Household Appliances: Measurement in Single Family Houses

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A general objective since the 1980s has been to reduce the consumption of electricity in Sweden. The reduction of electricity used in households can actively support this trend.

The purpose of this specific project has been to demonstrate the possibility to reduce the electricity used for household appliances. In 12 single family houses built in 1972 the electricity was monitored to each unit before and after the change to new units (refrigerator, freezer, range, microwave oven, dishwasher, clothes washer, and clothes dryer). The families were selected and expected not to change in number and living habits during the two-year measurement period. The old equipment was in general the original equipment. The new appliances were selected to be the most energy efficient available. All 12 houses were equipped with appliances of the same size and brand.

The electricity saved by a new refrigerator was about 50 % and by a freezer about 75 % compared to an old unit. The other appliances have not shown that significant a reduction. However, smaller savings have been indicated for food preparation and washing.

Introduction

In the middle of the 1980s there was a shift in Sweden to reduce electricity consumption and make more efficient use of electricity. After the accident in the Chernobyl nuclear power plant, more effort was paid to research, development, and demonstration of efficient uses of electricity. For the last two years this is not a matter of high political priority. Today the technical lifetime rather than the "political" lifetime is important. However, a political review may be the case in the middle of this decade. The main objective today for efficient use of electricity is the possibility for energy export to Germany.

In Sweden a substantial quantity of the energy is supplied as electricity. In the year 1990 the total energy consumption was 365 TWh and about 1/3 of it was supplied as electricity. The production is approximately 50% by hydro power and 50 % by nuclear power. In buildings, except industrial production, the consumption of electricity is about 53 % of the total 130 TWh. The distribution of electricity consumption in various building types is given in Figure 1.

Estimations have been made on the consumption of household appliances in the dwellings. Most of those are given in the range of 3000 - 5000 kWh/yr. However, not very many measurements have been made and most of them are made on units of various brands and sizes. The number of houses in which measurements have been carried out is also small. The estimates are mainly based on laboratory tests on new units and not in field use by any occupant.

All dwellings in Sweden have an electric range and a refrigerator. In single family houses all have a freezer and a washing machine and in most of the houses a dishwasher. However, the majority of the houses are not yet equipped with dryer machines and microwave ovens.

The mean value of the electricity consumption in dwellings (other than heating) is about 1900 kWh/(person, year). In single family houses the population density is 2.8 persons/dwelling and in multi family houses 1.7 persons/dwelling. Thus the average household consumes 5300 kWh/yr in a single family house.

Objective

The main objective of the project was to increase the efficient use of electricity. Another purpose was to substantially decrease the use of electricity for household appliances by changing all old units to the most modern and energy efficient on the market.

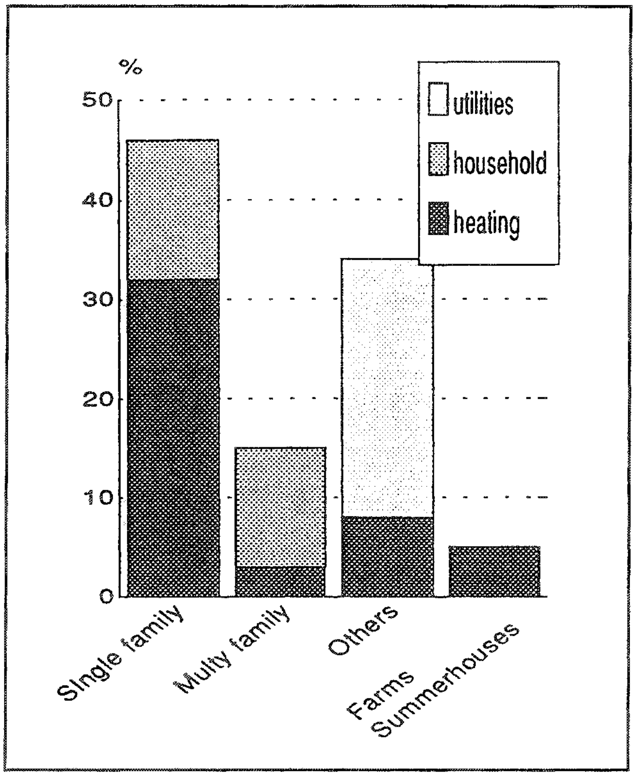


Figure 1. Electricity Used in Buildings

Research Approach

This project is one of four in which we demonstrated how to use electricity more efficient in single family houses heated with electric radiant heating panels. All 40 houses were monitored before and after retrofitting in order to save energy, which in these houses is equal to saving electricity. Changing all the household appliances was only a main objective in this specific project.

Selection of Houses

Many single family houses in Sweden are completely or partly dependent on electricity for heating. In Figure 2 is shown how the 1.8 million single family houses are heated. As can be seen, approximately 2/3 of all can be heated by electricity and 30 % of all single family houses are heated with electric radiant panels.

From Figure 3 and 4 we see that about 50 % of the houses were constructed during the last 25 years and that in those houses electrical radiant panels are quite frequent.

Additionally, it is also common to use such panels in houses constructed before 1940.

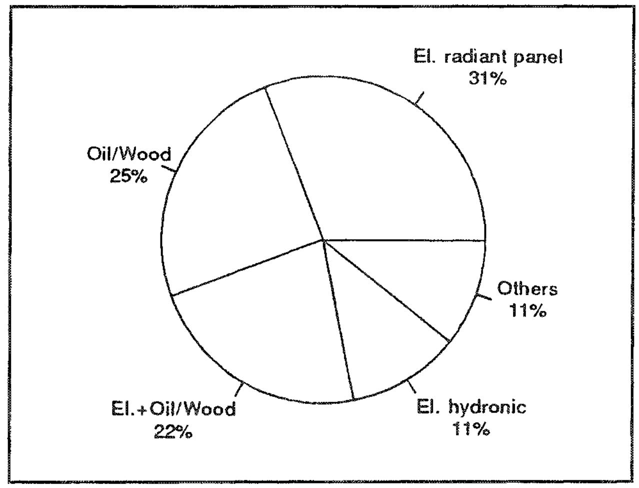


Figure 2. Heating Systems in Single Family Houses

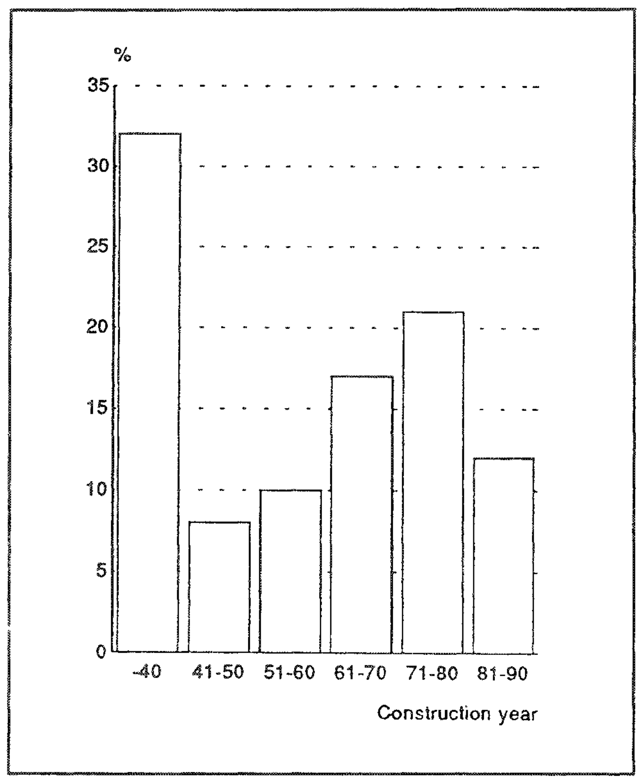


Figure 3. The Construction Year of All the 1.8 Million Single Family Houses

Detailed studies of statistics reveal that the most frequent single family house heated with electrical panels was constructed between 1966 and 1976, in groups with 50 to 200 houses of the same size and shape. These houses represent 1/4 of all houses heated with electrical radiant panels. The variety in size, material of walls, shape, etc. is covered by all the 40 houses in the four projects. The

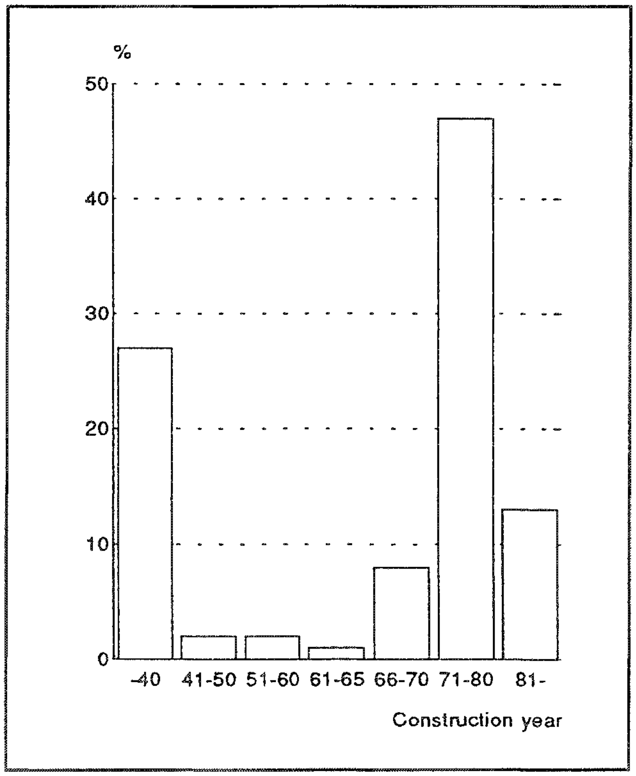


Figure 4. The Construction Year of the 550,000 Single Family Houses Heated with Electrical Radiant Panels

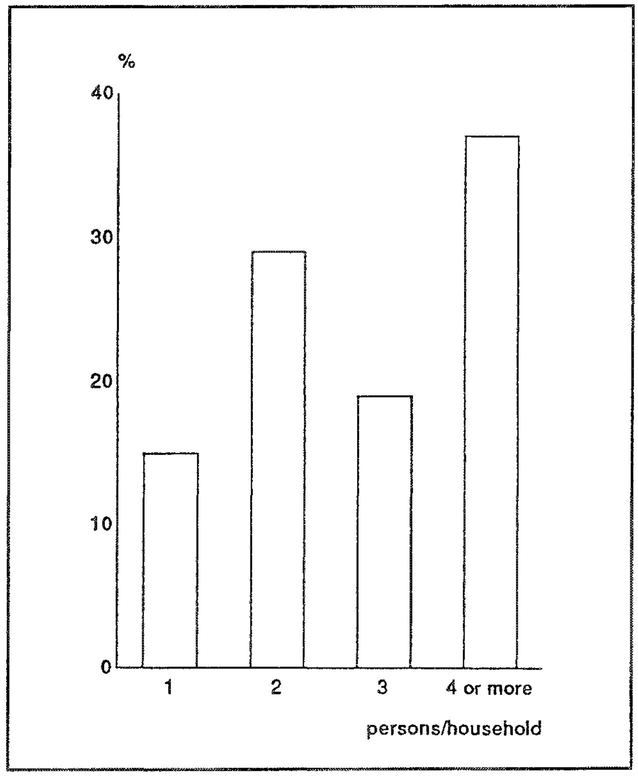


Figure 5. Number of Persons Living in Each Single Family House, as a Percentage of all 1.8 Mill Houses

number of occupants and their habits is of course of great concern for the electricity used by the appliances. In Figure 5 the distribution of the number of people living in single family homes in Sweden is given.

Research Houses

The characteristics discussed above of the Swedish single family houses were the basis when selecting the test houses. Other criteria were that the families living in the houses were supposed to stay constant in number and habits during at least two years, and these families had to have been living in the house at least 3 years. Two areas were chosen, H and L. The studied houses are described in Figure 6 and 7.

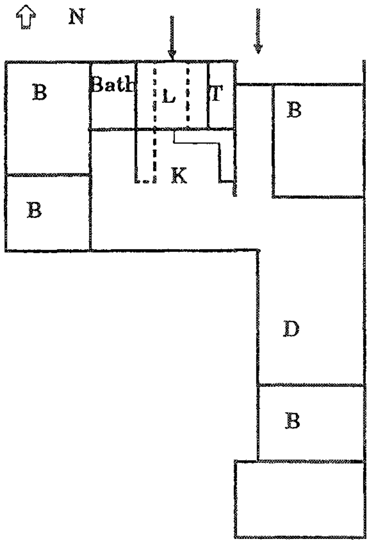
In most houses the original appliances from 1972 were still running, but in many houses people were just about to buy new appliances. In two houses all the appliances had been changed, and in 8 of the houses the clothes washer had been changed and was now from 2 - 10 years old. None of the new appliances was of the most energy efficient type.

The study was carried out in 12 houses. During the research period 11 houses were occupied and the 12th house unoccupied only before the appliances were changed. Unfortunately, the owner returned earlier than expected from employment abroad.

Data Acquisition

An automatic monitoring system has been used in all the 12 houses. The sampling method used is that for each 5 Wh a registration is made. In the computer in each house the hourly energy consumption is collected and sent by the telephone net every working day to a central computer. The hourly values are then used in the analysis.

The electrical consumption of the individual appliances has been monitored during one year before and also one year after the installation of the new appliances. One exception, however, is the dishwashers which were monitored only three weeks before the change to the new ones. The electric consumption of clothes dryers was not possible to measure. Only 2 households were equipped with dryers. Most of the households used drying cupboards in which the original fan and heating element were not in use.

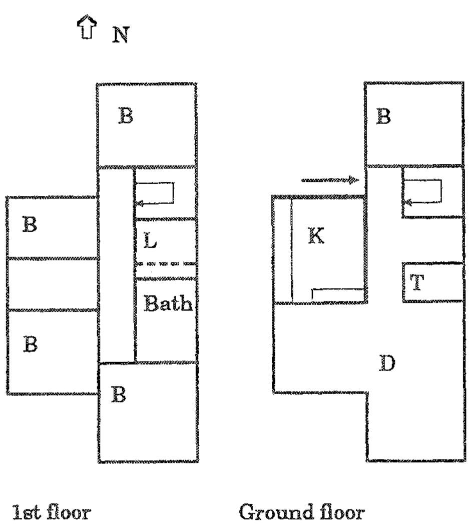


6 houses were selected from the 90 present

Living space 129 m^2
1-storey woodframe
Flat roof
Double glazed windows
Natural ventilation with range hood fan
After retrofit 3 houses have exhaust ventilation by heat pump (# 3, 4, 5)
Air tightness
n_{50} 6.6 ach/h
Mean indoor temperature:
before 21.0 C
after 21.1°C

Interested to participate 42 %
Population density 3.87 persons/house in average and 3.83 persons/house in test houses
One house without children (# 1)
Teenagers in four houses (# 2, 3, 4, 5)
Houses (# 1, 3, 4) have not changed owner.

Figure 6. Short Description of Test Houses at the Area H (# 1 - 6)



6 houses were selected from the 60 present

Living space 158 m^2
2-storied wood frame
Flat roof town houses
Double glazed windows
Natural ventilation with range hood fan
After retrofit 2 houses have exhaust ventilation by heat pump (# 9, 12)
Air tightness
n_{50} 5.9 ach/h
Mean indoor temperature:
before 21.0°C
after 21.1°C

Interested to participate 55 %
Population density 4.12 persons/house in average
4.33 persons/house in test houses
Teenagers in all houses
House # 11 only 1 person every other week.
Two houses (# 9, 10) have not changed owner.

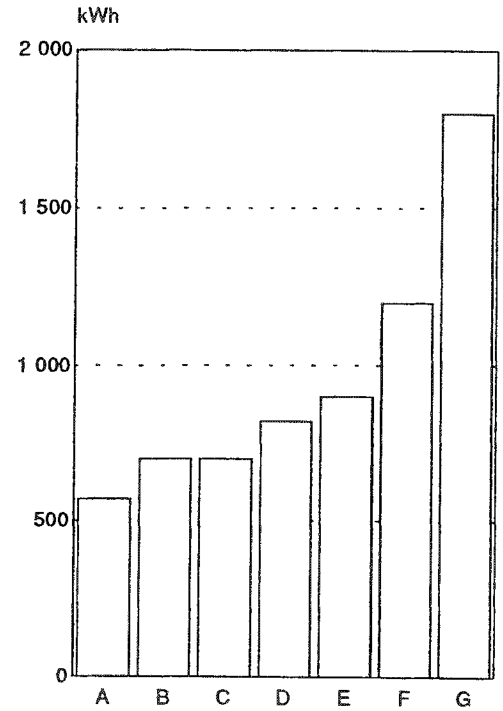
Figure 7. Short Description of Test Houses at the Area L (# 7 - 12)

To assure data quality the energy consumption for refrigerators and freezers was checked during two weeks. Additional checks were made on three of the freezers. One had used extremely little energy and two had used more than three times the average. Service was ordered to tighten the units and the work had to be checked by measurements.

In all 12 houses room temperatures and electricity to the radiant heating panels, hot water production, and the heat pump were monitored. Various functions were measured in the houses such as air tightness, and air change rate, and insulation quality and leakage locations were checked by the thermography method.

Results

The freezer is the most energy consuming product in the household. As its potential for savings is the highest, much effort was made to identify the lowest energy consuming product on the market not only in Sweden but also in Europe. Products that were on the threshold to be launched on the market were identified. There were two main criteria besides the energy efficiency. The first criterion was that the volume or the height should be similar to that in houses in area L. The minimum height would then be 1.75 m and the depth and width, according to the standard in Sweden, 0.6*0.6 m. Thus, the houses in area H got an increased volume in the freezers and refrigerators. The second criterion was that both freezer and refrigerator should be of exactly the same design, since they are placed beside each other in the kitchen. As the most interesting value was minimizing the sum of the energy consumption for both freezer and refrigerator, this is given in Figure 8 based purely on the manufacturers' data.



A = Best combination regadless the brand
B = Best combination the same brand
C = Best outside Sweden
D = Commonly chosen brand
E = Automatic defrost, best
F = Automatic defrost worst
G = With icemachine

Figure 8. The Annual Energy Consumption for Refrigerators and Freezers Based on Manufacturers' Data. The height is 1.8 m for all except C (1.6 m).

The freezers installed were the first delivered from the factory and were regarded as the first 50 test units. After a couple of months the ordinary mass production was scheduled to start. The refrigerator was of ordinary construction and was only changed in design. The freezer was newly constructed and that was probably the reason why all units had to be tightened because of the air leakage. The consumption has been cut down considerably; see Figure 9. The mean value of the annual energy savings is 850 kWh, or a reduction of 75 %. It should be noted that house # 9 had an automatic defrost freezer only 4 years old, and house # 8 had an ordinary freezer, also 4 years old. The estimated consumption of 0.95 kWh/d made by the manufacturer was closely adhered to and the measured average consumption was 0.80 kWh/d in spite of the mediocre performance in two houses. In the empty house the consumption of the old freezer was measured as 1080 kWh/yr. As there was no occupant in the house the indoor temperature was reduced to 17°C.

Both the old and new refrigerators showed a more varied consumption pattern than the freezer. The individual households have kept their life styles constant in their use of the refrigerator. As can be seen in Figure 10 households with high energy consumption still have high energy use after the installation of new units. It should be noted that house # 8 had a 4 year-old refrigerator of a brand which was found in the survey to have the lowest energy consumption. The average annual energy savings is 210 kWh, giving a 55 % decrease. The manufacturer's data indicated 0.9 kWh/d and the measured average consumption was 0.48 kWh/d if house # 12 is excluded.

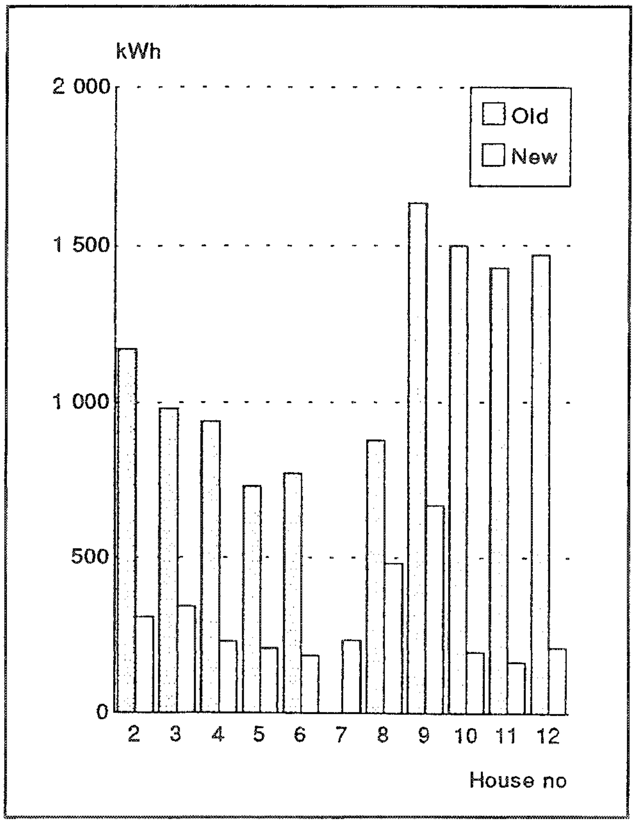


Figure 9. The Annual Energy Consumption for the New and Old Freezers

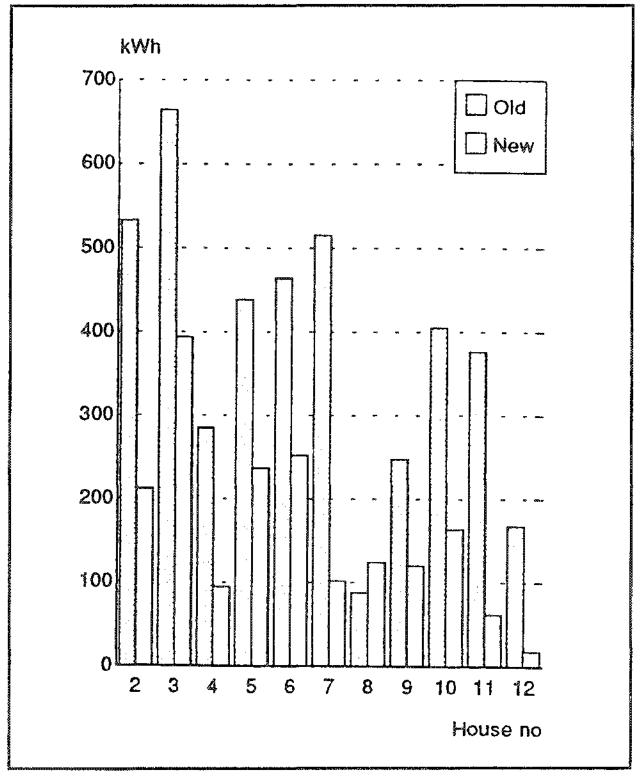


Figure 10. The Annual Energy Consumption for the New and Old Refrigerators

In house # 1 136 kWh was measured as the annual consumption of the old refrigerator without the influence of any occupant.

All food preparation was made on the original installed range except in houses # 2, 8, and 9, which were equipped with 4 year-old ranges. After installation of the new ranges, preparation of food also could be made in microwave ovens. In most households a slight reduction in energy consumption was measured; see Figure 11. The exceptions were found in houses # 2 and # 4. A considerable decrease in the energy use was measured in house # 9, which probably depends on the high energy consuming oven of the old range. A change in the occupants' pattern has been observed in house # 11. The average annual energy savings is 100 kWh or 18 %. However, a considerable savings was not foreseen.

The dishwasher could be supplied either by hot or cold water. The latter alternative is supposed to be the most energy efficient one as it isn't necessary to use heated water in the whole process. Tests initiated by the National Swedish Board for Consumer Policies indicated an annual energy consumption of 400 kWh when using hot water (including the energy for heating the water) and 280 kWh when using cold water. This is based on the use of the machine every day. With this assumption the energy for each run of the machine is 1.9 kWh with hot water and 1.3 kWh with cold water.

In the study the monthly frequency of dishwasher use varied from 11 to 31 times, giving an average annual consumption of 480 kWh with hot water and 390 kWh with cold water; see Figure 12. The savings is approximately 18 % if cold water is used instead of hot, compared to the theoretical 29 % based on laboratory tests. The frequency of use was stable in all houses except # 4, 6, 10, and 11 in which the use of the machine was increased from the period when using hot water to the period using cold water. The energy for each run of the machine was considerably higher than measured at the laboratory. With hot water the range was 1.5 - 2.9 kWh and with cold water 1.1 - 1.8 kWh.

Use of a dishwasher supplied by cold water was not accepted in houses in area H. The machine caused more noise because of the longer running time. It was perceived as an annoyance in this type of house without doors which could be closed to the kitchen. No relation was found between the energy used for food preparation and dishwashing.

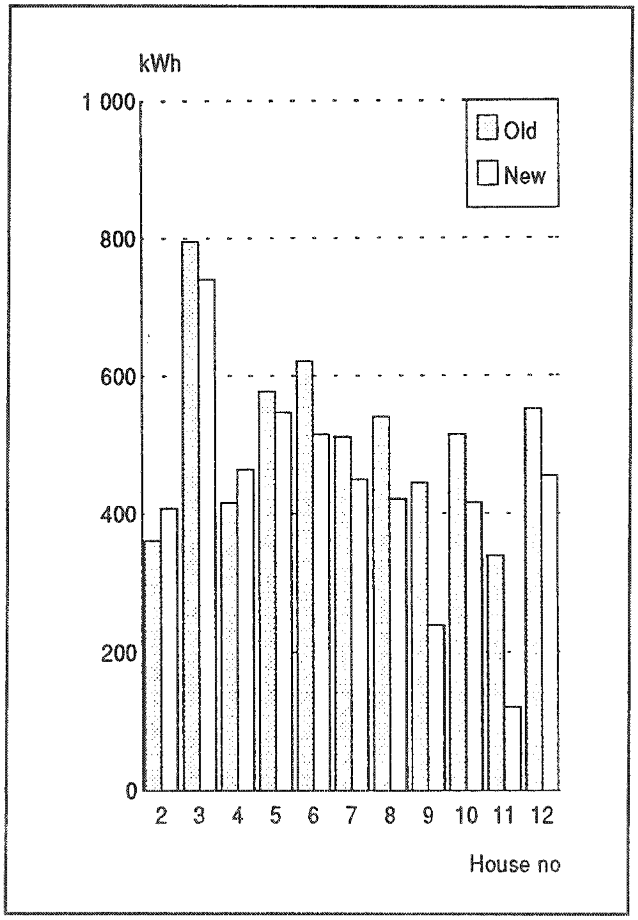


Figure 11. The Annual Energy Consumption for the Old Ranges and the New Ranges + Microwave Oven

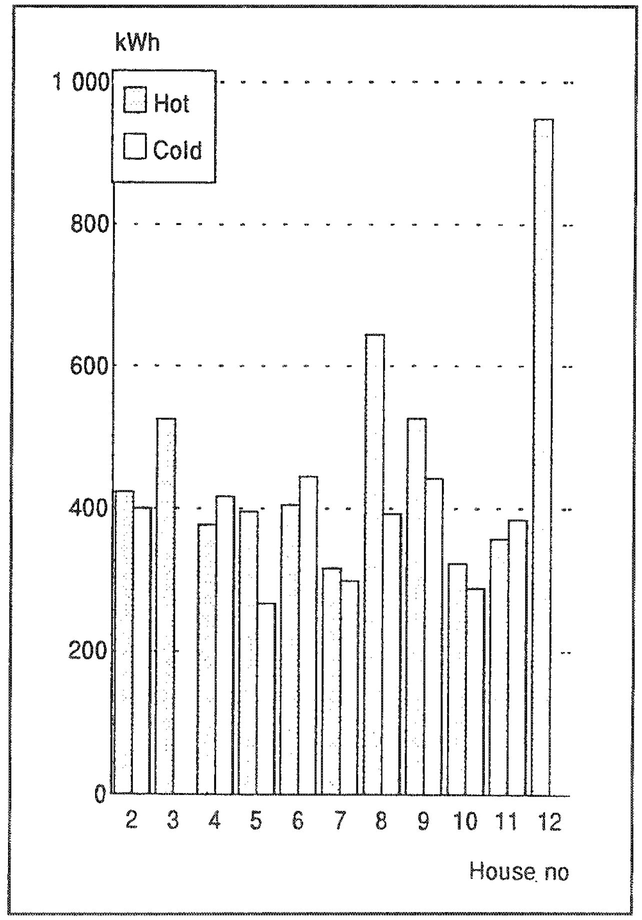


Figure 12. The Annual Consumption for the New Dishwashers Supplied by Hot or Cold Water

The energy consumption for washing and drying clothes is very much dependent on the various materials of the clothes, the various colors, the "need" to refresh, the number of items, and the mix of the laundry. All this results in a more or less full washing machine and the need for heating the water. If the water can be adjusted to the need for washing some savings can be achieved. The machine used in this project can adapt the water needed for washing the laundry according to the load level in the machine.

In most of the households a small decrease in energy consumption was found. However, in two houses a slight increase was measured. In house # 6 there are no teenagers and in # 11 no children's clothes are washed; see Figure 13. The annual average savings is 100 kWh. The monthly frequency of use is 11 - 31 washes which changed from the use of the old to the new clothes washer but not systematically. For 5 houses the frequency of use was increased,in 4 houses decreased, and in 2 it remained equal. The energy consumption of the old machines was in the range of 1.2 - 2.2 kWh per run, with one extreme value at 5 kWh/run. The new washers consume in the range of 0.7 - 2.3 kWh/run, with an extreme value of 3.9 kWh/run in the same house as with the old high energy-use machine. This can be compared to 0.9 kWh/run for synthetic materials and 2.1 kWh/run for cotton, measured in the laboratory by the National Swedish Board for Consumer Policies.

When examining peak values, it is obvious that in some houses a more energy efficient strategy has been found when washing laundry. For the old machines the peak was up to 2.0 kWh/run. In house # 4 a very efficient energy use strategy at 0.2 kWh/run had been found and this could not be duplicated for the new machine. In those houses that achieved the best savings the occupants have found a strategy betweem 0.4 and 1.0 kWh/run instead of 1.6 kWh/run for the houses with higher energy consumption.

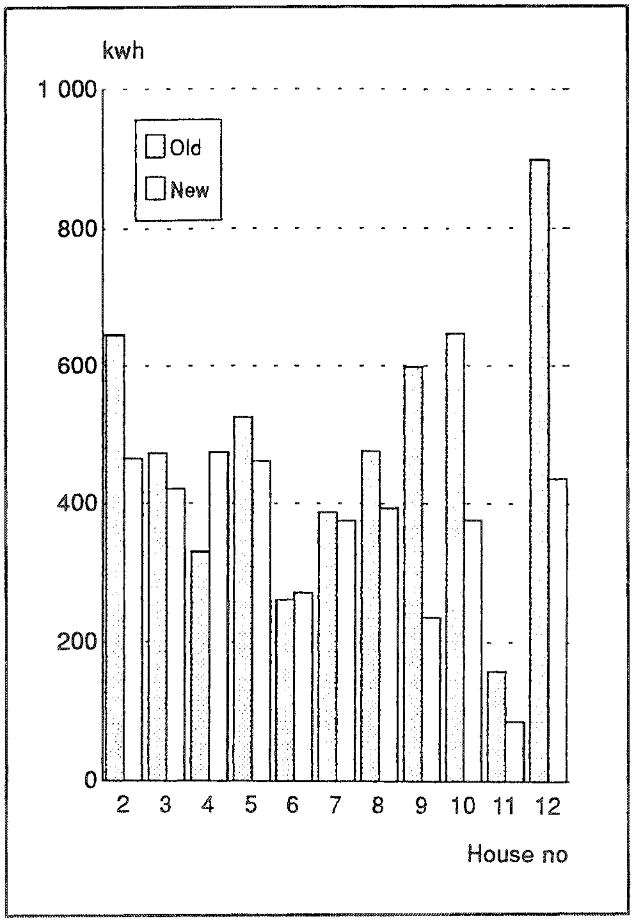


Figure 13. The Annual Consumption for the Old and New Clothes Washers

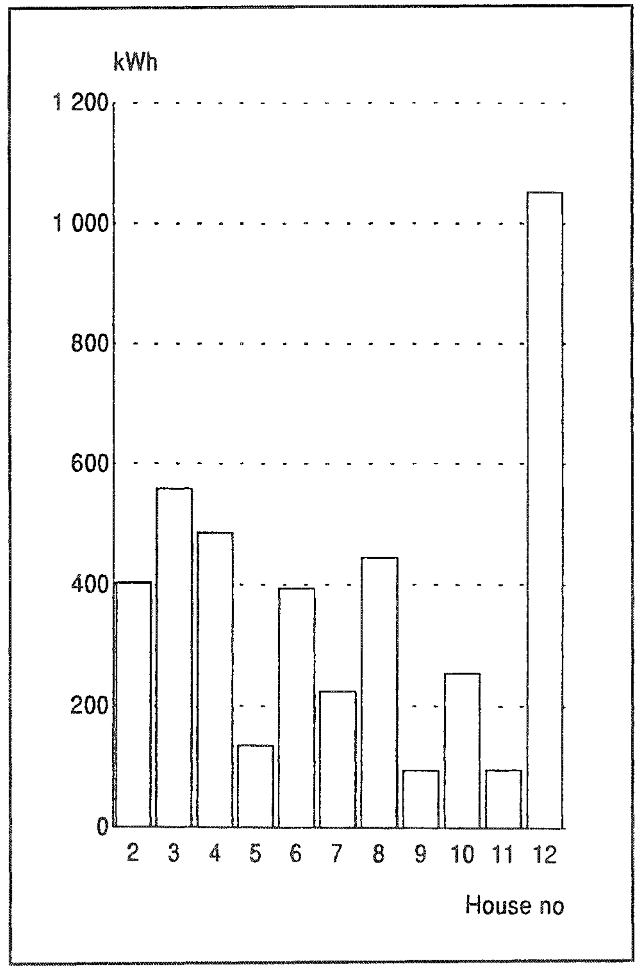


Figure 14. The Annual Consumption for the Clothes Dryers

The dryer installed was of the condensing type, which provides the opportunity to use waste heat recovery during the heating season. However, in some cases the result is that the warm air causes too high a temperature. As nearly all the households did not have dryers before, and most of the drying cupboards were out of order, the result was an increased energy consumption. The average annual consumption is 380 kWh but the variation is considerable and the range is 100 - 1000 kWh/yr; see Figure 14. In Sweden air pollution is usually not a problem. This gives the possibility to dry laundry in open air during spring, summer, and fall. This is obvious when studying the frequency for using the dryer, but only in the area H. In the other areas it is too uncomfortable to carry the laundry downstairs and then outdoors and then back again. The frequency during the winter varies in the range of once a week to once a day. During the warmer periods, use is cut down with 50 % if it is comfortable to bring the laundry outdoors; otherwise it is kept to the same level as during wintertime. The running strategy varies significantly and the consumption in the households has been found in the range of 0.8 - 4.0 kWh/run. It is not possible to observe any correlation between the consumption for washing and drying. However, house # 12 consuming the most energy for washing also do so for drying. There is no correlation between teenagers in the household and high energy consumption for drying the laundry.

Discussion

This study indicates that there is a great potential for saving electricity in the household appliances. The variation can be quite considerable and the annual savings is estimated to be from about 600 kWh to 1800 kWh. It must, however, always be kept in mind that in electrically heated houses the savings in electricity is very marginal and occurs only during the four summer months when no heating is needed (in Sweden no cooling is necessary). At that time of the year there has always been a surplus of electricity in Sweden. For all the other houses the savings in electricity can be considerable but then the energy for heating the house has to be supplied by other means. The average annual savings is estimated to be 1100 kWh. If this can be achieved in all Swedish houses, including the electrically heated homes it will result in a reduction of 2.0 TWh. If the household appliances in the electrically heated houses during wintertime are excluded, this results in a potential of 1.4 TWh annually for the reduction of electricity.

Factors affecting the long term savings for individual appliances are especially related to improved performance of the freezer and the refrigerator. The better the appliances are, the more sensitive for slight faults in the manufacturing process and life time durability. The experience from the project shows that it is not easy to notice if and when the performance is not in agreement with what can be expected. The possibilities for further decreases in energy consumption are somewhat smaller after the initial big step but the energy consumption for the refrigerator can still be cut down by at least 50 %. The exceptional low consumption in one of the houses gives a hint of the potential.

Food preparation still has potential to cut down on energy use. The way to do so is to change both preparation habits and the appliances. The development may be speeded up if the time for food preparation can be cut down, as there is a reduction of electricity without any corresponding increase elsewhere. Probably this needs development in the microwave technique and a complete redesign of the kitchen.

The dishwasher connected to cold water still has a potential to be accepted if the occupants can use the machine during nighttime and with a slight decrease of the noise level. The next step will be to use colder water, but acceptance of this can be difficult for people.

There is still a substantial potential for saving energy in handling the laundry. In the long run the habits must be changed to use lower water temperature, shorter running times, and less use of cleaning substances, especially when the clothes are just needed to be "refreshed". Drying the laundry is still a problem if the washing is not planned during the week. The main strategy is to fill the drying machine and keep the temperature down in the room in order to increase the efficiency of the machine. Usually this can be met by keeping the door opened to the laundry and accept some noise.

The main energy reduction in the household will happen when the number of people is reduced. This will occur when the children move out. The average number of persons in the test houses is 4.1, and the difference is 1.3 persons compared to the average number in all single family homes in Sweden. This implies that the savings potential might be smaller. However, the main energy savings will be made by the new freezers. On one hand many homes have an extra freezer, making the potential bigger, but on the other hand there is a risk for using inefficient appliances, thus increasing the total volume.

Conclusion

It can be concluded that the potential annual savings in household appliances can be up to about 1800 kWh. This can be achieved with very small efforts and little expense. The only requirements are better use of appliances by the occupants, further development of refrigerators and food preparation appliances, and high efficiency appliance performance.

The knowledge of "best buy" must always be easily available so that the consumer can make the best energy choice when a new appliance is needed to be installed.

Acknowledgments

The project has been funded by The Swedish Council for Building Research.

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