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Improving Energy Performance of the UK Housing through the Implementation of Passive House Standards

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Abstract: The UK government has committed itself to achieve net-zero on Greenhouse Gas (GHG) emissions by 2050. The UK housing sector is one of the major contributors to GHGs and over 60% of the energy used in the UK residential sector relates to heating. Thanks to their extremely high fabric standards, Passive House strategies and standards can significantly reduce the heating energy demand by 80%. Yet, these strategies are not widely implemented in the UK compared to other European countries such as Germany. This paper aims to explain such strategies and assess the effects of upgrading a typical UK house to both Part L of the UK Building Regulations and Passive House standards to compare the energy performances before and after upgrading. The case study building is modelled in EnergyPlus and the energy performances are compared. The results reveal that the heating energy consumptions reduced significantly by over 78% when the Passive House standards were implemented.

Keywords: Energy Performance; Energy Efficiency; Heating, Passive House; Housing.

1. Introduction

More than half of the billed energy in the housing sector in the UK and EU is related to heating [1]. This high energy bill is associated with poor building energy performance, caused by factors such as poor construction detailing, occupants' behaviours, and building fabrics [2]. Energy performance is defined as measuring the relative energy efficiency of a building, including its equipment or building components, measuring the total amount of energy required to power all the building services and equipment [6]. These have a direct impact at the same time on the home's energy bill, CO_2 emissions and the wellbeing of the building occupants. A passive house requires 10% of the energy for heating compare to a typical one [3]. In countries such as Germany, a pioneer in passive design strategies, cities such as Heidelberg have adopted the passive design concept as the building standards [4]. The passive house design can potentially improve energy performance of the UK housing, providing indoor thermal comfort and reduce the energy bill as well as reduce Greenhouse Gas emissions gases emissions.

According to passipedia [5], a passive house is an integrated concept to ensure the highest indoor level of comfort, rather than an energy standard. The achievement of this thermal comfort is gained through extensive passive measures such as adequate insulation, heat recovery system, passive use of solar energy and internal heat sources. At the same time, a passive house should be energy-efficient, affordable, comfortable and ecological [6,7]. A large part of the heating demand of a Passive house is sourced by the sun, household appliances, human occupants as well as the heat from the air extractor [8], . Fresh air is provided by a heat recovery system that efficiently allows for the heat contained in the exhaust air to be re-used [9]. "Passivhaus buildings provide a high level of occupant comfort while using very little energy for heating and cooling" [7].

The passive house concept was developed for the first time in 1988 by Dr Wolfgang Feist, a German physicist, and Dr Bo Adamson, a Swedish scientist driven by the effort to refine the principal to design techniques for the Passive house performance metric, which lead to the design and construction of the first passive house in Darmstadt, Germany in 1991. Demonstrating and showing a vision for the construction's future, that combines energy efficiency, optimal comfort, affordability, sustainability as well as good indoor air quality. More than 2 decades later the Darmstadt terrace first passive house was built, is giving a consistent amount of fewer than 15 kWh per square metre of living space, remaining the same exactly as planned when it was built [4,10]. This house is occupied by four families, and year after year, its energy consumption is monitored.

A passive house is a high energy efficient building, consuming over 75% or less energy for cooling or heating in comparison to a new average building and 90% compared to a typical building [6]. According to Ovoenergy, n.d., the energy needed for heating for a leaky house in the UK is around 300 kWh/m^2 and 15 kWh/m^2 for a passive house that is 5% of the energy used for a leaky house. The energy savings are similar in warm climates where energy is required for cooling [5]. For a building to be called a passive house, it must meet certain requirements from the design to the completion. Also, the low amount of energy needed for the daily building operation needs to be covered by renewable resources such as biogas or solar [12]. A passive house must be fitted with adequate insulation, demanding a minimum amount of heating. The energy demanded either for heating or cooling should not exceed 10 w/m2 and 15kwh/m2a. The primary energy used in a passive house must not be greater than 120 kWh/m2a. However, it is advisable to keep this demand lower than 60 kWh/m2a [3].

The cost of building a passive house is higher compared to a traditional building. However, this cost difference has reduced considerably by the time; the extra additional capital cost is directly related to the thermal insulation for the walls, slab, roof, triple glazing windows, and heat recovery system [7]. The production of a passive house varies depending on the country where the project is developed; in Germany, the cost of building a passive house is 5%-8% higher than a typical building, in the USA 5%-10%, meanwhile in the UK is from 8%-10% [13,14]. Passivhaustrust, 2019 , in a report from a case study from the Exeter council which has been building passive houses since 2010, has found that cost price production has reduced by 25% over the last 5 years. This cost reduction is believed associated with the widely adopted technology to build passive houses.

1.1. Passive house building design

To design a Passive house, many factors must be considered, such as the orientation of the building, its form, materials u-values as well as choosing the right design approach. According to BRE, n.d, the building should be orientated along east/west facing 30 degrees to the south to allow the building to gain the maximum benefit of the direct solar. If this orientation is not possible, the result could be an extra annual heating demand of 30%-40%. However, the overheating in hot seasons must be considered as this is being more intense through the years, and it is expected to be increased by 1.2-8.1 degrees in England by 2080, due to the global warming that could cause the premature death of an estimated of 7, 000 people [15,16].

The ratio area/volume (A/V) between the internal volume and the external surface of a building has an important impact on the overall energy demand. It is advisable to design small compact buildings rather than a large in order to reach the desirable A/V ratio ≤ 0.7 m^2/ m3 [17]. The passive house standards demand that all the elements that made up the building have a very good U-value and airtightness. These U-values vary depending on the building context; location, building form and so on, being the recommended values limit for the walls, floors and roofs ≤ 0.15 W/m^{2}K complete window installation ≤ 0.85 W/m^{2}K; meanwhile, the airtightness should not be greater than 0.6 air change per hour at 50 Pascals pressure (ACH50) [17].

The airtightness causes an important impact on the energy performance of the building. Up to one-third of the heat losses is associated with the air infiltration through the building envelopment in older buildings in the UK [18]. In a comparison of UK existing buildings to European countries and America, the UK dwellings tend to be leakier [19] and the reason could be associate with the way that buildings are constructed in the UK This leakiness can lead to an increase of the annual energy consumption, moisture accumulation and risk of condensation [20], as well as degradation of the structure and reduction of the effectiveness of the insulation [21].

The importance of the airtightness was addressed in a consultation in the UK in 2000 [22] leading to the implementation of a minimum airtightness requirement of 10m3/(h.m2) @ 50Pa for new dwellings within the Building Regulations Part "L" [16]. The airtightness in new dwellings has improved in the last years; however, a study by the Energy Efficiency Partnership for Homes (EEPfH), in England and Wales, where 100 new dwellings were assessed, it was found that 20 per cent did not achieve the minimum air permeability required [21]. Johnston et al., 2011, concludes that the airtightness could be improved by paying more attention to detail on-site and ensure the maintenance of the primary barrier is maintained [19].

All the designing team members must understand the principal and standards of a passive house design to integrate passive design strategies from the beginning, as in many cases, some wrong early decisions can be difficult or impossible to change later, such as the orientation or building form. To check if the targets are being achieved, it is suggested to use the Passive House Planning Package (PHPP). This is a tool developed by the Passive House Institute to help the designer to achieve passive house standards [15].

1.2. The current situation in the U.K and the world.

Since the first passive house was built in Germany, 65,000 more have been built around the world, and from that amount, 1,000 are in the UK The first passive house built in the UK was a detached rural self-build in Wales in 2009 [4]. Countries such as Austria, Germany and Canada have implemented either the passive house concept as building standards or applied loan discounts to encourage a wide implementation of passive houses.

The total number of homes in the UK is 29 million, from that 1,000 are passive houses [23]. The remaining 28,999,000 homes in the UK are relatively consuming extra energy to achieve indoor comfort conditions. This extra consumed energy not only increases the household energy bills but also emits green gases contributing to global warming. The wide implementation of passive design strategies in new and existing homes would reduce the energy bills as well as cut CO_2 emission to the atmosphere. Building passive houses is a long-term investment that has an important impact on the energy performance and the human's wellbeing providing a healthy indoor environment.

1.3. Barriers and solutions

For the implementation of new energy efficient design is often required new techniques and technology, creating technical barriers and risks, as well as no technical barriers such as cultural, social and economic [24]. Government incentives for the implementation of this system can react against schemes affecting the industry if there is not enough personnel qualified to cope with the crescent demand [25]. This is the case of Japan, where the industry suffered a backlash after a premature fast growing of solar installation due to a government grant scheme. [26]. In the UK most developers are not motivated to produce zero carbon homes, and they are not interested in delivering a quantity of these building until strict legislation is in place [27]. Housebuilders pay an extra cost to build Zero Carbon homes that benefit the future occupants reducing the operational cost; however, housebuilders are unable to attract clients for such premium. Also, another barrier is that the local authorities, QUANGO, developers and architectural consultants do not have a strong social responsibility as a driver [27]. This issue is probably one of the most important as they are the motor of the construction development

The delivery of a passive house is 8-10% more expensive compared to a typical house [28]. However, a study by Newham and Whidborne 2012, demonstrate the advantages of implementing passive design strategies. The study compares a typical house that complies with the UK building Regulation, Part L 2010 and a passive house. The construction cost for a Part L 2010 house is £99,957 with 25 years at 3.9% APR mortgage and the price for a passive house at £115,623 with the same mortgage characteristics as the previous one. The passive house is £16,665 (15%) more expensive than a typical house; however, in the long term (25 years), the passive house owner is £1,293 richer than the other, a product of the energy bill savings. In this scenario, the passive house is 15% more expensive; however, studies have demonstrated that the actual difference price is from 8%-10%, as discussed previously [28].

A solution may be to increase gradually the level of standards within the building regulations emphasising both the embodied energy of the building material and the energy use of the buildings. Another effective solution would be to apply loan discounts when buying a passive house, as in Australia, or offering monetary grants, as encouragement as in Heidelberg, Germany [4].

1.4. Domestic energy consumption

Most of the energy utilised in the housing sector in the EU countries is related to heating. Over 64.1% of the energy used in the residential sector is for space heating (Figure 1), [1]in the case of the UK was about 70% in 2016 [1]. Rogers et al. [29] discusses that around 27 million houses in the UK used gas natural for heating that accounts the 66% of the bill. Understanding the main usage of energy in the domestic sector as well as where the most efficacy gains could be made is vital to improving energy efficiency [25].

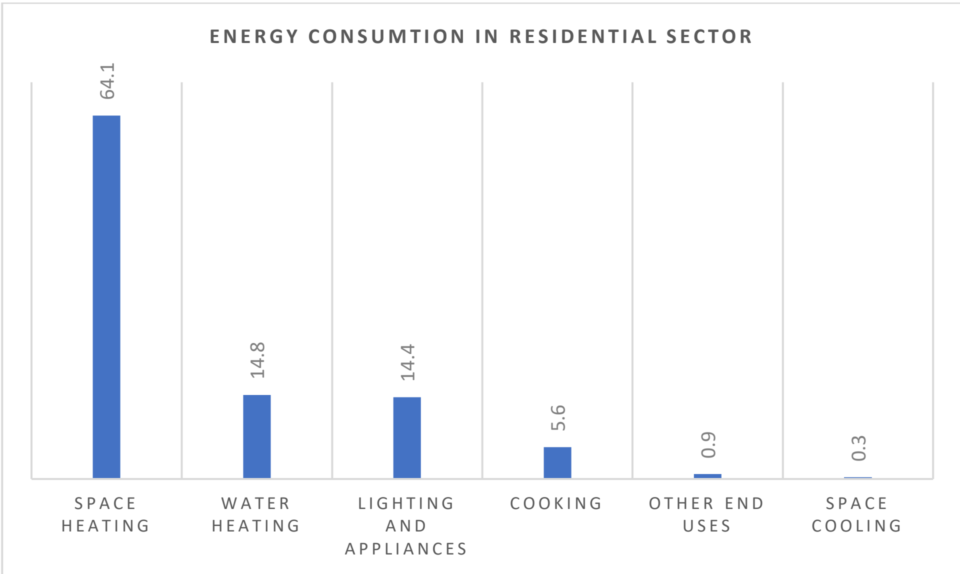

Figure 1. Final energy consumption in the residential sector by use, (Source of table EU-28, 2017 [1]).

The DECC, 2013 report classifies domestic energy consumption into 5 categories: heating, hot water, appliances, cooking and lighting. From the list, heating is the most predominant, with 10,494kwh from the 19,800kwh between gas and electricity needed to cover the energy demand for a dwelling (Table 2)[31]. Also, microclimates should be considered; for instance, in the north of Scotland, the use of heating tends to be higher in comparison to the South of England [30]. The estimated yearly energy bill in term of gas is around £608 based on 16,500kwh and £424 in electricity based on 3,300kwh for a dwelling emitting around 5.5 t CO_2 to the atmosphere [25].
Installation of central heating systems has significantly increased in the domestic sector in the last 40 years, leaving less than the 3% of houses without a central heating systems. According to Palmer & Cooper, 2012 , this is due to the aspirations of warmth and how this thermal comfort can be achieved [30]. Another report shows the central gas heating continues to increase steadily; from 1996 it increased from 73% to 85% in 2014, from 14.8 million dwellings to 19.9 million respectively [32].

In an attempt to reduce greenhouse emission (GHE) and to improve the energy performance, the European Union (UE) as well the UK have created many schemes and set many targets. The EU has committed to reduce GHE from primary energy use by 20% as a minimum, compared to 1990 levels, as well as 20% improvement in energy efficiency and 20% production of renewable energy by 2020 [33], which is being reached for most of the members in some areas [34]. Also by 2050 the climate change act commits the UK to reduce GHG by 80% as minimum compared to 1990 levels [23,35].

To reach such targets, the UK settled schemes such as the Low Carbon Building Programme launched in 2006 that grants the installation of heat pumps, solar power panel and other systems to generate energy on-site, but only 444 from 2006 to 2008 were granted for ground source heat pumps [25]. By 2016 all new homes were planned to be Zero-Carbon Emissions within the UK; however, this was abolished in 2015 [36]. These measurements resulted in a wave of pioneers and innovations with the aim to reduce heat loss through the building envelop, increasing the insulation levels and airtightness [37]. Installation of renewable system required skills and the UK may not have enough skilled personal to cover the crescent demand consequence of the incentives, that could make the government react against the scheme affecting the industry [25], that is the case of the backlash against the industry suffered Japan after a premature fast growing of solar installation due to a government grant scheme[26]. This was also evident in the recent rushed through Green Home Grants offered by the UK government in 2020 before a premature end to the scheme in 2021 due to various logistics and lack of enough installers to answer to the demand. Similarly, the Green Deal Scheme was introduced in 2013 to address the fuel poverty in England that accounted for 18% of the households; aiming to reduce fuel poverty from 250,000 to 125,000 by 2023 [38]. However, the scheme was scrapped in 2015 [39]. According to House of Commons Business Energy and Industrial Strategy Committee, 2019 [40]the scheme failed because of an uncompetitive interest rate (7%); while the scheme was operating, only 14,000 households took the loan from the 14 million expected. Since 2014/15, the number of households living in fuel poverty has increased by 210,000 to reach 2.55 million people [41], in the "Zero carbon homes: Perceptions from the UK construction industry", found that the developers are not motivated to produce zero carbon homes, and they are not interested in delivering a quantity of these building until strict legislation is in place. They also noticed the local authorities, QUANGO, developers, design consultants and architectural consultant, and contractor interviewed do not have a strong social responsibility as a driver [27].

1.5. Energy efficiency

Different tools have been developed to measure and assess the building energy performance. In the UK, to assess and compare the environmental impact as well as the energy performance within domestic dwellings. The Standard Assessment Procedure (SAP), developed in 1992, was adopted by 1995. Lately, the Reduce Data SAP (RDSAP) was introduced to cut the cost of the performance procedure [42].

Innovate UK (IUK) launched in 2010 the Building Performance Evaluation (BPE) programme to assess the buildings' performance. The programme four years monitored postconstruction buildings for at least one year after being occupied to determine the occupants comfort satisfaction, behaviour, heating affordability and to see how buildings affect the occupants [37,43][43]. The BPE found that the majority of the monitored buildings consume 3.6 times more energy than predicted, emitting carbon 2.6 times more than the design intent to [44]Among these tools is the Passive House Plan Package (PHPP) used to evaluate a P.H. performance. In the Camden Town P.H., in London, using the PHPP tool in the design process 65kwh/m² energy consumption demand was achieved [45], 55kwh/m2 less than the P.H. standard requires, which makes this tool quite efficient.

In the case study "Comparison of building performance between Conventional House and Passive House in the UK" by Liang et al. 2007 [46]in Newcastle North East of England, that monitored the energy performance of a traditional house built in 1978 and a P.H. in 2014, it was found the primary energy demand was 169.85kwh/m²/year and 64.11kwh/m²/year, respectively [46]. Also, a simulation using DesignBuilder software was run for the conventional house after improving the building elements were suggested the heat loss happened (Table 1), the results were a significant reduction from 169.85kwh/m²/year to 110.85kwh/m2 year at indoor temperature of 16°C, with an important reduction in heath energy of 77.7% [46].

Table 1. Comparison of U-Values for different envelop elements [46].

Item	Passive House U-Value (W/m2.k)	Typical House current U-Value (W/m2.k)	Typical House retrofit U-Value (W/m2.k)
Walls	0.15	0.54	0.12
Floors	0.15	0.25	0.10
Roofs	0.15	2.93	0.13
Windows (Glazing)	0.85	1.96	0.78

The energy performance of a building depends on many factors such as the quality of the building material, building design strategies, and the occupant's behaviour [2]. Failure in detailing the construction, building material fabrics and installation can end up in a significant gap between the energy performance prediction and the actual performance [47,48]. An example of accurate design and execution of a building is the Caning Town P.H., where the heat loss through the fabric was expected to be 66w/k, and the actual measure was 56w/k +/- 5w/k, which suggest the building envelopment was built as planned, with no significant defects [2]. Around 53% of the energy used in a whole dwelling comes from heating; passive house design strategies have the potential to minimise in an 80%.

2. Materials and Methods

The strategy used for this research is a concurrent mixed method to form analysis for the research problem with qualitative and quantitative data. This combination of methods has been chosen as they can be carried out independently, allowing the draw of reliable and accurate conclusions about the research. To compare energy performance of a typical semi-detached house (Figure 2) [50] and a passive house, a case study is selected, and simulations are conducted in EnergyPlus. Two models were developed, one to comply with Part L, UK building regulation and the other to comply with the Passive Housed standards.

Figure 2. Pair houses viewed from the front (left); Pair houses viewed from the rear (right) [50]

The houses are located in Loughborough, Nottingham, UK (52.771071° N, 1.224264° W), in a suburban residential area. These are unoccupied semi-detached two-storey houses (fig 9&10), with a mirrored floor plan (Figure 3). The houses are naturally ventilated and both houses are designed with identical window sizes and openings with an 85m2 floor area, 209.2 m^3 volume and three bedrooms.

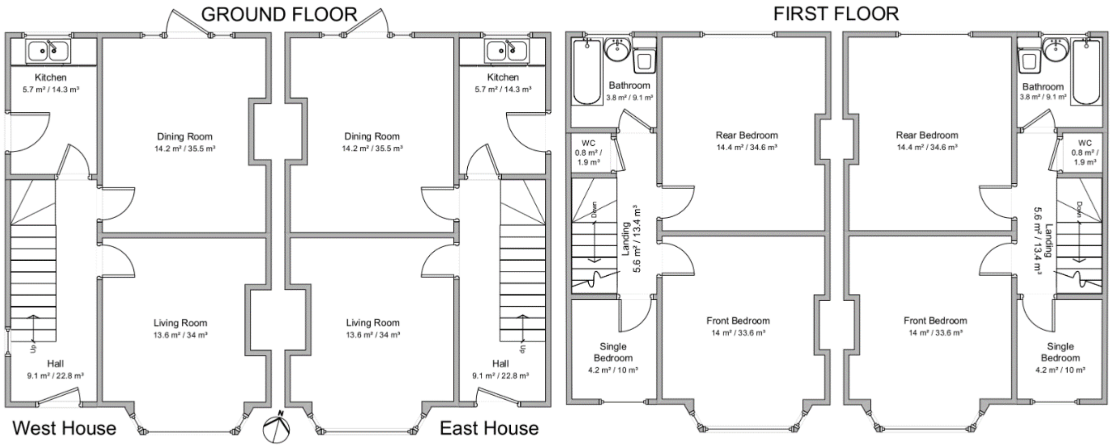

Figure 3. Dwellings floor plans [50].

The front of the dwelling is orientated south-southwest (160°). The access for each house is gained through the south side into an entrance hallway with stairs that leads to the first floor; the kitchen is on the north, with separate dining and living rooms. The living rooms have bay windows facing south, and the dining rooms with glazing doors facing north. There are 3 bedrooms, a landing, a small W.C. and a separated bathroom facing north on the first floor. The three bedrooms include a small room on the south side and two large bedrooms over the living and dining rooms facing north and south.

The houses are adjoining side-by-side therefore will influence each other. One house shades the other during the morning and the other in the afternoon. Also, through the party wall between houses will be inevitable heat transferrer.

The building materials' density (kg/m^3), thermal conductivity (W/mk) and specific heat capacity (J/kgK), for both passive and part "L" building standards houses, are settled based on the CIBSE Guide A [51] the Chartered Institution of Building Services Engineers., 2019. To reach the passive and part L houses building elements U-values requirement, the insulation thickness is increased as this is the element that makes the biggest impact in terms of insulation among the building elements (Table 4).

An air changes rate of 0.05 (ac/h) and 0.5 (ac/h) were considered for the passive house and the Part "L", respectively. The heating setpoint for both houses is; 21°C bathroom, 18°C bedrooms/kitchen, 21.5°C halls/stairs/landings, 22.5°C living/dining rooms and 20°C W.C. [51]. The occupancy was considered as 24/7 without any cooling system.

3. Results

The total yearly energy consumption for heating for the Part L 209 house (west house) is 3,537.85 Kw/h and 3,623.93 for its pair 207 house (east house) and the Passive houses 754.95 Kw/h, and 829.47 Kw/h, respectively (Table 4 & 5). The results suggest significant reduction in energy consumption in both houses 207 and 209. The energy consumption difference after the upgrade is 2794.47 Kw/h (77.11%) and 2782.90 (78.66%). This annual energy consumption reduction is close to the expected, which is 80%. This 2-3% extra energy consumption could be associated with Passive House's use of a heat recovery system to supply good indoor air quality but retain the heat that is generally wasted. The minor difference between houses (209-207) could be associated with higher exposure to the solar radiation of house 209 located on the south-west side. The optimal orientation of a house (30% facing south-west/east) could end up in a 30% to 40% in heating energy saving, as a product of the solar gains.

Most energy reduction has occurred in the 209 Passive House in the hall and landing in this order; a reduction of 729.45 kw/h year and 605.09 kw/h years in the hall and the landing, respectively. The dining and living rooms also show significant energy reduction for heating. In the part L scenario, the house 209 dining room energy consumption is 654 kwh and 662.87 for the 207. The energy consumption difference between both houses is minimal, the reason could be because both are facing the north with no solar heat gains. Upgrading to the PH, the energy performance of the spaces improves on 400.38 kwh (209) and 413.38 kwh (207). In the living rooms located on the front of the houses (facing south) the energy consumption is 503.09 (209) and 521.95 (207) for the part L houses. This rooms are around 1m² smaller than the dining room and consume around 130 kwh less. When upgraded to PH the energy reduction for heating is 400.38kwh for the 209 house and 413.04 for the 207.

The only spaces that do not consume energy for heating in both Part L and Passive house are the kitchen. This could be due to the high internal heat gains due to cooking. The energy consumption for the single bedroom 209-part L house is negligible (0.02 kwh and 0.36 for its pair) thanks to the high solar gains and high ratio of glazing to the floor area. Once both are upgraded to the passive house standards, their energy consumption is reduced to 0 kwh.

Table 2. Passive and part "L" houses components thickness and U-values.

Part "L" house			
Building element	**Description**	**Thicness (metres)**	**U-Value (W/m2k)**
External walls	Brick Insulation (polyurethane foam, 80mm) Concrete block Plasterboard	0.28	0.30
Party walls	Plasterboard Insulation (polyurethane foam, 125mm) Plasterboard	0.15	0.20
Half party walls	Plasterboard Insulation (polyurethane foam, 0.60mm) Plasterboard	0.08	0.40
Ground floor	Concrete slab Insulation (polystyrene foam, 0.96) Floor screed	0.32	0.25
Roof	Tiles Insulation (polyurethane foam, 125mm) Plasterboard	0.16	0.19
Window	Planilux 4mm Argon gass Planilux 6mm	0.02	1.96
Internal floor	Carpet Concrete slab	0.22	6.19

Passive House Standards			
Building element	**Description**	**Thicness (metres)**	**U-Value (W/m2k)**
External walls	Brick Insulation (polyurethane foam, 165mm) Concrete block Plasterboard	0.37	0.15
Party walls	Plasterboard Insulation (polyurethane foam, 165mm) Plasterboard	0.19	0.15
Half party walls	Plasterboard Insulation (polyurethane foam, 79mm) Plasterboard	0.10	0.31
Ground floor	Floor screed Insulation (polystyrene foam, 162mm) Concrete slab	0.39	0.15
Roof	Tiles Insulation (polyurethane foam, 165mm) Plasterboard	0.20	0.15
Window	Planilux 4mm Argon gass Planilux 6mm	0.03	0.79
Internal floor	Carpet Concrete slab	0.22	6.19

Table 3. Passive and part "L" houses settings.

Settings House 209										
Items	**Living Room**	**Dining Room**	**Kitchen**	**Hall**	**Front Bedroom**	**Rear Bedroom**	**Single Bedroom**	**WC**	**Bathroom**	**Landing**
Lighting load (Wm2)	2	2	2	2	2	2	2	2	2	2
Electric equipment load w/m2	22.09		71.45		14.73	16.2	30.61			
Temperature set point©	22	18	18	22	18	18	18	20	21	22

Settings House 207										
Items	**Living Room**	**Dining Room**	**Kitchen**	**Hall**	**Front Bedroom**	**Rear Bedroom**	**Single Bedroom**	**WC**	**Bathroom**	**Landing**
Lighting load (Wm2)	2	2	2	2	2	2	2	2	2	2
Electric equipment load w/m2	23.06		72.86		15.1	17.99	23.85			
Temperature set point©	22	18	18	22	18	18	18	20	21	22

Table 4. Part "L" house annual Kw/h energy consumption.

Part "L" House 209 (West house)		
ZONE AIR SYSTEM SENSIBLE HEATING ENERGY [J]		
	Area	Joules/Year
1	209_ HALL	3172040000
2	209_ KITCHEN	0
3	209_ LIVING_LR	1811130000
4	209_ DINING_LR	2354390000
5	209_ SINGLEBEDROOM_BR	57334.81
6	209_ FRONTBEADROOM_BR	61993363.77
7	209_ REARBEADROOM_BR	443228000
8	209_ WC	319365000
9	209_ LANDING	2796020000
10	209_ BATHROOM	1778050000
11	209_ ROOF	0
	TOTAL Kw/h	3537.85

Part "L" House 207 (East House)		
ZONE AIR SYSTEM SENSIBLE HEATING ENERGY [J]		
	Area	Joules/Year
1	207_ HALL	3350820000
2	207_ KITCHEN	0
3	207_ LIVING_LR	1879020000
4	207_ DINING_LR	2386320000
5	207_ SINGLEBEDROOM_BR	1313808.52
6	207_ FRONTBEADROOM_BR	0
7	207_ REARBEADROOM_BR	0
8	207_ WC	339849000
9	207_ LANDING	3267070000
10	207_ BATHROOM	1821790000
11	207_ ROOF	0
	TOTAL Kw/h	3623.94

Table 5. Passive House annual Kw/h energy consumption.

Passive House 209 (West house)		
ZONE AIR SYSTEM SENSIBLE HEATING ENERGY [J]		
	Area	Joules/Year
1	209_ HALL	546038000
2	209_ KITCHEN	0
3	209_ LIVING_LR	369746000
4	209_ DINING_LR	435664000
5	209_ SINGLEBEDROOM_BR	0
6	209_ FRONTBEADROOM_BR	0
7	209_ REARBEADROOM_BR	67364.55
8	209_ WC	111617000
9	209_ LANDING	617702000
10	209_ BATHROOM	636976000
11	209_ ROOF	0
	TOTAL Kw/h	754.95

Passive House 207 (East House)		
ZONE AIR SYSTEM SENSIBLE HEATING ENERGY [J]		
	Area	Joules/Year
1	207_ HALL	592867000
2	207_ KITCHEN	0
3	207_ LIVING_LR	392075000
4	207_ DINING_LR	397960000
5	207_ SINGLEBEDROOM_BR	0
6	207_ FRONTBEADROOM_BR	0
7	207_ REARBEADROOM_BR	0
8	207_ WC	120407000
9	207_ LANDING	817909000
10	207_ BATHROOM	664856000
11	207_ ROOF	0
	TOTAL Kw/h	829.47

According to the results of simulation, upgrading a Part L Building Regulations house to a Passive House Standards could reduce energy consumption by up to 78.66%. Accordingly, the energy bill would have an important reduction of £223.55 per year taking as a reference the actual average gas cost of a kwh is 3.80p [52] . The energy consumed by the heating system make up around the 70% of the total energy bill which would have an important improvement in this scenario, additionally around 0.23 tons of CO_2 emissions would be saved.

5. Conclusions

A good technical understanding of the energy usage in the domestic sector and the building occupants' behaviours and culture is vital to draw accurate and effective paths to reach energy efficiency targets. The EU and the UK have settled objectives and created various schemes to encourage the implementation of building passive design strategies, improve the domestic building performance, as well as to decrease the GHG emissions as well as improve the wellbeing of their inhabitants. Yet, at least in the case of the UK, many of these strategies have been doomed to failure due to various shortcomings. For a successful implementation of sustainable and passive design strategies in the housing industry, all the sectors such as authorities, QUANGO, developers, design consultants and architectural consultant, and contractor must have a strong commitment to these strategies. Heating (space and water) is the biggest contributor to energy consumptions in the housing sector in the UK, accounting for more than 60% of the energy consumed. Adopting Passive

House standards in the UK could have a big impact contributing to the Government's targets to achieve net zero emissions by 2050. Passive design strategies can potentially reduce heating energy consumption by nearly 80% providing indoor thermal comfort, while reducing emissions and energy bills for the occupants. More research is required to assess effects of building technology, materials and occupants' behaviours on the energy performance.

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