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## Abstract

An increasing body of research is underlying the need to foster energy behaviors and interaction with technology as a way to achieve energy savings in office buildings. However, engaging office users into more "forgiving" comfort-adaptive behavior is not a trivial task, since neither consequences nor benefits for changing behavior have visible or tangible effects on them personally. Since the 70's, survey studies in the field of building science have been used to gain better understanding of multidisciplinary drivers of occupant behavior with respect to comfort and energy requirements in buildings. Rather than focusing on individual behaviors – and influencing factors – purpose of this survey research is to provide quantitative descriptions on the collective and social motivations within the complexity of different social groups in working environment, under different geographical context, culture and norms. The resultant questionnaire survey emerges as a combination of traditional and adaptive comfort theories, merged with social science theory. The questionnaire explores to what extent the occupant energy-related behavior in working spaces is driven by a motivational sphere influenced by i) comfort requirements, ii) habits, iii) intentions and iv) actual control of building systems. The key elements of the proposed occupant behavior motivational framework are grounded on the Driver Need Action System framework for energy-related behaviors in buildings. Goal of the study is to construct an additional layer of standardized knowledge to enrich the state-of-the-art on energy-related behavior in office buildings.

***Keywords: energy-related occupant behavior, questionnaire survey, motivation, DNAs framework, office buildings***

## 1. Introduction

In Europe and US, about 40% of the total primary energy consumption derives from building construction and operation. Specifically, more than 60% of this amount depends on the energy consumption for heating, cooling, ventilation and lighting, meaning a huge proportion of world energy consumption is spent to maintain comfortable and healthy inhabited environments. As demands for low energy consumption is constantly increasing, architects and engineers are facing great challenges of saving energy while maintaining or even improving current comfort levels for occupants. The implications of occupants' behaviors seeking for comfort conditions in indoor environments are undoubtedly essential for building energy requirements.

Recent advancements in energy researches have brought about more awareness of the importance of the human dimension as part of the energy system. Achieving energy conservation emerged as a double challenge, partly technical and partly human. Energy consumption may vary largely due to how occupants interact with system controls (thermostats, lights, equipment, etc.) and the building envelope (windows, blinds, shades, etc.) to adapt themselves to the thermal and visual environment.

There is a growing body of research underlying the need to foster energy conscious behaviors and interaction with technology as a way to achieve energy savings [1-4]. Results from a simulation study to evaluate the impact of occupant behavior on energy use of private offices [5] demonstrated that occupants with wasteful work-style consumed up to 90% more energy than standard users, while austerity work-style occupants used half of the energy of the standard occupants. Accordingly, the development of energy conservation technologies is a necessary but incomplete step toward energy efficiency goals and net zero energy buildings. However, it is a challenging task to develop reliable scenarios of the impact of occupant behavior on final energy usage due to the stochastic nature of human behavior [6].

It is shown that users allowed to interact with control systems are more satisfied with their own working environments [7], since they became more *forgiving* to adapt themselves to the variation of indoor climate conditions and to tolerate greater fluctuations in acceptable temperature ranges [8]. In this context, leading building occupants in workspaces towards comfort-adaptive energy-saving behaviors can be seen as an effective and low-cost investment [9] to reduce energy consumption by up to 30% [5]. This can be achieved by maintaining comfort condition and increasing satisfaction and productivity [10]. Yet, in office buildings, engaging users into more "forgiving" indoor climate conditions [11] – sometime at the expenses of indoor environmental quality and comfort – is not a trivial task. Differently from the household context, neither consequences nor benefits for changing behavior (i.e. saving money from the energy bill) have visible or tangible effects on them personally. For this reason, it is necessary to achieve a deeper understanding of the *motivation structure* towards the concept of "forgiveness" and comfort-adaptive (and energy-saving) behaviors within the complexity of different social groups in working environment.

The future of occupant behavior studies remains a multidisciplinary and controversial field [12], since comfort condition and energy use is recognized not

merely related to physical parameters but also factors. In order to fully understand occupant behavior based on facts rather than hypothesis, there is a need for discovery of a layer of social, contextual and group interaction constructs related to individual motivations, which overlap the four key components of the human-building interaction: i) the Drivers of behavior, ii) the Needs of the occupants, iii) the Actions carried out by the occupants, and iv) the building systems acted upon by the occupants [13]. Motivation emerged as a key unlocking parameter for behavioral change, as largely discussed in the field of behavioral science theory [14, 15]. As described in the Theory of Planned Behavior [16], motivations are driving behavior, and can be assumed as a proxy to describe actual behavior. Questionnaire studies conducted in the field of behavioral studies [17-18], also confirmed motivation can be assumed to be the immediate antecedent of behavior. Building occupant behavior research commonly focuses on direct observations such as sensor or other non-self-report data. In contrast, social science research generally deals with self-report data or latent variables such as motivations, beliefs, perceptions, emotions, and attitudes. To the extent that *perceived behavioral control* communicated by the questionnaire respondents is veridical, it acts as a latent variable for actual control and can contribute to the prediction and estimate of the behavior in question. Social science provides quantitative methodological descriptions on how to develop survey researches related to human subjects [19]. Since the 70's, a wide spectrum of building science researches started dealing with the variables of occupants' comfort satisfaction, need, acceptance and energy concerns. Yet, surveys have been widely used to gain a better understanding of occupant behavior and comfort requirements in office buildings, as reviewed in Ackerly et al [20].

## 2. Methodology

The purpose of this survey research is to provide standardized quantitative descriptions on the motivations driving occupant behavior in office buildings. Rather than focusing on individual behaviors and influencing factors, key results aim to be generalized under collective and social conventions shaped by geographical and climatic contexts, culture and norms.

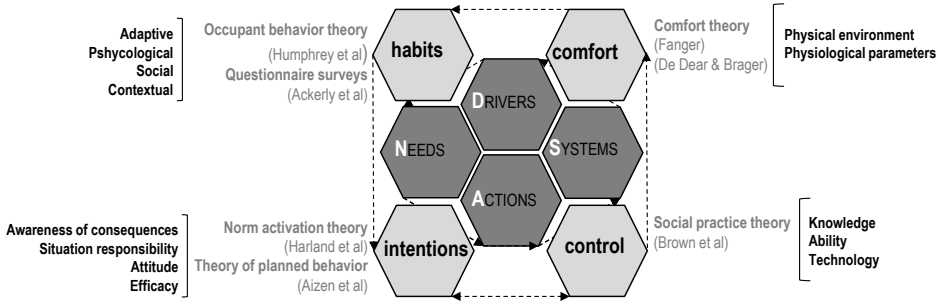


Figure 1. Structure of the OB Motivation Framework

The survey structure is primarily grounded on the DNAS ontology for energy-related occupant behavior in buildings [13]. In this framework, the goal of the study is to create an additional layer of standardized knowledge on energy-related behavior in office buildings, to enrich the state-of-the-art. The resultant self-report questionnaire is a combination of key questions emerged in a comprehensive literature review of occupant behavior questionnaire surveys [20], Humphreys' principle of occupant's interaction with control systems in buildings [21], traditional [22] and adaptive comfort theories [23] merged with social science theories [15-18, 24]. The questionnaire explores to what extent the occupant energy-related behavior in working spaces is driven by an individual motivational sphere influenced by i) comfort requirements, ii) habits, iii) intentions and iv) actual control of building systems (Table 1)

Table 2. Structure of the OB Motivation Survey Framework

| Section | Context | Focus Area | References |
|---|---|---|---|
| Comfort | physical environment | thermal comfort | Brager et al, 2004 [23] |
| | | visual comfort | |
| | | IAQ | |
| | physiological parameters | gender | Fanger, 1987 [22] |
| | | age | |
| Habits | adaptive | past behavior | Ackerly et al, 2012 [20]<br>Humphreys et al, 1995 [21] |
| | phsychological | response automaticity | |
| | social | social norms | |
| | contextual | workstyle routine | |
| | | empolyment role | |
| | | country of origin | |
| | | enviromental factors | |
| Intentions | awareness of consequences | perceived subjective norms | Onwezen at al, 2013 [15]<br>Ajzen et al, 2001 [16]<br>Harland et al, 2007 [17]<br>Stern et al, 1986 [18] |
| | situation responsability | perceived social norms | |
| | attitude | perceived willingness | |
| | efficacy | perceived effectiveness | |
| Control | knowledge | perceived control | Brown et al, 2009 [24] |
| | | actual control | |
| | ability | perceived access | |
| | | perceived impediments | |
| | technology | perceived achievements | |

## 3. Results

As the first step towards the development of the motivational framework, a field survey structure is settled in order to understand the predictor variables leading occupants to adapt to and to accept more rigid comfort conditions reducing or not relying on the mechanical control systems in offices.

The occupant motivation survey is structured into the following 4 *sections*, corresponding to the framework structure. For each *section*, the questionnaire defines *i)* the *context* of the question and allocates distinct *ii) focus area* categories, and provides background references, as follows:

1. *Comfort* (Table 2)
    a. *Physical environment*: thermal comfort; visual comfort; acoustic comfort; IAQ
    b. *Physiological parameters*: gender; age
2. *Habits* (Table 3)
    a. *Adaptive:* past behaviors
    b. *Psychological*: response automaticity
    c. *Contextual*: workstyle routine; employment role; country of origin; environmental factors
3. *Intention* (Table 4)
    a. *Awareness of consequences*: perceived subjective norms
    b. *Situation responsibility*: perceived social norms
    c. *Attitude*: perceived willingness
    d. *Efficacy*: perceived effectiveness
4. *Control* (Table 5)
    a. Ability: perceived and actual control; perceived access and impediments

For each of the *focus area* categories, the questionnaire allocates iii) *survey questions* and specifies *iv)* the *scale* or the options for the questionnaire responses.

Table 2. Comfort Section: Occupant Behavior Motivation Survey Framework

| Context | Focus Area | Survey question | Scale |
|---|---|---|---|
| physical environment | thermal comfort | Grade your typical thermal comfort satisfaction in your working space | ASHRAE 7 points scale |
| | | What's the most frequent cause for thermal discomfort? | § Air draft<br>§ Floor too cold (cold feet)<br>§ Too cold during winter<br>§ Too hot during summer<br>§ Too aggressive heating during winter<br>§ Too aggressive cooling during summer<br>§ Zones at different temperatures<br>§ Cold nearby windows |
| | visual comfort | Grade your typical visual comfort satisfaction in your working space | dissatisfied/satisfied 7 points scale |
| | | What's the most frequent cause for visual discomfort? | § Improper office lighting<br>§ Excessive office lighting via natural means<br>§ Glare on my computer/working plane<br>§ Lack of view from outside (eye tiredness) |
| | IAQ | Grade your IAQ satisfaction | dissatisfied/satisfied 7 points scale |
| | | What's the main cause for indoor air quality discomfort? | § Stuffy air<br>§ Co2 concentration<br>§ Bad/strong/offensive odors/scents |
| physiological parameters | gender | What's your gender? | male/female |
| | age | What's your age? | cardinal |

The questions and scale/options for self-report responses are designed to comply with the principles of specificity (qualitative responses) and generality (quantitative responses) [20]. Insights from social science are borrowed to design a correct order of the questions to avoid biased effects on the answer of the respondents [19].

Table 3. Habits Section: Occupant Behavior Motivation Survey Framework

| Context | Focus Area | Survey question | Scale |
|---|---|---|---|
| Adaptive | past behavior | I typically perform these adaptive actions to make myself comfortable because:<br>§ feeling hot (summer)<br>§ feeling cold (winter)<br>§ for airing spaces<br>§ for providing natural lighting<br>§ for preventing glare<br>§ for preventing overheating<br>§ for preventing overcooling | § never<br>§ once a week<br>§ more than once a week<br>§ once a day<br>§ more than once a day |
| | | I typically perform these adaptive opportunities in my working space in order to:<br>§ restore my comfort conditions<br>§ conserve energy | § opening/closing windows<br>§ turning up/drawing blinds/shadings<br>§ turning on/off the heater/cooling when feeling too hot/too cold<br>§ using flexible dress code |
| phsychological | response automaticity | Preference of indoor environmental control in your office space | § Free manual control (operable windows and shading, manual heating and cooling set points)<br>§ Automatic mechanical control (mechanical ventilation, automatic shading and heating and cooling set point) |
| contextual | workstyle routine | What's your workstyle schedule? | full time/part time |
| | employment role | What's your employment role? | employee, manager, student, professor |
| | country of origin | What's your country of origin? | nominal |
| | environmental factors | What's the spatial configuration of your office? | § Open Space<br>§ Shared office (max 4 people)<br>§ Shared office with another person<br>§ Single office |
| social | social norms | Do you feel free to dress as you like? Do you have a formalized dress code in your office? | yes/no |
| | | How much does the building management encourage/discourage these adaptive actions/opportunities?<br>§ opening/closing windows<br>§ turning up/drawing blinds/shadings<br>§ turning on/off the heater/cooling when feeling too hot/too cold<br>§ using flexible dress code | § encouraging<br>§ don't care<br>§ discouraging |
| | | How much does the building management encourage/discourage flexible dress? | § encouraging<br>§ don't care<br>§ discouraging |

The elements of the questionnaire identify at times a specific action or motivation, by means of qualitative responses. Other times the generality of the questions is increased by aggregation of typical behaviors, by means the adoption of unpaired numerical scales (7 points). These elements constitutes the predictor variables for measuring the impact of motivational drivers over the likelihood of adopting motivation-driven rather than adaptive-unconscious interaction with the building control systems, having impact on energy and comfort requirements.

Table 4. Intention Section: Occupant Behavior Motivation Survey Framework

| Context | Focus Area | Survey question | Scale |
|---|---|---|---|
| awareness of consequences | perceived subjective norms | Saving energy in my workspace will cause me to reduce my comfort level | very much/not at all 7 points scale |
| | | Reducing comfort in my workspace will cause me to reduce my productivity | very much/not at all 7 points scale |
| | | Interacting with the control systems to make myself comfortable in my workspace will influence:<br>§ Energy consumption<br>§ My comfort level<br>§ My productivity | § reducing<br>§ any change<br>§ augmenting |
| situation responsability | perceived social norms | I am prone to accept more forgiving indoor environmental condition to conserve energy in my workspace:<br>§ to help my company to reduce budget costs for energy provision<br>§ to be visible among my coworkers<br>§ to be environmentally friendly | likely/unlikely 7 points scale |
| attitude | perceived willinginess | Are you willing to use windows/other devices to make yourself comfortable? | very much/not at all 7 points scale |
| | | Are you willing to use windows/other devices to save energy in your workspace? | very much/not at all 7 points scale |
| efficacy | perceived effectiveness | Which are in your opinion the barriers to overcome to turn your willingness into a habit? | § Lack of time<br>§ Lack of convenience<br>§ Technical barriers due to control system usability issues<br>§ Technical barriers due to space layout issues<br>§ Comfort issues |
| | | Which are for you the benefits of adopting energy saving behavior in your working space? | § Visibility among employers<br>§ Visibility of my employers/company<br>§ Comfort issues |
| | | Which type of reward would you willing to receive, to motivate you towards energy saving behaviors? | § Being financially rewarded when performing energy saving behavior (peer comparison)<br>§ Being praised when performing energy saving behavior (incentives)<br>§ Receiving negative messages or criticism when not performing energy saving behavior (naming and shaming) |
| | | How effective are the adaptive actions in helping you to stay comfortable? | very ineffective/very effective 5 point scale |

A selection of statistical models typically adopted for survey data analysis (e.g. multivariate analysis, frequency distribution analysis, marginal homogeneity test, Pearson Chi-Square test, Cronbach's alpha test, likelihood ratio test, correlation analysis, single and multiple regression models.) and data mining methods (cluster analysis, decision tree, association rules, etc.) will be applied for the investigation of the predictor motivational variables. The evaluation of the magnitude of different perceived control opportunities will establish new knowledge about the motivational sphere driving decisions of similar profiles of office users' to engage towards the energy-related measures under scope of investigation. A wide variety of survey distribution method and tools are available for survey delivery. To align with the authors' expertise, project goals and budget, the open-access and web-based Google Forms will be used.

Table 5. Control Section: Occupant Behavior Motivational Framework questionnaire

| Context | Perceived control opportunity | Survey question | Scale |
|---|---|---|---|
| ability | perceived control | How would you grade your knowledge in terms of?<br>§ how is comfort control provided in your workspace<br>§ who is responsible for comfort controlling in your workspace | § very knowledgeable<br>§ don't care<br>§ not at all knowledgeable |
| | | Who is responsible for controlling? | not at all knowledgeable/very knowledgeable |
| | actual control | During the last six months, I performed these adaptive actions to make myself comfortable:<br>§ opening window when feeling hot<br>§ closing window when feeling hot<br>§ opening window for airing spaces<br>§ turning up blinds/shadings for providing natural lighting<br>§ drawing blinds/shadings for preventing glare<br>§ drawing blinds/shadings for preventing overheating<br>§ turning on the heater when feeling cold (winter)<br>§ turning off the heater when feeling too hot (winter)<br>§ turning on the cooling/fans when feeling hot (summer)<br>§ turning off the cooling/fans when feeling too cold (summer)<br>§ removing/adding extra layers of clothing | § never<br>§ once a week<br>§ more than once a week<br>§ once a day<br>§ more than once a day |
| | perceived access | My authority (I am allowed to) to interact with control systems in my working space is | not allowed/allowed 7 point scale |
| | | My ability (I manage to) to interact with control systems in my working space is | no control, full control 7 point scale |
| | | How satisfied are you with your degree of control/ability to make yourself comfortable? | very dissatisfied/very satisfied 7 point scale |
| | perceived impediments | What are your main perceived impediments to interact with the control systems? | § Access<br>§ Knowledge<br>§ No need<br>§ Upset coworkers<br>§ Security<br>§ Outdoor pollutant |

Regarding the sample needed to assure validity and robustness of the survey question, insights from social science provide a formula to determine the survey respondent sample size and response rate acceptability, as a function of population sizes and characteristics at confidence intervals [25]. Another approach is to refer to the average sample number – about 1000 interviewed – of the occupant survey researches published in literature.

## 4. Discussion and Conclusions

The prospect of comfort theory is still debated as a multidisciplinary and controversial field [12], since comfort condition is not only related to building physical and environmental parameters but also to social constructs reflecting beliefs, values, expectations, and mostly motivation of occupants. The key elements of the proposed occupant behavior motivational framework are grounded on the DNAS framework for energy-related behaviors in buildings [13]. The resultant questionnaire is based on extensive literature review of previously developed occupant behavior surveys [20] and emerges as a combination of traditional [22] and adaptive *comfort* [23] theories, merged with occupant behavior [21] and social science theories [15-18, 24]. Behavioral insights introduce the concept of behavioral *motivation* by means of i) *individual* behavioral beliefs – leading to favorable or unfavorable habits towards the behaviour; ii) *social* pressure and *normative* beliefs – influencing individual intention; and iii) *control* beliefs, giving rise to perceived behavioral control with respect to the actual IEQ control opportunities for the specific office configuration. As a rule, the more favorable the individual habits and intention, the more encouraging the social pressure and norms, and the greater the perceived control, the stronger should be the person's motivation to perform the behaviour in question [16].

In line with this work, outcomes from Shove [1] argue building occupants' motivations, i.e. to adopt more energy conscious behaviors in offices, depends on the diffusion of sustainable beliefs and actions through society. The study establishes that users are generally not aware of their routines and habits, above all in energy field, leading to overrated existing consumption patterns. Hence, Shove [1] concludes that routine behaviors leading to consumption patterns are largely driven by social norms, and are deeply molded by cultural and economic factors. However, the connection of such correspondence remains controversial and quite undiscovered. Bridging this causality gap is one of the scope of the proposed framework and questionnaire.

The starting-point of this work is that human behavior is stochastic by nature and interactions among the several factors that influence occupant's motivations towards consumption practices are dynamic. Influencing factors change over time, rendering individual consumer (occupant) behavior and the process of (energy) consumption practices to some extent irrational, and therefore unpredictable. One of the main conclusions curtailing from this research is that rather than focusing on *individual* behaviors – and influencing factors – research should focus on the rise and alteration of *collective* and *social* conventions shaped by geographical context, culture and norms, driving occupant motivations, as they are crucial in fastening behavioral patterns, with different consequences for building energy consumption and indoor environment comfort. Further advancements of the presented study is the operative rollout of an extensive survey questionnaire campaign in different geographical locations, among the international research community embracing the IEA EBC Annex 66 on "Definition and Simulation of Occupant Behavior in Buildings" [26]. The final aim of this study – in a broader perspective – is to provide a standardized tool to drive effective occupant behavior data collection, to enhance the state of the art on knowledge, methodologies and tools.

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