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An Investigation of Occupants' Energy Perceptions in Energy Efficient Retrofitted Residential Buildings: A Review Paper

Elham Maghsoudi Nia[1], Queena Qian[2], Henk Visscher[3]

[1,2,3] Department of Management in the Built Environment, Delft University of Technology, 2600 GA Delft, The Netherlands

Emails: [1]E.MaghsoudiNia@tudelft.nl , [2]K.Qian@tudelft.nl, [3]H.J.Visscher@tudelft.nl

Abstract. Buildings are the main sector in energy consumption and CO_2 emissions. Retrofitting of existing building has been identified as one of the significant strategies for reducing the impacts of buildings on energy and environment. However, recent studies have shown that low energy buildings mostly do not perform as expected. These differences are related to different factors including the interaction between occupants and building technologies. Thus, most renovation initiatives have not considered occupant behavior equally to the energy efficiency process. Many of the existing studies have been focused on technological improvements rather than behavioral-related parameters. Hence, this study aims to review the literature on the occupants' energy perceptions and their behavioral interventions in energy efficient retrofitted residential buildings. The results of the literature review reveal that household's energy consumption significantly differs according to the various factors including social-economic, cultural, household composition as well as individual attitudes, habits, experiences, and occupant practices. Moreover, the energy consumption in the residential sector is highly dependent on demographic parameters. The demographics factors are classified according to type of family, level of income, age of the occupants, and individuals' educational status. The findings shows that energy perception gap formulates the energy behavior and it is related to the lack of personal interest, accurate information and individuals' awareness about how to consume efficiently. Therefore, it is suggested that the level of occupant's perception on energy, control, or comfort have to be considered during energy efficiency retrofits. The study contributes to understanding of occupants' behaviors which cause energy performance gap and enlighten approaches to encourage more energy efficient behavior.

Keywords: energy efficiency retrofit, occupant behavior, energy performance gap, energy perception, people intervention, residential buildings

1. Introduction

Humans are sensitive and conscious beings, with needs, attitudes and emotions, and change the comfort and health conditions, depending on their needs [1]. Behaviors are the result of a response to environmental stimuli, guided by an emotional response [2]. Comfort level of the occupants can be defined as lighting comfort, winter thermal comfort, summer thermal comfort, acoustic comfort, indoor air quality/ ventilation [1, 3-6]. Therefore, occupants may intervene or adjust the renovation measures in order to reach to the level of comfort. However, this level of comfort differs for each individual and affected by different factors. Recent research has shown that energy efficient buildings usually do not perform as expected [7]. The large differences between the expected and actual energy consumption have been found in dwellings with same characteristics [8]. These differences are related to different factors such as rebound [9], pre-bound effects [10], and the interaction between occupants and building technologies [11]. These effects are linked to the different household typologies, comfort preferences and lifestyles of occupants [12]. Subsequently, the people intervention in renovation measures and energy consumption based on their demand can not be neglected [13]. It should be highlighted that the technologies such as building materials and technological equipment, can partially contribute to the energy mitigation, specifically to reduce the over-consumption behavior. Therefore, a fundamental change in how individuals use energy in their lifestyle is essential [14]. In addition to the household typologies, the characteristics of the buildings is effective on energy consumption by the occupants. For example, building characteristics have a higher impact on the elderly than on younger people [13]. Hence, the older people may have a different level of comfort. The aim of the study is to investigate the energy performance gap caused by people behavior and the occupants' interventions in energy efficient retrofitted residential buildings. The objectives are: 1) To review the occupants' energy use perceptions/misperceptions, 2) To identify the people behavior in energy efficient buildings in terms of use/improper use the energy efficient technologies 3) To recognize the possible improvements in order to reduce the people intervention and increase the awareness of occupants, and to reach the actual energy performance. Therefore, this study identified two types of the behaviors including user related and building related behaviors, issues and concerns involved, hence provides a set of recommendations for further study in this area.

2.Literature Review on Energy Related Behaviors

This study has reviewed several literature related to the energy behaviors of occupants and classified it into three sections including energy perceptions of occupants, users related behaviors and building related behaviors as follows:

2.1.Energy perceptions of the occupants

Energy use perception or misperception differs between individuals due to the information gaps, consequently affect habitual energy behavior. The energy perception gap is related to tendency or awareness of the individuals about energy efficiently consumption or misperceive of energy conservation due to the lack of interest and accurate information. [15]. As Swan and Ugursal [16] stated that the key factors in the total household consumption are mainly dependent on the climate, physical dwelling characteristics, appliance and system characteristics, ownership and occupant behavior. Moreover, the research of Guerra-Santin, Boess [12] showed that demographics characteristics (age, gender, household composition), socio-economic level (education and income level), and lifestyle and occupation type of the households (retirement, full-time work, unemployment) [11, 17] are effective factors on energy consumption in houses. Furthermore, it is shown that similar household types can have diverse behavioral patterns based on their particular situation, attitudes and thermal comfort preferences. For example, two single households with the same income possibly might have different levels of energy consumption due to the age, background, employment status and health condition. It should be noted that the presence of children and elderly people, are effective on energy consumption. [18]. Generally, household type (single or family household and presence of children), number of occupants, income, the energy efficiency of the dwelling, building characteristics (type of ventilation system and energy label of the building), occupation (number of employee, occupation time [19, 20], type of dwelling, construction or renovation type are effective on factors on gas consumption. Moreover, household type, income level, number of household, type per energy label are effective factors on electricity consumption [13].

In addition to the occupant related (habits, social-economic, household composition) issues, the perception of occupants is influenced by the systems and interfaces in their house before and after renovation, as well. An occupant might turn up the thermostat if he is confronted with draughts and therefore cold. And he might turn down the ventilation system (and opens a window instead) if the system makes too much noise. Or open a window if the bedroom (in winter) is too warm due too heavy insulation. So behavior is partly also a response on the renovation measures. Therefore, two types of energy related behaviors have been defined including building related and user related behaviors. There is a direct relationship with occupants' comfort and the energy consumption by HVAC systems, lighting and other systems. This energy usage is affected by the occupants' needs (indoor temperature setting), lifestyle and type of occupation (retired, working at home, full-time working) and the type of household (single adult, couple, family). Moreover, user related energy consumption is linked to the end usage of domestic hot water (DHW), appliances and cooking [21]. These two types of behaviors are discussed in the following sections.

2.2. Users related behaviors
In terms of intervention of households in the energy consumption, it significantly differs according to the various factors including social-economic, cultural, household composition and occupant practices resulting from the affordances, the interfaces and performance levels of the indoor environment and energy systems. There is no definition for the average occupant behavior, rather domestic energy consumption practices. It is suggested that human behaviors are interplays of environmental, personal, and social factors. For instance, the level of occupant's perception on energy, control, or comfort can affect their actions and the environment. Hence, it is important to understand human perception from a behavioral point of view, by understanding their knowledge of the context surrounding them [22]. Several recent reseaches have investigated the effective factor on energy related behaviors of people [22-25]. The review of the studies show that the energy consumption in the residential sector is mainly dependent on households demographic characteristics. They categorized demographics elements to type of household (nuclear family, single parents), level of income, age of the occupants, individuals' educational and professional factors (self-employed or migrant workers). The other parameters to classify an energy consuming behavior are type of the occupancy (tenants or home owners), physical characteristics of the home (building type, age of the property, size, building thermal envelope), residential physical environment (land use density, accessibility to public transport), location (housing area, neighbourhood attributes), contextual conditions (cost-implications, availability of products, energy supplier and price, infrastructure), individual attitudes (behavior specific predisposition) and individual habits and experiences (household daily routines, occupants' heating patterns, lifestyle), heating system of a dwelling, quantity and type of used appliances (devices' technical specifications) and outside temperatures [15]. In relation to the household energy consumption behavior, personal attributes such as psychological, habitual, structural or cultural variables, should be further considered since they highly contribute in the individual behavior impact on energy consumption [26]. Additionally, income was also found to be a determinant of energy use, as does the type of occupancy of a house. It means increase in income results in an increase in energy use. In addition, privately rented houses are used more energy than in those with socially subsidized rent or owned due to the lower quality of privately rented houses compared to others. Moreover, households use more energy when heating is included in the rented house [19]. In conclusion, Pothitou, Kolios [15] based on the surveys which were conducted [27-32] has shown consumption patterns and practices in daily occupants' life, which can be summarized as follows:

- Generally a minor numbers of occupants are aware of their annual heating, electricity and water consumption.
- Daily practices which are developed along with the different types of technologies influence occupants energy use. An awareness of energy consumption or practices to decrease waste energy, indeed do not lead to a new behavior adoption, since old habits continue.

2.3. Building related behaviors
As aforementioned, living environment of the houses and their operability such as mechanical ventilation systems, are significant factors which affect occupants' perceptions of energy efficient houses, and accordingly their adoption [33]. In order to reduce the energy consumption, different energy efficient building technologies and renovation measures are developed. However, the role of the people

in energy efficiency contribution and their participations have to be considered. As the recent studies shows, highly educated occupants, homeowners, older households, women, and people with high level of income have more participation in energy efficiency [19, 34-36]. Effective factors on energy usage of dwellings can be divided into technical, building characteristics and behavioral factors. Temperature settings (the use of a thermostat: tend to turn it on more often, the setting of temperature during the evening and night), type of insulation are related to the technical factors. Presence of different spaces and their functions (presence of garage, shed, basement, open kitchen and number of heated bedrooms), size and type of the house are the effective factors related to the characteristics of the buildings on increasing or decreasing energy use. Age (usually older residents use more), occupation (income, the presence of people during the day), the temperature settings by the occupants and type of occupancy (socially subsidised rent or privately rented dwellings or privately owned) are the common factors related to the behaviors of residents that can affect energy usage of dwelling [13, 19].
In zero-energy building concepts, indoor temperature, humidity and noise level and the systems operation (such as mechanical ventilation systems) are effective factors in occupants' perceptions of energy efficient houses [33]. The end-user experience research in energy efficient houses can be summarized as follows:

- Sceptical about mechanical ventilation systems [37, 38]; mechanical ventilation in housing may have been negatively perceived due to problems related to poor installation [39-43],
- Overheating in summer (a perception of insufficient summer comfort particularly in the bedrooms) [33, 38, 41, 44-46],
- Controllability: Level of control of their heating system/ temperature control in winter [33, 38, 42, 47],
- Provision of good air quality (particularly air humidity): dry air in living rooms/ and in winters [33, 38],
- Noise from equipment or odour problems [33, 38],
- Maintenance problems [38],
- Related deficiencies in heating and ventilation to perceived poor quality or installation [39-41, 43].

It can be concluded that there are some design deficiency, for instance, lack of shading or ventilation bypass, or technical deficiencies in the heating and ventilation systems. Therefore, it is recommended to improve user-friendliness systems and provide specialised information on building services, especially mechanical ventilation systems [38].

3. Discussion

The user and building related behaviors have been reviewed in the previous section. Table 1. shows the reasons for some of the occupants' behaviors, the way in which the residents' respond and some recommendations to reduce the people intervention. Accordingly, the possible improvements and some recommendation in order to reduce the people intervention and increase the awareness of occupants, and to reach the actual energy performance are as follows:

- Match people's needs with technical possibilities [48],
- Improving the design and installation of indoor systems, including noise protection, sufficient air humidity control and odour removal strategies [33, 38],
- Simplicity and the user-friendliness of control systems [33, 40, 49],
- Detailed information provision, including initial oral instructions and providing written manuals [33] and improving user-friendliness and information on building services [38],
- (Long-term) follow up information about the use and maintenance of systems. Manuals only are not enough [50],

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- Feedback from occupants [33], investigation of aspects like residents' satisfaction and experiences, take resident's complaints seriously and investigate further possible malfunctioning of components and installations and mismatches with their use [50],
- Additional and better user information (short introduction to the house, information on passive houses, how to behave in normal and exceptional circumstances, operation manuals, detailed instructions on the advanced housing concepts [33, 43, 49, 51-54],
- Behavior change over time: Ensure that people have not lost enthusiasm and monitor their satisfaction and interaction over time, act on it [48],
- User-oriented technical information and/or training by qualified persons [33],
- Design for people's needs: a) Anticipate how the needs will be served, b) Involve them in decisions,
- Develop standardized methods for actual needs and interaction with systems, heating and ventilation set points. This could strongly enrich existing simulation models [50].

In conclusion, residents' interventions in residential buildings, which cause energy performance gap, is due to the different comfort perceptions, maintenance issues, their awareness, and improper use of the system. These interventions can be reduced by designing user-oriented, and simple systems, and by providing the occupant with detailed information and long term monitoring and feedback to track their behaviors over the time.

Table 1. Occupants' behaviors and intervention in energy efficient houses and the suggestions for improvements [48, 55, 56].

Causes		Resident intervention	Improvement
Comfort condition perception	Thermal comfort	Leave the thermostat on 24° to catch any heat they can possibly get	Monitor reasons for setpoint/Create greater variability in heating
		Distrust the heating, buy electric heaters	Smarter heating configurations to allow for greater flexibility in use
	Need for fresh, clean air	Not familiar with the ventilation principles of a ZE house.	System should monitor itself.
		Non-use of the ventilation control/high CO2 values over several hours in some rooms	Monitor HRV (WTW) use, window use and CO2.
		Windows are trustworthy ventilation – summer and winter/ for aerating, or letting pets in and out	How to instruct and monitor effect
Maintenance issues		Contradictions in how residents are expected to interact with their house (Level of involvement)	Set up a coherent interaction concept for deep renovation, based on the needs and experiences of residents in combination with the technology and monitor if it works
		Problems with heat pumps due to the bad maintenance	Attention in design stage to the position and spaces for technical equipment and maintenance

Unawareness	Residents are not aware of the current consumption	Energy monitoring with smart meter, Direct feedback in-house via an energy consumption manager, The bimonthly specification of the current use, compared to a previous period, Sufficient motivation and Increasing awareness and urgency
Unawareness	Wasting energy, Accustomed to the certain degree of comfort (Unreasonable comfort requirement)	Motivate people to prevent waste, Use the waste checker
Improper use of system	To heat a large part of the house almost continuously during the heating season	A direct price incentive
	The infrared panel can remain on The heat recovery ventilation on position 3	

4. Conclusion
This paper has presented a review on occupants behaviors and intervention on energy performance in residential buildings and classified it to user related behaviors and buildings related behaviors. The findings and discussions within this paper shows that people mainly are not aware of their annual consumption of electricity, heating, and water. However, an awareness of domestic energy consumption or practices do not lead to the new behaviour adoption. Therefore, besides, the motivations, feedback and energy monitoring, long term follow up and monitoring of people interaction is important in reaching to the target of actual energy performance. Technical, building characteristics and behavioral factors are effective on energy consumption of the dwellings. Comfort perception and maintenance, awareness and improper use of the system can be linked to the user/building related behaviors. Through review of the possible improvements of the systems design, providing user friendly and simple system according to the desire of the people with detailed information and feedback from occupants is recommended.

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