	13048	14004	15902	16716	17546
- Principal, Gwh	889	3611	4186	4186	4250	6740	6472	6870	7417	7711	8056	9787	10444	11146
Saturation, %	16.1%	24.9%	31.7%	34.6%	35.5%	38.2%	39.7%	45.3%	48.6%	50.5%	53.7%	56.8%	58.0%	59.0%
Use per household, Kwh	5136	11180	9624	8544	8333	11743	10698	9857	9810	9626	9477	10802	11291	11844
- Secondary, Gwh	1375	2232	1884	2727	3985	3722	3983	4667	5042	5337	5948	6115	6271	6400
Saturation, %		57.4%				46.6%				44.6%				
Use per household, Kwh		3000				5318				7624				
WATER HEATING,GWH TANKS	2764	4462	4657	4783	4772	5155	5222	5389	5472	5327	5332	5325	5318	5321
Saturation, %	70.0%	85.0%	87.8%	89.2%	89.4%	89.9%	90.5%	91.5%	93.0%	94.0%	94.5%	95.0%	95.9%	0.96
Use per household, Kwh	3673	4047	3881	3796	3714	3818	3786	3827	3782	3612	3567	3526	3475	3475
COOKING STOVES, GWH	611	780	845	859	868	894	897	902	900	900	892	884	882	890
Saturation, %	74.4%	92.5%	96.6%	97.3%	97.4%	99.2%	99.3%	99.3%	99.5%	99.7%	99.5%	99.4%	99.7%	0.998
Use per household, Kwh	764	650	640	625	620	600	593	590	581	575	566	560	555	554
LIGHTING, GWH	860	1297	1640	1625	1724	2103	1981	2078	2178	2275	2373	2542	2552	2552
Use per household, Kwh	800	1000	1200	1150	1200	1400	1300	1350	1400	1450	1500	1600	1600	1600
APPLIANCES, GWH w Hwater	1029	2013	2510	3225	3331	3731	3969	3972	4072	4225	4277	4258	4448	4531
Use per household, Kwh		1552	1836	2282	2318	2484	2604	2581	2617	2693	2704	2679	2789	2841
of Which:		1286	1611	1784	1889	2311		2459		2571		2554		
TOTAL REFRIGERATION	161	362	432	440	454	578		640	691	687		686	660	
Use per Household, kWh														
REFRIGERATORS, GWH														
Saturation, %	0.5	74.5%	79.0%	79.0%	79.0%	77.0%		77.0%	74.0%	73.0%		72.0%		
Use per appliance, Kwh	300	375	400	400	400	500			600	600		600		
FREEZERS, GWH	129.0	413.1	584.4	674.7	722.1	849.8		882.6	875.3	882.6		845.3	835	
Saturation, %	0.2	45.5%	57.0%	63.7%	67.0%	73.0%	? ->	74.0%	75.0%	75.0%		76.0%		
Use per appliance, Kwh	600	700	750	750	750	775		775	750	750		700		
COMBI, GWH		37.3	82.0	116.7	133.4	189.3	205.7	205	215.0	225.0		244.7	250.0	
Saturation, %		5.0%	10.0%	14.0%	16.0%	18.0%	0.2	22.0%	23.0%	25.0%		28.0%		
Use per appliance, Kwh		575	600	590	580	700	675	650	625	600		550		
CLOTHES WASHERS, GWH		460.4	492.1	516	531.7	599.3		604		627.6		626.5		
Saturation, %		71.0%	72.0%	73.0%	74.0%	76.0%		77.0%	79.0%	80.0%		83.0%		
Use per appliance, Kwh		500	500	500	500	525		510		500		475		
Of Which Hot Water		425	425	425	425	436				415		394		
DISHWASHERS, GWH		13.0	20.5	37.1	47.4	94.6		127		149.1		151.0		
Saturation, %		2.0%	3.0%	0.05	6.0%	12.0%		16.0%	17.0%	19.0%		20.0%		
Use per appliance, Kwh		500	500	525	550	525		515		500		475		
of which Hot Water		425	425	446	468	446				425		404		
CLOTHES DRYERS, GWH		116.7	164.0	171.0	165.3	187.8				251.0		262.2		
Saturation, %		15.0%	20.0%	0.22	23.0%	25.0%		30.0%	0.31	32.0%		33.0%		
Use per appliance, Kwh		600	600	550	500	500				500		500		
Hot Water in Washers, GWH	97.2	375	436	475	492	578	600	610	630	648	640	648	650	675
REMAINING APPLIANCES, GWH		610.1	734.6		1277.3	1231.6		2244.7		1402.5		1441.5		
"" per HH, kWh		470.41	537.34		888.83	819.96		1458.5		893.86		907.17		
		EST	BF	FU			est	BF		FU		FU		

SWEDEN*

Total electricity consumption for Sweden for the residential sector is not defined or recorded unambiguously by any national statistical authority. **El- och Fjaerrvaermestatistik** (Electricity and District Heating Statistics), published yearly by the Central Bureau of Statistics, [1] and unpublished data provided by Vattenfall show electricity use in farm and non-farm premises, with and without heat. Additionally consumers are divided into single-family dwellings and multi-family dwellings metered individually and collectively. Thus there are many customer classes that must be summed. Schipper (1984),[2] and Carlsson (1984 and 1989)[3,4] developed procedures that add consumption in single-family dwellings, multi-family dwellings, homes in service buildings, and farm houses (excluding the estimated consumption for machines, as explained in Schipper [1984]). We also include electricity consumption in common spaces in apartments (50% of "fastighets foervaltning", or building administration, the likely part going to residential buildings), ie., electricity for running lights, elevators, washing machines., etc, in larger apartment buildings, is usually recorded on a single meter This consumption, which is an input to making total use, is included under appliances, but probably includes some space heating. Our total use estimates were very close to those provided by the Swedish State Power Board (using the same customer categories), so we adjusted our final figures slightly to theirs.

Population is from the Central Bureau of Statistics. Total number of dwellings were estimated by Carlsson, based on revised census data for 1975, 1980, and 1985. (This number is slightly greater than the number of occupied dwellings or households because of vacancies in multi-family dwellings, but the error introduced is small, on the order of 2-3% of total dwellings.) Degree days were taken from the Bureau of Statistics (base 17C, approximately 9 month heating season) and adjusted upward to the base 18C by multiplying 250 days times one degree. House area is tabulated in **Energistatistik** from 1978 onward (SFD) and from 1983 onward (MFD)[5,6] by fuel type, but estimates of area for electrically heated homes were available for earlier years from Carlsson.

Schipper (1984) derived detailed energy-use balances for the residential sector for 1972, 1975, 1978 - 1982. These were updated to 1983 - 1986. The bases for these estimates are the **Energistatistik** for 1978 onward, and estimates discussed in Schipper (1984) for previous years. Other information was taken from a series of market studies done by and for the SM division of the Sw. State Power Board. [7] For 1972, the figure in Schipper (1984) was modified to reflect more recent information provided by Carlsson (1989). Heating and water heating consumption was then extrapolated to 1973, using a survey from the Swedish State Power Board (Vattenfall) covering 1973. For 1978 and 1982, the figures from Schipper were used, with slight modifications based on Power Board surveys. For 1987, totals were estimated by Schipper using Malinen's new breakdowns and Vattenfall's preliminary market analysis. Because estimates were provisional, we also made a detailed breakdown of 1985, for which much greater information was available. The major uncertainty in the data after 1982 is the role of secondary or hidden ("dold") heat.

Space Heating.

Main space heating includes most homes with electric heating (including those that likely used some wood as well), but there were a significant number considered to use electricity in a secondary roll according to **Energistatistik**, relying wood and oil as well as electricity. Total consumption of electricity for main space heating was taken from Schipper (1984) and extrapolated to 1973 on the basis of changes in the numbers of electrically heated homes and the change in the average number of degree days. For 1978 and onward, the various classes of heating customers were taken from **Energistatistik foer Smaahus**. Those SFD using electricity only, and 90% of those using electricity plus wood, were considered main electric heat users; the rest of the homes indicating use of electricity for heating were considered to be using electricity as a secondary fuel, which is reflected in the considerably lower unit consumptions for these "secondary" users. For 1978, 1982, and 1985/6, the number of new homes using electricity for some form of heat but not counted by the survey was estimated from new construction statistics and added to the totals. For MFD, all with heat

* Because much of this study focuses on Sweden, which was included in the first study prepared for the International Energy Agency, the notes and derivations for Sweden, including notes on conservation potentials, have been specially prepared, with extra documentation at the end.

were considered "principal" through 1982, but after 1983 those listed by the Survey as having combined oil-electricity systems were apportioned so that heat pumps were treated as principal systems but oil and resistance electricity were considered as back-up systems.

From unit consumption for each kind of dwelling with electric heating, we subtracted assumed consumption for cooking and appliances (see below), which yielded space and water heating consumption. (These two uses are usually paired when electricity is the source.) Unit consumption for each class of customer was multiplied by total number of customers to give total water and space heating for SFD and MFD. Subtracting off water heating yielded space heating. Based on the literature surveys in Schipper (1984) and Carlsson's work, we adopted an estimate for water heating that was nearly 500kWh/dw higher than that of the State Power Board. Consequently, our space heating figures are lower than those put forward by the State Power Board by about the same amount per dwelling with electric space heating.

Secondary heating with electricity is very significant in Sweden. The combinations of electricity and oil or electricity, wood, and oil are considered to be secondary use of electricity, whether with direct resistance units, or in combination electric boilers. Total use in non-farm SFD can be derived from **Energistatistik**; For farm-SFD, consumption is not given, so this has to be estimated by comparison with consumption in non-farm SFD, and for consumption of farm dwellings given in the SCB **El och Fjaerrvaermestatistik.** Consumption for cooking, water heating, and appliances must be subtracted. These operations yield a residual, which is attributable to electric space and/or water heating. Figures for ownership of small, portable electric heaters were available for a few years only, and these are not important. Vattenfall estimated unit consumption in 1978 only.

For 1986 we tabulated the stock of electrically heated dwellings by type of system (direct resistance, boiler, heat pump, combinations with fuels) from **Energistatistik.** We did not have any data on night-time storage heating, but some utilities do offer a night-time tariff. We estimate that there may be as many as 50 000 SFD using such a tariff.

Water Heating, Cooking, Lighting, and Appliances.

Water heating. Schipper (1984) judged that every homes with electricity as its main heating source also derived hot water from an electrical system. (The 1985 Vattenfall Survey bears this assumption out.)[8] Schipper used data on saturation of electrical water heating tanks to estimate the number of homes with electric water heating but *not* electric space heating.

Water heating unit consumption is poorly known in Sweden. Energiberedskapsutredning (1975),[9] Energikommission (1977),[10] and Anderlind *et al.* (1980)[11] for unspecified years and dwelling types. Unit consumption was most recently estimated by Carlsson, using a formula relating electricity use to household size. His formula is

$$\text{energy use (in MWH)} = (4.3+(0.65*(hh-3))/0.9),$$

where hh is household size and 0.9 represents the ratio of energy used in the hot water to energy consumed (electricity), ie., the standby losses. Using his estimates (based on SFD and MFD household sizes separately) and the saturations taken from Vattenfall surveys, electricity consumption in water heaters in MFD and SFD are added separately. The unit consumption figure given reflects main tanks only.

In principle, Carlsson's formula includes the water heated for dishwashing and clotheswashers, since households without these appliances use hot water for those purposes anyway. Since nearly all of the washing machines are cold-fill (A. Horovitz, State Board of Consumer Protection, priv. comm., 1988), an adjustment to Carlsson's figures was made for water heated by machines. This water heating was based on data on unit consumption for these machines from Vattenfall, assuming that approximately 80% of the unit consumption for clotheswashers heats water. For dishwashers, Horovitz indicates that roughly 90% of machines today are hot fill, and he figures that perhaps 95% of the machines in use in 1973 were hot fill. Therefore, the main hot water supply only heats water for the remaining machines, whose water heating electricity consumption was estimated and included in total hot water supply. For 1986, we made a rough estimate of the share of homes with tanks vs those with central boilers that provide space heating as well. Additionally, there are approximately 35000 SFD (and a large number of MFD) with exhaust-air hot water heat pumps.

Cooking. For cooking, saturations were obtained from Vattenfall surveys of 1973, 1975, 1979, 1982, and 1985, as well as "Hushaallens Energi Anvaending" ("HEA", 1978 - 1981)[12] from the Bureau of Statistics. We obtained estimates of unit consumption from Vattenfall, Konsumentverket (Board of Consumer Affairs), and FERA (Association for Rational Electricity Use) for 1973, and Vattenfall for 1978. For 1982 and 1985/6, we weighed the Vattenfall estimates for SFD and MFD to obtain averages for all dwellings. The saturation of microwave ovens was estimated in 1985 at slightly less than 3%, but may exceed 12% by 1988 (M. Malinen, Vattenfall, priv. communication, based on sales statistics).

Lighting. Vattenfall estimated consumption of electricity for lighting in 1978, 1982, and 1985, and Energiberedskapsutredning made a similar estimate for 1973. This figure does not include common areas in apartments (part of "fastighets foervaltning"). We believe this would add roughly 25kWh/MFD, or 0.5TWh to lighting.

Electric Appliances. Total electricity use for appliances and electric cooking was obtained from data on consumption of electricity in MFD and SFD without heat, respectively. These data were given by the **El- och Fjaerrvaermestatistiken** for 1972 onward, and from **Energistatistik foer Smaahus** from 1978 onward. From this figure we subtracted the consumption for electric cooking stoves to obtain electric appliances aggregated over all dwelling types. Vattenfall estimates of electricity use for lighting, per dwelling, were then subtracted to yield electricity uses for appliances. Unit consumption for individual uses was take from Vattenfall Surveys.[13] For 1982, 1985, and 1987 we took weighted averages of unit consumption and saturation in single-family dwellings and multi-family dwellings, while for previous years Vattenfall estimates did not distinguish between dwelling types. Finally, consumption electricity for hot water in washing machines and dishwashers was subtracted from electric appliances. **Ownership figures are given as saturation (share of homes owning) except for refrigeration equipment, where we give diffusion, or (appliances per one hundred households)/100.**

For refrigeration, M. Malinen of Vattenfall (priv. comm.) built a model that estimated the number of refrigerators, combis, and freezers in any given year *broken down by the year they were built*. With estimates of unit consumption of each year's new production, Malinen arrived at historical series of numbers of units, unit consumption, and total consumption. He also took into account multiple ownership. In the worksheet we do take into account multiple ownership, showing units per household. *Saturation* of refrigerators (ie., share of households owning one or more) in 1973, 1978, 1982, 1985, and 1987 was 88%, 82%, 80%, 79% and 79%, respectively. Saturation of freezers was 40%, 48%, 55%, 61.6% and 62.5%, respectively.

We included estimates of electricity use all made by Vattenfall for clotheswashers, dryers, and dishwashers. For washer and dryers, we estimated that in 1982 and 1985/6, approximately 25% of families in multi=family dwellings use these appliances in common areas, whose electricity use is included under residential electricity consumption. figures adds approximately 30% to the total electricity used.) We therefore counted the electricity consumed by these families for washing and drying as if they had used these appliances in their own dwellings. (The 1973 and 1978 surveys asked how many households had access to these appliances, while later surveys only counted those in dwellings.) We used the Vattenfall saturation and use estimates for saunas, car warmers, and central-heating circulation pumps in SFD, as these uses accounted for 0.9TWH in 1986.

DATA SOURCES.

Most of the data sources for Sweden are published. However, we acknowledge many unpublished data (listed in Schipper (1984)) and estimates from experts at the Swedish State Power Board, and above all from Lars-Goeran Carlsson, PREDECO, Stockholm, who kindly provided information that updated his published reports. G. Larsson of Vattenfall provided important cross-tabs of appliance and heating equipment ownership data from Vattenfall surveys of 1971, 1973, 1975, and 1979, which were used in Schipper (1984).

REFERENCES

1. SCB, 1972 - 1989. **El och Fjaerrvaermestatistik.** Stockholm: Central Bureau of Statistics.

2. Schipper, L., 1984. **Internationell jaemfoerelse av bostaedernas energifoerbrukning.** R131:1984. Stockholm: Byggforskningsraadet.

3. Carlsson, L. G., 1984. **Energianvaendning i Bostaeder och Lokaler.** R123-1984. Stockholm: Byggforskningsraadet.

4. Carlsson, L. G., 1989. **Energianvaendning och strukturomvandling i byggnader 1970 - 1985.**. R22:1989. Stockholm: Byggforskningsraadet.

5. Bjoerck, G., 1978 -. **Energistatistik foer Smaahus.** E16SM Series. Stockholm: Central Bureau of Statistics.

6. Pettersson, K., 1977-. **Energistatistik foer Flerfamiljshus.** Stockholm: Central Bureau of Statistics.

7. For example, Larsson, G., *et al.*, 1984. **Elkonsumtionen i Sverige 1982 - 1995.** Stockholm: KRAFTSAM. The predecessor to KRAFTSAM, Centrala Drift Ledningen, coordinated a similar effort that included 1978 data on household appliances. The State Power Board made available their updated 1985 estimates of household electricity use for appliances. Other studies were carried out in the early 1970s and in 1979/89 (basis 1978).

8. Anon, 1987. **Maetning av hushaallens elkonsumtion, uppdelad paa de viktigaste elapparaterna.**. SM-MM 2128/1. Stockholm: Vattenfall. See also earlier Vattenfall and Kraftsam market forecasts, and Kraftsam's yearly studies of single-family dwellings.

9. Energiberedskapsutredning, 1975. **Energiberedskap foer Kristid.** SOU: 1975:60, 61. Stockholm: Liber Foerlag Chapters 3.5.4 and 3.5.5 study multi-family dwellings and single-family dwellings, respectively.

10. Hoeglund, I., *et al.*, 1977. **Energibehov foer bebyggelse, hushaallningsmoejligheter.** Ds I 1977:13. Stockholm: Industri Departementet.

11. Anderlind, G., *et al.*, 1980. **Energispareffekter i bostadshus daer aatgaerder genomfoerts med statligt energisparstoed.** Ds Bo :1980:8. Stockholm: Bostads Departementet.

12. Lille, J., 1978 -. **Hushaallensenergianvaendning (HEA).** Stockholm: Statistiska Centralbyraa.

13. Carlsson, L.G., 1980. **ERA**, V. 2.

SWEDEN: RESIDENTIAL ELECTRICITY USE

	1970	1973	1975	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Population, 10e6	7.99	8.07	8.12	8.29	8.21	8.23	8.22	8.36	8.20	8.21	8.38	8.40	8.45
Occuped Dwellings/HH 10e6	3.09	3.27	3.38	3.49	3.52	3.55	3.58	3.59	3.61	3.64	3.67	3.67	3.66
Dwelling Stock, 10e6	3.15	3.27	3.49	3.60	3.62	3.67	3.67	3.72	3.75	3.79	3.82	3.86	3.88
TOTAL ELECTRICITY USE, GWH	12.0	15.2	17.3	22.5	24.1	24.3	25.4	27.6	29.1	31.8	36.73	37.2	37.6
Climate Index	1.079	0.968	0.876	1.037	1.064	1.054	1.019	0.967	0.911	0.928	1.134	1.070	1.170
Climate Corrected, GWH	11.8	15.3	18.1	22.1	23.5	23.8	25.2	28.0	30.4	32.9	34.4	35.9	34.7
Per Capita, KWH	1473	1896	2225	2672	2862	2892	3070	3353	3700	4011	4104	4278	4105
Per Dwelling, KWH	3807	4684	5353	6354	6679	6697	7061	7804	8398	9049	9369	9799	9475
END USES, GWH													
Main Heat, GWH, Uncorr	2065	3306	4518	7432	8324	8299	8910	10540	11451	13525	17304	17453	18024
Secondary Heat, GWH, Uncorr	453	614	646	986	1049	1057	1261	1256	1343	1585	2365	2345	2026
Total Heating, GWH, CCorr	2333	4050	5894	8114	8810	8879	9978	12201	14046	16274	17346	18502	17136
Water Heating, GWH*	1243	1952	2201	2817	2956	3064	3247	3584	3929	4212	4493	4669	4949
Cooking, GWH	1854	1943	1982	2084	2067	2016	2056	2058	2054	2043	1984	1906	1834
Lighting, GWH	1547	1796	1823	2179	2216	2273	2288	2286	2295	2319	2352	2347	2416
Refrigeration, GWH	3800	4309	4600	4925	4950	5000	4900	5041	4750	4600	4586	4649	4130
Other Appliances, GWH**	999	1246	1566	2030	2491	2557	2772	2857	3280	3491	3643	3864	4218
SHARES, % (CCorr)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Main Heat	16.2%	22.3%	28.5%	32.3%	33.3%	33.1%	34.6%	38.9%	41.4%	44.2%	44.4%	45.4%	44.4%
Secondary Heat	3.6%	4.1%	4.1%	4.3%	4.2%	4.2%	4.9%	4.6%	4.9%	5.2%	6.1%	6.1%	5.0%
Water Heating*	10.6%	12.8%	12.2%	12.7%	12.6%	12.9%	12.9%	12.8%	12.9%	12.8%	13.1%	13.0%	14.3%
Cooking	15.7%	12.7%	11.0%	9.4%	8.8%	8.5%	8.1%	7.3%	6.8%	6.2%	5.8%	5.3%	5.3%
Lighting	13.1%	11.7%	10.1%	9.8%	9.4%	9.6%	9.1%	8.2%	7.6%	7.0%	6.8%	6.5%	7.0%
Refrigeration, %	32.3%	28.2%	25.5%	22.2%	21.1%	21.0%	19.4%	18.0%	15.6%	14.0%	13.3%	12.9%	11.9%
Other Appliances	8.5%	8.1%	8.7%	9.2%	10.6%	10.7%	11.0%	10.2%	10.8%	10.6%	10.6%	10.8%	12.2%

* Main water heat, washers/dishwashers

AVG ANNUAL GROWTH RATES, %	'63-70	70-73	'73-78	'78-82	82-87	73-87
Space Heat (all)	51.3%	20.2%	14.9%	10.7%	7.0%	10.9%
Water Heating*	19.3%	16.2%	7.6%	6.2%	6.7%	6.9%
Cooking Stoves	3.1%	1.6%	1.4%	-0.3%	-2.3%	-0.4%
Lighting		5.1%	3.9%	1.2%	1.1%	2.1%
Refrigeration		4.3%	2.7%	0.6%	-3.9%	-0.3%
Other Appliances**	7.9%	7.6%	10.3%	8.9%	8.1%	9.1%

	1970	1973	1975	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
PER CAPITA CONSUMPTION, kWh, CC													
Main Heat, kWh, CCorr	239	423	635	864	953	957	1063	1304	1533	1774	1821	1942	1823
Secondary Heat, kWh, CCorr	53	79	91	115	120	122	151	155	180	208	249	261	205
Water Heating, kWh *	155	242	271	340	360	372	395	429	479	513	536	556	586
Cooking, kWh	232	241	244	252	252	245	250	246	250	249	237	227	217
Lighting, kWh	193	223	224	263	270	276	278	274	280	282	281	279	286
Refrigeration, kWH	475	534	567	594	603	608	596	603	579	560	547	553	489
Other Appliances, kWh	125	154	193	245	303	311	337	342	400	425	435	460	499
PER OCCUPIED DWELLING CONSUMPTION, kWh													
Lighting	500	550	540	625	630	640	640	636	635	637	640	640	660
Refrigeration	1229	1320	1363	1413	1407	1408	1371	1403	1314	1264	1249	1268	1128
Other Appliances**	323	381	464	582	708	720	775	796	907	959	992	1054	1152

* Includes water heated in clothes- and dish-washers

SWEDEN: RESIDENTIAL ELECTRICITY CONSUMPTION

	1970	1973	1975	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
SPACE HEATING, CC, GWH	2333	4050	5894	8114	8810	8879	9978	12201	14046	16274	17346	18502	17136
Climate Index													
SPACE HEATING, GWH	2518	3920	5164	8418	9373	9357	10171	11796	12794	15111	19668	19798	20049
- Principal, GWH	1913	3416	5156	7164	7824	7876	8741	10903	12572	14567	15260	16311	15405
Saturation, %	4.8%	7.9%	10.2%	14.2%	15.2%	16.1%	17.2%	19.3%	21.7%	23.7%	25.4%	26.8%	27.5%
Use per Dwelling, MWH	13.38	12.56	14.21	13.52	13.40	12.46	12.82	12.05	12.80	13.55	12.01	11.96	ERR
- Secondary, GWH	420	635	737	950	986	1003	1237	1299	1474	1708	2086	2191	1731
Saturation, %	1.9%	2.8%	3.2%	3.9%	4.1%	4.2%	5.5%	7.9%	8.4%	9.0%	10.0%	8.7%	9.8%
Use per Dwelling, MWH	5.43	5.85	5.97	7.22	7.27	6.99	6.28	4.34	4.33	4.77	6.31	7.14	5.49
WATER HEATING, GWH, TANKS	743	1129	1421	1937	2046	2164	2347	2706	3054	3352	3615	3833	4100
Saturation, %	5.7%	8.8%	11.3%	15.4%	16.3%	17.3%	18.9%	21.6%	24.2%	26.3%	28.4%	29.9%	31.2%
Use per Dwelling, MWH	4.21	3.92	3.73	3.62	3.57	3.52	3.48	3.49	3.49	3.49	3.50	3.50	3.58
COOKING RANGE, GWH	1854	1943	1982	2084	2067	2016	2056	2058	2054	2043	1984	1906	1834
Saturation, %	83.0%	85.0%	87.0%	92.0%	92.0%	90.0%	92.0%	92.2%	0.93	0.94	94.0%	94.5%	93.3%
Use per Dwelling,(kWh)	722	700	675	650	639	631	625	622	611	597	575	550	537.03
LIGHTING, GWH	1547	1796	1823	2179	2216	2273	2288	2286	2295	2319	2352	2347	2416
Use per Dwelling, kWh	500	550	540	625	630	640	640	636	635	637	640	640	660
APPLIANCES, GWH, With Washer Water	5299	6378	6946	7835	8351	8457	8572	8776	8905	8951	9069	9348	9198
Use per Dwelling, kWh	1713	1953	2058	2248	2374	2381	2398	2444	2464	2459	2470	2549	2513
of Which :		5476		6385				6519			6043	6048	5482
TOTAL REFRIGERATION	3800	4309	4600	4925	4950	5000	4900	4864	4750	4600	4408	4421	3902
Use per Dwelling, kWh		1320		1370				1354			1200	1206	1066
REFRIGERATORS, GWH		1666		1780				1584			1316	1309	1189
Diffusion, %	94.0%	91.1%	0.9	88.8%				86.1%			85.9%	86.0%	80.9%
Use per appliance, (kWh)		560		575				512			417	415	401
FREEZERS, GWH		2408		2536				2620			2431	2425	2073
Diffusion, %	46.4%	55.0%	65.0%	60.6%				68.5%			75.4%	76.0%	73.3%
Use per appliance, (kWh)		1340		1200				1065			877	870	773
COMBI, GWH		235		458				660			661	687	639
Saturation, %		6.6%	10.0%	14.3%				21.6%			23.2%	24.5%	24.6%
Use per dwelling, kWh		1100		920				850			775	765	709
CLOTHESWASHERS, GWH		963		1052				1057			1020	1014	1031
Saturation, %	44.0%	59.0%	0.62	71.0%				78.5%			78.4%	79.0%	80.5%
Use per Dwelling,(kWh)		500		425				375			354	350	350
of which hot water		425		351				300			283	280	280
DISHWASHERS, GWH	50	108		230				313			293	298	307
Saturation, %		11.0%		22.0%				30.1%			28.4%	29.5%	29.9%
Use per Dwelling,(kWh)		300		300				290			281	275	280.54
of which hot water		12.5		15				30			22.5	22.5	22.5
CLOTHESDRYERS, GWH		96		178				284			322	315	242
Saturation, %		9.0%		17.0%				35.1%			38.4%	40.0%	27.3%
Use per Dwelling,(kWh)		325		300				226			228	215	242.57
Hot Water in Cl, Di, GWH	500	823	780	879	910	900	900	878	875	860	840	836	850
Washers, Dryers excl HW, GWH		343		580	0	0	0	777	0	0	795	791	731
ALL APPL-H WATER IN WASHERS, KWH/DW	1551	1701	1827	1995	2115	2128	2146	2199	2222	2223	2241	2321	2281

LAWRENCE BERKELEY LABORATORY
INFORMATION RESOURCES DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720