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Original Article

P-15 Passive Housing Systems: A Comparative Analysis against Timber Manufacturing and the Feasibility of Implementation in the United Kingdom

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Abstract: *Passive Houses are a new sustainable development option that has been appearing more frequently across the UK in the last 25 years. The houses offer huge benefits in terms of energy saving, comfort and host a multitude of sustainable technologies within. The houses use an increased amount of timber in the structure and there is a question on whether this increased use of timber combined with the current UK timber shortage could potentially mitigate the sustainability of the house. The research assesses the problem from both the worker and consumer viewpoints using collected primary data and analyzes the feedback well as this alternate solution Passive Houses are explored and compared and the market for these kinds of technologies is researched to conclude whether these houses could potentially become a widespread product across the UK. This research concludes that making passive houses more widespread is possible, but it would rely on a countrywide push to make it happen. Standards need to be raised and an increased level of continuing professional development in this specialised field would need to be put in place to allow for sustainable innovations to become more common.*

Keywords: *Passive Housing Systems, Timber Manufacturing, Saving Energy, Comfort, Retrofit, UK.*

I. INTRODUCTION

The term passive house translates from the German word 'Passive house as the idea of a passive house directly originates from Germany (Janet Cotterell, 2012). This technology is evident in most P-15 Passive House builds as many of the sustainable technologies used in the systems come from German engineering. "A Passive House building is designed to use vastly less energy than conventional buildings, irrespective of the climate" (Janet Cotterell, 2012) and these houses aim to achieve the same comfort and affordability of traditional housing whilst making the home much more energy efficient (Passive House Institute, 2015). To classify a house as passive, the building must meet specific requirements set by the Passive House Institute with requirements mainly surrounding the thermal energy used in the house (Feist, 2017). The first of these requirements is the "Airtightness" of the build. Airtightness refers to the amount of fresh air that goes in and out of a specified volume in a given time and is measured in air changes per hour (ACH). The formula for calculating said value is given as ACH = 60Q/Vol, Q being the air flow rate (Jenny Crawley, 22) and the required airtightness of a Passive home must be below 0.6. To put this into perspective the regulations for the current UK builds is 10ach, how, ever the average existing home in the UK exceeds this value (Janet Cotterell, 2012). From these statistics, the airtightness in standard housing is a fraction of that of a Past house, which is one of, if not the primary contributing factor in a Passive house's drastically increased thermal sustainability. Air infiltration occurs when air travels in or out of gaps in the building's envelope and is often responsible for up to a third of heat losses in UK buildings (M.C.Gillott, 2016).

Sealing the building and improving its airtightness in turn, leads to lower heat levels being required to heat specific volumes and therefore decreasing the airtightness as little as possible reduces the heat needed to maintain a building's temperature levels. This necessary thermal energy is known as annual specific space heating and by passive house definition, it is the energy required to heat an area to 20°coololing to below 25°C, dependent on climate (Janet Cotterell, 2012). The unit for this measurement is kWh/m^2 (kilowatt hours per square meter) and this measurement directly translates to the amount of energy that is needed to heat an area for an hour at a specific temperature; 20°C in this case. The requirements for a passive house state that this value must be 15kWh/m^2. A specifies that the area must be usable internal floor areas, such as rooms or hallways. There are no current building regulations in the UK for annual specific heat space suggesting a lack of concern for the energy needed for the occupier to heat the home (Janet Cotterell, 2012). This also means that some homes in the UK will need extreme amounts of energy to heat spaces, especially older homes which are poorly insulated or homes in colder climates, for instance along the coast.

The UK has one of the oldest average housing stocks in the EU, many of the UK homes having been built in Victorian times; a period known for its issues with heating homes. While most of these houses will have undergone modern improvements since then, it's extremely difficult to properly insulate a pre-existing building to a high standard (Charlotte N. B. Grey, 2017). This highlights the need for high amounts of energy to heat homes, especially in low-income areas. The average annual specific space heat in existing UK stock is around 200kWh/m^2. This is a massive increase in comparison to passive house regulations, especially considering the previous point which suggests that some older homes will need significantly higher levels of energy than this to maintain a comfortable temperature (Janet Cotterell, 2012). The third requirement for a passive house follows from the last statement that the specific heat load must meet 10kWh/m^2. This differs from the previously mentioned annual specific space heat as it refers to the maximum energy needed to maintain a 20°C when the temperature is -10°C outside (Janet Cotterell, 2012).

In the UK there are no requirements in this area or previous data surrounding existing UK stock as extreme temperatures of this magnitude are extremely rare in some areas and unheard of in most (Met Office, 2021). It is important to note that either one or two of the previous two requirements are needed for passive homes due to the rarity of temperatures dropping that low (Janet Cotterell, 2012). The final requirement relates to the primary energy needed for the build. Primary energy is a form of energy that has had no human interference or is, in other words, a naturally occurring form of energy such as a natural gas well (Hitchin, 2018). The specific term used for passive house requirements is annual specific primary energy demand, which translates to the amount of primary energy needed to meet all energy demands of the home/ year. For a passive house, this value is 120kWh/m^2. a' whereas on average the build uses upwards of 400kWh/m^2. This again showcases the marked lack of energy needed to maintain a passive home (Janet Cotterell, 2012). These figures show a definitive pattern when it comes to the sustainable use of thermal energy in the passives. Every regulation set for these systems is a fraction of that set for standard homes. The statistics also show that on average UK homes often don't meet the regulations set indicating a lack of care when it comes to home's sustain homey. On a further note, the lack of regulations in some categories shows that very little time or effort will be used to make a standard home of high sustainable quality.

A. Timber Usage in Passive Houses

A passive house comes with many sustainable features that differ from a regular UK home. A primary focus of this study is the airtight timber frame as well as the wood fibre cladding used in the P-15 system (Passive House Homes, 2021). These specific passive systems use more timber in these elements than standard British homes; the reasoning being that the material is more economical for these already expensive projects and the wooden joists markedly reduce thermal bridging as well as increase the strength (Janet Cotterell, 2012). Simply put the wooden frame increases the structural performance whilst also improving one thermal insulation of the structure. The increased use of timber however comes with major drawbacks, the main issue being the concerns about sustainability. Timber is a natural resource and cannot be grown at a fast enough rate to cope with the demand (Theos Timber Limited, 2018). This has led to large issues in the UK timber industry as there is a shortage of land where forests can be grown and climate change has also had negative effects on the number of trees that we are acan (Timber Trade Federation, 2021) leading to a timber shortage. This shortage in turn will lead to more imported products or more deforestation in the UK to meet the timber demand, with neither option being unsustainable.

B. Alternate Options for Passive Housing

Passive houses aren't the only other option available when looking for sustainable housing; solar-powered housing and P.A.T.H housing are two other viable options (Starck, 2014). Passive houses are renowned for setting the highest standards (Janet Cotterell, 2012) and also have many successful projects across the UK and mainland Europe. Passive homes are leading the way in terms of completely sustainable modern homes and, though there are many other sustainable technologies in the industry, there are very few options for complete sustainable eco-friendly buildings that can offer the same level of quality as a passive home (Passive House Homes, 2021). The importance of this technology in the future cannot be understated and with the worsening trends in climate change predicted (Brown, 2020), there is a huge UK-wide emphasis on the need for new sustainable solutions and passive housing may solve some of these issues.

The significance of this study is to assess the overall importance of passive housing in the UK and determine whether it could be a feasible widespread option in the future. Passive houses clave a massive advantage over the current UK traditional builds and from this data alone look like a viable route to take, however, the current data from the timber industry in the UK shows alarming trends and the increased use of timber in the passive builds will not help with this. The overall assessment will be to consider whether the increased energy saving of the homes outweighs the problems caused manufacturer of the timber. The Aim and Objective of this researcher investigate whether lading the P-15 Passive House

systems out of timber will compromise built the building's sustainability other whether breathing regret is feasible to increase the number of these systems in the UK. Also, there are more research objectives as follows:

- Explore Passive House's method of timber construction in the UK.
- To investigate the pros and cons of transitioning from traditional standard housing to timber Passive Housing.
- Investigation of the negative impacts of timber manufacturing in the UK.
- To address the barriers and implications behind Passive House timber construction.
- To conclude whether to make Passive House developments more widespread in the UK.

II. LITERATURE REVIEW

A. Current Climate Change Issues

To predict future patterns of climate change and CO_2 emissions, previous and current trends up until this point are studied and analysed to anticipate the effects that these will have on the climate throughout the next century. The ICPP released a report on long-term climate change predictions from 1986 to 2015 (ICPP 2019). The report looks at Co_2 output as "carbon dioxide represents 80 to 90% of total anthropological forcing" (Mathew Collins 2018). These predictions indicate that, by the end of the century, UK temperatures will increase to up to 4°C above pre-industrial levels (Met Office 2018). The Climate Change Committee aimed to reduce this value to 2°C and this was deemed achievable, assuming that industrial organizations put strong mitigating measures in place. The last decade has been 0.3°C warmer on average than the previous decade which puts it 1°C warmer than temperatures in preindustrial times meaning that, if the current trend continues, the UK will not meet its climate change target of 2°C (Met Office, 2021). In 2014 emissions from the construction and usage of buildings accounted for 34% of the UK'S total greenhouse gas emissions, with 64% of these buildings being in the residential sector (Climate Change Committee, 2021). These statistics show that the area in need of the most improvement in sustainability is the construction of homes. A large percentage of greenhouse gas emissions in the UK can be significantly decreased if building standards are shifted to a passive approach.

B. Drawbacks of Passive Housing

Passive houses outperform a standard UK home in all areas when it comes to sustainability, however, it does, not come without cost. To achieve the required building standards increased financial input and construction times are needed, as is the case in higher-quality structures (The Green Journal, 2020). The cost of a passive home is always going to be higher than that of a traditional build due to the need for specialized materials and systems, and the trend often shown in the construction industry is that the more advanced the levels of engineering needed for a project the greater the cost. Previous projects show the increased costs for specific materials and the majority of extra costs, ignoring any specialized sustainable products due to the extra insulation that is needed in the homes. Passive houses need much more insulation to create the building envelope and remove any thermal bridging. This includes insulation right down to the concrete footings, as well as across all walls, ceilings and floorboards (The Passivehaus Trust, 2020). Depending on the site the insulation costs vary and structures in warmer European climates, for example, may need less insulation how, ever the current data shows that the average passive house needs much more insulation than any current traditional build (The Passivehaus Trust, 2020).

Another factor that must be taken into consideration is the extra glazing in the windows or any external glass features. Most passive homes require triple-glazed windows which will increase the costs. As the materials themselves need to meet certain passive standards, these products are often imported from mainland Europe which in turn markedly increases the ases price compared to the standard method of acquiring single glazed planes of glass from local suppliers. These triples glazed imported windows can cost upwards of £4000, including importing costs (Janet Cotterell, 2012). As all areas of passive house construction are very new and specialized, this also creates the need for specialized tools and materials in every aspect, not just the main components such as insulation and windows. Specific items such as tapes, membranes and boards are needed to ensure the airtightness of the build (The Passivehaus Trust, 2020) and these items are available from major retailers in the UK (Travis Perkins, 2021), but they cometh a higher price tag. The initial cost of materials is not the only area where the traditional system may have the financial edge ever, as the homeowner must also take into consideration the cost of things such as home insurance which will be significantly higher due to the elevated costs of products and materials in the home (The Green Journal, 2020). Many of these Passive homes have a much higher market value than a simple traditional home (Barns, 2015) and with the main home insurance in his being sum insurance, which estimates based on how much it would cost to rebuild the property from scratch (Hamilton Fraser, 2021), the increased insurance premium is positively correlated to the increase in market value.

Therefore, passive some esthesias a large expenditure for the homeowner. Another important economic issue to look at in passive house construction is the cost of the labour needed. Multiple studies show that one of the largest expenses on a construction project is the hiring of labour (Shahid Hussain, 2020). This doesn't necessarily mean that it is the most

expensive, but there will be a return on the investment in materials when the structure is sold whereas the cost of labour does not pay itself back. It is important to keep track of the on-site labour, especially in passive houses, as specific skill sets are required (Janet Cotterell, 2012). Regular, is irregular will be teams of labourers that can carry out the most task, ho we ve on a massive site, experience with using some of the sustainable products or training will be required (Janet Cotterell, 2012) and this will often result in one skilled labourer amongst a team of regular workers. When planning the project and assigning manpower it must be ensured that there is a professional with the necessary skill set on-site at all times. This can lead to higher costs for contraband and raise the price of the building as the contractor must either spend time and resources training the workers on the passive house specific or hiring an outside professional to come in and complete the works which will cost significantly more than regular labour, especially if they are working throughout the majority of the project (Janet Cotterell, 2012).

C. Thermal Conservation in Passive Houses

P-15 passive houses are a specific type of passive house construction which focuses mainly on the thermal energy conservation of the structure. The P-15 systems are airtight structures that are free of 'thermal bridging'; also known as a building envelope (Passipedia, 2019). Thermal bridging is the movement of thermal energy across a component that is more conductive than the components surrounding it (Foam, 2021). This is an important issue in many traditional builds as it is a major contributing factor to heat loss. The P-systems is a thermal bridge-free design consisting of many sustainable components that allow the structure to maintain a fairly constant internal temperature with little to no thermal energy input (Passive House Homes, 2021). The common assumption with the P-15 system is that it requires no external heat to maintain the temperature, especially ie hotter climates; this isn't entirely true as the system requires a small amount of energy to heat the home. The house aims to not provide an excess of heat, but instead to maintain a constant 20 degrees Celsius regardless of the size of the home and the number of occupants (Janet Cotterell, 2012).

D. Passive House MVHR System

These systems often contain no radiators or boilers but instead employ a state-of-the-art mechanical ventilation system that consistently filters out old moist air from the home and replaces it with fresh air (Passive House Homes, 2021). The way this system differs from a traditional system in that it extracts thermal energy from the old air that has gathered inside the home and uses that energy to reheat the fresh air, thereby constantly recycling fresh warm air into the home to provide improved indoor air quality whilst also maintaining the temperature levels (Foam, 2021). This big improvement in energy conservation is showcased using thermal images taken from the Tevesstrasse project in Germany before and after its passive upgrade. The images show the massive heat loss through the external walls of the building before the redesign and then a significantly reduced level of heat loss afterwards. The only notable loss comes from the windows and this loss is still reduced by the inclusion of sustainable triple-glazed windows (Janet Cotterell, 2012).

Ventilation is an essential part of why these passive houses are as so sustainable. The basic premise of ventilation is to assure that fresh air is being consistently regulated throughout the building (Raffaele L. Dellaca). Poor ventilation can have many negative effects, from high moisture and therefore a build-up of mould in the structure, to larger amounts of airborne pollutants including higher CO_2 values in the air (Architreecture, 2021). Higher quality air will have an increased effect on the comfort of the occupants as constantly recycled fresh air will remove the effects of hot, damp or dry air that are often noticeable in homes with poor ventilation (Janet Cotterell, 2012). The two main types of ventilation are usually known as natural ventilation and mechanical ventilation (Architreecture, 2021).

The P-15 passive house system opts for a 'mixed mode' ventilation strategy (Janet Cotterell, 2012), which uses a combination. It has a mechanical ventilation system as mentioned above but also in the hotter months uses a natural approach for cooling the house. The natural element of the system is very simple and just incorporates large openable windows that allow for large amounts of hot air to dissipate out of the structure and into the atmosphere (Janet Cotterell, 2012). It is a basic and effective method but must be paired with a complex mechanical system to provide high high-quality low. The system is designed for high functionality and the basic principles behind it are to extend the period in which windows can be comfortably left open, therefore P-15 passive properties will often have their windows left open for much longer than traditional builds (Janet Cotterell, 2012).

Natural ventilation comes with its advantages, the biggest of these being the lower energy usage and maintenance costs; however, this is slightly nullified in passive homes as they also incorporate mechanical ventilation. Studies have shown that natural ventilation can have other benefits to the occupants, such as fewer health symptoms and higher productivity (Mendell et al. 1996), but it is shown to be difficult to maintain the high levels of airflow that can be achieved via a mechanical system (Architreecture, 2021), especially that of the highly efficient P-15 system. Typical ventilation systems in traditional houses consist of trickle ventilators, which are little vents at the top of windows that allow small amounts of air in

and out (Glass and Glazing Federation, 2021), as well as small extractor fans which are often found in bathroom or kitchen units. These systems are useful and do extract odours and harmful chemicals, but not at the same efficiency as that of the P-15 system. They are also loud and, in many households, neglected and perceived as more of a nuisance than an aid. Most of these systems do not regulate heat and therefore have a hard time controlling the set internal temperature of the building (Janet Cotterell, 2012).

The passive house system's mixed mode strategy allows constant fresh air to be ventilated throughout the house, even when all windows are closed. This controls the air leakage requirement of 0.6ach, as mentioned previously, which is the lowest air leakage standard of any building currently in the world (Janet Cotterell, 2012). The incredible ventilation in these houses is down to the mechanical ventilation heat recovery system or MVHR. Unlike many mechanical systems, it has no heat pumps or coolers, but simply maintains a constant flow of incoming and outgoing air (Passive House Institute, 2015). The system covers the entire inside of the building and freshly ventilates any space that is habitable to the occupant while removing moist old air from specific rooms of the house, in most cases bathroom sheds. The constant stream of air is directed into the habitable, such as large living rooms or bedrooms, and then extracted from the other damper rooms and filtered into the atmosphere (Janet Cotterell, 2012). The standout piece of technology is the heat recovery system. Unlike most mechanical ventilation systems there is no external heat, but the cool fresh air is instead heated by the warm outgoing a, therefore incorporate incorporating conservation of energy (Passive House Institute, 2015). To achieve this, extremely innovative pieces of technology are used called counterflow heat exchange chambers (Janet Cotterell, 2012). These are thin plates with large surface areas placed in between the ingoing and outgoing air streams, this stops the old outgoing air from midair from maintaining the fresh air being pumped in, but also allows the transfer of thermal energy between the two flows (Passive House Homes, 2021). This system creates no energy wastage and also eliminates draughts throughout the house as none of the air is allowed to get below a temperature of 16.5°C, thereby increasing user comfort (Janet Cotterell, 2012).

E. Issues with Poor Ventilation

Recent studies have shown that the average UK citizen spends 90% of their time indoors (Opinium, 2018). This is an extremely worrying statistic, especially considering the poor ventilation found in the majority of UK homes, as mentioned previously. On top of this around 12% of the UK, the population suffers from asthma (NICE, 2021) and when you consider the delicate nature of young developing children's lungs, the need for clean uncontaminated air in homes is of extreme importance. Many research studies have been conducted on the increase in asthma in the UK and how it's directly linked to the poor ventilation found in many UK homes (Asthma UK, 2020). With an increasing number of harmful chemicals that are now considered everyday household items, things such as cleaning products or decorating chemicals like varnish or paint, not to mention the increased dust levels found in standard UK housing (Paliament Uk, 2010), more focus must be put on proper ventilation systems such as the MHRV found in passive homes.

F. Passive House Timber Frame

The timber frame that is used in the majority of this system is a 3D airtight frame than is modelled on structural engineering software and pre-cut offsite (Passive House Homes, 2021). The frame consists of all the floor components such as the joists and panels, as well as the internal frame of the structure's walls. The process is very fast and simple, as once pre-cut it is then flat packed and erected on-site with minimal work (Passive House Homes, 2021). The simplicity of the process allows for increased sustainability as all the cutting and manufacturing that could potentially lead to pollutants in the air is done in a controlled environment. The use of timber allows for very precise measurements and easy fittings. The shell is made airtight with the use of specialized grommets and membranes that cover any gaps between elements and it allows for the insulation to be fitted easily around it. The timber itself is also very thermally efficient and is a key part of meeting the 0.6ach requirement (Vison Developement, n/a). The timber on a whole is considered an eco-friendlier material than the standard block work that is used in most buildings and therefore contributes to the overall sustainability (Vison Developement, n/a).

G. Negatives of Passive Housing

Timber is considered an eco-friendlier material, say brick or concrete, due to it forming naturally in the environment and also due to its ability to store embodied carbon. The timber on average stores 1 ton of CO_2 per $1m^3$, which is huge compared to concrete, and only provides a solution to the CO2 problem (Kuittinen, 2021). The Climate Change Committee has conducted studies which show that a timber frame can reduce embodied carbon emissions by up to 20% compared to a masonry frame (The Climate Change Committee, 2019). The issue in sustainability with the timber doesn't stem from the material itself but rather comes from its manufacturing. Locally sourced timber manufacturers are currently covering the UK and most construction companies have always had plenty of options when sourcing the material, however because of the benefits explained above on top of the coconutty wide for sustainable construction, the material is in very high demand

(Proffessional Builder, 2021). Currently, the balance between supply and demand is very slim and predictions of shortages in the later stages of 2021 are beginning to surface (pbctoday, 2021).

As timber is now being marketed as the best sustainable material, demand is likely to increase which may lead to shortages, especially from local UK suppliers unfortunate time mere isn't a material that can be replenished quickly due to its long growth time. Local shortages may lead to companies importing the material; however, this can also be problematic as many suppliers close during the summer (pbctoday, 2021), also, transporting the materials thousands of miles can mitigate the positive effects of using wood as the pollution from the transport itself will increase emissions. Another key issue is that wood from slow-grown trees is known to be stronger than that of fast-grown trees and therefore colder climates often provide the best timber (Woodknowledge Wales). This does not help with demand as it means that this process cannot be rushed. At the current rate, demand will overtake supply capacity and the need for another sustainable material will become apparent. The key findings from this process are that, if feasible, more forests or farms need to be on the planet to allow companies to build with this sustainable material.

III. METHODOLOGY

A. Methods of Study

The main emphasis of the research is qualitative data; however, quantitative data will also be used to create an overview. The mixed methodology allows for trends and demographics to be created between the participants whilst also attaining specific unique opinions from relevant participants. The qualitative results seek an in-depth understanding of the topic and are highly useful when the participant has a strong base of relevant knowledge (Ahmad, 2019), while the quantitative data achieves an easy-to-follow statistical analysis, usually in the form of tables or charts, that allows for a more general insight the topic at hand. The mixed methodology creates a dual approach of discovering new information from the qualitative answers and then justifying this information with quantitative statistics (Park, 2016). It also includes data from three different areas including literature research, which will allow me to conduct a comparative discussion on the issues presented in the literature review concerning the potential solutions and new information gathered from the primary research. The incorporation of these techniques increases the validity of the single methods analyzed separately.

B. Research Questionnaire

The first primary research method adopted in this report is an 18-question questionnaire surrounding the importance of passive houses. The questionnaire covers all areas, from why the houses are essential to their increased use of timber, as well as potential alternate options and finally, the feasibility of promoting these houses to a more widespread market. Each area of the questionnaire includes a mixture of quantitative and qualitative data to allow for a simple statistical analysis as well as in-depth answers. The qualitative data comes in the form of opinion-based questions, where the participants are given multiple lines of writing to encourage a detailed answer. The questions are aimed in a specific direction but are open enough for the participants to freely express their opinions.

The quantitative data on the other hand comes from a series of multiple-choice questions, again mostly opinion based but it allows for trends to be set and analyzed. The structure of the questionnaire is multiple-choice yes or no questions to show the participants' general thoughts, and then follow up with an explanation. The mixed methods are helpful for this topic as a lot of the data is opinion and experience based and the questionnaire's respondents are all current workers or previous workers in the passive House industry, so the different approaches allow for a more useful comparison of the results when all data is collected. The questionnaire was made private, and links were sent specifically to passive house workers and passed amongst a company involved in passive house construction. The link was also posted using social media to an online passive house workers group, where anyone within the group who had, an interest was asked to take part. Due to the nature of the parties, pants the importance of the qualitative data cannot be stressed enough, as it will produce informed opinions and information from a group of professionals that are well versed in all things relating to passive houses. The slight downfall of this method is the difficulty of analysing the two sets of abortion each other as the qualitative data is hard to quantify in any way and it's therefore difficult to form a comparison. This however can be overlooked multiple sets of quantitative data can still be compared and used to conclude on their own.

C. Research Interviews

The second methodology I have opted for in this study was purely qualitative interviews. I adopted a solely qualitative approach due to the lack of interviews possible, as comparing results on a quantitative scale would not provide sufficient pieces of strong data with such a small sample size. Fifteen-minute interviews, giving the participants a rough outline of the topic at hand and then allowing them to freely give their opinions, would provide a more comprehensive set of data. All interviewees are recent passive house customers and are extremely useful as, not only have they done their research on passive houses and can therefore comfortably weigh in on benefits and concerns, but they have also researched other

sustainable options and could give their insights as to why they opted for a passive home. The final research question is all about promoting passive houses and making them more widespread across the UK.

Qualitative answers from the customers are priceless pieces of information as they can explain how they became aware of these systems and suggest how to promote them further, providing a unique and useful insight into the other side of the market. The data provided by the customers may give a slightly biased approach to the beneficial aspects of passive housing however, paired with the literature review research; it gives a well-rounded insight into the vantages and disadvantages of these systems. The interview also covers their experience of the homes thus far and highlights any aspects of the design that they feel could be improved upon as well as their overall experience.

D. Research Questions

1. Does the increase in the sustainability of the Passive Houses' uses of thermal energy might the gate negative effects of increased timber consumption?
2. What are the alternative solutions to timber Passive House construction?
3. How are we able to promote this method of construction in the UK housing industry?

IV. RESEARCH DATA & DISCUSSION

A. Analysis of Research Interviews

a) Increased Sustainability in Passive Housing

The first research question initially focuses on the increased sustainability of the P-15 systems, the importance of which cannot be understated. When questioned whether these houses were essential in the future, both participants 2 and 3 answered “definitely” and “absolutely”. Participant 1 also agreed but noted that “our building standards are rubbish” and that not only do we need these passive houses as a means to pave the way for sustainable development, but also to encourage the construction industry in this country to put a heavy focus on increasing the minimum environmental standards. Participant 2 stated that in their previous house, their annual energy costs were “£3200” and they are now expecting a bill of around “£200” as “they won’t be turning the heat on”. These interviews were conducted in the middle of summer with a temperature of around 28 degrees Celsius, however, Participant 1 mentioned the notice of temperature changer here “you’re hot and it’s a comfortable 20 degrees in here”. All participants noted that the houses are “way more comfortable” than a traditional build. To be able to massively surpass traditional building standards while keeping the heat at a comfortable regulated temperature is extremely important, especially with “no heating, just the heat recovery system working”.

b) Increased Use of Timber in Passive Housing

The first research question focuses heavily on the increased use of timber. When questioned about it all participants had a similar response, which is that the increased use of timber is irrelevant when the overall sustainability of the house is taken into account. Participant 2 stated that “No, I don’t feel as though it makes it less sustainable, as timber itself is sustainable except that it’s sustainable over 80 years or so”. Much like the secondary research conducted, the information gathered shows that the use of the material itself is sustainable, as timber has a long-life span and naturally rots away. Participant 1 said, “No, I, think timber is probably the right route to go down because you’re because of CO_2”. Similar to my secondary research, the information states that timber is the best material for reducing CO_2 emissions and is the ref, theis the refresh forward. Participant 3 stated that “wood’s the answer for now, but it will eventually run out so at some point we may be becoming part of the problem”.

This implies that the overall consensus from these customers, who have all done extensive research into the use of eco-friendly materials, is that timber is the right way forward, forward r pain, ringing his kno edge with the increased demand for this material suggests that new solutions must be created to either regulate the amount of timber used or increase the supply of it. Participant 3 also goes on to say “I think that the timber is being used in the right way. I’m comfortable with what we’ve got here in terms of materials and where it’s come from”. The sustainability viewpoint from the customer perspective is that as long as the timber is sourced properly and is being used in a positive eco-friendly way then there isn’t a problem with using it as a primary material. Participant 1 notes, “If anything you’ll be capturing more CO_2 in the framework of your house rather than building block work where you will be using concrete blocks which is creating CO_2”.

This perspective adopts an alternative point of view, implying that not only is there not another option as sustainable as timber but other solutions such as conically positive effects are part of the problem. All three participants see the other primary option former as being bricks or concrete. Participant 3 mentioned the use of a concrete frame as being negative because on top of its carbon emissions it’s also not reusable. Participant 2 noted that the architect who built the (timber)

frame is trying to get to a stage where it is very carbon neutral" which cannot be done with large amounts of concrete being used.

The basis of making a house carbon neutral is to reduce the amount of concrete used as it contains high levels of embodied carbon (Phil Purnell, 2012) and therefore using something such as "ICF", as Participant 3 mentioned, will not benefit the carbon neutrality of the build. Insulating concrete formwork (ICF) is a self-insulating concrete formwork that consists of "concrete pumped into polystyrene" (Participant 3) and has excellent thermal properties. Participant 2 noted that when talking to builders, they confirmed that it was possible to build a passive house with this material, however there, is an extremely high use of concrete and it would therefore be impossible to keep the building carbon neutral. The overall consensus from all the customers was that the timber in no way mitigates the sustainability of the houses. The mutual feeling was that if you are trying to achieve a build as complex and sustainable as a passive house, materials like timber will always be needed however there do need to be some focus on potential future solutions.

B. Alternate Options for Passive Housing

The unique participants selected in this survey allowed gathering information about alternative sustainable construction methods and products from people who have conducted extensive research when deciding on their homes. The focus was primarily on completely different solutions to passive housing that may compete in the sustainable construction market but also looked at alternative ways of implementing the passive house systems in the future. When quizzed about any alternative options, Participant 1 stated that passive was the only one he considered when constructing his current house, "it ticked all the boxes". He noted that passive houses were the only entirely complete system that fully suited his needs. This decision was based on years of constructing multiple houses "with better levels of insulation", however, these houses were still allowing drafts and air leakages. He noted that the houses he was building had insulation that was "virtually passive house standard", however, they did n, to have the air tightness requirements and were therefore falling short of his expectations. This discovery suggests that although there are ways of improving insulation in houses, the actual passive house design has benefits that better is better insulated not achieved. An interesting point was that passive houses have "been running for 25 years or so and they've even gone back to the original passive house and it's still operating wells suggests that not only do these houses perform better than most other options, but they are also will perform at these extremely high standards for a long time.

Participant 2 has done "environmental investing for 15 years, becoming aware of multiple sustainable technologies, and spent a long time researching different options before settling on passive housing. "Solar panels" and "ground source heat pumps "were the initial ideas and the idea of passive housing grew from there. The idea of building a passive house was described as an "iterative process" where they considered "changing their windows to triple glazing" but then we're told that air will still be lost. The process involved researching multiple different options that in their ways were all sustainable improvements, however, when asked about it stated that the appeal came from having multiple different technologies in one place. Solar panels, for example, are an excellent sustainable product however in many cases do not entirely power a large property and therefore still rely on external energy input (Mehreen Gul, 2016).

Also, most traditional homes as mentioned in the literature review lose large amounts of heat through poor insulation therefore large levels of thermal energy will still be lost without the passive house airtight design. Ground source heat pumps as a very viable sustainable option that could be explored and Participant 2 mentioned that they are a very common technology in France. Similar to solar panels these energy sources take thermal energy from natural layer occurring heat sources, unlike passive radiators, and traditional heating systems are still needed, often underfloor heating (Pullen, 2021). A similar problem occurs in that the heat is still Los the traditional homes. Passive sets itself apart by trapping the heat and although there are many other sustainable energy options none other contains and reregulates heat like the passive MVHR system. Participants 2 and 3 suggested that ground source heat pumps could be a good viable option for sustainable energy if implemented properly. "If you were a real community you would go to a nearby field and drill multiple boreholes down next to each other and heat all the houses". The problem with ground source heat pumps is that they are usually implemented for a singular house and done in the garden (Pullen, 2021) which isn't very sustainable or efficient, however, if one large construction of pumps was implemented in one area this source could sustainably "heat the whole street".

C. Retrofitting Current Properties

A key finding when researching the alternative options was that all participants suggested that passive was the way forward, but a potential solution to the standard new build would be to retrofit the houses instead. About Participant 2, "the bottom line is we still had to knock down a house, which is a pretty unsustainable thing to do". The take from this is that, although the house is completely sustainable and will help battle the problem once constructed, the actual process of knocking down the house and rebuilding isn't, "but I don't know how many years of using less energy it will take to offset

that". They even went on to state that "Should everybody knock down their house and build a passive house? not", therefore retrofitting is essential to consider. Participant 2 mentioned a friend who, rather than knock their house down and build again, "fitted foam blocks inside all the rooms" which cost them a lot of house space but required a very short and efficient construction process. Participant 3 commented that "It's not a Passive house but, if you're getting a percentage of what a passive house achieves without knocking it down, you're going to be much more sustainable". This is an essential viewpoint to consider for the future as the passive direction is an important route, however, the entire, country cannot knock their houses down and build fresh as this would be a huge step in the wrong direction. It may become beneficial in the end, but it would take a huge period for the entire process to be considered sustainable. Participant 1 also covered retrofitting, saying "it's a case on older properties of picking the biggest gain". If you were to retrofit a house and get it "80% passive rather than 100%", this is a huge benefit and with the construction process may be a more sustainable option than knocking it down.

D. Issues with Retrofitting

Retrofitting, like every construction method, comes with its problems. Participant 1's house was a retrofit of a traditional block workhouse, and his view of the process was that it was "a complete nightmare". He stated that more work had to be done to the house, stripping it back to try and get it in line with the passive design, than there would have been having they demolished it The process of stripping the house back to the block work added an extra "3 or 4 months" to the program, whereas Participants 2 and 3 "had theirs all fitted within a week to get to the same point". They also noted that the process of retrofitting is a much more difficult task and requires "even more training to be careful that you are not building in condensation and moisture traps".

The process of building a passive house from scratch requires a certain level of training as it is, however retrofitting a traditional build to papas comes the o lot more complications and higher levels of training and experience will be required. From this information, a balanced view of retrofitting and building from new should be taken. All participants acknowledged that if it was a decision between retrofitting a house or demolishing it, retrofitting is the most sustainable option, however, Participant 1 stated that if it's "a house that needs a lot of work and has some existing faults, it's probably easier to demolish it", so judgment is needed when deciding on the best approach. Participant 1 also went on to say that he believed "every new build should be a passive house" and that "we should go down the passive house route where builders are trained properly and retrained every 5 years with the latest ideas and technologies". To take this approach the government standards need to be greatly improved. The "standards of workmanship vary immensely" and these houses require an extreme amount of skill and knowledge to construct as they have very strict requirements when it comes to air tightness. Participant 1 recalled a situation where a professional "went in to do an air test in some homes and they quite literally had to strip the houses right back and redo the wood to meet the requirements". It's clear from this information that these houses can be a potential solution to the sustainability problem, however, it's important to note that a government initiative needs to be put into action or the professionals with thought ski the ll and knowledge to construct them to a high standard.

E. How to Make Passive Houses More Widespread in the UK?

When it comes to the promotion of these homes the participants, being customers, are the ideal people to ask. Participant 3 felt that being able to experience the homes is essential. "Practicality is important", "you've got to get used to no heating and no radiators". The idea of the house is almost unrealistic and therefore the experience of being inside one and feeling the effects is essential. Participants 2 and 3 noted that they stayed "in a holiday house that was passive and that's what appealed to us". A potential marketing tool for these homes would be to construct passive buildings that will have a high traffic use; schools or holiday homes that will have many people coming in and out who can experience the structure for themselves. There are a few Passive House schools in Germany that have taken this approach, and they are very highly regarded (Janet Cotterell, 2012).

Participants 2 and 3 said, "The purpose for us doing this is to also persuade other people to do this" and even mentioned holding an "open house" to allow people to come and experience it. One of the main factors that put off passive houses is the price tag. As mentioned previously, making the house passive will cost more than a traditional build, however getting people to understand that "you can have a much smaller house and still be passive" is important. Not every passive house needs to be a million-pound investment. An interesting point that Participant 2 made, is that they didn't want to get the house certified as the plaque cost £2000. They have however decided to get it, "as it's good for getting the word out". Perhaps making the certification of the house a standard element when one is built rather than charging the owner would allow for more certified houses, which could be a good way to spread awareness. An essential part of making these houses more widespread is a government lead initiative. Participant 1 has been asked to talk at a council lead "eco day" to promote these systems. Initiatives such as this, with a large audience where correct information about the houses is spread, could be a key part of making these houses widespread across the country. As well as all these options, every participant stated that

word of mouth is one of the best methods and all have been extremely involved with the construction community to promote these houses further.

F. Analysis of Research Questionnaire

Question 1 – What do you feel is the importance of Passive Housing in the current UK housing market?

When questioned about the importance of these houses the workers gave a mixed set of feedback. A common trend amongst the answers was that recently there has been a particular emphasis in the construction industry on sustainable development. One respondent noted that currently the UK housing sustainability standards are poor and therefore these houses are an essential way of driving the standards in the right direction. Most answers lean towards the fact that sustainable construction will be key in the future as CO_2 emissions are becoming worse and that these houses may therefore be a future-proof solution.

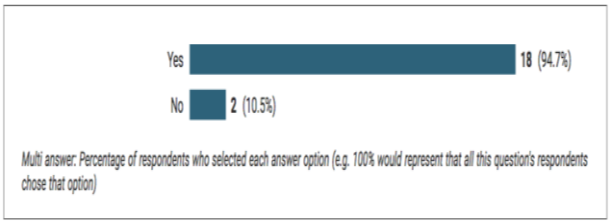

Figure 2: Question 2 Participant Responses

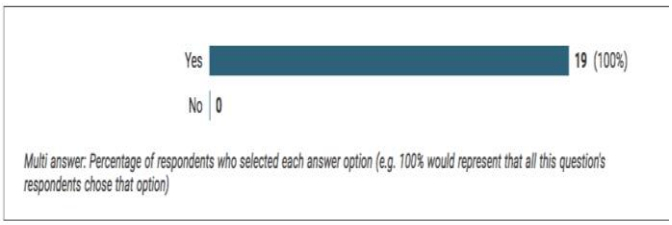

Figure 3: Question 3 Participant Responses

Questions 2 and 3 – Do you feel Passive Houses will play a vital role to improve sustainability in the UK construction market? Are Passive Houses the best option when it comes to sustainable housing?

As can be seen from the figures above the majority of workers feel that these houses are vital when it comes to improving sustainability. 100% of the respondents believe that passive housing is the best option in sustainable development, something that is becoming an increasingly popular opinion across the sustainable construction market. On looking at these sets of data, the trends show that to strive for the best sustainable future in the UK the best sustainable developments must be constructed, and as passive housing is seen as the best these homes must become more widespread.

Question 4 – If possible, could you name any other options for sustainable housing that provide similar advantages to Passive Houses?

From analysing the qualitative data above, the majority of the professionals who work in the sustainable construction industry couldn't provide another sustainable housing option. Many of the answers mentioned technologies such as solar panels or ground source heat pumps, which provide sustainable energy but don't provide a completely sustainable heat recovery system like a passive house. The recurring trend is that other options can provide the energy sustainably but cannot trap and reuse it in the same way, again reinforcing the idea that passive houses are the best sustainable option.

Questions 5 and 6 – Are you aware of the increased use of timber in Passive House construction? Are you aware of the negative effects of timber manufacturing?

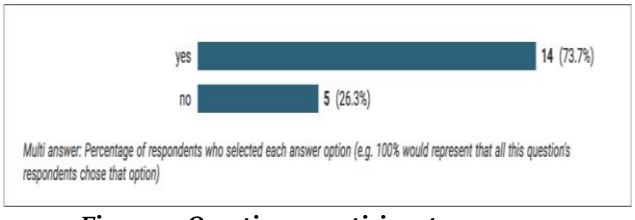

Figure 5: Question 5 participant responses

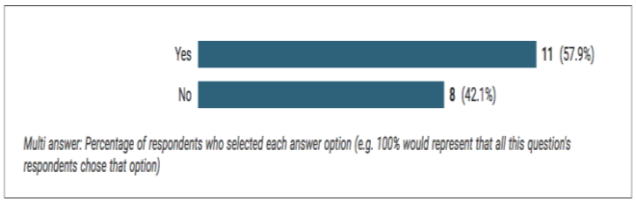

Figure 6: Question 6 participant responses

This section of the questionnaire focuses on timber usage in passive house construction. The figure above shows 73.7that % of the professionals was aware of the increased use of timber. The 26.3% that said no could potentially have come from workers who haven't worked with the timber frame but rather work on retrofitting projects or projects that opted for a blockwork frame. The second figure shows a fairly even split between the professionals. These values are surprising coming from inside the construction industry and suggest that more information about the materials being used should be made available. An observation made from this data could be that making the workers more aware of the negative effects and the need to mitigate the problem may lead to more innovative ideas to solve the timber issue surrounding these houses

Question 7- With these negative effects in mind do you feel as though the increased timber used in Passive Housing can mitigate the houses' overall sustainability?

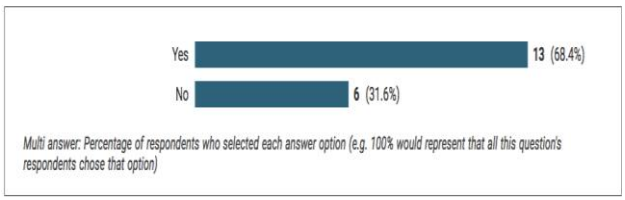

Figure 7: Question 7 participant responses

As shown in the data above, the majority of the workers felt that using timber in the frame will mitigate the house's overall sustainability. Roughly 70% of participants answered that it would be an issue, however when asked to explain their answers the majority of the participants who answered yes reasoned that the effect would be minor. On looking at the answers, most felt that the house's overall sustainability significantly outweighed the slight decrease in sustainability from using the timber. Some even commented that using timber may even increase stainability due to its ability to absorb CO_2. The consensus from the results is that the use of timber is negligible as long as it's sourced sustainably, due to the massive increase in sustainability that the house provides. Therefore the 68.4% that said yes shouldn't be taken as a reason not to use the timber frame.

Question 8 –Do you feel as though there could be other options explored as a replacement for a timber frame that would not affect the sustainability?

When asked about a replacement material for the timber frame there was a mix of suggestions, the most prominent being concrete. As mentioned previously concrete has high-embodied carbon levels meaning it leaks CO_2 into the atmosphere, which reduces sustainability. Although concrete is much more readily available than timber and may help battle the timber shortage issue, it hugely reduces the sustainability of the structure and makes it virtually impossible to build a carbon-neutral house with a block work framework-frame of the answers agreed that timber is currently the most eco-friendly material to use, which therefore suggests that the solution to the problem would be to increase the supply rather than find alternative solutions.

Question 9 – Locally sourcing the timber from the will increase sustainability surrounding the timber manufacturing however as there is only a certain amount of timber to be sourced locally do you feel as though this puts a limit on the number of Passive Houses that can be constructed sustainably in the UK?

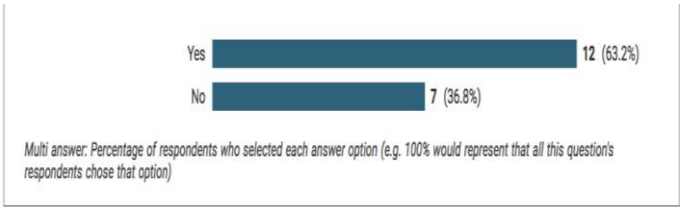

Figure 9: Question 9 Participant Responses

The data above shows that the majority of participants do feel that the ability to make these houses is reliant on the timber supply. This could potentially limit the number of houses due to the current timber shortage in the UK. Most think that there are ways around the issue of importing timber sustainably. While the general idea surrounding the issue is that there is not enough land to cope with the increasing demand for timber, there are solutions including reforestation. Even though the majority of participants feel that the lack of timber can limit the number of houses built, all the comments suggest that there are ways around the issue rather than limiting the number of houses.

Question 10 – From working with Passive Houses could you suggest any areas where the construction process could be improved in any way and explain how?

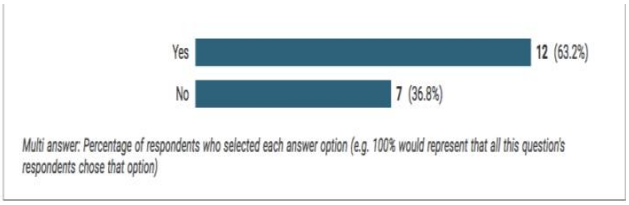

Figure 10: Question 10 Participant Responses

When asked about improvements to the passive housing process many of the professionals believed it is as sustainable as it can be for now. Perhaps with the introduction of new sustainable technologies in the future, new innovative processes could be incorporated to improve sustainability. The other suggestion from a few of the workers related to the initial build. The process of constructing a passive house begins in a similar way to a traditional built building the foundations of the initial block work its very similar, therefore there may be room to incorporate new processes or technologies that could improve the process and the product. One of the participants suggested prefabrication and while some of the houses are already prefabricated, the timber frame, for example, other aspects such as the insulation panels or some of the external walls could be constructed offsite and transported to make for a more accurate and efficient build.

Question 11 – Do you feel as though Passive Houses are found frequently enough in the UK? How could they be promoted better as a sustainable solution?

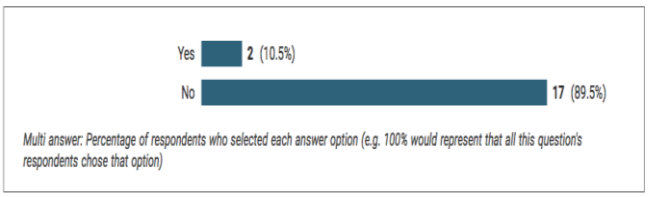

Figure 11: Question 11 Participant Responses

The large majority of professionals felt as though passive houses are not found frequently enough in the UK. This was expected as these workers have experienced these houses and have seen first-hand how impressive and sustainable, they are. When asked how better to promote them, much like the interviewees, the main answer pointed to government backing. While these houses have been increasingly popular over the last decade, a UK-wide incentive from the government is needed to direct people towards the idea of sustainable development. A higher focus on eco-friendly housing is needed and many of the participants felt that either financial backing or a financial incentive from the government would be the best way to promote this system.

Question 12 – Do you feel that it is feasible to largely increase the number of Passive Houses in the UK?

Figure12 participants believed it was feasible to make these systems more widespread in the UK. This shows overwhelming support from the workers within the industry to push for an increasing amount of these houses to be built.

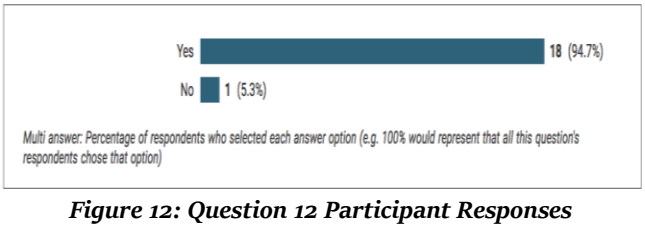

Figure 12: Question 12 Participant Responses

From the data above the trends show that almost all the professionals think it is essential that more passive houses are available and that it is a viable option in this country. The consensus is that there is room for these houses in the current market and some of the participants even noted that there is enough timber available currently to build them. The underlying point from a lot of the workers is that there needs to be a countrywide stainability and therefore these houses are a feasible solution to the problem.

Question 13 – Do you feel as though the demand for Passive Housing is increasing in the UK?

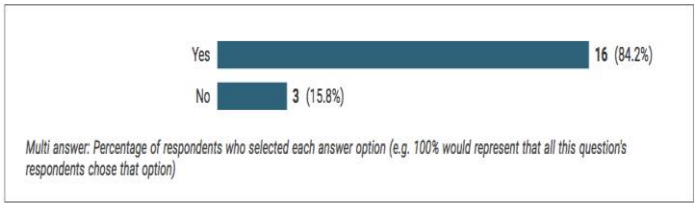

Figure 13: Question 13 Participant Responses

When asked about the demand for these houses again the majority of respondents said that it is increasing. Similar to the previous answers in the questionnaire, the current emphasis on sustainability is the key factor. The need for sustainable innovation is what could be increasing the demand. The worse the CO_2 emissions get, and in turn the worse climate change gets, the more the need for these technologies grows and will continue to grow in the future. Many of the workers put the increase in passive house popularity down to this fact. One of the participants noted that contractors and clients may not opt for this technology as they aren't informed enough about it, but another client mentioned that they have been seeing more information appearing. These factors may complement each other and as people learn more, they may be more inclined to try going down the passive route. One of the participants commented on a noticeable increase in passive houses in their area which could potentially be a positive sign for the future.

V. CONCLUSION

This project aimed to assess the sustainability of P-15 passive housing and determine whether the increased use of timber in the frame, especially paired with the current timber shortage, mitigates the energy-saving advantages. It also includes researching alternative options as well as exploring the possibility of making these systems more widespread. From the primary and secondary data obtained in this project, the overwhelming consensus is that these houses perform way above standard traditional housing. The high levels of sustainability achieved by passive houses are unrivalled and are well above the standards set by the UK government, therefore their sustainability is not in question. From assessing the primary research conducted, the most common opinion from customers and passive house professionals is that the negative impact on sustainability from the increased use of timber is negligible in relating about fits to the low levels of energy the houses use on an ongoing basis. The research shows that timber is the most eco-friendly material to use due to its ability to absorb CO_2 emissions.

The lack of other sustainable materials that can match the qualities of timber further reinforces the current thinking that timber is still the best option. Most of the participants from the interviews and questionnaires were aware of the current timber supply concerns as well as future sourcing problems that could arise. The research shows that decreasing the amount of timber from the design is not the best option rather finding sustainable ways to source it should be the next focus. The issue lies in timber manufacture and not the passive houses themselves, therefore solutions to the problem such as local reforestation and potentially importing from sustainable suppliers in Europe may be the solution. A key point taken from this study is that timber will continue to be used in the same way and that decreasing the timber used in passive house design will not significantly affect timber demand. Therefore, the use of timber in an eco-friendly manner as these systems do will not significantly add to the problem.

As far as alternative options to passive houses are concerned, the research concludes that there isn't another option that can achieve the improvements in sustainability to the degree that a passive house can. The primary data suggested an array of sustainable technologies, such as solar panels or ground source heat pumps, but no actual housing options that recycle the energy as efficiently as a passive house. A point of note is that passive houses do still use a small amount of energy to heat and maintain the house. Incorporating some of these other sustainable energy sources into the passive house design could potentially create a completely sustainable product. Other possible solutions suggested using different materials, but these were primarily aimed at combating the timber concerns however, as this project concluded that timber is still the best option, alternative materials would not be of any real benefit. The most interesting point to take from considering alternative options is related to the degree to which a house can be made passive. The information gathered

from the interviews indicated that retrofitting an existing house what the most sustainable option, as demolishing and rebuilding increased the carbon footprint of the building. The approach of retrofitting current buildings in the UK in order them more sustainable is a very viable option. Making these homes 100% passive may not be feasible as a high level of training, money and resources would have to go into it, however, opting to retrofit houses to a higher standard than what is current in the UK may be the best way forward. The data suggests that making a house passive to some level by increasing airtightness and insulation would be very beneficial as, though not all houses do not have to become completely passive, the sustainability standards must improve.

The feasibility of making these houses more widespread raised some interesting questions. All participants felt that it would be the correct decision to increase the number of passive houses, however, there was a more mixed response when asked about how this might happen. The data has shown that these houses are becoming increasingly popular, however, it also shows that steps could be taken to further improve this. To increase market demand for these houses, word of mouth seems to be essential. Customers and workers all believed that experiencing the difference would attract people to the concept. Participant 1's comments about speaking at council-led eco daringness up an interesting point and the government could support more of these functions to raise awareness. There is currently a strong emphasis on sustainability in the UK construction market, however, the living standards are still low and the government could do more to promote solutions to the problem. The opinion of the professionals and customers was that govern government meant-wide active would need to be put in to make these systems more widespread. Participant 3 also noted that a "culture change" is needed. UK residents need to understand that the way we are currently constructing isn't the future and that refusing to change to more eco-friendly ways of living is necessary.

This research concludes that making passive houses more widespread is possible, but it would rely on a countrywide push to make it happen. Standards need to be raised and an increased level of continuing professional development in this specialised field would need to be put in place to allow for sustainable innovations to become more common. As things stand, the likelihood of the situation improving in the immediate future is low, however a current increasing trend toward these houses is promising and the number is set to increase, and retrofitting has the greatest potential for providing a feasible route forward. At the time of writing today, an IPCC report has declared a "code red for humanity", but scientists say catastrophe can be avoided if the world acts fast.

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