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Perceived Comfort and Adaptive Process of *Passivhaus* 'Participants'

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Abstract

Passivhaus methodology leads to buildings with very high thermal efficiency and high levels of airtightness. The focus of research in Passivhaus is energy performance. The experience of occupying a Passivhaus is often overlooked. This research takes into account social factors of comfort among Passivhaus 'participants'; draws comparison between their expectations and evaluations of the 'perceived comfort'; and investigates the behavioural and psychological adaptive processes that contribute to this 'perceived comfort'. A diverse range of Passivhaus projects built in the past few years in the UK is studied with a mixed method approach. The findings suggest a strong correlation between social aspects of comfort and the participants' evaluation of their Passivhaus, where the adaptive processes are potentially reinforced (or reduced) by this association.

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Keywords: Perceived comfort; Behavioural and psychological adaptive process; Comfort model; Passivhaus occupant behaviour; Mixed methods

1. Introduction

Ever since the 1970s, the comfort model has experienced a major paradigm shift from PMV/PPD (Predicted Mean Vote/ Predicted Percentage Dissatisfied) to the 'adaptive comfort' model [2]. This new model advocates individual control, natural ventilation and passive design, suggesting that occupants of naturally ventilated buildings have a wider range of comfort [1,3]. This 'perceived comfort', as opposed to the rigid comfort standard suggested by PMV/PPD model, can be achieved by three adaptive processes: Behavioural feedback (adjustment), Physiological feedback (acclimatization), and Psychological feedback (expectations and habituation), amongst which behavioural feedback and psychological feedback are the most influential factors [1]. Passivhaus as a new sustainable housing typology shares features of a naturally ventilated building (or 'free running' building) and a mechanically controlled building. The internal conditions are created by an extremely air-tight building fabric, with the ventilation provided

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mechanically by MVHR (Mechanical Ventilation and Heat Recovery) [4]. In most cases through our case studies, a backup heating source (such as wood burner, combi boiler, electric heater etc.) is required in winter. Occupants have the opportunity to open windows in the summer to ventilate naturally, though are encouraged to use 'summer bypass' option to ventilate mechanically but without retaining the heat gain. This MVHR dictated, semi-'free running' building poses the questions how comfort of occupants link to its physical and psychological characteristics. Previous research into POE (Post Occupancy Evaluation) of Passivhaus suggests high level of comfort among the occupants [5]. The majority of the research focuses on physical comfort such as heating, ventilation and air quality, without taking into account the social factors of comfort [5-7]. Meanwhile, it is unclear if Passivhaus occupants experience behavioural, and psychological adaptive processes as they would in a naturally ventilated building, and if the adaptive processes contribute to the 'perceived comfort'. A combined quantitative and qualitative approach is used to analyze a diverse range of Passivhaus projects built in the past five years in the UK, in order to investigate the social factors associated with perceived comfort of Passivhaus occupants. The geographical location of the studied cases can be found in appendix A. The study also investigate the behavioral and psychological adaptive processes taking place and how these are linked to perceptions of comfort.

2. Research Context

2.1. Comfort as a cultural artifice

As a tradition in thermal comfort research, subjective assessments of thermal comfort typically use the rating scale method [8], and the rating results predominantly reflect the air temperature. This methodology however, views the occupants as passive receivers of built environment, and the comfort as an 'attribute' [9]. It has led to the principle that buildings be as weather-proof as possible, and separate occupants from the outside environment [10]. On the other hand, Rybczynski [11] suggests from socio-historical point of view that comfort is highly dependent on social, cultural and historical context. The dominant concept of 'comfort' at one stage of history would soon be overtaken by another concept as society progresses, and becomes only a perspective or a layer of the concept of 'comfort'. For instance, 'privacy' according to Rybczynski [11], only started to become an important trait and valued by the vast majority in the 17th century. 'Efficiency and convenience' only started to hold a predominant position in home environment comfort in the early to mid-20th century when the marketing of the domestic electric appliances influenced the ideology of consumers. This point of view, known as 'the onion theory of comfort' [11] argues that 'comfort at home' is not a static and quantitative figure that can be represented solely by temperature and humidity, nor can it be purely described as a single-dimensional 'comfort scale'. The values of the different aspects of comfort appear to differ between individual households, although, also derived and constructed in a collective socio-historical, socio-technical framework.

Rybczynski [11] has further painted a picture of how comfort relates to the user of the space. This explains the reason that appearance and arrangement of rooms (in terms of layout, style, furnishing, services, etc.) made sense through different periods of history, as they contrived '*a setting for a particular type of behaviour*'. This point of view sees the occupants as active controller or 'participants' of their own comfort in built environment, and sees the concept of comfort as an 'achievement' that can be exercised, adapted and acquired [9, 12].

2.2. Adaptive process - Behavioural, Physiological and Psychological feedback

The adaptive comfort model represents a similar school of thought, as occupants are seen as participants. In this model, the influencing factors are beyond the fundamental physics and physiology. The generic term 'adaptation', as de Dear [1] broadly defined, is '*the gradual diminution of the organism's response to repeated environmental stimulation*'. As for the built environment, this adaptive process is believed to be exercised by building occupants (or rather participants) in order to achieve an equilibratory state where comfort is acquired. Within the adaptive process, three distinctive aspects are found: behavioural feedback; physiological feedback; and psychological feedback [1]. Behavioural feedback includes a change in behavior, such as adjusting clothes; operating windows; or alternating activity schedules. Physiological feedback entails either longer or shorter terms of physical adjustment by the human

body. The most delicate and least explored adaptation is the psychological adjustment, which in de Dear's [1] article involves '*an altered perception of, and reaction to, sensory information*', which '*may vary across time and space*'.

In various field studies, an evident connection is found between occupants' comfort range and their opportunity to adjust clothes, windows, etc. This correlation is even stronger in naturally ventilated building than in mechanically controlled building [13-15]. On the other hand, the evidence of psychological adaptation is less visible. Paciuk [16] has identified the correlation between 'perceived control', which measures the expectation and perception of control opportunity and comfort satisfaction. Other research suggests that occupants of mechanically ventilated building tend to have lower tolerance of temperature fluctuation [17]. Furthermore, Agnieszka Zalejska-Jonsson [18] suggests 'green' buildings have a certain impact on the occupants' environmental awareness. Occupants tend to behave with greater regard for the environment and have greater control and awareness of their energy use. These findings confirm the adaptive processes and their effect on comfort evaluation.

In the following case studies, the term 'occupants' is replaced by 'participants' to address the active role that Passivhaus residents adopt, in an attempt at normalizing the concept of behavioral and psychological adaptation.

3. Methodology

A mixed method approach using an online questionnaire survey, and interview (in-person or skype) was adopted. This approach was chosen in order to better integrate social perspective into data collection and analysis. It structures quantitative and qualitative methods with different weighting, and sequential implementation (quan → QUAL) [19, 20]. As the sample size is relatively small (12 households), the mixed method enables a focus on qualitative analysis, with a quantitative overview of the Passivhaus typology. This approach suits the research enquiry and provides an empirical context for in-depth discussion of the social perspective. The selection of case studies in this paper falls into the methodological framework of my doctorate research, which uses 'grounded theory' in data collection and analysis. As the first stage of data collection, the data is collected by indiscriminate, sampling to make sure the data is grounded [19, 22]. The online questionnaire survey was sent through email to architects and/or housing associations that had completed Passivhaus projects in the last few years, including both private and public sectors. 34 residential projects were identified from the Passivhaus Trust database [21] that were built and occupied no earlier than 2011 in the UK at the time of the survey. These households were contacted. 18 architects/housing associations responded to the emails, four of which declined any research on their projects. Subsequently six residents completed the online questionnaire (House F, G, H, I, J and L). One other house (House K) is included in this study even though it was built in 2009 due to the availability of the resident. All of the seven households are private house owners.

Parallel to the online questionnaire survey, in-person interviews have also been conducted with Passivhaus participants in Scotland, namely House A, B, C, D, E, F and J. Meanwhile, follow-up skype interviews are executed with three participants of online questionnaire survey (House I, K and L). Although, two residents are yet to arrange a time slot for a skype interview (House G and H), hence are not included in qualitative data analysis and discussion. The interviews use semi-structured method, to allow participants to clarify and elaborate freely their opinions about the Passivhaus at the same time answering designated questions. Each interview takes approximately 30-45 minutes.

As part of both questionnaire survey and interview, a sorting game was designed to find out more on the participants' experience of comfort at home. The sorting game asked the participants to sort several aspects of comfort – both physical and social - in terms of importance to them, then rate their Passivhaus on a multi-dimensional comfort scale regarding these aspects. This exercise is proved useful in finding the discrepancy between residents' expectation of comfort, and what the Passivhaus has actually delivered.

4. Data analysis

4.1. General Information

The studied cases (Table 1) include a public residential project consisting of four semi-detached houses (House A, B, C and D), and eight private detached houses. The floor area ranges from roughly 88sq.m to 297sq.m. The majority of the houses accommodate two or three participants. In all habitats, electricity is the primary energy consumption, only three households use gas in heating and DHW (Domestic Hot Water). Two other households have photovoltaic

panels installed which provide the national grid with electricity. The energy consumption varies across the different projects, although the figures and units need to be unified, and will be correlated in further research along with energy behaviour. The geographical locations can be seen in Fig.1.

Table 1.General Information (PuR: Public Residential; PrR: Private Residential; ~: approximately; £/m: pound per month)

Project code	Floor area (sq.m)	Occupation Date	Household size	Building sector	Thermostat setting in winter	Electricity (kWh/y or £/m)	Gas (kWh/y)	Electricity generation (kWh/y)
House A	~108	2011	3	PuR	20	£41/m	n/a	n/a
House B	~108	2011	5	PuR	20	£54/m	n/a	n/a
House C	~88	2011	2	PuR	18 - 22	£33/m	n/a	n/a
House D	~88	2011	2	PuR	20	3426	n/a	n/a
House E	297	2012	2	PrR	17 - 18	9262	n/a	n/a
House F	184	2013	2	PrR	20 - 23	3037	5484	n/a
House G	219	2013	2	PrR	18 - 20	2211	4454	n/a
House H	162.5	2013	2	PrR	20 - 23	£75/m	n/a	n/a
House I	210	2013	4	PrR	18 - 20	6395	n/a	3290
House J	177	2013	2	PrR	18 - 20	2500	~4165	n/a
House K	240	2009	2.5	PrR	20 - 23	11520	n/a	9948
House L	193	2014	3	PrR	20 - 23	2166	n/a	n/a

Fig. 1. Geographical location of studied cases

4.2. Perceived Comfort – expectation and evaluation

In order to understand ‘comfort at home’ in a broader social context, the ‘sorting game’ is designed to include 9 aspects of comfort from Rybczynski’s analysis through the history of the concept of ‘comfort at home’, namely Privacy and Intimacy; Domesticity; Layout and Furnishing; Efficiency and Convenience; Heat, Air, Light; Style; Health and Safety; Sustainability; Leisure and Ease. The participants are asked to score them from a scale of 1 to 5, 5

being most important feature for them to feel comfort at home, then to evaluate their Passivhaus by rating their satisfaction level with their Passivhaus regarding these aspects from the same scale of 1 to 5.

The result of the evaluation from all 12 studied cases are as shown below (Fig.2). Not surprisingly, for most of the households, the physical environment earned the highest points of satisfaction (Heat, Air, Light) with an average rating of 4.8, as well as the sustainability of the built environment (Sustainability). Participants also appreciate the efficiency and convenience in terms of the mechanical systems, appliances, etc. However, with regards the category of 'Leisure and ease' or 'Domesticity', which measure how much they feel relaxed or how comfortable to handle everyday domestic matters, the ratings are relatively lower (4.2-4.3 in average). The lowest rating occurred in the category of 'Privacy and Intimacy' with an average score of 3.4.

A more interesting comparison can be drawn from the discrepancy between participants' expectation of 'comfort at home' and their evaluations of current Passivhaus. The analysis is based on the discrepancy between the ratings for the importance of each comfort aspect and for the actual experience in their houses. For instance, House B participant put the card of Privacy and Intimacy in the importance level '4', while rated the value of Privacy and Intimacy in her Passivhaus as '2', House K rated 'Layout and Furnishing' as the most important '5', but gave a mere '3' for the actual appearance of their Passivhaus on the trait.

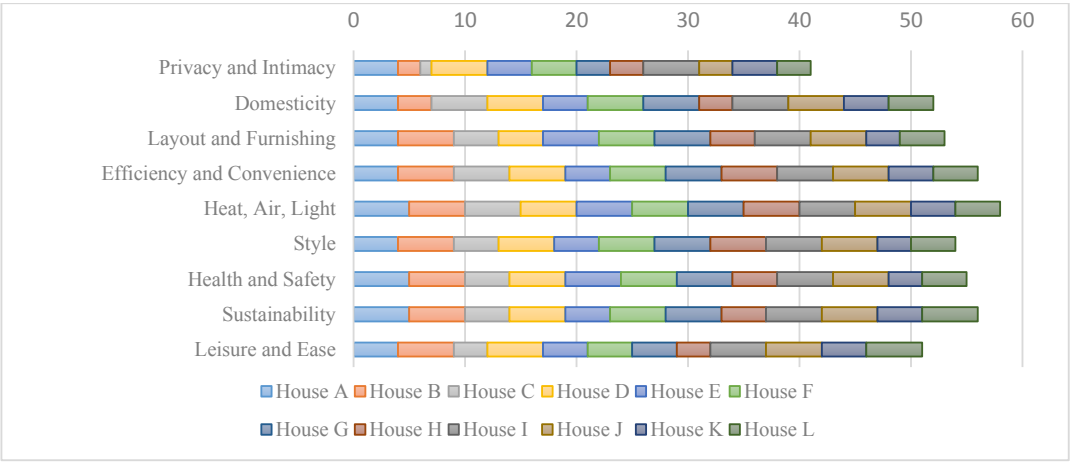

Fig. 2. Perceived comfort in nine aspects (scale 0-60 represents the sum of each participant's rating of 1-5)

The mostly valued aspect of comfort by far is 'Heat, Air, Light', followed by 'Efficiency and Convenience' and 'Sustainability', the category of 'Style' is the least concerned. The following diagrams (Fig.3) compare the importance of each trait of comfort to the individuals (in dashed line) and the comfort they perceived in their Passivhaus (in solid line). The majority of the traits match or are higher than participants' expectations, however the result indicates that all households believe their Passivhaus have at least one aspects of comfort that have failed their expectations. The results are consistent with the evaluation above, where 'Privacy and Intimacy' received the biggest discrepancy rating from the comparison between expectation and evaluation, with 4 out of 12 dissatisfying residents. On the other hand, 'Heat, Air, Light', 'Style' as well as 'Layout and Furnishing' failed only one participant's expectation respectively. Each of the other aspects has disappointed at least two households.

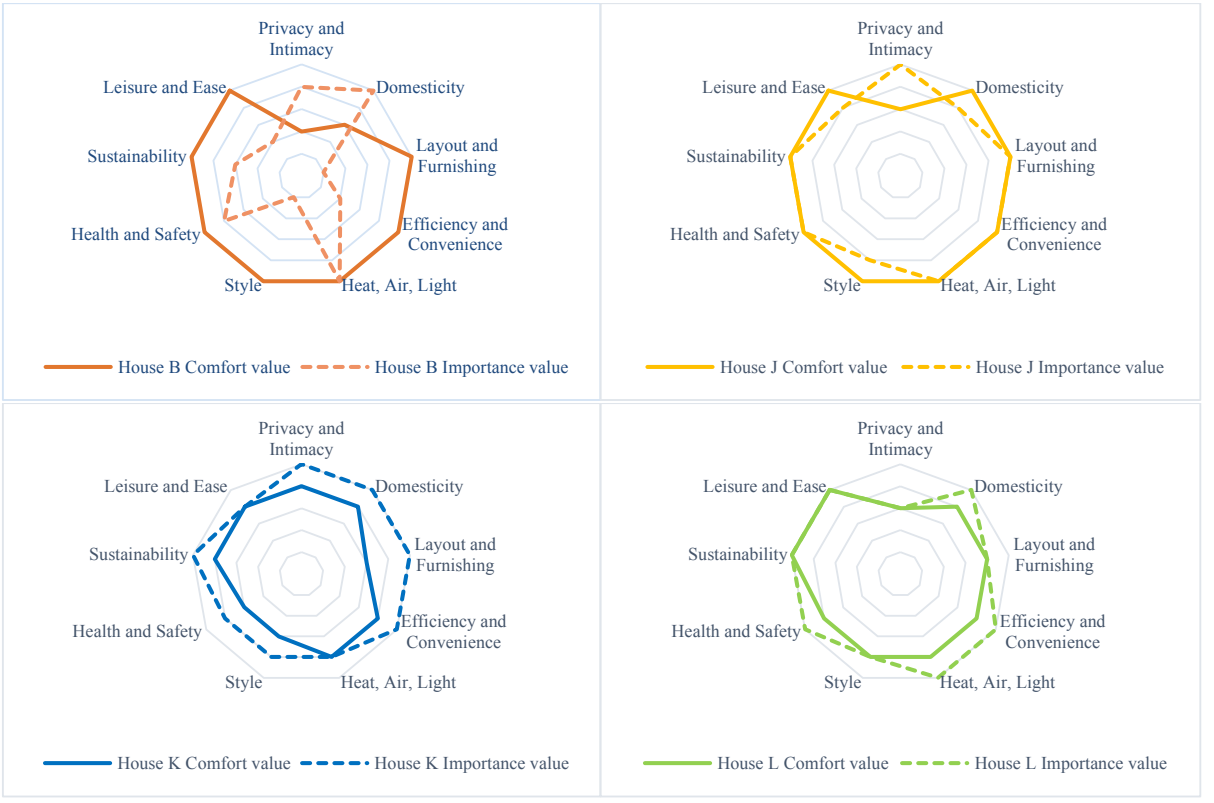

Fig. 3. Comparison between comfort expectation and evaluation.

- Privacy and Intimacy vs Heat-Air-Light,

Among all 9 aspects of comfort, at the end of the spectrum stand 'Privacy and Intimacy' and 'Heat-Air-Light'. For the physical environment comfort, the only one dissatisfying resident explained the reason is because of the lack of daylight, since 'we have slightly small windows, to stop too much heat coming in in the summer and loss in the winter…' (House K). On the other hand, 'Privacy and Intimacy' value failed to meet four of the households' expectations, the main issue they have is to do with the big windows to the south to meet Passivhaus standard (House E, I), this finding responds to previous research. However House J participant pinned another less positive point regarding privacy down to sound proof inside the house.

> *… We noticed that when you in the bathroom you can hear through the ceiling and...That just the stud wall rather than proper wall. It's not... But here, if somebody went to the bathroom, you would hear the toilet flush. So although there's quite a gap there, and full of insulation, I saw the man pushing it in, it still the wet room, still aren't very sound insulated. That's a less positive thing… (House J)*

- Domesticity, Leisure and Ease vs Layout and Furnishing, Style

Despite a relatively low rating for the category 'Domesticity' and 'Leisure and Ease', the comment from the home owners on this category are mostly positive, including low maintenance of the house - no condensation issue, no dust (House C, D, E, I, J) - as a result of triple glazed window and air tightness. High efficiency of drying laundry (House B, L). Although, these two categories depend quite largely on the participants' previous experience of their homes. E.g., if they were used to tending the wood burner, etc. On the other hand, 'Layout and Furnishing' and 'Style' which show higher satisfaction among the participants, have been reported with certain problems during the follow-up interview. Such as 'lacking choice of low energy light bulbs' (House K), 'Shower area under the pitched roof is too

low' (House D, they have resolved this by converting a toilet into a shower room), 'windows too small as a result of minimizing heat loss'(House K). Since the majority of the interviewees participated in the design process, or designed the house themselves, the outcomes for them are satisfactory. The major concern shared by two participants is that Passivhaus style is always going to be 'a box' (House E, I).

> *Well they [the architect] wanted a box didn't they, they initially wanted a box...Yh I like shapes like angles and ... sure enough because we are on a slope you...to get all these beautiful angles you see it from below… You see it from above and... And... You need to have different shapes I think… (House E)*

- Efficiency and Convenience, Sustainability, Health and Safety

The overall ratings for these three categories are very high, however each category has at least two unsatisfying participants. Almost all participants agreed that the air in the house is fresh and purified, many liked the triple glazed windows as they act as burglar proof (House J, C). House K participant has a website dedicated to his Passivhaus, in which he discusses problems of his house regularly and quite frankly, he realized the MVHR unit didn't have summer bypass option which resulted in the house being 'warmer than I would have liked during the hottest weather'. In terms of energy performance, the House K participant was disappointed as the energy use was 'higher than I had hoped' in the first winter (House K). Although the same participant said that he had very high expectation of the Passivhaus model, and he still thinks it's the 'perfect place to live', but certain downsides of his house have decreased his comfort level. House L participant rated 'Efficiency and Convenience' lower than his expectation, is because of the change in hot water system, this will be explored further in the Discussion section.

4.3. Adaptation process

In the questionnaire survey, the majority of the participants suggests their habits/lifestyle have gone through quite a lot of positive changes after living in the Passivhaus. Consciously or unconsciously. Dressing code and beddings at home appear to be the most evident changes among all. Many have also showed a change in behaviour, and suggested this change is necessary as they believed that failing to do so would be 'defeating the idea' of Passivhaus (House F).

- Behavioural adaptation

The changes included in behavioural adaptations are as follows: developing the habit of checking the weather frequently (House A, C, D, I, K), adapting new ways of operating the wood burner (House A, B, C, D, L) and hot water heater (House I, L) etc. For households that have photovoltaic panel installed, the schedule of using washing machine and dish washer has changed, the participant tries to use the appliances only when the sun is out (House I). Furthermore, some of them got used to shifting the focal point of living room away from the stove (House A, B, C, D). Many mentioned they have learned the way of heating the house through internal gain, e.g. 'turn on the lights' (House K), 'do some exercise' (House B), 'the dog heats up the house' (House D) [23], 'the big iMac screen warms me up' (House I), 'if I cook, that tends to bring it up another degree, and then it [the house] holds it' (House J). The changes are essential to successfully operate a Passivhaus to its design intention.

- Psychological adaptation

Meanwhile, the previously less-observed and studied psychological adaptation has also appeared in the conversation with Passivhaus participants. In answering the question 'During your occupancy, have you found yourself becoming more or less patient in controlling your Passivhaus system?', over half of the interviewees said they became more patient, and their confidences of controlling the system have all increased during their occupancy. This increased level of 'perceived knowledge' is believed to have contributed to their comfort level.

On the other hand, another two participants suggested that because of living in a constantly warm environment with minimum temperature fluctuation. They are now 'much more sensitive to temperature change and radiant heat', and can 'detect one degree change' in temperature (House I), or need to 'put on two pairs of socks if going somewhere else' as he has become more vulnerable to cold floor (House K).

5. Discussion

5.1. Some like it cold

One of the most interesting findings through the interviews is the mixed review about 'even temperature', putting aside the debate of whether Passivhaus can actually achieve 'even temperature' throughout all rooms, the evaluation of 'even temperature' varies among Passivhaus households. The majority of the participants appreciate the lack of temperature fluctuation, where they can use all rooms, and wear 'thin dressing gown, don't even think like it's winter's day I'd better put something on before I go in there [study] (House F)'. Although there are two interviewees expressed the preference of a colder bedroom and individual control of room temperature (House J, L), and made adaptation or are planning to make adaptation in order to achieve it.

We…try and keep bedroom cooler than the living areas, it's usually about 1 degree maybe 2 degrees less. (Q: How do you do that?) Well heat the house through underfloor heating... so we just don't have any underfloor heating [in bedroom] at all, Yh...just 1 or 2 degrees difference. Also, the living room is on the south side facing the sun, so... (Q: You are quite happy with the variation?) Yes, good it's fine. (House L)

5.2. To adapt or not to adapt

The adaptations between participants from different projects made an interesting comparison. Although the majority of the participants showed either a conscious or unconscious change of lifestyle relating to features of Passivhaus, one participant suggested that he experienced a few negative changes as well (House L). In the follow-up interview, he explained that the reason is because the Passivhaus is 'tight', by which he meant the inconvenient change of heating the house:

In terms of the heating,… We have a wood burning stove with a back boiler, heats the water, to be able to run underfloor heating, at very low temperature, hm... That works as long as you got enough hot water in your tank, and the way you got the hot water in your tank is through the stove, so you got to make sure you light the fire reasonably regularly, hm... So initially when I filled in the form I thought that was a bit of negative change, tight to having to do that. (House L)

As discussed in the previous section, the participant of House L gave a low score to 'Efficiency and Convenient' precisely because of this issue. This has to some extent reduced the opportunity for the resident to be both behaviorally and psychologically adapting to the house. On the contrary, the resident has resolved the inconvenience soon enough by making changes to the heating system to adapt himself:

Now we've got a little electric heater, which means that if the... the temperature of the tank will never drop below the temperature which the underfloor heating runs…. It increases our energy bill slightly yes, but it's mainly comfort and easy use, it's much much easier, it worth it… I think we are learning how to work the house better. (House L)

This paper is part of an ongoing Doctoral research by Jing Zhao, with a small sample size and limited number of interviewees, the conclusion can be partial or incomplete. More Passivhaus projects and participants are scheduled to further explore the Passivhaus system and its social impact on the participants, and vice versa.

6. Conclusion

The findings suggest a strong correlation between social side of comfort and the participants' evaluation of their Passivhaus comfort. The rating reflecting importance of comfort aspects indicate a collective social attitude towards comfort among the participants, where the physical comfort (heat, air, light), as well as certain social factors (such as if the Passivhaus system is efficient and convenient, or if it's environmentally and economically sustainable, etc.) are

agreed to be important contributors to the comfort value of their Passivhaus. The social factors that share a relatively lower importance rating though a bigger discrepancy between expectation and evaluation (such as privacy issue, leisure and ease) suggest the design of Passivhaus has to some extent neglected or been restricted in such areas. On the other hand, the correlation between the social factors of comfort and the adaptation process among the Passivhaus participants are even more evident. The way the participants expect and evaluate these social aspects of comfort has affected greatly the way they chose to (or not to) adapt to the new system. This finding has potentially provided a new angle to study issues related to behaviour change in low energy homes.

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