REDUCING BUILDING ELECTRICITY USE BY INCREASING OCCUPANT PERCEIVED CONTROL

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This paper demonstrates the impacts of increasing the perceived level of control that building users have over the energy performance of a building. The study was conducted at the Student Services Building at the University of Reading in 2009 – 2011. Building occupant perceived control was influenced by engaging the user with high resolution building energy data. Increasing this perceived level of control contributed to overall savings in the building of 25% in small electrical items and lighting. The majority of a building's carbon emissions are a result of operational activity. Further to this, post occupancy evaluations of new buildings regularly demonstrate that operational energy use and carbon emissions are higher than those quoted during design. A key factor in this design-operation performance gap is the actions of building occupants. Often building occupants are not aware of the level of control they have on the energy performance of the building they occupy. Two behavioural models have been developed that include perceived control as a key factor for enabling and motivating environmental behaviour. Ajzen's 'Theory of Planned Behaviour' and Stern's 'Value-Belief-Norm' model demonstrate increases in the amount of influence an individual believes they have over the outcome of a situation will increase their action to make that change.

Keywords: building users, communication, energy, facilities management, values.

INTRODUCTION

Buildings are responsible for approximately 40 per cent of the UK's energy use (Perez- Lombard 2008). The majority of a building's carbon emissions are a result of operational activity (Ramesha 2010). Post occupancy evaluations have shown that operational energy use can be up to five times higher than estimates during design. Even in highly automated buildings, occupants can affect their energy use (Menezes 2012). Often building occupants are not aware of the level of control they have on the energy performance of the building they occupy (Clements-Croome 2011).

This new research is designed to explore current advances in construction management research through the quantification of the effects of increasing building occupants' perceived control over electrical energy use in an office environment. It was undertaken in the Student Services Building at the University of Reading: a modern administrative office building. Interventions have been designed within the context of Ajzen's Theory of Planned Behaviour (TPB) (Ajzen 1975). The design of the specific interventions within this theoretical framework is based partially on the literature and adapted according to the practical experience of the authors, as detailed

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in the 'Intervention Design' section below. Results indicate that actions completed as part of the research led to reductions in electricity use of 25% in small electrical items and lighting within the building.

This paper records a pilot study on the use of psychological behavioural change theory to complement traditional construction management techniques. It is the opinion of the authors that much more cross disciplinary research is yet to be completed that will help guide reductions in carbon emissions from our built environment. This paper is part of a Ph.D research program that aims to combine state of the art construction management techniques with psychological theory. As described later in the paper, this is common place in research focussed on energy saving techniques in the domestic context, but much less so in these areas of impact at work (Davis 2009).

LITERATURE REVIEW

According to the TPB, human behaviour is guided by three kinds of considerations: beliefs about the likely consequences or other attributes of the behaviour (behavioural beliefs), beliefs about the normative expectations of other people (normative beliefs), and beliefs about the presence of factors that may further or hinder performance of the behaviour (control beliefs). It follows that given an actual level of control over their actions, if the criteria above are met, then the individual would change their behaviour (Ajzen 2002). Ajzen designed the TPB by developing his earlier research on the theory of reasoned action (Ajzen and Fishbein 1975, 1980). Bortoleto (2012) summarised the development between the theory of reasoned action and the theory of planned behaviour as the addition of consideration for perceived control. However, it may be that users are in possession of environmental knowledge and environmental awareness, yet do not display pro-environmental behaviour (Kollmuss 2000).

Stern (2000) presents a Coherent Theory of Environmentally Significant Behaviour, suggesting that the gap between environmental attitudes and knowledge, and environmental behaviour is influenced by beliefs that individual actions could alleviate threats to valued persons or things. This may be interpreted as individuals perceiving that their actions, which they have control over, can remove threats, for instance climate change or risks associated with energy security.

This idea, presented by Stern (2000) is part of the wider value-belief-norm theory. The theory links value theory, norm-activation theory, and the New Environmental Paradigm (NEP) (Dunlap 2000) perspective through a causal chain of five variables leading to behaviour: personal values (especially altruistic values), NEP, adverse consequences and ascription of responsibility to self-beliefs about general conditions in the biophysical environment, and personal norms for proenvironmental action (Stern 2000). This theory shares perceived control as a variable with Ajzen’s TPB.

The concept of perceived behavioural control can be traced back through research outside of the environmental management and construction management literature. Rosenstock (1966) refers to perceived control ideas as termed barriers, and in the model of interpersonal behaviour (Triandis 1977), it takes the form of facilitating conditions. Rothbaum (1982) goes further and splits perceived control into two perspectives: primary control – the degree to which the subject believes they can control their environment and secondary control – the degree to which they adapt themselves to fall in line with external environmental forces (Rothbaum 1982). However, perceived behavioural control was most fully developed by Bandura in his research on self-efficacy (Bandura, 1977, 1989, 1997). More recently, Bortoleto

(2012) has defined perceived behaviour control as including two factors: (a) the effects of external conditions on the ability of an individual to adopt certain behaviours, and (b) the individual's perceived ability of themselves to adopt a particular behaviour. On this basis, perceived behavioural control predicts specific behaviours directly and indirectly using intentions.

A prevailing theme in the literature is that a level of perceived control must be present in order for people to feel their efforts are worthwhile (Rothbaum 1982, Stern 2000, Ajzen 2002, Poortinga 2012, Bortoleto et al 2012). It follows that this topic presents a valuable opportunity for research, yet relevant literature is limited. The World Business Council for Sustainable Development report (2007) recognised the role of occupant behaviour as having 'as much impact on energy use as the efficiency of equipment', yet little research has been carried out specifically on these behaviours or on potential interventions that address their negative impact on energy conservation (Mindy 2009). Davis (2009) warns of a lack of research undertaken in the areas of environmental impact at work – from a review of 8,595 articles returned from their multiple database search the vast majority looked at green behaviours in the home while the workplace was almost entirely overlooked. Further review of the literature confirms that there is no quantification of cost and carbon savings that could be expected from implementing this theory in administration buildings in the higher education sector. This paper seeks to address that gap.

The review of literature suggests that perceived control is significant in influencing individuals to change their behaviour, yet it has not been applied to energy saving behaviour in an administrative environment.

METHODOLOGY

The Student Services Building at the University of Reading is a three storey office building. The building was finished in 2007. The building is heated by a two ground source heat pumps. It was designed to be environmentally efficient, with additional insulation and efficient lighting beyond the requirements of contemporary legislation. The user population consists of office-based University staff with students coming to the building for various services. The building was specifically chosen following the belief of the Energy Manager that if energy efficiency improvements were possible within this building, they would be easily replicated elsewhere. This is justified as, at the time, the building had the best Display Energy Certificate score on Campus.

Monitoring approach and installation

Monitoring equipment was installed in the Student Services Building during October 2009 to collect high resolution electrical data. Existing sub-meters in the building did not provide sufficient coverage and were supplemented with wireless current transducers.

Metering exclusions include lifts as these were rarely used and the emergency lighting circuit as users did not have control over this. Due to the electrical layout in the building, the monitoring of the main floors combined lighting and small power. The cost of metering these circuits individually was prohibitively costly as a retrofit.

The monitoring equipment is managed by Carnego Systems Limited and was fitted by University of Reading electricians. A team of two completed all works within 2.5 hours. The metering equipment was set up to collect data at 1 or 5 minute intervals and transmitted back to a central database. Data transfer was achieved using a GPRS connection. All data is stored on a database and accessed by users via a secure online application. Data collection started in October 2009 and is ongoing. Data was separated according to 'occupied' – working days and 'unoccupied' – weekends. A potential improvement to the research could be to include evenings in 'unoccupied' periods.

Understanding the building

Through July 2009 to January 2010, the building was reviewed by the project team. During this period, no interventions other than observational visits were carried out. These visits facilitated a relationship of trust between the project team and building management team (BMT). The building management team consisted of the Building Manager (BM) and Deputy Building Manager (DBM). Additionally, basic information about the structure and operation of the building was gathered. Building user behaviour and 'quick win' observations were also made.

During initial visits to the building, lighting and office equipment (personal computers, photocopiers, etc.) was consistently 'on' in offices and corridors even on bright summer days and out of hours. Conversations with building occupants revealed lighting was switched on when people came into the building and usually turned off when people left in the evening. Little thought was given to energy used by office equipment out of hours.

Some building occupants reported awareness of the 'environmentally friendly' nature of the building. They felt that this removed the need to conserve energy in the building. This was demonstrated when questioned about why lights and other equipment had been left on unnecessarily.

Feedback mechanisms

Full detail of the live high resolution data was available in graphical format to show electricity use. This was primarily used by the building management team. This data was used to communicate data about occupied and unoccupied electrical use.

Live data was more widely presented to building occupants in a star chart format. A star chart was chosen as it provides concrete feedback and reinforcement (PENT n.d.). Each of the six teams had a row on the chart. A daily star was awarded based on how close the unoccupied energy use came to the pre-set electricity use baseline. Unoccupied use within 10% of the baseline was rewarded with a gold star, 10-20% over the baseline received a silver star and more than 20% from the baseload was marked with an exclamation mark. The star chart was communicated via email, and displayed on a live screen in the building foyer.

Intervention Design

For the purposes of this research, interventions were designed and mapped to the three considerations highlighted by Ajzen in his 2002 research. Behavioural beliefs must produce a favourable attitude towards the behaviour. Therefore the individual, their individual beliefs and individual behaviours must be addressed. Normative beliefs are established by demonstrating that behaviour is normal or standard. The research aims to ensure people want to instinctively do things because that's what 'we' do, as a group. Control beliefs are reinforced as the project aims to demonstrate to users that their actions will have an effect in reduced energy use in the building, thus strengthening the belief that they have control over the outcomes. This can be as simple as a light switch or being able to shut down personal computers or as complex as settings in the building management system.

The project addresses these aims by completing a feedback loop: a/ collect detailed, granular data on energy use; b/ process and analyse this data to produce meaningful information relevant to TPB; c/ present the information to people in ways that promote understanding and prompt action; d/ implement the actions; e/ continue this loop, assessing the impact of the interventions to advance subsequent iterations, improving and reinforcing behaviour change.

Communications were designed to support the TPB by aligning with one or more of these behavioural beliefs. Initiatives focussed on unoccupied behaviour as it was agree by the project team that this would be less disruptive to the working environment. The following communication principles were adopted:

Non-directive: As suggested by Paterson (1985), some clients comply with recommendations more frequently when exposed to nondirective versus directive counselling interventions. Where possible the project team did not provide solutions or interventions but rather facilitated the occupants to self-discover improvements that can be made. Some mediation around technical issues was necessary.

Outcome based to align priorities: A principal (project team) can achieve control (i.e., actual impact on agent behaviour) by focusing on its agent's (building user) outcomes so as to co-align their interest (Celly 1996). Based on conversations during the initial building review, the project team recognised that energy use is a low priority for many building users. To align interests of the project team and building users, communications were designed to show whether an outcome had been achieved. This could be meeting a target for 'unoccupied' energy use using a star chart or a very clear change in the energy profile on the online system.

Information granularity: Information was provided on a location specific basis to groups of building occupants rather than for the building as a whole. This was designed to in highlight small changes, for instance a water heating running for a minute or two, providing feedback specific to individuals and their actions. To facilitate this, information was made as granular as practicable, available at up to one minute intervals.

A selection of interventions is described in Table 1. Each intervention relates to a vertical line in Figure 1. An opportunity to develop the research in the future would be to determine the individual impact and significance of each intervention on overall energy use. However, this is beyond the scope of this project.

Table 1: Examples of Categorised intervention timeline, interventions are listed by date, with a short description and labelled as one of Ajzen's belief base categories, described above.

Date	Intervention	Belief Base
24/01/10	Monitor Sunday energy use before any communication	N/A
25/01/10	First detailed discussions with building management team	Belief
27/01/10	First communication with building users by email and 'Sunday switch off'	Control
29/01/10	Email reminder of 'Sunday switch off'	Norm
31/01/10	Monitor Sunday energy use following emails on 27 and 29/01/2010	N/A
01/02/10	Email thank you for participating in 'Sunday switch off'	Control
19/03/10	Email issuing 'Sustainability Matters'	Norm
26/03/10	Email reminder about Earth Day on Saturday 27/03/2010 at 8.30pm.	Norm
30/04/10	Email reminder of the continuation of 'Switch off Sunday'	Norm
07/05/10	Email reminder to switch off as per 'Switch off plan'	Norm
14/05/10	Email reminder to switch off as per 'Switch off plan'	Norm
21/05/10	Email auditors visit and switch off reminder as 'Switch off plan'	Control
11/06/10	Email reminder to switch off as per 'Switch off plan' and close windows	Belief
16/06/10	Information on improvement in People and Planet Green League	Control
24/06/10	Email reminder to switch off as per 'Switch off plan' and close windows	Norm
09/07/10	Email reminder to switch off as per 'Switch off plan' and close windows Completion of new energy efficient lighting installation	Control
20/07/10	Email reminder of 'Big Tidy Up' litter picking 23/07/10	Norm
02/08/10	Email notice of Reading Buses travel ticket offer	Belief
12/08/10	Email: Announcement of Green Impact Award 09/10 – Student Services Building silver award - energy use reduced by 24.8%	Control
20/08/10	Email: Explanation of new energy efficient lighting installation (timed and photocell control to regulate the amount of light) Reminder to switch off as per 'Switch off plan'	Norm Control
01/10/10	Email announcement Green Impact Silver Award	Control
08/11/10	Green Week (generic University wide)	Norm
16/12/10	Email message from the Deputy Vice Chancellor about the University's commitment to reduce carbon emissions targets (generic University wide)	Norm

Interventions were initially focussed on the BMT. The BM was 'on board' from the start; however the DBM was more sceptical. It was understood that this reflected the level of perceived control each member of staff had over operations within the building. Initial interactions focussed on demonstrating how their actions affected energy performance of the building.

The BMT were trained in the use of the energy data. This was achieved by introducing simple concepts, for instance: how to identify a set of water heaters that were on 24 hours per day, 365 days per year; how the unoccupied baseline varied when different equipment was shut down, and; how the operation of vending machines affected electricity use. Presenting the high resolution energy performance data increased support from the BM and DBM.

As building users recognised that their actions affected building energy performance, further suggestions were made. The first addressed suggestion was to remove the vending machines from the building. Building users could see from the data that the vending machines used a disproportionate amount of energy and were outside of their control. Building users decided that they should be removed. Following this, data highlighted a set of water heaters (not for space heating) that were on permanently. These were altered so heat was only provided during the expected hours of building usage. This action was initiated by the BMT, following an increase in their perceived and actual control of the energy use within the building. Finally, the building was visited a number of times during bright days where all lights were found to be on. This behaviour was reported by building users as being consistent throughout the year. Following dissemination of the 'Switch Off' emails, lights are used more sparingly and are clearly being turned off at night when the building is not in use.

RESULTS

Data analysis shows a clear reduction in energy use in the areas targeted (lighting and small power) across the Student Services building. All savings are for lighting and small power only (i.e. the power used across the floors of the building that can be influenced directly by the users). Analysis of the space heating and mechanical load is not within the scope of this research.

To evaluate the savings, daily energy use was calculated between October 2009 and January 2011. The Periods between 14th October and 31st January were compared for the 2009/10 period and 2010/11 period. Savings were then extrapolated for the year. Degree day data was not considered relevant as no heating will have been provided. Seasonal variations, including weather, daylight and occupancy were assumed to be constant across the periods, due to monitoring the same periods each year.

The results outlined in Figure 1 show a consistent pre-intervention baseline with no significant trend, at 5% confidence level, between 14th October 2009 and 31st January 2010. This is followed by a significant downward trend, at a 5% confidence level, during the intervention period between 1st February and 13th October 2010. This, in turn precedes consistent electricity use with no significant trend, at 5% confidence level, between 14th October 2010 and 31st January 2011.

Comparison of the 2010/11 data against the 2009/10 baseline demonstrated an average reduction of 25% in electrical use during unoccupied (weekends and holidays) periods. This is in addition to an average reduction of 20% during occupied periods (working week days). Although outside the scope of this initial research, there is an opportunity for future research to investigate whether interventions aimed at reducing unoccupied electricity use would influence electricity use during occupied periods.

Extrapolation of this saving rate across the year provides calculated savings of £2,570 (based on 2012 prices of £0.11p/kWh) and 14.4 tCO2e per annum. The total cost of implementing the works was approximately £7,000. This figure includes capital and revenue costs and is based on consultancy costs, equipment supply and installation plus an estimate for University staff costs. On this basis a simple payback period of 33 months was achieved. This compares favourably with a typical lighting controls upgrade project, implemented at the University of Reading. The lighting controls upgrade project achieved savings of 22 tCO2e per annum and £4,295 with a total project cost of £25,374. This lighting upgrade project delivered a simple payback period of 71 months. In order to improve future studies, a more detailed record of

University staff time should be made to provide more accurate data for cost and payback analysis.

Figure 1: Initial energy use results

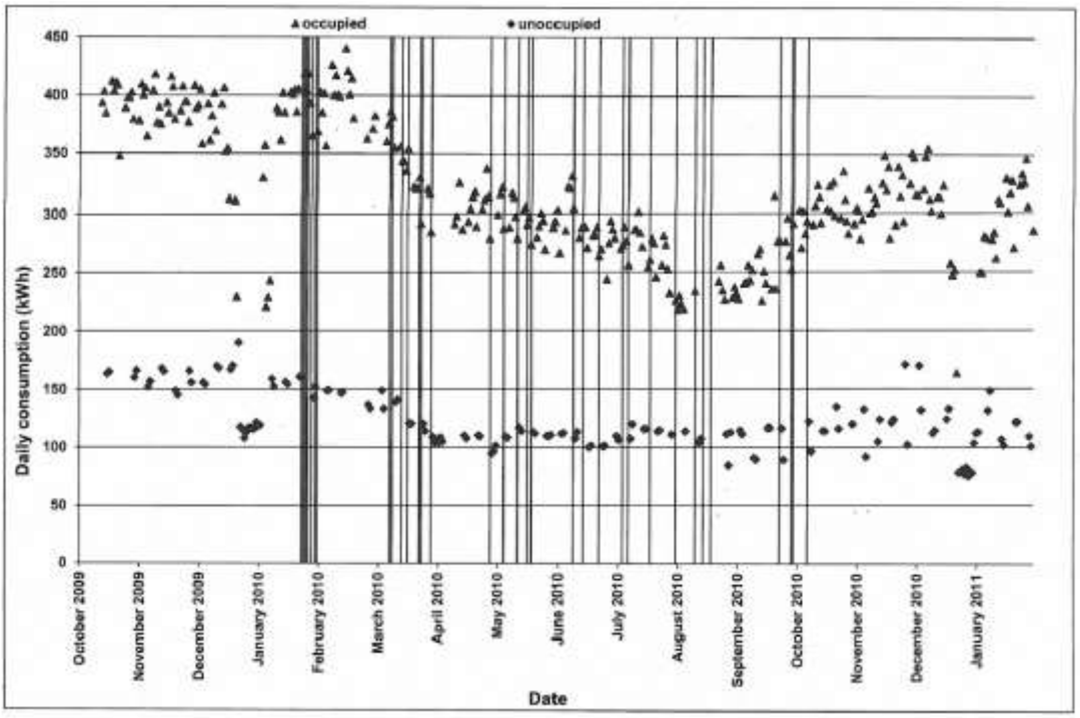

Figure 1 summarises electricity use between October 2010 and January 2011. Triangular marks represent occupied use and diamonds unoccupied use. Vertical lines represent interventions specific to the Student Services Building, with examples listed in Table 1.

An opportunity for future research could include analysis of the implementation costs in future iterations of the project as the team gains experience. Future research may also identify economies of scale that could be recognised should the pilot be extended across the University estate and prove scalable.

The broad specification of the experiment limited the conclusions to general observations. There remains an opportunity for further research into the detail of the degree to which each intervention influenced overall behaviour. There is also further research opportunity to test Stern’s Value-Belief-Norm model against the same project. The data could also be refined to separate office hours and out of office hours.

It was not possible to track building user behavioural beliefs at this pre-survey stage. This could be included in future research.

CONCLUSIONS

In targeted areas, annual savings of £2,570 and 14.4 tCO2e per annum have been achieved. Project costs were approximately £7,000 resulting in a simple payback period of 33 months. This human controls project compares favourably to an automated lighting controls project. However, future analysis could be improved by keeping more detailed records of University staff time invested in projects.

Despite the main focus of the project being on unoccupied energy reduction, significant savings were also made during occupied periods. This difference could be investigated further to identify whether the savings made during occupied periods were largely due to evenings as opposed to actual occupied savings.

This paper presents many opportunities to further research in this field, combining construction management and psychology theory. An attitude and behavioural survey could be included in future research to compare energy reductions with reported levels of building user perceived control. Additionally, future research could be conducted to investigate the impact of individual interventions on energy savings. Further research could also be conducted to test the performance of Sterns Value Belief Norm model in comparison to Ajzen's TPB.

It is clear that there is significant potential for research into the use of psychological theory to improve building user perceived control over energy use to contribute to the field of construction management and reduction of atmospheric CO2 levels.

REFERENCES

Ajzen, I, Fishbein, M, (1975) Attitude–behaviour relations: a theoretical analysis and review of empirical research. "Psychology Bulletin" 84, 888–918.

Ajzen, I, Fishbein, M, (1980) "Understanding Attitudes and Predicting Social Behaviour". Englewood Hills, New Jersey, USA: Prentice-Hall.

Ajzen, I, Sparks, P and Hall-box, T (2002) Perceived behavioral control, self-efficacy, locus of control , and the theory of planned behavior. "Journal of Applied Social Psychology", 32(4), 665-683.1, 665–683.

Bandura, A (1977) Self-efficacy: Toward a unifying theory of behavioral change. "Psychological Review", 84, 191—215.

Bandura, A (1989) Human agency in social cognitive theory. "The American Psychologist", 44(9), 1175–84.

Bandura, A, Wood, R (1989) Effect of perceived controllability and performance standards on self-regulation of complex decision making. "Journal of Personality & Social Psychology", 56, 805-814.

Bortoleto, A P, Kurisu, K H, and Hanaki, K (2012) Model development for household waste prevention behaviour. "Waste Management", 32(12), 2195–2207.

Celly, K S and Frazier, G L (1996) Outcome-Based and Behavior-Based Coordination Efforts in Channel Relationships. "Journal of Marketing Research", 33(2), 200-210.

Clements-Croome D J (2011) Sustainable Intelligent Buildings for People. "International Intelligent Buildings Journal", 3, 2.

Davis, M C and Challenger, R (2009) Climate change –Warming to the task. "The Psychologist", 22(2), 112–114.

Dunlap, R E, Liere, K D Van, Mertig, A G, and Jones, R E (2000) Measuring endorsement of the new ecological paradigm: A revised NEP scale. "Journal of Social Sciences", 56(3), 425–442.

Kollmuss, A, Agyeman, J (2002) Mind the gap : why do people act environmentally and what are the barriers to pro-environmental behavior? "Environmental Education Research", 8(3), 239-260.

Hadi, M and Halfhide, C (2009) "The move to low carbon design: Are designers taking the needs of building users into account? A guide for building designers, operators and users". Bracknell: IHS BRE Press.

Menezes, A C, Cripps, A, Bouchlaghem, D, and Buswell, R (2012) Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. "Applied Energy", 97, 355–364.

Patterson, G R, and Forgatch, M S (1985) Therapist behavior as a determinant for client noncompliance: A paradox for the behavior modifier. "Journal of Consulting and Clinical Psychology", 53(6), 846-851.

PENT (Positive Environments, Network of Trainers) n.d., "Using Star Charts for Positive Behavior Intervention", California Department of Education Diagnostics Centre, Available from: < http://www.pent.ca.gov/>. [6th June 2013].

Perez-Lombard, L, Ortiz, O and Pout, C (2008) A review on buildings' energy consumption. "Energy & Buildings", 40, 394–398.

Poortinga, W, Spence, A, Demski, C, and Pidgeon, N F (2012) Individual-motivational factors in the acceptability of demand-side and supply-side measures to reduce carbon emissions. "Energy Policy", 48, 812–819.

T. Ramesha, R. P (2010) Life cycle energy analysis of buildings: An overview. "Energy and Buildings", 1.

Rosenstock, I (1966) Why people use health services? "Milbank Memorial Fund Quarterly", 44, 94- 124.

Rothbaum, F, Weisz, J. R, and Snyder, S S (1982) Changing the world and changing the self: A two-process model of perceived control. "Journal of Personality and Social Psychology", 42(1), 5–37.

Stern, P C (2000) Toward a Coherent Theory of Environmentally Significant Behavior. "Journal of Social Issues", 56(3), 407–424.

Triandis, H C (1977) "Interpersonal behaviour". Monterey, California, USA: Brooks/Cole.

World Business Council for Sustainable Development (2007) "Energy efficiency in buildings: Business realities and opportunities: Summary report". Centre for Climate and Energy Solutions, Available from: < http://www.c2es.org/>. [14th June 2013].