Households' energy use - which is the more important: efficient technologies or user practices?

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Households' energy use – which is the more important: efficient technologies or user practices?

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Abstract: Much policy effort focuses on energy efficiency of technology, though not only efficiency but also user practices is an important factor influencing the amount of consumed energy. This paper will explore to what extent energy efficiency of appliances and houses or user practices are the more important, both for understanding why some households consume much more energy than others, and when looking for relevant approaches to a future low carbon society. The paper uses several sources to explore this question, including results from the researcher’s own projects, review of other studies and national statistics. Through the presentation of these different projects and examples it is shown how user practices are at least as important as the efficiency of technology when explaining households' energy consumption. The paper concludes that more research in this field is necessary. In relation to energy policy it is argued that it is not a question of efficiency *or* practices, as both have to be included in future policy if energy demand is actually to be reduced.

Keywords: *Households, Consumption, User practices, Energy efficiency.*

1. Introduction

In Western societies households stand for approx. one third of the energy consumption, and throughout the last thirty years efforts to reduce this has included research on and development of more efficient technologies and buildings, as well as policy activities directed at households encouraging them to purchase these more efficient technologies. To a much lesser extent focus and interest have been directed at how the actual use of technologies and houses influence the final energy consumption. However, recently an emerging interest is seen in research documenting the importance of user practices.

A Dutch study documents that building characteristics determine 42% of the variation in energy use for heating (water and space), leaving more than 50% of the explanation for user practices, though only 4.2% extra explanation of the variation in energy consumption can be explained by occupant characteristics [1]. This indicates that user practices are important, though only to a limited degree determined by objective occupant characteristics. A study based on US data concluded in line with this that besides weather characteristics, building characteristics are the main determinant of energy for space heating and cooling purpose followed by behavioral aspects, though in this study they further include the relation between occupant characteristics (like age and income) and building characteristics (like size and type of dwelling) making the indirect effect of the occupants much more important [2]. Besides building characteristics, some studies also include information on type of heat control system, like programmable thermostats, manual thermostats or manual valves and contrary to many assumptions, these studies conclude that those with programmable thermostats have the radiators turned on for more hours than others [3], and do not keep lower temperatures [4], and furthermore they conclude that the type of heating system has an influence on occupant behavior.

In this paper focus will be on presenting and analyzing different types of data which can further enlighten the question of how important user behavior is compared to efficient technology. The final energy consumption in households is a result of the number/size of the technology, the energy efficiency of the technology and the user practice in relation to the technology. In the following a distinction will be made between electricity (for appliances and lighting) and energy for heating (space and water) when exploring the relation between these four elements.

2. Analysis and results

2.1 Danish national statistics on electricity consumption

From the Danish national statistics [5] we have obtained data on the development of energy efficiency of appliances during the last thirty years and the development in the numbers of appliances in Danish households in the same period (see Figure 1). Data in this figure are based on analysis from a bottom-up computer model (ELMODEL-bolig), where input comes from surveys of some thousand households every third year on ownership and use of appliances, combined with information on numbers and types of sold appliances from industry and trade organizations. By combining the left and the right part of this figure, we learn that the growing energy efficiency gained over the last thirty years in the appliances in Danish households is counterbalanced by the growing amount of appliances in use.

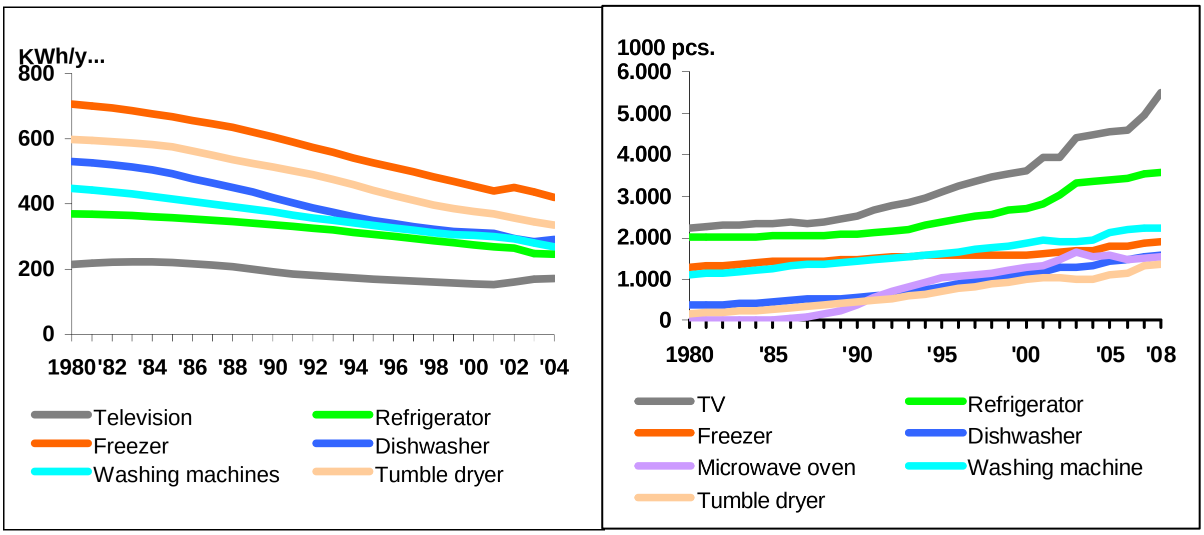


Figure1: Energy efficiency of Danish household appliances 1980-2004, left (KWh/year) and number of appliances in Danish households 1980-2008, right, (1000 pcs). Source [5].

2.2 Different energy consumption in similar houses

The explanatory power of energy efficiency, user practices and the number of appliances to explain energy consumption has been investigated in a study of 1000 quite similar houses, which in spite of similarity show huge variation in energy consumption. Comparing identical houses for heating (space and water) show that those using the least, use less than a third of those using the most, and for electricity (appliances and lighting) those using the most use five times as much as those using the least. The study included among others a survey with a response rate of 50%, combined with heat, electricity and water consumption as delivered by utilities and technical calculations and measurements of temperature and air exchange. The study has previously been reported in Danish [6], and different aspects have been published in English as well [7], [8].

For heat consumption the simple fact that technically completely identical houses can have heat consumption varying with a factor 3, show that user behavior related to heat consumption plays an important role. In this case the size and the energy efficiency of the technology (the house) are identical and variations in energy consumption thus have to relate solely to user practices related to space heating and hot water use.

In relation to electricity the analysis is more complicated as appliances and lighting is bought individually and we have to rely on self-reported data from the survey on number, efficiency and use of appliances. Statistical analysis of data divided households into three equal groups consisting of a third of the households with the highest level of consumption, a third with the lowest and a third with the middle level. Statistical analysis between this grouping and questions of (self-reported) use of appliances, number of appliances and energy efficiency of appliances has been conducted for different types of appliances. As self-reported information on energy efficiency cannot be completely reliable, people are only given the possibility of indicating whether their cold appliances are low-energy or not, or whether they do not know. For light bulbs, they have been asked, whether the share of low-energy bulbs is less than 25%, 25-50%, or more than 50%. In Table 1 it is seen that there is no correlation between people having indicated that their refrigerator is low-energy and the household being among the high, middle or low energy consumers. Correspondingly analysis shows that there is no correlation between the share of low-energy bulbs and which consumer group the household belongs to (not shown in table). On the contrary, there are other factors which do correlate with the energy consumer groups. The question of how many appliances people have show strong correlation as seen in Table 2, where the number of cold appliances per households is shown, and correspondingly analysis for how many televisions and videos the household have also correlates strongly with the energy consumer groups (not shown here). Furthermore the use of appliances also shows strong correlation to the energy consumer group: in Table 3 the correlation between use of tumble dryer is shown, and similar correlation can be found e.g. for the use of washing machine (not shown here).

Table 1. The share of households indicating whether their refrigerator is energy efficient or not is divided into three different energy consumer groups of households. The table should be read vertically. Analysis shows that there is no correlation (n=214, gamma=-0.055, not significant p=0.628).

	Consumer group Low	Consumer group Middle	Consumer group High	Total
Inefficient refrigerator	38%	26%	37%	100%
Efficient refrigerator	26%	35%	29%	100%

Table 2. Households' information on their number of refrigerator-freezer units, compared with the energy consumer group of the household. The table should be read vertically. Analysis shows a strong positive relation (n=286, gamma=0.306, significant with p=0.000).

	Consumer group Low	Consumer group Middle	Consumer group High	Total
1 Refrigerator-freezer unit	41%	31%	28%	100%
2 Refrigerator-freezer unit	21%	37%	42%	100%
3 Refrigerator-freezer unit	17%	35%	48%	100%

Table 3. Households' information on their weekly use of tumble dryer, compared with the energy consumer group of the household. The table should be read vertically. Analysis show a strong positive relation (n=199, gamma=0.334, significant with p=0.000).

Use of tumble dryer	Consumer group Low	Consumer group Middle	Consumer group High	total
1 time a week	28%	33%	38%	100%
2 times a week	13%	39%	48%	100%
3 times a week	14%	28%	58%	100%
4 times a week	8%	28%	64%	100%
5 or more times a week	9%	21%	70%	100%

In general the energy efficiency of household appliances does thus not contribute to the explanation of the huge differences that can be found between the electricity consumption in these households. What does contribute to the explanation is the number and the use of the appliances. However, the number and the use of appliances also correlate to the number of people living in the house. Analysis confirms that number of persons in the household is a strong determinant for the size of the electricity consumption, however, it also shows that it is more energy efficient to live more people together. This will be further explored in the following section.

2.3. Socio-economics in the understanding of user practices

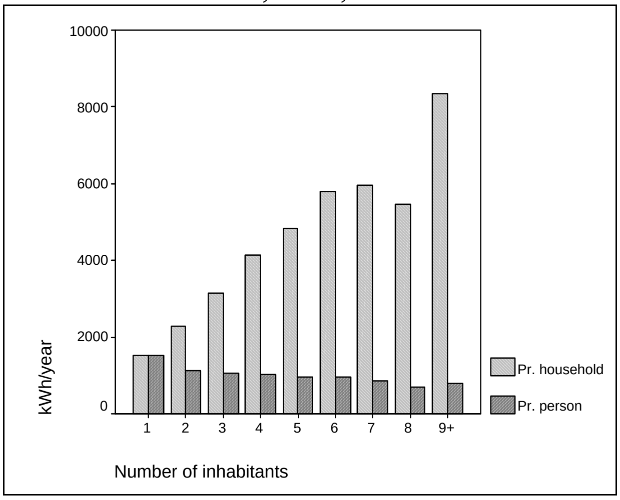
A database with registered data of approx. 50,000 households including socio-economic information on their inhabitants, building information (building type, year, size, installations etc.) and meter readings from utilities on heat (space and water) and electricity consumption (lighting and appliances) show some correlations between users, buildings and energy consumption [9]. Even this type of data does not include any direct information on user practices or energy efficiency, the data can throw light on some of the questions raised in this article. For electricity consumption, regression analysis for 8,500 detached houses is shown in Table 4. The number of inhabitants in the home is the strongest explanation of electricity consumption; income is the second most important and the size of the home the third. Similar relations between socio-economics and electricity consumption have been found in a study using detailed measurements of electricity consumption in Northern Ireland homes [10]. Furthermore Table 4 shows that other variables like age and education of the inhabitants only contribute with little extra explanatory power. Households’ electricity consumption is strongly dependent on the number of members of the household. If, however, we compare electricity consumption per person with the number of members of the household, it becomes clear that it is more energy efficient to live more people together (see Figure 2). This is an important result related to user practices as still more people in most Western societies live alone. Today this applies to almost 40% of the population in Denmark, which thus can be seen as a main driver towards still higher energy consumption. From Table 4 it can furthermore be learned that even if we compare households in detached houses of the same size and with the same income, they can have huge variations in the electricity consumption as income and household size together only explain approx. one third of the variation in electricity consumption. The variation in households’ electricity consumption can only to a very limited degree be explained by the age of the inhabitants or the level of education of the inhabitants; the greater part of the understanding of this user practice thus has to be understood by applying more qualitative approaches to the understanding of the everyday life of households.

When analysing heat consumption, the database includes type, size and year of construction. The year of construction can to some extent be equated with energy efficiency, especially for more recent buildings. As the building type is an important factor in the technical description of the houses, analyses has been separated for different types. As an example of the analysis, detached houses will be used. Regression analysis on heat consumption of 22,000 detached single family homes show that the size can explain 28.3% (R^2) of the variation in heat consumption, and the year of construction can explain an added 10.5 % (R^2) of the variation in heat consumption (not shown in tables). When these two factors have been accounted for, other characteristics of the household members such as age, number of persons living in the house and income only contribute all together with approx. 4% (R^2) explanation of the variation.

Table 4. Regression analysis, detached houses: Background variables effect on electricity use, n=8.573

Background Variables	Effect on Electricity Use (kWh/year)	Explanatory Power, Change in R2 (%)
Per person in the household	541	27.6
Per 100,000 DKK in gross income	90	5.8
Per 10 m^2floor area	95	2.5
Per age square of oldest person	-0.35	1.3
Per 0-6 years old children	-158	
Per 13-19 years old children	179	0.5
Long education - primary school	-278	0.02

Figure 2. Average electricity consumption per household and per person compared with the number of inhabitants in the household, including households in detached housing, sem- detached housing and in apartments. 9+ refers to 9 or more inhabitants, n=53,804



In relation to the question of this article it is obvious that heat consumption is much more dependent on building characteristics than electricity consumption is, even though heat consumption also includes water heating which must be considered quite dependent on the number of inhabitants. Related to both heat and electricity consumption it is furthermore apparent that there is a huge variation in energy consumption which must be explained by differences in user practices. Furthermore it can be concluded that these differences in user practices only to a very limited degree can be explained by socio-economic descriptions of the inhabitants.

2.4. Low-energy buildings and user practices

As it seems that heat consumption is more dependent on building physics than electricity consumption is on energy efficiency of appliances and lighting, it is thus relevant to focus explicitly on new low-energy buildings and user practices. In Sweden a comprehensive study of 20 low-energy row houses have been conducted and measurements of total energy consumption (heat and electricity) show that user practices account for a variation of factor 2 as those using the least uses 49.2 kWh/m^2, and those using the most use 101.7 kWh/m^2 [11]. In UK similar studies of 26 low energy houses with post occupancy evaluation show that those using the least uses 46 kWh/m^2 and those using the most use 144.9 kWh/m^2 for space and water heating, equivalent to a factor 3 in variations in heat consumption depending on user practices [12]. The average in these UK low energy houses was 92.9 kWh/m^2 and the corresponding average for the local area is 172 kWh/m^2. In this study there is thus a factor 2 between the average for heat consumption for "normal housing" and the average for low energy housing, which could be interpreted as a factor 2 related to the energy efficiency of the house, whereas the user practices correspond to a factor 3.

3. Discussion

Above the different approaches to answering the question whether energy efficiency or user practices are the most important has been presented. In the following two different discussions will be introduced. First a discussion of the rebound effect, and second a discussion of the future developments in the composition of households' energy consumption.

3.1. Rebound effect and how it relates to discussions on user practices vs. efficiency

There is a huge international amount of literature on the rebound effect indicating that improvements in energy efficiency make energy services cheaper and thereby encourage to an increased consumption within the same services. In a recent review of empirical estimates of the rebound effect within the household sector, it is concluded that the rebound effect of household energy consumption for heating is approx. 20% [13]. This means that 20% of the efficiency gained through technical improvements of building and appliances are turned into increased consumption (higher comfort) following from direct change in user behavior. This understanding of the rebound effect builds on an economic understanding of household behavior i.e. that people consume more because they can afford it, which follows from the reduced energy consumption gained by energy efficiency. It should not be denied that economy can partly explain household behavior related to energy consumption. However, it should be emphasised that there are other relevant explanations than economy, including psychological and social understandings. If people feel they have done something to save energy, like buying an energy efficient appliance, then they might feel that they do not have to think so much about how they use it. Growing consumption however does not necessarily relate to energy efficiency. The growing number of appliances and inhabited floor area must also be understood as a consequence of other societal processes, which have been described as drivers behind consumption, including changing social norms and expectations following from new technical possibilities [14].

3.2. Future development in the composition of household energy consumption

As shown previously, heating consumption seems to be more dependent on the energy efficiency of buildings, whereas electricity consumption is more dependent on user practices including the number and size of appliances. There are, however, good reasons to believe that this relation varies with the different types of appliances. In Figure 1 (left) it is shown that energy consumption of freezers, dishwashers and tumble dryers has been reduced by approx.

one third the last thirty years, whereas no substantial energy reduction has been seen related to televisions. In general it must be expected that households' energy consumption to a still higher degree will be caused by information and communication technology (ICT) in the future. A Danish study showed that ICT from 2000 to 2007 rose from approx. 10% to 20% of a household’s total energy consumption and that it can be expected to rise up till 50% of a household's total energy consumption within the coming 5-10 years [15]. These scenarios include assumptions of a continued efficiency of ICTs; however, they also assume that the size and number of ICTs will continue to grow. As it must be assumed that energy consumption related to refrigerators and freezers are more dependent on appliance efficiency than on user practices, compared with the use of ICT, these assumptions point towards a future where it must be expected that user practices as compared with energy efficiency will be even more important for the final electricity consumption in households.

4. Conclusions

This paper has dealt with the question whether user practices or energy efficiency is the most important for the size of a household’s energy consumption. The answer to that question is slightly different if it is asked for heating (space and water) or for electricity (lighting and appliances). For heating it is shown that building characteristics, including size and year of construction, can explain approx. 40-50% of the variation in energy consumption, whereas inhabitant characteristics can only explain very little of the variation when the building characteristics has been accounted for. Furthermore studies confirm that completely identical houses can have heating consumption that vary with a factor 2-3 depending on user practices. This means that user practices are at least as important as building physics when it comes to energy consumption related to heating, though the user practices can only to a very limited degree be explained by objective characteristics.

Data analysis on electricity consumption for lighting and appliances suggest that this is more dependent on user practices than on energy efficiency, especially if the number of appliances are counted as part of the user practice. On a national level, a 30-40% increase in efficiency has been gained during the last thirty years. However, in the same period the number of appliances in households has risen more than the energy efficiency. When comparing households living in similar houses, electricity consumption can vary with a factor 5, thus indicating that electricity consumption is less linked with building size and type than with heating consumption. Analysis of data on type, use and number of appliances shows that the number and the use of appliances have a strong correlation to household electricity consumption, whereas information on energy efficiency does not show any correlation. Regression analysis on large databases shows that the number of inhabitants in households is the most important factor for describing electricity consumption; the more inhabitants in a household the higher the consumption. Electricity consumption per person shows the opposite correlation, meaning that it is more energy efficient to live more people together. Data also show that economy correlates with electricity consumption, which corresponds to the fact that the more affluent households can afford to have more appliances.

Even this article raised the question whether efficiency or user practice is the more important, it is relevant to establish that both efficiency and practices are important when seeking to reduce energy consumption. To realise substantial energy reductions, which is an important part of a future renewable energy system, we need consumers who choose efficient technologies, reduce the number of appliances and think about how they use them.

References

[1] O. G Santin, L. Itard, H. Visscher, The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock, Energy and buildings 41, 2009, pp 1223-1232

[2] K. Steemers, G. Y. Yun, Household energy consumption: a study of the role of occupants, Building Research and Information, 37:5, 2009, pp 625-637.

[3] O. G Santin, L Itard, Occupants' behaviour: determinants and effect on residential heating consumption, Building Research and Information, 38 (3), 2010, pp 318-338.

[4] M. Shipworth, S. K Firth, M. I. Gentry, A. J. Wright, D. T. Shipworth, K. Lomas, Central heating thermostats settings and timing: building demographics. Building Research and Information, 38 (1), 2010, pp 50-69.

[5] Danish Energy Authorities. Energy statistics 2009.

[6] K. Gram-Hanssen, Boligers energiforbrug - sociale og tekniske forklaringer på forskelle. By og byg resultater 029. Statens Byggeforskningsinstitut, 2003.

[7] K. Gram-Hanssen, Residential heat comfort practices: Understanding users. Building Research and Information, 38(2), 2010, pp 175-186.

[8] K. Gram-Hanssen, Domestic electricity consumption - Consumers and appliances. In: L. Reisch and I. Røpke (Eds.): The ecological economics of consumption. Edward Elgar publishing, 2004.

[9] K. Gram-Hanssen, C. Kofod, K. N Petersen, Different Everyday Lives - Different Patterns of Electricity Use. Proceedings of the 2004 American Council for an Energy Efficient Economy Summerstudy in Buildings. Washington, D. C.: ACEEE

[10] Y.G. Yohanis J.D Mondol, A. Wright, B Norton, Real-life energy use in the UK: How occupancy and dwelling characteristics affect domestic electricity use, Energy and Buildings 40, 2008, pp1053–1059

[11] J.F Karlsson, B Moshfegh, A Comprehensive investigation of a low-energy building in Sweden, Renewable energy 32, 2007, pp. 1830-1841.

[12] Z. M. Gill, M. J. Tierney, I. M. Pegg, N. Allan, Measured energy and water performance of an aspiring low energy/carbon affordable housing site in the UK. Energy and Buildings 43, 2010,117–125.

[13] S.Sorrel, J Dimitropoulos, M. Sommerville, Empirical estimates of the direct rebound effect: A review, Energy Policy 37, 2009, pp 1356-1371.

[14] I. Røpke. The dynamics of willingness to consume. Ecological Economics 28, 1999, pp 399–420

[15] J.O. Jensen, K. Gram-Hanssen, I. Røpke, I., & T. H. Christensen, Household's use of information and communication technologies - a future challenge for energy savings? I: Conference proceedings: ECEEE Summer Studies 2009. Ile Saint-Denis: ECEEE.