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Smart and Healthy within the 2-degree Limit

Passivhaus Lived Experience More Than a Spreadsheet

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ABSTRACT: The ideology of Passivhaus is clear. It is a building standard associated with a really well insulated and airtight building that saves energy – in both hot and cold climates. There is evidence from that shows how important this approach to building is in achieving carbon reduction targets. Passivhaus is a credible way for large scale energy reduction in the built environment and has gained in popularity with policy makers tasked with meeting the internationally agreed climate change targets. The reality of living in a Passivhaus is not so clear. There is evidence of some Passivhaus projects using much more energy than the design models anticipate. There is also emerging evidence of the difficulties some people face in living in a Passivhaus. Issues of air quality, systems control problems, inadequate technical knowledge and skills. While the overall picture is positive there are clearly issues to be overcome in the delivery of a promising carbon reduction strategy for the built environment. This research explores the limitation of the PHPP software in addressing the lived experience of Passivhaus. The emerging issues with some PH projects suggest a better understanding of the interactions between people and the building is required.

KEYWORDS: Energy, Comfort, Passivhaus, People

1. INTRODUCTION

The ideology of Passivhaus is clear. It is a building standard associated with a really well insulated and airtight building that saves energy – in both hot and cold climates. There is evidence from [1] that shows how important this approach to building is in achieving carbon reduction targets. Passivhaus is a credible way for large scale energy reduction in the built environment and has gained in popularity with policy makers tasked with meeting the internationally agreed climate change targets.

The reality of living in a Passivhaus is not so clear. There is evidence of some Passivhaus projects using much more energy than the design models anticipate. There is also emerging evidence of the difficulties some people face in living in a Passivhaus. Issues of air quality, systems control problems, inadequate technical knowledge and skills [2],[3]. While the overall picture is positive there are clearly issues to be overcome in the delivery of a promising carbon reduction strategy for the built environment.

While not exclusively a residential standard the majority of projects are dwellings [4]. The emerging issues with some PH projects suggests a better understanding of the interactions between people and the building is required. Understanding how people engage with a Passivhaus, will reveal some of the complexity of the lived experience of a Passivhaus.

2. PASSIVHAUS LIVED EXPERIENCE

Passivhaus is a standard for high-performance, low-energy sustainable buildings. It embraces a new level of comfort, based on providing stable temperatures with minimal need for energy input. Passivhaus is based on a system of post heating and cooling of air, achieved through a system of air heat recovery. This finely tuned system is designed to work optimally without human interaction. In order to understand how people engage with living in this 'new' type of housing the social grounding of the typology needs to be considered. If Passivhaus can be considered as a typology, then the preconceptions and prior knowledge of the typology are likely to affect how a person will respond to what is a slightly different way of living.

2.1 Passivhaus – A Paradigm Shift for the Home?

This raises the question – is a Passivhaus so very different from a 'normal' house? And what does it take to live in one 'well'? The Passivhaus epitomises the relationship between the building fabric, the technical systems and the people within it. However this is not a new relationship. The hearth as a central focus of the home demonstrates the cultural and physical significance of the inter-related nature of systems, people, and buildings in the ideology of the home.

Passivhaus has emerged as a successful method for creating low energy homes that use significantly less energy than most housing built to national codes. Comfort is characterised by thermal consistency

achieved through minimal amount of energy. This is defined at the design stage, and has been shown to be reasonably accurate. Evidence from the first Passivhaus project built in Darmstadt-Kranichstein, Germany, shows consistently low energy consumption across heating, hot water, cooking and ventilation [4]. This performance is well documented and is famously occupied by its designer and the inventor of the Passivhaus methodology, Wolfgang Feist. The project has been constantly monitored and maintained or improved to keep this performance. The one thing that is often overlooked is the engaged and committed participation of the occupant.

The ability to understand and then fine tune the building has been invaluable in testing and proving the Passivhaus approach. Since the first Passivhaus project in 1991, 60,000 Passivhaus now exist [4]. The majority of these are houses. As a typology it does not require any particular change to current housing design practice for either layout or spatial configuration. Where the main difference lies is in the careful balance of energy that is determined by a fabric first approach closely coupled with a finely tuned heat recovery ventilation system. Occupant response to this and the potential to achieve comfort in a Passivhaus is the subject of this research.



Figure 1: Air conditioner advertisement (model IT & T Coolerator, 1953)

2.2 Comfort and Evolution of the Home

The hearth is a central concept of the home, and its relationship with comfort. The physical placing of the fireplace was always inter-related with the social condition in the home, and by extension comfort. The compact form of the Rumford stove was designed to enable a social space around the hearth which had previously been inhibited by the egress of smoke from earlier broad and open fireplaces. This both

changed the way in which a room might be used, and the efficiency of the system in providing heat. In the early 20th century, the service system gained even more attention in architecture with the escalating role played by technology in the philosophy of design and the process of architectural form-making. Introduction of air-conditioning is not such a modern concept as perceived by many. In a house designed in 1839 in Edinburgh, flues were built into gable walls, openings were hidden behind cornices and empty spaces were left between the ceilings of the attic space so that fresh, warm air could continuously circulate throughout the six-storey house [5]. From the early 19th century in Europe, ongoing trials of central heating using warm air, hot water and steam were performed with the aim of finding the safest and most efficient way of providing thermal comfort. Old-fashioned fireplaces gradually came to be replaced by gas-powered central heating systems.

Each evolution of technical system is coupled with a change in the social dimensions of comfort and the expectations of householders. This suggests that Passivhaus is likely to require an evolutionary step in the idea of comfort in the home.

2.3 Achieving Passivhaus 'The PHPP Spreadsheet'

The use of a spreadsheet to evaluate the design of a Passivhaus results in an emphasis on quantitative measures of achieving the low energy standard. The realisation of Passivhaus buildings is determined through close control of energy balance, achieved through thermal performance of the fabric and controlled ventilation strategies coupled with solar gain. The role of human behaviour is often overlooked by assumptions that are built into the spreadsheet. This research is important in exploring the links between the design of Passivhaus projects and the people that move into them. Positive linkages will lead to energy reductions, but also a wider acceptance of a more sustainable lifestyle. Where there are negative links, these can be counter-productive to the Passivhaus ideology, in terms of a gap between predicted and actual energy use, but more widely a rejection of a way of building, proven to reduce carbon emissions

PHPP stands for Passivhaus Planning Package. It is a rigorous and evolving software that is used to define if a design will achieve Passivhaus standard. The approach has been used since the first Passivhaus, albeit the software has been developed and improved in response to its use. The PHPP methodology requires designers to incorporate robust building fabric, and evaluation of window orientation and shading strategies to enable meeting exacting standards for heating, cooling, primary energy and airtightness.

Specific building demands with reference to the treated floor area		
	Treated floor area	351.4 m ²
Space heating	Annual heating demand	14 kWh/(m ² a)
	Heating load	9 W/m ²
Space cooling	Overall specific space cooling demand	kWh/(m ² a)
	Cooling load	W/m ²
	Frequency of overheating (> 25 °C)	0.0 %
Primary Energy	Space heating and cooling, dehumidification, household electricity, DHW, space heating and auxiliary electricity	kWh/(m ² a)
		kWh/(m ² a)
	Specific primary energy reduction through solar electricity	kWh/(m ² a)
Airtightness	Pressurization test result n ₅₀	0.6 1/h

Figure 3: PHPP excerpt

The Five basic principles of Passivhaus are: Thermal Insulation with a max $0.15\text{W}/(\text{m}^2\text{K})$; high performance windows; ventilation heat recovery; airtight construction; and absence of thermal bridges. These are built into the PHPP and so designers can test design iterations within the spreadsheet. The results are based on numerical evaluation. This creates the real benefit of PHPP in terms of the architectural resolution. There are no perceived design limitations for Passivhaus beyond the five basic principles set out above.

Really interesting modulation of the data within PHPP can be used to create multiple design solutions that fulfil the PHPP requirements for Passivhaus. The optimum wall to window ratio can be calculated for particular climates [10]

2.4 Comfort in Passivhaus

The concept of comfort is closely aligned to the primary benefit of Passivhaus. The ability to retain heat and maintain a constant temperature with minimal energy. This key characteristic of the Passivhaus building typology adopts a systemic view of comfort, and the scope is limited to a thermally empirical view.

There is increasing concern about overheating of Passivhaus in summer periods [6], and this is set to worsen with global warming. The methodology for Passivhaus confines allowable overheating to only

Meanwhile, distinct from the learning process, home occupants will develop habitual strategies for using the controls as part of their daily routine. In learning to use the Passivhaus system, the occupants develop an understanding of the control panels and the principles of MVHR. However, the Passivhaus system needs to be fine-tuned to be compatible with individual's needs. A fine-tuned system can only be achieved through daily interaction and adaptations in habitual strategies. Those strategies include changes in household behaviour such as laundry schedules and thermostat settings, as well as psychological changes such as the increased awareness of energy use. Behavioural change has been recorded in previous research on Passivhaus occupants. For instance, due to the presence of large south-facing

windows, behavioural change occurred whereby the occupant participants either stayed away from windows or used curtains. Participants' ventilation habits also changed, with a shift from them manually operating windows to using programmable controls [7] Another study comparing feedback from three pairs of occupants of both Passivhaus and conventional houses suggested that the Passivhaus occupants tended to behave with greater regard for the environment and have greater control and awareness of their energy use [8]c

3. RESEARCHING THE LIVED EXPERIENCE

This research examines the scope of the PHPP in achieving Passivhaus and builds an argument that the spreadsheet alone cannot lead to a comfortable home. A careful understanding of and sensibility to the human experience is required for success in the uptake of Passivhaus projects. Case study analysis using a primary study of UK projects, and secondary case studies from International context are used to develop the findings. Research has tended to focus on the achievement of energy savings, but this work represents a departure from this technical grounding into a broader social anthropological study. The work is underpinned by a traditional framework for comfort in the home and widens the focus from thermal comfort to issues that frame a broader concept of social comfort. This paper presents part of a PhD study on the lived experience of Passivhaus.

3.1 Research methodology

The PHPP framework is evaluated to identify the key characteristics that define a Passivhaus. This is then used to evaluate case study projects. The architectural features in the project that were closely related to receiving or reconciling comfort are examined in the context of the transitions made by people moving into Passivhaus projects.

Research with ten households living in UK Passivhaus projects was carried out to understand the perception and experience of comfort in these houses. This case study analysis informed the development of new understanding in the lived experience of Passivhaus. The research moved beyond technical achievement of standards to an anthropological interpretation of comfort in the Passivhaus.

Working with households that had moved into a Passivhaus home in the last three years, research was undertaken to understand their a priori knowledge, engagement with and adaptation to the building, and the relationship this has with energy consumption. The work developed an understanding of comfort and how people came to receive and reconcile comfort in their Passivhaus homes. It explores prior knowledge and perceptions with the physical

interactions people made with the buildings to attain comfort. The participants were surveyed on their understanding of Passivhaus prior to moving in, and then their experience of comfort in their current home [9]. Exploration of the adaptations made by people moving into a Passivhaus reveals a strong connection between the comfort and physical interaction and the mental image held of Passivhaus.

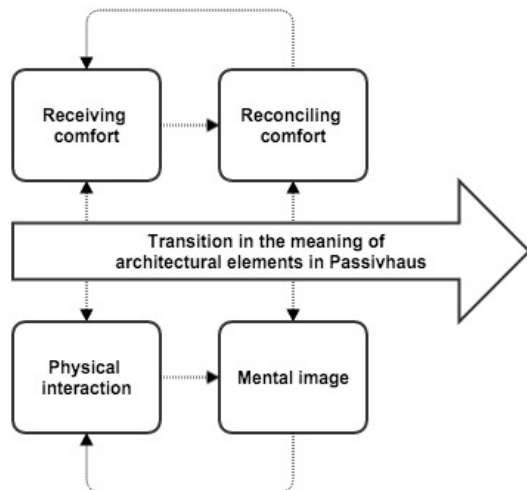


Figure 2: Adapting to a Passivhaus

Further examination of Passivhaus projects in light of these findings reveals a strong relationship between technical systems, human interactions and energy consumption. The case study analysis shows emerging themes that connect architectural features with the concept of comfort as it evolves in a Passivhaus.

The variables that are included and excluded from the PHPP software are examined in relation to the narratives of lived experience in Passivhaus. This provides insight into the process of designing a Passivhaus that is cognisant of how people may live within the typology. The analysis highlights features that are more likely to impact on the comfort of occupants. The analysis focuses on ten UK Case study examples, then further explores this in the context of some international examples.

3.2 The role of occupants in low-energy housing

Ten case studies (15 households) participated in the research. Seven were privately commissioned and owned (Projects B-H). Eight were social housing tenants (Projects A, J & K). Interviews explored their attitudes and expectations of Passivhaus [11]. Health, energy efficiency and heat+air+light were perceived as the most positive aspects of their Passivhaus. Occupants were asked about their knowledge of Passivhaus before moving in, and their experience of living in one. 14 of 15 households were confident in operating the Passivhaus, including four social housing tenants with no a-priori knowledge of

Passivhaus. Of those with prior awareness of Passivhaus, five (3 Private, 2 Social) had equal prior knowledge and confidence in operating their Passivhaus. Of the remaining six households, four became more confident, and two less so. This demonstrates the importance of learning by experience. Most occupants were given training to control the technology, but more than half would call an engineer to get assistance if something went wrong. Compared with other low-energy housing, one distinct feature of the Passivhaus is its MVHR system. This mechanical ventilation heat recovery systems provides warm fresh air without the need to manually operate windows. This new system, along with other technologies in a Passivhaus, requires a certain understanding and technical knowledge on the part of occupants. Occupants will develop habitual strategies for using the controls as part of their daily routine. A fine-tuned system can only be achieved through daily interaction and adaptations in habitual strategies. Those strategies include changes in household behaviour such as laundry schedules and thermostat settings, as well as psychological changes such as the increased awareness of energy use.

Not only do home characteristics have a direct impact on energy requirement, they also indirectly affect household energy behaviour. Lindén et al. [12] found that occupants of detached houses used lower thermostat settings than occupants in a multi-family flat. Another study comparing the experiences of occupants in a conventional building with those of the occupants of a green building suggested that the occupants in a green building tended to be more aware of environmental issues and behave in a pro-environmental manner [8]. The more a building is insulated, the more the lifestyle proportionally influences the heating loads'[13]. That is to say, highly insulated low-energy buildings are more sensitive to household behaviour in terms of energy performance. In one case study house the relationship with external conditions became more important – *“so it's a question of changing your lifestyle really according to the weather”*. They also noticed that internal temperatures were sensitive to activity levels – *“if the kids do exercise the whole house would be roasting. I told them if they get cold, go do some exercise”*.

3.3 Architectural Features

In the Passivhaus design guide, several design features are highlighted as being the most important in terms of their effect on the performance of the Passivhaus. These are: **building form factor**; **orientation**; and **U-value**. Each of these features was examined in the case studies and correlated with the lived experience of occupants. These are all variables

within the PHPP that are defined numerically. This research tries to understand the relationship that these features have on the lived experience of occupants.

Building form factor is used to optimise the floor area, the footprint of the building, the plot ratio and other parameters. A smaller ratio of external envelope area to the volume of the building (A/V ratio) indicates a lower heat loss. A favourable compactness ratio is considered to be where the A/V ratio $\leq 0.7\text{m}^2/\text{m}^3$. The form factor is established by dividing the exposed surface area by Total Floor Area (TFA) with a benchmark of 3.

Table 1: Exposed Area to Volume Ratio of Case Studies

Project code	A/V	A/TFA	Experience+
Project A (4 houses)	0.70	2.57	3,5,3,5
Project B	0.80	3.46	5
Project C	0.76	2.94	5
Project D	0.80	2.35	5
Project E	0.71	2.75	5
Project F	0.73	3.28	1
Project G	0.71	2.96	5
Project H	0.76	2.16	3
Project J (2 houses)	0.58	2.42	5,3
Project K (2 houses)	0.60	2.23	5,1

With the exception of the Projects B and F, the case studies have all achieved the benchmark of 3 for the form factor. In terms of the A/V ratio, the three multi-family projects, A, J and K, achieved a ratio of no more than $0.70\text{ m}^2/\text{m}^3$, whereas the single-family projects all scored slightly above the average A/V ratio, with the largest occurring in Projects C and G, a reflection on the client wishes at odds with the PHPP guidance. The form factor does not seem to have a direct bearing on physical comfort, probably as they all achieve the Passivhaus standard. Table 1 shows a rating from 1 to 5 of comfort experienced by occupants. It is notable that the greatest incidence of poor comfort was experienced by the social housing. Perhaps due to less familiarity with the concept of Passivhaus. However the layout and orientation of homes is clearly linked to the satisfaction of occupants. Correlational examination between these properties and occupants' comfort evaluation revealed strong relationships between orientation and occupants' perception of certain comfort values such as heat+air+light and the energy efficiency of their houses, increasing when the house faces south.

To maximise solar gain, the main façade is oriented within 30 degrees south. Poor orientation can increase annual heating demand by 30% to 40% [14]. The majority of the projects (6 houses) are oriented due south. The remainder, with the

exception of the Projects H and K, are oriented within 30 degrees south. Project H and the K face 57.7 degrees and 46.6 degrees southwest respectively. Both these projects have higher energy use. Very few of the projects have any natural shading from vegetation or adjacent buildings. 11 of the 15 case studies experience overheating in summer months. This was frequently experienced in upstairs bedrooms. PHPP calculates heat distribution across the whole building, and does not allow for differential heat gradients. When evaluating the floor to window ratio in these projects it was much higher for the rooms experiencing overheating. The design to maximise solar gain has influenced by the requirement specified in the Passivhaus design guide.

Table 2: U Values of the Case Study Houses in W/m²K

Project code	Wall	Ground	Roof	Energy kWh/m ²
Project A	0.120	0.110	0.120	23.4
Project B	0.094	0.075	0.099	14.02
Project C	0.100	0.100	0.080	36.7
Project D	0.145	0.088	0.121	30.45
Project E	0.097	0.094	0.077	16.93
Project F	0.116	0.125	0.115	27.14
Project G	0.100	0.090	0.090	21.34
Project H	0.123	0.090	0.064	30.43
Project J	0.120	0.140	0.098	28.07
Project K	0.110	0.080	0.110	54.74

The external envelope in Passivhaus design must achieve U-values of $\leq 0.15\text{ W}/\text{m}^2\text{K}$. When correlating with energy consumption of the studied cases, it can be seen that houses with the best U-values – projects B, E and G - are also the projects with the best energy performance. However, project H which has a similarly low U-value, consumes much more energy than the other cases.

In examining the relationship between comfort traits and architectural design, these quantifiable factors have been taken into consideration. A quantitative correlational analysis carried out separately [11] has revealed two clusters of factors between the occupants' evaluation of comfort and their lifestyle change, ideology and knowledge of Passivhaus. These two clusters of factors are: 'physical interaction' and 'mental image' of Passivhaus living. Figure 2 shows the relationship between these two clusters and achieving comfort. The Lived Experience of Passivhaus involves more complexity than the PHPP approach incorporates, and while this tool is valuable in defining a well-balanced design, it is important to understand the wider context of comfort for a Passivhaus home. These two strands of investigation are needed to

study the lived experience of Passivhaus occupants. Moreover, the correlation between energy consumption and the occupants' evaluation of comfort, knowledge and ideology revealed even more interesting connections. It can be concluded that the deviation in energy consumption of the studied cases needs to be examined with a holistic consideration of occupants' experience and architectural design. The specified features in Passivhaus design guide are able to direct a satisfactory and qualified Passivhaus building, however, in order to ensure a high energy performance, other design features as well as occupants' behaviour and comfort need to be taken into consideration in the design of Passivhaus.

4. CONCLUSION

It can be observed that the majority of single family projects are detached, two storey houses with three or four bedrooms. Project B is single storey. One major observation made during the study of the layouts is that for most of the houses with two storeys, bedrooms are placed on the upper level as per conventional housing layout. However, for projects E, F, and H, the bedrooms are designed to be on the ground or lower ground level. Correlating with the evaluation of the layout in the comfort value for Projects J and K 2 (households) occupants expressed dissatisfaction with their house layouts. One thing the three households had in common was that they all moved into a ready-built Passivhaus without any participation in design or construction process. It can be understood that this was perhaps the reason why the layout was not to their satisfaction. On the other hand, comparing with other social tenants (in Project A) and J1 household, who were content with the layout of their houses, J2, K1 and K2 households also share a relatively short period of occupation time. This could also suggest that occupation time plays a role in the evaluation of the layout of Passivhaus dwellings. During the period of occupation, it is likely that the residents make adaptations or adjustments to the layout of their houses to suit their preference.

People are an important part of the Passivhaus ideology. The PHPP is a robust and seemingly accurate way of predicting energy use in many PH projects. There remains a potential area for unpredictable energy performance associated with people and their interaction with the system of Passivhaus. As demonstrated above the interaction between comfort and physical interactions, has a relationship with the acceptance of Passivhaus as a housing typology. This requires much deeper longitudinal research to be better understood.

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