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A Brief Review of Literature and Methodology in OEB Research

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This paper reviews the research completed in the field of Occupant Energy Behaviour (OEB), examines the previous research findings and methodologies in order to identify gaps and suitable methodological approaches in understanding OEB in Passivhaus for better energy efficiency. The research suggests that Passivhaus as a new housing typology, its socio-cultural, socio-economic and socio-technical groundings would need to be reconsidered from empirical data, and would benefit from more qualitative research into the field.

1. Introduction

As more and more emphasis is given to energy efficiency, advanced environmental equipment and technology have started to play an increasingly important role in the built environment. To provide comfort with less energy, a new system of building has been devised with integrated hardware (balanced MVHR, super insulation, etc.) as well as smarter software (programmable control, network control, etc.). *Passivhaus* and Bed Zed are a few examples. The application of such systems is a giant leap into sustainable living. However many POEs (Post Occupancy Evaluations) suggested unsatisfying responses from occupant comfort surveys and from energy consumption data [2, 13, 14, 17]. How have low-energy buildings resulted in high energy use? Just as Janda stated in the title of his article, 'Buildings don't use energy: people do' [11] Empirical studies suggested that OEB (occupant energy behaviour) is a major factor in determining energy use. As a matter of fact, it has contributed to over half of all heating use according to a study [6].

The previous research into the field of OEB identified several factors affecting energy behaviour. These include set point temperature, building characteristics, daily schedules, knowledge, value patterns, folk theories and personal beliefs, etc. [5, 8, 16, 21]. As quite a few studies have been completed on OEB in generic building or low-energy building, research done on *Passivhaus* focused more on the design of technological controls [19], suggesting that a smart system isn't necessarily better at saving energy until its interface is as intuitive as its design intention. However, the proposed research will try to argue that *Passivhaus* as new building typology is built upon new ideas of comfort, where expectations, backgrounds and attitudes of occupants are expected to change. Therefore, whether the same factors that explain OEB in generic building would still take part in the shaping of *Passivhaus* OEB is in question. The distinctive technological usability research is just part of the new research regime where other variables from end-users also need to be

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reconsidered and studied. With more and more *Passivhaus* planned to be constructed over the next few decades, to address the OEB here again is essential. On the other hand, the majority of the previous research has been done using a quantitative approach whereas only a few studies have adopted case-focused qualitative methods. The findings using qualitative approaches showed potential benefits in gaining a better understanding of sustainability in people's everyday lives and the nature of their energy use. The proposed research also hopes to address the issue of methodological approaches to advocate more qualitative research in the field. This work in progress paper will give a brief review of the research context and methodologies used in OEB research, then discuss gaps in previous research and suitable methodology.

2. Brief review of OEB research

Verhallen and Van Raaij suggested that household behaviour contributes to 26% of the variance in energy use after their study on 145 households [20]. Even for low-energy housing, the energy consumption could vary by 14 times between two similar houses [7].The same research team has also quantified occupants' behavioural factors with a TPB (Theory of Planned Behaviour) questionnaire in relation to energy use in low-energy housing – 51% for heating, 31% for electricity, 11% for water [6]. We can gather from the above studies that occupant behaviours contribute greatly to energy use deviation, whereas on the other hand with regard to the comfort model, individual control opportunities also seem to have a stake in perceived comfort of indoor conditions [12].

2.1 OEB – On generic housing type

In the 1980s Van Raaij and Verhallen from the department of Economics, Erasmus University completed research on energy use and occupant behavioural models [16]. This is by far the most comprehensive, albeit conceptual, model available. Among the variables, the dominant factors are home characteristics and household behaviour, in which set point temperature and ventilation are the two main variables of home characteristics [16]. Unfortunately, a major part of the model doesn't have empirical evidence to back it up, and as the author clarified himself, the model 'is not a process model. Processes mediating the effects on energy use, e.g. socialization, attitude change, and learning, are not described in full detail' [16]. Santin's research of 15,000 houses in the Netherlands confirmed the importance of the thermostat (set point temperature), and suggested that insulation of the dwelling, presence of occupants, household characteristics (size and income) and age are also significant factors that would affect occupant behaviour and cause fluctuations in energy use. Furthermore, Santin suggested that occupants' employment and economic state would affect energy consumption based on their choice of dwelling type, since building characteristics are determinant to energy use [10]. Another study which related energy use to occupants' value patterns has been done by Vringer, which adopted the value system of Rokeach and the work of Schwartz and Bilsky, but concluded that

no correlation between value patterns and energy use was evident, and motivations of saving energy only showed slight influence on actual energy use [21]. However, the targets of this research were general households where each individual's value pattern varies greatly, along with their housing type and other factors discussed in previous research. The sole consideration of socio-economic profiles to calculate reference energy use as a base for comparison is therefore partial and might have consequently resulted in a non-significant relationship between studied variables. Determining the importance of one variable in the field of behaviour and energy consumption is hard, as not all variables are identified or are quantifiable. Especially when low-energy housing came into play, along with a paradigm shift into the 'adaptive comfort' model, many more dimensions have been added where a comprehensive understanding of these variables is needed. One dimension that plays huge role in such relationships is the perception and understanding of new technology in smart energy systems.

2.2 OEB – Targeting smart systems

Peffer suggested that it is a usability issue after reviewing thermostat usage in American homes and found that half of the homes don't use programmable thermostats [15], he then suggested the interface design should be even smarter, using network and voice recognition to de-complicate it. He also expressed concern that progressive innovation in thermostats (e.g. Energy price adjusted control) may fail to further save energy if not given a proper design interface. To dig deeper to find the connection between occupancy and thermostat use, another study was conducted where programmable thermostats and manual thermostats were differentiated. This research suggested that more often than not, occupants with programmable thermostats tended to have longer heating hours than those with manual thermostats or valves. Similarly, Households with balanced ventilation (referring to heat recovery ventilation) would tend to use it for more hours than households with mechanical ventilation [10]. The counter-productive result of adopting smarter system and controls has therefore raised more questions than it has solved. Shipworth compared data on central heating demand temperatures and durations with building, technical, and behavioural data based on the first national survey of energy use in English homes and concluded that contrary to assumption, adding controls doesn't necessarily reduce energy use [18]. It is then not surprising to see that in Brager and de Dear's review, the research on thermal comfort showed a new trend towards less complicated, more intelligible and responsive technological systems [4].

2.3 OEB – In Passivhaus

Compared with other low-energy housing, one distinct feature of *Passivhaus* is the MVHR system, which allows occupants to control ventilation fan speed and heaters to regulate the temperature and air-flow in the air-tight house. The system is integrated and has developed smarter features such as programmable controls, among others. This new system along with other technologies

featuring in *Passivhaus* require a certain understanding and technical knowledge background from the occupants. Meanwhile, distinct from learning process, home occupants will develop habitual strategies in using control as a daily practice, As a result, Stevenson suggested, 'These habits can effectively bypass thoughts about values and motivation and are highly dependent on the usability of control interfaces' [19]. Indeed, aside from energy decisions based on value, age, household size, etc., this form of interaction with the house uncovers a deeper correlation in habitual behaviour. It is the occupants' perception and expectation of service technology and control behaviour in relation to other social factors that is in need of exploration to effectively reduce energy consumption. Another study comparing feedback of three pairs of *Passivhaus* and conventional house occupants suggested that *Passivhaus* occupants tend to behave with greater regard for the environment and have greater control and awareness of their energy use, but didn't give information on OEB [22]. This has highlighted the need for greater social study in this new housing typology.

3. Brief review on methodological approach

The majority of the research done in this field adopted a quantitative research method. In Van Raaij and Verhallen's study over two years, 157 questionnaire surveys were sent out and 145 occupants responded, mainly housewives. This was undoubtedly successful in terms of response rate, and the questionnaire was also rich in content where 17 energy behaviours were reported [20]. The questionnaire design and data collection were done by an external organization, which might explain the good response rate. Santin's data was originally collected by KWR of the ministry of Housing of the Netherlands on 15,000 houses, the survey was interview-based, carried out randomly along with another set of 3 years' energy data from energy providers. This was a good combination of data sources to study energy behaviour, however, as the author suggested himself, the data was obtained from 9 years previously, but the analysis didn't take energy price growth or other development into account, and variables were categorical values and only relevant to one or two categories [8]. Likewise, Blight and Coley's research used a third party tool on a survey of 20,000 weekly UK household journals to measure data from *Passivhaus* around central Europe using a computer model [1]. It is a growing trend to use simulation in energy research, but it is arguable that this is not based on real life scenarios when behaviour data gathered was not from actual Passivhaus users to test theory. As an example of semi-qualitative research, De Meester's case study into 11 buildings with controlled building characteristics quite satisfyingly examined empirical" studies of OEB in relation to insulation levels [3], as a theory testing method, it is successful in controlling parameters and drawing valid comparisons. Another case study was done on low-energy housing by Stevenson [19], where technological control usability was examined, it used surveys with both closed questions and open-ended questions where occupants could express their opinions more freely in order to discover design problems. Another methodologically relevant study was done using a combination of monitoring data and interviews with occupants to better

understand their everyday lives, which has showed its potential in understanding social practice with the transformation of technology [23].

4. Discussion

It can be concluded from the literature review that research in the field of OEB has built up a quite comprehensive framework, but to apply this framework onto *Passivhaus* directly is questionable as both comfort paradigm change and technological change have occurred in the new housing type. More research on *Passivhaus* focused on end-users' experience than actual energy behaviour. And more OEB research focused on technological issues such as control usability and responsiveness while taking previous results of OEB research in normal buildings for granted. Although technological issues have their root in social construction, in the context of sustainability, *Passivhaus* should be taken as a new typology that generates new ideas of comfort and habitat. Occupants living in such new housing types will have different behaviour generators. Thus, the social grounding of such new typology needs to be reconsidered, not only from a technological perspective but from a broader socio-cultural and socio-economic domain. Meanwhile, the research into OEB currently involves more quantitative research than qualitative, and much of the quantitative research was done in alignment with a third party. The quantitative approach has provided valuable data for understanding the variables, but qualitative approaches may be able to identify and create a better understanding of occupants' behaviour.

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