361: Dutch Research into User Behaviour in Relation to Energy Use of Residences

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Abstract

The results of a literature review into user behaviour characteristics in relation to Dutch household energy use are reported. In succession, an extended probabilistic parameter study into the influence of variation of user related parameters on energy use has been executed. The probabilistic tool developed for the study will deliver characteristics of four fixed behavioural profiles which can be implemented in the energy performance calculations. Further, the probabilistic tool will be used to evaluate consequences of various user behaviour related to room ventilation and heating. The insight gained with this probabilistic study is used to define an approach to improve the interface of several building related energy devices in such a way that the user is challenged to behave more energy efficiently. Starting point for this approach has been knowledge on human technology interaction in the field of domestic appliances.

Keywords: energy use, user behaviour, residences

1. Introduction

In the Netherlands more than one third of the energy is used in the built environment. Insulation of buildings, more efficient comfort installations and local production of sustainable energy have strongly improved the energy performance of buildings in the previous decades. The potential for even better energy performance however has still not been exhausted. The urgency to bring all measures for improvement of the energy performance into action, and thereby connecting to nationally and internationally pursued policy, increases.

The Dutch research institutes TNO and ECN have started the strategic cooperation Building Future (BF) in the field of energy in the built environment in order to jointly give an impulse to this transition. A scenario study, carried out by this cooperation [1], indicated that by the middle of this century energy neutrality in the Dutch built environment can be reached, provided that the developments to this end are tackled energetically.

Energy reduction can only be achieved if user comfort and health are seriously addressed. When occupants of residences and work environments act upon discomfort, their main goal is removal of the source of the annoyance. Very often, energy use increases because of our interventions, for example when we install additional cooling or heating devices. It goes without saying that the building occupants with their need for comfort and health have an enormous influence on the energy performance of their building. Especially in the Netherlands, where energy reduction regulation is in force since in 1995 the Energy Performance Coefficient [EPC] was introduced, residences are designed to be more and more energy efficient. Overall building related energy use for HVAC, lighting and domestic hot water is therefore decreasing, making the role of the occupant and the way s/he operates the devices even more important.

2. Literature Survey

2.1 Average energy use Dutch residences

In 2006 the average energy use in Dutch residences was 1652 m^3 of natural gas for heating, cooking and hot water and 3402 kWh of electricity for appliances, see table 1.

Table 1: Average energy use of Dutch household in 2006, [2].

Natural gas	activity	m^3
	Heating	1204
	Hot water	385
	Cooking	63
Total gas use		1652
Electricity	**activity**	**kWh**
	Washing/drying	708
	Cooling	590
	Lighting	543
	Heating/hot water	500
	Appliances	1061
Total electricity use		3402

2.2 Trends in energy saving

Fig. 1 shows that since 1980 the natural gas use has been decreased slowly from 3145 m^3 to 1650 m^3 (a decrease of 48%). The share for room heating decreased from 88% in 1980 to almost 73% in 2006. In the same period the share for hot water has been doubled to 23%, the share for cooking increased from 2,5% towards 4%. The electricity use per residence is increasing since 1988 with more than 1,5% per year, [3].

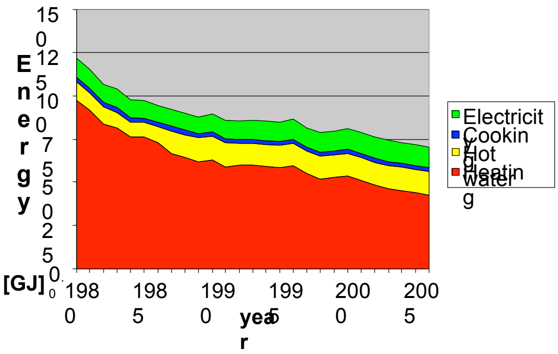

Fig 1. Yearly domestic energy use 1980-2006 in the Netherlands, [3].

In his 2005 thesis, Piet Boonekamp [4] explained the causes of changes in overall household energy use between 1990 and 1995. He focused on seven energy using household functions:

- Room heating;
- Hot water;
- Washing and drying of laundry and dishes;
- Cooking;
- Cooling of food;
- Lighting; and
- Appliances.

By using the simulation model SAVE, Simulation and Analysis of Energy Use in Energy Scenarios, Boonekamp found that an increasing overall amount of people in the Netherlands together with a decreasing average amount people in one residence causes a 7% increase in residential energy use. Other causes of increasing energy use are increasing use of coolers, freezers, dryers and other electrical appliances (+5%) and a larger amount of hot water use (+3%). At the same time energy was being saved through better insulation of residences (-4%), more energy efficient cooling, heating, hot water preparation, lighting and other appliances (-5%). Result was an increase of domestic energy use of 5% between the years 1990 and 1995.

2.3 Energy use and behaviour

In 2001 ECN and IVAM investigated the energy use in energy efficient residences built before the year 2000 in nine different Dutch municipalities [5]. During one year (November 1999-November 2000) the energy use of in total 180 households was being registered. The technical parameters of the residences were retrieved from building plans, brochures and other studies. The participants were questioned twice.

In the first questionnaire, at the beginning of the energy use registration, general household specifications were being asked, such as family size, age distribution, and possession of appliances.

In the second questionnaire, during the heating season (February 2000), the questions were related to heating and ventilation behaviour of the residents.

This investigation resulted in a number of behaviour characteristics that influence energy use:

- The bandwidth in heating demand is mainly determined by set point heating temperature.
- When the participant keeps a record of their energy use, the set point heating temperature turns out to be lower.
- Preferred set points are not influenced by type of thermostat (programmable or analogue).
- Participants with an analogue thermostat tend to more often adjust the temperature set point to a lower temperature, in case of a longer period of absence, than participants with a programmable thermostat.
- The hot water demand is influenced significantly by shower and bath frequency.
- Participants with one or more children under five have the highest bath use.
- As children grow older, bath use decreases and shower use increases.
- As the family size increases the possession of appliances increases.
- All families of two or more persons posses a washing machine and the frequency of use is increasing as the number of persons increases.
- All families of five or more persons posses a tumble dryer.
- Participants who use energy consciously are willing to adjust their heating behaviour, but not their shower and bath behaviour.

The investigators concluded that an energy intensive lifestyle in a very energy efficient residence can lead to a higher energy use, than an energy extensive lifestyle in a less energy efficient residence.

2.4 Energy use and income

Vringer [6] investigated the influence of household characteristics such as total income, total expenditures, age of main resident, and family size based on pattern of expenditures and energy use of 2800 families.

Vringer concluded that total household income is closely related to energy use: 1% increase in income results in a 0,63% increase in energy use. However, within the same income category the bandwidth of energy use is substantial: the standard deviation is approximately 20%. Further, within the same income category one person families use almost 20% less energy than more person families.

Nevertheless, not all variation in energy use can be explained by variations in income. Even if the influence of family size, level of education and age distribution is taken into account, unexplained differences in energy use exist. These differences are being ascribed to behaviour characteristics. The only characteristic for which Vringer found a significant relationship is the motivation to save energy: The families that were least motivated to save energy used 4%

more energy that the families that were averagely or highly motivated.

2.5 Influencing User Behaviour

Uitdenbogerd concludes in her 2007 thesis [7] that individual consumers, organized into households, largely determine what kind, how much, and in what way goods and services are produced. To save energy, transitions are needed on this micro level, which in turn affect the macro level. Changes in demand-side consumption structures are expected to be supportive in achieving long-term national energy reduction targets. Uitdenbogerd investigated both the performance and the organization of functional household activities by means of three surveys: a case study of textile care with 6 energy reduction options to do with laundering among 104 households; a general survey that included a range of 31 different reduction options for direct and indirect energy among 376 households; and a follow-up survey a year later, in which the actual change was investigated (62% of the original participant returned the questionnaire). She concludes that feedback measures and information can help to change self-perception and increase knowledge of households, but adding in-depth coaching on changing routines and decreasing the complexity of household organization or the perception of this complexity can probably result in a larger number and more lasting effects. Three foundations must be laid to achieve behavioural change:

1. **Awareness**: Change the valuation of how the environment already plays a role in household tasks and change the perception of the energy friendliness of behaviour.
2. **Feedback**: Increase knowledge about behaviours that reduce energy consumption.
3. **Easy accessible**: Reduce time constraints and complexity within households by coaching on routines and easy-choice options for investments.

Jelsma [8] describes that attempts for strategies to change behaviour, only aiming at changing the mind set of people, have little effect if not also the corresponding technological surrounding is adapted. The other way around, it is not true that behavioural change can be provoked by providing an proper infrastructure. The most effective are technological designs that facilitate energy efficient behaviour, while hinder energy wasting behaviour. Jelsma presents three conditions needed for an integral, socio-technical approach for technological design of an artefact:

1. An adequate representation of the use of the artefact in practice;
2. A reconstruction of the underlying logic of human-technology interaction.
3. An empirical validation of the use of the artefact in practice.

The reconstruction can not only be derived form available theoretical models on user behaviour; an empirical validation is inevitable.

3. Probabilistic Approach

The energy performance requirements have led to more and more energy efficient new buildings in the Netherlands. It can be expected that the same will happen in the other Member States of the European Union due to the introduction of the Energy Performance of Buildings Directive (EPBD). While the energy efficiency of residences increases, the importance of user behaviour becomes more and more evident. However, the energy performance of residences is based on an average user. Until now no country in Europe has experience with the variety of behaviour in relation to the energy performance of buildings related to the EPBD.

In a feasibility study we tested a probabilistic approach to analyse the impact of varying some of these parameters on the overall energy use [9]. The literature survey into research related to user behaviour in Dutch energy efficient residences made clear that the main occupant related parameters influencing the energy use are:

- Amount of occupants;
- Age of occupants;
- Amount of time that someone is present in the residence;
- Income;
- Shower and bath frequency;
- Heating behaviour (preferred temperature, amount of heated rooms);
- Ventilation behaviour (preferred ventilation setting, opening windows);
- Use of available devices; and
- Motivation to save energy/ life style.

Based on these findings, focussing on energy use for space heating and cooling only and restricted to the boundaries of the Dutch energy performance method, we used the following parameters: preferred temperatures (heating and cooling), preferred ventilation capacity, internal heat sources (including people), and set point for the external sunshield.

The study showed that our probabilistic approach is able to simulate behaviour profiles. However, in the case with energy performance calculations related to the EPBD the calculations are related to building legislation. When the probabilistic approach is used two calculations must result in exact the same figures. Even with 10.000 samples taken from the behaviour patterns, the results of two probabilistic calculations didn't match, while the calculation time at that point rose to more than 7 minutes. We conclude that variety of behaviour in energy performance calculations can best be performed in an analytic way. This means that instead of taking random samples from a behavioural frequency pattern, fixed behavioural profiles are used.

Four household profiles already are defined:

1. Profile *Ease*: Persons in this profile act to create comfort and have no sense or

interest in energy use, costs or environment;

2. Profile *Conscious*: These households choose for comfort, but take into account costs and environment;
3. Profile *Costs*: Persons are aware of costs and save energy to reduce costs;
4. Profile *Environment*: These households act mainly from the point of view of environment.

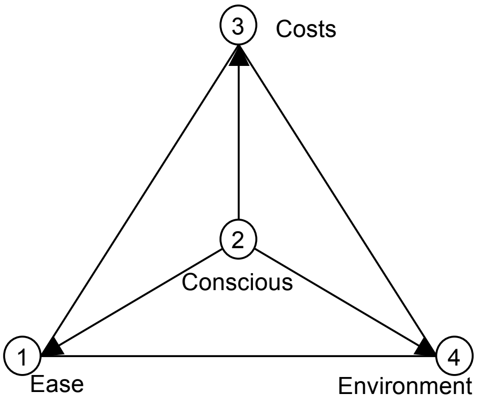

Fig 2. Scheme of four behavioural profiles.

In future projects the probabilistic tool will be used to generate characteristics of these four fixed behavioural profiles which can be implemented in the energy performance calculations. Further, the probabilistic tool will be used to evaluate consequences of various user behaviour related to room ventilation and heating.

4. Interaction between Residents and Building Related Energy Devices

Recent research [10, 11] has shown that the technical savings potential of advanced control systems in the whole Dutch built environment is estimated to be in the order of 190 PJ of primary energy per year (19% of the total energy usage of the Dutch built environment). This potential could be harvested by the development of advanced control systems: environment-adaptive, user-adaptive and most of all user-educational control systems. Environment-adaptive control involves adaptation of system settings to environmental conditions. User-adaptive control is characterized by adaptation of control to the behaviour and the preferences of the user. User-educational control goes a step further and aims to influence the behaviour and the preferences of the user, for example by providing feedback on the consequences of the current behaviour.

Before, or at least in parallel to, the development of user-educational control systems, emphasis should lay on the design of the user interface of control systems in general. These controls are the point where the technical world meets the world of the end-user. The success of climate control depends on the user control, but unfortunately little research on control devises has been done until now. The scarce studies that were performed focused on offices mainly. They show that often even simple control systems are not properly understood by their users.

Kempton [12] interviewed inhabitants of apartment buildings in the US on how they use their air-conditioning system. Three quarters of the inhabitants didn't use the thermostatic control, but instead only used the on/off button as a means of control. Often they were not aware that their equipment contained a thermostat.

Karjalainen and Koistinen [13] performed interviews and observations in 5 offices in Finland and asked the interviewees to show and tell them how they use their local temperature control. The controls present in the offices were standard thermostatic valves or simple room thermostats. They found that almost half of the people they interviewed don't use the temperature control. More remarkably, they found that various people who were dissatisfied with the thermal comfort in their office didn't use the temperature control or were not able to do this effectively. User problems they found included the following:

- Controls are unreachable because they are blocked by furniture;
- People don't recognise the purpose of the room thermostat;
- People don't dare to touch the devise, thinking it is there for service personnel only;
- People misunderstand the labels on the thermostat, thinking that '+' means 'more cooling power' instead of 'higher temperature';
- When the room is equipped with heating and cooling, people often mistake the heating control for the cooling control.

Karjalainen and Koistinen argue that user problems with individual thermal control lead to thermal dissatisfaction, but also waste energy. When a user doesn't understand the heating control (or cannot find or reach it!), he will open a window when he is hot, instead of turning down the temperature of the heating system. And with separate heating and cooling controls a user is almost destined to heat and cool the room at the same time.

In a follow-up study Karjalainen [14] investigated *why* users find it difficult to use a simple device. He analysed the information needs and possible misunderstandings which could occur while using a simple room thermostat. He concludes that users need a lot of information to use a simple thermostat, which users don't appear to have, even though most users were working in the office for years. He argues that designers often overestimate the knowledge users have. Which can easily lead to problems with the control and eventually to dissatisfaction with, or even disuse of, the climate system.

Bordass et al. [15] also found via case studies that many control devices of climate control systems do not work as the designers intended. The scope of their study included electrical devices but also simple switches, window gear and sun blinds for which unfortunately the same conclusions seems valid. They found that user controls which are found too complex simply are by-passed. They state that many control systems in buildings 'challenge rather than assist, and confuse rather than inform'. The key to working control systems is that they give unambiguous clues to the user about which actions will be appropriate. Bordass et al. define 6 criteria to score user controls of climate systems:

1. clarity of purpose
2. intuitive switching
3. usefulness of labelling and annotation
4. easy of use
5. indication of system response/ feedback
6. degree of fine control

All researchers in this field emphasise the need of involving the end-user in the design process of control interfaces.

5. Conclusions

Overall building related energy use is decreasing in the Netherlands due to Dutch building regulation, making the role of the occupant, and user related energy use (energy for house hold appliances), more important. Next to general household characteristics, motivation to save energy plays an important role in user related energy use. It is thus important to create awareness and provide feedback on energy efficient or deficient behaviour and make energy efficient solutions easy accessible.

We are working on the generation of behavioural household profiles using the probabilistic approach and already defined four profile types.

Further, we think the interface between residents and building related energy devices, for example the thermostat, needs to be reconsidered. The most effective are technological designs that facilitate energy efficient behaviour, while hinder energy wasting behaviour. The starting point of these designs should be the knowledge-level of the end-user, which should not be overestimated. This exemplifies the potential of user-adaptive and user-educational control strategies and interfaces. The key here is that experts realise that end-users need to play a role in the design process, a role which cannot be filled by experts under the argument that experts are users too.

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