Comparative Performance Analysis of Passivhaus and Building Regulation Certified Properties Built in The United Kingdom

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Abstract: This paper compares the energy performance of Passivhaus and Building Regulations certified properties constructed in the UK. The Passivhaus criteria and construction principles are explained and the certification criteria for both standards are rationalised for a direct comparison. Relevant data was collected from case studies, building certifications, and the approved local planning submissions. The results reveal that, on average, Passivhaus properties were twice as thermally efficient from a numeric U-value standpoint, though are likely to perform even better due to the construction quality standards. This notion is backed up by the overall energy savings which on average come out to 75% compared to a conventionally built home.

Keywords: Passivhaus, Passive House, Energy Performance, Sustainability.

1. Introduction

Passivhaus is a German term that translates to passive house. Currently Passivhaus is a voluntary building design and performance standard, around the basis of low energy demand [1]. In addition to being a performance standard to aspire to [2] there are regions of Europe that in fact impose it as a necessary requirement for new builds to be commissioned and signed off. Passivhaus is a design guideline for buildings that was birthed out of Germany in the nineties. It aimed to derive a process in which buildings can be constructed such in service they draw a fraction of the energy demands that conventional construction depends on. Passivhaus has greater targets for building performance relative to mandated regulation. Though in the recent years this gap is being bridged. This research aims to define the Passivhaus design criteria and practices compared to current UK regulation. In addition to this, data will be collated of built homes in the United Kingdom and their performance for each of the design standards and compared commenting on the results.

Passivhaus takes into account the overall building performance (Table 1) instead of the performance of key building elements as the United Kingdom building regulations outlines. Overall, this contributes to a comfortable ventilated internal environment throughout the seasons that requires a fraction of the energy to operate. This reduces the energy grid demands of the building, a primarily environmentally detrimental energy source. Any fluctuations in energy pricing are not felt so harshly due to the already low energy demands. Outside of the energy efficiency Passivhaus compliant construction boasts, it also by proxy ensures good quality of work [2].

The word passive implies no need for intervention though it does require a fractional amount of energy to keep it within the comfortable range, but at least not from conventional forms such as a fully-fledged grid reliant central heating system [3]. This saves on material and labour costs as the radiators would not need to be purchased or someone contracted to install them. With the absence of radiators, this in turn frees up wall space and functional floor space as there are not any unsightly protrusions you would otherwise have to work around. The house has such low energy demands, it is as if it is passively existing due to the reduced impact on the environment.

Table 1. Passivhaus criteria [4].

Properties	Passivhaus Criteria
Annual space heating or cooling demand	Not to exceed ≤ 15 kWh/m²a annually
Average daily heating or cooling demand	≤ 10 W/m²
Primary energy demand	Not to exceed 120 kWh annually for all domestic appliances (Heating, cooling, ventilation, hot water, power and all other energy demands)
Airtightness	0.6 air changes per hour at 50 pascals ≤ 0.6 h
Window U-value	≤ 0.85 W/m²K
Thermal comfort	Not more than 10% of the hours over 25°C per year

The little energy it does require can be supplemented from a variety of low impact sources. The simplest, a space heater, may suffice. Other potential sources include air source heat pumps implemented as part of the building's infrastructure or a small combination boiler that draws its energy from renewable sources such as photovoltaic panels or wood burning. With the principle of airtight construction, you may assume that internally this will result in stagnant and stale air though this is where the mechanical ventilation heat recovery (MVHR) system comes in. This manages air flow through the building as well as bringing in fresh air. This air is generally not at a temperature you would like to be directly funneling into the property. Ingeniously the system uses the thermal energy of the expelled air on its way out to heat the fresh incoming air. This is also supplemented by a small 3kW heating element [1]. Comfortable range as the term suggests is the range in which environmental variables are such that it contributes to a comfortable environment. Spaces are at 20°C-22°C with a humidity of 50-60%. The Passivhaus concept was the brainchild of a physicist, Wolfgang Feist [5]. Who then went onto the Passivhaus Institute (PHI) in 1996, an institute that was setup around Passivhaus. The standard initially revolved around four main criteria, airtightness, annual space heat demand, specific heat demand, and annual specific primary energy demand [3].

The bulk of Passivhaus compliant buildings are in European Union where the standard was conceived because the local climate results in the need to raise the temperate of spaces to the comfortable range and maintain it. But this has not stopped the standard being implemented globally in significantly hotter climates like Asia where the need is to cool the temperature of spaces down to the comfortable range instead. This proves its principles of thermal isolation between environments can be applied the world over. As passive as the house may seem, at times some intervention is required from the inhabitants to manage and maintain it, albeit simple tasks. Users would need to be able to know when it is appropriate to purge excessive heat build-up, by opening windows, how to actuate the MVHR system dependent on the season, and when to change filters [1]. Though the stress of managing such systems can be taken over by smart technologies that are able to learn about the user's energy use and preferences as well as taking into account weather and acting accordingly. For example, identifying that it is the tail end of a heatwave and the weather will soon take a turn. Therefore, instead of purging the heat, the system can choose to retain it to maintain the internal temperature during the upcoming cool weather.

2. Design and construction criteria

Table 2 compares the U-value rates for the key building elements in Passivehaus and the current Part L of the building regulations in the UK. A key criterion in achieving high thermal performance is the airtightness. This refers to how well the building controls the flow of air as a lot of heat can be lost during the exchange of air from the building. This is measured in 'air changes per hour', ach, how much air can passively flow in and out of a building, i.e. how airtight it is. Both the Passivhaus design standard and Building Regulation recommend *0.6ach @ 50pa ph* (Table 2) although the limiting value in the building regulations is 10 $m^3/h.m^2$@50 Pa.

Table 2. Passivhaus criteria & United Kingdom building standards.

Criteria	Passivhaus standard	UK Building Standard (limiting/ notional)
u-value for walls	0.08-0.15 W/m2K	0.30 W/m2K/ 0.18 W/m2K
u-value for floors	0.08-0.15 W/m2K	0.25 W/m2K/ 0.13 W/m2K
u-value for roofs	0.08-0.15 W/m2K	0.25 W/m2K/ 0.13 W/m2K
u-value for windows	≤ 0.8 W/m2K	2.00 W/m2K/ 1.40 W/m2K
Airtightness	≤ 0.6ach @ 50pa ph	10 $m^3/h.m^2$@50 Pa

Superinsulation and ventilation and the other two principle criteria considered in Passivhaus standards. Passivhaus design has an envelope of insulation that wraps around the building, this thermal isolation creates a separation between the external and internal environments, reducing the energy required to keep internal environments in the comfortable range. The insulation does not only serve to heat, but also contribute to the prevention of overheating in the hotter months. In addition to the wrapping insulation, efforts are made to keep the insulator, air, within the internal spaces. An airtight barrier that perimeters the construction limits the transfer of air. A lot of energy can be expended to raise the ambient air temperature therefore it is paramount to prevent it from being exchanged with external air that is of a significantly different degree of temperature [5]. In addition to the design itself, there are several practises to ensure the integrity of the airtight barrier. The principle of airtight construction leaves little capacity for natural convection to bring fresh air into the space. Therefore, Passivhaus buildings rely on a mechanically ventilated heat recovery system. This exhausts air from the property but allows the exhaust air, on its way out, to transfer some of its thermal energy to warm the incoming air that is being pulled in by the MVHR system. It is suggested that 30m^3 of fresh air per person, per hour is necessary though the MVHR system needs to be setup such that it is able to pass a greater volume of air through more inhabited spaces of the house. Failing to meet the airflow requirement can result in uncomfortable stale environments that are susceptible to condensation, mould, and the subsequent issues they inflict. The MVHR system is a continuously operating unit therefore it is constantly outputting noise. This places a restriction on how much noise it can produce because of how close it is to the living space. The unit itself can operate up to 35db but only a maximum sound level of 25dB can penetrate into the living space [5].

Glazing is the next major design and construction criterion. In conventional construction, glazing is a point of contention as it is where a lot of energy is lost. In Passivhaus construction it forms part of the thermal fabric. Highly insulative triple glazed windows contribute to the airtight barrier and allow the building to take on solar gain during the day and harbour the energy rather than simply being a medium that it is exchanged through. Any building openings usually involve a dense structure to support the required span, as well as a change in material to fill the opening, be it a door or window. This can lead to thermal breaks in the building fabric where energy can be lost making insulation efforts void. In construction an effort is made to prevent this due to the energy implications though special consideration in Passivhaus construction is made in the marrying of materials [5].

2.1. Energy consumption of Passivhaus

Annual space heat demand, the amount of energy required to bring the internal temperature up to 20oC in cold climates and down to 25oC in hot climates, on average per hour over the course of the year. The Passivhaus standard deems 15kWh/m2 be sufficient energy expenditure to achieve this (Table 1). Passivhaus criteria states the specific heat load ought to be at most 10W/m2, being the maximum amount of energy to be expended per usable building area per metre to bring the internal temperature to comfortable range when it is -10oC externally. Annual specific primary energy demand is the amount of energy that can utilised from one source that is capped at 120kWh/m2 for Passivhaus [4]. To put it in perspective of the current United Kingdom building performance, on average there is more than 10ach, 200kWh/m2 to maintain internal temperature and over 400kWh/m2 annual specific primary energy demand [3].

In service this allows for an average reduction of 75% in energy consumption in Passivhaus built homes relative to conventional construction [6], and over the course of the building lifecycle these savings are magnified and contribute to offsetting any extra costs incurred in meeting the Passivhaus standard. All sorts of numbers are heralded, even up to 200,000 Euros, though this is quite context dependant in addition to the initial cost of construction. Some basic estimations put it at a 14,000 Euros addition to construction cost, as it becomes more widely adopted and technology advances year on year the cost of implementation is reduced, 9500 euro as of 2015 [7]. Which can be quantified as an extra cost of 15-25% [8].

3. Research Methodology

Qualitative research is conducted to assess the initial criteria of the different building design standards, Passivhaus certification criteria and United Kingdom building regulation. This provided a side by side representation of each design criteria. Since different accrediting bodies have different methods of assessment, key elements of criteria will be outlined to attempt to rationalise areas of assessment. Performance of building elements are collated and compared. The walls, floors, roof and glazing will be the main basis of comparison and where possible data on airtightness will also be noted. The aim is to compile data on properties built to satisfy mandated building regulation and Passivhaus certification comparing their built performance. In addition to commenting on building practices that contribute to their relative performance and trends that arise. This will illustrate the significant performance disparity and encourage better design standards going forward. To make comparison of the data at a glance an arbitrary performance was used. This is an average derived from the thermal performance of the building elements: walls, floor, roof and glazing. Although not 100% accurate in terms of thermal performance and energy consumption comparisons, this strategy would give an indication on the overall energy performance of the buildings.

4. Results and Discussion

In order to be able to draw a research-based conclusion the thermal performance of 100 properties split over the relative building standards was put together and rationalised. Collectively this data illustrates that Passivhaus performs significantly better. Without having taken into account air permeability, Passivhaus achieves an overall arbitrary performance of 0.28 (Table 3), half that of Building Regulation's 0.56 (Table 4). To further refine the results the data was condensed and averaged based on region (Table 3 and Table 4, Figure 1).

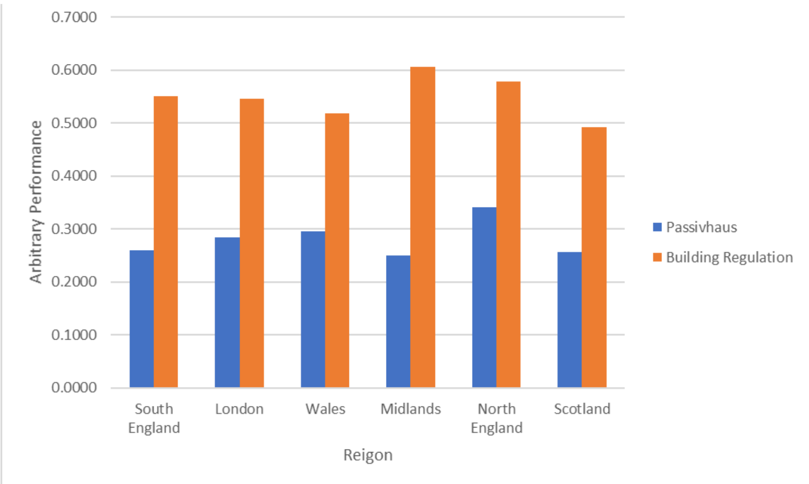

Figure 1 - Passivhaus vs. Building Regulation certified building thermal performance per region

Interestingly, the further north the building, the better the arbitrary performance, with Scotland having the lowest scores across both building standards. This could be down to the lower temperatures experienced in the north and the buildings are designed as such. Therefore, in future construction, a further assessment of homes built in the north could be undertaken to shed light on building practices for a more robust design in the United Kingdom. Additionally, the lower the element u-value, the more effective the superinsulation effect is, another driver to aspiring to the lower targets.

Table 3 - Collated results per region illustrating raw data collected on building element performance for Passivhaus certified properties

PASSIVHAUS - AVERAGED DATA FOR THERMAL PERFORMANCE							
Entries	Region	u-value for walls	u-value for floors	u-value for roofs	u-value for windows	Airtightness	Arbitrary Performance
NA	Criteria Benchmark	0.18-0.30 W/m²K	0.13-0.25 W/m2K	0.13-0.25 W/m2K	1.4-2.0 W/m2K	≤ 0.6ach at 50pa ph	NA
6	London	0.11	0.12	0.12	0.78	0.50	0.28
11	Midlands	0.10	0.11	0.09	0.69	0.48	0.25
9	North England	0.13	0.12	0.12	1.00	0.53	0.34
7	Scotland	0.10	0.11	0.09	0.72	0.46	0.26
10	South England	0.11	0.11	0.10	0.72	0.46	0.26
7	Wales	0.12	0.12	0.11	0.82	0.54	0.30

Table 4 - Collated results per region illustrating raw data collected on building element performance for Building Regulation certified properties

BUILDING REGULATION - AVERAGED DATA FOR THERMAL PERFORMANCE							
Entries	Region	u-value for walls	u-value for floors	u-value for roofs	u-value for windows	Airtightness	Arbitrary Performance
NA	NA	0.18-0.30 W/m2K	0.13-0.25 W/m2K	0.13-0.25 W/m2K	1.4-2.0 W/m2K	≤ 0.6ach at 50pa ph	NA
12	London	0.23	0.19	0.18	1.58	NA	0.55
12	Midlands	0.25	0.21	0.21	1.75	NA	0.61
7	North England	0.23	0.21	0.21	1.66	NA	0.58
7	Scotland	0.19	0.15	0.16	1.47	NA	0.49
9	South England	0.23	0.19	0.20	1.59	NA	0.55
3	Wales	0.21	0.16	0.19	1.50	NA	0.52

4.1 Thermal material performance

Data was based upon material to see if there was a trend that could highlight what building materials overall performed best (Table 5, Table 6). The materials arbitrary performance sits quite close to one another in the realm of their relative design standards. One clear thing that the data illustrates across the two design standards is that timber buildings have better overall thermal performance (Figure 7). When looking for outliers in the raw data of Passivhaus, Table 7, one of the timber buildings had an arbitrary performance of 0.21 – Entry 9. So as much as Passivhaus is the next step from Building Regulation for building performance, there are things that exist beyond that. A noted benefit of timber construction is that it is innately an insulating element whereas other materials such as concrete would have to be designed to act as a thermal mass with the aid of insulation to prevent thermal bridging. In regards to the building lifecycle, wood is a sustainable material. With additional trees being planted to offset the ones cut for construction and at the end of life the building has a wider use cases for the material involving less energy intensive procedures to repurpose it. This further reinforces timber being the future of sustainable design and efficient properties. In the Nordic region of Europe, a plethora of their towering housing blocks are timber with engineers pushing the height for tallest timber building year on year. Brick is one of the most common building materials and so a pull away from it to timber may not happen overnight despite its performance, therefore some investment into reducing its thermal transmittance could provide dividends in long term energy savings.

The performance of the materials is consistent across both building standards which is to be expected as there has been no change in the constitution of the materials themselves and their properties. Though evidently the way in which they are applied and brought together has significant implications on performance. As such some simple practices that Passivhaus dictates could be brought into the mandated building regulation, such that in time there is an improvement to the overall stock of property in the United Kingdom. This in turn could have far reaching effects on people's lives. Better personal well-being due to improved internal habiting environments, greater disposable income as less is spent on energy bills, and the initial added upfront cost of Passivhaus design standards could contribute to the economy.

Table 5 - Collated results per region illustrating raw data collected on building element performance for Passivhaus certified properties ordered by construction material

PASSIVHAUS - AVERAGED DATA FOR CONSTRUCTION MATERIAL THERMAL PERFORMANCE							
Entries	Construction	u-value for walls	u-value for floors	u-value for roofs	u-value for windows	Airtightness	Arbitrary Performance
NA	NA	0.18-0.30 W/m2K	0.13-0.25 W/m2K	0.13-0.25 W/m2K	1.4-2.0 W/m2K	≤ 0.6ach at 50pa ph	NA
3	Concrete	0.12	0.12	0.10	0.80	0.52	0.28
21	Timber	0.11	0.11	0.10	0.76	0.48	0.27
12	Brick	0.12	0.11	0.11	0.83	0.48	0.29
7	Brick & Timber	0.11	0.12	0.09	0.75	0.52	0.27
7	Steel	0.12	0.14	0.11	0.85	0.52	0.31

Table 6 - Collated results per region illustrating raw data collected on building element performance for Passivhaus certified properties ordered by construction material

BUILDING REGULATION - AVERAGED DATA FOR CONSTRUCTION MATERIAL THERMAL PERFORMANCE							
Entries	Construction	u-value for walls	u-value for floors	u-value for roofs	u-value for windows	Airtightness	Arbitrary Performance
NA	NA	0.18-0.30 W/m2K	0.13-0.25 W/m2K	0.13-0.25 W/m2K	1.4-2.0 W/m2K	≤ 0.6ach at 50pa ph	NA
6	Timber	0.21	0.16	0.18	1.51	NA	0.51
9	Concrete & Steel	0.21	0.16	0.17	1.50	NA	0.51
35	Brick	0.23	0.19	0.20	1.64	NA	0.56

4.2 Limitations and additional improvements

When gathering data on building performance for standard building performance it was at times difficult to find case studies and data to add for comparison as building performance in that context was not readily available which is understandable. Such buildings are designed using conventional methods to current building standards. The certification process that mostly interrogates the setting out of elements in the building rather than the performance of individual building components and as such the complete data for conventional dwellings was at times hard to come by. Whereas with

Passivhaus, it is quite a conscious construction, it is something you set-out to do, in having a building being able to adhere to such low energy demands and high performance.

A consideration that had to be made when collating domestic properties is that they were certified at least after the year 2010. The year when a major revision to the government building energy standards was issued as the benchmark building performance of buildings designed to United Kingdom regulation was noted from this.

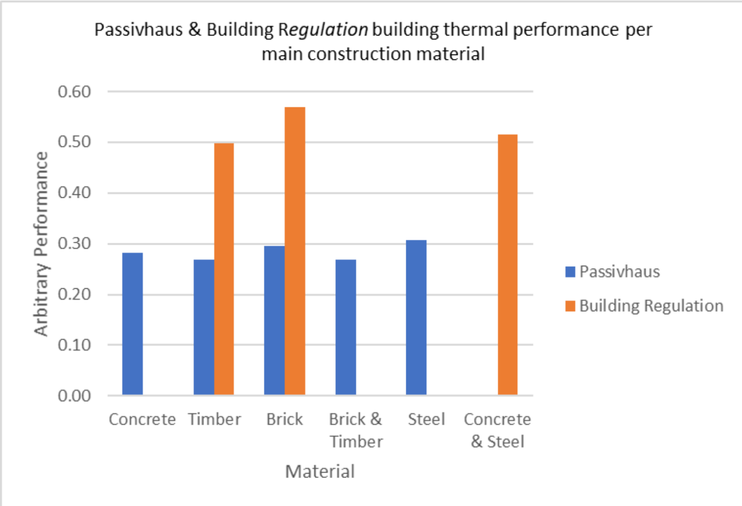

Figure 2 - Chart illustrating Passivhaus & Building Regulation building thermal performance per main construction material

As case studies highlighting building performance were not readily available for standard domestic properties, the available information on the planning portals of councils of approved construction within the areas were used in order to acquire such information. The quality of information included varied, though amongst each council there were submissions that had the full data set for comparison in terms of structural elements. Tests and regulation for air permeability are not as stringent for standard domestic homes and therefore the explicit data was scarce. The overall air permeability as an effect of the overall building performance. It means the air in the cavity is being exchanged quicker therefore is not as efficient as acting as an insulator. To add, with air comes moisture. With the increased levels of moisture within the cavity, the degradation of the insulating material occurs faster, in turn reducing its functional operating lifespan. The recommended standards for air permeability are the same across both building standards though the practice of constructing building fabrics differ (Figure 2). In fact the average air permeability figures for new build properties in the UK are significantly (up to 10 times) higher than the Passivehaus standards.

There are millions of properties in the United Kingdom therefore the number 100 for the sample size seems so minuscule. Despite this the data was quite illustrate as there was a significant gap of performance of buildings built to their relative standards. In construction there are an abundance of variables that effect the performance of the property from design to construction, in effect every building is bespoke. A larger sample size in addition to access to air permeability rates for the constructed buildings in the UK would help to have a more comprehensive picture on the overall performance of the UK housing stock.

5. Conclusion

This research outlined the criteria of both of the aforementioned design standards as well the performance of properties built to these criteria. The research highlights the disparity in the thermal performance of built homes between Passivhaus and Building Regulation, this shows that there are improvements that can be made to current mandated building regulation as there is a capacity to improve. While this means an increased cost of construction, over the lifespan of the building it will be offset by the reduced operating energy costs of the building. Additionally, the embodied carbon of Passivhaus certified homes is comparatively lower than the current building regulations which is both beneficial to the environment and easier to offset. This ongoing saving can contribute greatly to the circular economy as individuals have more disposable income. The push to Passivhaus conventions that utilise sustainable materials contributes to the environmental impact of construction, a conventionally intensive undertaking. This research illustrates the significance of better design standards and principles that ought to be aspired to when designing properties as well as taken into consideration when defining building regulations; such as implementing more insulation into the building fabric to isolate external and internal environments in all climates to maintain a comfortable range with minimal energy expenditure, in addition to an air barrier to limit the passage of air. Going forward it opens up further avenues of consideration such as using timber as the main building material. Future research could look into increasing the sample size to observe if there are different trends with a larger sample size, and to be more representative United Kingdom property stock. Also, an investigation into Scottish construction practices and that of colder climates for comparison and understanding. Finally, research into reducing the thermal transmittance of bricks would prove useful to both Passivhaus and current building practices.

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Conflicts of Interest: The authors declare no conflict of interest.

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