SAME COMFORT IN BUILDINGS WITH ONE THIRD OF PRESENT ELECTRICITY CONSUMPTION

Jorgen S. Norgard
Technical University of Denmark

ABSTRACT

For more than a decade we have conducted research at our laboratory on the potential for improving the energy efficiency of electrical equipment in buildings. The work was originally analytical only, but has in recent years been expanded to include experimental work.

In this paper we review some of the analytical results in relation to actual development. In 1979 we found through analysis that two thirds of the electricity used domestically could be saved through what we then termed 'radical' measures of improvement. Is has later turned out to be easier to achieve these savings than we then anticipated. Half of the savings can be reached today simply by choosing the most efficient equipment on the market.

Some of the huge potential for electricity savings anticipated in the analyses have been confirmed by the experimental work we are conducting. This work consists in actually building prototypes of some of the common appliances. It is carried out in cooperation with manufacturers of appliances and components.

For all buildings, including private dwellings, we discuss the uses of electricity for comfort in lighting, refrigerating, washing, pumping, ventilating, and cooking, and for other miscellaneous purposes, leaving out electricity used for hot water supply and space heating. The results presented are both from our analytical investigations and from our prototype experiments. The behavioral patterns used as background, such as size of refrigerator, patterns of washing, etc., are typical for Denmark today. But the technical results can in most cases easily be transferred to other countries.

In recent years we have extended our analyses to include all use of electricity and have found similar encouraging results.

SAME COMFORT IN BUILDINGS WITH ONE THIRD OF PRESENT ELECTRICITY CONSUMPTION

Jorgen S. Norgard
Technical University of Denmark

INTRODUCTION

In this paper we look at electricity used to provide comfort in buildings. This comfort we have interpreted as a pleasant environment in buildings we live and work in, plus the daily conveniences in private households and in similar areas of the society. Electricity used for hot water supply and space heating is not included, partly because this use of electricity is not common in Denmark and partly because this electricity can relatively easily be replaced by more thermodynamically appropriate sources of energy.

We are dealing basically with Danish data with respect to the distribution of the various electrical equipment, their types and size(see Table I), and the patterns of utilization. All this can vary among the European nations, but there are a lot of similarities, too, and Denmark does not show any significant deviation from other European nations. Compared with the United States, there are some differences.

Table I. Development over the past 10 years in possession of major household appliances in Denmark. The figures show the percentage of households with one or more of the appliances.

Type of appliances	1974 (%)	1982 (%)	1983 (%)
Refrigerator	78	74	75
Refrigerator-freezer	19	27	28
Freezer	45	60	60
Washing machine	46	58	60
Clothes dryer	3		8?
Dishwasher	9	20	20
El. cooking range	60	68	70
T.V.	86	93	92

This paper will mainly report on the work we have been doing in our Energy Group at Physics Laboratory III, Technical University of Denmark. We have conducted analytical work in connection with energy planning as well as experimental work on efficient electrical appliances. The research has been financed by grants from the Danish National Research Council, the Technical University itself, various other Danish Government sources, the European Community, and a few other sources.

First we will in general terms describe our analytical and experimental work as well as the actual development in the efficiency of equipment on the Danish market over the past ten years. Later we will more specifically go through some of the major utilizations of electricity related to the provision of comfort to people in buildings, namely lighting, refrigeration, washing, pumping, ventilation, cooking, and miscellaneous.

ANALYSES AND HARDWARE

Analytical Research

Back in 1974 we initiated at the Technical University of Denmark a project on analyzing Danish long-term energy options using the System Dynamics method. In this DEMO-project (Dynamic Energy MOdelling), which is still running, we have focused on the energy consumption options and hence the potential for energy conservation.

Being practically without fuel resources of its own, Denmark has a long tradition of being energy conscious. But almost all electric appliances were introduced in Denmark during the brief period around the 1960s when energy was cheap and perceived as unlimited. This, together with increasing wealth and a general short-sightedness, was the reason why little research was done on improving the efficiency in the use of electricity. For the DEMO-project we therefore started investigating the potential ourselves. The first analyses were surprising, showing room for saving two thirds of the electricity used in private households by what we then termed 'radical' technical conservation measures (Norgard,1979a, Harding,1978, Norgard,1979b).

Later we conducted a more detailed analysis of a Danish rural community, Nysted, and found similar electricity conservation potential (Norgard et al.,1981). Recently we extended our analysis to all uses of electricity in Denmark. Even though the reference point for this research was the present efficiency of electrical equipment, which is somewhat improved since 1975, we still found an almost identical conservation potential (Norgard, Holck, and Mehlsen,1983). Two thirds of electricity consumption can be saved in the long run without affecting comfort, production, etc., and it seems to be with good economic pay-off.

Actual Development on the Market

The fact that relatively little research is reported in the literature on efficiency of appliances and other electrical equipment does not really reflect the activities in that area. A lot of experiments are being conducted by manufacturers of these goods, but most results are not published. This is clear from the significant improvements of the models on the market over the last ten years.

Experimental Work

A natural consequence of our analysis was to try to verify the results experimentally. In 1982 we started a project aimed at building prototypes of some low-energy appliances. The targets for electricity savings have been based on the analytical work.

Three of the most widespread uses of electricity in private households are being investigated experimentally, namely refrigeration, washing and cooking. The work is carried out in cooperation with manufacturers of household appliances and with the Danish Government Home Economic Council.

So far we have made the most progress in the field of refrigeration, where a few prototypes have been tested. But we have also built experimental versions of washing machines, hot plate controllers, and ovens as desribed in the following.

COST-EFFECTIVENESS

In this paper we will not focus on the cost-effectiveness of the various measures to save electricity. It is extremely difficult to estimate the extra production cost of a better designed appliance, lamp, or other equipment. Every once in a while the models are changed anyway, causing large investment in new production lines. The extra cost of introducing energy conserving features in connection with such a regular design change will often be very small. The extra cost for such changes in production lines to be ascribed to each single appliance will obviously depend on how well it sells. Nevertheless there are some very concrete extra costs such as more insulation materials in a freezer or an extra valve in a washing machine.

The higher prices for some low-energy versions of equipment observed on the market seem merely to reflect what the buyers are willing to pay. In such cases it makes little sense to calculate a payback time and find that it just pays to buy the efficient version. That is probably what the company already did when setting the sale price.

All the measures described in the following are estimated to be cost-effective with Danish electricity prices of 7 cents per kWh. If we make a broader socioeconomic assessment, such as including the costs in the form of air pollution from power plants and dependence on imported energy supplies, we will find it considerably more advantageous to conserve electricity than to supply it. This is the case even when we go as far in conservation as we have suggested in this paper.

Free heat gain has been taken into account when judging the economic saving achieved by reducing electricity consumption. Each kWh reduction in domestic electricity consumption requires some 0.4 kWh extra heat from the heating system since we will lose some of the free heat provided from the electrical equipment. In Denmark the cost for heat supplied from an oilfired heating system is only half of the electricity cost per energy unit. This means that the actual savings from reducing electricity consumption is 20 percent lower than what appears on the electricity bill.

In some cases, such as in schools and office buildings, there will often be a surplus of free heat, and the heat from lamps, etc., will be not a gain, but a load on the ventilation system. In such cases the conservation of electricity counts twice and saves more than what is directly assumed. This is especially true in cold storage buildings and in warmer climates where refrigerated air conditioning is used.

LIGHTING

An estimated 15 percent of Denmark's electricity consumption is used for artificial lighting in buildings. Investigations of electricity savings options in connection with lighting have focused on more efficient light sources. This is an area of great progress, but a closer look at the whole lighting system, including fixtures, shades and control systems, also shows large potential for conservation.

Incandescent lamps are now being replaced at an increasing rate with fluorescent lamps. A rather wide selection of such small fluorescent lamps are now on the market in Europe as well as in the United States. Most of them are made as screw-in lamps in order to fit the traditional sockets. This means, however, that the ballast system is discharded together with the lamp itself. It is likely that the screw-in fluorescent lamps will be a transition solution until the present fixtures are gradually replaced with some containing a ballast. Lamps for such fixtures have also been on the market for a while in Europe. The smallest on the market uses 7 Watt and gives off light corresponding to a 30-Watt incandescent bulb.

The quality of fluorescent lamps have been greately improved with the introduction of three-color fluorescent phosphor powder. However, it is still not a uniform continous color spectrum like that of an incandescent bulb, and hence the quality of light from fluorescent lamps in this respect is not quite as high.

In the non-residential sector, fluorescent light has been widely used already for decades. But improved fluorescent tubes together with electronic ballasts can now provide a light source with around half the earlier electricity consumption combined with increased quality of light, such as better color, no flickering, instant start and continously variable light output.

The lamp fixtures and shades often absorb a large portion of the output from the light source. This loss can be reduced, by such measures as by putting reflecting coating in directions where no light is wanted.

Adjustment of light output according to need can be controlled by clocks and by light sensors, which register the natural light available. Also making manual switches available at appropriate places has turned out to provide significant savings.

We have not done any experimental work on lighting, but we have analyzed the options. For all lighting in buildings we have found a potential for reducing the consumption of electricity to 30 percent of the 1975 level without lowering the comfort. Compared to present 1984 standards, consumption could be down to 35 percent, all without any technological breakthrough. A recent experiment in a Dutch office building applied various of the measures mentioned and brought electricity for lighting down to 20 percent.

REFRIGERATORS

Refrigerators are the type of household appliance which have most often been used to illustrate the potential for electricity conservation. This is the case also in our analytical as well as experimental work. Refrigerated air conditioning is not used in Denmark, and hence the following includes mainly domestic refrigerators and freezers, plus similar equipment in institutions such as schools, hospitals, old people's homes, and nurseries, altogether accounting for an estimated 13 percent of Denmark's electricity consumption. We do not here include commercial cold storage.

The purpose of refrigerators and freezers, like that of the houses we live in, is mainly to sustain a temperature different from the ambient temperature. In normal use of the traditional versions of these appliances 75% of the electricity consumption is due to heat transmitted through the walls. Consequently the thermal insulation is crucial. Manufacturers of refrigerators, however, have normally settled on less than one third of the U-value required for new houses in Denmark, where the aim is to maintain a similar temperature difference, namely 15^{o}C. Mineral wool was replaced in most European refrigerators by polyurethane foam during the 1960s so that option was no longer available in the 1970s, as it was in the United States. Improved insulation could then mainly be achieved by increasing the thickness.

No energy used for defrosting

In Denmark most households have a separate freezer, so when we talk about a refrigerator, we mean a cabinet with a temperature of +5^{o}C, while a freezer maintains -18^{o}C. Automatic defrosting of refrigerators is achieved in each cycle simply by not starting the compressor until the evaporator is above freezing and all frost has melted and run out through a small tube. In freezers there is normally no automatic defrosting, but since they are very air tight and not opened nearly as often as the refrigerator, frost will built up quite slowly. Manual defrosting is necessary only every one or two years. Considering the low price of a compressor unit, there seems to be no good reason for using one compressor for both a refrigerator and freezer compartment with the temperature control problems this involves.

Early analyses of refrigerators

In our group we have done both analytical and experimental work on refrigerators. A typical size Danish refrigerator has a 200 liters inside volume. In 1978 we analyzed that by 'radical' measures the electricity consumption for such a refrigerator could be reduced from the average in 1975 of 500 kWh/year to 100 kWh/year, when referring to standard test conditions with 25°C ambient temperature and no door openings. As 'radical' measures we then included a very heavy insulation, 10 to 15 cm thick. Likewise for freezers, which are typically also 200 liters, we suggested electricity consumption reduced from the 1975 average of 800 kWh/year to 150 kWh/year by even heavier insulation.

The above suggested savings have turned out to be easier to obtain than we anticipated. The best refrigerators and freezers on the market today consume less than half of the 1975 level, namely 230 kWh/year and 300 kWh/year respectively. These savings have been reached with very small changes in insulation thickness in the refrigerators but with an increase from 6 to 9 cm in freezers.

Prototypes of low-electricity refrigerators

By 1980 we decided to do some experimental work. From the background of the actual development we now analyzed that our target of 100 kWh/year for a refrigerator could be reached by only increasing insulation thickness from around 3 to only 6-7 cm. We cooperated with manufacturers of refrigerators and compressors in building a couple of prototypes with such insulation and with improved compressor and heat exchangers. Electricity consumption for this low energy refrigerator has now been measured to <u>104 kWh/year</u>. Despite this low consumption, the refrigeration system is running very inefficiently. Even the smallest compressor unit available is greatly oversized and consequently running only around 20 percent of the time. This means that the heat exchangers are also used only 20 percent of the time. We are now working on a low-capacity compressor with a relatively good efficiency, and it is safe to say that we can reach an electricity consumption in standard tests well below the 100 kWh/year. Preliminary tests with an imitation of practical utilization patterns indicates with our present prototypes a consumption lower than 100 kWh/year, achieved because actual average kitchen temperature is around 18°C, compared to the 25°C test temperature.

For freezers we have performed no experiments yet, but we find that an electricity consumption of 150 kWh/year is an achievable target with insulation thicknesses between 10 and 15 cm.

Compared with the average equipment in use today we found that all electricity used for refrigeration purposes in buildings could be reduced to

35 percent cost-effectively on a private economic basis.

WASHING

An estimated 7 percent of Denmark's electricity consumption is used for washing clothes, drying clothes, and washing dishes. All this we term washing. It is an area where it is difficult to distinguish between technical savings and behavioral savings. We will assume that the purpose is to provide clean clothes and dishes. On that basis there is a wide margin for electricity savings, but it might break with some traditions. North Europeans have been accostumed to washing as much as possible in hot water. Originally this took place in boiling water in the wash boiler, and the turbulence from the boiling was part of the washing process.

Today hot water is hardly required for any clothes washing, because of (1) better detergents available, (2) less dirty work, and (3) more frequent washing, which on the other hand is necessary, because artificial textile fibers normally can not absorb as much sweat as natural fibers can. Most artificial fibers actually can not stand 'hot wash', which is defined as wash with water at a temperature around 90°C. Surveys on Danish washing habits point toward a decreasing use of hot wash from 50 percent of the laundry in 1975 to around 30 percent today. 'Warm wash' (60°C) today accounts for 30 percent compared to 25 percent in 1975. Finally 'fine wash' (40°C and below) is now used in 40 percent of washings in Denmark compared to 25 percent in 1975.

Electricity for low-temperature purposes

As seen from Table I washing machines is much more widespread than dishwashers and clothes dryers are. The three types of washing equipment have the common characteristic that most of their energy consumption is used for low-temperature heating purposes. Less than 20 percent is used to replace the work associated with manual washing. For the washing appliances in Scandinavia the heat is always provided by electricity. Due to that, combined with the above described washing habits, these appliances rank among the big electricity users in Danish households. Only recently have clothes washing machines with intake of both hot and cold water been available on the Danish market, and still they are not much advertised, despite the fact that this feature has been used for more than a decade in other nations.

Analyses and experiments

In our early analysis of electricity savings potential we have suggested for all three appliances the use of lower temperatures in general and the use of more appropriate heat sources than electricity. Heat from gas- or oil-fired heating systems costs about half as much as electricity. Of special interest is the use of district heat from combined heat and power plants with a price around 30 percent of that of electricity. Better motors, pumps, ventilators, and control systems are other options for reducing electricity consumption for washing clothes, drying clothes and washing dishes. We estimated in 1977 the potentials for savings by 'radical' measures to be a reduction in electricity consumption down to 12 percent of the 1975 level, but with the use of hot water to substitute some of the electricity.

For clothes dryers improvements have included recycling of the heated air and better control of temperature and humidity. Heat recuperators, however, are only used for larger commercial dryers. Gas-heated clothes dryers are used in laundromats and other commercial laundries, but no domestic gas-heated models are on the market today.

Experimentally we are presently working along two lines with clothes washing machines. One path consists of testing low-temperature washing with appropriate detergent. The other path is a low-water washing process, based on minimizing the amount of water which needs to be heated. Improvement of the motors in the machines will also be considered. It is too early to tell any final results of these experiments. However, with proper adjustments in washing habits it is possible with machines already on the market, to reduce electricity consumption for washing machines to around 15 percent of the present level if the hot water required is taken in from the hot water system instead of being heated by electricity. For all the washing appliances, we estimate an electricity consumption on 25 percent of present as a possibility in the future.

PUMPING

In connection with comfort in buildings, pumps are used mainly for distributing the heat in central heating systems. Even though we do not include energy for heating in this paper we will look at the circulation pumps. There are pumps also in washing machines and dishwashers as described, but their efficiency plays a smaller role because of their short running time, compared with circulation pumps.

A circulation pump in a one-family house has typically been equipped with a 65-Watt motor. For space heating it usually runs 220 days a year, using 350 kWh/year. In a few cases hot water in the one-family house is also circulated by a pump which then runs all year with a 65-Watt motor consuming 570 kWh/year. One-family houses make up 60 percent of Denmark's dwellings. In multifamily houses and other buildings pumping is also used in the central heating system for both space heating and hot water supply. Furthermore 35 percent of Denmark's buildings of all kinds are supplied with heat from district heating systems, which use pumps in their distribution pipe grid. Altogether it is estimated that 4 percent of Denmark's electricity consumption is used for pumps in heating systems.

<u>Oversized circulation pumps</u>

The traditional small 65-Watt circulation pumps used in one-family houses in 1975 were greatly oversized and inefficient. In our analysis in 1978 we found that a 13-Watt pump should be sufficient even with only 10 percent efficiency. If we furthermore assume retrofit insulation of the houses and that the pump is used as an on/off control of the heating system, we suggested that the typical 1975 consumption of 350 kWh/year could be reduced to 45 kWh/year.

Today 20-Watt circulation pumps are marketed, and often the pump is integrated into the heat control system, most simply by a clock switching off the pump during nights. In a well-insulated one-family house it is possible with equipment on the market to cut down electricity for circulation pumps to something like 20 kWh/year or 6 percent of the 1975 level.

The potential for saving electricity for pumping in larger heating systems is not quite as good. However, proper sizing of pumps, continous variation of speed according to heat requirement, and better design of district heating systems are some of the options available, beside the indirect one of reducing demand for heat by insulating the houses.

We have not yet conducted any experimental work on pumps, but based on our recent analyses we find that for all pumping in Danish heating systems, it is possible to reduce electricity consumption to 25 percent of what is used today. When the changes are made in connection with the regular replacement of pumps, it is a very cost-effective conservation area.

It should be pointed out that heating systems using air flow to distribute the heat are essentially unknown in Danish dwellings. They are used in some commercial buildings in connection with ventilation systems for fresh air. Both in theory and in practice it is very inefficient to use air as a medium for transporting heat.

VENTILATION

Mechanical ventilation is seldom used in one-family houses in Denmark except for an exhaust fan in the kitchen. Over the last 10 years a few houses have been equipped with a mechanical ventilation system with heat recuperators to save energy for heating. In multifamily houses kitchens and bathrooms are often connected to an exhaust system in the building but also here mechanical ventilation systems with both inlet and outlet air are rare.

The primary use of mechanical ventilation is in commercial and institutional buildings, where it serves three purposes: (1) provide clean air, (2) provide cooler air, and (3) supply heat. Ventilation is estimated to use 16 percent of Danish electricity consumption if we include the ventilation to comfort domestic animals in stables.

As already mentioned the third purpose, to supply heat, plays a small role. Cool air is required in some buildings part of the year, but the need can be reduced by using means such as window shades and more efficient lighting systems that give off less heat. The major role of ventilation systems in Denmark is then to provide clean air.

Reducing the necessary air flow

We have analyzed ventilation and have found large potentials for saving electricity. Without going into details it can be mentioned that the amount of fresh air necessary can be reduced to half of what is now used. The power to be provided by the ventilator to maintain a certain flow of air is roughly proportional to the third power of the flow. Halving the volume should hence in theory mean a reduction of the ventilator power to 13 percent.

If we further add the possibilities for better designing of ventilation distribution duct systems, of electrical motors, and of the ventilators themselves, it is safe to assume it possible to reduce the need for electricity for ventilation to 15 percent of what is presently used to give the same comfort.

COOKING

Around 70 percent of Danish households use electricity for cooking, which consumes approximately 5 percent of the country's electricity. Just as for space heating and hot water supply, one can claim that electricity is not required for cooking, but we will describe some of our considerations on possibilities for saving electricity in cooking.

An average household with an electric cooking range was found to spend 950 kWh/year for cooking in 1975. Only 15 percent of this ends up as heat in the food, which indicates a large theoretical potential for higher efficiency. In our analysis in 1978 we found it possible by 'radical' measures to cut this 950 kWh/year for cooking to 450 kWh/year. The suggested measures included a reduction in the use of hot plates, which are rather wasteful. Instead we proposed for all water for coffee or tea to be boiled in special equipment such as the already common domestic coffee makers or kettles with immersed heating elements. They are 2 to 3 times as efficient as the hot plate. Also we designed a small 8-liter well-insulated oven which would be sufficient for maybe 90 percent of the oven cooking. The normal 50 to 70 liter oven would still be there for the turkey, etc. This small oven would in many cases be less energy consuming than hot plates.

Experiments with ovens and hot plates

Experimentally we are working with cooking along two lines, namely the small oven and better control systems for hot plates.

Two experimental low-energy small ovens have been built. One has a volume of 23 liters and is found to use 0.15 kWh for heating it up to 200°C and thereafter 0.14 kW to maintain this temperature. This should be compared with average figures estimated for 1975, around 0.35 kWh and 0.70 kW respectively. Improvements have been observed on the market since 1975. The most efficient oven on the market has a volume of 38 liters and uses 0.26 kWh to heat up to 200°C and 0.35 kW to maintain that.

Our work on cooking on hot plates is concentrated on better automatic control, aimed at eliminating excess heat in the hot plate after cooking. The idea is to make an automatic controller break the power in just enough time before the desired temperature in the pot is reached to make it possible for the heat in the hot plate to make up for the last heat needed. An extra benefit of better control is that it will be easier and safer to use reduced amounts of water for boiling potatoes, etc.

We have found that total electricity consumption for cooking can be reduced to half of the present or 40 percent of the 1975 level.

MISCELLANEOUS

Many items of electric equipment play a minor role in electricity consumption for comfort, for example, electric clocks, alarm systems, toasters, hand tools, and irons. Despite the relatively low electricity consumption it is worth noticing that they can also be made more efficient, often by just giving a little thought in the design.

Electronics

A dominant kind of miscellaneous equipment is what is termed electronics, including TV, radio, computers, control systems, and hundreds of other items. Together with other small miscellaneous equipment, electronics for comfort is estimated to account for 5 percent of Danish electricity consumption.

No other electric equipment has shown an increase in electricity efficiency like electronics, although no special effort has been directed toward reducing electricity consumption. This benefit has come about as a by-product from efforts to lower prices and improve reliability. In the 1960's a color TV typically used around 300 Watts. Today the same size is on the market with a power rating of only 50 Watts. Similar developments are found for radios. If we define the efficiency of a computer as the ratio between output in the form of number of operations and input in the form of electricity, we have already experience more than a hundredfold increase in efficiency over the past 20 years. This development seems to continue for a while, and if we compare to computers in use today, the efficiency improvement will be significant.

We have done no experimental work in this area. But we have found that the same comfort and conveniences from miscellaneous equipment can be provided in the future with 20 percent of present electricity consumption.

CONCLUDING REMARKS

We have summarized the results in Table II, which shows that all the use of electricity for comfort in Denmark can be reduced to less than one third of what is presently used without lowering the level of comfort.

Table II. Electricity savings potential is here shown for each of the categories of comfort. Electricity conservation factor is the fraction of 1984 level to which consumption could be reduced without lowering the comfort level.

Comfort Category	1984 electricity consumption (%)	(kWh/cap·yr)	Electricity conservation factor	Possible future electr. consumpt. (kWh/cap·yr)
Lighting	15	700	0.35	250
Refrigeration	13	610	0.35	210
Washing	7	330	0.25	80
Pumping	4	190	0.25	50
Ventilation	16	750	0.15	110
Cooking	5	240	0.50	120
Miscellaneous	5	240	0.20	50
Total for comfort	65	3060 →	.28	← 870
Total	100	4700	?	?

The next important question,then, is whether the level of comfort will grow in the future. We discuss that in another paper (Norgard and Christensen,1984). Here we will just mention that (1) growth in the use of electronics will have little impact on electricity consumption and (2) increase in the number of appliances leads to less use of each. Today 12 percent of the owners of clothes dryers and 4 percent of the dishwasher owners never use them.' (Statens Husholdningsraad,1983).

Finally we want to point out that our analysis of and experiments on electricity savings are generally based on well known and 'soft' technology. This means that the risk of negative side effects is very small. It also means that future development in technological science will point toward higher savings than what we have here suggested.

The environmental impact of producing electricity is often quite large. In Denmark the power plants now use coal for around 90 percent of their fuel. The result is air pollution with sulphur acid which now seems to be threatening forests in Denmark and other Scandinavian countries. This pollutant from power plants will be reduced is proportion to the savings in electricity for comfort in the buildings, resulting in increased comfort outside the buildings.

REFERENCES

The paper presents our work over the last ten years, using information from hundreds of references. The following list includes mainly our own reports, in which all the basic references can be found.

Harding et al. 'Danes Design Efficient Household Appliances', Soft Energy Notes p. 8, Vol. 1, March 1978.

J.S. Norgard, a, Husholdninger of Energy, Lyngby, Polyteknisk Forlag, 1979. (A draft translation, Households and Energy, is available from Friends of the Earth, San Francisco).
J.S. Norgard, b, 'Improved efficiency in domestic electricity use', Energy Policy, Vol. 7, no. 1, p. 43, March 1979.

J.S. Norgard, 'Low-electricity Future Household', in Effective Use of Electricity in Buildings, IEE conference publication no. 186, London, 1980.

J.S. Norgard et al. El-forbrugets udvikling i en landkommune, Nysted Energy Project, report no. 5, Nysted, Denmark, 1981.

J.S. Norgard, J. Holck and K. Mehlsen, Langsigtede tekniske muligheder for-el-besparelser. Physics Lab. III, Technical University of Denmark, Lyngby, 1983.

J.S. Norgard and B.L. Christensen, 'Individual Attitudes in Scandinavia Point Toward a Low-Energy, Saturated Society', Proceeding from ACEEE Summer Study, Santa Cruz, 1984.

J.S. Norgard and J. Heeboell, 'Racidal Reduction in Domestic Need for Electricity, Exemplified by the Refrigerator', in Energy Savings in Buildings, Proceeding from EEC-seminar, The Haque, Nov.1983, D. Reidel Publ. Co., Dordrecht/London, 1984.

Statens Husholdningsraad (Danish Government Home Economic Council), 'Udbredelse og brug af elforbrugende apparater', Notat 1. August 1983.