Occupants Influence on the Energy Consumption of Danish Domestic Buildings

state of the art

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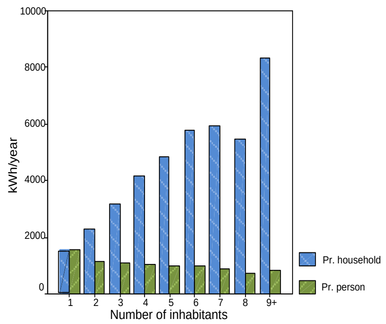

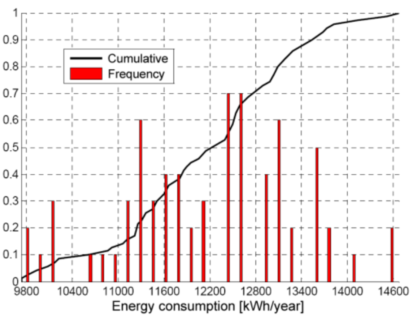

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Institut for Byggeri og Anlæg

Aalborg University
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Section for Architectural Engineering

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by

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Preface

This report is one of the results from the project “Occupants influence on the energy consumption of Danish domestic buildings – Phase 1”, which is partly funded by EUDP (Journalnr.: 64009-0248, Programområde: Energieffektivisering)

The report provides state-of-the-art reviews within the various disciplines represented in the project by the project members, which all represent areas that relate to the title on occupants influence on the energy consumption.

Aalborg University, December 2010

Tine Steen Larsen
Assosiate professor

Contents

1. Occupants influence on the energy consumption

Tine Steen Larsen, Henrik Brohus and Per Heiselberg
Department of Civil Engineering, Aalborg University

The energy political agreement signed in 2008 set a target for an overall saving in the Danish gross energy consumption by 4% in 2020 compared to 2006 levels. When looking at the distribution of the Danish energy consumption it is found, that the Danish households spend 31% of the total Danish energy consumption, see Figure 1.1. Thereby, a huge saving potential lies within our buildings.

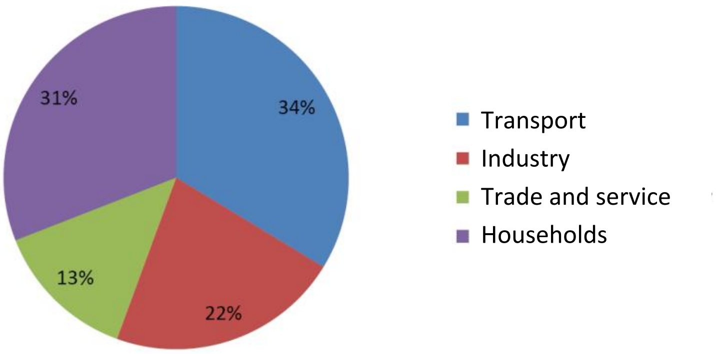

Figure 1.1. Distribution of the Danish energy consumption in 2009. [Energistyrelsen, 2010]

The energy political agreement also required that the requirements for consumption tightened as early as 2010, so that standard construction here would correspond to an energy reduction of 25% of the 2008-level. Rules will be tightened again in 2015 and 2020 - both times by another 25%. The new and tighter rules are an essential part of the government energy policy and the fulfillment of external agreements, including the reduction of CO_2 emissions.

Since new constructions only account for approximately 1% of the total building stock, the existing buildings will be responsible for the main part of the building-related energy consumption. There is therefore a significant need for comprehensive energy conservation here, when the total energy consumption must be reduced in the short and medium term.

However, there is a lack of knowledge of the effect of various energy saving measures, especially because the influence of user behaviour and lifestyle has not been studied to the same extent as the technical aspects. The total energy consumption of buildings is an interaction between architecture, engineering, installations and user behaviour. One of the major reasons for the above problem is, that today, the main focus is laid on the building's energy consumption, while the energy consumption related to user behaviour is largely ignored, or dealt with in awareness campaigns which only to a limited degree build on research results. This is partly due to lack of knowledge about the relationship between user behaviour and energy use, including the importance of building operation and maintenance, user activities and behaviour and also the current climate. User behaviour and lifestyle means that energy consumption in otherwise identical homes can vary by a factor 2 – 3.

As the requirements for energy use in buildings are tightened, the technical knowledge of energy efficient buildings are continuously being realised in the construction of new buildings, however, there is not correspondingly seen any substantial attempts to transfer knowledge on user behaviour into energy savings. To meet the high expectations for energy savings in the future, it is therefore important to obtain much more knowledge on the user related part of the energy consumption in order to include and affect this part of the consumption. By increasing the knowledge on this topic, it will also be possible to obtain more accurate predictions of the expected energy consumption in future buildings.

1.1 EUDP project 2010-2012

Occupants influence on the energy consumption is characterized by being relatively unexplored and solution of the problem requires skills across traditional science and professional environments. It is therefore vital for success within this area to establish a multidisciplinary team of specialists with technical background, background in communication and behaviour and sociological background. Such a team was formed in 2009 in connection to the EUDP project “Occupants influence on the energy consumption of Danish domestic buildings – phase 1” and it is this team, which has made the state-of-the-art review in this report.

The project will focus on developing a new interdisciplinary approach to the analysis and assessment of user influence on the building energy consumption. The method will be based on surveys of energy use and user behaviour which will provide an opportunity to establish a knowledge and experience base for the assessment of real obtained energy savings and hence better opportunity to direct future energy policy.

As the title indicated, the project is made as a pilot project for a larger phase 2 project. Phase 1 will contain the following:

1. Participation in IEA Annex 53 “Total Energy Use in Buildings”
2. State-of-the-art investigations (this report)
3. Pilot projects and knowledge acquisition from previous and existing energy projects
4. Development of a new interdisciplinary method for the analysis of the influence of occupant behaviour on the energy consumption
5. Evaluation of how existing calculation models for domestic building energy consumption can be developed to include also occupant behaviour
6. Dissemination of results (reporting and publication)

1.2 State-of-the-art reviews

In order to find a common offset for this project and the development of a new interdisciplinary method for the analysis of the influence of occupant behaviour on the energy consumption, literature reviews were made for the different professional disciplines of the project participants. The results of these reviews are given in the following chapters.

The first review handles possible interactions between indoor climate and occupant behavior, which may affect the energy consumption. Indoor climate may affect occupant behavior for different reasons, e.g. as a reaction due to a perception of one or more indoor climate parameter(s) or as a reaction due to concerns about health issues related to the indoor environment, e.g. status of asthma and allergy among family members. The indoor climate parameters that may affect occupant perception and thereby their behavior and affect energy consumption are numerous and may be related to the thermal, the atmospheric, the acoustic and the visual indoor environments. The review focuses on studies of occupants' interaction with various systems in the building, since it may have a significant impact on the energy consumption and the indoor environment. It includes for instance occupants' interactions with building controls, such as opening of windows, adjustments of heating set-points, turning lights on or off, using solar shading and turning an air conditioning system on or off.

User influence on electricity consumption in households are threated in chapter 3, where key findings from review studies of IT-supported conservation are summarized. The chapter draws on literature from the field of behavioural studies focused on feedback motivated electricity consumption and literature from the field of interaction design focused on sustainable interaction design. The literature calls attention to a tendency to design of solutions where information is directed to active users. The conclusion is a call for a more broad perspective on how to support users' conservation behaviour: a focus on at least four types of information, i.e. acknowledging at least four ways that users can perceive information. This is called an "information ecology perspective" which is outlined as a road map with directions that engineers can follow to take the context of technical solutions into consideration without violating their effectiveness.

Chapter 4 discusses the households' energy use and ask whether efficient technologies or user practices are most important, when understanding and predicting households' energy consumption. The chapter reviews national and international studies and use national energy statistics to show that the actual energy consumption in households is at least as dependent on user behaviour as it is on energy efficiency of buildings and appliances, and maybe even more dependent. Furthermore the chapter points out that user behaviour constantly change together with the introduction of new technologies, and it is thus relevant to a higher degree to think about user practices, and not only energy efficiency, already in the design phase.

In chapter 5 a review is given on selected Danish policy instruments of relevance to the energy consumption in housing. This shows the experiences of how different policy instruments affect the energy consumption, with focus on how the users of the buildings can be influenced to reduce their energy consumption. Both economic, informative and more normative policy instruments are described. The challenges within policy making for energy efficiency the building sector is introduces leading to a description of interfaces with the other research fields.

The influence of occupant behaviour in relation to energy consumption and HVAC systems in domestic buildings are discussed in chapter 6. The review includes different models describing the topic. The models are divided into "engineering models" and "integrated models". The engineering models comprise quantitative models based on mathematical expression of physical laws like mass conservation and energy conservation including means to describe the influence of occupant behaviour directly and indirectly. The integrated models are models combining the social and the technical perspectives of energy consumption related to occupant behaviour, typically, with a starting point in the social perspective comprising sociology, anthropologi, and psychology.

Finally, the problem regarding modelling of user behaviour in whole building simulation is discussed in chapter 7. This literature review concludes that modelling occupant influence on energy use should be divided into simulating occupant presence and simulating occupant influence. Stochastic models are an obvious choice and previous research has established a promising base for further development. This project should focus on developing stochastic models based on white-box principles in a 1 + 6 model hierarchy, i.e. presence + appliances, windows, solid waste, lighting systems + blinds, HVAC and hot/cold water.,

1.3 References

Energistyrelsen. Energistatistik 2009. Energistyrelsen, 2010.

2. Indoor climate and occupant behaviour

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2.1 Introduction

Occupant behaviour may affect indoor climate and it can cause large variation in energy consumption in otherwise identical housing. It may also work the other way round, that the indoor climate may affect occupant behaviour that may, one way or the other, lead to a change in energy consumption.

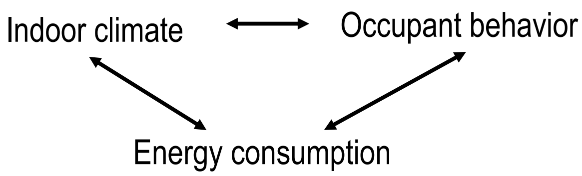

Figure 2.1. Possible interactions between indoor climate, occupant behaviour and energy consumption

Indoor climate may be affected by occupant behaviour for different reasons, e.g. a reaction due to a perception of one or more indoor climate parameter(s) or a reaction due to concerns about health issues related to the indoor environment, e.g. status of asthma and allergy. The indoor climate parameters that may affect occupant perception and thereby their behaviour are numerous and may be related to the thermal, the atmospheric, the acoustic and the visual indoor environments.

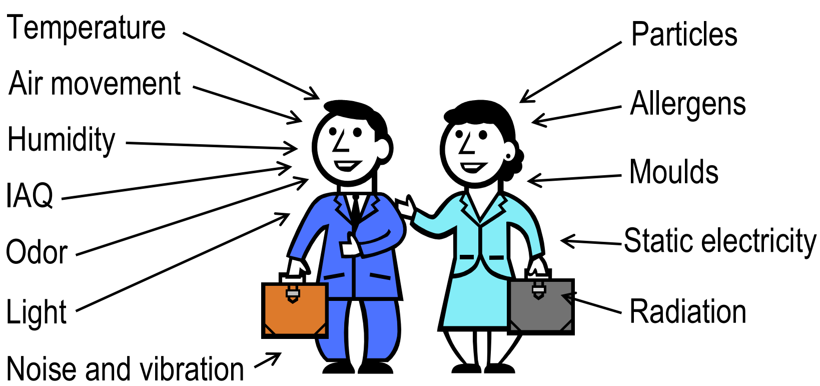

Figure 2.2. Numerous indoor climate parameters may affect occupant behaviour that again can affect energy consumption.

Examples of how indoor climate parameters may affect our behaviour can be taken from our everyday life. If the temperature is perceived as uncomfortable, this may cause us to act, e.g. by adjusting a thermostat, opening/closing a window, changing clothing, adjusting an air-conditioning unit etc. If the perceived air quality is uncomfortable, this may also cause us to act, e.g. by finding and removing the odor source, opening a window or increase ventilation by adjusting the airflow of a ventilation system. If occupants feel draft due to cold air supplied to the occupied zone during winter through an inlet device in the wall, it is often seen that they close the inlet. This leads to reduced base-ventilation and may lead to high humidity in the apartment. Such adaptive actions are defined by Nicol and

Humphreys (2002) who state: “If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort”.

Indoor climate parameters may be considered as possible input parameters in a total "model" for energy consumption. It can be discussed whether indoor climate parameters should be considered per se or they have to be seen in relation to other factors affecting energy consumption.

This review is an attempt to give an overview of relevant literature on the link between indoor climate and occupant behaviour that may affect energy consumption.

2.2 Review

The review focuses on studies of occupants’ interaction with various systems in the building, since it may have a significant impact on the energy consumption and the indoor environment. It includes for instance occupants’ interactions with building controls, such as opening of windows, adjustments of heating set-points, turning lights on or off, using solar shading and turning air con on or off.

In Danish dwellings the energy consumption is, among others, related to the two parameters indoor temperature and air change rate. Mechanical cooling is (not yet) almost never used, which means that the indoor temperature depends on the heating set-point in winter and on the air change rate and use of solar shading in the summer. As a consequence, window opening behaviour and heating set-point behaviour of occupants play an important role in determining the energy consumption and indoor environment of a household.

A central Danish work that focus on the indoor climate aspect and energy consumption was recently made as a PhD study by Andersen (2009). The title of the thesis is "Occupant Behaviour with regard to Control of the Indoor Environment". The purpose of the study was to investigate occupants’ interactions with building controls with special focus on control of the indoor air quality and thermal comfort. A key objective was to identify variables with influence on occupants’ behaviour and to quantify this influence. The main focus was window-opening behaviour and heating behaviour but also electrical lighting and solar shading were investigated. The results of the work have been presented in a series of papers.

Andersen et al. (2007) investigated the influence of occupant behaviour on energy consumption in simulations of a single room occupied by one person. The simulated occupant could manipulate six controls that relates to his/her thermal comfort, such as turning on or off the heat and adjusting clothing. All control actions were carried out with the aim of keeping the PMV value within predefined limits in accordance with CR1752 (1998). An energy consuming and an energy-efficient behavioural mode were simulated. A reference simulation was made during which the occupant had no control over the environment. The occupant was able to keep the thermal indoor environment close to neutral when he/she had the possibility to manipulate the controls. The energy consumption was similar within each behavioural mode regardless of the PMV limits. However, the energy consumption in the energy consuming behavioural mode was up to 330% higher than in the energy-efficient behavioural mode.

In another study Andersen et al. (2009) quantified behaviour of occupants in Danish dwellings by means of a questionnaire survey. Repeated surveys of occupant control over the indoor environment were carried out in Danish dwellings from September to October 2006 and again from February to March 2007. The summer survey comprised 933 respondents and the winter survey 636 respondents. The surveys were carried out by sending out invitations to addresses obtained from a Danish register along with information on dwelling characteristics. Meteorological data were obtained from the Danish Meteorological Institute. Four control mechanisms (window open/closed, heating on/off, lighting on/off and solar shading in/not in use) were analyzed separately by means of multiple logistic regression in order to quantify factors influencing occupants' behaviour. The window opening behaviour was strongly related to the outdoor temperature. The perception of the environment and factors concerning the dwelling also impacted the window opening behaviour. The proportion of dwellings with the heating turned on was strongly related to the outdoor temperature and the presence of a wood-burning stove. The solar radiation, dwelling-ownership conditions and the perception of the indoor environment also affected the use of heating. The results of the statistical analyses form a basis for a definition of standard behaviour patterns which can be used to make calculation of energy consumption of buildings more accurate.

As a follow up on the questionnaire survey, measurements of occupant's window opening and heating set-point behaviour were conducted in 15 dwellings in Denmark in the period from January to August 2008 (Andersen, Submitted to Building and Environment). Indoor and outdoor environmental conditions were monitored in an effort to relate the behaviour of the occupants to the environmental conditions. Logistical regression was used to infer the probability of opening and closing a window, while linear regression was used to determine the relationship between the environmental conditions and the heating set-point on thermostatic radiator valves. The behaviour of the occupants was governed by different but distinct habits in the 15 dwellings. This applied to both the window opening and the heating set-point behaviour. The outdoor temperature, indoor temperature and the indoor CO_2 concentration were the most important variables in determining the window opening/closing probability. The most influential variables in determining the thermostatic radiator valves set-point were the outdoor temperature, outdoor relative humidity and the wind speed. A method for defining occupant behaviour patterns in simulation programs based on the measurements is proposed.

The PhD thesis by Andersen (2009) includes a comprehensive paper review in paragraph 3 'Background', which therefore is a good starting point to get an overview of previous literature. Andersen (2009) has structured his review around a series of central topics, which are mentioned in the following together with relevant references:

The adaptive principle, Nicol and Humphreys (2002).

Window opening behaviour, (in offices) Rijal et al. (2007), Haldi and Robinson (2008), Herkel et al. (2008), Yun and Steemers (2008), Yun et al. (2008).

Effects of window opening behaviour on air change rates, a series of foreign studies are referred to together with relevant Danish studies, Keiding et al. (2003), Kvistgaard et al. (1985), Kvistgaard and Collet (1990)

Degree of opening windows, Fritch et al. (1990), Herkel et al. (2005).

Drivers for window opening behaviour, Haldi and Robinson (2008), Rijal et al. (2007), Herkel et al. (2008), Yun and Steemers (2008), Johnson and Long (2005), Warren and Parkins (1984).
Heating set-point, Weihl and Gladhart (1990), Xu et al. (2009), Karjalainen (2007), Rathouse and Young (2004), Peeters et al. (2008).
Clothing adjustment, Newsham (1997), Baker and Standeven (1994), Baker and Standeven (1996), Morgan and de Dear (2003), Markee White (1986), De Carli et al. (2007).
The adaptive model of thermal comfort, de Dear and Brager (1998), Hoes et al. (2009).

The rebound effect
Upgrading homes and the use of new technology may not always have the anticipated effect on energy consumption and should be considered when modeling energy consumption. This phenomenon is known as the so called "rebound effect". An example is better insulation when people do energy renovation that gives better comfort, like higher temperatures, but energy consumption does not decrease as expected. Another example could be the use of a heat pump for cooling even though it was installed to save energy for heating.

Raw (2010?) address this subject. "As with the financial incentive, becoming more comfortable or healthy does not correlate perfectly with reducing CO_2 emissions, indeed there can be a weak or even negative relationship. A particular example of this is the widespread finding that upgrading homes may achieve only a fraction of the anticipated reduction in energy consumption because the occupants take the benefit in higher winter temperatures rather than reduced bills. This is sometimes for good reason (i.e. it was uncomfortably cold before the upgrade) and sometimes a result of inadequate heating controls (or explanation of how to use the controls) or simply a desire to have the luxury of moving around the house in a constant high temperature and light clothing (“trophy warmth”). In extreme cases, energy consumption may actually increase because heating is seen as better value for money when it keeps the home warm, more of the home can be heated and more time is spent in the home.".

An example of not achieving the expected or desired result by using a thermostat was found in a study by Guerra-Santin (2009). The use of a thermostat for temperature control was shown to increase energy use, in contrast to houses with temperature control in the form of taps. This, she speculates, could be explained by the fact that in dwellings with a thermostat, occupants are more aware of the temperature in the home and therefore tend to turn it on more often that those without a thermostat. The presence of a thermostat seems to have a large effect on occupant behaviour. Nevius (2001) supplements this finding with what she calls a "technological fix" when subsidizing the replacement of manual thermostats with programmable ones, and asks whether programmable thermostats actually save significant home heating energy. The data show that households with programmable thermostats appear to use no less energy than do households with manual thermostats, and that it is behavioural norms, not the type of thermostat, that determine thermostat setting behaviour. The results suggest strongly that in aggregate, the installation of programmable thermostats in residential households cannot be expected to deliver the promised energy savings.

Home vs. office

People may not act the same way at home or at the office. Thermal comfort and use of thermostats in homes and office rooms were examined by a quantitative interview survey with a nationally representative sample in Finland (Karjalainen, 2009). The total number of respondents was 3094. The results show that thermal comfort levels are lower in offices than in homes. People feel cold and hot more often in offices than in homes during both the winter and summer seasons. The perceived control over room temperature is remarkably low in offices. Higher thermal comfort levels and perceived control in homes are supported by greater adaptive opportunities. In offices people have fewer opportunities of controlling the thermal environment, people deal worse with thermostats, and people have fewer opportunities to adapt to different thermal environments. This is in agreement with Humphreys and Nicol (1998) who note that people are more ‘‘tolerant’’ if they have control over their own thermal environment, and may find exactly the same temperature variation acceptable or unacceptable, depending on whether it is chosen or imposed.

Pollution sources and ventilation

Occupant behaviour can, in a broader perspective, also include behaviour in relation to purchase of or selection of potential pollution sources, e.g. building materials or consumer products. This choice will affect the perceived air quality indoors and thereby the required ventilation rate to achieve a desirable IAQ (Knudsen et al., 1998). Recently it was demonstrated that the use of low-polluting materials should be part of a strategy for good perceived air quality in sustainable buildings. The use of low-polluting materials reduces the ventilation rate required to achieve an acceptable level of perceived air quality and thereby prevents unnecessary use of energy for ventilation (Knudsen and Wargocki, 2010). Special attention should be paid to some natural products, e.g. products with linseed oil since they may influence the perceived air quality more negatively than similar synthetic products without linseed oil (Knudsen et al., 2007). Using such a product may cause occupants to want higher ventilation rate than if low polluting materials were used.

The acceptance and thereby a possible reaction of an occupant to an indoor climate parameter may be affected by the information that has been given. This was demonstrated for perceived air quality when an odour panel assessed the emissions from some building products with or without information. When information was provided about the identity and type of building material during an evaluation, i.e. by labeling the materials in a test chambers either as "organic" or "synthetic", the odor intensity was significantly lower for the "organic" materials compared with evaluations without information (Wilkins et al., 2007). Similarly, odor acceptance was increased significantly for most "organic" samples, but not the "synthetic" ones. The major effect is probably that odor acceptance is increased when people are given information about the odor source. This is just one example of the possibility of affecting people's acceptance by information which may be relevant when modeling how occupants affect energy consumption.

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3. (Re)Directions for IT-supported electricity conservation in Private Households

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3.1 Introduction

The increasing awareness on climate crisis and the need to reduce fossil fuel consumption has given rise to a series of Information Technological (IT) systems and devices meant to support conservation behaviour among consumers. Additionally, there is a rapidly growing body of research on IT solutions for sustainable consumption behaviour. Overall: to understand and influence the human factor is regarded as a key issue for sustainable solutions.

The objective of this literature study is to summarize key findings from review studies of IT-supported conservation. Focus is on electricity consumption in households in an European and North American context. The review literature sums-up research from USA, Canada, Scandinavia and Europe: primarily Netherlands and UK.

This overview of research is concluded with an outline of a perspective on IT-devices and systems, which enables designers to see electricity conservation in households as an informational interplay between people, places, habits, and needs. We call this an “information ecology perspective” and in the conclusion we translate this perspective into a road map with directions that engineers can follow to take the context of technical solutions into consideration without violating their effectiveness.

The information ecology perspective mimic the relationships found in natural ecologies. Here adaptations, distribution and abundance of organisms, the movement of materials and energy through living communities, the successional development of ecosystems, and the abundance and distribution of diversity in context of the environment is paramount. Elements in a system are in relationship to other elements, and the outputs of one element become the inputs of another. The roadmap is suggesting points in the landscape of the information ecology to visit, not prescribing a recipe for how to make sure that a given IT-solution will work as intended: in an information ecology, use can not be predicted, it can only be designed for.

In section two we present how we have approached literature on related work, before we in section three give an overview of the research, which we then discuss in section four and from this concludes with an example of what we call an information ecological design. The overall contribution is found in the clear focus on design of pull technologies with direct information and secondary push technologies with undirect information. From the literature and from our theoretical perspective we argue for an expanded perspective including a mix of directions for messages and awareness. This is our first step towards an information ecological perspective on IT-supported electricity conservation.

3.2 Method

The objective of the literature review is to provide a summary of key findings in review studies from what we have identified as two central fields concerned with IT support for electricity consumption. These two fields are:

- Behavioural studies
- Interaction Design

Peer-reviewed papers were identified using Google Scholar as a broad on-line research database and ACM-digital library as an IT-focused on-line research database. Keywords has been feedback, feedback motivated electricity conservation, electronic metering. Additional sources has been identified and used via reference lists in papers from the search.

Within the field of behavioural studies consumer behaviour in relation to energy consumption is well researched. However, we found only few studies and publications on IT-supported consumption behaviour. Our search has identified review papers by Sara Darby summing up literature on electronic feedback for electricity conservation. The results from Darby's literature review are published in several versions. We have used the most elaborated version which is the first published report (Darby 2000) supplemented with further readings into references from the report.

Within the field of interaction design the focus on energy conservation is fairly new. Around 2006 a focus on sustainability in interaction design was put forward, and the concept "sustainable interaction design" (SID) was coined (Blevis 2007). "Sustainable interaction design" SID is however still a new phenomenon in interaction design. Our search has identified two review paper from 2010 both by DiSalvo, Sengers and Brynjarsdóttir. The papers sum up literature on SID and are published in a conference version and a journal version. We have used the most elaborated version which is the conference paper (DiSalvo et al. 2010a) supplemented with further readings into references from the paper.

The literature review shows that there is no/low co-operation between the field of behavioural research and the field of interaction design/SID, and in general co-operation between research fields working with energy conservation seem to be low. To make the research landscape concerning IT-supported electricity consumption in the households as comprehensive as possible, we have categorized themes according to a generic model of information search widely applied in information science (Bates 2002). The model focuses on ways of relating to information, and it emphasizes the information ecology perspective, which we are applying here.

Based on level of directedness and action, the model comprises four basic types of information search: directed active, which is what we normally mean by 'search', undirected active, which is called 'browsing', directed passive called 'monitoring', and undirected passive called 'awareness', see Table 3.1.

Directed information is information, which users seek. Undirected refers to information that the user is more or less randomly exposed to. 'Active' and 'passive' refer, respectively, to whether the user actively acquire information or is passively available to absorb information, but does not seek it out by intentional effort. Pull technologies (e.g. websites, meters etc.) are generally designed for active relating to information, while push technologies (e.g. e-mail, sms, alerts) are designed for passive relating to information.

Generic ways of relating to information	**Active**	**Passive**
Directed	searching	Monitoring
Undirected	browsing	being aware

Table 3.1. Four generic types of information related behaviour (Bates 2002).

3.3 Review of literature on user influence on electricity consumption in households

Behavioural studies are primarily occupied with human values and attitudes towards sustainability and have contributed a lot of knowledge about structural factors of habits of daily living (e.g. Gram-Hansen 2005; Pedersen & Brohus 1997). Results from behavioural studies point towards the importance of a stronger focus on interaction design. Examples from the literature are:

- Behaviour research on electronic feedback on consumption points out that “much information about energy use ... is presented in dull, uninteresting formats” (Costanzo et al. 1986).
- There is a call for “user-friendly displays ... as part of any meter specification” (Darby 2000) since “Consumers who have their supply metered in the standard way are unlikely to consult their meter: it will probably be hidden away and difficult to understand” (Darby 2006).
- In general there is an acknowledged lack of knowledge about how to obtain fit between the form of feedback and the context of its use: “Achieving energy conservation is a twofold challenge, partly technical and partly human... Unless adopted by a significant segment of consumers, the impact of technical innovations will be negligible” (Costanzo et al. 1986)
- As summed up by Wood and Newborough (2003) in a review paper “it is unclear how best to achieve feedback in the home and several research questions emerge. For example, how frequently to feedback the information; in what format to present the feedback (e.g. as numbers, graphics, energy/cost/C02 data); and whether the feedback should be displayed centrally or at the points of end use” (Wood & Newborough 2003).

The main review reported by Darby sums-up knowledge on effectiveness of electronic feedback on electricity consumption to householders. Feedback is the term used for information on consumption. The purpose of feedback is to change people’s behaviour and save energy. Since the first studies in 1970 with display monitors, it has been clear that feedback has a measureable effect. Feedback is regarded as a learning tool through which users learn how to use energy more effectively over a long period of time.

Darby categorize feedback generally as direct and indirect feedback

- **Direct feedback**: immediate feedback on consumption from a meter or displays. Savings range from 5-15 %.
- **Indirect feedback**: raw data processed by the utility and sent out to customers (e.g. bills). Savings range from 0-10%.

In our categorization we place direct feedback as directed and indirect feedback as undirected (cf.Table 3.1).

A wide range of feedback types and technical products exists under each of these categories. Darby summarize these as follows:

Direct feedback e.g. include:

- **self meter reading**: standard meters regarded as a very basic form of consumption feedback. This calls for commitment to reading the meter regularly but is proven an effective tool in advice programs in conjunction with information on energy savings. Savings can be 10-20%.
- **Displays**: these are a supplement to the meter and show electricity consumption for instantaneous information and/or information on previous consumption and some includes alarm. Savings are app. 10% for relatively simple displays.
- **Interactive feedback via PC**: Interactive displays with more complex information than direct displays. Examples are digital TV and interactive web pages, which have proved savings from 8,5 - 18%.
- **Pay-as-you-go meters** /keypad meters: semi-smart meters which allow transfer of information such as tariff-changes and meter reading data to and from the keycode at the payment shop. Savings vary. In Northern Ireland Keypad metes are used in app. 25% of households and savings are estimated at 3%. In contrast experiments from North America with pay-as-you-go systems claim 25% savings.
- **Ambient devices**: This is displays, which do not show text or numbers but simply alert the householder to the fact that something relevant to their electricity supply has changed. Experiments with flashing light gave savings for 16%.
- **Cost plugs** or similar devices on appliances: Information on end-use, which supports immediate feedback on one appliance at a time. If combined with the meter this can provide disaggregated feedback, i.e. information on which end-users consume most energy. There are no data on the effect of this type of feedback.

Generally, there is a focus on direct feedback designed for users' active relation to information. Except ambient devices where focus is on awareness, i.e. undirected and passive relation to information, all other types of feedback products require active relation. Users must actively read the meter, approach and search the direct displays or interactive PC-applications for information, plug in cost-information devices to get information on specific appliances or actively pay meters.

Indirect feedback include various types of informative billing. These can be:

- Frequent bills
- Frequent bills based on readings plus historical feedback
- Frequent bills based on readings plus normative feedback
- Frequent bills plus disaggregated feedback
- Frequent bills plus detailed annual or quarterly energy reports

Savings from informative billings are 0-12%.

Billings are indirect feedback designed for users' passive relation to information. The billings keep householders aware of their consumption in a designed frequency and support reading and reflection.

When categorized according the generic information search model the literature from behavioural studies shows a picture of solutions, which are primarily directed feedback designed with the intention to support users active relating and secondary indirect feedback designed for users passive relating to information. Undirected active information is not found. Directed passive information is not found. We have summarized this classification in Table 3.2:

Generic ways of relating to information	**Active**	**Passive**
Directed	Self-meter reading Interactive feedback via PC/websites Pay-as-you-go meters Cost plugs Direct displays	
Undirected		Billings. Ambient devices

Table 3.2. Categorizing solutions regarding feedback on electricity consumption in private households, found in behavioural studies in relation to information search behaviour

Darby concludes in her review that a combination of feedback types / synergies between feedback and other types of information is an important factor, and additionally, that scale and timing of feedback is important: while the indirect feedback provides a compelling picture of the consumption level, the instantaneous direct feedback illustrates the impact of smaller use. Indirect feedback shows longer-term effect best, while direct displays will show the significance of moment-to-moment behaviour.

In general we find that the social studies research all in all emphasize the importance of understanding and designing for the complex patterns of electricity conservation in households.

When it comes to the discipline of interaction design, and more specifically sustainable interaction design (SID), focus is on both technological solutions, and critical studies, and reflection on technological development and use. Interaction design's tradition of working with IT as material is here the key. Future opportunities for different solutions playing with various types of interfaces, interactions and information will inevitably come from here, but not necessarily based on what we know from behavioural studies. Notice that there are no known savings effects on the various types of solutions, which must be caused by a primary focus on designing IT and a secondary focus on sustainability. An explanation is also found in the literature review by DiSalvo et al. summing up diversities within SID such as

- diverse genres: from persuasive design to critical lens studies and studies of users' attributed to the environment
- diverse understandings of problems and solutions: e.g. call for focus on individual consumes vs. other groups or scales, perspectives on users as the problem vs. solving users' problems, arguments for improving vs. fundamentally changing lifestyles etc.

- noticeable redundancy of studies with similar approaches and similar conclusions
- limited interdisciplinary connections to related fields: like e.g. behaviour or engineering research
- limited debate between different orientations

In the review paper DiSalvo et al. categorize SID-research in what they term ‘genres’ or emergent clusters of research that draw from similar sources, share general problem formulation and have similar ideas of approach. These are summarized as follows:

Persuasive technology comprises 45% of the literature. Success is counted on the basis of behaviour change. However, not all papers evaluate the sustainability effect of the design. Several papers use sustainability as a target domain to test theories of persuasion rather than aiming to enhance sustainability.
Applications are devided by DiSalvo as follows

- Strong persuasion: information provided about the extent to which user’s behaviour is or is not sustainable
- Passive persuasion: information about consumption, waste or other broad impact effects presented to the users usually implicitly contextualized with the topic of sustainability
- Few papers where the strategy is to enforce particular behaviour patterns

Ambient awareness comprises 25% of the literature. These are systems based on perspectives like calm computing and ambient displays. The ambition is to make users aware of aspects of sustainability of their behaviour. Examples are flower lamps that blooms as energy consumption in a household decreases over time. DiSalvo et al. point to a large overlap between ambient awareness and persuasive technology.
Two types are listed:

- Designs which makes consumption visible in order to prompt awareness of use
- Designs which makes desirable consumption patterns visible.

Pervasive and participatory sensoring comprises 22% of the literature. This is an emerging strand of work which uses sensors to monitor and report environmental conditions. Focus is by DiSalvo et al. summarized as

- Participatory sensing which means involvement of non-experts in collecting data from sensing platforms. A keyword from this type of research is “citizen science” which is a label used to emphasize the democratic potential of involving end users in data collection.

Additionally, SID includes

- philosophically and critically oriented literature (ca. 10%) focused on reducing resource wastage and pollution especially due to rapid obsolescence of technology
- formative users studies (ca. 15%) with focus on how users think about and approach sustainability

We see here a focus on directed information with call for users to relate actively to the information (cf. figure 3), especially in the field of persuasive design which comprise the largest pool of SID research. Even what is by

DiSalvo termed as “passive persuasion” is directed information designed for users to actively search information on consumption or other sustainability perspectives. Similarly we have categorized participatory sensoring as directed and active information because of the call for users to actively search information on consumption from sensors and report data further as part of the collective citizen science. Similar to behaviour studies ambient awareness is undirected passive information.

In sum we find a picture in SID literature which corresponds the literature on behaviour studies: the main part of solutions and research is found within the categories directed and active information (persuasive design comprise 45% of the literature plus 22% on participatory sensoring) and undirected passive information (ambient awareness comprise 25 % of the literature).

We have categorized the literature from sustainable interaction design in the framework of search behaviour in Table 3.3.

Generic ways of relating to information	**Active**	**Passive**
Directed	Persuasive Technology Pervasive and participatory sensing	
Undirected		Ambient awareness

Table 3.3. Categorizing solutions found in the SID literature in relation to information search behaviour.

3.4 Discussion

The literature study shows

- a primary focus within both fields (behaviour studies and interaction design) on directed active information
- a secondary focus on undirected passive information.

Literature on interaction design is poor on effect and behaviour studies point out savings estimates which are quite identical (0-15% in awarage). However, Darby emphasize that the different types of information has different effects and that a mix of different types of feedback is needed:

- Direct active information have significance in moment-to-moment behaviour
- Undirect passive information provides a compelling picture of the consumption level and show long-term effect best
- A mix of feedback is needed

This leads us to the same conclusion as DiSalvo et al. (2010) that there is a wealth of unexplored opportunities for design and engineering of solutions/devises. However, this literature study has sharpened our understanding of directions for such designs. The introduction of Bates model (2002) was first to provide overview of information types but secondary we suggest a rewriting of the model as design direction.

In general the conclusions can be summarized with what is called ‘Mooers law’ (http://projectinfolit.org/st/morville.asp), the paradox that many people avoid using a system precisely because it gives them information, because if you have information, you must first read it, which is not always easy. You must then try to understand it, which may show that your work was wrong. Thus not having and not using information can often lead to less trouble and pain than having and using it – seen from an end users point of view. Still, in case of electricity conservation, society wants the households to save energy, and information is seen as one of the instruments for this. The households are as units self-regulated in their attitude towards electricity consumption. And we know from social psychology that self-determined learning depends on informational feedback – which means feedback, which is to the point, not too much, not less than perceived sufficient, it opens for choices, and it acknowledges mixed feelings (Deci & Ryan 1985).

Taking the above facts into consideration, we suggest an information ecology perspective: Humans are the key to action, there are many technologies that can lead to a desired goal, but whether feedback information leads to action and change in behaviour depends on the human factor. The information ecology, comprising people, motivation, location, situation, and technology, integrates different types of information, and seeing the interaction with information as an ecology makes us acknowledge the evolutionary character of the development. We are not dealing with machines to be regulated, so small changes somewhere in the ecology may – over time – lead to major changes in the whole of the ecology (Davenport & Pruzak 2000).

3.5 A direction for supporting user influence on electricity conservation based on an information ecology perspective

In the introduction we said that according to the research reviewed here, to understand and to influence the human factor is a key issue. The question, challenging the designer and engineer, is of course, how.

We suggest that the designer/engineer apply an information ecology perspective, meaning that the designer/engineer avoid cause-effect thinking, and embrace the idea in an information ecology, use can not be predicted, it can only be designed for. The above review gives us the following leading points

- Results from behavioural studies point towards the importance of a stronger focus on interaction design
- Feedback is regarded as a learning tool through which users learn how to use energy more effectively over a long period of time
- Darby concludes in her review that a combination of feedback types / synergies between feedback and other types of information is an important factor
- Research tend to focus on direct active information solutions and secondary on undirected passive information solutions.

In conclusion: designers/engineers need a daring hand when designing and engineering devices meant to influence consumers in the direction of more modest energy consumption. The road map described below is meant to help in this endeavor.

In order to employ the information ecology perspective, the designer/engineer must have two sets of glasses: The near-sighted, and the long-sighted. The near-sighted help the designer/engineer to empathize with the use-context, and put the empathic insights into narratives, scenarios, which describe use-situations, detailed enough to be recognized by all stakeholders as common. The long-sighted glasses allow the designer/engineer to map out the key points of motivation and awareness, which helps design the elements in the system of informational feedback.

From this we present a model, which is our first step towards direction for design of IT-design which supports users electricity conservation in private households. The figure draw on Bates notion on direct and undirected information which we have translated to IT-terms: pull and push technologies. And the model draws on Bates' focus on whether user relates actively or passively to information which we according to the information ecological perspective has rewritten to focal and peripheral sight.

Direction of message / Direction of awareness	**Pull**	**Push**
Focal (near sight)	Search: d	Monitor: b
Peripheral (long sight)	Browse: c	Awareness: a

Table 3.4. A first outline of an information ecological design model.

The map is built on Bates' search paradigm. The designer/engineer has to make sure that each energy consumer of a private household *and* the household as such perceive

a. informational feedback from the home environment
b. alerts in preferred ways and places
c. extra informational feedback such as the opportunity to see what comparable households use
d. opportunity to find tips and tricks and product info through directed search

These examples are put to the Table 3.4 using the letters (a – d).

To sum up: the long-sight glasses help create fit between device and environment, which affords 1. passive undirected awareness, 2. passive, directed monitoring, 3. active, undirected browsing, and 4. active directed search. A map is, however, of no use outside of the landscape it is mapping. Hence designers/engineers must remember to use also their near-sight glasses to understand and describe the use-context. In our own work we have found that staging a playful interaction between users and their environment generates material for descriptions, which can serve as boundary objects in between the many stakeholders involved in any design and engineering project.

3.6 Design example

As conclusion we include what we find an information ecological design. The example is from the FEEBACK project where we worked on design of an on-line meeter in co-operation with eight Danish households (cf. references 20 – 25). In general the example is a display in the kitchen, at first glance inviting awareness. It displays an ordinary kitchen clock, which will be habitually glanced at, and frequently given focal attention. In the periphery the screen displays electricity consumption, while also ambiently, through lightning and colours, showing if it is night or day. Up till 15 device's consumption and on/off status is measured and displayed on the screen, too, so that an ambient picture of consumption is presented, inviting monitoring, and maybe giving rise to discussion in the family. It is a touch screen, and through touch the household can browse through various measures for comparison with own previous consumption and that of other households. If and when the households want to by new goods or get tips and tricks, the interface present links to where to search on the web.

The following presents details of the design elements and place these elements into the introduced model as a conclusion.

In the FEEDBACK-project, three concepts are coined as central on the basis of the above analytic results:

- *Speed* - visualizes the current invisible consumption. Several of the families, both adults and teenagers, remembered their joy of watching old meters spin fast or slow according to the consumption now replaced with digital numbers.
- *Remind*: central to the concept of reminding is that it visualizes an overview of the on/off status on central appliances in the household. The on/off status explain the speed when put next to each other.
- *Compare* - central to the concept of comparing is that it relates consumption to a norm or previous consumption or relates appliances to each other and thereby prompting changing and buying appliances and white goods. Comparing is a central basis for the families' acceptance or fight against the consumption of electricity in the household. Consequently, national guidelines and saving objectives are crucial for understanding whether a household consumption is high or low.

Interaction based on these three concepts has been designed for a medium screen solution to be placed at fix points in households at the choice of the individual family. The final outcome (a result of several sketches and dialogues with software developers) is presented in the figures two, three, and four: To make the display nice and decorative the back-ground changes twice a day from day to night and vice versa. A clock adds functionality and invites to also perceive actual consumption. The clock offers a combination of feedback and time providing a sense of the rhythm of consumption – becoming aware of when the household is 'speeding' or 'crossing the norm.'

Figure 3.1. Visualizing speed, comparing and remembering.

Speed is visualized with a pellet drifting from side to side in a tempo matching current measure of consumption; if the speed of the consumption is fast the pellet moves fast, if low it moves slowly. The text to the 'speed-bar' says: "Consumption right now: xx W", i.e. provides an accurate measurement of the current consumption.
Comparing is visualized in a bar displaying the total consumption since midnight *compared* to a norm. The bar is filled during the day. The red line is the norm (as default previous consumption minus 10 % savings). The text to the bar says "since 00:00 xx kWh" and "Expected today: xx kWh", i.e. provides an accurate measurement of the total consumption. A button labeled "Details" opens a window with information of the consumption per week, month and year (figure three). The details are displayed on graphs making it easy to compare. A red line shows the households goal savings.

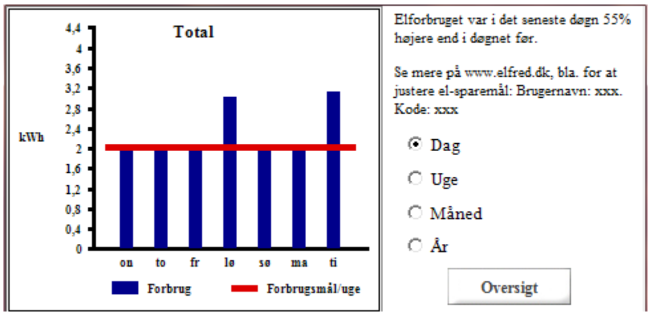

Figure 3.2. Details of the total consumption.

Remembering is visualized very similar to the first mock-up (Figure 3.1) as a list of appliances and their on/off status. A touch on an appliance in the list opens a new window with information on the use of the appliance for the day, week, month and year (Figure 3.3). A hot-line phone number and a "See more on www.elfred.dk"-link connects to a website with details on the household consumption, advice on how to bring down the consumption, possibility of adjusting the goal for savings (the red line displayed in the feedback-application), and links to a website supporting decision-making made by the Danish Electricity Conservation Fund (http://www.selvtjek.sparel.dk/).

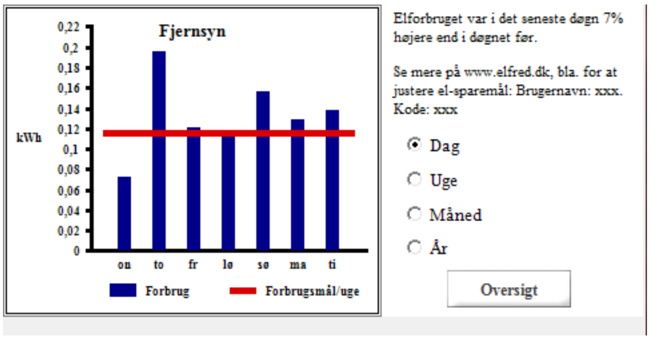

Figure 3.3. Details of the consumption on selected appliances

We have summarized these design elements in the model (Table 3.5) to show the mix of information types used and how they supplement each other in what we term as an example of an information ecological design example:

Direction of message / Direction of awareness	Pull	Push
Focal (near sight)	Search: on/off, electricity consumption.	Monitor: alert
Peripheral (long sight)	Browse: history – consumption related to privious week, month, year. Consumption related to other households/norms.	Awareness: rythm (colours, speed, changes in wall paper)

Table 3.5. An information ecological design concept – examples from the FEEDBACK project.

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4. Households' energy use – what are most important: efficient technologies or user practices?

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4.1 Introduction

In western societies households stands for app. one third of energy consumption, and throughout the last thirty years efforts of reducing this has included research and development in more efficient technologies and buildings, as well as policy activities directed at the households encouraging them to purchase these more efficient technologies. To a much lesser extent focus and interest have been directed towards how the actual use of technologies and houses influence the final energy consumption. Recently there are, however, seen an emerging interest in research documenting the importance of user practices in real life households.

A Dutch study document that building characteristics determine 42% of the variation in energy use, whereas occupant characteristics can ad 4,2% extra explanation of the variation in energy consumption[1], thus indicating that user practices are important though only to a limited degree are determined by objective occupant characteristics. A study based on US data concluded in line with this that besides from weather characteristics, building characteristics are the main determinant of energy for space heating and cooling purpose followed by behavioural aspects, though in this study they further include the relation between occupant characteristics (as age and income) and the building characteristics (as size and type of dwelling) making the indirect effect of the occupants much more important [2]. Some studies besides from building characteristics also include information on type of heat control system, as programmable thermostats, manual thermostats or manual valves and contrary to many assumptions these studies conclude that those having 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 behaviour.

In this paper focus will be on presenting and analyzing different types of data which can further enlighten the question of how important user behaviour is compared to efficient technology and also what link there might be between efficiency of technology and user behaviour. 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, where technology here include both household appliances, lighting, heating system and the dwelling. This article will explore the relation between these four elements at different scales by the use of national statistics, own previous research and a review of international research elaborating on these relations.

4.2 Analysis and results

4.2.1 Danish National statistics on energy consumption

From the Danish national statistics [5] we have data on development of energy efficiency in appliances during the last thirty years and development in the numbers of appliances in Danish households in the same period (se Figure 4.1). Data in this figure is based on analysis from a bottom-up computer model (ELMODEL-bolig), where input comes from surveys with 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 trades organizations. From the combination of the left and the right part of this figure we learn that the growing energy efficiency gained through the last thirty years in the appliances in Danish Households is counterbalanced by the growing amount of appliances that are in use in Danish households.

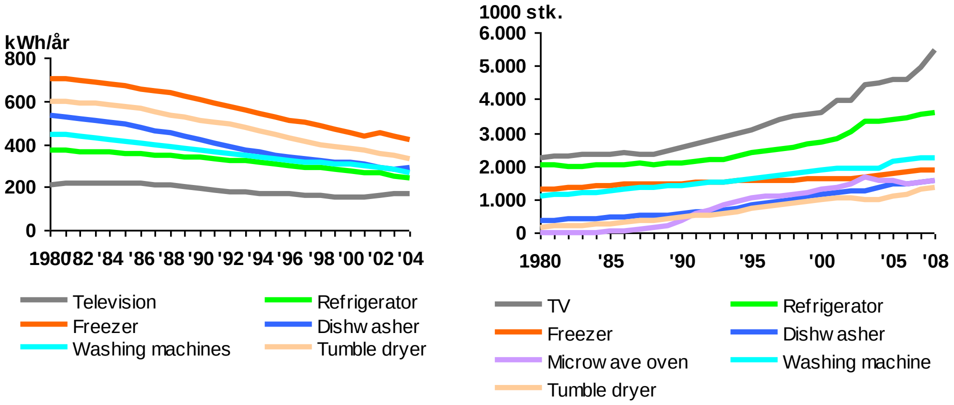

Figure 4.1. Energy efficiency of Danish household appliances1980-2004(left) and number of appliances in Danish households 1980-2008 (right). Source Danish Energy authority [5].

Figure 2 describes a correspondingly development within the housing sector in Denmark in the last thirty years. We see here that energy efficiency in this period has risen so that only 70% as much energy today is used per heated square meter as compared with 1980. In the same period the heated area has, however, raised with 30-40% compared to the heated area in 1980, and thus resulting in a final energy consumption that have been more or less stable in the last twenty years. When interpreting this figure it is important to notice that the growing heated area can not be explained by an increase in the Danish population as this has only been from 5,122 million in 1980 to 5,476 million in 2008, representing an increase in population of 7% in this period (statistikbanken.dk).

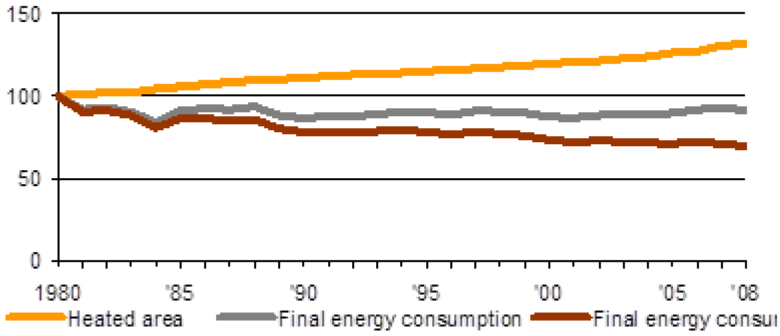

Figure 4.2. Energy consumption for space and water heating in Danish households. Index 1980=100, data are climate corrected. Source Danish Energy authority [5].

Interpreting these figures thus indicates that energy efficiency in itself is not sufficient. If the goal is to reduce final energy consumption then policy and research also need to engage with the discussions of why there is a growing consumption in the number of appliances and the living area.

4.2.2 Different energy consumption in similar houses

The explanatory power of respectably energy efficiency, user practices and number of appliances for explaining energy consumption has been investigated in a study of 1000 quite similar houses in a suburb of Copenhagen, which in spite of their similarity show huge variation in energy consumption. Comparing completely identical houses for heating show that those using least use less than a third of those using most, and for electricity we envision an even grater variation where those using most use five times as much as those using least. The study included among others a survey with a response rate of 50%, combined with energy and water consumption as delivered by utilities, 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 behaviour 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 behaviour related to room heating and hot water use. In this case there is, however, no possibility of comparing the effect of user practices to the effect of energy efficiency.

In relation to electricity the analysis is more complicated as appliances and lighting is bought individually and we has to rely on self reported data on number, efficiency and use of appliances from the questionnaire. In the statistical analysis of these data households are divided into three equal groups consisting of the third of the households having the highest level of consumption, the third having the lowest level of consumption and the third in the middle. 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 can not be completely reliably, people are only given the possibility to indicate if their cold appliances are low-energy or not, or if they do not know. For lighting bulbs they have been asked if the share of low-energy bulbs is less than 25%, 25-50%, or more than 50%. In Table 4.1 it is seen that there is no correlation between if people have indicated that their refrigerator is low-energy and if the household is 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 consumers 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 shows strong correlation as seen in Table 4.2, 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 4.3 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).

	Low consumer group	Middle consumer group	High consumer group	total
Not energy efficient refrigerator	38%	26%	37%	100%
Energy efficient refrigerator	26%	35%	29%	100%

Table 4.1. The share of households indicating respectively that their refrigerator is energy efficient or not, is divided into three different energy consumer groups of households. Table should be read vertically. Analysis show there is no correlation (n=214, gamma=-0,055, not significant p=0,628).

	Low consumer group	Middle consumer group	High consumer group	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 4.2. Households' information on their number of refrigerator-freezer unit, compared to the energy consumer group of the household. Table should be read vertically. Analysis show a strong positive relation (n=286, gamma=0,306, significant med p=0,000).

Use of tumble dryer	Low consumer group	Middle consumer group	High consumer group	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%

Table 4.3. Households' information on their weekly use of tumble dryer, compared to the energy consumer group of the household. Table should be read vertically. Analysis show a strong positive relation (n=199, gamma=0,334, significant med p=0,000).

In general the energy efficiency of households' appliances does thus not contribute to the explanation of the huge differences that can be found between the electricity consumption in these households. What do contribute to the explanation are 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 of the size of the electricity consumption, however, it also show that it is more energy efficient to live more people together. This will be further explored in the following section.

4.2.3 Socio-economics in the understanding of user practices

A database with register data of app. 50,000 households including socio-economic information on the inhabitants, building information (building type, year, size, installations etc.) and meter readings from utilities on heat, water and electricity consumption show some correlations between users, buildings and energy consumption [9]. This type of data thus does not include any direct information on user practices or energy efficiency, though the data can throw light on some of the questions raised in this article.

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 sq. meter floor 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 compared with only primary school	-278	0.02

Table 4.4. Detached Houses: Background Variables Effect on Electricity Use, n=8,573

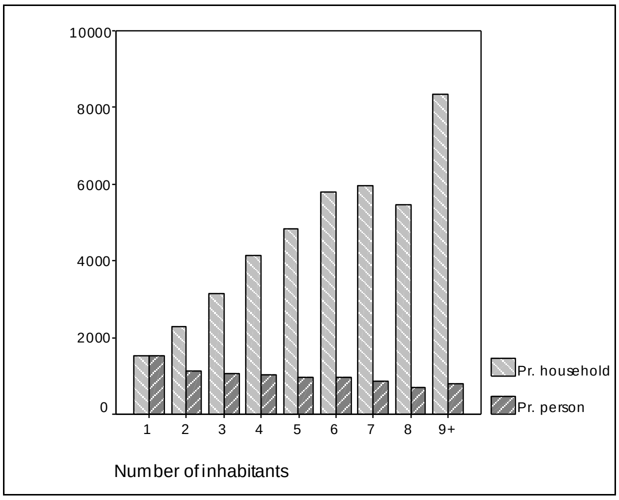

Figure 4.3. Average electricity consumption per household and per person compared with the number of persons living in the household, including households in detached housing, semi detach housing and in apartments. 9+ refers to 9 or more inhabitants, n=53,804

For electricity consumption regression analysis for 8,500 detached houses are shown in Table 4.4. The number of people living in the home has 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 4.4 shows that other variables as age and education of the inhabitants only contributes with little extra explanatory power. The number and the use of appliances in a household are strongly dependent on the number of people living in that household as we also learned in the previous paragraph. If, however, we compare electricity consumption per person with the number of people living in the household, it becomes clear that it is more energy efficient to live more people together (Se Figure 4.3). This is a very important result related to user practices as still more people in most western societies live alone, today this apply for almost 40% of the population in Denmark, which thus can be seen as a main drivers towards a still higher energy consumption. From Table 4.4 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 variation in the electricity consumption as income and household size together only explains app. on third of the variation in electricity consumption. The main part of 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 majority of the understanding of this user practice thus have to be understood by more qualitative approaches to the understanding of the everyday life of the households.

When analyzing heat consumption the database include the type, size and the building year, where building year to some extent can 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 analysis 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 single family detached homes show that the size can explain 28,3% (R^2) of the variation in heat consumption, and the building year can explain additionally 10,5 % (R^2) of the variation in heat consumption (not shown in tables). When already accounting for these two factors other characteristics of the household members as age, number of persons living in the house and income only contribute all together with app. 4% (R^2) explanation of the variation.

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. 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 and furthermore it can be concluded that these differences in user practices only to a limited degree can be explained by socio-economic descriptions of the inhabitants.

4.2.4 Low-energy buildings and user practices

As it seem that heat consumption is more dependent on the building physics than electricity consumption is on energy efficiency of appliances, it is thus relevant to focus explicitly on new low-energy buildings and see how user practices influence the final energy consumption for heating. A few recent studies have looked into this. In Sweden a comprehensive study of 20 terraced low-energy houses have been conducted and measurements of heat consumption show that user practices account for a variation of factor 2 as those using least energy uses 49,2 kWh/m2, and those using the most uses 101,7 kWh/m2 [11]. In UK similar studies of 26 low energy houses with post occupancy evaluation shows that those using the least uses 46 kWh/m2 and those using the most uses 144,9 kWh/m2 which equals 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/m2 and the correspondingly average for the local area is 172 kWh/m2. In this study there is thus a factor 2 between the average of heat consumption for "normal housing" and 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.

4.3 Discussion

Above different approaches for answering the question if energy efficiency or user practices are most important has been presented. In the following two different discussions will be introduced. First is discussions of the rebound effect and how it interprets the relation between user practices and energy efficiency, and second is a discussion on how future developments in the composition of household energy consumption might influence the relation between efficiency and user practice.

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

There is a huge international group of literature on the rebound effect indicating that improvements in energy efficiency makes 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 app. 20% [13]. This means that 20% of the efficiency gained through technical improvements of building and appliances are turned into increase in consumption (higher comfort) following from direct change in user behaviour. The review distinguishes between two different ways to investigate the relation: one is called the quasi-experimental approach, including comparing energy consumption before and after a renovation, or comparing measured energy consumption with calculated (predicted) energy consumption based on engineering estimates. The quasi-experimental approach are questioned and deemed inaccurate following from the methodological approach in most of the studies. The other approach is the econometric approach, typically estimating elasticities between variable as energy demand, energy service and energy efficiency, which is considered more accurate, however there are few studies of this sort. Through combining review of both types of studies, it is however possible to reach a conclusion

This understanding of the rebound effect builds on an economic understanding of household behaviour, where people consume more because they can afford it, following from the reduced energy consumption gained through the energy efficiency. It should not be denied that economy partly can explain household behaviour related to energy consumption, however, it should be emphasized that there are other relevant explanations than economy, including psychological and social understandings. If people feel they have done something to save energy, like bought an energy efficient appliance, then they might feel that they do not have to think so much about how they use it. In this understanding it is thus not only economy but also a broader societal moral and guilt/justice approach that can be part of the explanation related to individuals' behaviour. A different way of viewing the link between energy efficiency and growing consumption, however, is to say that there is no direct link between them, but they are two different but parallel trends that both has an impact on the final energy consumption. The growing number of appliances and inhabited floor area then has to 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 technical possibilities [14], [15].

4.3.2 Future developments in the composition of household energy consumption

As shown previously heat consumption seem to be more dependent on buildings energy efficiency whereas electricity consumption is more dependent on user practices including the number and size of the appliances. There are, however, also good reasons to believe that this relation varies with different types of appliances. In Figure 4.1 (left), it is shown that energy consumption of freezers, dishwashers and tumble dryers has been reduced by app. one third the last thirty years, whereas there is not seen any substantial energy reduction related to televisions. In general it must be expected that households' energy consumption to a still higher degree will be consumed by information and communication technology (ICT) in the future. A Danish study showed that ICT from 2000 to 2007 rose from app. 10% to app. 20% of a households 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 [16]. These scenarios include assumptions of a continued efficiency of ICT's, however, they also assume that the size and number of televisions and the number of computers will continue to grow even more than the efficiency and thus lead to a continued growing consumption within this type of energy end-use. As it must be assumed that energy consumption related to refrigerators and freezers are more dependent on appliance efficiency than on user practices, compared to the use of ICT, these assumptions point towards a future where it can be expected that user practices as compared to energy efficiency will be even more important for the final electricity consumption in households.

4.4 Conclusions

This paper has dealt with the question if user practices or energy efficiency are most important for the size of households energy consumption. The answer to the question is slightly different if it is asked for space and water heating or for electricity use for lighting and appliances. For heating consumption it is shown that building characteristics, including size and building year, can explain app. 40-50% of the variation in energy consumption, whereas occupant characteristics can only explain app. 5% of the variation when already accounting for the building characteristics. Furthermore studies confirm that completely identical houses can have energy consumption for heating varying 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 purpose, though the user practices can only to a very limited degree be explained by occupant's 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 efficiency of appliances have for some types of appliances meant that energy use have been reduced by 30-40% the last thirty years, however, in the same period the number of appliances in households has raised 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 heat consumption. Analysing 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 show that the number of persons living in the households is the most important factor for describing electricity consumption; the more people living in a household the higher consumption, though electricity consumption per person show 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 correspond to that the more affluent households, can afford to have more appliances.

Furthermore it is throughout the article described that there are several different links between energy efficiency and user practices. This is thus a fact that underlines that efforts of reducing energy consumption in households should not focus either on energy efficiency or on user practices, but should include the many different links between these two important parameters in reducing energy consumption in households.

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5. Policy instruments

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5.1 Introduction

An introduction is given to the Danish policy instruments of relevance to the energy consumption in housing. The aim is to outline the experiences of how different policy instruments affect the energy consumption, with focus on how the users of the buildings can be influenced to reduce their energy consumption.

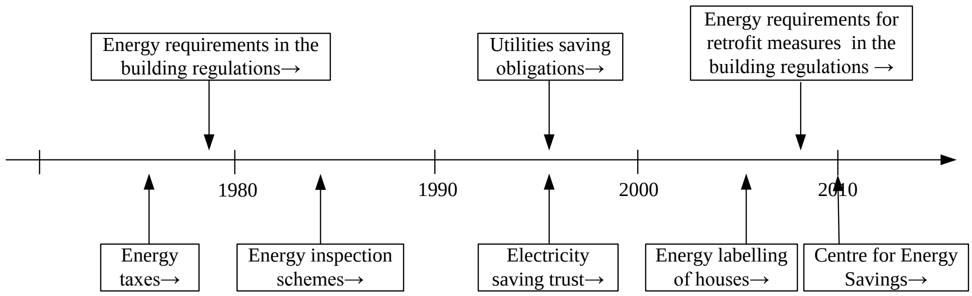

Figure 5.1. Chronological illustration of the main policy instruments introduced in the following

The challenges within policy making for energy efficiency the building sector is analysed in the following and the linkages and interfaces with other research fields are discussed.

5.2 Building regulations

Building regulations in Denmark sets energy requirements for new buildings. The first version of the building regulations was implemented in the 1960s. In the regulations are both specific and functional requirements. The specific requirements addresses how to construct single components of the buildings, they are easy compensable and sets clear limits for well defined circumstances. On the other hand they leave limited degree of freedom for innovative solutions. The functional requirements were introduced in 1972 and since then the regulations have had an increased amount of functional demands. These demands assign how parts of buildings shall perform, opposed to how they shall be constructed. The later revisions of the building regulations have an increased focus on functional requirements and detailed requirements for how to build a house. In 1979, minimum requirements for energy consumption were included, with demands for the performance of the single building component. The energy demands have changed since then and now address the total buildings energy performance. (Gram-Hanssen and Christensen, 2011)
BR08 from 2008 set standards for energy properties in facade windows. These requirements apply for both new buildings and retrofit measures in existing housing. (Danish Ministry for Economic and Business Affairs & Danish Enterprise and Construction Authority, 2008). Besides this, there are specific requirements related to replacement of roofs, changes of heat supply and replacement of oil and gas boilers. (Danish Ministry for Economic and Business Affairs & Danish Enterprise and Construction Authority, 2008).

An evaluation concludes in 2008 that building regulations have been efficient in reducing energy consumption in new buildings. Greater flexibility has been created by focusing on functional requirements for buildings rather than detailed requirements on building components. There are high expectations for the planned tightening of building codes in 2010 and 2015. (Niras, RUC & 4-Fact, 2008)

The content of BR2010 specifies that new buildings have a 25% reduction in energy consumption for heat and ventilation compared to the previous building regulation. Besides this there are specific requirements for e.g. the energy efficiency of heat pumps that are installed due to renovation of houses. This is indented to reduce the energy consumption from old houses over time. (Danish Ministry for Economic and Business Affairs & Danish Enterprise and Construction, 2010)

There are also plans to expand the legislation concerning energy efficiency improvements in new, renovated and existing buildings in 2015

At least one area is of importance for the possibility to influence the behaviour of the users of the buildings related to the building regulations, namely the specific demands related to renovation of the existing buildings.

The effect of these incentives for retrofit solutions is not yet evaluated, as they have only been in force for a few years (Gram-Hanssen and Christensen, 2011).

5.3 Energy label and energy inspection schemes

Energy labelling is seen as an important way to achieve energy savings in both existing buildings and new houses. (Kes McCormick and Lena Neij, 2009)

Energy inspection schemes of houses have been obligatory since 1985, for houses that are sold, however it has not been enforced effectively. (Gram-Hanssen and Christensen, 2011). In 1997 the existing scheme were replaced by schemes including energy labelling for both large buildings (of more than 1,500 m2) and small buildings, such as one-family houses and apartments. (Danish Ministry of Climate and Energy, 2008).

The success of the scheme was limited, as the real estate salesmen often did not do, what they were obliged to, namely to inform sellers or buyers about the scheme and about the buyers' legal right to get an energy label. Combined with lack of sanctioning by the authorities, when the energy labels were missing, this resulted in a relatively low coverage. (Gram-Hanssen and Christensen, 2011)

Due to the EU Directive (2002/91/EC) on the energy performance of buildings, the former labelling
scheme from 1997 was further developed and a new scheme introduced in 2006. Now buildings need an energy label, when they are newly constructed, when they are sold, and if they are rented out. New buildings must meet certain requirements. (Gram-Hanssen and Christensen, 2011) Energy consultants' labels the buildings. Besides this, two types of energy saving measures must be identified: immediately feasible ones and those feasible if carried out in addition to ongoing renovation. A handbook for the energy consultants specifies how this is done (IEA, 2008).

Despite the improved scheme, only around half of the sold one family houses have the required label and the same is the case for a large part of new buildings that also misses the energy label. The calculations that form the basis for the labels of the specific buildings are also marked by errors. Another obstacle for the labelling is the cost-benefit balance; consultants are required for labelling the buildings, and that is expensive. Few building owners are interested in the information provided by the consultant. Therefore getting the energy efficiency is significantly higher than the cost of supplying energy (Togeby et al., 2009)

The seller of the house pays for a consultancy service that the one buying the house does not use, thereby the energy labelling has limited effect in influencing the behaviour of the owner of the house, and thereby limited effect for getting energy efficient technologies implemented.

5.4 Utilities' obligations to promote energy savings

Since 1996 it has been a legal obligation for the utilities to promote energy savings. In the energy agreement from 2009 this was specified, and now the utilities are responsible for making their customers carry out specific reduction targets. The utilities have to realise 6,1 PJ saved energy, divided among the Electricity utilities (2,9 PJ) The district Heating companies (1,9 PJ), The natural Gas companies (1,1 PJ), and oil companies (0,2 PJ). (Gram-Hanssen and Christensen, 2011)

The energy authorities require documentation showing that the utilities have reached the targets, but they are free to choose their methods for securing energy savings. This is a market based instruments, where the government set the targets, but private companies are responsible for reaching the goals. It is assumed that a market based instrument will promote the most cost-effective ways of achieving the energy targets. (Gram-Hanssen and Christensen, 2011)

Especially, the district heating companies have had the households as target groups (Togeby et all, 2008). The activities towards renovation of the existing buildings have been scarce, as the focus is implementing more efficient heat supply e.g. district heating in stead of electrical heating. (Gram-Hanssen and Christensen, 2011)

Even though there are a large potential for energy savings in the existing housing stock this is not utilised so far. This might be due to the detailed rules for calculating the energy savings where only energy savings from the first year is counted. Thereby energy renovations of buildings with a longer payback time, is not an attractive area to pursue for the utilities. (Gram-Hanssen and Christensen, 2011) The same is the case for information and energy advices, where it in general is difficult to document a measurable effect in saved kWh.

For users of the buildings, in private households, the focus is more efficient heat technology and less focus on energy renovation of the buildings. General awareness and knowledge among the users of the buildings is not feasible to address by the district heating companies. Thereby it is far from all possible energy efficiency measures that are addressed, and it could be interesting to discuss a change in the rules that opens op for a wider spectrum of initiatives by the utilities.

5.5 Electricity saving trust

The Electricity Saving Trust was created in 1996. It promotes electricity savings in the public sector and households. The trust is primarily based on information activities. Socioeconomic and environmental considerations are taken into account before the activities are carried out. Substituting electric heating with district heating or natural gas has been one of the major tasks. Another area is energy efficiency appliances and more efficient use of appliances (Torgeby et al., 2009).

Purchasing guidelines have been made for the public and private sector for a number of product groups. All municipal and government institutions must purchase energy efficient equipment based on the purchasing guidelines; this was included in a voluntary agreement from 2007 between the Danish Ministry of Transport and Energy, and Local Government Denmark (IEA, 2008).

Evaluations show, that the trust to a high degree meets its goals (Gram-Hanssen and Christensen, 2011). The high taxes for electricity used in households and the public sector create also an incentive for energy savings; and therefore it is difficult to evaluate the impact of the trust. This especially accounts for communication towards households. Some of the areas where the trust has used mass-communication are campaigns for buying A-labelled refrigerators or circulator pumps. It is difficult to estimate how much the sale increased due to the information campaign (Gram-Hanssen and Christensen, 2011).

Related to private users the trusts own estimate is that Danish households would have had 10% higher electricity consumption today if it had not been for the Trust. In March 2010, the trust was replaced by a Centre for Energy Savings. In this centre heat consumption and energy renovation is included in the work (Gram-Hanssen and Christensen, 2011).

5.6 Energy taxes and other economic incentives

The first energy tax was introduced in Denmark in 1977 (Gram-Hanssen and Christensen, 2011). The CO2 taxes have increased gradually in especially the 1990s (IEA, 2008). It is estimated that the energy consumption in Denmark would be more than 10% higher if the energy taxes had not been implemented (Danish Ministry of Economic and Business Affairs, 2008). The taxes differ between sectors and end uses, but households and the public sector pays the highest taxes for electricity. The households in Denmark pay about 7 times more than the commercial sector in energy tax per kWh. (Gram-Hanssen and Christensen, 2011)

Gram-Hanssen and Christensen (2010) calculated that in 2008 a household pay 0,26 Euro per kWh. Roughly distributed in 20% VAT, 35% energy taxes, 20% for distribution of electricity and only 25% for the electricity itself.

Denmark is among those in Europe with the highest energy taxes in pct of GDP, especially for the households. It is also the households that have the highest reduction in energy consumption, due to taxes; the reduction is estimated to be 16% (Økonomi og erhvervsministeriet, 2008). Likewise there are high taxes across all sectors for energy used for heating (Togeby et al., 2009).

With a focus on the users of the buildings and the possibility to reduce their energy consumption, it is calculated that if the energy prise is raised by 1% the energy consumption for households is reduced with 0,31%. (Gram-Hanssen and Christensen, 2011)

A number of economic incentives, besides taxes and the electricity saving trust have been implemented in Denmark. These can be divided into following overall categories:

- Grants for energy saving measures for pensioners' dwellings (1993 – 2003)
- Grants for connection of old houses to district CHP systems. (1993 – 2002)
- Subsidiaries for renovation and building projects in private housing (2009)
- Scrap arrangements for oil-fired burners, that are substituted with heat pumps (2010)

(Gram-Hanssen and Christensen, 2011)

The evaluation of economic incentives shows that they lead to a reduction of the energy consumptions in private households. The more recent incentives are not evaluated yet. (Gram-Hanssen and Christensen, 2011)

Lately dynamic prices for electricity have been discussed as a way to reduce the electricity consumption in peak hours. It can also be used as a mean to integrate more wind energy, if the consumption becomes more flexible, and the electricity is consumes when it is cheap, namely when the wind is blowing.

5.7 Other informative incentives

A number of incentives, besides the ones introduced above have been implemented in Denmark especially within the last decade. These can be divided into following overall categories:

- Economic subsidies for NGOs and grassroot organisations used for communication towards house owners on energy renovation, ethnic minorities on energy savings and the same for school children has been a part of these projects.
- Promotion of energy savings in buildings by different stakeholders e.g. banks, NGO´s and local craftsmen.
- Feedback to households on their energy consumption e.g. development in electricity consumption or green accounts matching the households own usage with the average of the neighbourhood.
- Demonstration projects on energy renovations.

(Inspired by Gram-Hanssen and Christensen, 2011)

How these initiatives effects the users of energy in the private households is difficult to measure in direct energy savings, as the linkage between the information, the feed-back and demonstration projects and then the energy changes in private households are complicated to track. None the less, measured by the number of participants, brochures handed out or similar targets, a lot of the incentives have been a success (Gram-Hanssen and Christensen, 2011).

5.8 Challenges in getting the users to implement energy efficiency

Energy efficiency is advocated as a way to reduce energy consumptions (IPCC,2007), the energy use in the building sector stands for approximately 35% of total energy use in the EU (UNEP & CEU, 2007). There are a lot of cost-effective investments and the savings potential of these are estimated to at least 20% by 2020 (COM, 2006B). Behavioural measures are also important in order to implement a more efficient use of energy (COM, 2006A). What are the challenges in getting these measures implemented?

The figure below illustrates how different policy instruments can be applied in order to affect users of buildings to implement energy efficiency:

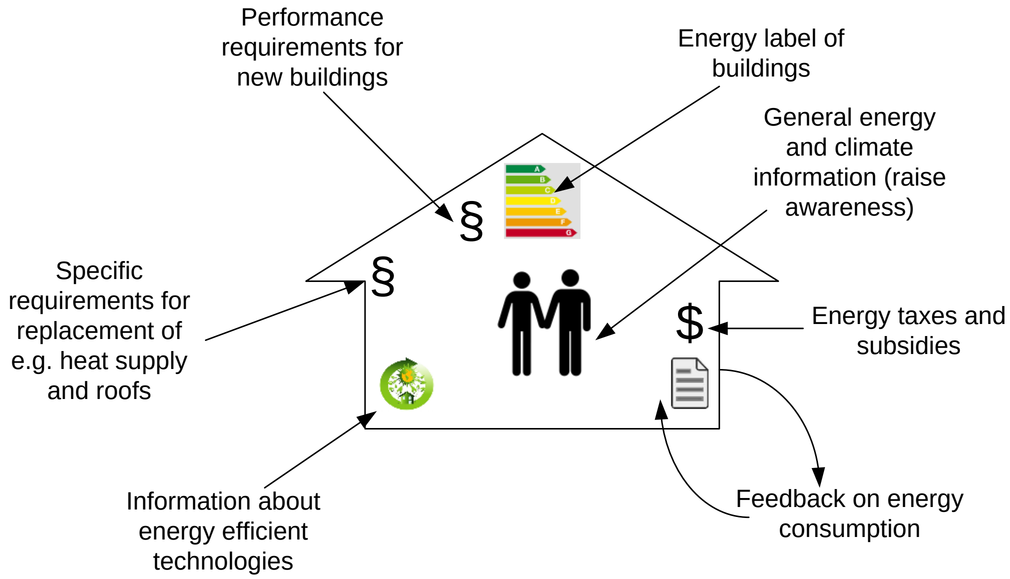

Figure 5.2. Policy instruments for reducing the energy consumption from users in housing

Some of the challenges in order for the users to reduce their energy consumption in buildings are:

- The users are not aware of the life cycle costing related to specific technologies, and therefore they do not want to invest in long term savings.
- The craftsmen that install new equipment in buildings are not the one paying the electricity bill, and therefore have limited incentive for installing energy efficient technologies. Especially because their expertise is often within old equipment, e.g. oiled-burners instead of heat pumps.
- The users are not energy experts, and energy labels and suggestions for energy improvements can be difficult to comprehend.
- When building new houses, the architect/entrepreneur and the end user is not the same person and mainly the end user have an incentive for energy efficient technologies.

The building code and the other policy instruments have been implemented to improve the energy efficiency in buildings. Evaluations of the effectiveness of these policy instruments often focus on effectiveness and not the potential for facilitating innovations. Some studies, which have focused on the innovation aspect, concludes that existing policies have had limited effects on innovation, as they mainly results in diffusion of existing technology or incremental innovations in existing products (Kemp 1997; Beerepoot 2007). How can policy instruments be designed in order to facilitate innovation?

As another approach to energy efficiency of household appliances are the "EcoDesign Requirements for Energy Using Products (EuP) Directive". This directive sets EcoDesign requirements for any group of products which use energy. Thereby only products with a certain standard for energy efficiency can be sold in Europe. (European Parliament and Council, 2010)

5.9 Interaction with the other themes

Indoor Climate: How to secure that the incentives for energy efficiency does not make the users implement technical solutions or habits with a negative effect on the indoor climate?

Life Cycle considerations: Assessments of the life cycle impact of technical solutions and new habits.

Technological solutions: How can we design recommendations for new technologies that take into account existing technologies in the local area; e.g. decentralised heat and power production and surplus of district heating in some areas versus heat pumps or oil combustion?

User driven innovation: How to secure that the policies lead to actual energy efficiency in buildings.

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6. Energy Consumption, HVAC System, and Occupant Behaviour

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6.1 Introduction

From the literature on the influence of occupant behaviour in relation to energy consumption and HVAC systems in domestic buildings a number of characteristic publications are chosen to represent the span as well as the main ideas of the available literature. Overall, the papers are divided into two main categories, namely "engineering models" and "integrated models".

Engineering Models (quantitative models)

- Sensitivity Analysis and Uncertainty Analysis; Building Simulation/Stochastic Modelling (Brohus et al., 2010)
- Safety Factor (Brohus et al., 2009)
- Artificial Neural Network (Mihalakakou et al., 2002)
- Decision Tree (Thun et al., 2010)
- Review of Modelling Techniques (Swan & Ugursal, 2009)

Integrated Models (qualitative and quantitative models)

- Habitual- and Purchase-related Behaviour (Barr et la., 2005)
- Consumption Model; Attitude Model (Lutzenhiser, 1992)
- Behavioural Model (Raaij & Verhallen, 1983a)
- Patterns and Clustering (Raaij & Verhallen, 1983b)
- Integrated Framework (Hitchcock, 1993)
- Total Energy Consumption, incl. embedded (Weber & Perrels, 2000)

The engineering models comprise quantitative models based on mathematical expression of physical laws like mass conservation and energy conservation (i.e. First law of thermodynamics) including means to describe the influence of occupant behaviour directly and indirectly.

The so-called integrated models are models combining the social and the technical perspectives of energy consumption related to occupant behaviour, typically, with a starting point in the social perspective comprising sociology, anthropologi, and psychology.

In the following the selected papers are briefly outlined for each category, respectively, and, finally, a general discussion is included trying to raise a number of questions relevant to further research.

6.2 Engineering Models (quantitative models)

The category of engineering models comprises a high number of specific models and techniques. All models include aspects of mass and energy conservation in shape of very different tools and techniques to determine the energy consumption including the influence of occupant behaviour. The chosen papers present, thus, only a fraction of the many different available methods and techniques.

Brohus et al. (2010) undertakes a theoretical and experimental study of a number of almost similar Danish domestic buildings to investigate the influence of occupant behaviour on the energy consumption, see Figure 6.1 and Figure 6.2.

Figure 6.1. Example of red-bricked semi-detached domestic buildings applied for the sensitivity and uncertainty analyses (Brohus et al., 2010).

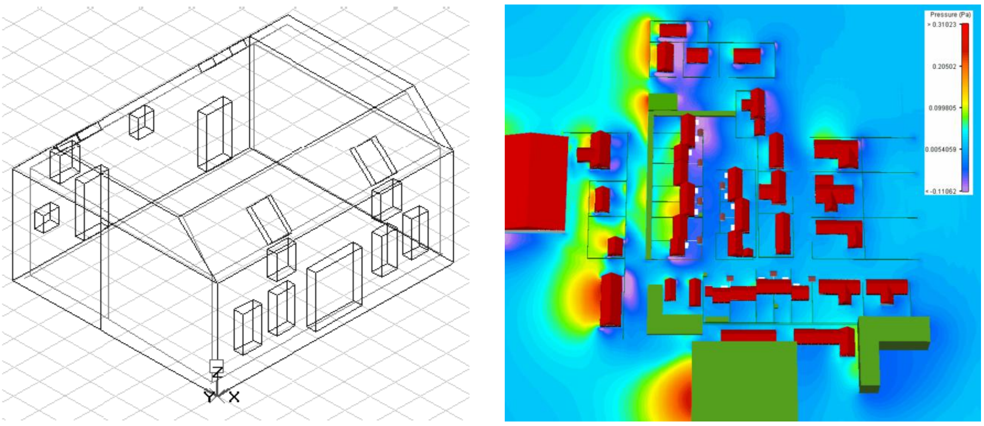

Figure 6.2. Thermal building simulation model of building (left) and Computational Fluid Dynamics model of pressure distribution around the building site (right) (Brohus et al., 2010).

Based on a variety of measurements and engineering models a sensitivity analysis is applied to identify the most sensitive and important parameters as to occupants' influence on the energy consumption. Using stochastic modelling in terms of Monte Carlo analysis an uncertainty analysis is performed quantifying the uncertainty related to the occupant behaviour, see Figure 6.3.

The engineering model comprises thermal building simulation supplemented with input from multizone modelling and Computational Fluid Dynamics. The occupant behaviour is considered via the input distributions applied in the thermal building simulation model. Overall, it is a rather detailed model being quite expensive in terms of input requirements and man power, however, providing detailed output and strong explanatory power.

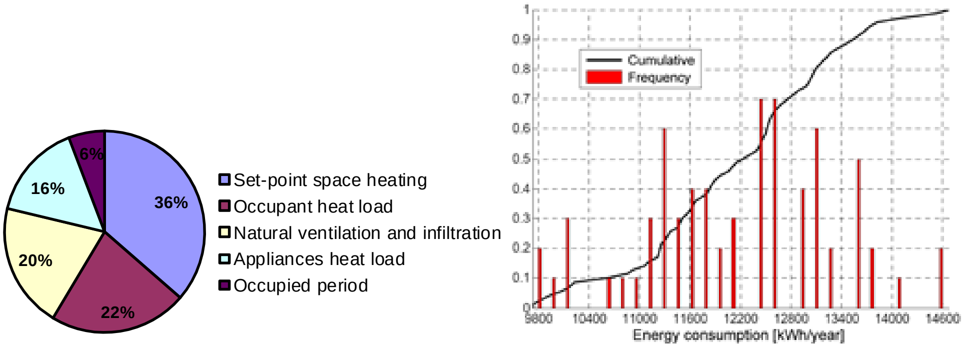

Figure 6.3. Quantitative sensitivity analysis (left) and uncertainty analysis (right) (Brohus et al., 2010).

Brohus et al. (2009) suggest a simplified way to include the influence of occupant behaviour on the building energy consumption using a so-called safety factor as part of the design process and the official approval. The safety factor reduces the "available" design energy consumption by multiplying the maximum building code energy consumption by the safety factor. The safety factor is based on a coefficient of variation (considering the uncertainty related to occupant behaviour among others) and an agreed upon probability of failure of exceeding the building code maximum energy consumption, see Figure 6.4.

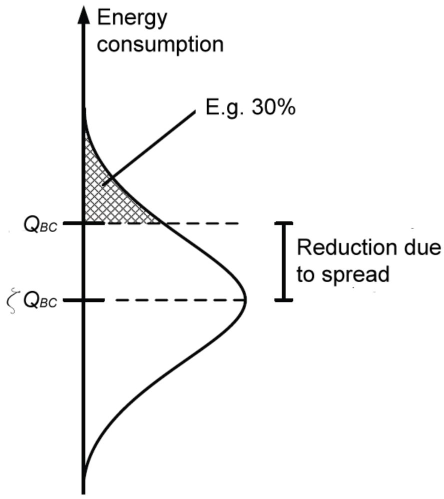

Figure 6.4. Distribution of building energy consumption and application of a safety factor approach (Q_{BC} is building code maximum energy consumption and z is the safety factor; Brohus et al., 2009).

Mihalakakou et al. (2002) present an artificial neural network approach to determine the energy consumption in residential buildings, see Figure 6.5. The hourly values of heating and cooling energy consumption are estimated for several years using a feed forward backpropagating neural network. The influence of the occupants is embedded via the data set applied for the training of the artificial network. An immidiate advantage of this approach is that occupant influence "follows naturally" from the input data set, however, at the expense of limited possibilities of specific analyses as to the influence compared with other factors affecting the energy consumption, i.e. a black box approach.

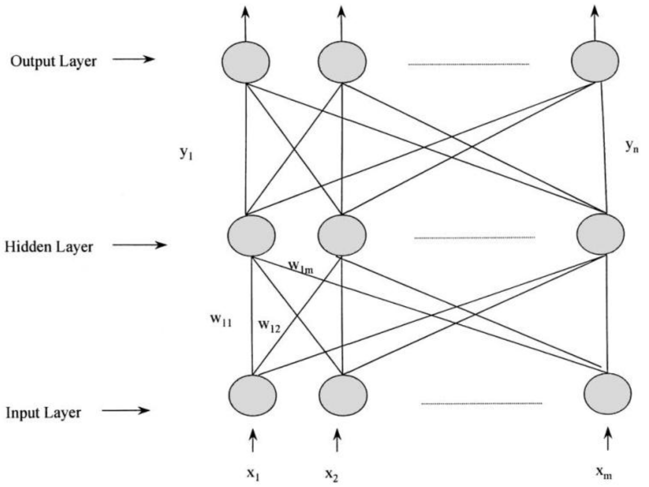

Figure 6.5. Architecture of neural network system applied for the determination of building energy consumption (Mihalakakou et al., 2002).

Zhun et al. (2010) apply a decision tree method to estimate the energy demand. Based on training data and an appropriate decision tree algoritm a decision tree is generated, see Figure 6.6. In that way categorical variables can be classified and predicted, see Figure 6.7. Compared with regression methods and neural network methods the advantage of this approach is the ability to generate predictive models with flowchart tree structures. The model may generate information on significant factors and on threshold values the will lead to high building energy performance including occupants' influence.

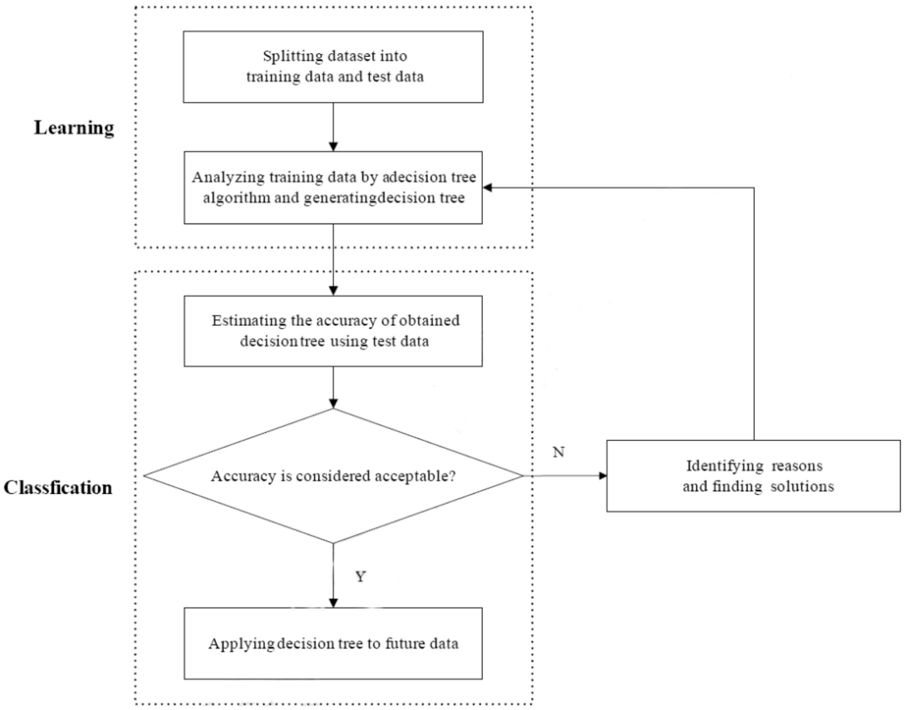

Figure 6.6. Procedure of generation of a decision tree (Zhun et al., 2010).

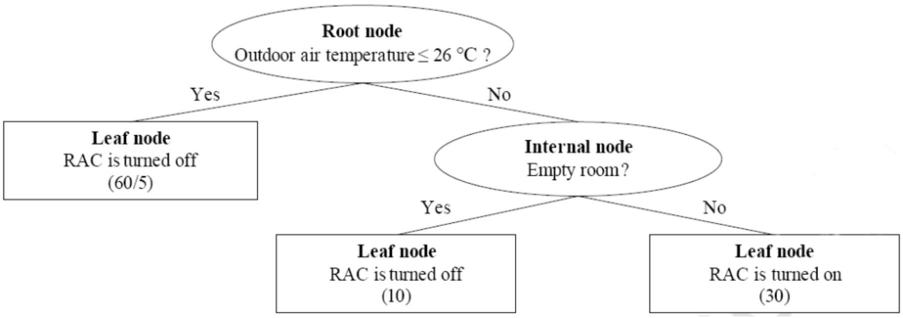

Figure 6.7. Illustration of a simple hypothetical decision tree (RAC is room air conditioners; Zhun et al., 2010).

Swan and Ugursal (2009) perform a review of techniques for modeling end-use energy consumtion in the residential sector. Two distinct approaches are identified termed top-down and bottom-up, respectively, see Figure 6.8. The top-down approach treats the residential energy sector as a collective “energy-sink” disregarding individual energy users. Historic aggregate energy consumption data of the housing stock is analysed as a function of macroeconomic indicators (like gross domestic product, unemployment, and inflation), energy price, and general climate. The bottom-up approach extrapolates estimated energy consumption of a representative set of individual buildings to national level. The bottom-up approach comprises two different methodologies, namely the statistical method and the engineering method. The statistical method includes regression, conditional demand analysis and neural networks (like Mihalakakou et al., 2002 and Zhun et al. 2010). The engineering method includes application of distributions, archetypes, and samples (like Brohus et al., 2010). The pros and cons of the methods are outlined in Figure 6.9.

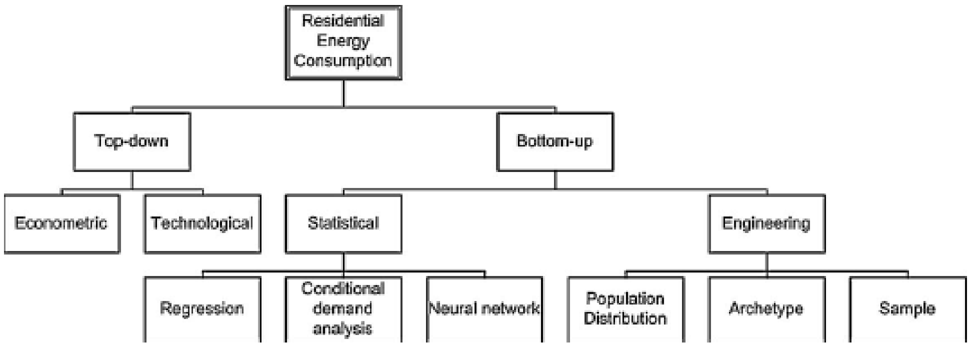

Figure 6.8. Top-down and bottom-up modelling techniques for estimating large-scale residential energy consumption (Swan and Ugursal, 2010).

	Top-down	Bottom-up statistical	Bottom-up engineering
Positive attributes	• Long term forecasting in the absence of any discontinuity	• Encompasses occupant behaviour	• Model new technologies
	• Inclusion of macroeconomic and socioeconomic effects	• Determination of typical end-use energy contribution	• “Ground-up” energy estimation
	• Simple input information	• Inclusion of macroeconomic and socioeconomic effects	• Determination of each end-use energy consumption by type, rating, etc.
	• Encompasses trends	• Uses billing data and simple survey information	• Determination of end-use qualities based on simulation
Negative attributes	• Reliance on historical consumption information	• Multicollinearity	• Assumption of occupant behaviour and unspecified end-uses
	• No explicit representation of end-uses	• Reliance on historical consumption information	• Detailed input information
	• Coarse analysis	• Large survey sample to exploit variety	• Computationally intensive • No economic factors

Figure 6.9. Positive and negative attributes of the two (three) major residential energy modelling approaches (Swan and Ugursal, 2010).

6.3 Integrated Models (qualitatively and quantitatively models)

In general the category of integrated models takes a starting point in the social perspective usually including aspects of sociology, anthropologi, and psychology. As part of the integrated models the technical issues – i.e the engineering perspective - are considered in various ways as appropriate.

Barr et al. (2005) examine the energy saving behaviour in the home related to habitual-related and purchase-related conservation behaviour. Additionally, the association between energy saving behaviours and other environmental actions is considered. The findings are used to investigate the characteristics of energy savers as related to other environmental actions using cluster analysis.

Among the findings a range of energy saver personality and perceptual caracteristics are identified:

- Personal comfort
- Concern for environmental and energy-related issues
- Price concern
- Personal responsibility to save energy
- Normative influences on behaviour
- Self-presentation

Figure 6.10 presents a framework of environmental behaviour.

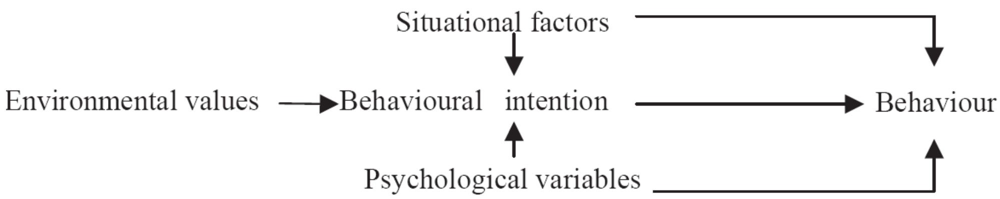

Figure 6.10. Conceptual framework of environmental behaviour (Barr et al., 2005).

The energy saving behaviour is structured as a high number of variables aggregated in three distinct factors: purchase decision, habits, and reycling. Based on a thorough analysis the energy saver is identified in four clusters termed: committed environmentalist, mainstream environmentalist, occasional environmentalist, and non-environmentalists, see Figure 6.11. Social value factors may be outlined under the headlines: altruistic, openness to change, conservative, and egoism. Similarly, environmental value factors may be outlined under the three factors: faith in growth (anthropocentism), spaceship Earth (biospherism), and Ecocentism-technocentrism.

It is concluded that consideration of specific behavioural types should assist policy makers in forming energy reducing policies making sure that the embedded behavioural contexts of action are properly recognised.

Lutzenhiser (1992) investigates the prospects for a cultural model of household energy consumption. The cultural analysis focuses on the group in stead of the individual. Taking a starting point in existing models that focus mainly on physical, economic, psychological and social factors the cultural perspective is discussed including its ecological foundations. Figure 6.12 outlines the disciplinary specialities involved. As an example of a psychological model of occupant behaviour related to energy consumption (as well as other behavioural conducts) Figure 6.13 is included.

The cultural model views humans and their energy use as inherently and naturally implicated in evolving and adapting cultures that are increasingly shaped by the standardizing Western industrial influences.

Variable	Sample	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Test statistic and significance
Cluster label		Committed environmentalists	Mainstream environmentalists	Occasional environmentalists	Non-environmentalists	
No. in cluster		294	412	505	43	
Age (mean)	49	55	52	46	43	Kruskall–Wallis $H = 596$ ($p<005$)
Gender	Male 35%	Male 35%	Male 31%	Male 38%	Male 50%	Chi-square = 88 ($p<005$)
	Female 65%	Female 65%	Female 69%	Female 62%	Female 50%	
No. in home (all residents)	1 16%	1 17%	1 21%	1 13%	1 11%	Chi-square- = 259 ($p<005$)
	2 37%	2 40%	2 40%	2 34%	2 29%	
	3 18%	3 18%	3 15%	3 21%	3 26%	
	4 19%	4 17%	4 15%	4 22%	4 17%	
	5+ 3%	5+ 8%	5+ 9%	5+ 10%	5+ 17%	
Car access (number)	0 20%	0 19%	0 24%	0 17%	0 27%	Chi-square = 151 ($p>005$)
	1 51%	1 51%	1 52%	1 52%	1 37%	
	2 24%	2 25%	2 20%	2 26%	2 32%	
	3+ 5%	3+ 5%	3+ 4%	3+ 5%	3+ 4%	
Tenancy	Owned 74%	Owned 83%	Owned 74%	Owned 71%	Owned 62%	Chi-square = 233 ($p<005$)
	Private tenant 11%	Private tenant 5%	Private tenant 11%	Private tenant 13%	Private tenant 19%	
	LA 15%	LA 12%	LA 15%	LA 16%	LA 19%	
House type	Detached 9%	Detached 4%	Det 12%	Det 10%	Det 10%	Chi-square = 634 ($p<005$)
	S-Detached 24%	S-Detached 16%	S-Det 34%	S-Det 24%	S-Det 26%	
	Terrace w pass 9%	Terrace w pass 8%	Terr/p 7%	Terr/p 10%	Terr/p 14%	
	Terrace 36%	Terrace 43%	Terr 28%	Terr 38%	Terr 36%	
	Flat 22%	Flat 29%	Flat 19%	Flat 20%	Flat 14%	
Income (Pounds)	<7.5 k 20%	<7.5 k 20%	<7.5k 23%	<7.5k 15%	<7.5 k 35%	Chi-square = 299 ($p<005$)
	7.5–10k 9%	7.5–10k 20%	7.5–10k 10%	7.5–10k 8%	7.5–10k 6%	
	10–15k 17%	10–15k 11%	10–15k 20%	10–15k 15%	10–15k 9%	
	15–20k 19%	15–20k 15%	15–20k 18%	15–20k 22%	15–20k 12%	
	20–30k 21%	20–30k 19%	20–30k 20%	20–30k 23%	20–30k 21%	
	>30k 14%	>30k 15%	>30k 9%	>30k 17%	>30k 18%	
Education (formal)	None 38%	None 51%	None 41%	None 35%	None 53%	Chi-square = 216 ($p<005$)
	GCSE 27%	GCSE 20%	GCSE 30%	GCSE 29%	GCSE 19%	
	'A' level 17%	'A' level 18%	'A' level 15%	'A' level 18%	'A' level 16%	
	Degree 17%	Degree 21% Adds up to 110%	Degree 14%	Degree 18%	Degree 12%	

Figure 6.11. Demographic characteristics of behavioural clusters (Barr et al., 2005).

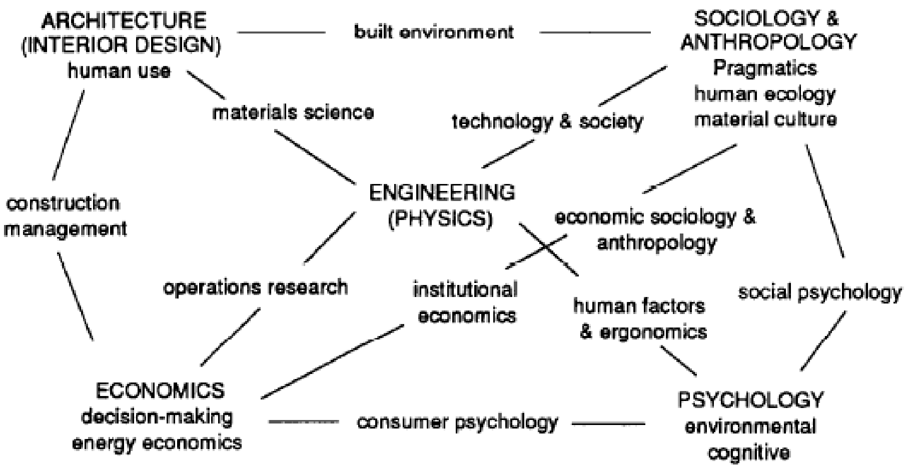

Figure 6.12. Models of consumption – concepts relevant to study of human/environment and human/technology relations (Lutzenhiser, 1992).

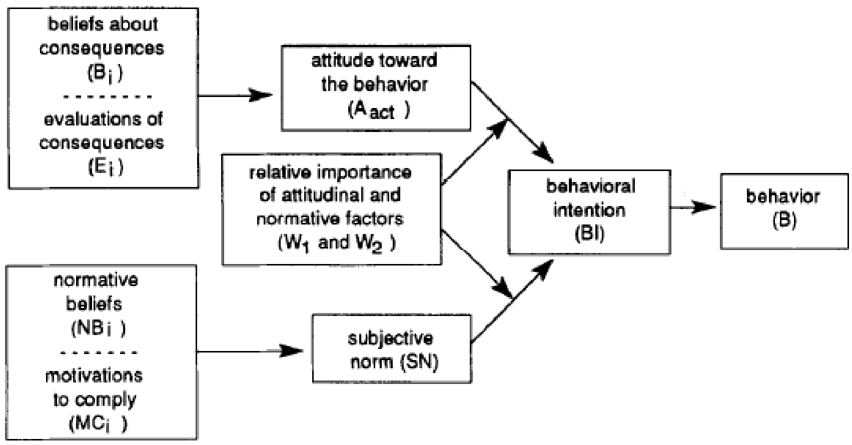

Figure 6.13. Models of consumption – a psychological attitudes model of energy consumption (Lutzenhiser, 1992).

Raaij and Verhallen (1983a) propose a comprehensive model of residential energy use that relates personal, environmental (e.g. building and climate) and behavioural factors, see Figure 6.14.

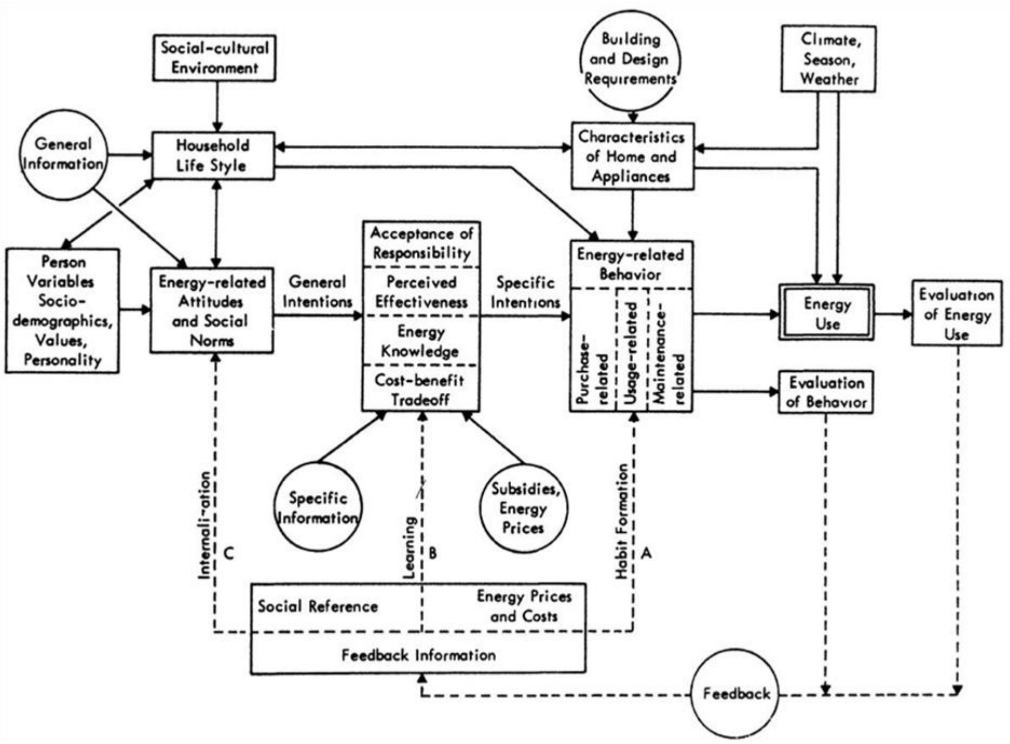

Figure 6.14. Behavioural model of residential energy use (Raaij and Verhallen, 1983a).

The factors influencing residential energy use are divided in three types of energy-related behaviour:

- Purchase-related
- Usage-related
- Maintenance-related

Purchase-related behaviour considers purchase of household appliances, heating and cooling equipment including ventilators. Usage-related behaviour comprises day-to-day usage of appliances and the building itself. Maintenance-related behaviour refers to appliances and HVAC-system servicing and small repairs as well as small home improvements.

An extensive list of specific and important factors is presented and discussed:

- Lifestyle
- Characteristics of home and appliances
- Socio-demographic factors
- Energy-related attitudes
- Responsibility, effectiveness, and knowledge
- Cost-benefit trade-off
- Energy prices
- Feedback information
- Social reference and community approach

Raaij and Verhallen (1983b) investigate specific patterns of residential energy behaviour. Two aspects of energy contingency are considered, namely home temperature and ventilation. Five clusters of predefined behavioural patterns are identified (so-called Conservers, Spenders, Cool, Warm, and Average), see Figure 6.15. For instance, Spenders use more energy than the Average group whereas Conservers use less energy.

It is concluded that consideration of behavioural patterns are important for energy policy making due to the fact that different strategies for changing and maintaining the energy-related behviour must be applied.

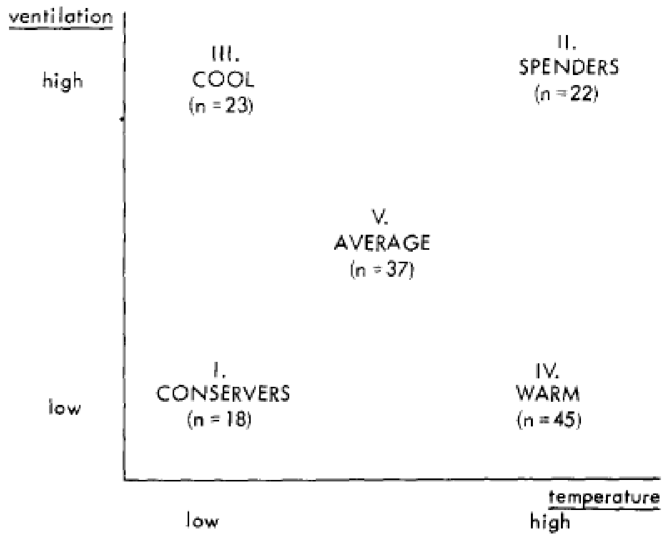

Figure 6.15. Five behavioural patterns (clusters) based on temperature and ventilation (Raaij and Verhallen, 1983b).

Hitchcock (1993) presents an integrated framework for energy use and behaviour in the domestic sector. It is stated that energy consumption patterns are a complex technical and social phenomenon that must be viewed from both engineering and social perspectives to be fully understood. An integrated view is suggested in shape of a descriptive framework based on systems theory, Figure 6.16.

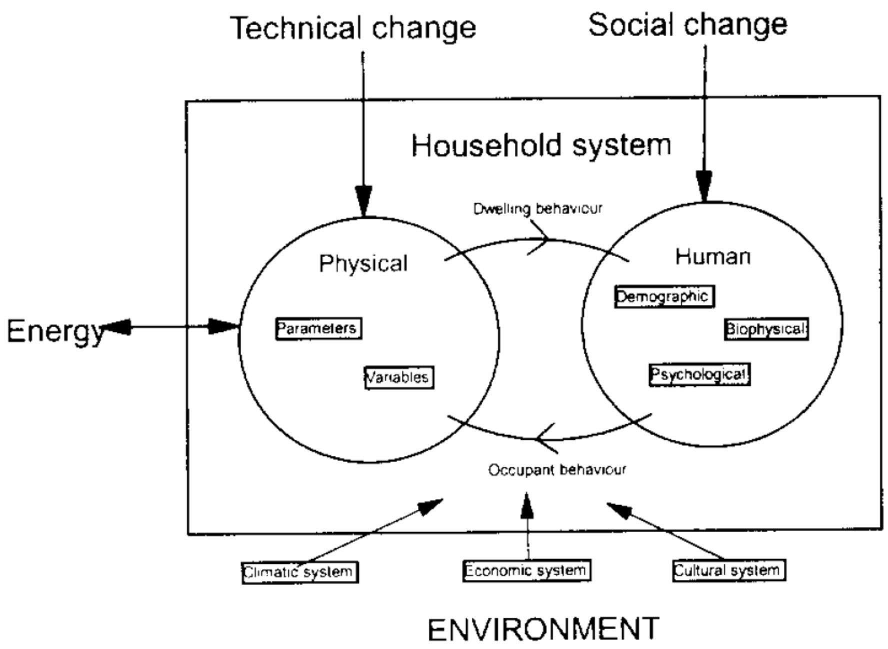

Figure 6.16. Expanded household system including engineering perspective and social perspective (Hitchcock, 1993).

The framework – or model – suggests the main components of the technical and social perspectives, respectively, as well as the important interaction between the perspectives. For most other models "occupant behaviour" expresses the two-way interaction between the physical and human spheres, whereas this paper defines "occupant behvaiour" as the one-way link from the human system to the physical system and the so-called "dwelling behvaiour" as the opposite one-way link from the physical system to the human system, see Figure 6.16..

The social perspective comprises the human system together with the two environmental factors: economic system and cultural system. The engineering perspective comprises the physical system together with the climate system as an environmental factor.

Weber and Perrels (2000) propose a comprehensive approach to analyse and quantify the lifestyle impact on current and future energy demand. Compared with previous approaches this one is more extensive, including also for instance car use, and it considers environmental damage through the production of the consumed goods. The overall model comprises societal hyperstructure, manifest lifestyle, energy use, and environmental impacts, see Figure 6.17. A general structure of lifestyle-oriented energy and emission models is presented, see Figure 6.18.

Four descriptive scenarios are applied for examplification and quantification: "Stagnation", "Business as Usual", "Sustainability through Technological Breakthrough", and "Sustainable through Reflective Consumption".

Again, it is concluded that "consumer orientation" is important and usefull for efficient policy making applied for instance in the context of information campaigns.

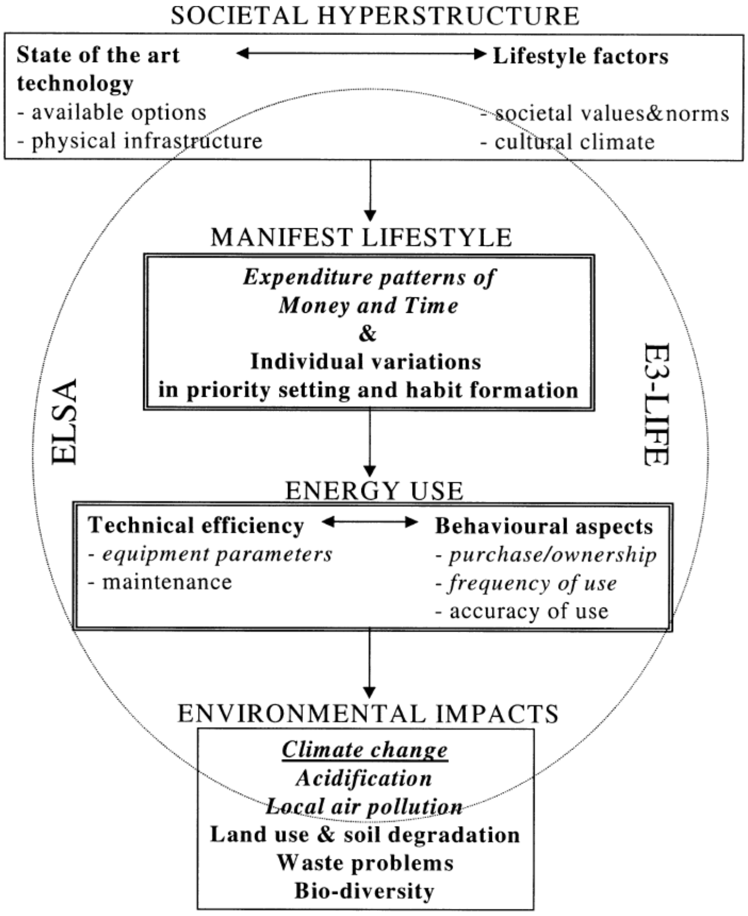

Figure 6.17. Embedded long-term lifestyle approach and coverage in energy demand and emission related models (Weber and Perrels, 2000).

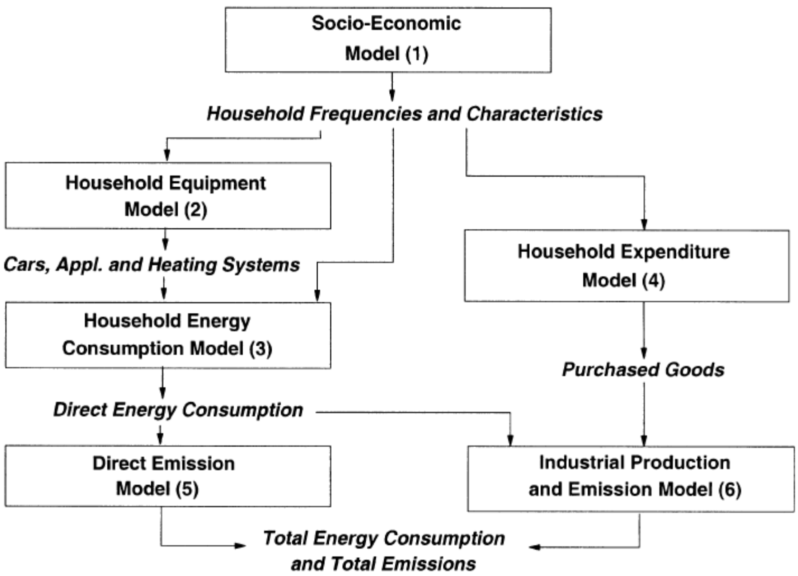

Figure 6.18. General structure of lifestyle-oriented energy and emission models (Weber and Perrels, 2000).

6.4 General Discussion

Based on the review a number of research issues arise as well as questions related to the interface between the social and technical perspectives. A rough working list – not-ranked and non-exhaustive – of topics and questions is included:

1. Can energy-related occupant behaviour be isolated from other kinds of behaviour?
2. Integrated models: the human and the physical aspect ("Buildings do not use energy"; humans influence the use of systems and appliances, etc.)
3. Combination of engineering and social perspectives (occupant behaviour + dwelling behaviour)
4. What factors can be modified? Is it possible to model? Qualitatively and/or quantitatively?
5. What factors/tools should be considered? Can sensitivity analysis be applied (sensitive vs. important factors – are the importance of factors common across models and sciences)?
6. Are the occupants to be considered as opponents or fellow players? Should both perspectives be considered and modelled?
7. Occupant response to change of physical systems
8. Views on indoor climate? Bio physical (mechanistic) model and/or... How do we consider several views at the same time?
9. What level of detail is appropriate? How to combine models (frameworks) on different levels of detail? One challenge is the single occupant/household (vs. aggregated population focus); micro- vs. macro level (technically as socially)
10. Combination and connection between component-, engineering- and policy-levels
11. Data-driven (e.g Artificial Neural Network) vs. Model-driven (fx Building simulations)
12. Should economy be included (econometry)? Homo economicus vs. real person...
13. Aggregated and disaggregated models
14. Suggestion of hypothesis partly verified based on current knowledge and literature to be verified/falsified later on (new projects, etc.)
15. Models heavy in terms of data and analysis (requiring additional non-existing data) vs. more "theoretical" models (accessible by current knowledge and data)

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7. Modeling User Behaviour in Whole Building Simulation

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7.1 Introduction

This document represents a summation of the information gathered during a state-of-the-art review (SOTAR) on the subject of "modeling user behaviour in whole building simulation". In the SOTAR, focus has been on mapping existing research in two primary fields concerning the modeling of user influence on building energy use and indoor environment;

1. Occupant presence
2. Occupant influence on energy use/indoor environment.

Occupant presence is an (obvious) precondition for occupant influence on energy use/indoor environment, and the two can be simulated separately, i.e. a model first determines if an occupant is present and, if so, a series of models simulate the occupants influence on the building. Figure 7.1 shows how the occupant influences the building energy use and indoor climate in both direct and indirect ways.

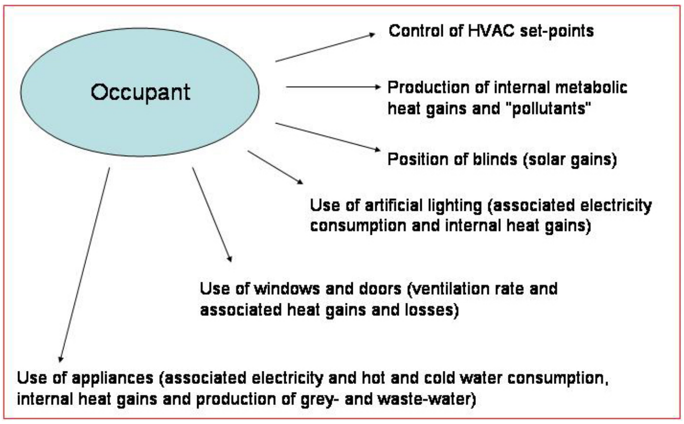


Figure 7.1. Occupant impact on building energy use and indoor climate, Page [1].

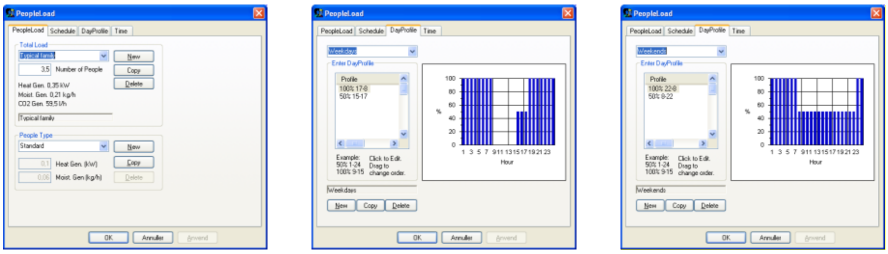
In 2007 Page [1] did a detailed state-of-the-art review on occupant presence and occupant influence on energy use/indoor environment. Therefore, the present work will be based on his work. His model(s) represents more or less the state-of-the-art concerning occupant presence and behaviour, and therefore his model(s) are presented in more detail.

7.2 Background

Building energy use is strongly dependent on systems operation and general behaviour of occupants. The occupant influences the building energy use and the indoor environment by presence and actions in the building, but also through interaction with the controls of inherent building systems designed for adjusting indoor environment variables.

During the last decades focus has dramatically increased on reducing building energy use (CO_2 emissions), which have resulted in a demand for sustainable and thereby more passive buildings. This will inevitably increase the influence of the occupant presence and interaction on energy use and therefore detailed modeling of these processes are necessary in order to predict energy consumption, indoor climate and in particular peak loads of heating, ventilation and air conditioning (HVAC) for system and whole-grid dimensioning.

The most common way in which building simulation tools consider occupant presence and interaction with buildings is through so-called diversity-profiles. Diversity-profiles are used in order to estimate primarily internal heat gains from people, household appliances and lighting, but also moisture loads and definitions of loads on heating, ventilation and air conditioning systems (HVAC). The profiles will depend on the type of building being analyzed, i.e. typically distinguishing between residential and commercial buildings, but with possibilities of refinement within each of these main groups. For a residential building, a typical diversity-profile will include information on how many occupants the household has, which type of occupants they are and when and to which extent these occupants are present in the building. Figure 7.2 shows an example on how this is handled in BSim [2].



a) b) c)

Figure 7.2. Typical definition of occupants in building simulation software.

Figure 7.2a shows that the household has 3.5 occupants of type 'standard'. This results in a total internal heat gain of 0.35 kW, a moisture generation of 0.21 kg/h and a CO_2 generation of 59.5 l/h. These data represents the potential heat gains etc. that the occupants can add to the building. The two 'dayprofiles' in Figure 7.2b and c, defines when and how many occupants are present, and theoretically these can be as detailed as necessary, i.e. down to a level where each hour of the year has a separate percentage load.

The use of these types of standard profiles is a very simple and effective way of considering occupant presence, however is has a series of obvious shortcomings especially when considering low energy buildings where optimization of energy use and indoor climate is a key element.

The precision with which building simulation tools can describe the physical behaviour of buildings today, has reached a level where occupant influence has become the primary source for discrepancies between simulated and measured results. There are many examples where low energy buildings perform poorly compared to what was expected from the simulations, often resulting in a higher energy use or a bad indoor climate. The explanations for these problems can typically be traced back to inadequate or erroneous definitions of occupant influence.

The problem with the simplistic definition of occupant influence is that it typically consists of a maximum of 2 profiles (i.e. weekdays and weekends) and that the profiles are to represent the combined behaviour of all occupants. This means that there is no temporal variation in the profile describing seasonal variations or differences between weekdays. Furthermore, it implies a reduction in the variety of patterns of occupancy particular to each person through the use of an averaged behaviour.

Therefore there is a need for developing more precise methods for modeling occupant presence and occupant influence on whole building physical properties.

7.3 Purpose

The purpose of this state-of-the-art review is to establish the basis for developing detailed models for occupant presence and occupant behaviour that can be used in whole building simulation programs. This is necessary in order to be able to obtain reliable results from building simulation tools, especially when working with very low energy buildings where occupant presence and interaction with the building play an extremely important role for the buildings energy performance and indoor climate.

This project focuses on residential buildings. Through the literature study, it has become evident that most previous research on occupant presence has focused on commercial buildings (i.e. in particular office buildings). This is not a coincidence, since occupants typically play a more important role when it comes to office buildings (i.e. indoor climate has been an issue in office buildings for many years, whereas in residential buildings it's a relatively new problem). However, as we move towards nearly zero energy buildings, this problem is becoming more and more relevant in residential buildings as well.

However, there are still a lot of similarities between modeling occupant presence and influence in commercial buildings and in residential buildings, and hopefully it should be fairly easy to convert any existing models from one to the other.

7.4 Review – Models for predicting occupant presence

As mentioned in the introduction, this SOTAR will use Page [1] as a starting point for the review. A brief review of Page's 'state of the art' is given in order to give a historic overview of the development in the field.

The modeling of occupant presence was initiated by researchers developing lighting models, as this could be directly linked to electricity use. From an early point it was obvious that detailed modeling and thereby optimization could mean huge savings. As early as 1980, Hunt [3] points out the importance of occupant interaction with lighting appliances and thereby occupant presence.

In 1995 Newsham et al. [4] presents the first simple stochastic model for occupant presence in connection with the so-called Lightswitch model. The purpose of the Lightswitch model was to create more realistic times of arrival and departure of occupants to and from their offices. The basic principle of this model is a combination of a traditional day-profile, as the one shown in figure 2, and a stochastic variable randomly scheduling arrivals and departures from offices within a ±15 minute interval around their official starting time, i.e. people could arrive from 7.45 – 8.15 in the morning. This added more realism to the model and helped to avoid the unrealistic peaks that would occur if everybody arrive and leave at the exact same time. However, the major part of the profile is still fixed, i.e. a presence of 100% during most of the day and 0% during evening/night, and furthermore, the profile is repeated through all weekdays and it is assumed that the zone is unoccupied during weekends. In addition this model does not account for people being absent during holidays, business trips, leaves due to sickness etc. These shortcomings lead to an overestimation of the total yearly presence and thereby the associated energy consumption.

A truly stochastic model was proposed by Wang et al [5] in 2005. They proposed a non-homogeneous Poisson process model (a stochastic process in which events occur continuously and independently of one another) with two different exponential distributions to simulate the occupancy sequence in a single person office, i.e. one for occupancy and one for vacancy. The work clearly indicates that periods of intermediate absence can be described using an exponential distribution, however presence did not follow the same pattern. First arrival and last departure to and from the office was modeled using a normal (Gaussian) distribution. This model represents a clear move away from the fixed profiles of presence. Their work clearly shows that periods of presence cannot be reproduced by an exponential distribution with a homogenous coefficient, and times of arrival, departure and intermediate absences, i.e. during lunch breaks, are not normally distributed. In addition to these shortcomings, the model supposes that all weekdays are alike and that offices are unoccupied during weekends. As for the model proposed by Newsham et al. [4], periods of long absence are also neglected, resulting in an overestimation of presence and energy consumption.

The latest model of occupant presence (according to Page's review in 2007) was proposed by Yamaguchi et al. [6]. This model was similar to Wang's, however it replaces the sequence of Poisson processes by a mathematically equivalent Markov chain. Markov chains are much better suited for computational purposes than Poisson processes, and therefore they are a natural choice for whole building simulation software as optimization of computational time is important. The model amalgamates the information concerning occupant presence and appliance use, as it defines 4 possible types of state for each individual; 1) absent, 2) present but not using a computer, 3) present and using one computer and 4) present and using two computers. This means that the model can not be used directly for occupant presence. Furthermore, the model apparently does not consider periods of long absence and it is unclear whether the model is used to simulate one day which is then repeated for a year or whether is it used to simulate an entire year. In addition, the paper does not mention how weekends are handled.

From the research presented by Page, it is clear that generating a model of occupant presence that can be used as an input for any model of occupant behaviour of any type of building is the best way forward. By doing so, the sub-models of occupant behaviour can be developed and refined individually simply using the occupant presence model as an input parameter.

This approach was adopted by Bourgeois [7] in developing a Sub-Hourly Occupancy Control (SHOCC) model. SHOCC is a “self-contained simulation module that targets all occupancy-related phenomena in whole-building energy simulation". SHOCC works independently and handles all information related to the presence and behaviour of the occupants. This means that the output from the module can be used directly in whole-building simulation tools (ESP-r was used for the development of SHOCC). The model of occupant presence used in the module is the one used in Lightswitch-2002 [8], and the models concerned with occupant behaviour encompasses manual and automated control of lighting and blinds along with a simplified model simulating the use of a laptop computer. The input needed for SHOCC is collected in a database containing all the information related to the occupants and the objects they use. Bourgeois claims that any model of occupant presence and behaviour can in principle be used within SHOCC, and that SHOCC can communicate with almost any building simulation tool; its main asset is to provide a platform linking the former to the latter.

Page [1] proposes a model for simulating occupant presence that builds on the experiences gathered from his predecessors in the field. This means that he makes a clear distinction between models of occupant presence and occupant behaviour and influence on the building's consumption of resources, se Figure 7.3.

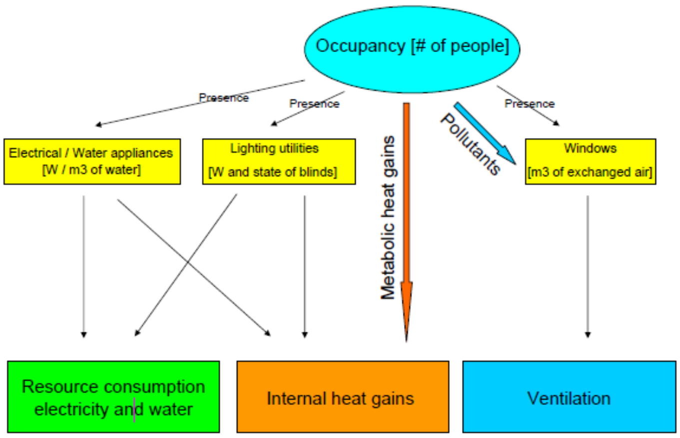


Figure 7.3. Outputs of the occupancy model and their direct and indirect impact on a building's consumption of resources, Page [1].

The purpose of his model was to develop a time-series of "zeros" (absence) and "ones" (presence) rendering arrivals and departures to and from the zone (i.e. for residential buildings corresponding to "going to work" and "arriving home from work"), as well as alternating short periods of presence and absence in between. The model is based on the inverse function method (IFM) and can be categorized as a Markov chain model. This method is used to generate a sample of realizations of events from a given probability distribution function (PDF). The model assumes that the value of occupancy at the next time step is only dependant on the present state and the probability of transition to either the same state or its opposite state (T_{00} = 0→0, T_{01} = 0→1, T_{11} = 1→1 and T_{10} = 1→0). This means that there are only four probabilities and these are dependant in pairs of two, i.e. $T_{00} + T_{01} = 1$ and $T_{11} + T_{10} = 1$. The model needs input in the form of a profile of probability of presence, and from this can be derived the relationship for the probability that the occupant is present at time step t + 1 (based on the probability of the occupant being present at time step t and the probabilities of transition from state 1 to 1 and 0 to 1, i.e. staying present in the zone or arriving at the zone). However, in order to determine the values of T_{01} and T_{11} for all time steps, it is necessary to have one more input parameter and therefore the author defines the so-called "parameter of mobility" as the ratio of a change of state to that of no change, $\mu(t)$, i.e. how likely is it that the occupant either arrives or departs from the zone. For simplicity, this parameter is considered constant, and it is suggested that values of $\mu(t)$ should be defined for "low", "medium" and "high" mobility, taking into account the length of the time step used in the calculations. Unfortunately, defining $\mu(t)$ as a constant will create problems in the model whenever an almost deterministic change in behaviour occurs, i.e. at regular times of arrival and departure to and from the zone. In these situations the model replaces the calculated μ with a value that fulfils the specified conditions.

The model described above was calibrated with data of occupancy recorded in an office building, and a validation was made by comparing the cumulated presence over a week. This validation clearly indicated a weakness in the model concerning the modeling of long periods of absence (i.e. holidays, leaves due to sickness etc.), and therefore the model was expanded with probabilities of these long periods of absence along with the parameters that determine the distribution of their duration.

7.5 Review – Models for predicting occupant behaviour

Models for predicting occupant behaviour can be split into two groups; those that have an influence on indoor environment and those that have little or no impact on indoor environment. For the last group it is less important to model the exact occurrence of events and therefore these models need only to produce cumulated profiles on e.g. daily or weekly basis – unless of course, more detailed modeling is necessary for i.e. grid optimization. The first group of models however, will need a level of detail that reflects the level of influence they have on the indoor environment, i.e. the use of lighting appliances will need to be modeled quite precisely as the effect on internal heat gains are significant (this is naturally more relevant in office buildings than in dwellings).

7.5.1 Use of appliances

The use of appliances and their influence on the buildings indoor climate, electricity use etc. is very dependant on what type of appliances are installed. Furthermore, some appliances are directly influenced by the occupants (turning on or off) and some are more or less independent of occupants. Page [1] splits appliances into four different categories;

1. Those that have a constant consumption (e.g. fridge) or a fixed profile of use (e.g. hot water boiler) and are independent of occupant presence.
2. Those switched ON by a user and therefore depend on occupant presence but switch OFF independently (e.g. washing machine).
3. Those switched ON and OFF by an occupant (e.g. shower and television).
4. Those that are too small to be modeled individually but can be collectively significant.

He defines the input to the model as;

- Which appliances are present in each zone of the building and how many are there of each type?

- What are the rates of electricity and water (hot/cold) consumption for the appliances?
- For how long will they be used (distribution of use)?
- What is the individual stand-by power for the appliances, and are they left in this state when not in use?
- What is the probability that an occupant will turn ON an appliance at each time step?

Appliances that fall into category 1 and 4 can be considered in a pre-process phase. The sum of the consumption of these appliances serves as an occupant-independent base load (similar to the diversity profiles mentioned earlier). Appliances from category 2 and 3 both rely on occupant presence and must therefore be simulated in the processing phase. The simulation is performed by applying the IFM to the probability of switch ON given by the probability profile for that particular appliance for that particular time step.

The model is validated by comparing to measurements in three offices. At the same time the model results are compared to results obtained by the diversity profiles proposed by Abushakra [9], which at the time were the most up-to-date method in practice. Page concludes that the model is capable of reproducing the random aspects of occupant behaviour towards appliances.

7.5.2 Use of windows (opening)

In the modeling of the use of windows several different approaches have been proposed. One of the key elements in the models is the trigger for opening windows, i.e. indoor temperature, outdoor temperature or a combination of the two.

The use of the outdoor temperature as a stimulus for opening/closing windows is generally preferred (see [10] and [11]), as this temperature is typically directly available and does not need to be calculated first by a building simulation tool. Furthermore, as the outdoor temperature is common to all buildings, it is implied that the occupants of different buildings will react in the same way.

Rijal et al. [12] proposes the use of a combination of in- and outdoor temperature, as opening of a window will mean that the outdoor air temperature will influence the indoor air temperature, i.e. if the indoor temperature is considered to high by occupants they will open a window to lower the temperature only as long as the outdoor temperature is lower than the indoor temperature.

Page [1] proposes a stochastical model for simulating window opening.

7.5.3 Use of lighting and blinds

Modeling of occupants' use of lighting and blinds were one of the first fields in which modeling of occupant behaviour caught interest, as the energy saving potential in optimizing lighting systems were obvious.

There are different strategies that can be applied in order to reduce the energy use for lighting systems and accompanying peak loads, i.e. installing more energy efficient light sources and better control systems, replacing global by individual lighting systems etc. [1]. In 1995 Newsham and Mahdavi developed the first Lightswitch model [4] and Reinhart expanded the model [8]. The primary purpose of this model was to create the possibility to assess different strategies for reducing energy use and peaks loads. The model in itself is stochastic and uses the input of a stochastic occupancy prediction model along with input from a stochastic dynamic daylight simulation model in order to determine the annual electric lighting energy demand.

In 2008 Mahdavi et al. [13 & 14] published the results of an extensive empirical study of control oriented user behaviour related to lighting and shading devices. Their investigations were performed on the occupants in 42 offices in two office buildings over a period of 12 months and occupants in 6 offices in a third building over a period of 9 months. They monitored states and events pertaining to occupancy, systems, indoor environment and external environment, and based on the collected data, they were able to establish a series of correlations between the use of artificial lighting, indoor climate and outdoor climate.

7.5.4 Use of HVAC systems

Occupant use of HVAC systems and the influence on building energy use is a topic that only relatively few have covered in the past. Glicksman and Taub [15] propose a simplified model of the thermal environment created by an occupant-controlled HVAC system and the behaviour of the occupants within it. The behaviour of occupants is controlled by a probabilistic model. They divide the conditioned space into cells and every cell is assumed to fall into one of four categories; 1) unoccupied areas such as corridors, 2) unoccupied work stations with equipment turned off, 3) unoccupied work stations with equipment turned on and finally 4) occupied work stations with equipment turned on. All cells falling into category 1 is known in advance. Two parameters then control a random process that assigns category 2, 3 and 4 for the remaining cells; "occupancy rate" and "equipment leave-on rate", i.e. what is the probability of occupancy and what is the probability of equipment being left on when people leave a cell. For category 1 and 2 cells HVAC control is turned off and the temperature is allowed to rise to a maximum value at the extreme of the comfort range. For category 3 and 4 HVAC control is on keeping them at a specified temperature determined by the occupant. The HVAC control behaviour, i.e. occupant's climate preferences, is modeled using the ASHRAE standard comfort zone [16]. This implies defining a temperature and humidity range which is acceptable to 80% of the occupants, and then using a normal distribution for the individual temperature preferences of the occupants.

7.5.5 Use of hot/cold water

As with use of HVAC systems, occupant use of hot/cold water has not been studied by many in the past. Lutz et al. [17] proposes an expansion of the EPRI (Electric Power Research Institute) model described by Ladd [18]. The original EPRI model assumes that all households have a clothes washer and a dishwasher whereas the proposed expansion of the model adds functions for these. The expanded model also adds coefficients for approximating the effect of "senior only households" and "occupants not paying for hot water". The primary focus of both the EPRI model and the expanded model is on electricity use, i.e. electricity use for heating water, however, the models also present equations for determining the hot water consumption. The generic structure of the expanded model is shown below:

$$Use = [a_0 + a_1 \cdot per + a_2 \cdot age1 + a_3 \cdot age2 + a_4 \cdot age3 + a_5 \cdot therm$$
$$+ a_6 \cdot tank + a_7 \cdot wtmp + a_8 \cdot atmp + a_9 \cdot athome + a_{10} \cdot spring$$
$$+ a_{11} \cdot summer + a_{12} \cdot fall + a_{13} \cdot winter \div no\_cw \div no\_dw]$$
$$\cdot senior \cdot no\_pay$$

The variables included in the equation are:

Use	= hot water consumption, (L/hr);
per	= number of persons in household;
age1	= number preschool children (0-5 yrs);
age2	= number of school age children (6-13 yrs);
age3	= number of adults (14 yrs and over);
therm	= water heater lower thermostat setting, (°C);
tank	= water heater nominal tank size, (L);
wtmp	= water heater inlet water temperature, (°C);
atmp	= outdoor air temperature, (°C);
athome	= presence of adults at home during day;
spring	= dummy variable for Spring (1 if “spring”, zero otherwise);
summer	= dummy variable for Summer (1 if “summer”, zero otherwise);
fall	= dummy variable for Fall (1 if “fall”, zero otherwise);
winter	= dummy variable for Winter (1 if “winter”, zero otherwise);
no_cw**	= a function indicating impact of not owning a clothes washer, (L/hr);
no_dw**	= a function indicating impact of not owning a dishwasher, (L/hr);
senior**	= a coefficient approximating effect of senior only households; and
no_pay**	= a coefficient approximating effect of occupants not paying for hot water.

Coefficients a_0 – a_{13} are determined by empirical investigations, however the data dates back 10-15 years ago, and the authors recognize the need for more updated data for the definition of new coefficients.

7.6 Conclusion

Page [1] draws two important conclusions from his review:

- "White-box models are more flexible than black-box models and will therefore be easier to adapt to changes in occupants’ behaviour and in the objects they use. Their use should therefore be preferred as long as this is possible."
- "The presence of an occupant is a necessary condition for her/his interaction with a building. Occupant presence should be simulated separately and serve as an input to models of occupant behaviour. Developing an excellent model of occupant presence should be our first priority as the quality of its output will limit the quality of the outputs of occupant behaviour models."

He also identifies the need for a set of 5 stochastic models:

- the presence of occupants within a zone,

- their use of appliances in that zone,
- their use of windows of that zone's façade,
- their production of solid waste,
- their use of the lighting system and blinds of the zone.

Based on the present review, it is suggested to also include:

- their use of/interaction with HVAC systems
- their use of hot/cold water

7.6.1 Comments concerning the interdisciplinarity of the research

Research in the field of occupant presence and influence on energy use/-indoor environment is interdisciplinary as it encompasses a wide variety of disciplines ranging from studies of human behavioural patterns to statistics.

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