Lawrence Berkeley National Laboratory
Recent Work

Title
RESIDENTIAL ENERGY USE AND CONSERVATION IN SWEDEN

Permalink
https://escholarship.org/uc/item/6j70j96q

Author
Schipper, L.

Publication Date
1983-03-01

eScholarship.org Powered by the California Digital Library
University of California

LBL-14147 c.2
Preprint

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

RECEIVED
LAWRENCE
BERKELEY LABORATORY
JUN 8 1983
LIBRARY AND
DOCUMENTS SECTION

Submitted to Energy and Buildings

RESIDENTIAL ENERGY USE AND CONSERVATION IN SWEDEN

Lee Schipper

March 1983

TWO-WEEK LOAN COPY
This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 6782.

ENERGY
AND ENVIRONMENT
DIVISION

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

LBL-14147 c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

RESIDENTIAL ENERGY USE AND CONSERVATION IN SWEDEN

Lee Schipper

Energy Analysis Program
Lawrence Berkeley Laboratory
Berkeley

and

VVS Tekniska Föreningen
Stockholm

April, 1983

ABSTRACT

We describe energy use in Swedish homes from 1963 to 1980 using data assembled and analyzed for the first time. Changes in energy use by fuel and purpose before and after the 1973 oil price shock are illustrated and discussed, and savings in space heating in the year 1980, compared with the pre-embargo period, are quantified. We discuss two important elements of Swedish energy conservation policy, the building codes and the system of grants and loans to homeowners. We conclude that the grants and loans probably accelerated home retrofit measures, while the building codes will play an important role in reducing residential heat losses over the long term.

This article is based on Lawrence Berkeley Laboratory Report LBL-14147. The work was supported by the U.S. Department of Energy, Buildings Energy Research Division, under contract DE-AC03-76SF00098, and the German Marhsall Fund. The author also acknowledges the support and hospitality of the Beijer Institute of Energy and Human Ecology, Royal Swedish Academy of Sciences, Stockholm, and the close collaboration of Lars-Göran Carlsson and the Swedish National Board of Industry. All opinions expressed, however, are those of the author. The author's address is Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720.

1 INTRODUCTION

Sweden has the lowest energy use for heating, relative to climate, dwelling size, and indoor temperatures, of any country in the Organization for Economic Cooperation and Development (OECD). A careful examination of recent trends in Sweden may reveal programs and technologies worth adopting elsewhere, although such an examination also teaches the importance of particular characteristics of different countries' housing stocks.

Policies towards energy and housing can have a great impact on residential energy use, and any comparison of energy use and conservation among countries must take them into account. Unfortunately, it is difficult to understand the impact of policies quantitatively, in part because many were cast before a quantitative measure of residential energy use was available. It is even more difficult to isolate the effect of particular policies on decisions that cause observed changes in energy use. Accounting problems, such as the counting of wood, electric and district-heating when they substitute for oil, are often confusing. Fortunately, the differences in consumption between Swedish homes and those elsewhere, as well as the overall change in patterns and consumption levels in Sweden over the last ten years, are greater than the uncertainties associated with their measurement.

The goal of the LBL residential energy project[1] is to develop and analyze quantitative information on energy use patterns, and to analyze issues such as those posed above. This goal requires the reconstruction of residential energy use patterns from original data sources. This paper first presents time-series data on various factors that are important for understanding trends in energy use. It then presents energy use in terms of indicators of the major uses of energy in homes. A full exposition of data on residential energy use in Sweden is presented in a working paper.[2] We review trends in space heating (by fuels) and appliances, with emphasis on single family dwellings. Subsequently, we evaluate the energy conservation achievements and evaluate two key elements of residential energy-conservation policy.

We use the following abbreviations: SEK, Swedish crowns (worth about US$0.19 before 1971, US$0.21-0.24 from 1972-81, US$0.18 1981-1982; $0.134 Oct. 1982-); SIND, Sw. Nat'l Board of Industry; SFD and MFD, Single and Multi-family Dwellings; SCB, Central Bureau of Statistics and their yearly publications: ESH, Energistatistiken för Småhus (Energy Statistics for SFD); EFH, Energistatistiken för Flerfamiljshus (for MFD). EOF, El och Fjärrvärme Statistik (Electricity and District Heating Statistics).

2 THE DETERMINANTS OF RESIDENTIAL ENERGY USE IN SWEDEN

This section we summarize data on some of the key factors that shape energy use in homes.

2.1 Economic and Demographic Data

Key economic and demographic data for Sweden for the period 1965-1980. Data on income and prices are taken from various SCB publications. The most important forces that shaped energy use include continued growth in population, disposable income, the drop in persons/dwelling, the increase in dwelling area, and the abrupt changes in energy prices. We discuss these factors in the following sections, noting that we normalize energy use to the dwelling.

Population growth slowed from a relatively low 0.7%/yr. to an even lower rate after 1972, 0.3%/yr. Because we have normalized most uses to the dwellng, we do not discuss population size or growth per se, but do pay attention to people/dwelling.

People/dwelling decreased steadily in the period studied, both in SFD and MFD. Because living area per dwelling for SFD increased significantly, while that for MFD did not change much, total living area per capita increased by more than 1/3 during the study period. Heated area tends to be somewhat larger, including basements and other spaces, but also varies as people attempt to reduce heating costs.

Disposable income. We have chosen disposable income (DI) as a measure of consumers' ability to pay for energy services. Since many expenses are met through subsidized services paid from tax revenues, or from tax advantages, disposable income underestimates living standards. Moreover, the share of DI in the total GNP has fallen steadily in Sweden, so that a bias is introduced over time by using one or the other. We show DI and GNP in Table 1. DI/capita grew at an average annual rate of 1.2% through 1972 and 2.6% thereafter.

Energy prices. Real prices for most energy forms fell from 1960 through 1972. The period 1972-1980, by contrast, was characterized by increases in oil prices during 1973-75 and 1979-80, reflecting the increases in the world price of crude oil, deterioration of the dollar exchange rate of the Swedish Krona (SEK), and addition of taxes to the price paid by consumers. During early 1982, for example, the oil security tax, which finances oil storage in Sweden, was raised by about $1.00/bbl. Most of the oil consumed was #1 heating oil. Heavy oil, burned in apartments and district-heating plants, has always been 10-30% cheaper than #1 heating oil, but more difficult to use, and actually lost part of the market to #1 oil.

The prices of district heat (DH) and electricity have not increased nearly as quickly as that of heating oil, in part because the fixed charge, while indexed to inflation, is a significant part of the total average cost of these energy sources. Moreover, electricity in the late 1970s was generated principally from hydro and nuclear power, while DH relied on cogeneration from oil and wastes as well as the direct burning of heavy oil. Electricity is taxed directly, and the oil that is the principal fuel in DH stations is also taxed. In late 1982, there was almost no difference between the marginal price of heat from electricity, DH, or oil converted to heat at 66% efficiency.

2.2 Housing Stock and Equipment

The indoor standard of living in Sweden, as defined by space per capita and indoor temperature, was the highest in Europe in 1960. Central heating was found in 74% of all homes, hot water in nearly as many, and major appliances were highly saturated. (Virtual saturation of these devices was reached by 1980.) Average living space per capita was also the highest in Europe in 1960 and remained so in 1980, despite the fact that the majority of dwellings have always been apartments.

Table 1 summarizes important characteristics of the housing stock for Sweden. During the 1960s, the number of single-family dwellings (SFD) was almost stagnant, with new construction only slightly outpacing demolition. The number of apartments (MFD), on the other hand, increased rapidly because of a massive government program. In the 1970s, higher incomes and tax deduction rules applied to higher marginal taxes, as well as increased auto ownership, made SFD ownership very attractive. The share of SFD, which dipped through 1975, rose to 44% of the available stock, and the numbers of second homes almost doubled. All during the period studied, the average area of dwellings, as well as area/person, increased steadily until construction and heating costs caused the increase in home area to cease. Although MFD still dominate, per capita consumption of heat and electricity is not much lower in apartments than in SFD. Thus, total energy use in Swedish homes is not greatly reduced because of the predominance of MFD.

As a consequence of high central heating (CH) penetration, hot water equipment was nearly saturated in Sweden by 1970. The long heating season made combined heat/hot water production attractive until oil prices increased in 1973. Cooking equipment was saturated in the early 1960s, but there was a marked conversion from wood and gas stoves to electricity. Appliance ownership increased even more rapidly than central heating penetration during the 1960s and 1970s (see Table 1).

These data show that the 1960-1975 period was characterized by important increases in the standard of housing and equipment in Swedish homes. We believe that these increases were almost entirely responsible for the increases in energy use observed during that period. Leveling off of these trends after 1975 appears to have been overlooked by key Swedish forecasts in the 1970s.

2.3 Heating Fuel and Equipment Choices

Because of the cold climate, heating fuel and system choice have always figured in consumer decisions about housing, even to the large companies that manage thousands of apartments. Table 2 summarizes key elements of the evolution of heating systems and fuels in Sweden. These distributions were derived from mostly unpublished surveys from a variety of sources (see Ref. 2). Solid fuels, particularly wood, were important in the 1960s. By 1972, however, there had been a considerable move away from them. More than 90% of the dwellings heated by wood, kerosene, or coke in the 1960s switched to oil, and by the early 1970s, electricity. New dwellings were increasingly heated by electricity (for SFD, up to 60% in the late 1970s) and by district heat (for MFD, up to 75% in the late

1970s), and conversions to electricity and DH from oil increased after 1973. Thus, fuel substitution was a key feature of the recent evolution of space heating. (Most of the data in Table 2 are published here for the first time. There being virtually no official data on heating systems or consumption before the surveys of the late 1970s, the present study turned to a large number of unpublished surveys undertaken or maintained by energy companies and the Sw. Inst. of Public Opinion.)

3 RESIDENTIAL ENERGY USE

We have been able to derive energy consumption by end-use and fuel for several years in the 1963-1980 period using a combined "bottom-up" and "top-down" procedure. We first present some detail on the most recent year for which we had data. In this study "end-use" energy is that passing the building boundary, also called secondary or purchased energy. We exclude conversion losses in powerplants, district heating stations or distribution systems, and gas production facilities, but include all losses incurred from energy conversion within homes or within heat centrals in apartment buildings and complexes ("kvartercentral").

3.1 The 1980 Picture

The mix of fuels, systems, and end-uses in Sweden in 1980 is shown in Table 3. In correcting for climate, we divide consumption for heating by a normalization factor to adjust total consumption for climatic differences among years. This factor was the ratio of the long-term average number of degree days (base 18°C) to the actual number.[+] [3] The normal year has 4010 DD_{18c}, based on the published Swedish average 3760 DD_{17c} adjusted to our 18°C base, and weighted for the distribution of dwellings.

In Table 3, we show the number of consuming units, energy intensity, and total consumption of each energy source for each end-use. It can be seen that oil and electricity dominate the picture, especially if the oil base of DH is included. Coal, coke, and kerosene, as well as city gas, have all but

+This differs somewhat from the corrections made by SIND and others.

disappeared, although natural gas is slated for introduction in southern Sweden in the mid-1980s. SFD are heated 1/3 by electricity (counted as central heat), 1/2 by oil, and the remainder by wood or DH. There are a few thousand SFD still using kerosene or coke in non-central stoves, and 15,000 using principally wood stoves. Multi-family dwellings, which outnumber SFD (55%-45%), are heated by DH (48%), direct-fired oil (48%), electricity (3%), and gas ($< 1\%$). Less than 10,000 are heated non-centrally with gas or kerosene. While the Swedish climate is one of the coldest in Europe, (4010 DD_{18C}), the tightness of building shells keeps the share of heating in end-use energy at under 66%, low for Europe.

Sweden has seen a revival of wood use in main boilers and as a secondary fuel in quantities that rival the thermal content of electricity used for heating. The first wood figure in Table 3 represents the use in principal heating systems; the second figure for SFD represents wood used as a secondary heat source in homes with electric or oil-fired systems. Wood use reached a low point in the 1972-75 period, but has increased since. Similarly, a smaller quantity of electricity is used as a supplement in oil-burning homes, particularly for hot water production.

We aggregate and summarize the energy intensities (energy/unit consumption) into indicators, shown near the bottom of Table 3. These indicators relate energy use to the structural factors discussed above, including dwelling size and climate, and facilitate international and intertemporal comparisons of residential energy use. The heating indicator shows that space heating in 1980 required 184 $kJ/DD/m^2$ of floor space. Consumption expressed in similar terms in England is slightly lower, but indoor temperatures are several degrees below those in Sweden, and central heating saturation in England is only 60%.

In order to draw conclusions we bring indicators together with summary data from other years to illustrate important trends in Swedish residential energy use. Readers familiar with OECD residential energy use patterns will see immediately that heating consumption in Sweden is relatively low.

3.2 Residential Energy Use Trends

We have assembled summary energy intensities in Table 4. Also shown is total energy use (with the heating portion corrected for climate), and the shares taken by fuels, electricity, and DH. Both primary and secondary (or end-use) energy are given. We give the shares of dwellings using electricity or district heating, which are calculated at their end-use consumption values. This allows the reader to judge the impact of fuel structure changes on end-use consumption.

The increase in energy use per dwelling between 1963 and 1972 was caused principally by increases in saturation of central heating, hot water systems, and electrical appliances. The latter two uses contributed somewhat to actual heating of homes, since part of the waste heat from these activities is captured in tight Swedish homes. Additionally, the number of occupants per dwelling decreased. The nominal size of homes increased from about $75 m^2$ to $88 m^2$ from 1960 to 1980. SFD area increased from $92 m^2$ in the early 1960s to over $120 m^2$ in 1980.[+] Finally, the number of people per dwelling fell steadily. Thus, living space/capita increased 43% and heated space by an even greater amount. As a result, total energy use grew considerably faster than increases in population or the number of dwellings alone would indicate.

Total energy use by fuels is shown in Fig. 1, with primary energy use shown as well. The components of change discussed above are shown in Fig. 2. The drop in total energy use after 1975 is clear, as is the slower growth rate in primary energy use. This is an important observation; as population and the number of dwellings grow more slowly, and as energy-using systems are saturated in dwellings, residential energy use will in all likelihood virtually cease to grow. Modernization of existing homes, as well as the replacement of old stock with more efficient new stock will then cause a decrease in energy use. If energy prices increase, this decrease could be even more marked, because there is little evidence that new homes built today have by any means exhausted economic or technical possibilities for reducing heat needs.

+ The actual areas heated, including garages and other spaces, were typically 20% larger.

Actual heating intensities both increased and decreased during the 1960s and 1970s. Average oil use in homes with CH increased by only 10% between 1960 and 1972, according to oil and apartment company records. However, this growth was far less than the increase that occurred when a home with non-central heat converted to central heat. The increase in dwelling area and average indoor temperature also pushed up heating energy use. Growth in energy use did not keep pace with these factors, however, implying that homes became more efficient even though incomes grew and energy prices fell. The main reasons for improved efficiency were improvements in new and existing structures as well as improved boilers and control systems.[4] B. Hammargren of Riksbyggen, a firm operating tens of thousands of apartments, estimates that energy use in 1970 was 5% below what would have obtained if temperature increases during the 1960s were not offset by efficiency increases.

Hot water use increased markedly during most of the period we studied, reflecting the increased penetration of systems in which hot water production is combined with heat. For these calculations, however, we have assumed a constant quantity of oil allocated to co-production of hot water through 1972. This assumption is not unreasonable, considering that the known increase in hot water use per capita was probably partially offset by the decrease in persons/dwelling. There is, nevertheless, greater uncertainty in this intensity than in the others. One major review in the Swedish literature indicates no trend.[5] We have, however, attributed some of the drop in oil use to more efficient hot water after 1975. It is unfortunate that there are so few measurements of hot water use. Instead, hot water is lumped with space-heating in most studies and data bases, even though it has considerably different characteristics.

In contrast to hot water, energy use for cooking fell steadily for both gas and electric stoves. The cause of the decline is predominantly social: more working couples cook fewer meals, more young children get hot meals in schools or day-care centers, less time is spent cooking, and families themselves are considerably smaller. In addition, electricity has replaced city gas for hot water and cooking in all but about 180,000 dwellings, most of which are apartments.

In order to relate changes in these intensities to important physical or economic factors, we form indicators of energy intensity, shown in Table 5. These indicators also allow better comparisons among countries or dwelling types.

We form indicators such as heat/dwelling/deg. day, heat/area/degree day, hot water/capita, and appliance electricity use/disposable income.+

The heating indicator in Sweden changed little during the 1963-72 period. By contrast, these indicators grew markedly in other countries because of the rapid growth in central heating, which typically doubled heat use in a home compared with stoves. If the heating indicator is divided by average dwelling area the resulting figure is unchanged during this period. This is significant; we have found that Swedes did not really become wasteful of heat during a time of increased prosperity and increasingly cheaper energy. While standards in Sweden were already high in 1963, the indicator suggests that constant progress in improving efficiency offset increased heating needs. After 1972, the heating indicators began to fall in Sweden.

The hot-water and appliance indicators grew considerably through 1978, consistent with what we have seen in most other countries. Indeed, appliance electricity use grew considerably faster than income, at least through the late 1970s, as equipment ownership increased. After 1978, however, growth in these indicators slowed, as the number of systems approached saturation and use became more efficient.

Based on the changes in prices and incomes after 1972, we would expect a strong drop in residential oil use. Increasing appliance saturation should raise electricity consumption for non-heating somewhat, and stable or falling electricity prices should encourage the consumption of electricity for heating and hot water. First, the declining price of electricity relative to fuels could cause substitution for present use of fuels. Second, the absolute decline in electricity prices could cause increased intensity of electricity use for each application. To see whether these expectations have been fulfilled, we next examine

---

+ In order to account for the differences between electric, district, and fuel-based heat and hot water, the first two are counted at a nominal 66% efficiency, as if oil. If only end-use energy were counted, the space heating indicator given above in the text would be 161 $kJ/dd/m^2$. Using this conventional indicator, however, the time series of energy consumption would be biased downward because of the rapidly increasing share of electricity and DH, with no combustion losses within the building. Counting primary energy would bias the indicator upward. The convention we have adopted is a reasonable compromise.

heating and appliance energy use in detail.

4 ENERGY CONSERVATION SINCE 1972

Here we compare energy use for heating among fuels and dwelling types to obtain a picture of energy conservation in Sweden since 1972. There are no official data covering the whole decade of the 1970s, so one must take care in making comparisons from different surveys. Fortunately, the data we have collected can be merged to yield time series of the use of heating fuels and energy for other purposes.

4.1 Heating and Hot Water in Single-Family Dwellings

Table 6 shows energy consumption for heating and hot water in SFD in Sweden over the 1963-1980 period. The three fuels (oil, electricity, and DH) in the table represent over 85% of the energy consumed in SFD in 1980. Data were taken from several annual surveys of residential energy use. Approximations were made only for purposes of estimating consumption in new homes relative to existing homes and in reconstructing the likely use of coke and kerosene in the few remaining homes using these systems. Heating is corrected for climate.+

About 40% of the SFD are now equipped to use two or three fuels for heating. Fully half or more of these homes converted to these multifuel systems in the last few years. Most use boilers that can utilize oil and wood or electricity. Presently, electricity is competitive with oil for heating, and probably cheaper than oil during the summer months when oil furnaces used only for hot water have a very low efficiency and when the electric system has excess capacity. Wood is purchased or gathered by at least 500,000 households.

+ If the correction is not made, comparisons become meaningless. The number of degree-days in 1972, for example, was about 97% of normal, while it was nearly 112% of normal in 1980. Comparing these years with no adjustment for climate could obscure great changes in consumption habits and efficiency.

The presence of wood as a backup fuel is important for understanding developments in Swedish energy use. Is it possible that the decrease in oil use was caused in part by increased used of electricity or wood? Data from the largest heating oil distributor, OK, show that oil use for their customers has indeed fallen steadily. Their customers are representative of "normal" users who heat predominantly or only with oil.+ The OK data agree with Energistatisken för Småhus (ESH), the yearly energy surveys performed since 1977 by SCB,[6] according to a comparison made by K. Munther[7] and by our own comparison. (These surveys cover homes built before 1977 and so do not take into account new stock, but the number of new homes using oil or oil and a backup is about 4% of the stock. ESH excludes groups of homes using collective oil-fired centrals or DH from the consumption averages they publish.) This suggests that the OK data are representative of the changes in unit consumption of oil in SFD. Although we believe that the time series for each fuel presents an accurate picture of changes in energy use in Sweden, caution is advised when comparing "all users" of a given heating fuel with those using "only" that fuel. In Table 6, users of a single fuel are labeled "only".

4.1.1 Heating oil

Data for heating oil use were obtained back to 1973 from OK, and we have added consistent data for 1970 and 1972 from other companies, which we average for those two years. For comparison, data from homes using "only oil" from ESH and the Nat. Board of Industry (SIND),[8] are included. Movements are similar. We have removed 35GJ/dwelling before 1975 for hot water, 34 GJ for 1976/7, and 30GJ in 1980.

According to the OK series, oil consumption fell during the years in which the real price of oil was stagnant or dropping (1975-8). When prices jumped, however, consumption dropped noticeably. Total oil consumption per SFD, corrected for climate and including hot-water use, dropped 18% from the 1970/72

+ These customers belong to a computerized delivery service steered by a program that analyzes past use patterns and weather to predict the next fill-up. Consumers using little oil or using oil irregularly would by definition not be "automat kunder", as these customers are called.

average to 1978, 7.4% between 1978 and 1980, and about 4.3% more in 1981. Between 1972 and 1978, the size of an oil-heated dwelling increased somewhat (about 5%), but after that period the largest oil-heated homes tended to convert to multiple fuels. The drop in intensity between 1975 and 1979 is somewhat surprising, given stable or falling real oil prices; our data from other countries[1] show increases in intensity during these years. This drop may be a sign that government and indivual efforts had an effect on consumption, but that the response to the 1973/4 price increases was lagged because of the time it took people to plan and execute retrofit investments.

The increase in prices in 1979 and 1980 had an obvious effect on consumption, but many conservation measures were already in place. If consumption had not drifted downward between 1975 and 1978, there likely would have been a more dramatic decrease in actual consumption in 1979 and 1980, as was the case in Germany and Denmark.[9] It is not known, for example, whether falling real prices caused indoor temperatures to rise during this period, or whether there was a rebound in 1975 after the initial oil crisis of 1973/4, when these temperatures were undoubtedly suppressed. It is believed that consumption in the years 1975-78 was closer to "normal" in terms of comfort.[10]

We conclude that energy intensities in oil-heated homes in Sweden fell by about 38 GJ/dwelling for heating and hot-water between 1972 and 1980. However, about 9PJ of wood and 0.75PJ of electricity were used as secondary fuels in 330,000 SFD in 1980. It is likely that 3/4 of this backup heating was added since 1972. If these fuels are averaged into the entire oil-heated stock in 1980, about 9 GJ/dw should be added to the actual oil use intensity. This means that about 1/4 of the reduction in oil-use from 1970/2 to 1980 was accounted for by the use of back-up fuels that presumably were not used in 1972.

4.1.2 Electric heating

Electricity use has taken a somewhat different course than oil. Prices were relatively constant until 1978. Correspondingly, there was only a small drop in the apparent intensity in homes using only electricity for heating. However, the data on electric heat are clouded by several uncertainties, and it is difficult to look back before 1977.

The SCB data in Table 6 are based on total electricity consumption in all non-farm homes subscribing to electric heat. The non-heat part of electricity use is estimated from each year's average consumption in SFD without heat and removed from the data. This procedure is risky since homes with electric heat pay significantly less at the margin for electricity and therefore may use more for appliances than those without electric heat. Moreover, there were few with boiler circulation pumps before 1977, most being heated with resistance heat. However, total consumption per dwelling obtained this way agrees well with that in ESH.

There are unfortunately several crucial structural changes that affect interpretation of electric heating data. First, homes that used electric heat previous to 1972 were mostly those converted from solid fuels or non-central heating. These homes were of varying insulation, size, and numbers of appliances. Many electric heat subscribers were probably not using their heat fully. During this period (1965-1972) average use per dwelling increased consistently, as an increasing fraction were new and fully heated. On the other hand, these new homes were considerably better insulated. These changes make it difficult to define a "base case" before 1972.

This problem has been examined by Askerlund,[11] who notes that even in 1975 about 45,000 SFD with electric heat had a second heat source as well. Whether electric heat was considered the primary or secondary source is uncertain, although the number of homes registered with electric heat was large enough to include the 45,000 homes. Askerlund also shows that more than 1/3 of the electrically-heated homes in existence in 1975 were built before 1930 (i.e., conversions from older homes that were probably small). By the end of the 1970s, however, the majority of electrically heated SFD were built after 1970. These new homes were considerably better insulated and much larger than the conversions. In 1979, for example, only about 36% of the non-farm houses using only electric heat and built before 1960 used less than 175 kWh/m^2. By contrast, 73% of the houses built after this period (but before 1976) used less, reflecting better building practices. Thus, it is difficult to make useful before-after comparisons in the stock of electrically-heated dwellings.

Finally, a third of homes using electric heat used a second fuel or back-up in 1980, twice the fraction in 1975. Moreover, the homes with back-up used as much electricity as those with no back-up, principally because they were the largest homes. These homes obtained roughly one-third of their heating energy (ignoring combustion losses) from wood in 1980. This keeps the average electricity consumption for heating down significantly. Furthermore, wood use had a greater impact on electrically-heated dwellings than on oil-heated dwellings. Thus the nature of the use of electric heating and the nature of the dwellings heated, have changed greatly in the last 15 years. Significantly, real electric heating prices began to rise only in 1978. PP Data available from 1977 to 1980 covering non-farm SFD do show important and meaningful trends. Comparing the 265,000 SFD using only electricity in 1977 (about 3/4 of the electrically heated stock) with the the 236,500 remaining in 1980, we find that energy use for heating and hot water has decreased by 20% when the heating portion is corrected for climate. This change suggests some conservation. During the same period, however, the largest electric-only homes converted to boilers using several fuels. The average area of an electric-only home dropped about 5%, according to ESH. If the change in area/dwelling is noted, the drop in heating intensity is only about 15%, reasonably consistent with the drop in oil use over the same period. Note, however, that oil heating intensity was significantly lower in 1977 than it was before 1973, while electric heating intensity had not changed much during this period of nearly constant electrcity prices. Since the price increase for electricity was only significant after 1979, we expect to see similar movements for electricity and oil after this time, as the data show. The decline before 1979 might have been caused by the program of grants and loans, discussed below. Data from ESH for farms are not complete and difficult to analyze, and wood use is far more prevalent than in non-farm dwellings.

In summary, our figures for non-farms show a savings of approximately 7.4 GJ/dwelling between 1975 and 1980, which we have assigned to heat. These savings are somewhat larger than the thermal energy content of the increased wood burned as a backup in some of these homes in 1980.+ Furthermore, homes built before 1970

+ Unpublished surveys from the State Power Board show that at least 20% of the homes claiming to use electric heat in 1971 or 1975 also used another source, presumably wood. Thus, only part of this wood represents incremental consumption since 1975, which we estimate at 3PJ.

and heated (in 1980) only with electricity had an average area of 112 m^2; those built after 1971 were 21% larger. Hence, electrically heated non-farm SFD appear to have used about 20% less electricity/area for heat in 1980 than in the 1972/75 period. Clearly, the effect of back-up fuels, hidden before 1977, has been to allow consumers to reduce their demand for electricity for heating more than otherwise. Even so, factors are considered when all homes with electric heat appear to have reduced consumption of heat by about 10% between 1972 and 1980.

4.1.3 District heat

Dwellings with district heat (DH) are included in the table for the years in which accurate data are published, 1974 onward. Most SFD are metered, and prices have risen in real terms. Connections have increased, mostly in new homes built in groups, since single connections of isolated homes are very costly. Many are row-, town-, or double-houses. SFD with DH are thus the newest and are somewhat smaller than those heated by oil.

We measure DH, like electricity, at the building boundary. The differences in unit consumption between these two sources is surprising, since there are in principal no conversion losses associated with DH, and the homes with DH are on the average newer and more likely row-houses than those heated with electricity. However, the greater heating intensity for DH probably reflects heat losses in subcentrals, culverts and heat exchangers at the site of homes heated with DH, and quite possibly in the hydronic systems in the homes themselves. These are a reminder that DH entails losses (and great expense) in relatively sparsely populated areas.

Table 6 gives unit consumption of SFD using DH, calculated by dividing sales by the average number of dwellings in each year. The effect of the oil interruptions of late 1973 and early 1974 are clear. Consumption in 1974 was severely depressed below 1973, rebounded noticeably in 1975, but then moved downward as DH prices increased. The prices given in Table 6 are for average yearly costs based on tariffs in apartments; in SFD the connection charges are larger. However, the variable cost, which is proportional to energy actually consumed, is considerably lower. The low variable heating cost probably explains why there is little evidence of use of backup fuels in homes heated with DH. Moreover, the young age of the stock means that virtually all are built to standards close to (or better than) those in effect in the early 1970s.

It should be noted, however, that the rapid growth of the stock in recent years itself contributed to the drop in intensity. Most of this growth consisted of connections to new homes. Homes built after 1976, which are included in these data, are much tighter than average, and comprise nearly half of the stock in 1980. This effect probably accounts for half of the decrease in unit consumption shown in Table 6.

4.1.4 Conservation actions

Since 1972, energy intensity in SFD has decreased, as the data in Table 6 show. The decrease in energy/unit area was even greater, but was offset in part by an increase in the size of SFD, particularly in those with electric heat. The decrease in heating energy use was furthered to a certain extent by the decrease in persons/dwelling and the number of hours spent by wives and children at home, which decreased residential energy needs. Increased appliance ownership may also have contributed as much as 2GJ/dwelling of useful heat gains in 1980. However, there is no question that energy, particularly oil, was used more sparingly in 1978 than in 1972. Consumption of the three principal heating fuels dropped even more in 1981.

Several factors have contributed to these changes. The use of electric appliances has increased by about 20% since 1972; at least 2GJ/dw of this increase has been captured as "free heat". Indoor temperatures average slightly above 20°C, probably somewhat lower than before 1972, but still the highest in Europe. Most important, conservation investments made between 1974 and 1980 have had a significant penetration, as the following data from ESH show:

14% (18%) of the non-farm (farm) SFD added or increased wall insulation;
19% (17%) " " " " " " " " " attic "
10% (15%) " " " " " " installed 2 or 3 pane glazing;
27% (18%) " " " " " " installed thermostats
36% (26%) " " " " " " installed new burners or boilers
53% (38%) " " " " " " installed caulking or weatherstriping
24% (36%) " " " " " " did nothing.

Given the high thermal integrity of Swedish homes in 1972, the level of retrofit activity is impressive. In addition, 100,000 homes added a back-up fuel between 1978 and 1980, and at least twice that number did the same between 1974 and 1978. Most of these involve conversions to multi-fuel boilers. There is almost no record of homes using back-up fuels in combination boilers before 1974, though wood was used in stoves or as a principal fuel, and electric radiators served as a supplement to fuel in at least 10% of all SFD.

There is some evidence that indoor temperatures were lower in 1980 than in 1972. However, 79% of all households in SFD (all fuels) reported trying to keep about 20-23°C, with 1% higher and 19% lower, in 1978. For MFD percentages were about the same, but more were in the 22-23°C interval. These temperatures are high by present Danish, American, or German standards, where greater drops in consumption were recorded and far less use of secondary fuels appeared. It is not yet known how much temperatures have been reduced since oil prices increased again in 1979. The available information suggests that temperatures have not fallen much, lying somewhat above 20°C. Elmroth (1982, priv. comm.) suggests that temperatures in SFD in Sweden are still "rarely under 20°C" today, which suggests much higher temperatures before 1973. This was confirmed by a recent measurement of temperature in several hundred homes carried out over several months by Statens Institut för Byggforskning. J. Nörgaard (1982, priv. comm.) makes the same estimate for Denmark before 1972. An investigation of SFD heated only with oil, carried out in spring, 1980,[12] found that the median temperature was about 20°C during the day, hardly different from that obtained for a sample of all SFD with all heat forms by SCB in 1975.[13] This agrees with a 1978 SCB inquiry.[14] While it is risky to compare surveys carried out under different circumstances, there is little evidence of any changes in indoor temperature in oil heated dwellings between 1975 and 1980. However, temperatures in this period were probably below those from before 1972, which may have averaged 22-23°C.

We conclude that households in SFD in Sweden responded to higher energy prices and other concerns primarily by making equipment investments, particularly in new boilers using of backup fuels. Temperature changes seem to have been important only immediately after the first oil embargo. Reductions in actual use of heat in oil-heated dwellings were greater than in electrically heated dwellings; by 1981 the marginal cost of heat in either was about the same. It is worth noting that about 1/3 of the SFD occupants claim they "did nothing" to save energy between 1974 and 1978. And temperatures are still relatively high. This suggests a considerable conservation potential remains.

4.1.5 Oil and electricity compared

Available data[6] permit an interesting comparison of dwellings using only electricity or only oil for heat in 1980. Since most homes in Sweden use direct baseboard electric heat or water borne radiators for oil heat, the difference in consumption represents to a first approximation the losses in energy associated with converting oil to heat and moving that heat to rooms.[15] Since the prices for heat from these two sources was close in 1980, it is reasonable to assume that the standards of indoor comfort are reasonably similar in homes of recent vintage. Moreover, there are few recorded differences in the building shells of homes as a function of heating system for recent years; location is far more important.

Comparing consumption per m^2 of heated area by climate zone for homes built after 1971, we found that oil heated homes use 1.37-1.75 times more energy for heating and hot water, measured as the heat content of energy at the building boundary, than do electrically heated homes. For older homes, these ratios are somewhat larger. The lower figures applies to northern Sweden, with the longer heating season (10 months), and the higher applies to southern Sweden (7-8 months). The difference between north and south reflects the effect of colder temperatures on seasonal efficiency as well as the share of heat in the total consumption for heat and hot water (higher in the North in both cases). If the electrically heated homes are considered to represent a 100% efficient conversion of energy to useful heat, the comparison suggests that properly maintained oil-fired boilers can perform at overall conversion efficiencies of close to 65% for heating.

If these figures are compared for 1978 and 1980 a small decrease in the ratio of oil to electricity use in 1980 is seen. This is probably caused by increased maintenance of oil burning equipment and exchange of components. Moreover, in dwellings built between 1971 and 1976 the oil burner consumes at the lowest ratio to electricity of all homes in all zones, between 1.5 and 1.8, suggesting again that good equipment and maintenance are important. Finally, inspection of all the SCB surveys show that for a given fuel, homes built in the 1970s tend to use less than those built earlier, and those built after 1975 less than those built before. Evolution of the building stock yields a conservation effect, even with constant energy prices, because newer homes are more efficient than old. Higher economic growth favors stock turnover, contributing energy conservation. Growth also favors larger homes, but the former effect has predominated during the 1960s and 1970s.

4.2 Multi-Family Dwellings

It is difficult to interpret the energy use changes in multifamily dwellings for several reasons. Surveys of energy use in apartments cover only the period from 1976 to the present.[16] Results are expressed as energy/area for oil and DH; dwelling area by fuel is not given. Although the consuming unit is the household or the dwelling, it is hard to measure energy use per household to see how much each household has changed its consumption. It is also difficult to subtract hot water use, which was assumed or measured on a per-dwelling basis in a variety of studies. However, unpublished data from two of the largest apartment cooperatives, Riksbyggen and HSB, corroborate our estimates of oil use, while data from EOF give some information on DH.

Heat is not metered directly in the majority of apartments in Sweden. This means that residents have no direct incentive to save energy through temperature control or other means. Owners may profit from improving building shells, heating equipment, or thermostat controls and then withholding the resulting energy cost savings for themselves. Temperatures in MFD (21.8°C) are higher than in SFD (20.3°C) according to the surveys conducted by Statens Institut för Byggforskning (SIB).

We can make some comparisons over time from the limited data. According to EFH, apartments with DH used about 0.75 GJ/m^2 in 1980 for heat and hot water, compared to 0.82 in 1977. This represents a drop of about 8%. For oil heat (excluding blocks that heat more than one home or apartment building), the reduction is about 12% (to slightly over 1 GJ/m^2). Significantly, the figure for either year is close to that for SFD, particularly if we include the consumption in MFD for commons (stairwells, laundry rooms, etc.). The changes in the oil heated buildings were somewhat greater than those with DH, because for the former, improvements in the boiler and burner affect total consumption, as recorded by these figures, while for the latter, these changes take place in the production plant. Unpublished data from the major apartment cooperatives suggest that 1977 consumption may have been 10% less than that before 1973.

Significantly, very few apartments heated with hydronic systems are metered individually for space heat, and only a few are metered for domestic hot water. The impact of common metering appears to raise the energy intensity of apartments to the same level as SFD. Considering the lack of direct metering, however, the reductions that have taken place are impressive and must have been caused by measures taken by owners.

Figures for DH that allow an approximate comparison of pre- and post- embargo practices are available back to 1973. In 1980, for example, we obtain 54 GJ/dwelling+, after correcting 2/3 of this consumption to the normal climate, a convenient approximation used by apartment companies. The average apartment used about 8% less energy in 1980 than in 1974. But use in 1976 was 6% higher than in 1974, close to what VVF considers the the historical value of use/dwelling, 63 GJ. Compared with this high value for 1976, 1980 use was about 14% lower.

Electric heating in apartments is increasing more slowly than in SFD, probably because most apartment occupants are billed directly, in contrast to those in buildings heated by oil and DH. Moreover, the number of dwellings paying directly for electric heat increased notably in 1980. The data from EOF or EFH are difficult to interpret, since it is hard to distinguish electricity use in

---

+ This figure is uncorrected for the proportion of area in buildings that is heated but not used for living (such as offices, stores, or garages.

collective space, in apartments, and for heating. EFH gives electricity use per unit area only for buildings in which tenants do not pay directly for their heat. This cannot be taken as representative for the entire stock.

It is worth pointing out that in Germany and Denmark, where apartments are more frequently metered, reductions in use per dwelling have been considerably greater than in Sweden, and have responded more swiftly to oil-price increases. Thus, metering seems to be effective in reducing energy use. Because of the lack of metering in Sweden, there has been little use of multi-fueled systems in MFD, since the tenant would pay directly for the secondary heat source.

An interesting trend in MFD is the appearance of electric heat pumps to provide hot water, particularly in oil-heated buildings. Hot water and heat have historically been produced in the same boiler. These new systems are fueled principally by the warm exhaust air from apartments, the majority of which have mechanical ventilation.[17] These heat pumps show promising energy savings, particularly since the oil burners are so inefficient during the summer months. Heat pumps saved about 7.2 GJ/apartment, according to partial results gathered from 934 dwellings in 12 buildings. With a cost of about 530 SEK/GJ saved per year, the rate of return is around 7% (nominal) at 1980 prices. Significantly, all the tests received some government support, which appeared to be crucial to getting them underway. The test results also suggest that far greater economies are possible in the form of lowered investment costs.

We conclude that energy savings in MFD have, on the whole, been somewhat less than those in SFD, considering district heating and oil. This is not surprising, given the lack of metering. However, the trends of the last few years are encouraging. New apartments will now be outfitted for individual metering of hot-water use as well as for gas and electricity. However, there is no intention to meter heat, in part because of the problem of heat leaking between apartments. There will thus be no direct incentive for occupants to reduce heating use through behavioral changes or greater attention to valves and thermostats. Remaining heat conservation must be carried out by building owners and must concentrate on the building shell, heating equipment, or automatic control equipment.

4.3 Electric Appliances and Cooking

From data on consumption in homes without electric heat, we removed electricity use for cooking and for hot water heaters. The remainder represents electricity used in appliances, including some hot water for washers. To characterize appliance electricity use, we use an indicator incorporating disposable income, the measure of the household's ability to buy appliances. This indicator is shown in Table 5.

One can see from the data in Table 1 that saturation in appliance ownership appeared in the late 1970s, although recession may have depressed electricity consumption or ownership growth somewhat in 1978. Nevertheless, the rate of growth in consumption/dwelling (Table 4) was markedly slower after 1972 than before. Consumption per unit of disposable income also grew more slowly at 1% per year for 1972-80 compared with 4.7% per year before that period. Inspection of the details of appliance ownership confirms that there was less growth in ownership of major items after 1975 than in earlier years.

There is also some evidence that newer appliances are more efficient than older ones. Refrigerators advertised by Electrolux, the major Swedish manufacturer, use 30% less energy today than eight years ago for the most popular sizes. However, the relatively low price of electricity dampens interest in efficiency. Information from Germany, Denmark, Japan, and the USA,[18] where electricity prices have been higher and increasing more, indicates that virtually every appliance offered for sale is available in a significantly less energy-intensive version than a similar model 10 years ago. Whether consumers or builders actually buy more efficient appliances is another question.

Many Swedish experts point out that the heat given off by appliances is captured and used to heat houses. To the extent this is true, the economic incentive to reduce appliance electricity use may be somewhat reduced. The near equality of the price of electricity and that of oil underscores this point: why not let more of the heating load be satisfied by waste heat from appliance processes? One problem is that tighter houses use heat during fewer months than leaky houses, and not all of the waste heat from appliances is used in rooms where people need heat. Moreover, no heat is needed in much of the summer. We believe that the benefits of this free heat need to be examined more closely; there may be a greater incentive to improve appliance efficiency than previously thought. In MFD, tenants with water-borne heat have every incentive to reduce appliance electricity use since that is generally the only energy they pay for: "Free heat" is not free.

While improved appliance efficiency may have retarded growth in electricity use somewhat, we suspect that the main reason why growth has slowed is the saturation of appliances. Major areas of growth that remain include only dishwashers, and possibly seat and engine heaters for automobiles. In addition, there is a trend towards increased electrification and heating of second homes, but this is small compared with energy use in principal residences.

5 RESIDENTIAL ENERGY CONSERVATION POLICIES

The 1970s have been marked by determined policies on the part of the Swedish government to reduce the use of heat in homes through investments in technical improvements. A series of official government energy studies, induced by the oil crises of 1973/4 and 1979, and the Nuclear Power Referendum of 1980 have all focused Swedish politics on energy to the near exclusion of many other traditional issues. In the charged atmosphere that accompanied the nuclear-power debate, there was a great explosion of information for lay and technical people on how to save energy in an already efficient building stock. County ("kommunala") information programs, fairs, training, and publicity have had a wide impact, judging from the speed at which information on new technologies has reached even the most isolated parts of Sweden.

This section reviews two aspects of policy. Building codes have been in effect for many years. They were tightened with respect to energy, effective Jan. 1 1977, and will be tightened again in 1982. The other key policy influencing residential energy use has been the decision to provide loans and grants (for up to one third of the approved cost) for measures to improve the performance of existing homes. This policy began in 1974 and continued through 1980, at which time their effectiveness was evaluated. In addition, there has been a campaign supporting both prototype buildings with special energy conservation ideas and tune-up of boilers.

5.1 The Impact of Loans and Grants

Between 1974 and the end of 1979, 320,000 SFD and 840,000 MFD (about 20 and 40% of the stock of SFD and MFD respectively) were given conservation grants and loans. These were analyzed by the Energihushållningsdelegation, or EHD (Energy Conservation Delegation).[19] The total government cost during this period was 10^9 SEK in grants, while loans, which covered 90% of the remaining expenditures except free labor, extended to 2.5 x 10^9 SEK. The expected savings (all fuels mixed) were about 10.5 PJ per year, giving an investment cost of 360 SEK/GJ saved annually and a savings of about 10 GJ/dwelling. Since the cost of oil by 1980 had reached 39 SEK/GJ in 1980 currency, the simple rate-of-return of 10% is in the range that appears attractive to society, but below that normally demanded by consumers in making discretionary expenditures. (The cost of materials in these improvements -- perhaps 65-80% of the total cost considering the use of free labor -- includes the value-added tax (MOMS) of about 23% of the net cost. Oil and electricity, while taxed as energy, are not subject to MOMS. Hence this rate of return underestimates the actual return to society.)

The difficulty of measuring the impact of government programs has haunted conservation investigations in virtually every country. In Sweden, thorough investigations of the nature of the building stock began in 1977, three years after grants for conservation were begun.[20] The data from ESH have been collected since 1977 from a random sample whose population is well studied. The data from oil companies are less well understood, but records go back into the 1960s, as our survey of four companies showed. Thus, it is possible to compare the results of programs with the evolution of the entire stock, as Table 6 suggests.

In a wide-reaching investigation[10], a group of institutes working under the SIB examined consumption data from over 1,000 homes in several counties in Sweden covering periods before and after retrofits were undertaken. These homes were selected from lists of those that had received state aid, and included SFD as well as MFD. They divided their sample according to measures taken to see the impact of each measure or combination thereof. The group examined actual consumption records for homes they studied, and used a mathematical model to predict consumption and allow for the short-term reduction in temperatures during the 1974-75 period. Indoor temperatures were unfortunately not measured. There was no control group per se.

The most important finding was that the actual savings on average agreed well with that expected from theoretical considerations. That is, work indicated in applications for loans and grants was carried out successfully. It must be pointed out, however, that the typical spread in average consumption in any sub-sample of homes that all undertook a given measure or combination of measures was almost always larger than the average savings for that sub-sample. Moreover, the prediction of savings for any individual dwelling was poor, even if the predictions were accurate on average. In spite of these uncertainties, the savings are still statistically significant. Since changes in many of the parameters used to calculate theoretical savings could be made without changing the results significantly, the findings were robust. Examination of consumption after measures were taken showed that the reduction was persistent, remaining through the duration of the study period. There were a few cases in which savings exceeded calculations, though the possible impact of additional measures taken but not reported or changed indoor temperatures was not studied.

The interaction among measures was strong. Great increases in insulation accompanied by adjustments to heating equipment and thermostats had a greater effect than the sum of the individual effects. Indeed, a reduction in thermal losses without adjusting the equipment accordingly proved disappointing because the equipment was left overdimensioned, and therefore less efficient. These considerations emphasize the importance of careful scorekeeping to chart the effectiveness of measures.

The consumption in all dwellings that underwent each combination of measures was aggregated into a time series in such a way that the points in time when measures were taken coincided. This series exposes a striking feature of consumption patterns: during the periods before and after measures were taken there was little or no change in consumption upwards or downwards. The entire change appeared when the measure was taken. This effect, of course, is lost when the aggregate data in Table 6 are examined, since conservation measures may or may not have been taken in these homes. The very limited changes in consumption in individual homes, beyond those caused by retrofit, even in periods of rising prices, suggests that the demand for <u>heat</u> (as distinct from heating <u>energy</u>) in Sweden is inelastic, but that consumers will undertake physical modifications to their homes to keep costs down.

This finding suggests an important conclusion: it is possible through government programs to lower effective energy use during times of high but stable prices. Elmroth[21] pointed out that the kinds of measures he studied had in many cases payback times of 10-30 years. Private persons would not normally undertake these measures,+ but the government program apparently induced them to do so. Since consumption did not increase afterwards, it is possible to surmise that consumers withstood the temptation to increase temperatures when the cost of heating was lowered by conservation measures. Alternatively, indoor temperatures may have been already at a level where further increases were worth less to the occupants than their cost, at least in SFD. The effect of government programs, at least in Sweden, was to stimulate investments that resulted in effective energy savings, without giving away "free" comfort.

On the other hand, the homes in the sample for the Anderlind study were selected because their owners undertook measures. It is possible that other households varied temperatures instead and so reduced consumption, or undertook retrofits without government support. The reduction in oil use per dwelling for the <u>entire</u> oil-fired stock (see Table 6) was greater than that credited to the government program alone. It is likely that oil-heated homes reduced consumption whether or not they received state aid and whether or not they invested in conservation. Indeed, ESH-81 shows that twice as many conservation investments were undertaken without state aid as with. A more detailed investigation of a control group -- homes that did not receive aid -- is possible with material collected for ESH, and will be carried out to compare the overall economic impact of grants. It would desirable to compare the impact of grants and non-supported investments on homes with different principal heating fuels, since prices have moved differently over time.

Anderlind et al. noted that most (70-80%) of the owners of SFD that they analyzed claimed that they would have made these investments anyway; the fall in consumption in all homes also suggests this. In apartments, however, far fewer building owners responded similarly. In both cases, these questions were asked

---

+ A survey undertaken in Germany for German Esso, and a similar one undertaken by the magazine Der Spiegel, also found that consumers undertook predominantly the simplest measures with the shortest paybacks or lowest investment costs when no state aid was involved.

two years after the measures were undertaken, by which time energy prices had increased. When the homeowners were asked again after an additional year had passed, even more said they would have invested without government help. The authors concluded that the program at least accelerated the interest in conservation. We conjecture that many of those questioned recognized the benefits of conservation after the fact and therefore responded positively.

It should also be noted that for SFD, at least as many occupants carried out investments without state help as with, according to ESH for 1981, made available in late 1982. While analysis of the patterns of grants is underway by the author and several other workers, it is clear that much investment did take place without grants or loans even if investment was in every way eligible for such aid. It is important to see whether those that took grants had any greater or lesser incentive to invest in retrofit than those who did not, and understand the nature of those who claim they did nothing. Differences in housing vintage, behavior, and fuel type or system may explain some of the differences in response. For example, almost half of the "did nothing" subset of non-farm SFD lived in homes built after 1970, which may have been "tight enough" for the level of energy costs existing in 1981.

The data in Table 6 suggest reductions on the order of 30 GJ/dw have been achieved in oil-heated SFD since 1972 through all measures, reductions of about 10 GJ/dw in those with electric heat, and somewhat more for those with DH. The program itself seems to have been responsible for part of these savings (including those with the longest private payback times) and further appears to be responsible for the continuing drop in oil use (but not electricity use) during the period of steady prices. Significantly, oil consumption per dwelling was constant or even rising in the other well-heated OECD countries (Ref. 1). This suggests that the Swedish program succeeded in stimulating investments that might not have been made during this period. The program seems to be unquestionably responsible for savings in MFD, given the lack of metering and the indication of owners that the investments would not have been undertaken without government help.+

+ It is worth noting, however, that more tenant groups are pressuring owners in Sweden to undertake measures as the cost of heat, included in the rent, rises.

On the basis of this analysis, we conclude that the program in Sweden has been successful in supporting investments in efficiency and reducing consumption through long-lived measures undertaken during a period of otherwise lowered interest in efficiency. We conclude that, given the subsequent boost in oil prices, this program helped significantly to prepare Sweden for dealing with further hikes in energy costs. However, the impact of investments and behavioral change unaided by direct grants or loans was considerably larger. The main effect of the program may have been one of demonstration and acceleration.

5.2 Swedish Building Codes

In 1975 a new supplement to the Swedish Building Code was developed. It came into force Jan. 1, 1977 and required a significant decrease in thermal transmission and infiltration in new construction. The allowed transmission values of key components, and the allowed ventilation rate (in air changes per hour), along with the values in effect before that time and the proposed values for new homes with electric resistance heating, are shown in Table 8.

TABLE 7

Insulation Requirements in Sweden (Stockholm and South)

Component	External				Floor on crawl-	Ventilation
	Walls	Roofs	Glazing	Doors	space, ground	Air changes/hr
1967 Code (k)	0.30	0.35/-	3.0	-	0.40	0.7
(R)	17	15	1.5	-	13	
1975 Code (k)	0.30	0.20	2.0	1.0	0.30	0.5
(R)	17	26	3.0	4.5	17	
1984 Elec.(k)	0.17	0.12/0.17	2.0	1.0	0.20	0.5, MV
(R)	31	43/31	3.0	4.5	26	

Source: A. Elmroth, priv. comm., and Statens Planverk. K-value is in $W/m^2/^oC$; R-value in $(Btu/hr/ft^2/^oF)^{-1}$. The 1975 code took effect in 1977. The 1984 revision will apply only to direct electric-resistance heating. MV indicates mechanical ventilation and heat exchanger may be required.

We can compare these values with actual practice in the region in Sweden from Stockholm southward. Hammarsten found that K-values for walls in existing SFD in 1977 varied from 0.55-0.60 in those built before 1940, to 0.36 in those built between 1960 and 1975. This suggests no radical change between new requirements and actual practice at the time, particularly if we assume that this average reflects lower values in the 1970s. A single-storey home (without basement) of 130 m^2, built according to the SBN-75 standards, heated to 21°C with electricity, should consume about 9.4 MWh/yr, or about 72 kWh/m^2 for heat, in addition to hot water and appliances (@9000 kWh/dw for both), according to Elmroth. The same home built to SBN-67 required 141 kWh/m^2. Actual consumption in 1978 for homes in the south built in the 1970's (1971-1976) before SBN-75 was about 105 kWh/m^2. The precise value depends on how "heated area" is defined.

Unpublished estimates by Rockwool, a swedish insulation company, and by other officials, and examination of specifications from many house factors, suggest that the SBN-75 requirements were very much in line with practices after the oil embargo. Moreover, data covering the selection of insulation in homes built in 1981, based on the home loan system, suggest that the majority of homes built in that year had higher insulation levels than those required by SBN-75; similarly increasingly large fractions of homes built in the late 1960s and early 1970s (before SBN-75) were outfitted with triple pane windows, which was only required in 1977. This activity probably resulted from the generous loans for new homes, that could be increased to cover increased costs of weatherization.

The 1984 proposed requirements for homes with electric resistance heating are even stronger. The home referred to above should use only 7.8 MWh/yr for heating, or 60 kWh/m^2. A greater change will be noted because new homes will be tighter; many will use mechanical ventilation with built-in heat exchangers. Heat recovery is required in buildings exhausting more than 180 GJ/yr of heat, and hot water and appliance use (but not heat) must be metered individually in MFD. Of course, home loans will cover these extra investment costs.

Statens Planverk (SPV)[22] estimated SBN-75 would increase the cost of SFD by 7,500 SEK per dwelling (in 1977) and MFD by 6,000 SEK per dwelling. SPV estimated that these measures would reduce specific (and presumably net) consumption by 36GJ/SFD and 32GJ/MFD compared to "dwellings built in the early years of the 1970s." However, the difference between temperatures used to calculate these savings and actual temperatures in homes noted above may be different. Thus, it is difficult to compare expected savings with actual consumption in existing newer homes. It is noteworthy that according to SPV calculations the extra investments in control systems (2350SEK/SFD) will save 12.6 GJ at a cost of 185 SEK/GJ saved per year, while extra insulation (5000SEK also saving 12.6GJ/yr) will cost about twice as much. On the other hand, the comparison above shows that the actual increments of insulation will be considerably smaller, because homes have in fact already approached the levels of wall insulation demanded by SBN-75. Thus, it is very difficult to say how much energy savings the codes will generate.

There are few stock-wide or statistically selected measurements of consumption in homes built since SBN-75 took effect. Most of these are heated with electricity. It is too early to tell whether the new building code has led the building industry to build more energy-efficient homes, or whether such homes were already being built. Conversations with many officials and experts in Sweden suggest that when SBN-75 took affect its demands were not radically different from current practice. Currently (1982) most SFD are built to better standards than SBN-75 demands. However, an additional reduction of perhaps 20-25% seems likely as a result of the implementation of the 1984 code, which will spill over to all forms of new SFD construction.

6 COMPARISON WITH OTHER COUNTRIES

How does Swedish conservation experience compare with that of other countries? We display three indicators in Figs. 3-5; the data are from our OECD data base. Fig. 3 shows a heat indicator for all dwellings in eight OECD countries. Sweden lies well below values for Canada, Denmark, Germany, and France, countries with comparable or nearly comparable heating standards. Japan and the UK have considerably less central heating and far lower indoor temperatures than Sweden. By this indicator, Sweden has the most efficient building stock among the countries shown. On the other hand, the reduction in Sweden since 1972 appears less dramatic than in other countries, particularly Denmark and France. The increase in central heating penetration in France, Germany, UK, Italy, and even Denmark after 1972 also has been greater than in Sweden.

To illustrate the impact of conservation in dwellings with central heating, we show heating intensity for oil-heated dwellings with central heating, giving SFD and MFD separately, for selected countries in Figs. 4 and 5. It can be seen that oil-using homes in Denmark, Germany, and in the USA[23] have reduced their consumption by 30-45%, more than in Sweden. In these countries, oil prices have climbed somewhat more than in Sweden, and electricity and wood represent no realistic alternative (except in the USA). The apartment data (Fig. 5) show the impact of metering in Denmark and Germany, where consumption clearly followed price fluctuations more closely and where the relative decreases are far greater than in Sweden. Since homes in Sweden still use less energy per degree-day per unit area than those in Germany and Denmark, it is probably true that the Swedes had less room technically to reduce consumption in the years since 1973. However, many opportunities remain because indoor temperatures are high in Sweden, justifying greater expenses for saving energy.

At the same time, it should be noted that the Swedes did manage to reduce energy use in new and existing dwellings since 1972. This indicates that the relatively low levels achieved before 1972 are achievable in other countries, and that much technical improvement is possible.

7 SUMMARY AND CONCLUSIONS

We have shown that there have been great changes in the heating structure in Sweden. The share of electrically-heated SFD has increased from 15% in 1972 to 33% in 1980, and the share of district-heated MFD has increased from about 30% to nearly 45%. Nearly one-third of all SFD now use multiple fuel systems, including use of electricity for hot water when oil burning is least efficient.

Oil prices rose sharply in 1973/4 and 1979/80; district heating and electricity prices are now higher, though less relative increase has been recorded than with oil. Specific consumption for heating and hot water of most energy forms has fallen since 1972, but several important factors have moderated that decrease:

- Swedish homes were already the most efficient in the industrialized world before 1973. Indoor temperatures may have fallen since 1972, but remain the highest in Europe.

- Oil price increases were restrained somewhat by government policy. Electricity prices remained stable until 1978 and are still low compared to most other OECD countries. By 1981, electric heating cost nearly the same as oil used in boilers with 65% efficiency.

- Energy intensities in oil-heated SFD in Sweden fell by about 38 GJ/dwelling for heating and hot-water between 1972 and 1980. About 1/4 of the reduction in oil-use intensity from 1970/2 to 1980 was accounted for by increased use of wood and some electricity. About 10% of the oil-heated SFD stock in the early 1970s no longer used oil in 1980, reducing total oil use even more.

- Heating intensities in electricallly-heated SFD fell less than in those heated by oil, because electrically heated homes are newer and because electricity prices increased much less than did those for oil; District heating in SFD was intermediate to oil and electricity.

- In MFD, few consumers pay directly for heat according to actual consumption; not surprisingly, the drop in energy intensity has been considerably less than in SFD. Nevertheless about 40% of the stock has been affected by investments provided through a government program that may account for some of this drop. Nearly 1/4 of the oil heated stock was converted to DH between 1970 and 1981.

- Total direct consumption of oil decreased from 260 PJ in 1972 to 170 PJ in 1980 when climate variations are accounted for. Most of this decrease was caused by reduced oil use per dwelling; about 25% was caused by decreases in the number of dwellings using any oil or increased use of wood as an oil supplement. The most important substitutes for oil were electricity and wood in SFD and district heating, principally oil based, in MFD.

- While a signifcant number of homeowners and apartment building owners or administrators used government grants or loans to implement conservation, at least as many owners of SFD took conservation measures without government support.

- There is some evidence that homes built after the 1975 code took effect use less heating than those before, but those built in the mid-70s were already close to the levels subsequently required and far better than what was required in the 1967 code. Thus the codes appeared passive, at least through 1983.

- Although the role of the aforementioned and other government programs is undeniable, it is difficult not to assign higher energy prices the principal responsibilty for stimulating energy conservation in existing and new homes since 1973.

The government programs reviewed here seem to be important in stimulating investments that some private citizens might find uninteresting or might delay. The savings predicted were largely achieved. The Swedish government's goal is to reduce specific consumption stockwide by about 35% compared to 1977. By 1980, the country had achieved roughly 1/4-1/3 of this goal. Lower indoor temperatures could play a big role in extending these savings. Furthermore, homes built in the 1970s consume significantly less energy than those built earlier, although the effect of the building code has not yet been carefully measured. Thus, stock turnover, in addition to careful retrofit, will reduce energy use for heating even more. More efficient hot water systems (heat pumps, or use of electricity or solar heating in place of oil in the non-heating months) promise savings as well. In sum, it appears entirely feasible that the Swedish housing stock, already the most efficient among OECD countries with respect to heating, will continue to become more energy-efficient. Indeed, the drop in 1980, caused both by changes in behavior as well as by continued investment in efficient technologies, continued in 1981.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the helpful cooperation and assistance from Lars-Göran Carlsson, Statens Industriverk, during the two years in which the basic research for this paper was undertaken, and from Peter Steen, Försvarets Forsknings Anstalt. Additionally he has profited from discussions with Prof. Arne Elmroth, Royal Inst. of Technology, Jan Lagerström, Energihushållnings Delegation, Stig Hammarsten, Statens Institut för Byggforskning, and Ulf Rengholt, VVS-Tekniska Föreningen. Thanks go to the many individuals who provided invaluable help in locating obscure and unpublished data, including Kurt

Aastedt, Svenska Esso; Bengt Wallenberg, Malmös Energiverk; Kjell Wanzelius, Stockholms Energiverk; Rune Askerlund, Vattenfall; Jan Randers, CDL; Hans Berglund, SCB; and Anders Westholm, BP. Finally the hospitality of the Beijer Institute, Royal Swedish Academy of Sciences, is greatfully appreciated. Steve Meyers and the late Susan Rosse of LBL reviewed the text and made many helpful suggestions.

REFERENCES

1. Schipper, L., A. Ketoff, and S. Meyers, 1981. Indicators of International Residential Energy Use and Conservation. LBL 11703. Berkeley: Lawrence Berkeley Lab. See also Schipper, L. and A. Ketoff, 1983. Energy Policy. (June).

2. Schipper, L. and L.G. Carlsson (SIND), 1983. Reconstruction and Analysis of Swedish Residential Energy Use 1960-1980. LBL-11702. Berkeley: Lawrence Berkeley Lab. (in preparation)

3. Hammarsten, S., 1980. "Kan vi lita paa graddagsmetoden?" (Can We Trust the Degree-Day Method?) VVS, 1, January, 1980.

4. I. Höglund et. al., Energibehov för Bebyggelse (Energy Needs in Buildings), Expert report on Conservation, (Energikomissionen). Dept. of Industry DsI 1977:13. Stockholm: Liberförlag.

5. Larsson, O., 1975. in Energiberedskap i Kristid. (Energy Preparedness in Crises) (Energi Beredskaps Utredningen) Stockholm: Liber Förlag.

6. Energistatistiken för Småhus (ESH).1977-1981. (Energy Stat. for Single-Family Dwellings) Stockholm: Central Bureau of Statistics (SCB), 1978-1982.

7. Munther, K., 1980. Energiförbrukning i Småhus. Stockholm: Statens Råd för Byggforskning.

8. Carlsson, L. G. 1983. Energi för Uppvärmning. Stockholm: SIND.

9. Schipper, L., 1982. Residential Energy Use and Conservation in Denmark 1970-1980. LBL-14336. Berkeley: Lawrence Berkeley Lab.

10. Anderlind, G., A. Elmroth, B. Lindörn, T. Lundgren, and U. Norlen. Energy Saving Effects in Dwellings Where Measures have Been Implemented by Governmental Energy Savings Grants. Document D7:1981 (English Translation). Stockholm: Statens Råd för Byggforskning.

11. Askerlund, R., 1972 and 1977. Unpublished memos, Sw.State Power Board.

12. Enkät Våren 1980 om Bränsleförbrukning i Småhus i Sverige. Sollentuna: AB Marknadsforskning

13. Undersökningen om Energianvändaing. Rapport 1975-12-09. Stockholm: SCB Utredningsinstitut.

14. Lille, Jan, 1979-82. Hushållens Energianvänding. Stockholm: SCB.

15. Munther made the same comparison for 1978 using data for all homes with either oil or electric heat, possibly including hidden effects of back-up fuels.

16. Energistatistik för Flerfamiljshus (EFH), 1976-1980, and El- och Fjärrvärrmestatistik (EOF), 1973-1980. Stockholm: SCB.

17. Gezelius, Göran, 1982. "Värmepumpar i Befintliga Flerbostadshus" (Heat-pumps in MFD). Report T8. Stockholm: Council for Building Research.

18. As provided by RWE, Essen; Energiministeriet and Dansk Elverkers Foreningen Udredningsinstitut, Lyngby; Japan Inst. of Energy Economics, Tokyo; LBL data base, Berkeley.

19. Energihushållningsdelgation (EHD), 1981. Program för Energihushållning i Befintliga Bebyggelse (Conservation Program in Existing Buildings). Ministry of Housing. SOU 1980:43. Stockholm: Liber Förlag.

20. The series is published by the National Building Institute, Gävle, Sweden. See Hammarsten, S., 1979, "A Survey of Swedish Buildings from the Energy Aspect." Energy and Buildings 2, p. 125-134.

21. In a paper presented at the International Conference on Energy Use Management, Berlin, 1981.

22. English Summary of SBN-75 Stockholm: Nat. Bd. of Physical Planning.

23. Meyers, S., 1982. Residential Energy Use and Conservation in the United States. Berkeley: Lawrence Berkeley Lab.

FIGURE CAPTIONS

1. Total energy use in Swedish homes, 1960-1980, in peta--joules (PJ), based on figures developed for this study and corrected for yearly climate variations. For primary energy, electricity was counted at 34.6% efficiency (the OECD average for the period), and district heating at 75% efficiency. Electricity is split into space heating and other uses, including water heating. The figures are taken from Ref. 2.

2. Factoral Analysis of Residential Energy Use. Total primary energy use is factored into area/dwelling, dwellings/capita, and population changes since 1960. Note that total end-use (and its heating component) have fallen since 1972. Expressed as primary energy, these would increase like the primary figure.

3. OECD. Space Heating. Average Energy Consumption per dwelling per degree-day_{18}. Figures from Ref. 1.

4. OECD. Oil consumption per degree day per sq. meter in detached houses with central oil heating. From Ref. 1.

5. OECD. Oil consumption per degree day per sq. meter in apartment houses with central oil heating. From Ref. 1.

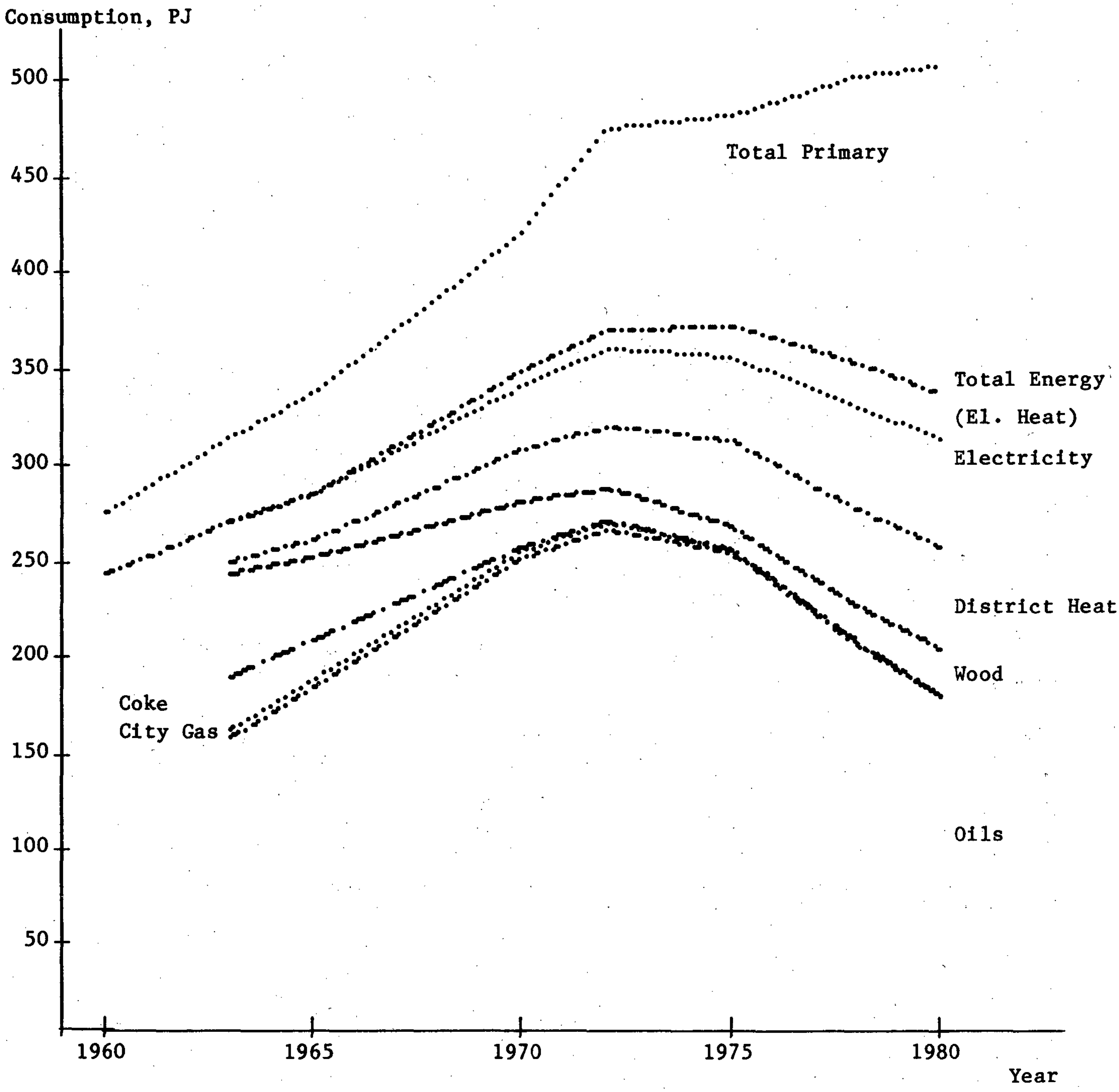


Figure 1. Total Residential Energy Use by Fuels, 1960–1980

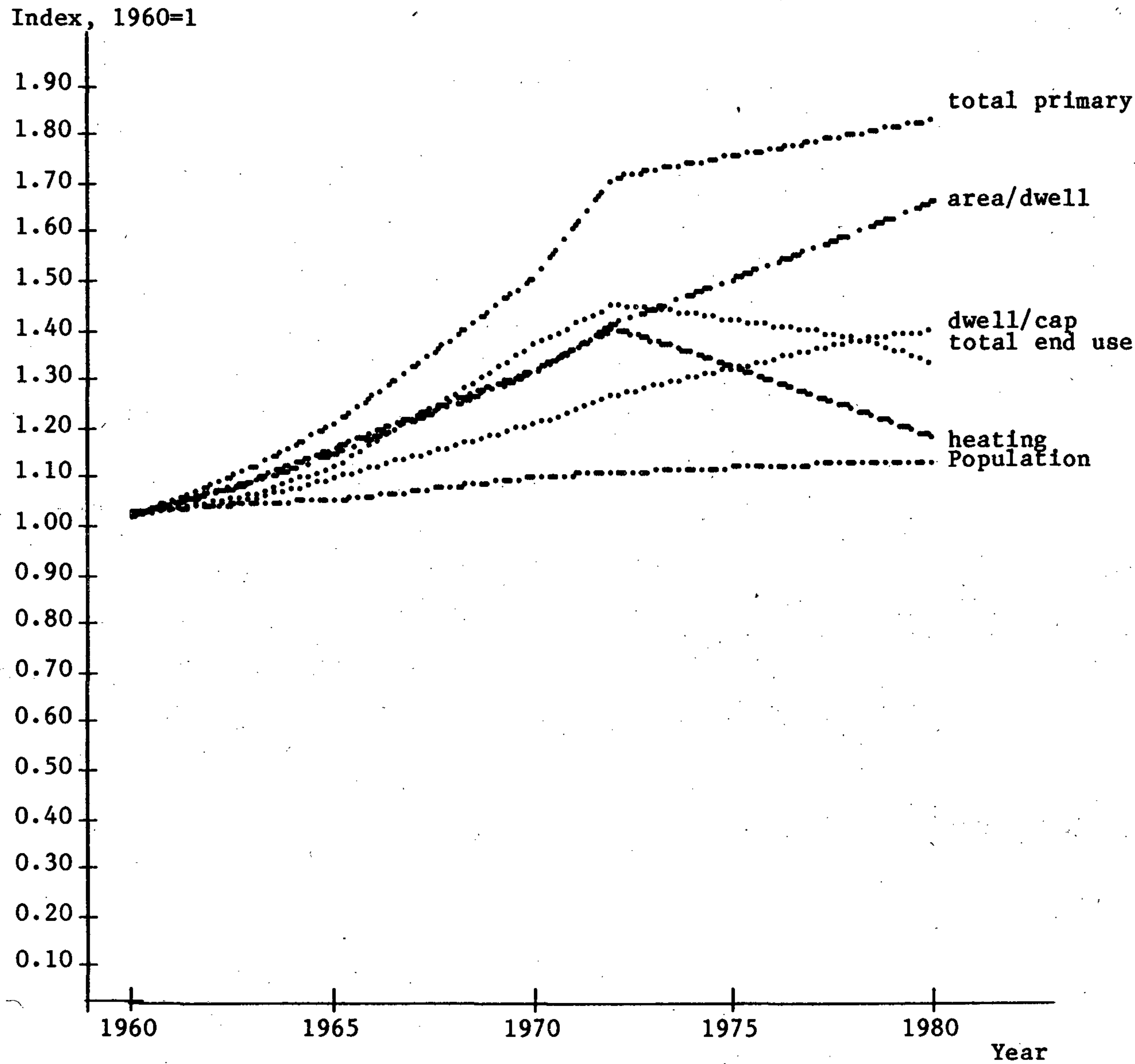
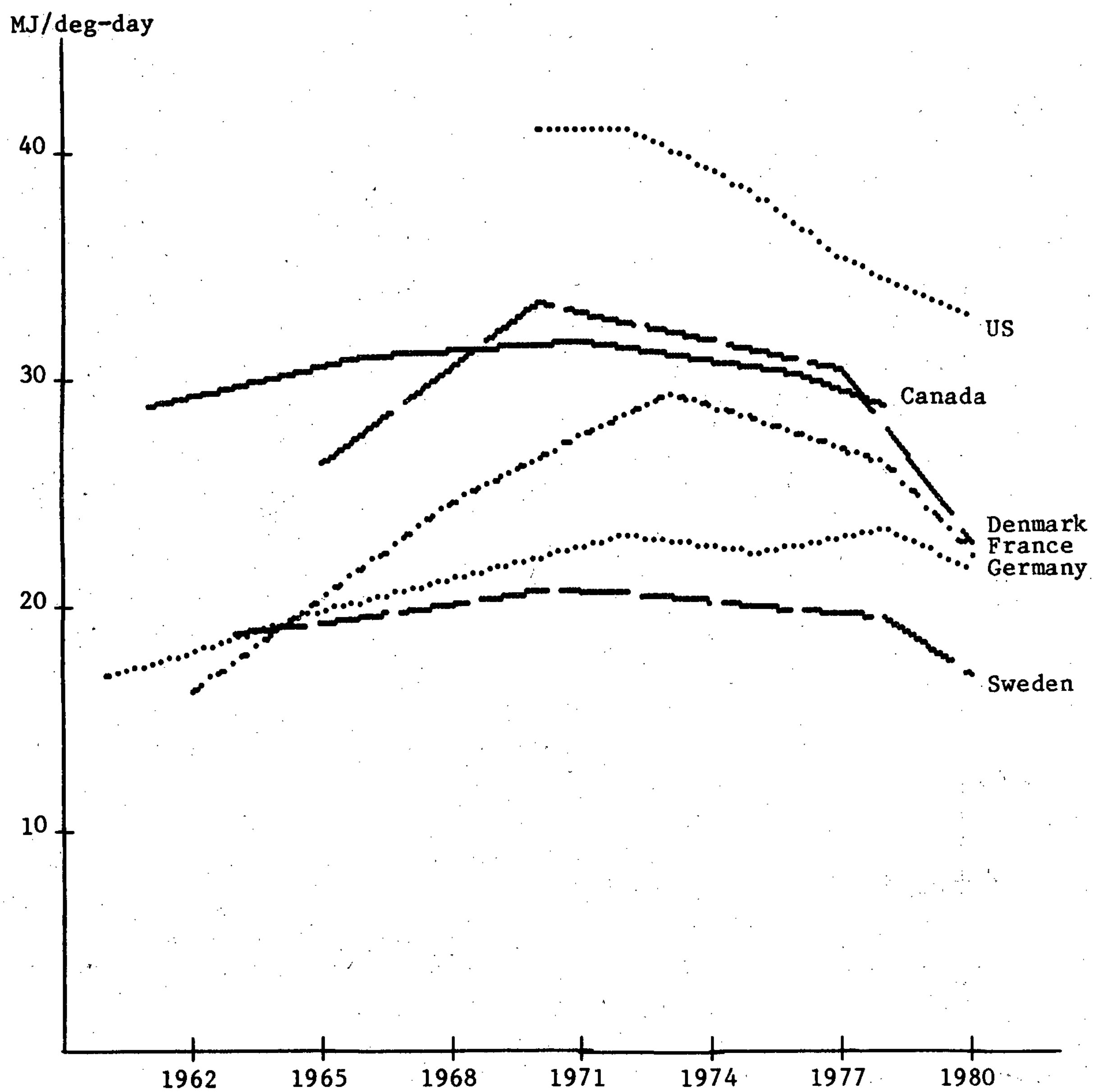
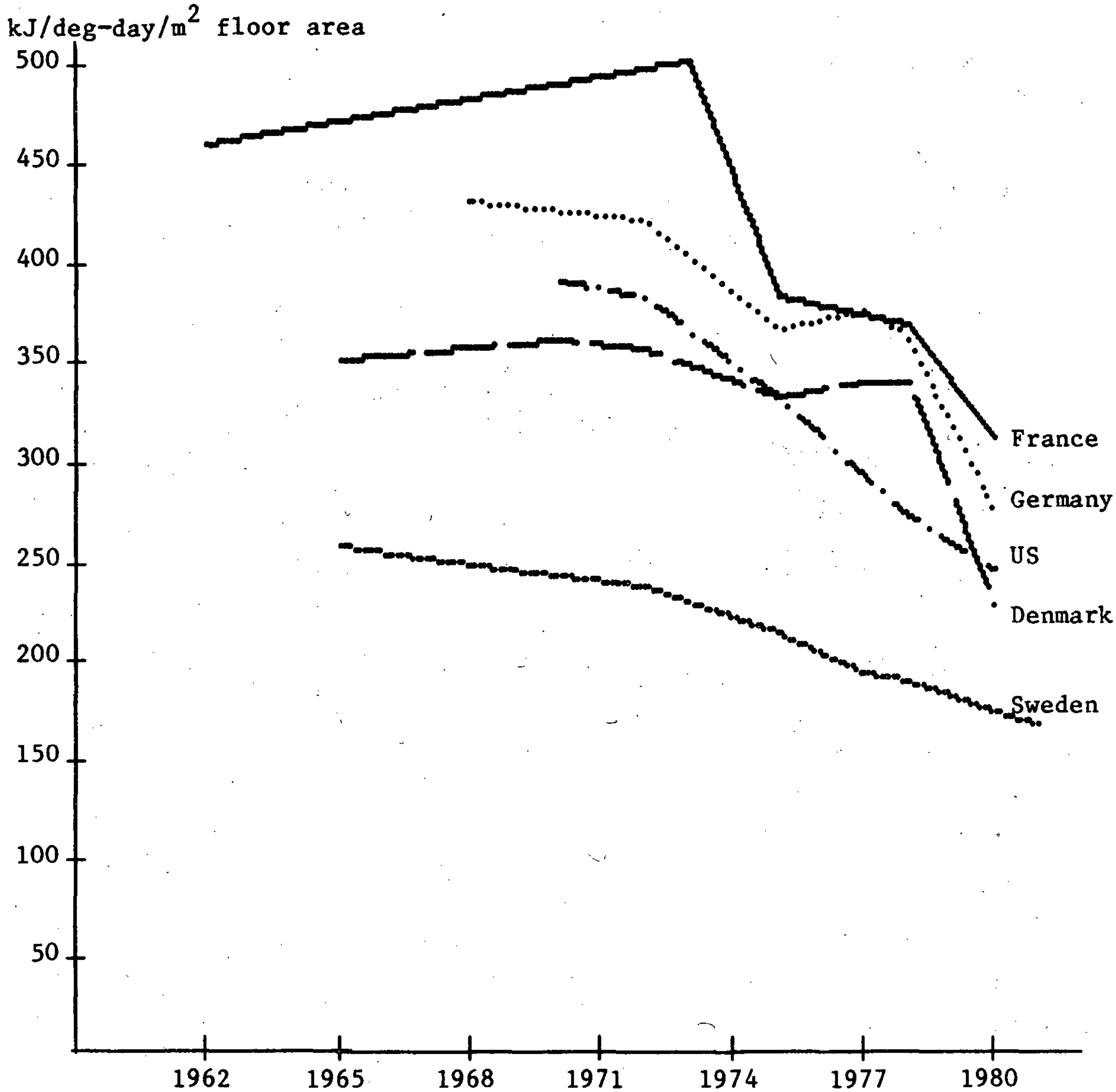


Figure 2. Indices of Residential Energy Use, 1960=1.0



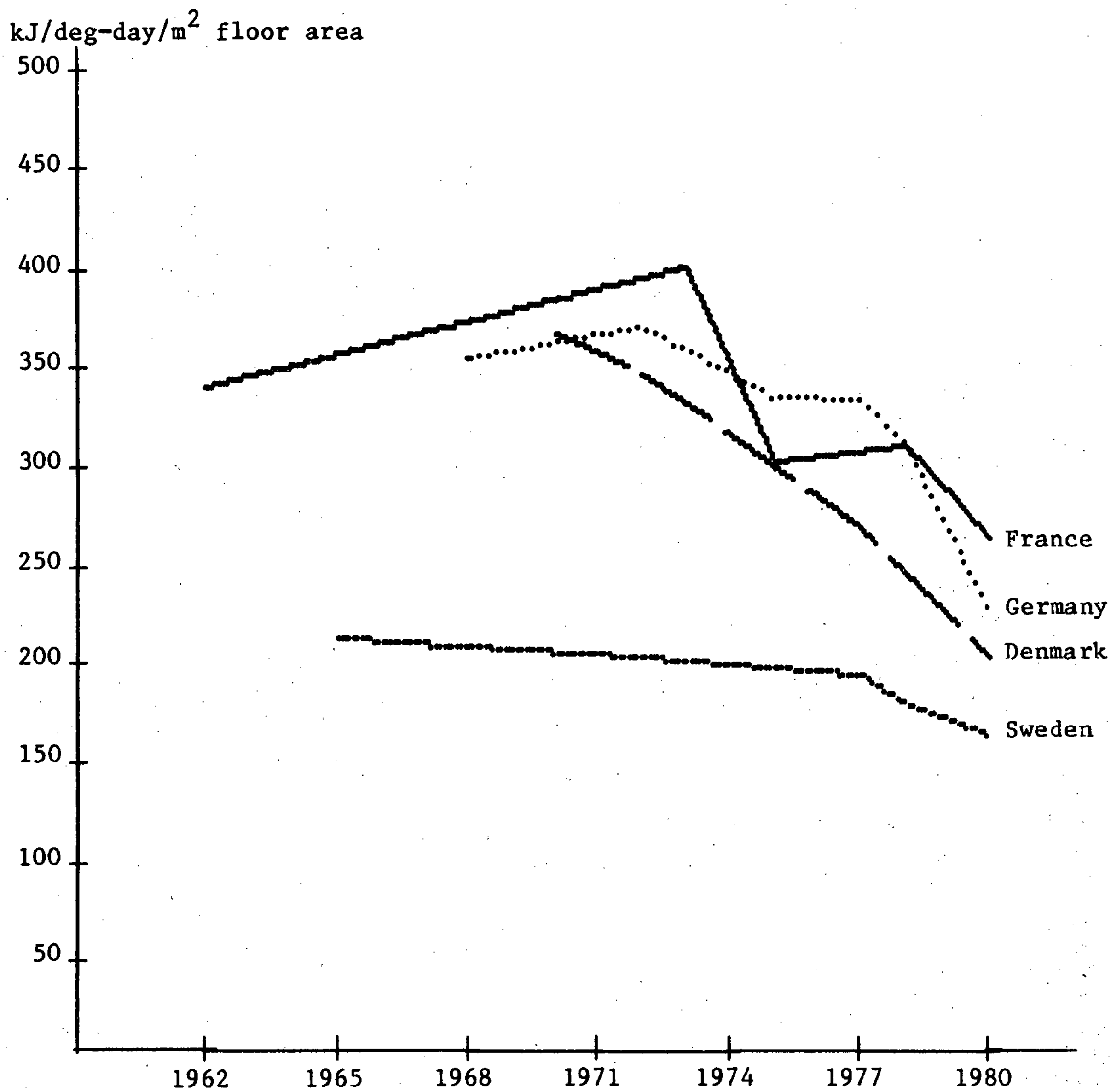
OECD Space Heat: Average Energy Consumption per Degree-Day

Figure 3



OECD Oil Consumption for Central Heating in Detached Houses

Figure 4



OECD   Oil Consumption for Central Heating in Apartments

Figure 5

TABLE 1

SWEDEN: Economic, Housing and Appliance Data

	1963	1965	1970	1972	1978	1980	Growth rate (%) 1963-72	Growth rate (%) 1972-80
ECONOMIC DATA								
Population, 10^6	7.66	7.73	8.08	8.12	8.28	8.32	0.7	0.3
GNP, $10^9 SEK_{1970}$	131.9	146.9	177.8	184.7	205.1	216.5	3.6	2.0
GNP/cap, $10^3 SEK_{1970}$	17.2	19.0	22.0	22.7	24.8	26.0	2.9	1.7
DI/cap, $10^3 SEK_{1970}$	10.2	10.9	11.9	11.9	13.7	14.2	1.8	1.9
Consumer Price Index	74	81	100	119	198	242	6.2	9.9
REAL ENERGY PRICES (1970 SEK)								
#1 Heating Oil, SEK/GJ	6.4	5.4	5.0	4.7	9.0	15.8	-4.0	16.4
Gas (cooking), SEK/GJ	-	27.3	26.9	29.9	33.2	-	1.0	1.8
Electricity, SEK/100kWh	16.9	14.1	11.4	11.4	13.7	14.6	-4.3	3.1
HOUSING								
Total dwellings, 10^6	2.76	2.85	3.15	3.30	3.61	3.65	2.0%	1.3%
Occupied dwellings, 10^6	2.70	2.76	3.02	3.14	3.39*	3.48*	1.7	1.3
Persons/dwelling	2.84	2.80	2.68	2.59	2.44	2.39	-1.5	-1.0
Area/capita, m^2	27.4	28.6	30.0	33.2	34.8	36.8	2.2	1.3
SFD share, %	47	46	43	43	45	46		

APPLIANCE SATURATIONS (% of households)	1964	1971	1979	1964-71	1971-79
Refrigerator	77	94	99	2.9	0.6
Freezer	22	48	77	11.8	6.1
Dishwasher	3	8	27	17.0	16.4
Clothes washer	31	47	64	6.1	3.9
Clothes dryer	-	6	22	-	17.6
BW TV/Color TV	77/0	80/11	32/76	0.5/-	/27.3
Gas stove/oven	19	12	4	-6.4	-12.8
Wood stove/oven	11	6	2	-9.3	-13.2
Elec. stove/oven	69	79	95	2.0	2.3
Elec. water heater	4	15	20	20.8	3.7

Sources: SCB (population, housing, and national accounts); Esso and SIND (oil prices); State Power Board (electricity prices; based on 5,000 kWh/yr w/o heating); Stat. Yearbooks (gas prices). Appliance saturation are from Foerening foer Electricitets Rationella Anvaending (1964), and State Power Board (1971 and 1979), and LBL survey (gas). The asterisk * refers to approximate figures because of the uncertain number of dwellings not used year-round.

TABLE 2

SWEDEN: Heating Structure

(Mid-year values)

	1963		1965		1970		1972		1978		1980	
	SFD	MFD	SFD	MFD	SFD	MFD	SFD	MFD	SFD	MFD	SFD	MFD
Dwellings, 10^3	1275	1490	1290	1565	1332	1820	1380	1922	1550	2061	1610	2050
Occupied, 10^3	1225	1450	1260	1500	1304	1721	1355	1786	1525	1870	1600	1880
Avg. Size, m^2	92	63	95	63	102	64	107	65	123	65	125	65
Ctrl. Ht., %	72	86	74	90	86	95	89	97	95	99	97	99
Central, 10^3	910	1280	955	1400	1150	1725	1230	1842	1480	2020	1565	2035
Oil	425	1000	555	1115	881	1250	920	1248	907	1138	860	1040
Gas	10	5	13	5	12	10	12	10	8	4	7	4
Coke	230	125	160	85	25	12	15	5	5	4	5	2.5
Wood	240	50	200	30	110	15	90	10	72	3	90	2.5
District Ht	5	100	5	165	11	420	15	540	48	816	63	921
Electricity	0	0	22	0	110	18	178	29	443	55	540	65
Non-Ctrl, 10^3	365	210	335	165	182	95	140	80	72	41	45	15
Kerosene, oil	70	60	80	80	45	46	30	36	16	5	3	3
Gas	3	20	3	15	1	12	0	11	0	8	0	8
Coke	25	20	20	15	15	5	12	0	8	0	0	0
Wood	262	110	223	50	111	27	83	25	40	18	32	3
Electric	5	0	10	0	10	5	15	8	25	10	10	2

NOTE: Central heat includes all systems with central distribution of heat (water or air-borne), district heating, block centrals (kvartercentral, counted with oil), and virtually all dwellings heated with electricity. A few with electricty are counted with non-central, reflecting very low consumption and combination with wood. In SFD, 1/3 of those using oil and nearly 1/2 of those using electricity as primary fuels also used a second fuel.

Area means living area.

Totals may not add due to rounding.

TABLE 3

SWEDEN: Residential Energy Use in 1980

Year: 1980 Population: $8.317x10^6$ Dwellings: $3.66x10^6$

CH Penetration: 98.5/99.8% DI/cap:14,160SEK_{70} Climate Index: 1.116

FUEL/Use	Heat	Hot Water	Cooking	Appl.	Total	Corrected
Oil,PJ	135.0	48.6	-	-	183.6	169.6
-Stock,10^3	860/1040	860/1040	-	-		
-Spec.Cons,GJ	95.0/50.6	29.9/22.0	-	-		
Kero,PJ	0.21	-	-	-	0.2	0.2
-Stock,10^3	3/3	-	-	-		
-Spec.Cons,GJ	40/30	-	-	-		
Gas,PJ	1.12	0.3	0.58	-	2.00	1.9
-Stock,10^3	7.8/12	7.8/10	8/268	-		
-Spec.Cons,GJ	80/42	25/15	3/2.1	-		
Coke,PJ	0.54	0.18	-	-	0.72	0.61
-Stock,10^3	5.5/2.5	5.5/2.5	-	-		
-Spec.Cons,GJ	80/40	25/15	-	-		
Wood,PJ	9.27+[17.4]	2.3	0.2	-	29.2	26.4
-Stock,10^3	90/2.5	90/2.5	100	-		
-Spec.Cons,GJ	80/42	25/18	2	-		
-Non-CH, 10^3	32+[400]/3					
-Spec.Cons,GJ	50+[43.5]/30					
Elect,PJ	26.15+[0.75]	11.25	7.6	37.51	83.25	80.46
-Stock,10^3	550/65	575/75	3300	3655		
-Spec.Cons,GJ	44.6/25.4	18/12	2.7/2.0	10.26		
-Spec.Cons,MWh	12.4/7.1	5/3.3	0.65	2.85		
Dist Ht,PJ	41.8	17.2	-	-	59.0	54.6
-Stock,10^3	63/921	63/921	-	-		
-Spec.Cons,GJ	79.0/40.0	20/17.3		-	-	
Total, PJ	232.2(208.1)	79.8	8.4	37.5	358.1	333.8
GJ/dw	63.5(56.9)	21.8	2.3	10.3	97.5	93.6
Share	60%	23%	2%	11%	104%	100%

INDICATORS:	STRUCTURE	INTENSITY	
% dw oil heat	52	GJ/Dw,secondary	91.3
% dw el heat	17	GJ/Dw,primary	137.9
% dw Dist heat	27	Heat/dw/dd,MJ	14.2(16.0*)
% dw other	4	Heat/m^2/dd,kJ	161(182*)
Appl elec/DI kWh/Skr_{70}	0.088	Hot Water,GJ/cap	9.6(10.7*)

NOTES TO TABLE 3

Where figures are separated by a slash, the first refers to SFD, the second to MFD. Where two figures are given in the heat column separated by a "+", the second refers to use of that fuel as a secondary heat source. An asterisk (*) in the Indicators table marks figures where DH and electricity are counted at 1.5x their actual values, to make them more comparable with the consumption of fuels. When primary energy is given it is assumed that electricity is delivered with 36.4% efficiency, district heating with 75% efficiency. For sources and explanation of how each quantity was derived, see Ref. 2.

TABLE 4

SWEDEN: Residential Energy Use, 1963-80

	1963	1965	1970	1972	1978	1980	Growth rate 63-72	72-80
TOTAL END-USE ENERGY, PJ	-	1026	1310	1340	1390	1390	3.9%	0.5%
TOTAL RESIDENTIAL, PJ	267	283	346	367	349	334	3.5%	-1.2%
(Fuels)	239	247	261	284	210	199	1.8%	-4.3%
(DH)	7	11	29	33	52	55	18.4%	7.0%
(Elec)	21	25	41	50	76	80	10.0%	6.1%
TOTAL PRIMARY, PJ	309	334	418	473	499	504	4.8%	0.8%
End-use energy, GJ/Dw	95.8	98.5	109.7	111.2	95.0	91.3	1.4%	-2.4%
Primary energy, GJ/Dw	112.4	117.0.	132.7	142.7	138.2	137.9	2.6%	-0.4%
End-use energy, GJ/cap	34.9	36.6	42.8	45.2	42.3	40.1	2.9%	-1.5%
Primary energy, GJ/cap	40.3	43.2	51.8	58.2	60.3	60.6	4.2%	0.5%
Electricity/dw, MWh	2.1	2.4	3.6	4.2	5.8	6.1	8%	4.8%
Climate (4010 DD_{18})	4370	4250	4505	3890	4370	4475		
(Index, 4010=100)	109	106	112.3	97.4	108.8	111.6		
Heat, GJ/dw	70.2	72.6	75.1	75.5	61.1	56.9	0.8%	-3.5%
(% w elec., DH)	5%	7%	18%	23%	39%	43%		
Hot water, GJ/Dw	17.5	17.7	24.3	23.3	22.3	21.0	4.0%	-2.1%
(% w elec., DH)	8%	10%	18%	26%	40%	45%		
Cooking, GJ/Dw	3.4	3.3	2.7	2.6	2.5	2.3	-2.9%	-1.5%
(% w elec.)	62%	66%	80%	85%	89%	94%		
Appl. elec., GJ/Dw	4.8	5.0	7.6	8.2	9.7	10.3	6.1%	2.9%
-- " --, MWh/Dw	1.33	1.39	2.11	2.28	2.69	2.86		

NOTES: The total energy consumption figures exclude bunkers and refinery losses, but include non-commercial consumption of the paper industry, and count hydro- and nuclear power at 3.6 MJ/kWh produced. All heating figures are corrected to normal climate; the actual value of the climate intensity is shown in the table. "Fuels" refers to liquids, solids, and gas, "Elec." to electricity, "DH" to district heat; all are counted at the point of entering the building (building complex in the case of heating centrals). In the primary figures, DH production was counted at 75% efficiency, electricity at 34.6% efficiency. In the end-use intensity figures, the shares of dwellings with fuel, DH, and electricity are shown. Appliance electricty excludes cooking stoves/ovens but includes hot water in clotheswashers and dishwashers.

TABLE 5

RESIDENTIAL ENERGY USE INDICATORS IN SWEDEN, 1963-1980

	1963	1965	1970*	1972	1978	1980	Growth rate 1963-72	Growth rate 1972-80
Dwelling Size, m^2	75	77	80	82	85	88	1.0%	1.2%
Heat, MJ/DD/dw	17.5	18.1	18.7	18.8	15.3	14.2	0.8%	-3.4%
Heat*, MJ/DD/dw	17.8	18.9	19.8	20.1	17.2	16.0	1.3%	-2.8%
Heat*, KJ/DD/m^2	237	245	248	245	205	182	0.4%	-3.5%
Hot water, GJ/cap	6.3	6.6	9.5	10.1	10.1	9.6	5.3%	-0.6%
Hot water*, GJ/cap	6.5	6.9	10.8	11.0	11.7	11.3	6.0	0.3%
Appl. Elec., (kWh/Skr_{70})	0.047	0.053	0.069	0.081	0.085	0.088	6.2%	1.0%

Note: Area refes to nominal living area; actual heated area is larger and may vary (relative to living area) with individual practices. All figures are derived from tables herein or in Ref. 2. (*) indicators are based on figures for which oil and DH use were multiplied by 1.5.

TABLE 6

CENTRAL HEAT AND HOT WATER in SINGLE FAMILY DWELLINGS: ENERGY USE BY FUEL

Year	1970	1972	1974	1975	1976	1977	1978	1979	1980
OIL: ALL SFD*									
GJ/dw (all)	174.6	165.2	-	137.2	151.8	142.4	146.0	145.8	138.8
Heat+HW, MJ/DD (all)	38.9	42.3	-	38.6	35.5	34.9	33.5	32.5	31.0
GJ/dw (oil only)	-	-	-	-	-	-	149.5	143.5	139.9
Hot Water, GJ/DW	35	35	-	35	34	34	33	32	30
Heat, MJ/DD (all)	31.1	33.3	-	29.6	27.5	26.8	25.9	25.4	24.3
Price, Skr_{70}/GJ	4.97	4.53	8.81	7.95	10.0	9.63	9.47	13.5	16.0
DISTRICT HEAT: ALL SFD									
GJ/dw,actual	-	108(73)	98.7	111.2	117.6	111.0	106.1	99.8	99.0
Heat+HW, MJ/DD	-	26.9(73)	25.9	29.3	28.4	27.4	25.3	23.4	23.3
Hot Water, GJ/DW	-	20	20	20	18	18	18	17	17
Heat, MJ/DD	-	22.0	22.0	25.6	23.3	24.4	20.2	18.5	18.3
Heat price, SEK_{70}/GJ	6.9	7.2	12.8	-	12.2	-	17.8	-	21
ELECTRICITY: NON-FARM SFD									
GJ/dw (all)	-	59.0	58.7	61.7	63.5	65.3	61.7	62.2	62.8
GJ/dw (elec only)	-	-	-	-	-	74.8	67.9	65.9	62.8
Heat+HW, MJ/DD (all)	-	15.1	14.7	17.4	15.4	15.8	16.3	15.4	15.5
Heat, MJ/DD(all)	-	10.5	11.1	13.3	11.5	12.5	10.8	10.7	10.8
Heat price, SEK_{70}/GJ	15.3	14.7	-	15.7	-	14.8	17.9	16.6	22.1
SEK_{70}kWh	5.2	5.0	-	5.4	-	5.1	6.1	57	7.8
Climate, DD_{18}	4490	3905	3580	3555	4280	4080	4365	4485	4475
Climate (4010=100)	112.3	97.4	89.2	88.6	106.7	101.7	108.8	111.9	111.6

NOTES: Oil energy content is 35.6 GJ/m^3. The 1973 climate index was 99.5. The average total heated area of electrically-heated homes in 1979 was about 134m^2, for oil about 165 m^2, for DH somewhat smaller. No correction is made for changes over time. For appliances, 3.5 MWh/dw were subtracted from consumption/dw in 1972, rising to 4.6 MWh/dw in 1977, 4.8 MWh/dw in 1978, and 5.0 MWh/dw in 1979 and 1980. We have assumed constant 5 MWh/dw for hot water in electrically-heated homes. The price data for electric heating reflect the variable (energy) cost including taxes only, and can be compared directly with the cost of oil. District heating prices to SFD alone were not available.

* Including 2-family houses.

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

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