The Effect of Technological User Control Systems on Occupants of Sustainable Energy Homes

The BASF house, Nottingham, UK

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ABSTRACT: In the UK, money and resources are ploughed into the development of sophisticated technologies, materials and control systems with the aim of improving energy efficiency within the Built Environment. Technical systems often demand that the occupant is educated in their use; and as systems become more sophisticated, this is too frequently overlooked. In order for a building to perform to its potential, users must understand how the building works and how they can control it. This is of particular importance in a house/home as, with no facilitating body, users are left to tailor their own surroundings to make themselves comfortable.
Users and their requirements vary tremendously and so it is important that the design of the control systems reflect this. By defining user groups and focusing on their behaviour; this paper aims to review the specific control systems and the implementation of renewable energy technologies employed in the BASF house, Nottingham, UK and ascertain probable conclusions as to what extent user behaviour demands specific knowledge of technologies and user control.
It is hoped that the insight gained from this probabilistic study will highlight the requirement to consider user behaviour in modern residential building.
Keywords: user control, control systems, behavioural profile, perceived user-knowledge.

INTRODUCTION

New housing in the UK; conditions, standards and codes In the UK up to forty percent of the total energy used is in the built environment, with up to half of this in housing [1].

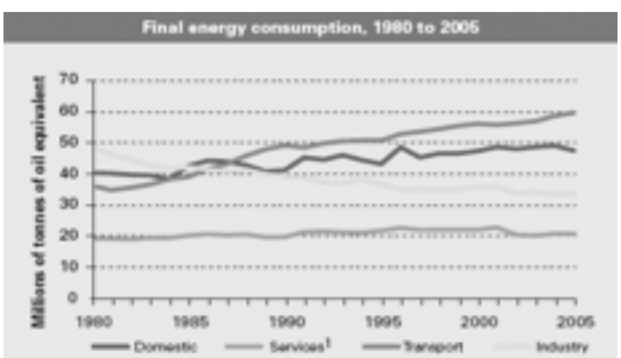


Fig 1. UK rate of energy consumption by final users, by sector (Source: Great Britain National Statistics, 2006).

With dwindling supplies of non-renewable energy sources, countries across the world are taking measures to minimise their reliance on gas, oil and solid fuel to reduce carbon emissions. In 2004, the European Union introduced the Energy Performance of Buildings Directive (EPBD) [EU Directive 2002/91/EC] which promotes the use of a common framework for calculating a building's energy performance.

The British government has set a target to improve the energy efficiency of housing by 60% by 2050 (based on 1999 levels) and reducing occupants' usage is expected to contribute up to 50%. Along with changing the attitude of society, the aim is that houses produce less CO_2 by consuming less energy by design and that they obtain the energy they need from renewable sources.
In order to achieve this, the government has introduced the voluntary UK 'Code for Sustainable Homes' (which replaced Ecohomes as the assessment in 2007). The Code states minimum/basic requirements and includes targets to reduce emissions of CO_2 in building design and construction.

The BASF House The BASF house is part of the Creative Energy Homes (CEH) Project at the School of the Built Environment, University of Nottingham. CEH is a research and educational showcase of seven low or zero carbon houses. The BASF house is the product of a collaborative effort by BASF, a chemical company that supplies raw materials, Derek Trowell Architects, and the University of Nottingham.

The house is currently occupied by PhD students who are pioneering innovative user control systems as well as testing renewable energy technologies, whilst monitoring every aspect of the house's performance. Despite its current occupants, the house is designed to function as a conventional home and act as a prototype for new housing in the UK. The BASF house has been designed to promote sustainable development. Beginning as a research project into the application of the German 'Passivhaus' Standard in Europe [2].

THE OCCUPANT

The Inhabitant of Housing Over the past decade or so, concerns about climate change have filtered into the public domain. It is becoming increasingly important to occupants to consider the energy efficiency of their home; especially when buying a new one.

The Halifax Building Society regularly conducts household surveys. In 1998 it reported energy-efficiency as the top reason why buyers bought a new rather than second-hand home [3]. Then in 2000, energy efficiency was stated as the third most common motivator for making home improvements [4]. Also in 2000, a Gallup survey reported that 70% of consumers would pay more for an energy efficient home [5]. Whilst it appears that overall the population is beginning to appreciate the significance of energy efficiency, it is important to realise that the occupant or end user of a house can be of any age, gender or cultural background. This means that they will inevitably have different requirements.

In 'Psychology in Practice' (2002) K. Oliver suggests that 'the cultural differences which dictate differing living styles also affect housing requirements and unless they are taken into account…the buildings will not fulfil their required function … [and] the space will be inefficiently utilised'[6]. Researcher Shulamit Reinhraz goes further than this and suggests that 'over – generalisation … is clearly inappropriate and possibly dangerous' [7]. It is arguable that in the typology of housing, the behaviour of the occupant is the most important as it is in their home the user will exert complete control (with no centralised control system as you might expect in an office).

Defining the Occupant Categorising parameters of behaviour in order to predict trends for occupants of housing, whilst difficult, would prove relevant. As proposed by de Groot et al. [8] in a paper evaluating residential schemes in Holland, the main occupant related factors which influence energy use are:

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

However, even with these simplified parameters, de Groot questioned 10,000 occupants and no two responses were exactly the same. Thus, in order to successfully categorise occupants, fixed behavioural profiles are used. Four household profiles are already defined as (Fig 2):

1. Profile Ease: Persons in this profile act to create comfort and have no sense or interest in energy use, costs or the environment;
2. Profile Conscious: These households choose comfort, but take into account costs and environment;
3. Profile Costs: Persons are aware of costs and save energy to reduce costs;
4. Profile Environment: These households act mainly from the point of view of environment. [8]

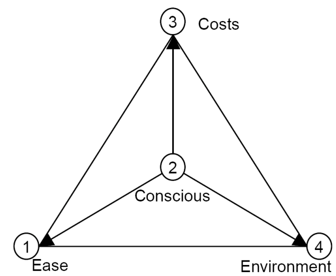


Fig 2. Ideogram of four household behavioural profiles [8].

Using these four fixed behavioural profiles a designer is able to more clearly define who the occupant of a house might be. Although it is still impossible to tell exactly who will use the building throughout its lifetime, applying schemes to suit any or all of the groups simplifies the task. For the purpose of this research we used this categorisation for BASF house occupants.

CONTROL SYSTEMS

In order for housing, or any other building typology to perform to the occupant's desires; methods of control are built-in or employed to make the building more comfortable and suited to the user.

Technological Systems in the BASF house The house employs two innovative technological design additions which, if used correctly, can reduce CO_2 emissions.

1. WebBrick; A home automation system which oversees and controls ventilation, heating, lighting and security.
2. 50 meters: Installed to measure the indoor climate parameters and the use of resources in the house, i.e. electricity and water, with the data being logged

every 6 minutes and presented on a touch screen panel in the kitchen.

The screen in the kitchen gathers information from 3am daily on energy usage in the house. It acts like a control centre from which the occupant can see the energy usage of each room, and each appliance; in kWh. Through looking at the screen, the system enables the occupier to control which spaces require heat, light, ventilation, etc. The WebBrick system also allows the conditions to be automated and controlled via the internet from anywhere around the world. For research and assessment purposes the data is being logged as *.csv files and can be accessed by researchers involved in the project, especially on specific periods of measurement, or set experiments.

Fig 3. House control system in the kitchen.

Besides the mentioned technological systems, the BASF house has implemented many other renewable energy and low carbon technologies and materials to enhance the energy performance of the house, some of them are:

Materials all BASF products	Technologies
Insulation Solutions for Ground Floor and Walls	Ground-Air Heat Exchanger
Sustainable Concrete Solutions	Biomass Boiler
Structural Insulated Panels	Solar Power System
Phase Change Materials (PCM) and Smart Board	Water Conservation & Rainwater Harvesting
Permeable Paving	Monitoring System

Table 1. BASF House Materials and Technologies¨[2].

The Need for a 'Home User Guide' A lack of understanding of the house as a whole would prevent the building performing to its potential; for example:

- How the biomass boiler works and how to use the pellets;
- Understand the basics of solar gain and how to use the sun space most efficiently;
- Be aware of how the natural ventilation system should work;
- Know the basics about the ground air heat exchanger;
- Know a little about the materials and techniques used in its construction; so any repairs and additions can be sympathetic and appropriate.

These interventions that imply use of sophisticated renewable technologies, which are crucial for the good performance and occupant's comfort, are often overlooked by designers and experts when handing the building over to the occupants. For example if they do not understand that the success of the natural ventilation (Fig 4) is reliant on achieving a cross-flow of air, then they may deem it a failure and plug in the Ground-Air Heat Exchanger when is not needed at all. Using more energy than the real demanded at a given time.

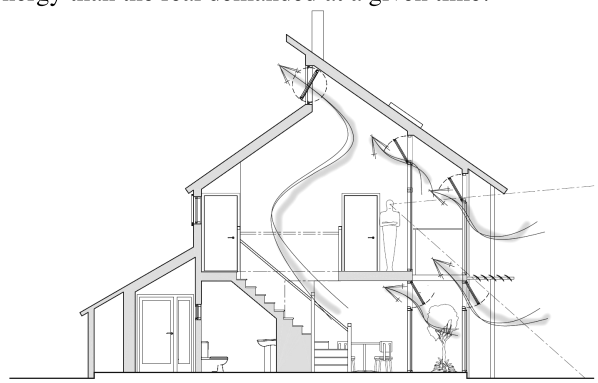


Fig 4. Natural Ventilation Flow, North-South Section [2].

Control System Failure Clearly, if it works successfully, a control system can dramatically improve a building's performance. In Holland, effective use of control systems has been proven to reduce the total energy consumption in the built environment by 19% [8]. However, if used incorrectly, control systems can hinder a building's performance and increase carbon emissions.

It is important that users know how to use equipment to ensure that their behaviour does not inhibit the performance of the building. This point is reinforced by Bordass et al. who tested systems in 'Controls for End Users' [10] and found that user controls which are deemed too complex are disregarded. As systems go unused, they are clearly a waste of resources, money and energy. In addition to this, if an occupant cannot access control systems, they are likely to find the space uncomfortable. In this case they will take measures to override it; i.e. open a window instead of turning down the thermostat.

POST OCCUPANCY EVALUATION (POE) + METHODS OF PROCUREMENT

Defining POE In this paper, the focus is on the end user and how their behaviour and education is suited to the new experimental BASF house. From an architect's perspective conducting a POE of sorts has always been part of a successful project. The RIBA 'Plan of Work for a Design Team Operation' states that Stage 'M' is

'Feedback' [11]. These work stages have been defined since the 1960s and since then have evolved into more sophisticated methods of collecting and displaying information.

Method of Procurement This POE is part of an on-going research in a real life 'field' setting [7]. Since June 2008 the house has been inhabited by 4 adults and a series of experiments continues to be conducted to assess different features in order to understand the building's performance. As such, the results presented in this paper are still preliminary and they concentrate solely on outcomes obtained from qualitative tools, analysis of BASF house information, in-situ observations and questionnaires.

The quantitative data (already being collected by the 50 sensors that are monitoring indoor climate and electricity consumption) is being logged alongside the qualitative data, behaviour/actions of the occupants (i.e. what do the inhabitants do to make themselves comfortable), which is being logged through 'Ubisense' tracking devices. The results obtained from these are not presented in this paper.

We have gathered and analysed all the BASF's **house information** available and any other supplier or manufacturer guides and manuals provided through BASF and the university. This information (if all is read and understood) should enable any person to use the equipment and the house efficiently.

Through **interviews** with the occupants, it would be beneficial to gauge which appliances they find difficult to use and which systems they deem unnecessary. Included in this interview would be questions about which appliances they consider unsuccessful and they find themselves overriding.

Ultimately, it is important that occupants from all four **'household behavioural profiles'** (as defined in section 2.2) attempt to use the systems in the house. Since this is not feasible, given the current occupants of the house are going to live in for a year, they were identified by categories. In either situation, how long the participant takes to competently use the equipment has been recorded; along with all the research sources they have used.

At each stage, every occupant/participant was asked to fill out a **questionnaire** which required both quantitative and qualitative responses. Questions were on their comfort levels, how easy they found using the systems and equipment etc. It was also useful to gauge their knowledge of the aims and intentions of the BASF house and their opinion on whether it could successfully be promoted as a new standard for modern homes.

Information on homes without the user-control strategies will come in the form of qualitative answers from the participants; as they compare the systems in the BASF house with what they deem to be 'normal'.

OUTCOMES AND SUGGESTED IMPLEMENTATIONS

The preliminary results of the research will imply a success of some user-control systems, but not all. Those which are concluded to be unsuccessful are probably either too complicated or unnecessary.

In order to address the house as a whole, it would be useful to categorise the control systems [8]:

1. Environment-adaptive control; adapts the control process to the environment; not applicable in the BASF House.
2. **User-adaptive control**; adapts the control process to the behaviour and specifics of the user; applicable for BASF House.
3. User-educational control; influences and 'educates' the user; aiming to change their preferences and desires; possible to adapt in the BASF house.

Through this approach was possible to decipher which 'type' of controls is unsuccessful. By using the 'household behavioural profiles' it is predicted that 'user-educational control' will be the least effective amongst all but group 4 (and possibly group 3) as it is the most extreme and intrusive. For the case study we classified occupants as it follows:

person	gender	age	race	single/ married	behavioural profile	bedroom location	activity
1	F	28	European	S	Conscious	SE	Engineer Phd student
2	M	47	South Latin American	M	Conscious	SW	Physicist Academic Visitor
3	F	43	South Latin American	M	Conscious/ Environment	SW	Architect Phd student
4	M	42	North Latin American	S	Conscious	N	Architect Phd student

Table 2. BASF House Occupant's Profiles.

A typical routine from Monday through Friday: all the occupants normally shower in the morning; they all open the bathroom window after shower, and very occasionally they take a second shower in the evening. All of them leave the house about 9:00am. Occupants 2 and 3 come back regularly for lunch, at 1:30 pm. remaining in the house for one hour approximately. Some afternoons Occupants 2, 3 and 4 come back to the house randomly for short periods of time. Occupants 2, 3 and 4, come back for dinner at 6:30-7:00pm cook and most of the time 2 and 3 remain in the house, while 1 and 4 go back to their offices at the university, returning past 10:30pm. On the whole, all of the occupants go to bed after midnight.

Weekends are more unpredictable; as routines vary. Most of the time the house is without central heating (CH), when temperature is under 18ºC Occupants 2 or 3, that stay in the house for more hours set the CH just for couple of hours, just to reach 21ºC, which is well shown when analysing data.

'Environment-adaptive' and 'user-adaptive' controls are likely to be preferred amongst all user groups as they require little commitment or change of lifestyle from the occupants. For the BASF house, the WebBrick system falls into 'user-adaptive' control. However, the natural cross ventilation can be fully automated, however, after automatic opening of windows under a default ventilation strategy for summer, the occupants preferred to control everything manually from the touch window in the kitchen.

Regardless of which category the control system falls into, the interface of the system must give unambiguous information about which actions are possible and advisable (whether it be a Smart Meter on a plasma screen etc.). They must be well designed with the end user in mind. Once again, employing the 'household behavioural profiles', they must relate and be usable by group 1, 'Profile Ease', as a minimum.

In order to ensure the success of a control system, Bordass et al define 6 criteria to score user controls of climate systems [11]:

1. Clarity of purpose
2. Intuitive switching
3. Usefulness of labelling and annotation
4. Ease of use
5. Indication of system response/ feedback
6. Degree of fine control

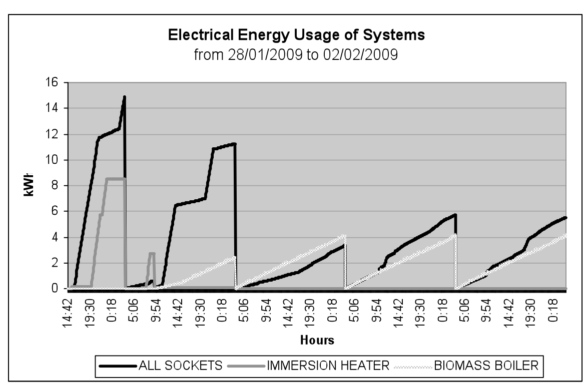
In this case study, it took occupants between 1 and 5 weeks to master the touch screen technology and successfully read the information displayed on lighting, windows, water heating, etc. Certain features, such as the Ground-Air Heat Exchanger and Ventilation Strategy Settings have hardly been used. Some occupants do not even know how they work or how to operate them; so there seems to be no real need for them. It could be suggested that there should be standards or guidelines which would aid consumer understanding of 'user-friendly' systems (this is perhaps considered the responsibility of consumer watchdogs, such as the company 'Which?') Perhaps the solution is to involve end-users from each 'household behavioural profile' in the design process of both the house designs and the systems themselves.

The 'Home User Guide' was not introduced to occupants of the BASF house and they were not involved in the development of the project. The occupants agree that they have taught each other in the use of the technology in the most part as the use of the control system has been mainly intuitive and based on the information on the features of the house, provided by BASF. These qualitative findings will be vitally considered in the production of the final home user guide and the development of the systems.

The high performance renewable energy technologies used in the house come with the manufacturer user guides in the house information pack. However, none of them were considered 'user-friendly', even by the highly educated science and environmental technology students occupying the house. Two of the sophisticated systems, the solar system and the biomass boiler have required several technician visits for repair and calibration and the Ground-Air Heat Exchanger has hardly been needed; prompting the question is a system like this necessary for a home in the UK? In addition, analysis of the energy data has suggested that the rainwater harvesting system has been using up to 6-8 kWh per day; signifying a fault. This type of evaluation goes to prove that every person throughout the design, construction and inhabitation lifespan of this building must understand the technologies, know how to use, adjust and maintain them and understand when there is a fault.

An extreme example of this is the biomass boiler experience in the house; it uses 'Oilseed Rape' pellets for fuel. Despite all of the occupants having read the Instruction and Operation Manual, it took them 7 months to run it properly and fully understand the system, (with a cost of several hours of engineer and technician's time). Sometimes, it was impossible to light it, then to ensure warm showers when there was not enough solar radiation, occupants needed to use the immersion control, which was very high in energy usage, considering this was an eco-home. And a few times, it was necessary to use electrical heaters, which are also not energy efficient at all.

The misuse of technology ends up affecting the global energy performance of the house, as shown in graph 1.



Graph 1. Electrical Energy Usage of Technological System Installed in the BASF House.

When adding electrical heaters plus immersion control to heat up space and water respectively, the consumption is three times more compared to a more typical day, like 01/02/2009, when the total consumption is close to 6 kWh per day, while for 28/01/2009 the electrical energy usage reached 15 kWh in one day.

The occupants were trapped and daily dependant on checking the temperature of hot water, which made their everyday life quite uncomfortable for some months. The use of biomass boilers is being highly promoted in the UK, for larger buildings, as schools. They are very common in some countries, like Denmark, Sweden and Australia. Also they are used in the agricultural sector in many places, proven to be energy efficient and ensure low carbon emission technology, the question then is then how can this technology be used properly in the domestic sector and what is necessary to learn in order to make this technology appropriated for housing?

CONCLUSIONS

In 2009, buildings themselves will be more energy efficient than ever before which means in order to reach the 2050 target to reduce carbon emissions by 60%, the behaviour of the occupant is increasingly important.

In housing, most occupants are not energy experts. The majority of the population are not educated in the effects of energy inefficiency, and perhaps not concerned by their personal effect on the environment.

Education alone is not enough; as problems stemming from a lack of understanding and education lead to user discomfort and wasted energy. It is then undoubtedly important that control systems are properly regulated and designed appropriately for users – perhaps the problem lies at the early design stage. It could be suggested, for example, that energy usage should be shown in monetary terms as well as in kWh.

Without doubt, the most effective systems are those that promote energy-efficient behaviour in users and educate them in the importance of energy conservation. Those that penalise attempts to be wasteful, without inhibiting lifestyle, are also successful, as they will help create a society more in tune with the important issues of the future.

This case study has highlighted the importance of user understanding in the success of control systems and suggested that the information which is displayed must be more explicit and comprehensive.

For innovative renewable technologies, user guides are crucial, they should not discriminate users and they need to be didactic and simple. If changes toward reduction on energy demand for energy homes are going to rely on technological solutions, the gap between common users and technology needs to be addressed and find ways to narrow it.

Ultimately, control systems are successful if they are used correctly; over the previous decade or so, we have seen a change in users' attitudes towards energy conservation. However, if the government is to achieve the 2050 target, more research must be carried out into user behaviour as it can ultimately be the making or breaking of a building scheme.

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Fig. 1 - UK rate of energy consumption by final users, by sector Great Britain National Statistics: UK Energy in Brief 2006. London: 2006, p.14
Fig. 2 - Ideogram of four household behavioural profiles. De Groot, E., M. Spiekman and I. Opstelten (2008) Dutch Research into User Behaviour in Relation to Energy Use of residences. PLEA 2008 Dublin, 22-24 October 2008.
Fig. 4 - Ventilation Flow through North-South Section. The BASF House. Available: http://www.basf.co.uk/en/uk/house/