Household classification according to electricity consumption

Toke Rammer Nielsen
Department of Civil Engineering
Technical University of Denmark
Denmark
trn@byg.dtu.dk

Jørgen S. Nørgård
Department of Civil Engineering
Technical University of Denmark
jsn@byg.dtu.dk

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Abstract

What is reasonable electricity consumption in households and what is low or high? This paper suggests different classes, A, B, C, and D, here referring to the household's consumption for running what is termed movable appliances, i.e. excluding equipment fixed as part of the building. The classes are based on scenarios built on bottom up analyses of how much energy service can be provided to a household from a certain amount of electricity. Using the most efficient appliances, it is possible for class A households, using less than 250 kWh/year per person, to provide a decent European level of services in a 3-4 person household. Class B has a maximum at 500 kWh/year per person. In Denmark the average figure for all electricity use in households is presently about 2000 kWh/year per person. Examples of services achievable within different classes are presented.

Electricity consumption in households falls into two categories: electricity used for fixed building installations like ventilation, circulation pumps, etc., now regulated by the EU Directive on energy performance of buildings, and that used for movable appliances, which is what this paper is about. The study excludes electricity used for purposes where other forms of energy are easily workable, for instance for space heating or for transport, even if such applications can be justified.

The classification can serve as 1) inspiration for consumers to set targets 2) a basis for stepwise progressive electricity taxes and other policies, 3) guidelines as a supplement to building codes. Bottom up analyses make people aware of choosing efficient appliances, as well as reconsidering the necessity of the appliances. This partly explains why bottom up analyses comes to significantly lower consumption than does a top down analysis based on what can be afforded.

Introduction

Considering that energy savings to a large extent constitute the most cost-effective way to reduce CO_2-emissions, in money terms as well as in environmental terms, it is essential to give the public some ideas on how much can be achieved. Often however, people do not know the level of their energy consumption - in this paper their *electricity* consumption – and especially they do not know how low it could be, if proper attention was paid to how much electric equipment they purchase, which models they choose, and how much they utilize it.

The idea of household classification was first presented in 1998 (Nørgård and Guldbrandsen, 1998). That paper referred to the first systematic proposal to improve the energy efficiency of domestic appliances in the 1970s, which showed significant potential for improvement as compared to the typical units in use at that time (Nørgård, 1979). For the same energy service performance, electricity consumption could be *reduced down to* around 20% of what it was for the appliances studied. In the wake of the oil crises in 1973 and 1979 the technological challenge was taken up by manufacturers, and by 1998, electrical equipment like refrigerators, washing machines, clothes dryers, lamps and pumps with efficiencies close to those proposals were available, but certainly not dominating the sale (Nørgård and Guldbrandsen, 1998). The situation today in 2009 is that the most efficient appliances on the market are not much better than the best on the market ten years ago, although they now have a much larger share of the market. A few of the most efficient models in 1998, like the refrigerator mentioned in the following, have actually been taken off the market. This lack of further efficiency progress can of course partly be explained by the fact that we are approaching some theoretical or technical limits for the efficiency possible. There are, however, still room for making even more efficient models (Danish Energy Agency, 1996; Nørgård and Guldbrandsen, 1998).

Despite the immense technological progress in *the most electrically efficient models* on the market, electricity consumption in households has not declined, which can be explained by the following factors:

1. The most efficient models on the market are not necessarily the models consumers choose when purchasing.
2. Even if they did choose the most efficient models, the full effect on total electricity demand would not show up until the full stock of appliances was replaced, which can take decades.
3. Finally, consumers have chosen to buy more and bigger appliances, for instance electronics, and thereby outdoing the energy savings obtained from the better technology.

Definitions and methodologies

Before going into details and examples, some points and definitions have to be clarified. On the basis of the EU directives and the Danish Building Regulation is first defined the two categories of households appliances, the fixed and the movable appliances, where the latter is the one dealt with in this paper. This is followed by a few words about the way we set up the various classes and built up the cases. The study is mainly based on rough Danish consumption data, because the main point is about developing various low energy scenarios by constructing a balance between service level and appliance efficiency.

BUILDING REGULATIONS AND FIXED APPLIANCES

The EU directive on energy performance of buildings imposes all member states to implement minimum energy performance requirements for buildings (EU, 2003). The directive dictates a general framework for what is included in the calculation of the energy performance of buildings. The framework of the directive roughly includes the energy consumption to provide heating, cooling, ventilation and fixed lighting in buildings. In this paper *fixed appliances* denotes all appliances where the consumed electricity is included in the framework of the directive. All other appliances are denoted *movable appliances*.

The directive is, however, implemented differently in the member states giving rise to several methods to calculate energy performance of buildings. To clearly define the difference between fixed and movable appliances in households, this paper uses the definition of the *energy performance frame* for dwellings in the Danish Building Regulations (The Danish Ministry of Economic and Business Affairs, 2007). For dwellings the Danish *energy performance frame* deviates from the directive by not including any energy used for lighting, because this is typically provided by plug-in lamps. The *energy performance frame* includes energy used to run the *fixed appliances* that provide the dwelling with space heating, hot water, cooling and ventilation. This includes boilers, circulation pumps for distributing space heat and domestic hot water, fans in ventilation systems, control systems, etc. The remaining energy consumed in dwellings is used to run *movable appliances* such as all lamps, washing appliances, refrigeration appliances, and plug-in units like TV-sets, etc. All typical equipment, which people could take along when moving out of the dwelling.

Besides the minimum energy performance requirement, Danish dwellings can furthermore be classified into two *low energy classes (low energy class 1 and 2)* with better energy performance than what is actually required. To qualify for the strictest class (low energy class 1), the *energy performance frame* of the dwelling, that is total energy demand for heating, ventilation, cooling and domestic hot water per m² of heated floor area, may not exceed 35 kWh/(m² year) plus 1100 kWh/year divided by the heated floor area. The Danish Energy Agency has decided that in calculating total energy demand for the energy performance frame, electricity used by fixed appliances is multiplied by a factor of 2.5 when added to the other energy forms used, such as gas, oil or district heating. This factor 2.5 reflects the high thermodynamic quality of electric energy, and the rationale behind its use here is that more than 80% of Denmark's as well as of the world's electricity is produced by thermal power plants, and here the factor 2.5 roughly reflects the fuel energy input necessary to produce one unit of electricity (IEA, 2008; Danish Energy Agency, 2007).

In a new Danish *low energy class 1* house 75% of the energy performance frame is used for heat (natural gas, oil, district heating) and 25% of the energy performance frame is accounting for electricity used by fixed appliances (pumps, boilers, fans). Taking into account the factor 2.5, this amounts to a typical yearly electricity consumption for fixed appliances of 600 kWh for a 140 m² house, which is a typical size. This is roughly 300 kWh/year per person based on a Danish average household size of 2.1 persons. More than 50% of the *electricity* consumption for fixed appliances is used in the balanced ventilation system where heat recovery reduces the yearly *heating* demand by the order of 4200 kWh for the 140 m² house.

FOCUSSING ON MOVABLE APPLIANCES

Contrary to the political option for setting minimum standards for fixed electrical equipment, it is not possible to directly come up with political requirement for maximum electricity consumption for the movable appliances, which are the focus of this paper.

On *average an existing* Danish household annually consumes 4200 kWh, or 2000 kWh of electricity per person (Danish Energy Agency 2007). Out of this, an estimated 20% or 400 kWh per person is used for fixed appliances, mainly circulation pumps, electric heating and boilers (Rahbar et al., 2008). The remaining 1600 kWh/person is what is used for *movable appliances*, and what is in focus of this paper.

As mentioned above movable appliances include not only directly plug-in units like TV-sets, vacuum cleaners or computers, but also washing machines, refrigerators and lamps. Contrary to the fixed appliances, the movable appliances are rather similar in new and in existing dwellings, and so are the options for reducing electricity consumption to run them. In a later section some of the most important appliances are discussed.

Table 1. Selected student results for electricity consumption of movable appliances in low electricity households of different sizes. The table footnotes summarize typical equipment chosen by the students for the different services.

Household size, person	1	2	3	3	4	4	4
Food storage[1], kWh/year	62	190	190	303	186	172	124
Cleaning[2], kWh/year	51	116	152	125	156	277	175
Light, kWh/year	51	118	260	225	136	176	249
Home entertainment[3], kWh/year	55	92	93	85	90	104	362
Other, kWh/year	41	69	194	230	344	246	219
Total pr. person, kWh/(person year)	260	293	296	323	228	244	282

[1] *Refrigerator or refrigerator with bottom freezer*

[2] *Washing machine and vacuum cleaner*

[3] *TV, DVD-player, game console, stereo, PC, modem, router*

SCENARIOS AND BOTTOM-UP ANALYSES

For three of the four classes suggested for classifying households according to their electricity consumption, some scenario cases are built. The purpose of these is not to suggest what would be the best way to save electricity, but rather to illustrate and ensure that at least it is possible to live well, even in class A with only 250 kWh of electricity annually available per person for movable appliances.

The scenario building process is a mix of bottom up analyses and trial and error. Starting with deciding how many people would be in the household we go on listing the services people would like to have at their disposal, like cool storing of food, cooking, cleaning of clothes, illumination, etc. With that lined up, a look at the efficient appliances available, the necessary electricity consumption is calculated and added up. The first result gives some ideas about how high to aim in the classes. Going through lists of important appliances presently found in Danish households (Rahbar et al. 2008) some less important services can be excluded if the result is a too high consumption for meeting the class aiming at. In other cases there might be room for some more appliances.

Students' task

Since electricity consumption is typically spread out over numerous small and big uses, ranging from electric clocks to cooking stoves, it is hard to get an overview of the stock of equipment and its electricity consumption. Therefore, the authors have over several years in a university course on energy savings given the students the group task to analyze the options for low electricity consumption in households. The task given was: Design a household which you would like to be part of, using no more electricity than 350 kWh/year per person for both fixed and movable appliances. This task forces the students to consider three determining factors: 1) number of people sharing the services (household size), 2) the electricity services they find most essential to have available, and 3) the electrical efficiency of the appliances chosen to provide the services. In the assignment it is assumed that gas is available for heating purposes e.g. cooking, space heating and hot water. Table 1 summarizes some student results for electricity consumed by movable appliances.

In this paper we have drawn on the experience from this group work as well as our own and other researchers' experiences. The general observation is that it is rather easy to have a satisfactory household within the limit of electricity 250 kWh/year per person, which is only ca. 16% of the 1600 kWh typical in Denmark for running the movable appliances, as mentioned above. Even without aiming for the 'A' target of 250 kWh, the exercise raises the question of what the remaining 84% is used for.

Ranking households according to electricity consumption

The idea behind this paper is to suggest some classifications for household's electricity consumption, denoted with 'A', 'B', etc., with 'A' referring to households with the lowest electricity consumption.

For single appliances, similar classes defined according to their electricity efficiency were introduced in the EU in 1995 and then termed 'A', 'B', 'C' etc. with 'A' being the most energy efficient class, and 'G' being the worst. Unfortunately, the performance required to qualify for an 'A' was set quite moderate. Less than ten years later appliances had improved so much that, for example, almost all models of refrigerators on the market were 'A' and a few 'B'. To retain its practical use, the scale was in some countries extended with A+ and A++, which was confusing to the consumer, since 'A' is now close to being the least efficient model (Nørgård et al., 2007).

HOUSEHOLD CLASSES

To avoid the above mentioned problem of starting with too low requirement for the energy classes, experienced for single appliances we have here from the beginning for movable appliances in households suggested a rather strict requirement for 'A', namely a maximum 250 kWh/year per person in the household (see Figure 1). At present the average household consumption in Denmark for movable appliances is around 1600 kWh/year per person. But as will be shown, it is nevertheless possible to live a decent and comfortable life within the class 'A'. Not many households can presently meet class 'A', and perhaps relatively few will in the future. Nevertheless, this framework can be useful as an inspiration for policy making, as we will show later. Class 'B' allows up to 500 kWh/year per person, while Class 'C' requires no more than 1000 kWh/year per person. Similar to what is suggested by the Danish Electricity Saving Trust as a target for total household electricity consumption per person

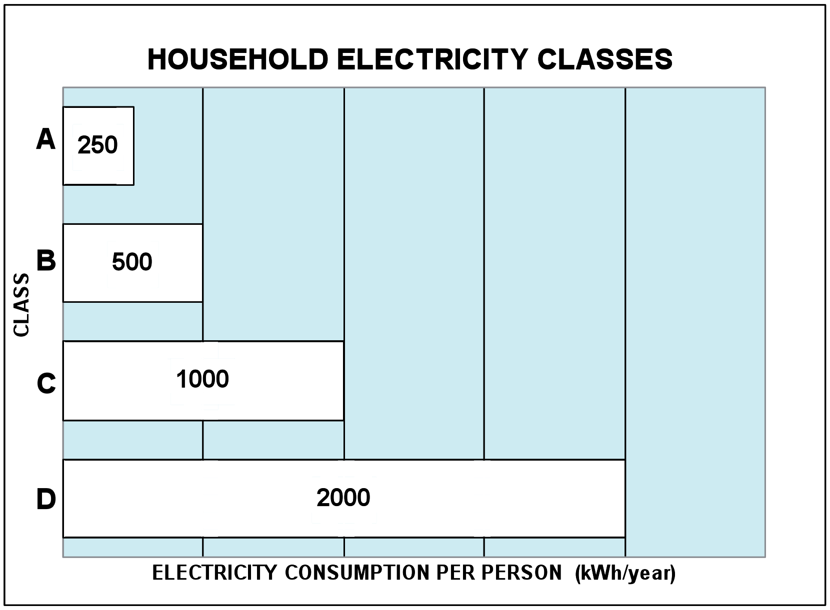

Figure 1. Suggested classification of households according to their electricity consumption used for 'movable appliances' , i.e. excluding electricity used for fixed, installed equipment like ventilation systems, etc.(see text). For comparison the average ***total*** *use of electricity in Danish households amounts to around 2000 kWh/year per person out of which around 1600 kWh is for the movable appliances.*

Finally class 'D' corresponds to the present average of 2000 kWh/year per person for all use of electricity in households.

The lives possible within classes A, B, and C are illustrated by cases later in this paper.

THE USE OF CLASSIFICATION

The directive for households' consumption of heat plus the electricity used by the fixed appliances in the building described earlier refers to mandatory requirements for buildings and their installations. Similar legal measures are not applicable to movable appliances, since they depend on the wants and habits of the users of the buildings. The classification suggested here can be seen as a supplement to the directive, covering people's more voluntary behaviour.

For ordinary electricity consumers, the classes can serve as an inspiration for reducing their own electricity bill as well as society's environmental pressure. It is not anticipated that all people will move to class A soon or maybe ever. On the technical side, it makes little sense to immediately replace all appliances with the best available, since it will cost money and resources, and because next year a better model could be available. When it comes to daily use of the appliances as well as how much energy service people consider sufficient, it can be hard and time consuming to adjust habits in a less wasteful direction. Typically, a Danish family of today could begin aiming at reaching class C with maximum 1000 kWh/year per person, as compared with the present 1600 kWh used for movable appliances in today's average Danish household. The classes can inspire people to look at why they are consuming 1.5, 3, or 6 times more electricity than suggested in the C, B, and A classes, respectively.

Politicians could use the classes to form policies for taxing electricity. Progressive electricity taxes could use the classifications as boundaries for the steps, for instance by making consumption corresponding to class A tax free, and tax the higher consumption in classes B, C and D more and more, for instance subjecting the excess consumption in class D to a 'luxury' electricity tax, for instance of 200%. This would ensure low income electricity consumers the benefit of a tax free *lifeline supply*, sufficient to provide a decent standard of living.

Another political use could be in connection with subsidizing renewable electricity supply from wind power or photovoltaic. Considering the environmental superiority of energy savings, it could, as a qualification for obtaining subsidies for renewable energy subsidies be required, that the applicants first reduce their electricity demand to class A or B. Also, the classes could be used as guidelines for many other ways to reward electricity savings.

It could be argued that it would be fairer to adjust the classes to the number of people living in the household as is done in the building regulations mentioned earlier. This could for instance consist of introducing a basic supply *per household* plus an amount per person. It could be worth considering, but on the other hand, it would reward small household sizes, which is one of the main causes of growing electricity demand.

Most efficient appliances

As indicated above, over the past decade the efficiency of the *best performing* appliances on the market has not made much progress as compared with the improvements during the preceding decades since the 1970s. The following summarizes a survey of what is best on the market within the various services in the households.

In this paper we include units which we know are, or have been, on the market. There might be better models available somewhere, unknown to us, but this uncertainty underlines that our assumptions are on the safe side of what is achievable.

It is assumed that people in class A and B households will usually choose the most efficient models.

It should be stressed, that the models shown here as best on the market are not the best that could be developed and eventually brought on the market. If no other references are shown, the data in this section are found on the website of Danish Electricity Saving Trust (DEST, 2009).

The energy intensity values illustrated by **bold** figures in the following are the ones used as basis for calculating the class cases.

FOOD STORAGE

Food can be kept fresh in different ways, the most obvious one being to buy it shortly before eating it. But usually it is convenient or necessary to store food for days or even months, and in that case a cool storage space is useful. In climates like in Northern Europe average outdoor temperature is around +9°C and this temperature is found year around in a cellar, which used to be a common food storage place. Today an electric driven refrigerator is used in households around the world, to some extent made necessary by the infrastructure developed and the associated lifestyles. Assuming we will require a cold storage space of +5°C, the question is how large we need it to be. A lot of the food items stored in refrigerators today do not need refrigeration, some because they are conserved in other ways (for instance, yoghurt, cheese, canned food, etc.). Many kinds of food actually have little taste when eaten cold. On the other hand, refrigerators are also wanted to provide cold beverages.

If we settle for a refrigerator only with +5°C, it is here suggested that a typical Danish sized 200 litres cabinet will be sufficient for a three person household. Such a unit, LER 200, has been marketed with an electricity consumption of just 90 kWh/year (Nørgård, 1989). This is measured according to European standard test procedure, but it turned out to be also the average in practical use in Denmark (Nørgård and Gydesen, 1994). As a step backwards, it should be noted that this model was later removed from the market, and the industry showed no interest in a follow up research model. Consequently, the best on the market today uses more energy. But since the 200 litres **90 kWh/year** refrigerator has been proven possible, this could soon again be made available, and we will here suggest this as the most efficient.

For longer food storage, a lower temperature is necessary, and typically –18°C is used in deep freezers. Most efficient large freezers are usually chest freezers, but an upright freezer is more convenient to use. For a normal household of 3, which does not grow its own food to store, a 100 litre A++ upright freezer will be sufficient, and the best model found consumes 155 kWh/year. A freezer can even have a lower consumption if placed in a cooler place than the kitchen, for instance in basement, utility room, outhouse or other unheated room. In such cases, electricity consumption for a 100 litre freezer can be only **135 kWh/year**.

Finally a combined unit with 200 litres refrigerated cabinet, and 100 litres freezer compartment, is available with a electricity consumption of around 280 kWh/year.

COOKING

Gas is usually the most energy efficient option for cooking food, when including for electric cooking the energy losses at the power plant, which are usually thermal power plants, see the earlier thermodynamic considerations in section Definitions and Methodologies. Even in countries with just part of the electricity supplied by thermal power plants they often supply the peak load for cooking. Only when using electric kettles, coffee machines, and ovens, electricity might be competitive on total efficiency with gas as suggested here.

In any case electricity is needed to run a cooker hood for ventilation, in order to prevent moisture and other pollutants from cooking from spreading in the house. A cooker hood is used only when cooking food, and while running, the best model consumes **320 W.**

When boiling water for tea or coffee **electric kettles** are close to 100% efficient in terms of turning the electricity into heat (and about 35% when going back to the fuel at the thermal power plant). The same is almost the case for coffee machines. Consequently, it takes **0.120 kWh** of electricity to boil one litre of water for tea or coffee.

A good electric baking **oven** uses **1 kWh** electricity to bring the oven up to 180°C and to keep it there for one hour.

Cooking with electric hobs, as used in case C, is estimated to consume **210 kWh/year** for an average Danish household consisting of 2.1 person (Rahbar, 2008).

CLEANING

Electric-driven clothes **washing machines** have been a welcome relief of the hard and wearing work of manual rubbing and beating the laundry. As it turns out however, only a small fraction, typically less than 25%, of the electricity used in today's typical European washing machines is spent on this appropriate task of sparing the human body. The remainder 75% electricity is spent thermodynamically inappropriately for heating water in the machine by simple electric resistance heating elements a process which waste most of the thermodynamic quality of electricity. (Thermodynamic Second Law efficiency of electric resistance heating to 40°C is less than 10%).

With that in mind, there are two obvious ways to save electricity used for clothes washing, taking into account that manufacturers have already over the decades after the oil crises in the 1970s reduced water use for the main wash by shrinking to a minimum the dead volume, that is the volume of water between the rotating drum and the stationary vessel, where no laundry is present. One path for further savings is to lower the washing temperature, which has already come a long way from the earlier habit in Northern Europe of using 90°C for most laundry to now doing with temperature around 40°C (Nørgård, 1989; Larsen, 2007). In fact in many regions, like Japan and USA, washing in cold water has been common practice (Nørgård, 1989). With today's detergents and with less dirty clothes this will often suffice. Another path to save electricity for heating water is to use other more thermodynamically appropriate sources of heat, such as district heat from combined heat and power production, gas or oil heated water or solar heated water. In the past decade manufacturers have marketed washing machines which take in both hot and cold water and automatically mix it to the set temperature. Electric heating is then needed only to maintain the temperature and in the rare cases where a higher washing temperature than the typical intake hot water of typically 60°C is required.

Washing machines with cold and hot water intake have an electricity consumption of 0.09 kWh/kg at 60°C and **0.04 kWh/kg at 40°C.**

Washing machine with an A+ rating with only cold water intake uses 0.17 kWh/kg electricity for 60°C washing and **0.11 kWh/kg at 40°C.**

The use of **tumble dryers** can be necessary where no options are available for drying on a clothes line. If gas is in the house, clothes dryers can be run on gas as has been common practice in the USA and other countries. But if a tumble dryer is found essential, and no gas is available, a European A-labelled model uses **0.27 kWh/kg** of clothes.

Washing the dishes by hand can, if carried out with care in a bowl of hot water, be done with no use of electricity and very little water and heat (Nørgård and Guldbrandsen, 1994). For a three person household, as in the following cases, a **dishwashing machine** might be a high priority, but in that case the choice should be a model with intake of both hot and cold water, like for clothes washing machines above. The best A-labelled dishwasher with only cold water intake requires an electricity consumption of **1.01 kWh per cycle**, while with both hot and cold water intake **0.75 kWh per cycle** will do (Persson, 2007).

In this group of cleaning, also is included a **vacuum cleaner**, where the best model found uses **1800 W.**

ENTERTAINMENT

This section deals with mostly electronic equipment like TVs, computers, etc.

For the same size a **TV** with liquid crystal display, LCD TV, will consume less electricity than the conventional TV with cathode ray tube, CRT, which are now by and large being phased out. However given the flat screens, people are tempted to buy LCD TVs with a bigger screen than the old CRT TV, and this increase in service level eats up the efficiency gain from LCD over CRT. An efficient LCD TV of 32 inch consumes **140 W**, while a 40 inch LCD uses **160 W**. In contrast, a small 19 inch LCD uses around 40 W only.

Like many other small electronic devices a laptop **computer** is made for battery operation, and hence designed to be very energy efficient. But the production of batteries and energy losses when charging them, counteract some of the advantages. So the most efficient use is to buy a battery operated computer, but not to run it on batteries! The computer suggested for class A is a laptop computer with a 15 inch screen and an acceptable performance for internet, email and text processing, consuming only 12 W. Access to internet is provided by a cable modem with an integrated access point for wireless networking. The best products on the market have power consumption of 10 W. Together with the laptop computer it all amounts to **22 W.**

In the classes B and C is included a computer with higher performance, for instance computer games and multimedia functions. These models consume **100 W to 150 W.**

ILLUMINATION

One of the first uses of electricity in households was for lighting, where incandescent lamps replaced the very energy inefficient oil lamps, gas lamps or candles, and for half a century it was essentially the only use of electricity in private homes. Despite the scores of other uses of electricity in households, lighting still accounts for typically 20% of use. Another step forward in efficiency was the invention of fluorescent lamps first as tubes and later as compact fluorescent lamps (CFLs). In the future the emerging light emitting diode (LED) lamps could dominate.

The quality of the light from CFLs and fluorescent tubes has been discussed for decades. In the meantime the producers have improved the quality, but are still struggling with a poor reputation based on bad experiences from the past. If, however, some people give high priority to having incandescent lamps for part of their home illumination, say just one 60W incandescent lamp on for 8 hours per day, the extra electricity consumption will amount to 135 kWh/year, which should then be compensated by other savings if aiming for a certain class. No matter which type of lamp is used, turning off the light when not utilized can easily halve electricity consumption. In the class cases below, we assume a number of CFLs being turned on for certain hours per day on average over the year, which can cover a great variation in usages. A 10W CFL provides around 600 lumens of light, corresponding to a little less than that from a traditional 60W incandescent lamp.

For the A class cases it is suggested that ten 10W CFLs, are turned on for 3 hours per day on average over the year, which of course can cover that some are on for maybe 6 hours a day. The result in these cases is an electricity consumption of 37 kWh/year per person. This compares well with a Belgian study of electricity consumption for lighting by 2-5 person household, finding a mean value of 90 kWh/year per person, with a maximum of 274 kWh/year per person and a minimum of 39 kWh/year per person (D'Herdt, 2008).

MISCELLANEOUS

A large number of appliances which may seem insignificant should be given attention for a household to fall into class A or B. In particular, two features of them should be noticed with respect to annual electricity consumption, namely whether the equipment 1) contains an electric heating element like an iron or hair dryer, and 2) is turned on all year like a standby function or various sensors. Electricity consumption can be surprisingly high for small things featuring both 1) and 2). For instance an aquarium for tropical fish can easily consume more than 1000 kWh/year.

In the class cases later we will just mention a few examples of miscellaneous appliances.

Sufficiency and household size

For a society or a community, overall **environmental Impact, I**, or in this paper the electricity consumption, can in a simple model be described by the equation $I = P \cdot A \cdot T$, where **P** is **Population**, **A** is **Affluence** or service level per capita, and **T** is the **Technology's** environmental intensity or energy intensity (Ehrlich and Holdren, 1972), or an extended version $I = P \cdot B \cdot A \cdot T$, where **B** refers to the **Behavioural** factor (Schulze, 2002). Reducing energy consumption can be achieved by lowering one of the factors, such as population and keeping the others constant, etc. However, in this study, results are reported in per capita numbers, so population is not a relevant factor here, except for the fact that the larger population is in a household, the less energy is needed per capita. What remains for improvement in this study are therefore:

1. the technology factor,
2. the desired service level,
3. the behavioural factor, (which can be considered part of the service).

TECHNOLOGICAL EFFICIENCY IS NOT ENOUGH

In the present political debate about climate change mitigation, the focus is on technological solutions, such as more efficient end-use technologies, that is, lowering energy intensity **T**. Utilizing these technological options plays a central role in this paper, and is also in general essential for achieving sustainable development as far as energy is concerned. As exemplified by the household sector, substantial improvements in electrical efficiency of appliances have been achieved in Europe over the past thirty years, enough to lower the use of electricity by around 30%.

European countries have, however, not experienced a corresponding decline in electricity consumption, in fact it has increased. The reasons for this are to be found among the two other factors, population, **P**, and material standard of living, **A**. Globally, population is still growing fast, but for Europe this is not the case, which from an environmental point of view obviously is fortunate, and here the reason for growth in electricity consumption is mainly the increase in material standard of living. In households, numerous new electric appliances have been added to the stock of equipment, and they have more than offset the savings achieved from the better technology.

It is indeed possible to improve the technology much more than what we have done, as will be illustrated in this paper, first of all by utilising the best technology already available on the market. Hence, for a while, we might be able to somewhat counteract growth in population and in material standards by struggling to develop technological options. However, in theory and even more in practice, there are limits to technological options, and with the target of reducing our impact on nature by a factor of ten for more affluent parts of the world like Europe, as has been suggested by Schmidt-Bleek (2000), it is also worth looking at how much benefit people really get from the extra material standard of living in the form of more appliances and other equipment. The top electricity classes in this paper can hardly be reached without some serious consideration of what is sufficient.

SUFFICIENCY TRENDS

Despite what seems to be an unlimited quest for more electrical equipment, there are also in some groups found trends towards a saturation (Alcott, 2008; Nørgård, 2009). An energy policy dedicated towards supporting such trends through education, tax policy, etc could no doubt have a beneficial impact.

The question of what is necessary, what is profligate, and what is just sufficient could provoke an endless discussion, as the answer depends on the person you ask. Traditions, habits, upbringing, wealth, social context and concern for the environment shape people's preferences and appetite for more equipment.

THE IMPACT OF HOUSEHOLD SIZE ON ELECTRICITY CONSUMPTION

Average household size in Denmark has dropped since 1960 from 3.1 persons to now only 2.1, and the most common household consists of just one person (Statistics Denmark 2008, Statistics Denmark 1962). This development accounts for a substantial part of the increase in total household electricity consumption, since many uses of electricity are shared and only partly depend on the number of people sharing.

For a few appliances like washing machines, dishwashers and clothes dryers, their frequency of use, and hence their electricity consumption, is proportional to the number of people in the household, assuming that they are started *only with a full load*. In these cases there are no electricity saving benefits of a large household, except that it is easier to obtain a full load.

However, even the smallest households usually have certain basic electrical equipment like refrigerators and freezers running all the time, and only a small difference in size depending on the number of people sharing it. Similarly for lighting, which is also to a large extent a shared service. In such cases there are large electricity savings per person from forming large households.

In between these extremes, for most uses, like TV-watching, lighting, music systems, computers, etc. their use depends on the size of the households, even though it is *not directly proportional* to the number of people.

For these reasons, it is obviously much easier for a large household than for a one person household to qualify for class A, with movable appliance use below 250 kWh/year per person, and we will therefore always assume a 3 person household when specifying cases for class A. For larger sized households it will obviously be easier to keep within the lower-energy classes. Or to put it differently, for a certain class, you can have more services available if you share with others.

A large household size can also be interpreted as a system where more households share some of the appliances. This can be the case for washing machines, clothes dryers, and freezer space in apartment buildings. For the washing machine, the saving from sharing will usually be zero, but it can be more affordable to install efficient washing systems. For appliances like a freezer, the savings are large, since for instance one 300 litres chest freezer consumes only about 40% of what three 100 litres freezers require.

Scenarios for energy classes

With objective knowledge on the most efficient technology available, and subjective suggestions on the electricity services needed, it is now possible to build up scenarios for how the classes could be met.

Within the maximum electricity consumption qualifying for a certain class, say the 250 kWh/year per person for class A, there are many possible combinations of electricity *services*, which a household can choose. This is illustrated below by a few cases. Some may give high priority to having certain appliances like a freezer or a dish washing machine, and in return choose

Table 2. Key numbers for one 3-person class A household for case 1.

SERVICE TYPE	TECHNOLOGY	SERVICE LEVEL	INTENSITY	ELECTR. CONS. PER HOUSEH. (kWh/yr)	ELECTR. CONS. PER PERSON (kWh/yr)
Food storage	Refrigerator	200 L, + 5°C	0.45 kWh/(L yr)	90	30
Cooking	Oven	1 h/week, 180°C	1 kWh/h	52	17
	Kitchen hood	3 h/week	320 W	35	12
	Electric Kettle	2 L/day	0.12 kWh/L	88	29
Cleaning	Washing Mach. H+C	500 kg cloth./yr	0.04 kWh/(kg yr)	20	7
	Vacuum Cleaner	0.5 h/week	1800 W	48	16
	Clothes dryer	250 kg cloth./yr	0.27 kWh/kg	68	23
Entertainent	TV, 32"	2 h/day	140 W	102	34
	PC+Internet	2 h/day	22 W total	17	5
Illumination	10 CFL lamps	3 h/day	10 W each	110	37
Others				122	41
TOTAL	→ → → →	→ → →	→ → →	**750**	**250**

Table 3. Key numbers for one 3-person class A household for case 2.

SERVICE TYPE	TECHNOLOGY	SERVICE LEVEL	INTENSITY	ELECTR. CONS. PER HOUSEH. (kWh/yr)	ELECTR. CONS. PER PERSON (kWh/yr)
Food storage	Refrigerator	200 L, + 5°C	0.45 kWh/(L yr)	90	30
	Freezer	100 L, -18°C	1 kWh/(L yr)[1]	100	33
Cooking	Oven	1 h/week, 180°C	1 kWh/h	52	17
	Kitchen hood	3 h/week	320 W	35	12
	Electric Kettle	2 L/day	0.12 kWh/L	88	29
Cleaning	Washing Mach. H+C	500 kg cloth./yr	0.04 kWh/(kg yr)	20	7
	Vacuum Cleaner	0.5 h/week	1800 W	48	16
Entertainent	TV, 32"	2 h/day	140 W	102	34
	PC+Internet	2 h/day	12	17	5
Illumination	10 CFL lamps	3 h/day	10 W each	110	37
Others				90	30
TOTAL	→ → → →	→ → →	→ → →	**750**	**250**

[1] *Location in unheated utility room reduces energy consumption by 25% compared to standard test*

to get along without a TV set or clothes dryer, while others have different preferences. Within the student groups, these choices gave rise to good discussions about the importance of different equipment and services.

In all scenarios it is assumed that stand-by consumption is avoided by switching off the equipment. The services are divided into five services considered necessary to have a good life: food storage, cooking, cleaning, entertainment and illumination. In all scenarios some energy is left for other services within the limit of the class. Washing temperatures are assumed to be on average 40°C.

CLASS A, CASE 1

The family lives in a town apartment. Gas is available for cooking hobs. A kitchen hood is needed to remove moisture from cooking and combustion gasses. A freezer is not needed as shopping is done nearby and frozen food is consumed the same day as it is bought. Drying of clothes indoors can give problems for the indoor environment and should mostly be avoided. Drying of clothes on a line is to some extent available in the building, but half of the clothes are dried in a clothes dryer. The washing machine is connected to both hot and cold water. Table 2 shows electricity services and electricity consumption for this case. In this case 15% of the energy is left for other services.

CLASS A, CASE 2

The family lives in a single family house in the suburb. Gas is available for cooking hobs. A kitchen hood is needed to remove moisture from cooking and combustion gasses. Shopping is done a few times per week and the family wants to store and utilise fruit and vegetables from their own garden which means a freezer is needed. No clothes dryer is used because clothes can be dried on a line outdoors or in the utility room all year. The washing machine is connected to both hot and cold water. The freezer is placed in the unheated utility room. Table 3 shows the services and electricity consumption for this case, which leaves 12% of the electricity for other services.

CLASS B

Gas is available for cooking hobs. A kitchen hood is needed to remove moisture from cooking and combustion gasses. The household has two televisions and two computers. The second computer is used for computer games which require rather high performance. Clothes are washed more frequently. Clothes are dried on a line outdoors in warmer weather but a clothes dyer is used during winter. A dishwasher is used efficiently which means that some larger items and not so dirty items are washed by hand. The washing machine is connected only to cold water because it is located in a room with no hot water connection.

Table 4. Key numbers for one 3-person class B household.

SERVICE TYPE	TECHNOLOGY	SERVICE LEVEL	INTENSITY	ELECTR. CONS. PER HOUSEH. (kWh/yr)	ELECTR. CONS. PER PERSON (kWh/yr)
Food storage	Refrigerator	200 L, + 5°C	0.45 kWh/(L yr)	90	30
	Freezer	100 L, -18°C	1.35 kWh/(L yr)	135	45
Cooking	Oven	2 h/week, 180°C	1 kWh/h	104	35
	Kitchen hood	5 h/week	320 W	59	20
	Electric Kettle	2 L/day	0.12 kWh/L	88	29
Cleaning	Washing Mach.	1000 kg cloth./yr	0.11 kWh/kg yr	110	37
	Vacuum Cleaner	0.5 h/week	1800 W	48	16
	Dishwasher H+C	4 cycle/week	0.75 kWh/cycle	156	52
	Clothes dryer	250 kg cloth./yr	0.27 kWh/kg	68	23
Entertainent	2 TV, 32"	2 h/day	280 W total	204	68
	PC+Internet	2 h/day	22 W total	36	15
	PC for games	1 h/day	100 W	37	12
Illumination	15 CFL lamps	3 h/day	10 W each	164	55
Others				203	68
TOTAL	→ → → →	→ → →	→ → →	**1500**	**500**

Table 5. Key numbers for one 3-person class C household.

SERVICE TYPE	TECHNOLOGY	SERVICE LEVEL	INTENSITY	ELECTR. CONS. PER HOUSEH. (kWh/yr)	ELECTR. CONS. PER PERSON (kWh/yr)
Food storage	Refrigerator	200 L, + 5°C	0.45 kWh/(L yr)	90	30
	Freezer	100 L, -18°C	1.35 kWh/(L yr)	135	45
Cooking	Oven	2 h/week, 180°C	1 kWh/h	104	35
	Kitchen hood	5 h/week	320 W	59	20
	Electric Kettle	2 L/day	0.12 kWh/L	88	29
	Electric cooking			300	100
Cleaning	Washing Mach.	1000 kg cloth./yr	0.11 kWh/(kg yr)	110	37
	Vacuum Cleaner	0.5 h/week	1800 W	48	16
	Dishwasher	7 cycle/week	1.01 kWh/cycle	368	123
	Clothes dryer	750 kg cloth./yr	0.27 kWh/kg	203	68
Entertainent	TV, 32" + 40"	3 h/day	300 W total	329	110
	PC+Internet	2 h/day	60 W total	94	31
	PC for games	2 h/day	150 W	110	37
	DVD/HDD	2 h/day	30 W	22	7
Illumination	15 CFL lamps	3 h/day	10 W each	164	55
Others				778	259
TOTAL	→ → → →	→ → →	→ → →	**3000**	**1000**

The dishwasher is located near to the sink and is connected to both hot and cold water because the connections are nearby. Table 4 shows electricity services and consumption for this case, in which case 15% of the energy is left for other services.

CLASS C

Electric plates are used for cooking in this class C household and electricity is for this 3 person household, based on the Danish average of 100 kWh/year per person mentioned earlier, set to be 300 kWh/year, although the larger than average household size could point towards a lower level. A kitchen hood is needed to remove moisture from cooking. Washing machine and dishwasher are connected only to cold water supply. The services for entertainment are higher and the equipment has higher performance compared to A and B cases. A clothes dryer is used for half of the washed clothes. Table 5 shows the electricity services and consumption for this case, and 25% of the energy is left for other services.

Conclusions

Energy consumption in building has come into focus as the climatic problems have led politicians and researchers to look for areas of the economy where energy can be saved. Most of the energy used in buildings is fixed to the building as heating, ventilation, etc., which can be addressed by governmental building regulations. Of what remains, a substantial part is due to movable appliances like refrigerators, lamps, etc. Reducing this part can to some extent be approached by legal means, namely through mandatory minimum efficiency standards of the equipment. How the consumers use the appliances and how big a stock of electric equipment they will possess is for good reasons out of direct political control.

The classification outlined in this paper offers some options and guidelines for addressing this dark horse in the buildings' energy consumption. The class strategy has been useful in teaching and could be used to inspire the public to aim for a reduction target and to reconsider their many uses of electricity, small and large, which makes their electricity bill several times larger than it need to be. Politicians can use the classes as criteria for various ways to reward or punish electricity consumers.

There is a striking difference between the electricity consumption you end up with when starting from the bottom and analyse what you need, and the consumption you will reach when just buying what you can afford.

Even though the scenario cases are established with European households in mind, the classification can serve well as a guideline for energy policies in developing countries by showing how good a life you can achieve with relatively little electricity.

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