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PERCEIVED KNOWLEDGE IN OPERATING A *PASSIVHAUS*

Research in Progress Paper

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Abstract: *Passivhaus* is a building methodology established in the 1990s in the sustainable construction industry. As a new building typology, *Passivhaus* features new and integrated mechanical heating and ventilation technology and building materials, thus requires a new set of knowledge and operation skills to deliver intended energy outcomes, the knowledge and familiarity occupants possess to control their *Passivhaus* is therefore an important factor in determining their energy behaviours. This research explores the 'perceived knowledge' of occupants in controlling their home environment and its relationship with their energy behaviour and energy use. Different from actual knowledge, 'perceived knowledge' measures the confidence, patience, willingness and accuracy of occupants in understanding and operating their home environmental equipment. The understanding of this process is important in understanding the deviation of occupant energy behaviour which occurs in a *Passivhaus* when compared with in generic buildings. This article demonstrates results from a preliminary pilot study on a private *Passivhaus* project and a case study on a social *Passivhaus* project in Scotland, uses a combined method of quantitative and qualitative approach to explore the relationship between 'perceived knowledge' and occupant energy behaviour in *Passivhaus*.

Keywords. *Passivhaus*; perceived knowledge; occupant energy behaviour.

1. **Introduction**

Sustainable construction in the 20th century showed an increasing trend in the application of renewable energy generation technologies (SVP, wind turbine,

etc.) to reduce the environmental impact of mechanical systems, also a growing interest in low impact materials (sheep wool, straw, hemp, etc.) to insulate buildings. In order to provide comfort with minimum energy input, a new system of building has been devised with integrated hardware (balanced MVHR – Mechanical Ventilation Heat Recovery) as well as smarter software (programmable control). *Passivhaus* is one of the examples that has taken this idea to the extreme end of the spectrum. However, research shows that not every *Passivhaus* project has been satisfying in terms of comfort and energy performance (Brunsgaard et al., 2012; Mlecnik, 2013; Molin et al., 2011; Rohdin et al., 2014). Previous research suggests that occupant energy behaviour (OEB), plays a very important role in determining energy use and are one of the main reasons why buildings aren't performing according to predictions (de Meester et al., 2013; Feuermann et al., 1992; Guerra-Santin and Itard, 2010; Van Raalt and Verhallen, 1983; Vringer et al., 2007). Comparing with other low-energy housing, one distinct feature of *Passivhaus* is the MVHR system, which allows occupants to control and regulate the temperature and air-flow in the air-tight house without manually operating windows. The system is integrated and has developed smarter features such as programmable controls, among others, and some add-on features such as post heater, defrost heater, active cooling, air source heat pump, etc. This new system along with other technologies (solar thermal collector, solar PV panel, log burning stove etc.) have been combined in different *Passivhaus* projects with different levels of integration. These technologies featured in *Passivhaus* require a certain understanding and technical knowledge background from the occupants to achieve predicted performance. This paper will examine a specific aspect of occupant energy behaviour – perceived knowledge and familiarity of occupants with their *Passivhaus* systems in relation to their energy use.

2. Research context

2.1. LITERATURE

As far as technology systems in relation to occupant energy behaviour research is concerned, a growing attention has been given to control and usability in this field (Guerra-Santin and Itard, 2010; Peffer et al., 2011; Shipworth et al., 2010; Stevenson et al., 2013), while the other side of the control problem - user's knowledge and perceived knowledge is still a relatively new territory. Brown and Cole (2009) conducted a case study of two office buildings - one 'green' while the other being regular – which used BUS survey, interviews to analyse the occupants' perceived knowledge level,

actual knowledge and comfort satisfaction in relation to how occupants control the environmental technology, suggesting that even with an induction session, heating and cooling systems are still less well understood among the occupants, a positive relationship between perceived knowledge and frequency of personal control has been detected in 'green' building. However neither knowledge nor personal control resulted in higher comfort rating in both buildings, which further suggests that a more complex relationship between comfort, personal control and knowledge is yet to be discovered. Brown (2009) concluded that the gap between the occupants' willingness to learn and the availability of information needs to be filled out.

Another interesting and more related research was found in a graduate dissertation (Richards, 2013) by Jacqueline Richards. The research took Ditchingham *Passivhaus* project as a case study, using energy data monitoring and a structured interview to compare designed energy performance predicted by PHPP (*Passivhaus* Planning Package) with the households' actual energy consumption. The comparison showed a big discrepancy between the two and the study demonstrates that the lack of knowledge and understanding in the *Passivhaus* system is one of the main reasons the discrepancy happened. According to Richards, the MVHR unit was 'largely misunderstood' and thus in many cases occupants rely on the boost heater or immersion for hot water (Richards, 2013). Although the result shows a gap between predicted and actual energy use, most of the households are satisfied with their energy bills and expressed no ambition to further reduce their energy consumption. From these findings Richards then suggests that it might be due partly to the occupants' assumption that *Passivhaus* system will perform automatically at level of best practice without adaption in behaviour and lifestyle, and this assumption might lead to a barrier towards behaviour change.

2.2. PILOT STUDY

The pilot study as part of a doctoral research was completed on a single family *Passivhaus* project in Scotland. This study comprises of a two-hour long semi-structured interview, and questionnaire surveys on comfort and control usability (Stevenson et al., 2013) completed by occupants after the visit. In general, the occupants expressed high level of satisfaction with the comfort of their house. The energy performance is relatively good given the area of the house. A major part of the semi-structured interview focused on the technology in relation to users' knowledge and their behaviour and several issues regarding the knowledge level of their *Passivhaus* system emerged. Lack of information about MVHR resulted in uncertainty of control, for example, if they wanted to make the house a little bit warmer, it was never

clear for them whether to turn up the fan speed on MVHR or to turn it down, and they were not convinced by the architect's recommendation – to turn up the fan speed – as it went against their own general knowledge. Their solution was to leave it alone and light up the wood burning stove. Further, the interview revealed some occupants' perception of technology as 'another thing that can go wrong', and were thus not keen on a complicated technological system. This could further explain their reluctance to explore the system's performance. They have also expressed their perception that living in a *Passivhaus* doesn't mean 'a change of lifestyle', and they weren't intentionally seeking to change their energy behaviour. Meanwhile, they were not completely clear about their energy expense compared with the average UK household or *Passivhaus* household, but gave a comparison to their energy bills in their old house, and expressed no intention in further reducing energy use.

This pilot study suggests that 'perceived knowledge' is highly relevant to occupant energy behaviour: it affects control frequency and occupants' energy decisions. The study also suggests that 'perceived knowledge' – confidence and willingness in controlling the *Passivhaus* system is shaped by various social factors (e.g. general knowledge, opinion on technology, lifestyle, previous accommodation, information accessibility, etc.) and that it is a learning process throughout the occupancy. To take the research forward, another *Passivhaus* case has been studied where four occupants of a social housing scheme in Scotland have been interviewed in detail.

3. Methodology

The study takes a combined approach of quantitative and qualitative methods. It includes a semi-structured interview, energy data collection and a web-based questionnaire survey targeting a wider range of sample size, the questionnaire survey is still under data collection process. The semi-structured interview with occupants in the following case study has both open-ended and close-ended questions, it ensures the documentation of a structured series of information (e.g. household size, MVHR settings, energy use, etc.), and qualitative issues that differ from household to household (e.g. experiences, lifestyle change, difficulties in operating the system, etc.).

The semi-structured interview in the following case study has four sections, the first section examines the tenants' perception of comfort and their lifestyle change, the second section asks about their knowledge and opinions on technology of the house, the third section deals with their perception of sustainability and the last section explores their actual energy behaviour and energy use. The energy behaviour mainly includes MVHR, stove and solar

panel system control. These four sections are key elements resulted from the pilot study. Different from previous research where occupants' knowledge were exclusively studied against only monitored energy data, the interview in this research was designed to include aspects other than technology and knowledge so the result could benefit from a bigger picture of everyday lives in *Passivhaus*. The four sections altogether examine the occupants' knowledge and familiarity with their *Passivhaus* systems against their energy behaviour and lifestyle change. The analysis of the interviews used NVivo 10 as assistant, the software was proved to be helpful in terms of organizing interview questions and comparing answers.

4. Case study

4.1. GENERAL INFORMATION

The studied *Passivhaus* project is located in the south of Scotland, consisting of 8 semi-detached houses completed in 2011 and occupied immediately. Four households took part in the interview, all of which have lived in their *Passivhaus* for more than two years. House A and B have three bedrooms and C and D have two bedrooms. Table 1 provides a comparison between energy consumption in general UK household and in Passivhaus standard. Table 2 on the following page shows briefly the building characteristics and general information on the households, it also covers energy behaviour and energy consumption of each household.

Table 1.Comparison of U.K domestic sector energy consumption and *Passivhaus* standard

	Heating or Cooling demand	Electricity use in 2013	Gas use in 2013
Average household	>= 55 kWh/m2/yr	4170 kWh/yr	14829 kWh/yr
Passivhaus standard	<= 15 kWh/m2/yr	Primary energy demand 120 kWh/m2/yr	

The mechanical system installed in this project benefits from an integrated hot water system: the wood burner heats up the water when solar energy isn't enough, and the immersion heater is the backup solution. According to the occupants' previous experiences, the immersion heater is the key to energy use deviation, all four interviewees are quite cautious about not using immersion heater more than necessary. MVHR and solar panel control patterns are all quite simple, and the occupants seemed to have developed

comfortable control habits, given they have been living in the *Passivhaus* much longer than their perceived learning period.

The house visit and general information collection was followed by interview. Each interview took about an hour. The following sections will be structured according to the interview sections: comfort and lifestyle, perceived knowledge, and perception of sustainability.

Table 2.General Information and control behaviour pattern

	House A	House B	House C	House D
Area	108	108	88	88
Household size (people)	3	5	2	2
Energy use (kwh/yr)	~ 3072	~ 4044	~ 2475	3426
Thermostat (°C)	18 - 22	21	20	20
Thermostat setting comparing with previous accommodation	lower	lower	lower	No thermostat in previous house
MVHR unit	Paul 200	Paul 200	Paul 300	Paul 300
Stove	Woodfire F12 Log burning Stove	Woodfire F12 Log burning Stove	Woodfire F12 Log burning Stove	Woodfire F12 Log burning Stove
Solar Panel	Worcester Greenskies flat panel solar thermal collectors	Worcester Greenskies flat panel solar thermal collectors	Worcester Greenskies flat panel solar thermal collectors	Worcester Greenskies flat panel solar thermal collectors
Immersion heater installed	Yes	Yes	Yes	Yes
MVHR setting in winter	Fan speed 1 or 2	Fan speed 1, on boost if cooking	Fan speed 1	Fan speed 1
MVHR setting in summer	Fan speed 1 during night, 2 during day	Switched off	Standby	Switched off
Average stove usage	Daily during winter, depends on hot water	Every two or three days in winter	Twice a week	When needing hot water
Learning period	6 months	8 or 9 months	Not long	3 months

4.2. COMFORT AND LIFESTYLE

In the first section, all four occupants showed satisfaction when being asked about the comfort value of their houses. All four tenants used to live in cold houses with expensive energy bills, therefore appreciate the warmness and the low cost feature of their *Passivhaus* very much. The occupants then were asked to complete a short survey on the comfort level of their *Passivhaus* from nine perspectives, namely *Privacy and Intimacy, Domesticity, Layout and Furnishing, Leisure and Ease, Heat, Air, Light, Efficiency and Convenience, Style, Health and Safety, Sustainability*. The occupants were asked to rate firstly the importance of the nine perspectives that contribute to 'comfort at home', then to rate the comfort level of their *Passivhaus* from these nine perspectives, on a scale of 1 to 5, 5 being excellent. The survey examines if the comfort value of *Passivhaus* matches occupants' expectation of 'comfort at home'. The following chart (Figure 1) shows respectively feedback from House A and House B. The comparison is quite interesting. For these two tenants, their *Passivhaus* provides very good physical environment (heat, light, air, layout, style, etc.), but are lacking in other aspects (privacy, leisure and ease, etc.). This also suggests the definition of 'comfort' has been pre-defined as physical comfort only, while the other aspects are quite easy to be overlooked by researchers.

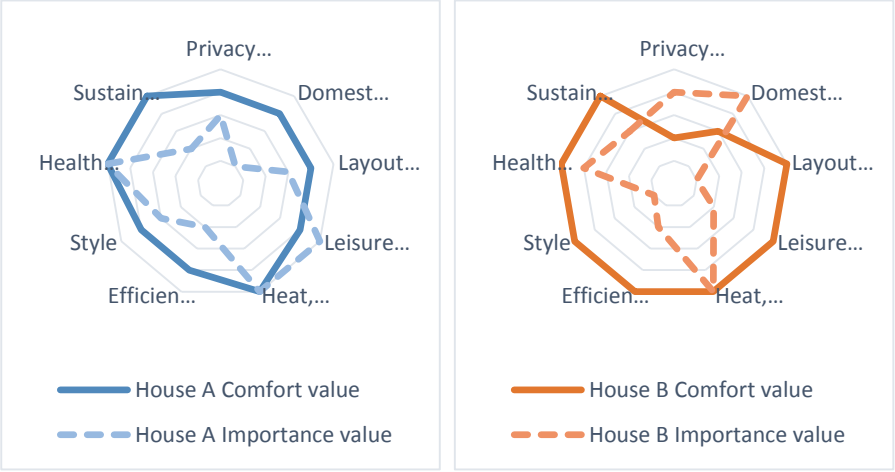

Figure 1. Comfort Value and Importance Value

When talking about lifestyle change, at the beginning they only stated the change as being moved to the countryside, or didn't think their lifestyles have changed at all, however later questions about technology reflected that they had developed new habits relating to the new house. For example, small things like checking the weather, or close/open windows, etc.

> …I think you do have to think yourself especially if you are gonna go out, you do have to think in the morning, is it going to get hot today, if it is you have to open your windows now, if you go out. Otherwise you come home to a boiling house, I just think about weather all the time, every day, new habit. (House A occupant)

When being asked about preference between automated control and manual control, all four interviewees chose manual control over automatic systems, saying that they would much prefer to manually control their own home environments – even it meant a change of behaviour and lifestyle. The answer is consistent with the fact that none of the occupants has used the programme option on the MVHR (which allows automatic setting of the MVHR on a weekly basis), some didn't or often forgot to use 'unoccupied' mode when away on holiday (which automatically exchanges the air every 15 minutes). However, this doesn't mean that they don't trust technology, it is recognized that a higher level of manual control suits a wider range of lifestyles.

All tenants bar one had quite a few issues with the system at the beginning of the tenancy, mainly with the wood burner. Differing from what a stove traditionally represents - a focal point with roaring flames in the living room - the wood burner in *Passivhaus* performs a different function, as 90% of its heat goes to boil the water. If the stove is to be lit the same way, the tank of water boils very quickly and the system automatically flushes in cold water to prevent overheating. Having battled with the problem for several months in the first winter, the tenants learned then to burn the stove slowly and only light it if necessary. The focal point of the living room has thus slightly shifted away from the stove because of this. The manager of the estate also installed a simple lighting system by the stove to indicate if it is necessary to light the fire.

> …it's been a bit of a change of lifestyle, … Particularly I think the fire, so before I would put the fire on and it was a nice thing to sit around and I still trying to use the fire like that just to have a nice thing in the room, then I realized it's just completely pointless, cuz you just sit there and take off all your clothes and open all the windows… (House B occupant)

4.3. PERCEIVED KNOWLEDGE

The second set of questions explores the tenants' confidence, patience, awareness and accuracy in operating their *Passivhaus*. All four interviewees had no previous knowledge about *Passivhaus* before getting to know this project, but their knowledge increased quite quickly during their occupancy. The learning period (from when they moved in until the time they felt very confident about using the system) ranges from 3 months to 8 months. Three of the tenants said the system was very easy to learn, if taking interests in learning. All four of them were able to explain the system confidently when asked, and didn't seem to have difficulties adjusting their home environment to their needs.

According to the conversation, there wasn't a collective induction given to the tenants, instead they were given booklets and a simple walkthrough of the system. Another part of the information came from MVHR engineers and *Passivhaus* specialists when coming in to fix the problems the tenants have been having with the system over the years. When being asked what they did when having trouble controlling the system, two tenants both mentioned 'trial and error', one other said she called the office for help but had also tried to resolve it herself at the same time. All four tenants said they were willing to learn more (if there's more to learn) to reduce energy, for financial reasons mainly, but one tenant said she would learn more about MVHR system purely for her own personal interest. The knowledge they have about *Passivhaus* systems is 'basic' but quite adequate for controlling their home environment, and they are quite clear about the ideology behind *Passivhaus*. This was reflected in the way some tenants talked about internal gains as the heat source.

> …if the kids doing exercise the whole house would be roasting. I told them if they get cold, go do some exercise… (House B occupant)

> …That's why we keep our dog during the winter, he heats up the house… (House D occupant)

On the other hand, all four tenants have very simple pattern of MVHR control (see table 1), MVHR is set on fan speed 1 most of the time in winter, and is turned off in summer, using natural ventilation instead. This result was not from a lack of interest or exploration, one tenant said she read the manual several times, and tried to set up the fan in different ways at the beginning before deciding on the best way. As for energy consumption, none of the occupants knew how their energy bill compared with the UK or *Passivhaus* average, the only comparison they have is with their previous accommodations.

Overall, all four interviewees showed a relatively high level of perceived knowledge of their *Passivhaus*, the MVHR settings were made after consideration of pros and cons and a series of 'trials and errors'. The simple setting is a balance between comfort, scale of behaviour change and energy reduction.

4.4. PERCEPTION OF SUSTAINABILITY

Among all four interviewees, only one of them said that she decided to move into the house specifically for its environmental values and showed enthusiasm in the sustainability issue.

> Q: About sustainability, environmental things, the whole issue of climate change, was that attached to your enthusiasm for *Passivhaus*?
>
> A: Yeah definitely. Big motivator. Even though it's not mine, can't take credit for this house but it's good live in something like this anyway, I suppose personally I'm not doing anything just by living this house, whereas the architect has done something by building it, so. (House B occupant)

It is believed for most of the tenants that the sustainability issue is not a big concern in deciding whether to live in a *Passivhaus*. Compared with environmental reasons, financial and physical comfort are bigger motivators for tenants in this project to live in *Passivhaus* or behave in certain ways to reduce energy use. This result matches many previous studies on motivations of saving energy.

> Q: Interesting to hear you say that, because the perception is that *Passivhaus* is for people who are environmental and care about these things.
>
> A: I don't think, if you go to everybody here you would find that quite a few that are not really concerned about that. (House C occupant)

5. Discussion

Differing from the pilot case study, tenants in this project showed an active change of lifestyle relating to features of *Passivhaus*. The changes include developing the habit of checking the weather frequently, and adapting new ways of operating the wood burner, etc. Furthermore, they got used to shifting the focal point of living room away from the stove, and only light the fire according to necessity. The changes are essential to successfully operate a *Passivhaus* to its design intention. With regard to the technology, they also showed a better understanding of the passive design concept and had a higher

level of perceived knowledge. The studied project has a more integrated mechanical system than in the pilot study, it requires more patience and willingness from the tenants to learn to control it properly, nonetheless the tenants showed more confidence and knowledge in operating it.

Another interesting finding is the way knowledge is shared by the whole community. Not only in the way that successful experiences are passed on, but mistakes as well. In three of the interviews, they all mentioned another neighbour who just moved out, who lived in a 2 bedroom house with her new born baby. According to other tenants, she wasn't used to lighting fires and only used the immersion heater for hot water, thus her energy bills were two to three times bigger than the others, but she didn't seem to acknowledge the difference. It was interesting to hear three of the interviewees talking about this incident voluntarily - it has become something of a cautionary tale shared among the community, encouraging the tenants to be quite strict about using the immersion heater. Differing from the pilot study, the 'trial and error' learning process shared among the whole community is what really adds up to the perceived knowledge of the occupants.

> …We did share what we do, obviously when you see somebody, we'd say try this and someone would say well try this, it was kind of, different ways because it was all kind of different families and... There was a collective mistakes say with the fire, and people do find the house a lot warmer, and better…. (House B occupant)

6. Limitations and further research

The two studies together demonstrate how energy behaviour in *Passivhaus* can be affected by occupants' perceived knowledge. The two case studies examined two typical existing *Passivhaus* types – single family house, private client and detached social house, commissioned by a housing institute. The only thing in common is the *Passivhaus* standard, which despite all other deviation in building characteristics, gives us a level ground to make a comparison. Although the two cases show quite a few differences in terms of perceived knowledge and lifestyle change, it is still uncertain whether these two cases are representative among their own categories. Given the complexity of the *Passivhaus* types and occupant characteristics, a web-based questionnaire has been circulated among a wider range of *Passivhaus* occupants, from which more conclusions can hopefully be drawn to complete the research.

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